STUDY AND DEVELOPMENT OF EMPIRICAL RELATIONS AMONG VARIOUS PHYSICAL PARAMETERS OF LPG CYLINDER MATERIAL AND SUGGEST FAIL-SAFE INSPECTION PLAN FOR MANUFACTURING

BY

AKULA RAMAKRISHNA

Submitted

in partial fulfillment of the requirement of the degree of

DOCTOR OF PHILOSOPHY

To

University of Petroleum & Energy Studies, Dehradun

February 2014

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UNDER THE GUIDANCE OF

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DEDICATION

This thesis is dedicated to my parents, wife and son

who have always stood by me and dealt with all of my absence from many personal occasions

with a smile.

DECLARATION

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

Akula Ramakrishna
Date: 06^{th} Feb 2014

THESIS COMPLETION CERTIFICATE

This is to certify that the thesis entitled ***"Study and development of empirical relations among various physical parameters of LPG cylinder material and suggest fail-safe inspection plan for manufacturing"*** submitted by ***Akula Ramakrishna*** to ***University of Petroleum and Energy Studies*** for the award of the degree of ***Doctor of Philosophy*** is a bona fide record of the research work carried out by him under our supervision and guidance. The content of the thesis, in full or parts have not been submitted to any other Institute or University for the award of any other degree or diploma.

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Akula Ramakrishna
Date: 06th Feb 2014

APPEAL

TO THE STAKEHOLDERS OF LPG CYLINDER BUSINESS IN INDIA

I respect national and international standards; their administration and enforcing bodies (including Indian standards and Bureau of Indian Standards, BIS) for their contribution to society in providing domain specific standards and guidelines. Also I respect enforcing authorities' efforts towards ensuring standard compliance requirement in business.

I respect all cylinder manufacturers in India, their production methods while producing LPG Cylinders in their facilities as per national standards and regulations.

I respect all Indian government oil companies that are marketing LPG for their untiring efforts, systems and procedures in delivering safe cylinders to public in a responsible way.

The stakeholders of LPG business are humbly requested to consider the gaps mentioned in this research work are not to be treated as criticism on any specific clause in any standard or on standards enforcement authority or on any testing laboratory or on any specific person or on any specific industry or organization.

With due respect, I appeal to all stakeholders of LPG cylinder segment to consider the recommendations given in this research work are purely to improve implementation of national standards with noble intentions towards consumer safety.

Akula Ramakrishna
Date: 06th Feb 2014

EXECUTIVE SUMMARY

LPG Cylinder material plays very crucial role in containing and transporting hazardous Liquefied Petroleum Gas (LPG). In the existing LPG Cylinder manufacturing process, cylinder testing practices are destructive in nature and only two cylinders (one in 203 cylinders for acceptance test and one in403 cylinders for Hydro-test) are tested for their parent material safety or compliance requirements. There are more than 150 LPG cylinder manufacturers in India and are producing approximately 18 million of cylinders to meet the Indian government oil companies' requirement alone. It is a difficult process to monitor all these cylinder manufacturing plants on continuous basis for any enforcing authority. Non-compliant cylinders can enter into market, if the sampling is biased before testing a batch at any manufacturing plant. These non-complied cylinders cannot be retrieved from market till the cylinder life cycle ends. Although, oil companies are aware of this fact, there is no process in place to identify or trace non-compliant cylinders in market for segregation. Cylinder consumers are not aware of this fact and may be using a non-compliant cylinder in their homes. Non-compliant cylinders can pose potential safety hazard, if they are subjected to adverse conditions or wrong handling. It is necessary to stop entry of such non-compliant cylinders into market at point of origin i.e manufacturing location itself.

If there is a method or process in which the cylinder material properties can be checked easily and quickly in a convenient manner, without destroying or damaging the cylinder; entry of such non-complied cylinders into market can be easily identified and thereby exists a chance to eliminate at the point of identification. However, for efficient implementation, such novel method or process should not demand skilled persons for testing or demand expensive test setups to conduct inspection on cylinders. In this research an attempt has been made to

develop a fail-safe inspection plan to cylinder manufacturer to test all cylinders (100%) in their manufacturing location easily and quickly without destroying or damaging cylinder. Further, LPG cylinder material properties can be verified effortlessly at any point time in its life cycle; especially at all critical stages of its life cycle for material compliance requirement.

Acceptance and hydro tests are the two important tests to be conducted on new LPG cylinders for ensuring cylinder parent metal material properties. These two tests are most important to accept a batch of newly produced cylinders in any LPG cylinder manufacturing location. In the existing sampling system as per Indian standard IS 3196, one cylinder in every 203 cylinders undergoes acceptance test and one cylinder in 403 cylinders batch is tested for hydro-test.

As per Indian standard, IS 3196, a batch of cylinders produced in a manufacturing location should be with same raw material and same production methods including same heat treatment process parameters. There are two possible scenarios in a manufacturing location for any batch produced in a plant. They are; cylinders produced by following all necessary guidelines and cylinders produced without or partially followed guidelines or standards. The second one could be intentional to reduce production cost or inadvertent action due to power failures, machine breakdowns, unavailability of skilled manpower for prolonged batch production etc. In both scenarios, if the cylinder batch passes the test, they are sent to market for usage at customer home. However, if the sample cylinder from the batch fails, Indian standard allows to test another random sample cylinder testing for verification by discarding the first sample results. If this second sample passes the test the batch can be sent for market. If not, entire batch needs to be heat-treated and conduct the testes once again on the batch. Current standard allows this repetition till the batch passes the acceptance test results. If the cylinder sampling is biased for acceptance testing non complied cylinders can enter into market, which cannot be traced afterwards in market due to vast area for circulation.

Although oil companies are having some system to act on new cylinder failures in market, there is no clear procedure or a system for old cylinders which are already in circulation. In case of new cylinders, the procedure is limited to impose suspension on cylinder manufacturer (which can be revoked later) and in case of old cylinders, the cylinder is just scrapped, if they are not under warranty (as per tender clauses / one year). However, there is no procedure for retrieving non complied cylinders of same manufacturer and same batch from market in both these cases. (Certification sample testing is only 1 in 203 cylinders)

Suppose, a cylinder fails during its first filling or initial entry in market, state owned oil company tender specifications allows to propose suspension of cylinder manufacturer from producing cylinder further. Upon suspension the manufacturer needs to produce a fresh trail batch of cylinders after correcting their manufacturing process parameters. This trial batch should meet all standard requirements. Once the trail batch is approved, the suspension is revoked on a particular manufacturer and the manufacturer can resume production. In addition to this suspension clause, government oil companies clearly outlined various kinds of restricted practices in cylinder manufacturing business and their disciplinary actions on such restricted practices in their tender documents. It means oil companies are aware of some restricted practices in the business but unable to act, as there is no comprehensive solution for addressing these issues. Further, it is evident from the past cases in competition commission of India that the cylinder manufacturing business is not so clean and there are certain grey areas in the business to survive peer competition in cylinder manufacturing business.

Although majority of the cylinder manufacturers are assumed to follow all the statutory guidelines and national standards, some manufacturers may tend to deviate these requirements and manages to pass their non-standard cylinders into market.

Suppose a batch of non-complied cylinders slips into market, it is absolutely not possible to trace these cylinders in the vast cylinder market in India. It means, although BIS mark is on LPG Cylinder, there is a chance that it need not comply existing Indian standard. Surprisingly it is a fact. The scope of the research is not to point the grey areas in LPG Cylinder business but to provide a solution to this issue which is acceptable to all stakeholders of LPG Cylinder business in a balanced way and to reduce the risk associated with LPG in customer kitchen.

To address this, current research is focussed on study existing standards, systems and procedures to focus on developing empirical relation among various physical parameters of LPG cylinder material and suggest fail-safe inspection plan for manufacturing.

Liquefied Petroleum Gas (LPG) cylinders in India are produced as per Indian standard IS 3196 part1: 2006, *Welded low carbon steel cylinders exceeding 5 liter water capacities for low pressure liquefiable gases – Specification*. These cylinders are produced undergo stringent procedures and critically scrutinized at every stage in their life cycle from manufacturing to withdrawal of cylinders from service. Indian standard IS 3196 part 3 states the guidelines for testing of new cylinders for Bureau of Indian Standards (BIS) certification. Every cylinder is having a permanent BIS logo on it and it certifies that the cylinder underwent stringent norms and tested as per the code of practice. In India, state-owned oil companies market different type of cylinders, intended for variety of business segments like domestic, commercial and industrial. Technically, all these cylinders are identified with volume of cylinder in water capacity. For example the domestic LPG cylinder marketed by state owned oil companies is 33.3 liters water capacity and are fabricated in two piece constructions. All the government oil companies market same kind of cylinder for domestic segment. Current research is carried out on this domestic cylinder.

Once a batch of cylinders is produced, manufacturer should test few sample cylinders from each lot for certification purpose. Those tests are Acceptance tests, Burst test, volumetric expansion test, hydrostatic stretch test, hydrostatic test, pneumatic leak test, radiographic examination, and fatigue /cycle test. The acceptance test reveals the parent metal mechanical properties and weld mechanical properties. As per the requirement, test tensile samples are cut from cylinder and tested for measuring yield strength, tensile strength, percentage elongation, weld tensile strength. One cylinder should undergo this test for every batch of 202 or above cylinders. Volumetric expansion test indicated permanent volumetric expansion of cylinder under test pressure conditions. One cylinder should undergo this test for every batch of 403 cylinders. The same cylinder can be subjected to burst test to measure burst pressure and nominal hoop stress in cylinder at burst pressure conditions. Radiographic examination is intended to check the weld quality and the depth of penetration. Fatigue test is a type test to check the cylinder under cyclic internal pressures. Leak tests are intended to check visible leaks in cylinders. Among these tests, acceptance and hydro-tests are the critical tests for BIS certification process and are conducted on sample cylinders as per Indian standard IS 3196 part 3. Once the batch is accepted by bureau of Indian standards, certified cylinders are released to market for use.

From the national standards and literature survey, the identified physical parameters for study are derived from acceptance and hydro-test viz. Longitudinal Tensile Strength (LTS), Longitudinal Yield strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield strength (CYS), Circumferential Percentage Elongation (CPE), Burst pressure (BP), Volumetric expansion (VE) and Nominal Hoop stresses (NHS).

Based on the scope, the objectives of the current research are divided into three broad categories and are

1. Establish LPG Cylinder life cycle and to study various phases in LPG Cylinder life cycle
2. Identify critical variables that influence cylinder material requirements and develop relations among these critical variables with primary test data. Establish dependent variables and independent variables among the critical variables. Conduct additional experiments (Hardness tests) on cylinders and develop empirical relations for estimating all critical variables from hardness values.
3. Suggest a fail-safe inspection plan for cylinder manufacturing.

Extensive literature review carried out under broad categories of LPG Cylinder design, manufacturing, testing, material properties, national, international standards, statutory guidelines, incidents etc. From the literature, it is evident that LPG cylinders are manufactured from low carbon steel. Yield strength and tensile strength are the critical material properties and for a low carbon steel. These two parameters can be estimated from material hardness. Material hardness can be measured or estimated either with conventional hardness test or advanced non-destructive test methods using a portable hardness tester.

Literature also states that material hardness, yield strength and tensile strength of low carbon steel are having a linear relation. Keeping in view of the hardness and the relation of tensile and yield strength with hardness, cylinder test data was analysed with correlation study, trend analysis and regression analysis, based on 11 critical parameters 37 relations were developed and these relations are grouped in to four different categories. Each group can potentially estimate all critical parameters of LPG cylinder material. Estimates are studies with actual and identified best possible group for estimating the result of acceptance and hydro test results. From the analysis, it is identified; test results on circumferential direction are less than longitudinal direction except percentage elongation. Lower values are always critical as the standard specifies only minimum requirements for material specifications. Thus if the empirical formulas are developed in terms of circumferential tensile strength cylinder critical properties can be estimated. Now the circumferential tensile value can be obtained by conducting surface hardness test. Surface hardness is not required to measure in existing practice and hence experiments were conducted on LPG cylinder to get surface and actual material hardness. Relations were developed among these parameters. From literature, it is also evident that if the surface hardness is known tensile and yield strength can be estimated. Thus with the help of surface hardness, circumferential tensile strength can be estimated and from circumferential tensile strength all other critical parameters related to acceptance and hydro test details can be calculated.

In order to estimate these properties quickly and easily Microsoft Excel based software was developed. The software is developed in such a way that the values can be estimated with all four methods instantaneously using the surface hardness values obtained from portable hardness tester in BHN. The dashboard provides all critical parameters instantaneously and with a single click after the surface hardness value is fed to the software.

The research concludes with proposed Fail proof inspection plan for manufacturing using the combination of spot hardness test and set of empirical formulas. This plan not only intended for manufacturers but can also be extended beyond manufacturing premises. The methodology was discussed with 4 different plans to estimate critical parameters of cylinder material i.e using any one of the critical parameters circumferential tensile strength, circumferential Yield strength, longitudinal tensile strength and longitudinal yield strength as independent variable to determine other critical parameters..

The literary contributions from current research are:

1. The state of art LPG Cylinder life cycle was documented. Various factors affecting cylinder life cycle were described in details with appropriate justifications.
2. Acceptance testing and hydro testing processes of LPG Cylinder at manufacturing premises were described in detail and highlighted possible areas, where the national standard can be interpreted wrongly against the interests of consumer.
3. Various factors that can affect LPG Cylinder testing process are outlined with necessary reasoning and appropriate clauses of Indian Standard.
4. Carried out an in-depth study on LPG Cylinder parent metal tensile test and proposed a method for preparing tensile specimen from LPG Cylinder.
5. The process dealing with non-compliant cylinder in market was pronounced with all supporting documents, which is the basis for this work.
6. Detailed study was carried out on LPG Cylinder longitudinal and circumferential tensile samples and proved that the circumferential samples exhibits lower yield and tensile values than longitudinal samples all the time. Hence, there exists a chance to discard longitudinal sample testing in existing acceptance testing practices.

7. Carried out a study on LPG Cylinder material hardness by measuring the hardness with two different methods. It was proved that the surface hardness of cylinder is higher than the actual material hardness. The reasons for this phenomenon was outlines in the current research
8. Correlation analysis was carried out for 55 combinations of 11 parameters of LPG Cylinders material properties. Trends between 55 combinations were established the reasons for correlation values that are deviating from the expected values were outlined with justifications.
9. 37 Empirical formulas were developed with 4 different plans to estimate all 9 critical parameters. Compared the actual and estimated values and suggested the best formulas for estimating critical parameters.
10. Reasons for compression in interquartile range boxes in box plots of actual and estimated values are described with appropriate justifications. As a result of this the empirical values can be used for indicative purpose only and not for replacing the existing test practices.
11. Microsoft excel based software was developed to estimate critical parameters quickly with four different plans to estimate critical values quickly. This can be used as a basis for modifying existing portable testers to get the critical parameters directly at the time of testing hardness.
12. Suggested a fail-safe inspection plan for cylinder manufacturers for estimating cylinder critical parameters quickly and effectively. With this methods cylinder manufacturers can ensure all cylinders produced in their plant are complying the requirements of Indian Standard.

Further it is recommended to discard longitudinal sample testing in existing acceptance testing of LPG Cylinder parent metal tensile test to save 50% of testing cycle time. Also, it is recommended to implement fail-safe inspection plan in manufacturing locations to inspect all cylinders using the combination of hardness test and empirical formulas, besides existing destructive test methods. This will avoid entry of non-complied cylinders into market.

While studying LPG Cylinder Life cycle, an opportunity is available to study the factors affecting the cylinder life cycle and a separate study was carried out on this area. Although, at every stages of LPG Cylinder life cycle from manufacturing to bottling are regulated or controlled with several statutory regulations, guidelines and best practices, they are ill-treated in market place i.e. from dispatch of filled cylinder to receipt of empty cylinder in bottling plant. This ill-treatment is mainly in the form of body rolling, dropping cylinders from heights on hard surface, usage of wrong adaptor for extracting gas from cylinders, using hot water baths for generating more vapours from cylinders, illegal transfers of liquid from one cylinder to another cylinder, wet and humid kitchen condition, usage of cylinder close to hotplate etc. This kind of abuse to cylinder affects cylinder life cycle and adoption of such practices on continues basis reduces the life of cylinders.

Similarly, while establishing the critical and influencing parameters for acceptance test, the results of longitudinal and circumferential tensile test specimens were analysed. This led the study towards various sample preparation methods in the existing practice and studies the sample preparation process in detailed. Several factors in sample preparation can affect the test results. An optimal method was suggested in this study for sample preparation for accurate results.

Following advantages are expected from implementation of research recommendations.

- Implementation of fail-safe inspection plan can ensure elimination of non-complied cylinders in to market (to consumer)
- If acceptance test sample failed twice in cylinder manufacturer location, they can segregate the cylinders and only non-complied cylinders can be sent for heat treatment process instead of the entire lot. This saves fuel cost to the cylinder manufacturer and also the implementation of fail-safe method can protect manufacturers from unwarranted suspensions from enforcement bodies and oil companies. The cylinder manufacturers can prove their point with valid and scientific data.
- Statutory authorities need no depend on cylinder manufacturers for compliance testing. A simple hardness tester is sufficient to check the cylinder parameters at any point of time in its life cycle.
- Oil companies being the owners of cylinders, they can assure safe cylinders to their customers and can verify the properties at any point of time
- Investigation agencies can verify the accident and incident analysis without destroying the sample.

Thus the research concludes with a solution to address the gaps in existing national standards with an aim to improve the regulatory compliance and to enhance public safety.

-: End of abstract:-

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ABBREVIATIONS

Acronym	Full Form
% EL	Percentage Elongation
BH	Brinells Hardness
BHN	Brinells Hardness Number
BHN-b	Brinells Hardness Number obtained from brinells test
BHN-p	Brinells Hardness Number obtained from portable hardness tester
BIS	Bureau of Indian Standards
BP	Burst pressure
BS	British Standards
CPE	Circumferential Percentage Elongation
CTS	Circumferential Tensile Strength
CYS	Circumferential Yield Strength
DOT	Department of Transportation
EBP	Estimated Burst pressure
ECPE	Estimated Circumferential Percentage Elongation
ECTS	Estimated Circumferential Tensile Strength
ECYS	Estimated Circumferential Yield Strength
ELPE	Estimated Longitudinal Percentage Elongation
ELTS	Estimated Longitudinal Tensile Strength
ELYS	Estimated Longitudinal Yield Strength
ENHS	Estimated Nominal Hoop Stress
EVE	Estimated Volumetric Expansion
FRC	Faculty Research Council
IS	Indian Standards

Acronym	**Full Form**
ISO	International organization for standardization
LP Gas	Liquefied Petroleum Gas
LPE	Longitudinal Percentage Elongation
LPG	Liquefied Petroleum Gas
LTS	Longitudinal Tensile Strength
LYS	Longitudinal Yield Strength
MPa	Mega Pascal
NDT	Nondestructive testing
NHS	Nominal Hoop Stress
TS	Tensile Strength
UTM	Universal tensile testing machine
UTS	Ultimate Tensile strength
VE	Volumetric Expansion
WLPGA	World LP Gas Association
YS	Yield Strength

Chapter-1

1. Introduction

The chapter outlines LPG Cylinder market in India. It also discusses some of the key areas of concern in LPG Cylinder business facing in India. The basis for research, scope and objectives are defined in this section. The methodology to achieve scope and objectives are also described in systematic research framework. Structure of this entire dissertation report is outlined at the end of this chapter.

1.1 General

India is the third largest consumer of Liquefied Petroleum Gas (also known as LP Gas or LPG) in domestic sector in the world after china and USA [34]. Approximately 3 million LP Gas Cylinders are delivered to Indian homes every day. It means, approximately 900 million cylinders in a year are delivered to homes for domestic consumption in India [34]. This demand for LPG is increasing every day. Oil companies in India are procuring approximately 18 million new cylinders every year to cater the needs of domestic market [18]. These cylinders are designed and manufactured as per Indian standard IS 3196 Part1 [25] and tested as per Indian standard IS 3196 Part3 [27]. All cylinders are certified by Bureau of Indian Standards (BIS) before they release to market for safe usage [30].

LPG Cylinders plays crucial role in containing and transporting hazardous LPG from LPG filling plant to end consumer [6]. Although the cylinders are playing important role in transporting hazardous LPG, often they are treated very badly in market right from the distributors' warehouse to end consumer [6]. In view of practical work conditions and handling methods, Indian standards stipulates, LPG Cylinders are to be manufactured from definitely prescribed raw material (IS 6240) to ensure safety of cylinders through material quality specifications [26]. Further, to ensure safety, cylinders manufactured in a manufacturing plant should be certified by statutory authority (Bureau of Indian standards) after conducting certain tests and inspections prescribed in IS 3196 part 3. Although there are clear standards and statutory norms for design, manufacturing and usage of LPG Cylinders in India, there are certain gaps in these standards in terms of ensuring material safety compliance [8].

In a LPG cylinder manufacturing plant [36] once the cylinder body is welded, severe internal stresses are developed in semi-finished cylinder due to welding process [7]. If these stresses are not relieved, cylinders are considered as un-safe. I.e., under adverse internal pressures due to fire or any other external means, such non stress relieved cylinders can burst with fragments. This kind of cylinder failure can cause potential safety hazard to human and assets due to flying fragments. Also such failure can be a potential source for secondary fires [1] due to hot flying fragments containing hazardous liquid petroleum gas (LPG). Thus it is necessary to relieve all internal stresses in a cylinder with appropriate heat treatment process in a manufacturing location. Indian standard recognizes this fact and incorporated as failure clause in burst testing of LPG cylinders [25] and ensures cylinders are not bursting in fragments when they subjected to burst test. Efficient heat treatment in cylinder manufacturing process brings LPG Cylinder parent metal properties to desired limits. After completion of heat treatment process, these cylinders material quality need to be checked and it should comply with requirements mentioned in Indian Standards [25]&[27].

Acceptance and hydro tests are two major tests to be conducted on LPG cylinders for statutory certification [25]. Acceptance test is intended for measuring parent metal physical properties like yield strength, tensile strength and percentage elongation [27]. Burst pressure, volumetric permanent expansion and nominal hoops stresses are measured in hydro test [27]. As per the current Indian standard (IS 3196), only one cylinder in a lot of 203 (or less) is subjected for acceptance test and one cylinder in a lot of 403 (or less) is subjected for hydrotest [25]. It is assumed that all cylinders in a specific lot are having same properties / parameters of the tested specimen cylinders in that lot [25] as they are manufactured from same raw material with same manufacturing process parameters. It means statutory testing of cylinders for certification is limited to two cylinders out of a batch contains 203 cylinders in a manufacturing location.

Ideally, if the cylinder manufacturing unit follows all the prescribed guidelines, there should not be any failure cases in sample cylinder testing. However, suppose if any cylinder sample fails at this stage in acceptance test, Indian standard allows manufacturers to conduct retest on one fresher sample cylinder from the same batch of cylinders [25] produced in a facility. Even if a retested sample fails, Indian standard does not explicitly impose to destroy the non-complied cylinder batch. It allows to reheat treat the batch and accepts for retesting of cylinder batch by treating this as a fresh batch. This process can be repeated till the batch passes acceptance test. This clause in existing Indian standard is favoring cylinder manufacturer [25].

Once a batch of cylinders is certified by Bureau of Indian standards and released in market, it is very difficult to trace that batch or a particular cylinder in use due to vast domestic market spread in India. Although it is not a compulsion (as the cylinders are released with BIS mark on them), Indian oil companies check some cylinders randomly for their quality conformance. In such case, suppose at any point of time in market, if any new cylinder found to be non-compliant with standards, it is absolutely impossible to trace that cylinder batch in the market. Possibility of such occurrence cannot be ruled out in present Indian LPG cylinder market [28] & [29]. In such cases, Bureau of Indian Standards have guidelines to imposes suspension orders on non-complied cylinder manufactures [31] and advised them to correct their manufacturing process to comply with standard requirements [25]. However, nothing can be done to LPG cylinders already circulating in the market. In simple terms, cylinders that are not complied with standard requirements can exist in LPG cylinder market in India. Unlike other commodities, the cylinder material quality cannot be checked on the spot at any point in its life cycle.

In India more than 150 Cylinder manufacturers are producing cylinders [31] to meet Indian LPG Cylinder market demand. There is severe competition among these manufacturers for bidding competitive rates and allows them to utilize every available opportunity [35] to cut their operating costs. In cylinder manufacturing process, heat treatment is one of the expensive operations [81]&[86] (to relieve internal stresses generated in cylinder material while manufacturing). This is mainly due to furnace operation is at elevated temperatures and usage of expensive fuel to raise the temperatures of furnace to the range of 600 to 700 degree centigrade (based on raw material specifications) from room temperature. If any manufacturer bypasses heat treatment process and manages to get good results to one or two sample cylinders as per the standard requirement for acceptance test, non-complied cylinder batch can enter into market and that cannot be traced once they released to market.

Although, it may be rare; due to cylinder order delivery pressure, and severe competitive rates, some manufacturers may adopt such shortcut methods and may inject such non-complied cylinders into market. Even such cylinders are traced at a later stage in their life cycle, only future or subsequent cylinder batches in production line can be corrected and nothing can be done to non-complied cylinders already in market. In simple terms, there is a possibility to present a non-compliant cylinder in any house in India and with existing practices, they cannot be traced. This is because, in the existing state of art technology, there is no method to check cylinders in market whether they comply with requirements or not without destroying a cylinder. Also as per the existing guidelines, cylinders need to undergo destructive testing for verification of material quality [18]. This destructive testing process involves, specialized laboratory set up skilled technicians to conduct experiments and skilled work force to prepare samples etc. [3]. As per the current standard, LPG cylinders are to be checked for acceptance and hydro tests to reveal their properties like yield strength, tensile strength, percentage elongation, burst pressure, nominal hoop stresses and volumetric expansion to comply with requirements of Indian standard [25].

In this research, several relations are established among these critical variables and a non-destructive test method is proposed to estimate these values of a material using cylinder hardness value. In addition to that user friendly software is developed to estimate these key values quickly and accurately. With this method, every cylinder produced in cylinder manufacturing location can be checked quickly. The method can be implemented along with the existing test methods prescribed in Indian standards to avoid entry of non-complied cylinders into market at the manufacturing location itself. Also, the method can be used to identify non-complied cylinders in market, as a part of failure or accident investigation.

An attempt has been made in this research to propose a feasible non-destructive inspection method to check every cylinder in a manufacturing location for their material compliance. In other words, Fail safe inspection plan is proposed based on certain sets of empirical formulas in this research to estimate all critical parameters or properties of LPG cylinder parent metal, without destroying. The proposed methods can be used for estimating critical properties of cylinder material at any time in its life cycle.

1.2 Research Scope

The scope of current research is 'Study and development of empirical relation among various physical parameters of LPG cylinder material and suggest fail-safe inspection plan for manufacturing'. The physical parameters are derived from acceptance testing and hydro-testing methods given in Indian standards. Among these two tests, acceptance test on a cylinder is conducted in two perpendicular directions of a cylinder i.e. one in longitudinal and other in transverse or circumferential direction [27]. Thus the scope of this research is to estimate the following physical parameters of LPG Cylinder parent metal.

- Longitudinal Tensile Strength (LTS)
- Longitudinal Yield Strength (LYS)
- Longitudinal Percentage Elongation (LPE)
- Circumferential Tensile Strength (CTS)
- Circumferential Yield Strength (CYS)
- Circumferential Percentage Elongation (CPE)

- Burst Pressure (BP)
- Volumetric Expansion (VE)
- Nominal Hoop Stresses (NHS)

Figure.1 shows bird eye view of research scope. Referring to the figure, cylinder manufacturing is one of the major phases in LPG Cylinder life cycle. Parent material quality is ensured only at this stage. Cylinder testing is one of the important activity manufacturing processes. Once the cylinder batch passes all tests, it is accepted for market use. This testing is either destructive or non-destructive type. Non-destructive tests on cylinders can be conductive at any point of time in its life cycle. However, destructive test can be conducted on sample cylinder only at the time of manufacturing due to its inherent nature of test. Again these destructive testing of LPG cylinder is mainly acceptance test and hydro test for accepting a batch of cylinders. Current research is focusing on these two tests

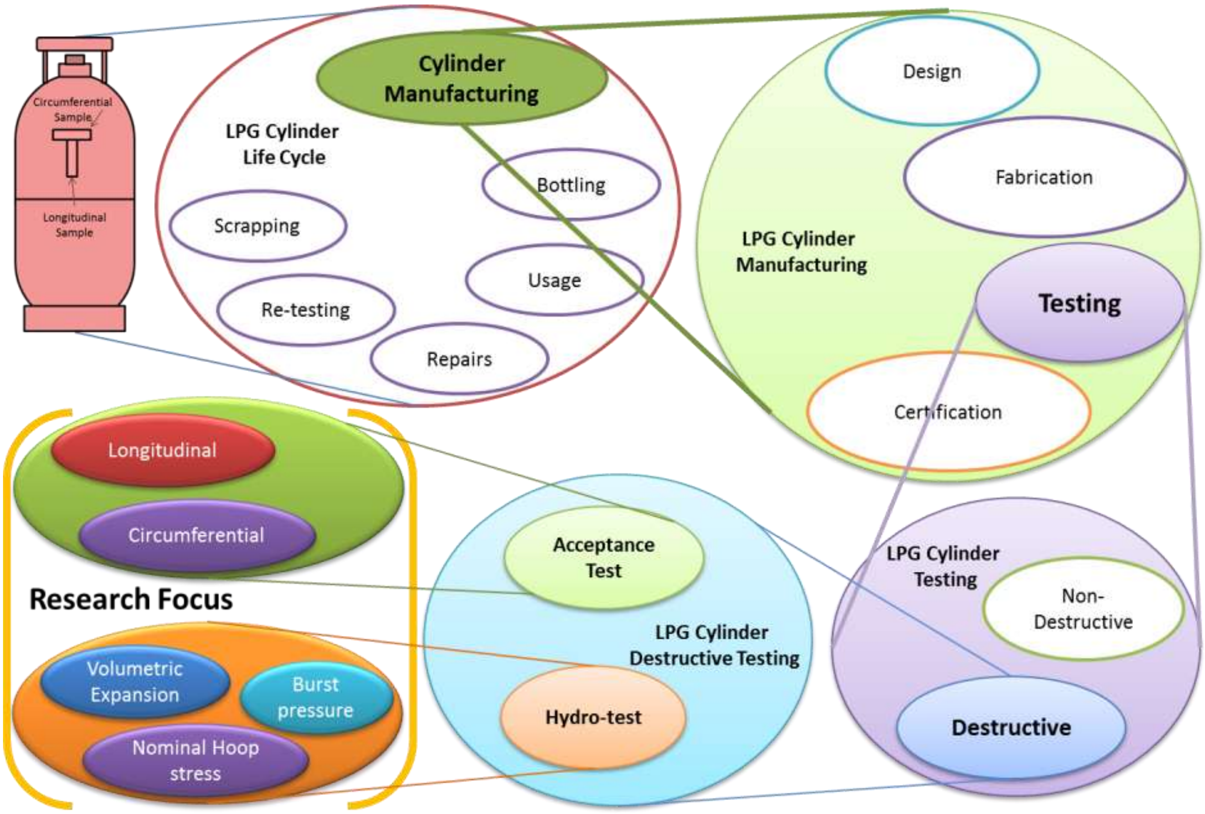


Figure 1: Research Focus - Bird Eye View

1.3 Research Objective

The research scope is further divided in to three major objectives and are

1 Establish LPG cylinder life cycle and to study various phases in LPG cylinder life cycle

2 Identify critical variables that influence LPG cylinder parent material safety or quality and develop empirical relations among these critical variables / parameters

3 Suggest a fail-safe inspection plan for LPG cylinder manufacturing

These objectives are shown in Figure.2 below for easy understanding

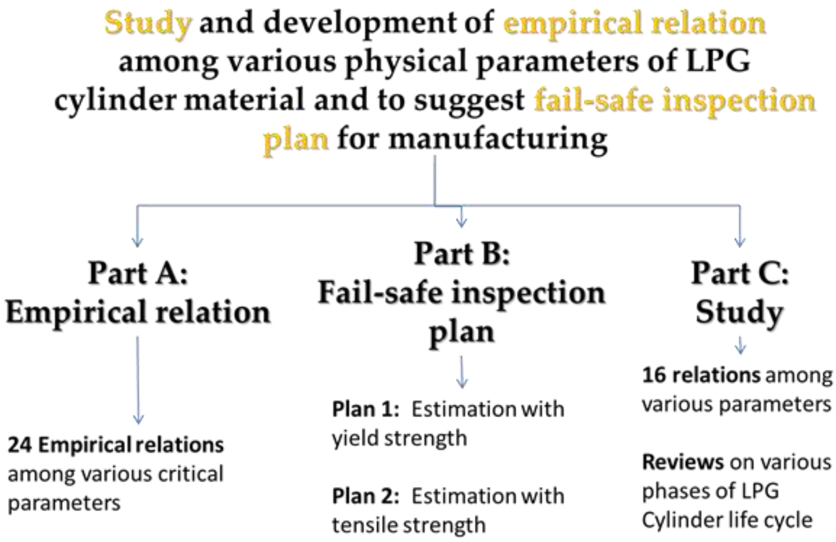


Figure 2: Research Objectives

1.4 Research Frame Work

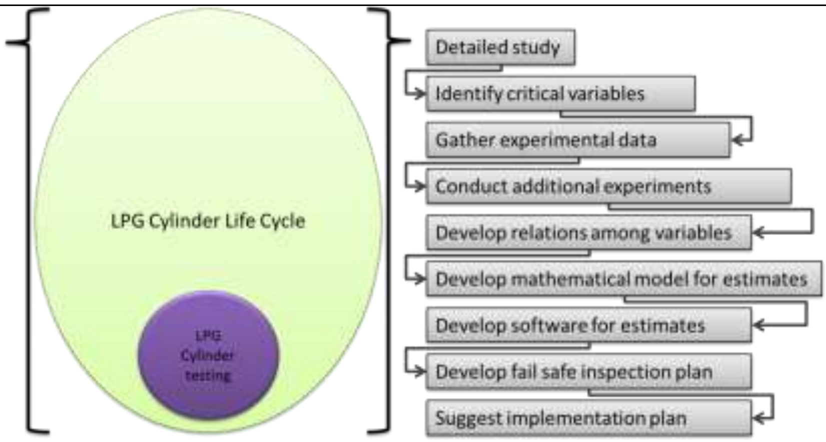


Figure 3: Research Framework

Research Framework is shown in Figure 3. It is aimed to study various phases of Cylinder life cycle and identify or justify critical variables for research. Primary test data is gathered from experiments and additional experiments are conducted on LPG cylinder to get additional data for research. Several relations are established among critical variables based on the experimental data and develop a mathematical model for estimation of critical variables. In addition to that software is developed to estimate critical variables and propose fail safe inspection plans for manufacturers. The framework also covers implementation methodology of the proposed plan without affecting the existing systems.

1.5 Content of This Report

The content of the thesis is structured in the following manner to achieve stated objectives of the research.

Chapter 1 deals with general introduction of research topics, its scope, objectives and over all research frameworks. Chapter 2 covers overview of LPG cylinder life cycle from manufacturing to scrapping. Chapter 3 deals with various tests on LPG cylinder during manufacturing with particular emphasis on acceptance test and hydro-test methods for cylinder certification process.

Chapter 4 reviews existing literature in LPG cylinder and allied field under various categories such as cylinder marketing, incidents, design, manufacturing, testing, transportation, policy development with appropriate interpretations. Chapter 5 outlines theoretical basis for the research and shows the pathway to research methodology. Research Methodology was described in detailed in Chapter 6. Chapter.7 outlines data collection process from primary source. It also states the necessity for additional experiments. Data analysis is documented in this chapter, which includes analysis of results and inferences from every statistical method adopted for the research outcome.

Chapter 8 describes the method of estimation of acceptance test results from empirical formulas. Chapter 9 gives the pathway to estimate hydro-test results from the derived empirical formulas. To ease the estimation process software was developed in Microsoft excel. This software system and methodology is described in Chapter 10. This chapter also discusses the future scope and the integration requirements with production process. Finally Chapter 11 describes fail safe inspection methods of LPG cylinders for manufacturers. This chapter describes ways to estimate critical parameters with four different sets of empirical formulas. This chapter also describes the integration requirements with the existing inspection system. Chapter 12 concludes the research with noticeable contributions in LPG Cylinder domain.

References and Appendix are consolidated and given at the end for cross reference or verification purpose. The appendix includes experimental data and key documents to support gaps in existing systems and practices.

Publications based on research are indexed and given at the end of the report. The work concluded with 9 published research papers and one international conference presentation. Four more publications are under publication process. This section concludes thesis report.

---End of Chapter 1---

Chapter-2

2. LPG Cylinder Life Cycle

An effort has been made in this chapter to document LPG cylinder life cycle from raw material to scrapping. The chapter starts with LPG cylinder terminology and sails through various phases of LPG Cylinder life cycle and ends with a discussion on various factors that can affect LPG cylinder life cycle. All critical phases of LPG cylinder life cycle are discussed in this section. Cylinder handling is the most important things that decide life span of LPG cylinders. This section ends with a brief discussion on cylinder handling with feasible solutions / remedial actions to avoid wrong handling of cylinders.

2.1 LPG Cylinder – Nomenclature

LPG Cylinder bodies are manufactured either with two pieces or three pieces construction. Terminology and parts of both two and three piece cylinders are shown in Figure 4 and is self-explanatory. Although valve is an important component attached to cylinder, it is not an integral part of LPG cylinder's body. This is required for pressure testing of cylinder during manufacturing. Hence cylinder valve is also shown in the figure.

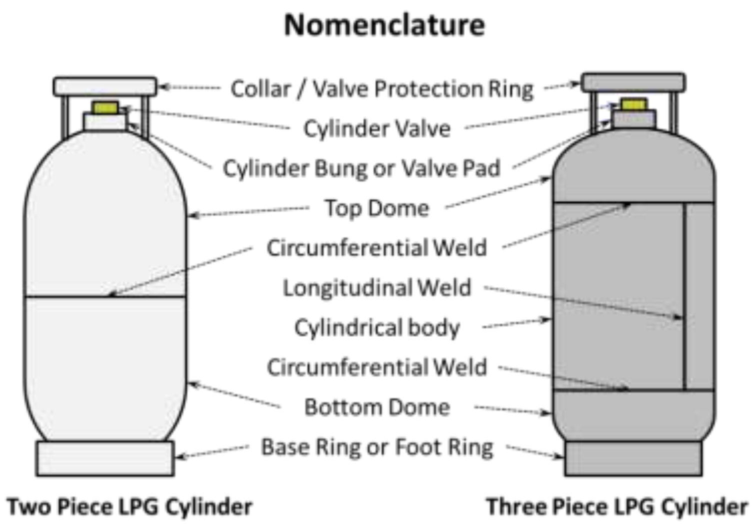


Figure 4: LPG Cylinder Terminology

2.2 Shapes of LPG Cylinder

LPG Cylinders are fabricated in three different shapes and are classified based on their domes [25] & [7]. The domes can be tori-spherical, semi ellipsoidal and hemi-spherical bodies as shown in Figure 5. Two piece cylinders (eg. Indian domestic LPG cylinders) are not fabricated with hemi-spherical domes as the body loses cylindrical shape and turns to a sphere. Design calculations for these shapes are discussed separately in this chapter. Although LPG Cylinder designs are different (based on domes), test methods to check with standards compliance is same for all shapes of cylinders and are as per Indian Standard IS 3196 Part 3 in India [27].

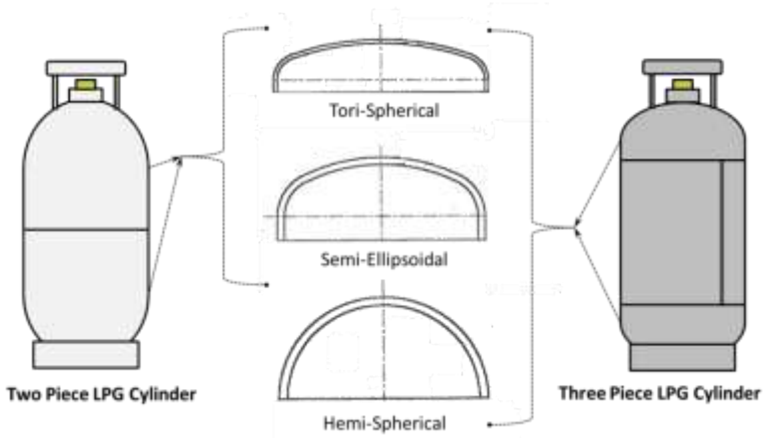


Figure 5: LPG Cylinder Shapes

2.3 Cylinders For Current Research

Indian LPG Cylinders marketed by Government oil companies for domestic use are considered for this current research. These cylinders are fabricated in two piece construction either with Tori-spherical or semi ellipsoidal domes. Water capacity of these cylinders are typically around 33.3 Liters and are manufactured as per Indian standard IS 3196 Part-1.These cylinders are tested as per IS 3196 Part 3 for Bureau of Indian Certification (ISI/ BSI Mark). Typical dimensions of LPG Cylinder for Domestic [18] use are shown in Figure 6.

2.4 Domestic LPG Cylinder Life Cycle

LPG Cylinder life cycle is described with a flow chart in Figure 7. In India, government oil companies estimate their new cylinder requirements and procure through tendering process [18]. The manufacturers supplies cylinders as per tender specifications. LPG Cylinders supplied by government oil companies are the property of respective marketing oil company (for example IOCL, HPCL and BPCL). The consumer is only owner for the gas present in it. Oil companies take ownership for the cylinder and they do all repairs and periodic statutory requalification of cylinder during its life cycle. This cost will not be passed on to consumer. Once the cylinder reaches a stage, where it is not fit for use, the cylinder is discarded from market and scraped. Below text describes various stages in LPG cylinder life cycle from cylinder manufacturing to cylinder scrapping.

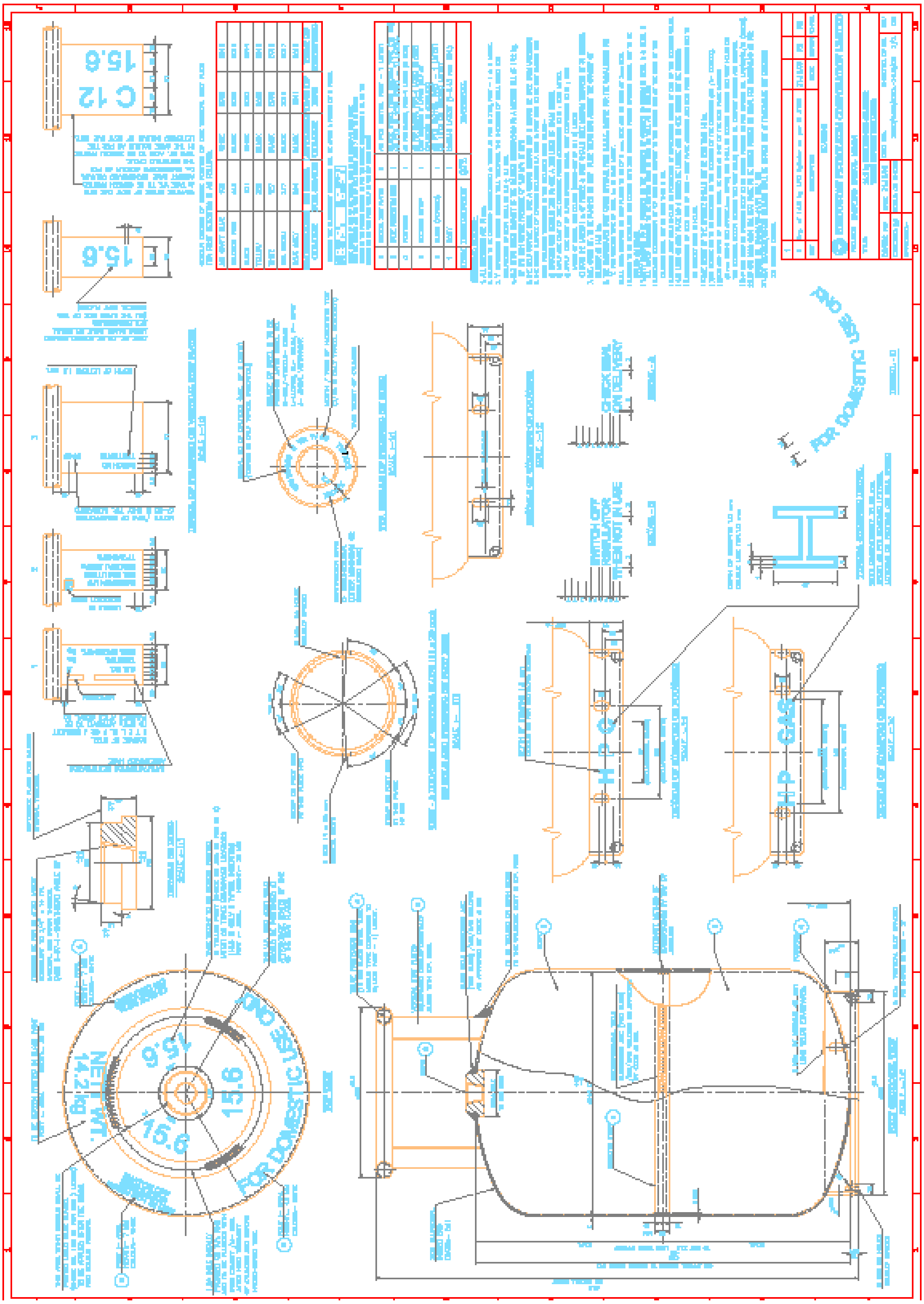


Figure 6: Domestic LPG Cylinder Specifications

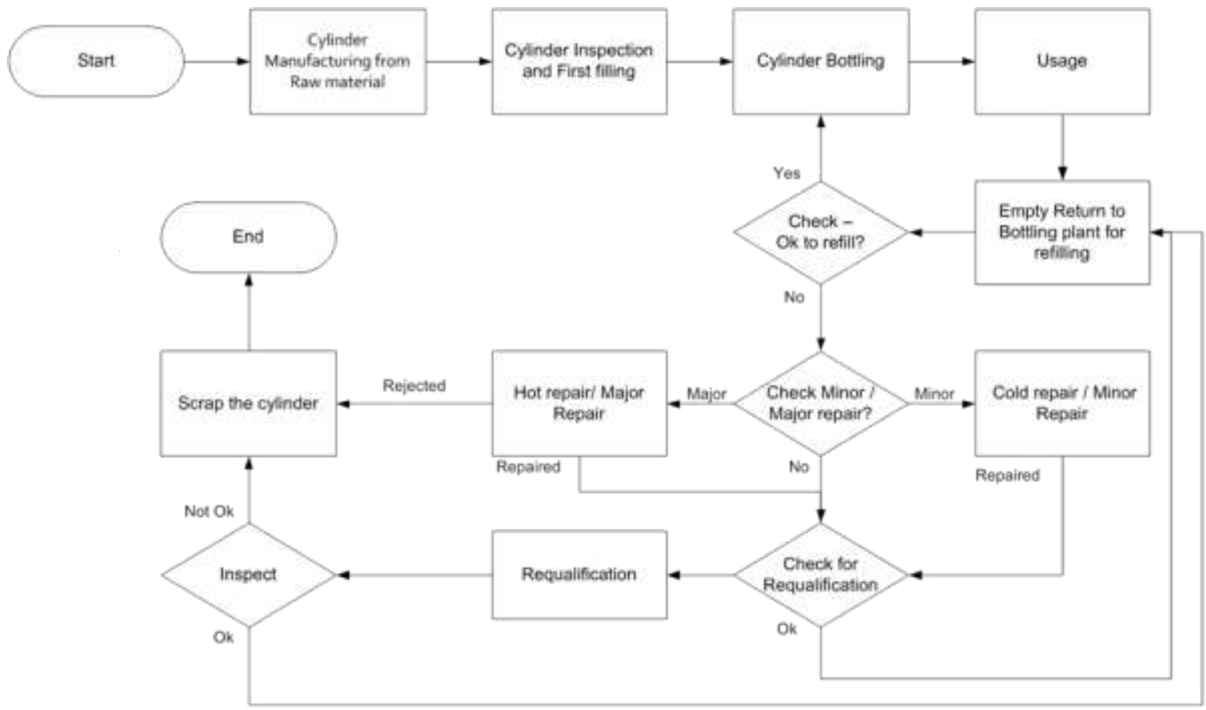


Figure 7: LPG Cylinder Life cycle

2.4.1 Raw Material

Raw material is the most critical parameter for LPG cylinder construction. Special grade steel complies with Indian standard IS 6240, *Hot rolled steel plate (up to 6 mm) sheet and strip for the manufacture of low pressure liquefiable gas cylinders* or equivalent is used for cylinder body. Standard IS 3196 specifies critical parameters of parent material viz. Yield strength, tensile strength, percentage elongation and material composition (see Table.1). The bung or valve pad should confirms to class 1A or Class2 of IS 1875, *carbon steel billets, blooms, slabs and bars for forging* or IS 2062, *Steel for general structural purposes.* Valve protection ring, Foot ring should confirm to Grade 0 of IS 1079, *Hot rolled carbon steel sheets and strip* or IS 2062 or IS 6240. If the cylinder is manufactured with a butt weld, the backing strip for the butt weld should confirm to IS2062. Majority of cylinder manufacturers are fabricating cylinders with joggling joint, where backing strip is not required for welding.

In case the manufacturer uses an equivalent raw material for cylinder construction, the finished cylinder should guarantee 240 MPa yield stress, 350MPa to 450 MPa tensile strength and the percentage of permanent elongation of parent metal should not be less than 25% when it is subjected to parent metal tensile test as per Indian Standards IS 3196 part3 (See Table.2).

Table 1: LPG Cylinder Raw Material chemical Composition

Constituent	Unit %	Permissible Variation Over max and under min. specified limit in %
Carbon (C)	0.16 max	0.02%
Silicon (Si)	0.25 max	0.03%
Manganese (Mn)	0.30 min	0.03%
Phosphorous (P)	0.025 max	0.005%
Sulphur (S)	0.025 max	0.005%
Aluminum (Al)	0.020 min	**--**
Nitrogen (N)	0.009 max	**--**

Table 2: LPG Cylinder Parent Material Specifications

Mechanical Properties			
Tensile strength MPa	Yield Stress MPa	Percentage Elongation in %	Internal diameter of bend
Between	*Minimum*	*Minimum*	*Maximum*
350-450	240	25	t

Note: where 't' is the thickness of test piece

2.4.2 Design

Wall thickness is primary factor to be arrived while designing LPG cylinder. Thickness depends on several factors such as cylinder test pressure, outer diameter of cylinder, shape of cylinder dome, yield strength of material, weld joint factor, ratio of domed end diameter to height, dishing radius, knuckle radius and length of straight flange [25]. In order to design the thickness, a test pressure of 23.53 bar and minimum yield strength is 240 MPa is considered as per Indian standard IS3196 Part 1. Further, weld joint factor to be considered as 1.0, 0.9

and 0.7 depends on type of radiographic examination adopted to check the welds during and after manufacturing process [25].

Design calculations of any cylinder are based on cylinder dome shape (see Figure 5). Thickness is calculated separately for domes and cylindrical portions of a cylinder body. The thickness whichever is higher among these two values is considered as a final thickness [25].

The thickness of cylindrical portion is calculated using below two formulas and the larger thickness value is considered as the cylindrical portion thickness of a cylinder [25][27]&[70].

$$t = \frac{PhDo}{200 \times 0.8\, J\, Re + Ph}$$

Or

$$t = \frac{PhDi}{200 \times 0.8\, J\, Re - Ph}$$

And

$$t = 0.136 \times \sqrt{D}o$$

Where

t = calculated minimum wall thickness, in mm

t_e = calculated wall thickness of doom, in mm

P_h = Test pressure, in Kgf/cm^2

D_i = inner diameter, in mm

D_o = outer diameter in mm

h_o = external height of domes end in mm

h_i = internal height of domed ends in mm

R_e = yield strength in MPa

J = weld joint factor

= 1.0 fully radio graphed welds

= 0.9 for two piece cylinder

= 0.9 where every 50 cylinders in batch are spot radio graphed as per standard

= 0.7 all other cases

K = ratio $D_o / h_o \geq 0.192$

R_i = dishing radius $\leq D_o$, in mm

r_i = knuckel radius $\geq D_o$

S_f = length of straight flange in mm

$\geq 0.3\sqrt{Dote}$

$$z = \frac{\frac{20ri}{Ri} + 3}{\frac{20ri}{20Ri} + 1}$$

Further, the thickness of a tori-spherical cylinder dome is calculated from the following formula

$$te = \frac{PhDo}{200 \times 0.8\, J\, Re + Ph} \times \frac{KZ}{5}$$

Thickness of a semi ellipsoidal cylinder dome is calculated using below formula

$$te = \frac{PhDo}{200 \times 0.8\, J\, Re + Ph} \times \frac{K(0.65 + 0.1K)}{4}$$

In addition to the above, the Indian Standard IS 3196 part 3 stipulates minimum cylinder thickness should be 2.0 mm for LPG cylinders up to and including 13 liter water capacity and 2.4 mm for cylinders above 13 liter water capacities [27]. Thus for a 33.3 liter domestic LPG cylinder thickness should be minimum 2.4 mm and maximum thickness should be as per above design calculations. Once LPG cylinder design is finalized, a prototype cylinder to be produced and to be subjected to various tests to ensure deemed fit [25]. Bureau of Indian

Standards authorities verifies and accept the design and allows the manufacturer to start production.

2.4.3 Manufacturing

Cylinder manufacturing process flow diagram is shown in Figure 8 [36]. Cylinder body manufacturing process is common across the world. However, the stay plates (also known as valve protection rings) and base ring (also known as foot ring) designs are different as per the requirements of customers (oil companies; to distinguish or to identify a cylinder). Normally cylinders are produced in batches of 203 and above. This process starts from raw material. The diagram shows both three piece and two piece cylinder manufacturing process. Steel plates are cut to the required dimensions to produce cylindrical body by rolling operation. This is only for a three piece cylinders manufacturing. Indian domestic LPG cylinders are in two piece construction and cylindrical portion does not exist for these cylinders. Valve protection rings (or collars) are fabricated by blanking; rolling and forming operations as shown in the Figure 8. There are no specific guidelines for the shape of valve protection rings as it is not an integral part of cylinder body. Hence, the shape can be differed from different marketing oil companies. Valve protection ring for Indian domestic LPG cylinder (marketed by government oil companies) is fabricated with a circular steel pipe with three stay plates attached to it (see Figure 6). The domes are manufactured by blanking and deep drawing process. The top dome undergoes trimming and piercing operations for attaching a bung to it. The bottom dome undergoes only trimming operation as shown in Figure 8. The base plates (also known as foot rings) are manufactured by blanking, rolling, welding and forming operations. Similar to valve protection ring, the base ring or foot ring shape is not specified in standard. It can be manufactured as per the requirements of marketing oil company specification. The foot rings design for Indian domestic oil company cylinders are slightly differ from these base rings shown in Figure 8 (see Figure 6).

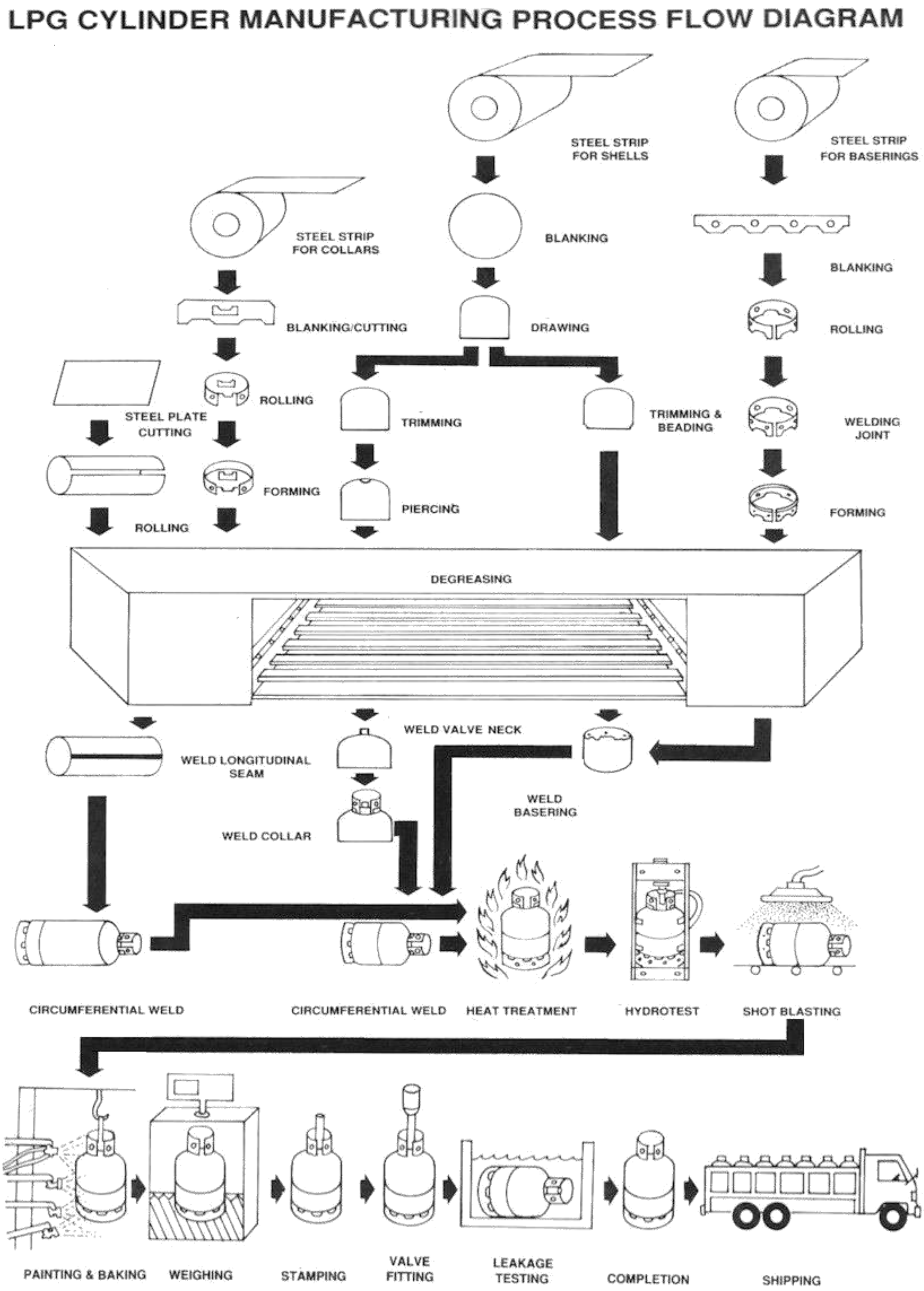


Figure 8: LPG Cylinder Manufacturing Process Flow Diagram

All these components undergo degreasing operation and then welded together to form either a two piece or three piece cylinders. The complete cylinder then subjected to heat treatment to relieve internal stresses developed due to welding operation. Welding and heat treatment are critical operation in cylinder manufacturing. The requirements of weld methods and welder qualifications are prescribed in IS 3196 Part1. Similarly the heat treatment process parameters are particularly important to get required mechanical properties in finished cylinder. Cylinder should be heat treated correctly as per the recommendations of raw material suppliers. Otherwise, the finished cylinder may exhibit tensile strength values above or below stated specifications in Indian Standard and leads to failure in cylinder mechanical properties testing (acceptance testing).

After the heat treatment process, every cylinder is subjected to hydro test. This test reveals leaks, if any in finished cylinders. At this stage LPG cylinder are subjected to test pressure for a specified period to check leaks from body and weld joint. All cylinders produced in a manufacturing location should undergo this test. Hydro test passed cylinders are sent for painting. At this stage cylinder surface is prepared either by shot blasting or grit blasting. Once the surface is prepared, cylinders are powder coated and baked to achieve smooth paint thickness all over cylinder body as per the oil company specifications. The cylinders are then weighed and stamped tare weight on their collars or valve protection rings. Also other details of cylinder like serial number, manufacturing date are punched on cylinder body. The cylinders are then fitted with a valve and tested for leaks, if any once again. LPG cylinder is ready for dispatch, if it crosses all these stages successfully.

In addition to the above, manufacturer should test few sample cylinders from each lot for ISI certification purpose. The tests to be conducted on LPG cylinders for certification are

Acceptance tests, Burst test, volumetric expansion test, hydrostatic stretch test, hydrostatic test, pneumatic leak test, radiographic examination, and fatigue /cycle test.

The acceptance test reveals the parent metal mechanical properties and weld mechanical properties. Tensile samples are cut from cylinder body and tested for measuring yield strength, tensile strength, percentage elongation and weld tensile strength. One cylinder should undergo this test for every batch / lot of 203 or above cylinders.

Volumetric expansion test indicated permanent volumetric expansion of cylinder under test pressure conditions. One cylinder should undergo this test for every batch of 403 cylinders. The same cylinder can be subjected to burst test to measure burst pressure and nominal hoop stress in cylinder at burst pressure conditions.

Radiographic examination is intended to check the weld quality and the depth of penetration. Fatigue test is a type test to check the cylinder under cyclic internal pressures. Leak tests are intended to check visible leaks in cylinders. All these tests to be conducted on sample cylinders as per Indian standard IS 3196 part3. Once the batch is accepted by Bureau of Indian standards, certified cylinders are released to market for use.

2.4.4 Filling and Usage

Typical process flow diagram of an LPG cylinder movement in a bottling plant is shown in Figure 9. Empty cylinders received in plant for filling are initially checked for body damage, repairs or requalification requirements. Once the cylinder passes this stage, cylinders are washed and dried to remove dirt and loose particles on their bodies. The dried cylinders are then sent for filling. The filling process may be either automated system on a carrousel or through standalone manual scales, depending on bottling plant size, market demand etc. Filled Cylinders undergo weight check to ensure the cylinders are filled with correct quantity.

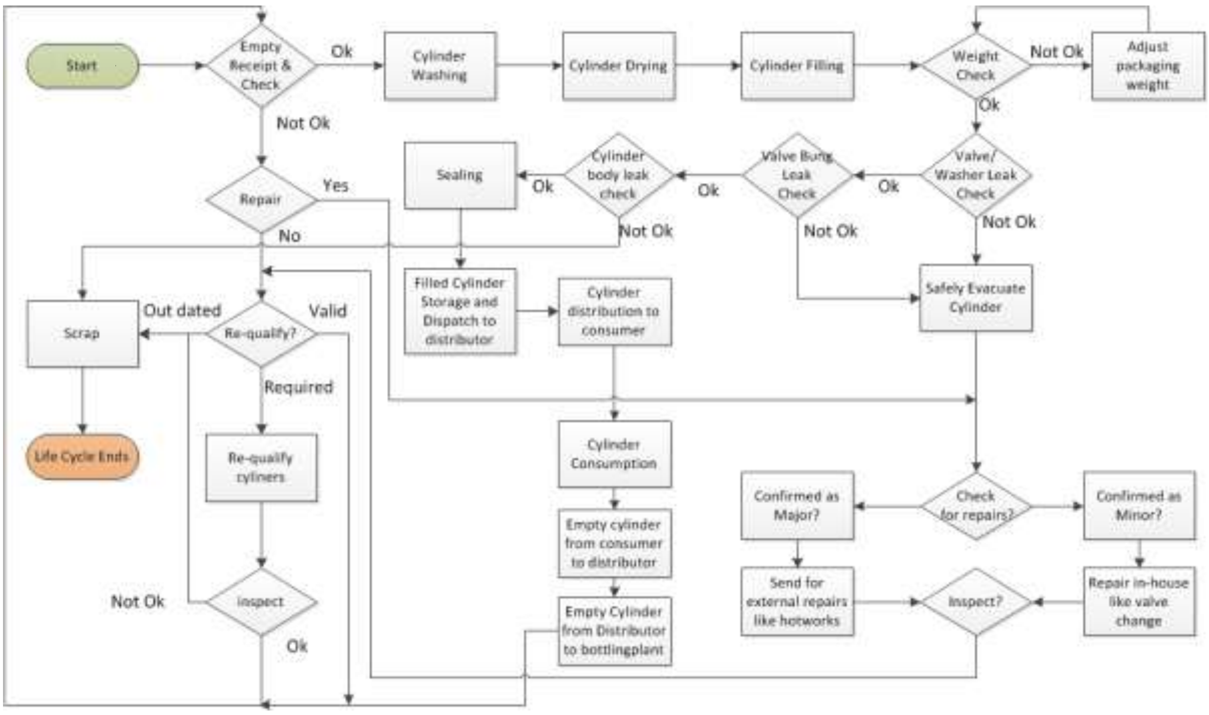


Figure 9: Cylinder Filling to Scrapping - Flow Diagram

In case of any deviation observed in weight, the quantity is adjusted in correction scale and then sent back for weight check. The filled cylinders are then sent for valve leak check, internal washer leak check and body leak checks. If the cylinder is found to be alright, the cylinder finally goes for sealing. Sealed cylinders are dispatched to dealer or customer from bottling plant. An empty cylinder from customer / dealer comes back to plant and follows the empty cylinder check and subsequent process in a cycle.

2.4.5 Repairs, Requalification and Scrapping

LPG cylinders subjected to wear and tear during usage. Suppose if any cylinder is found to be valve or internal washer or bung leak during filling, such cylinders are segregated and sent for evacuation. The product from LPG cylinder is evacuated in evacuation process (see

Figure 9). The evacuated cylinders are subjected to repairs and finally sent back to system for filling. If the cylinder found to be body leak during filling or any other stages, the cylinder needs to be scrapped, irrespective of the gravity of the leak. Similarly, if a cylinder is identified that it caught fire in its usage, it should be scrapped and no repair is allowed on such cylinders. In case cylinders are found to be severely damaged and needs replacement of foot ring or valve protection ring, such cylinders are considered as hot repair cylinders and they are transported to cylinder manufacturer or authorized hot repairer for necessary repair [96]. Hot repairing is a process in which the damaged foot rings and valve protection rings are replaced with new ones. This is performed by cutting the damaged component from cylinder body and welds a new part to cylinder. Due to involvement of welding operation, such cylinders needs to be heat treated after the hot repair process to relieve stresses generated in cylinders due to the welding operations. These cylinders need to be checked under hydrostatic test conditions for leaks before they dispatched to market. Once the cylinders are repaired and tested, they are inducted back to the system as empty cylinders for filling.

As per the statutory guidelines, all used cylinders needs to be re-qualified (Also known as retesting of LPG cylinders) at periodic intervals to ensure the cylinders are safe to withstand test pressures for its operation. Presently in India, new cylinders are to be first re-qualified after 10 years and there after the subsequent re-qualifications to be done once in 5 years. That means a new cylinder is subjected to hydrostatic test pressure after 10 years of manufacturing. At this stage, LPG cylinder is subjected to various tests including visual inspection, internal inspection, bottom pitting, corrosion and hydrostatic test. The cylinder requalification date needs to be punched permanently on cylinder body for future reference. In case the cylinder is not meeting the test hydrostatic test criteria, the cylinder needs to be scraped. LPG cylinder scraping is process, in which the cylinders are crushed after degassing a defective cylinder with the help of a hydraulic press to approximately 300 mm blanks. These blanks cannot be used in any way except steel scrap. Scraping is the end process in LPG cylinder life cycle.

2.5 Concerns in LPG Cylinder Handling

Although, at every stages of LPG Cylinder life cycle from manufacturing to bottling are regulated or controlled with several statutory regulations, guidelines and best practices, they are unfortunately ill-treated in market i.e. from the gap between dispatches of filled cylinder to receipt of empty cylinder in LPG cylinder bottling plant. This abuse is mainly in the form of body rolling, dropping cylinders from heights on hard surface, usage of wrong adaptor for withdrawing gas from cylinders, using hot water baths for generating more vapors from cylinders, illegal transfers of LPG from one cylinder to another cylinder, wet and humid kitchen condition, usage of cylinder close to hotplate etc. This kind of ill-treatment to cylinder affects cylinder life cycle and continuation of such practices reduces the life of a cylinder as described below [6].

Body rolling of cylinder in horizontal position on roads or on any hard surfaces like cemented or concrete floors, causes erosion of cylinder’s circumferential weld. This erosion leads LPG leaks from weld joint and may cause safety hazard while using a cylinder. Also this erosion causes leaks during hydro testing of cylinders when they are subjected to internal hydrostatic test pressures. As described earlier, kid of leak from hydro-testing should be scraped. Cylinders are recommended to handle only in upright positing by rolling on their foot rings. In such case, even foot ring is eroded; it can be replaced during its life cycle [6].

Dropping of cylinders from heights is a common concern in Indian market. Due to heavy weight of cylinder or insufficient infrastructure to carry cylinder, both filled and empty cylinders are dropped from trucks and from different heights at customer premises and cylinder distribution warehouses. This kind of ill-treatment badly damages foot rings, valve protection rings and cylinder body. Frequent replacement of foot ring and subsequent heat treatment process causes changes in metallurgical properties of parent metal. Such cylinders cannot withstand hydro test and needs to be scrapped much advance in their life cycle [6].

Usages of illegal or non-standard adaptors on cylinders are common in India, especially when the cylinders are connected to commercial burners while cooking large volumes of food. This practice can lead cylinder valve damage and requires valve replacement in plant. Further, Illegal product transfer from domestic cylinders to commercial cylinders or auto gas cylinders (due to duel pricing in India) is having an impact on cylinder life cycle. These transfers are performed in crude and unsafe manner. Cylinder valves are damaged severely in such crude operations and require replacement of valves in plant. Cylinder bung is having gas thread, which is a taper thread. The valve bungs are cleaned with appropriate National Gas thread (NGT) tap at the time of valve replacement. Frequent replacement of valve causes excessive wear of bung threat due to the tapping operation. This wear causes bung leaks and also regulators or adaptors cannot fit on cylinders due to insufficient gap between regulator base and the cylinder bung. Although, the cylinder body is in good shape, such bung worn out cylinders cannot be used and should be scraped [6].

Cylinder is having a limitation in LPG vapor generation in ambient conditions depending on the liquid level in cylinder. If the vapor consumption is excessive than vapor generation, sweating observed on the body of cylinder. Sweating is a phenomenon, in which the moisture from atmosphere accumulates on cylinder body due to low surface temperatures of cylinder body. This is possible if the ambient conditions are extremely humid when the cylinder is in use or the cylinder is connected to multiple appliances and the vapor consumption is more than generation. In such cases, often hot water bath is given to cylinders in Indian commercial establishments like hotels and restaurants by placing a LPG cylinder in hot water tub for producing more vapors. This practice is not advisable at all. Sweating and hot water bath leads body corrosion to cylinder. Excessive body corrosion leads erosion of cylinder body and weakens parent metal as the thickness reduces due to rusting. Such cylinders cannot pass hydro test during requalification and needs to be scrapped. Appropriate cylinder manifold design, avoiding usage of domestic cylinder for commercial purposes, avoiding usage of commercial non-standard adaptors and a system that comprises combination of cylinder with liquid withdrawal valve and a LPG vaporizer can be used for safe and reliable operation [6].

Most of Indian kitchens conditions are wet and humid. Cylinder foot rings can be damaged as a result of corrosion caused due to prolonged exposure to moisture in kitchens. This leads damage to foot ring or bottom pitting and reduction of parent metal thickness in bottom dome. Such cylinders are not fit for use. Also, in some kitchens the hotplates in kitchens are kept very close to the cylinders due to limitation in space. The pressures inside the cylinder can increase drastically if cylinder is exposed to heat. In such condition and a cylinder can fail due to internal fatigue loads and bulges its shape. This condition also ultimately leads withdrawal of cylinder from market i.e. from its life cycle [6].

Although, LPG cylinder confirms to applicable standards and statutory requirements, majority of its life is beyond cylinder manufacturer or bottling plant premises, where there is no control on wrong handling of cylinder. Any kind of wrong handling definitely affects LPG cylinder life cycle.[6]

2.6 Scholar’s Publications based on this Chapter

1. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review of Liquefied Petroleum Gas (LPG) Cylinder Life cycle." *International Journal of Advanced Engineering Technology* IV, no. III (July-Sept 2013): 37-41.

2. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review of Liquefied Petroleum Gas Cylinder Design and Manufacturing Process as per Indian Standard, IS 3196 (Part 1): 2006." *International Journal of Advanced Engineering Technology* IV, no. II (April-June 2013): 124-127.

---End of Chapter 2---

Chapter-3

3. LPG Cylinder Testing

The chapter outlines various tests that are conducted on LPG cylinder in its life cycle. Although cylinder subjected to several tests and inspections during its life cycle, Acceptance test and hydrotests are having particular importance in LPG cylinder testing. They can be conducted only on random samples and that to only in manufacturer premises at the time of manufacturing a batch of cylinders as these tests are destructive in nature. Current research focuses on these two tests and hence in-depth details are given on these two tests in this chapter.

3.1 Introduction

LPG Cylinders are inspected and tested several times in their life cycle. Critical mandatory testing stages in a cylinder life cycle are [27]:

1. Raw material testing
2. Prototype testing for design approval
3. Testing and inspections of cylinders during manufacturing
4. Statutory testing for certification
5. Quality checks at customer premises
6. Requalification / Periodic testing of LPG cylinders

3.1.1 Raw Material Testing

Before starting production, raw material needs to be tested to confirm the material is meeting raw material requirements stated in the standard. The material should confirm to Indian standard IS 6240, which states the chemical composition and material physical properties required for a LPG Cylinder raw material. Table.1 (see chapter 2.4.1) gives the chemical composition requirements and Table. 2 (see chapter 2.4.1) states material physical properties for cylinder raw material.

3.1.2 Design Approval

LPG cylinders are designed as per the chapter 2.4.2. Once the cylinder design is finalized, cylinder manufacturer need to produce few prototype cylinders as per the design specifications and the prototype cylinders needs to be tested as per IS 3196 Part1 and IS 3196 Part3. Once the prototype cylinders are meeting the requirements of IS 3196, the design is approved for production and a cylinder manufacturer can produce cylinders as per final design. The tests mentioned in IS 3196 ensure cylinder production methods adopted in a manufacturing plant can produce desired quality of cylinders. Further the following tests are conducted on cylinder to ensure the final product is exhibiting desired mechanical properties [25].

a) Acceptance tests;

b) Burst and volumetric expansion test;

c) Hydrostatic stretch test;

d) Hydrostatic test;

e) Pneumatic leakage test; and

f) Radiographic examination

3.1.3 Inspection and Testing During Manufacturing

LPG Cylinders can be produced in a manufacturing plant, after accepting prototype design testing. While producing cylinders several tests and inspections are to be carried out on cylinder at various stages during and after fabrication. These tests ensues cylinder are in line with the approved design and manufacturing standards and are [27]

- Raw material testing
- Welding inspection
- Agreed finished thickness test
- Cylinder circularity
- Surface defects examination of cylinder
- Profile regularity of cylinder
- Straightness of cylinder
- Verticality of cylinder
- Inspection of all individual components like bung, valve protection and foot ring
- Water capacity
- Radiography of welds, spot radiography
- Hydrostatic test
- Pneumatic test
- Cycle or fatigue test
- Inspection of certification markings

LPG cylinders are produced in batches. Once the batch starts producing the plant will not be stopped till completion of the batch. while producing batches, all the production parameters are kept uniform to all cylinders produced in that batch including heat treatment parameters to relieve the stresses in cylinders. Few cylinders from each batch is drawn out randomly and tested for statutory tests for accepting the batch for market use.

3.1.4 Statutory Testing

LPG cylinders produced in a manufacturing location intended for Indian market are required to be certified by Bureau of Indian Standards (BIS) and BIS mark is affixed on every LPG cylinder. In addition to that Indian LPG cylinder design specification (code number) is also mention on cylinder for market reference. In order to get BIS certification few cylinders from each batch are to be tested for compliance [25]. In every manufacturing location, two cylinders picked randomly from a fresh manufacturing batch and are subjected to statutory testing. Among these two cylinders, one cylinder is subjected to acceptance test and the other is subjected to hydrotest. Few additional tests / inspections are carried out on these cylinders along with acceptance and Hydrotests and are water capacity test, thickness test, and pneumatic tests. Further, cyclic tests are to be carried out on few cylinders to check the acceptance of cylinder for cyclic tests. Thus the following are the critical tests for statuary approval [27].

Acceptance tests

The aim of the acceptance test is to verify the parent metal properties like yield strength, tensile strength and percentage elongation of cylinder parent metal. Also, acceptance test reveals weld tensile strength of cylinder weld joints. Standard IS 3196 part 3 specifies the sample lot size, sample preparation requirements, and sampling location on a cylinder. Also, the standard states minimum requirements for accepting a lot of cylinders [25].

Burst and volumetric expansion test

Volumetric expansion test reveals the volumetric expansion of cylinder under test pressure conditions. Standard allows permanent volumetric expansion of 1/20000 the total cylinder capacity. Once the volumetric expansion test is carried out the same cylinder may be subjected for burst test to check he burst pressure of the cylinder. Based on the burst pressure nominal hoop stresses of a cylinder at burst pressure conditions are calculated. Standard states the sample size, minimum requirements of test parameters for verification purpose [25] & [27].

Hydrostatic test

All cylinders are subjected to hydrostatic test to check leaks if any, this is carried out at test pressure conditions and the pressure is applied for 30seconds to check any pressure drop or leaks from body and weld joints [25] & [27].

Pneumatic leakage test

Once service valve is fitted on LPG Cylinder every cylinder has to undergo pneumatic leak test. Under this test, pneumatic pressure of 1180 kPa is applied to cylinder to verify any leaks from cylinder body or weld leaks [25] & [27].

Radiographic examination

Radiographic examination is intended to check weld quality and the weld defects in a cylinder during manufacturing process the examination is conducted on weld overlap to check weld defects [25] & [27].

Fatigue test/cycle test

Fatigue or cyclic test is a type test. This test is conducted under cyclic loads to check the fatigue strength of cylinder and cyclic pressures [25] & [27].

3.1.5 Quality Checks at Customer Premises

Once the cylinders are manufactured and transported to customer premises, certain checks are conducted to ensure cylinders are meeting customer requirements. However at this stage only visual and body inspections can be carried out but not the material testing or non-destructive tests. Some of the tests conducted at this stage are; verification of cylinder dimensions, water capacity, tare weight check, paint thickness and primer thickness, visual marking on cylinder, dents, body damages and visual defects. Indian oil companies are having a joint venture laboratory, where they can test material quality by destroying a cylinder. However, it is not mandatory or practical to send cylinders samples across all location in India for testing purpose to this laboratory. However, every bottling plant tries to send two cylinders per LPG cylinder manufacturer in a year from their annual new cylinders receipts. These cylinders are tested in all respects to ensure quality.

3.1.6 Requalification of LPG Cylinders

All LPG Cylinders are required to undergo periodic inspection at frequent intervals to serve their remaining life. For instance, in India, new cylinders are tested first after 10 years of their initial entry and subsequently they are subjected to requalification tests once in every 5 years [45] & [Indian Standard IS 8868: 1988]. During requalification test, cylinders are tested for hydrostatic stretch test and inspected against other requirements stated in standard. If the cylinders are meeting all stated requirements, the cylinders can serve another 5 years in the market [45]. At this stage, cylinders are also checked for body corrosion, internals inspection, bung thread inspection visual damages, dents, digs, scratches, fire marks etc. and segregated accordingly or discarded from service.

3.2 Testing of LPG Cylinder at Manufacturers Premises

Although cylinders are tested and inspected as per IS 3196 particular importance is given to acceptance test and hydrotest as these tests are destructive in nature. Rest of the inspections like water capacity test, dimensions verification can be repeated if necessary, whereas acceptance test and hydrotests actually destroy cylinder for obtaining critical parameters or test results. These tests are covered in subsequent sections in more detailed manner.

3.3 Acceptance Test

Acceptance tests are mandatory tests as per statutory authorities to certify a cylinder batch and to ensure cylinders are meeting regulatory compliance as per Indian standard. These tests are conducted on Liquefied Petroleum Gas (LPG) cylinders in manufacturing location when new cylinders are produced as per Indian standard, IS 3196. For every batch of 203 cylinders or less produced in a manufacturing location, one cylinder must undergo the acceptance test. As a part of this test, a sample cylinder is selected from a manufactured batch and two tensile samples are cut from the body of this cylinder; one in longitudinal direction and the other in transverse direction or circumferential direction for testing purpose. Figure 10 below shows the sampling location for a two piece cylinder [10] & [27].

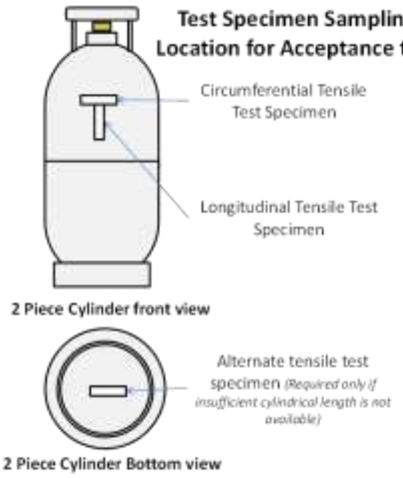


Figure 10: Acceptance Sample location

Also Figure 11below shows sample preparation method and Figure 12 refers sample dimensions for a tensile sample [3] & [27].

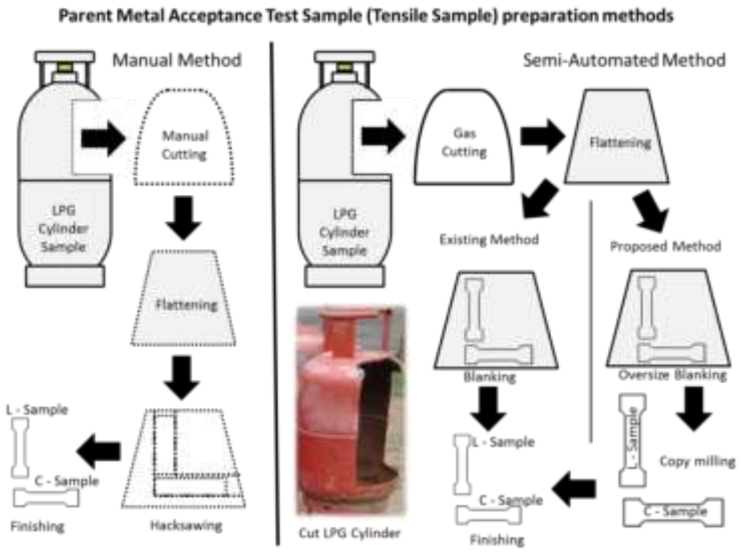
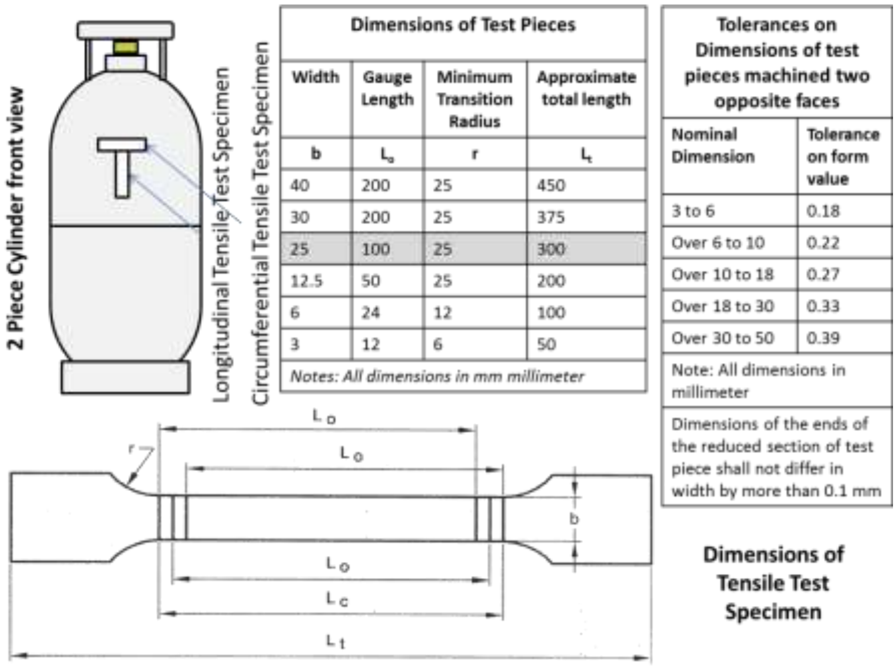


Figure 11: Sample Preparation Methods

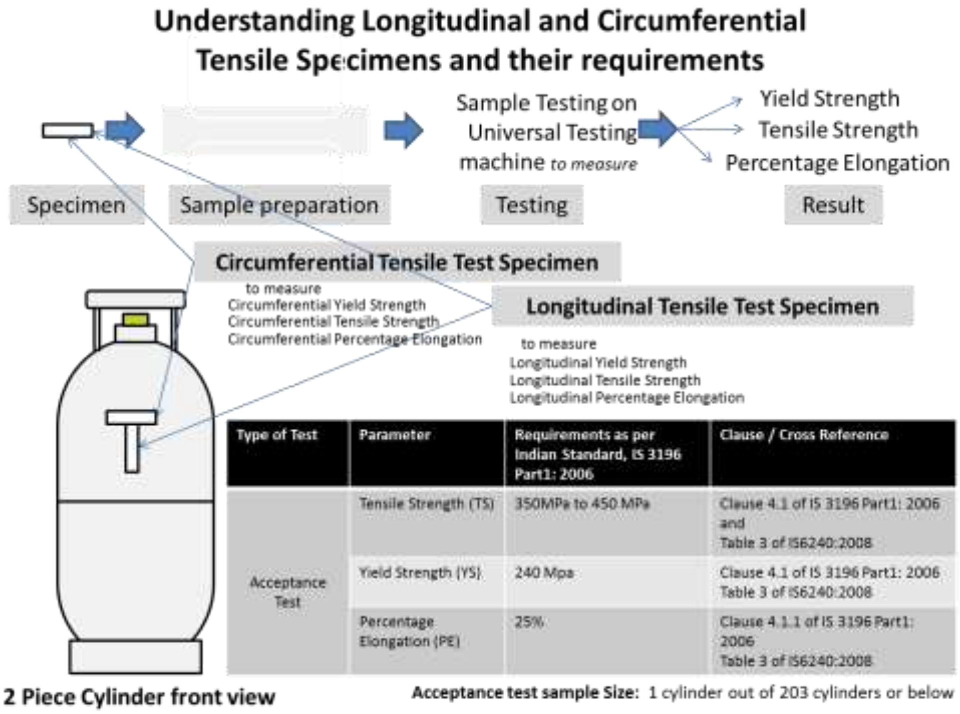


Dimensions of Test Pieces			
Width	Gauge Length	Minimum Transition Radius	Approximate total length
b	L_o	r	L_t
40	200	25	450
30	200	25	375
25	100	25	300
12.5	50	25	200
6	24	12	100
3	12	6	50
Notes: All dimensions in mm millimeter			

Tolerances on Dimensions of test pieces machined two opposite faces	
Nominal Dimension	Tolerance on form value
3 to 6	0.18
Over 6 to 10	0.22
Over 10 to 18	0.27
Over 18 to 30	0.33
Over 30 to 50	0.39
Note: All dimensions in millimeter	
Dimensions of the ends of the reduced section of test piece shall not differ in width by more than 0.1 mm	

Figure 12: Parent Metal Tensile Sample Dimensions

The tensile samples prepared as per Figure 12 [3][10]&[27] are tested on a universal testing machine to obtain physical properties of LPG Cylinder material. That is from this test; Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS) and Circumferential Percentage Elongation (CPE) of cylinder material can be measured. See Figure 13 below [10].



Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Strength (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

Acceptance test sample Size: 1 cylinder out of 203 cylinders or below

Figure 13: Understanding Parent metal tensile test

These parameters are needed to be checked against standard requirements to pass a freshly manufactured cylinder batch in manufacturing location. LPG cylinders are produced from a definitely prescribed raw material and batch production methods are implemented for producing a specific batch. Hence it is expected that all cylinders in a batch are identical and having similar physical properties. These properties are revealed from a sample cylinder subjected to acceptance test and the values are attributed to all other cylinders in the batch.

3.4 Hydro-Test

3.4.1. General

One cylinder for every manufactured lot of 403 cylinders and below is subjected to hydrotests [5][9]&[27]. Hydrotest on cylinder reveals cylinder water capacity, leaks, volumetric expansion, burst pressure and nominal hoop stress at which a cylinder bursts. Requirements of various hydrotests for LPG cylinders are mentioned in Indian standard IS 3196 part 1 and various test methods are described in Indian Standard, IS 3196 part 3. There are few factors that can influence these results during manufacturing process and are cylinder raw material selection, cylinder manufacturing process, heat treatment process parameters.

3.4.2. Types of Hydro-tests

Table.3 shows the critical parameters of hydro-tests, their acceptable limits with cross reference to Indian Standard [9] & [25]. Manufacturers should conduct the following hydro-tests on every cylinders lot produced in their units. Volumetric expansion (VE), Burst pressure (BP) and Nominal Hoop Stresses (NHS) are considered as critical parameters in hydro-testing of LPG Cylinders.

Table 3: Hydro-Test Qualification Limits

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Hydro-test	Burst Pressure	Minimum 54.92 bar	Clause 9.1.2 of IS 3196 Part3: 2012
	Nominal Hoop stress	Minimum 332.5 MPa	Clause 17.3.3 of IS 3196 Part1: 2006
	Volumetric Expansion	≥ 20% (for Tensile strength ≤410 MPa)	Clause 17.3.3.e of IS 3196 Part1: 2006

Water capacity test

In a water capacity test, cylinder water capacity is measured and checked whether they are within acceptable limits are not. Domestic LPG Cylinders in India are of 33.3 liter water capacity and its acceptable limit is within 33.30 liters to 33.95 liters as per Indian standard, IS 3196 part 1 [25].

Hydrostatic test

Every cylinder produced in a manufacturing location should undergo hydrostatic test. In this test, cylinders are subjected to hydrostatic test pressure of 25 kgf /cm2 and retain the pressure up to 30 seconds to check any pressure drop. Once the cylinder surface is dried, they are checked for leaks and pressure drop. If there is any pressure drop or any visible external leaks on cylinder body or on welds, the cylinder is disqualified for usage [25].

Hydrostatic stretch test

One cylinder from every manufactured lot of 403 and below should undergo hydrostatic stretch test. This test can be performed either with water jacket method or non-water jacket method described in IS 3196 part 3. The test cylinder is submerged in a water bath for conducting the test, in a water jacket method. In the contrary, the cylinder is tested openly in a non-water jacket method. In both cases there is a provision to control and measure the water pumped to cylinder. Initially a cylinder is filled with measured quantity of water say, C1. This filled cylinder is gradually pressurized with water till it reaches hydrostatic test pressure of 25 kgf /cm2 through an apparatus that can measure the pumped water quantity in a precise manner. Once the pressure reaches, the test pressure, the pressure is retained for not less than 60 sec and measures the water contained in the cylinder as C2. The water capacity of cylinder is measured once again after releasing the test pressure and recorded as C3. Based on the records, the volumetric expansion is calculated as; the difference between C1 and C2 represents the total volumetric expansion and the difference between C1 and C3 represents the permanent expansion. This value is within 1/5000 of the original volume of the cylinder [27].

Burst test and nominal hoop stresses

One cylinder from every manufactured lot of 403 and below should test for measuring burst pressure and nominal hoop stresses. Generally the cylinder tested for volumetric expansion test can be used for this purpose. In this test, cylinders are subjected to continuous hydrostatic internal pressure till it bursts. The internal pressure of cylinder at which it bursts is noted and recorded as burst pressure. Based on this burst pressure nominal hoop stresses are calculated using below formula [27]

$$fb=(Pb \times Di)/2t$$

Where, fb-nominal hoop stress at which destruction occurs; Pb-Internal hydrostatic pressure at which cylinder bursts in MPa; Di -Nominal original internal diameter of the cylinder in mm and t-minimum agreed finishing thickness of the cylinder in mm.

3.5 Scholar’s Publications Based On This Chapter

1. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review on Liquefied Petroleum Gas cylinder acceptance test as per Indian Standard, IS 3196 (Part 3): 2012." *International Journal of Advanced Engineering Technology* IV, no. II (April-June 2013): 119-123.
2. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Study on Hydro testing of LPG Cylinders." *International Journal of Engineering and Innovative Technology* III, no. I (July 2013): 167-170.

---End of Chapter 3---

Chapter-4

4. Literature Review

The chapter discusses existing literature available in LPG cylinder specifications and allied areas. Literature was reviewed under broad relevant heads and the inferences are recorded briefly under each category. It is evident from the literature that there is a chance to entry of non-complied cylinders into market due to gaps in national and international standards on cylinder sampling and test methods. Also, literature provides a basis for various cylinder parameters that can be studies for developing relations among several parameters. The chapter ends highlighting gaps in existing standards systems and procedures.

4.1 General

Literature review carried out under the following broad categories. Summary of inferences, gaps from literature review is given under each category.

Table 4: Summary of literature survey

Main theme	No of references
Cylinder marketing	5
Cylinder incidents	8
Cylinder design	13
Cylinder Material properties	8

Cylinder Manufacturing	6
Guidelines and Standards	29
Policy development and analysis	4
Other documents related to the field of study	10+

4.2 Cylinder Marketing

The following documents reviewed under the category of cylinder marketing

- LPG As a cooking fuels option for India[13]&[14]
- Management of Supply Chain in Petroleum Corporations in India [15]
- Understanding the political economy and key drivers of energy access in addressing national energy access priorities and policies [49]
- Scenario analysis of household energy use in India [16]
- Residential market for LPG [100]

It is understood that the 17.5 % of Indian homes are equipped with LPG as a cooking fuel and it is equivalent to 33.6 million numbers. This is a huge number. The supply chain of LPG Cylinder management is critical for the operating firms particularly the initiatives taken towards green supply chain, where in emphasis is on optimize the entire supply chain. Although the potential exists, infrastructure needs to strengthen in terms of reliability for increasing the access of energy

4.3 Cylinder Incidents

The following documents reviewed under this category

- Identification Of Technological Disaster Prone Areas In Province Punjab, Pakistan [1]
- Modelling The Performance Of Coated LPG Tanks Engulfed In Fires[42]&[43]

- Risks Of Fire And Explosion Associated With The Increasing Use Of Liquefied Petroleum Gas [85]
- Risk Reduction In Road And Rail LPG Transportation By Passive Fire Protection [73]
- Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity For Low Pressure Liquefiable Gases Part 3 Methods Of Test [3]
- Transport of dangerous goods through road tunnels [48]
- Boiling Liquid Expanding Vapor Explosions (BLEVEs) [64]
- Measures to avoid a hot BLEVE of a LPG tank [69]

Increase use of LPG enhances the risk of boiling liquid expansion vapor explosion (BLEVE). In simple terms, BLEVE is an intense explosion due to sudden and rapid expansion of LPG. It is evident from the studies that the BLEVE triggered secondary fires due to flying hot objects due to explosion. Although there is no direct study on material safety vs. BLEVE, improper heat-treat on LPG Cylinder can cause cylinder to burst with fragments in burst test of LPG Cylinder. These fragments are the main reason for secondary fires associated with BLEVE.

4.4 Cylinder Design

The following documents reviewed under this category

- Pressure-Temperature Diagram Analysis Of Liquefied Petroleum Gas And Inspection Of Retrograde Phenomenon [72]
- A New End-Closure Design For DOT-4BA Propane Cylinders [105]
- Burst Tests And Volume Expansions Of Vehicle Toroidal LPG Fuel Tanks [106]
- Determination Of Burst Pressure And Location Of The DOT-39 Refrigerant Cylinders [101]
- Determination Of Stress And Deformations Analysis On LPG Steel Cylinder [90]

- Determination Of Stresses Of LPG Gas Cylinder By Finite Element Method [78]
- Effects Of Weld Zone Properties On Burst Pressures And Failure Locations [104]
- Finite Element Analysis Of LPG Gas Cylinder [66]
- Minimum Material Design For Propane Cylinder End Closures [102]
- Stress Analysis Of LPG Cylinder Using Ansys Software [67]
- Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity For Low Pressure Liquefiable Gases Part 1 Cylinders For Liquefied Petroleum Gases (LPG) – Specification [25]
- Design and analysis of LPG cylinder using ANSYS software [33]
- Design and finite element analysis of FRP LPG cylinder [71]

From the literature, Cylinder thickness is the critical factor in designing. If the thickness is increased the cylinder safety increases in conventional design. However the weight of the cylinder increases proportional to thickness. The cylinder specifications states, the thickness is based on yield strength and test pressure, weld joint factor and the diameter of cylinder. Among these parameters the yield strength can be obtained only with tensile testing of cylinder material.

While analysis stresses and deformation studies on cylinders, critical factors are identifies such as tensile strength, yield strength, percentage elongation, burst pressure and volumetric expansion. Limits for these parameters are given in Indian Standards for further reference. From studies, it is evident that the burst test and volumetric expansion can be estimated using mathematical models for LPG fuel tanks that are large capacity cylinders that are not intended for domestic consumption. In small cylinder segment like refrigerated cylinders, the burst pressure and its location can be predicted with mathematical models. Softwares like FEA, ANSYS, Pro-E WILDFIRE can be used for estimation of stress in cylinders. However, this software cannot be used for routine laboratory tests as these are expensive, cannot be operative in shop floor and are not possible to integrate with online field equipment, where instantaneous response is solicited.

4.5 Cylinder Material Properties

The following documents reviewed under this category

- Comparison Of Hardness, Tensile Stress And Yield Stress, Depending On Temperature And Annealing Time Of Degradation Of P91 Steel [37]
- Correlation Between Hardness And Tensile Properties In Ultra-High Strength Dual Phase Steels – Short Communication [68]
- Effect Of Cooling Rate On Hardness And Microstructure Of Aisi 1020, Aisi 1040 And Aisi 1060 Steels [2]
- Effect Of Soaking Time On The Mechanical Properties Of Annealed Cold-Drawn Low Carbon Steel [76]
- Experimental And Analytical Investigation Of Thermal Coating Effectiveness For 3m3 LPG Tanks Engulfed By Fire [43]
- Fuzzy Regression Analysis: An Application On Tensile Strength Of Materials And Hardness Scales [95]
- Influence Of Degree Of Cold-Drawing On The Mechanical Properties Of Low Carbon Steel [74]
- Estimation Of Yield Strength From Hardness Measurement [84]

Form the literature; it is evident that correlations relationship is possible among hardness, tensile strength and yield strength. It is also evident that the heat treatment process on low carbon steel there is a relation between of steel effects its mechanical properties such as hardness, yield strength, tensile strength and ductility in other words percentage elongation.

This depends on soaking temperatures and time. The Indian standards on LPG Cylinder states repeated heat treatment on LPG cylinders till they pass the acceptance test instead of discarding a failed batch during the production process. This scenario affects mechanical properties, based on the literature study. Also the few studies revealed linear relation between yield strength and hardness on low carbon steel. Cylinder domes are manufactured with deep drawn domes. The cold drawing process can influence mechanical properties especially, tensile strength and hardness. Yield strength, tensile strength and ductility reduces with increased cold drawing operation on a steel sample.

4.6 Cylinder Manufacturing

The following literature reviewed under this category

- Effective LPG Cylinder Distribution To Shun Black-Marketing Of Gas Cylinders [65]
- Models For Resource Allocation Decisions: A Case Of Liquefied Petroleum Gas (LPG) Cylinder Manufacturing Company[86]
- Production As A Service: An Analysis Of Theory Of Constraints (TOC) Methods [81]
- The Increase Of Sustainability In Cylinder Manufacturing [79]
- Theoretical And Practical Evaluation Of Plastic Deformation And Straining Throughout Cupping The Shells Of Domestic LPG Cylinders [17]
- Code of practice for visual inspection of newly manufactured low pressure welded steel gas cylinders during manufacturing [53]

Cylinder manufacturing process, activity based costing of individual process in cylinder manufacturing process is reviewed. It is evident from the literature that the heat treatment is a critical operation in cylinder manufacturing to relieve the stress produced due to welding operation. The heat treatment is the most expensive operation in cylinder manufacturing process.

4.7 Guidelines and Standards

The following guidelines and standards are reviewed under this category

- Comparisons of DOT ISO BS Standards on LPG Cylinder Specifications [83]
- Indian LPG Cylinder Specifications IS3196 part1 2006 A1 to A5 [25]
- Indian LPG cylinder test methods IS 3196 Part3:2012 [27]
- BS 5045 - British Standard for Transportable Gas Containers[21]
- BS EN 1442-2006 British Standard for Transportable Cylinder Specifications[19]
- BS EN 10002-1 Metallic materials - tensile testing [22]
- BS EN 12807-2009 [23]
- US standards, DOT Cylinder Specifications 4BA [40]
- DOT Specifications for periodic testing and inspection of Cylinders [75]
- EN 10002-5 Metallic testing at elevated temperatures - tensile test [32]
- Gas cylinder Rule 2004 [70]
- Gulf standards for LPG Cylinders, GSO-ISO-22991-2008-E [99]
- Guide to Gas Cylinders - Newzeland standards on Gas Cylinders [39]
- Guidelines for Good Safety Practices in the LP Gas Industry [94]
- Hazardous Materials Requirements for DOT Cylinder specifications [40]
- Cylinder raw material standard, IS6240 2008 [26]
- ANSI standard on LIQUID PROPANE GAS (LPG) FUEL CYLINDERS [12]
- Gas cylinder standard ISO 4706-1 Standard [63]
- ISO Standard for LPG Cylinders, ISO 22991 Standard [99]
- LP Gas Serviceman's manual [77]
- Periodic testing and inspection of used LPG Cylinders Tender specifications [97]

- Steel - Conversion of elongation values part1 carbon and low alloy steels ISO 2566-1 1984 [50]
- Welding guidelines for a metallic material grouping system [30]
- Steel sheet and strip for welded gas cylinders [20]
- Rules for rounding off numerical values while calculating percentage elongation [24]
- Guidelines for liquefied petroleum gas cylinders [46]
- Code for unfired pressure vessels [52]
- Inspection and conditioning of used LPG cylinders [56]
- Oman LPG Standard 120 [93]

From various guidelines and standards, it is understood that Indian standard is similar to European standards in terms of test methods and sampling procedures. However, the American standard is slightly different in test methods. Cylinders than can meet European standards can also meet American standards. Whereas cylinders are compiled to American standards require additional tests to meet European standards. Reviewed raw material specifications, welding process parameters, inspection methods, test methods at various stages of LPG Cylinder life cycles studies in this section.

Only 1 cylinder out of 203 cylinders is tested for acceptance test as per Indian standard and one cylinder out of 403 is tested for hydro test to ensure material properties. The sample size is very small and is not fit into any of the statistical sampling methods. American standard requires only circumferential sample testing whereas Indian and European standards requires both circumferential and longitudinal sample testing for acceptance test. There is no clause for rejection criteria in Indian standard if the sample is not qualified in acceptance test. The standard is lenient and allows re-heat treatment of cylinder batch till the batch gets passed in the test.

4.8 Policy Development and Analysis

The following literature reviewed under this category

- Bureau of Indian Standards List of License holders for LPG Cylinder manufacturing [31]
- Bharat petroleum Tender specifications for New cylinders – Non complied cylinders and suspension clause [18]
- Bureau of Indian standard consolidated suspension list for a year [28]
- De-regulation of LPG and diesel prices: a look at an alternative policy [41]

There are more than 125 cylinder manufacturers in LPG Cylinder manufacturing to cater the needs of LPG Cylinder market in India. Oil companies witnesses LPG Cylinder failures in market and they include the inspection clauses in their tender documents on cylinder manufacturer suspension procedures, if they are not meeting the standards. It means there is possibility to present a non-complied cylinder in market, which is perfectly certified by BIS and marked with BIS logo on it. Interestingly from a BIS site, one can access the number of cylinder manufacturers' suspension details in a particular year. However, the consolidated list of suspensions of cylinder manufacturers shows no records, which is contradictory. In simple terms, even though BIS certifies LPG Cylinders, non-compliant cylinders can exist in market. This is recognized by Indian oil companies. There is no clear policy in the existing system to curb the entry of non-compliant to consumer. There are few cases on Cylinder manufacturers that show business practices adopted in this segment is not so transparent, due to demand and high competition [35]. There is no clear policy to control in the existing scenario.

4.9 Miscellaneous documents related to the field of study

The following literature reviewed under this category

- A handbook of the petroleum industry [38]

- Oil and gas production handbook [47]
- Code of practice for training and testing of metal arc welders [51]
- Glossary of terms used in gas cylinder technology [54].
- Steel - conversion of elongation values: part 1 carbon and low alloy steels [55]
- Carbon steel billets, blooms, slabs and bars for forgings[57]
- Hot rolled carbon steel sheets and strips [58]
- Steel for general structural purposes [59]
- Metallic materials - tensile testing at ambient temperature [61]
- Energy Access [92]

This is a general category in which the areas broadly covered are LPG cylinder testing, tensile testing, raw material, welding processes to support main research domain.

4.10 Summary

It is evident from literature, existence of non-complied cylinders in market is possible and there is no policy / method to curb this scenario. Lack of sufficient samples for the destructive test, no clarity on defective cylinders in market, vast LPG Cylinder population / market requires a system to control such occurrences. It is only possible with the verification of all cylinders produced in manufacturing with a fail-safe system. Literature provides the basis for the research by showing the gaps and the linkages for addressing the gaps. Although direct literature is not available on LPG material similar to cylinder parent metal is available for study. Based on the literature, a strong base can be established that clear relations can be established among various parameters of cylinder material. Also literature can provide various other aspects to be considered while establishing relations. From the literature base, it is possible to establish relations and estimate all critical parameters using hardness, tensile strength and percentage elongation.

---End of Chapter 4---

Chapter-5

5. Theoretical Base

The chapter explains theory and concept behind current research. The chapter outlines steps to achieve intended objective with a systematic description on research focus and the rationale behind identifying the critical parameters. Further, the chapter theoretical outline for relationships among various critical parameters with a feasible mathematical model to estimate these parameters.

5.1 General

The objective of this research can be achieved by the following broad steps and the dimension of each step is given in the subsequent section.

- Study various parameters of cylinder material
- Identification of variables
- Collection of experimental data
- Conduct hardness tests / experiments on cylinders
- Develop relation among the variables
- Develop empirical formula to estimate critical values

- Develop a fail-safe inspection plan for manufacturing
- Develop a software to estimate values
- Suggest feasible implementation plan

5.2 Identification of Various Parameters and Cluster of Focus

The current research focuses on estimating results of longitudinal and circumferential acceptance tests and Hydro-tests. The scope inclusions and scope exclusions are shown in below Figure 14 for easy understanding.

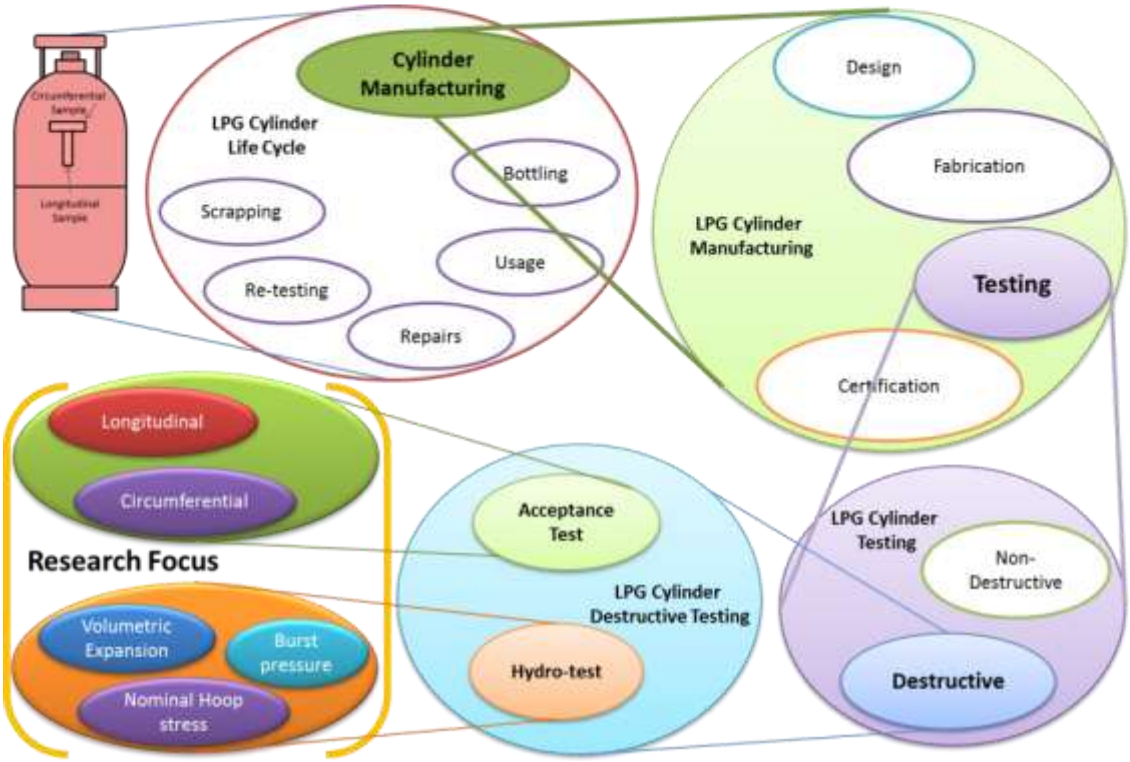


Figure 14: Cluster of Research focus

Based on current research, the critical parameters of acceptance test and hydrotest can be estimated

5.3 Identification of Critical Parameters

From the research focus, 11 critical parameters are identified based on the literature survey[27] and are Circumferential Tensile Strength (CTS), Circumferential Yield Strength

(CYS), Circumferential Percentage Elongation (CPE), Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Hardens (BHN), volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoop Stresses (NHS). Also from literature, it is evident that tensile strength and hardness are related [37]. Further, literature provides strong basis for obtaining hardness without destroying a sample [103]. Thus, hardness is also joined as one of the critical parameter for the study. Once again to establish reliability of hardness obtained by non-destructive methods can be verified with a conventional test. Thus, surface hardness and material hardness are added to critical parameters for the study. Figure 15 below shows how to get these values in conventional methods.

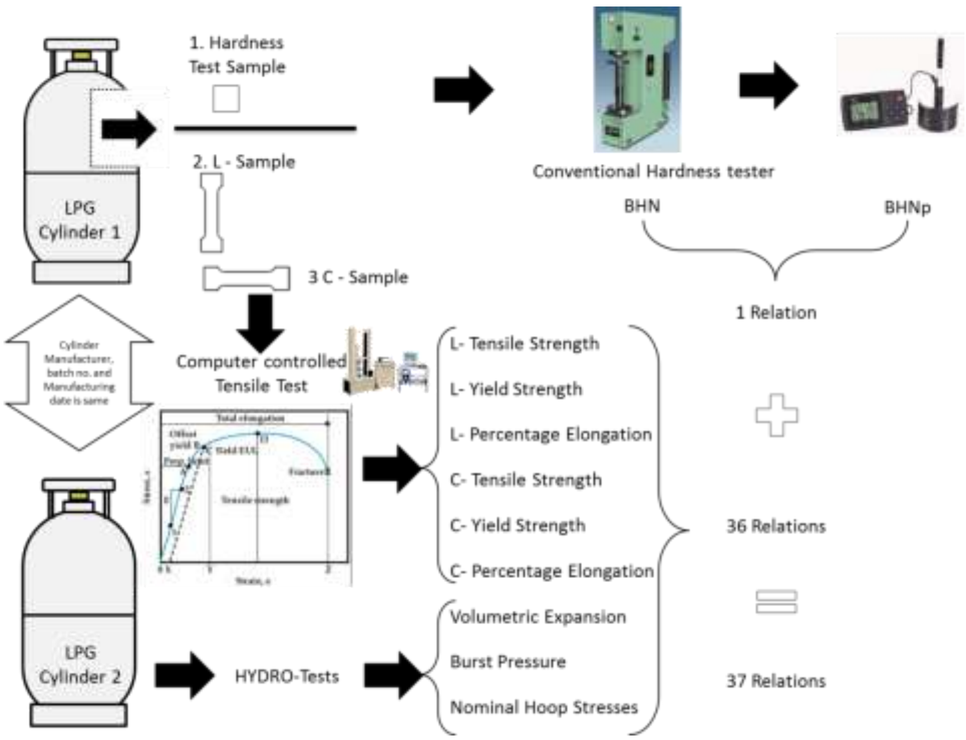
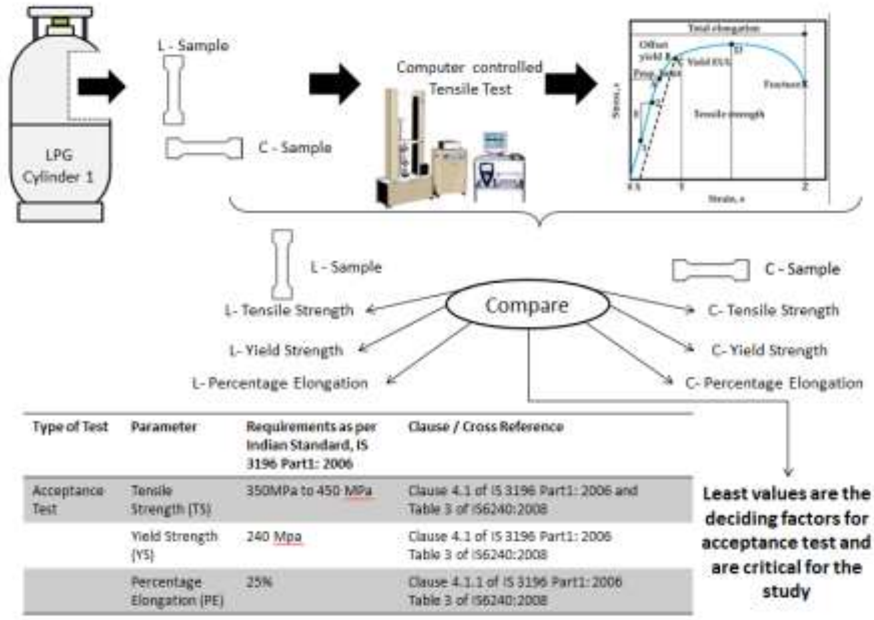


Figure 15: Critical parameters of Cylinder material

5.4 Relationships among various Critical Parameters

Among the 10 critical parameters, few critical parameters are carefully scrutinized and decided, which parameters to be considered for building the model and developing estimation plan. For this purpose, similar parameters (yield strength, tensile strength and percentage elongation) of longitudinal and circumferential values are analyzed to check the influencing parameter among the two values. The concept is shown in below Figure 16.



Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Strength (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

Figure 16: Comparison between Longitudinal and circumferential samples

5.5 Relationship among Hardness, Tensile Strength and Yield Strength

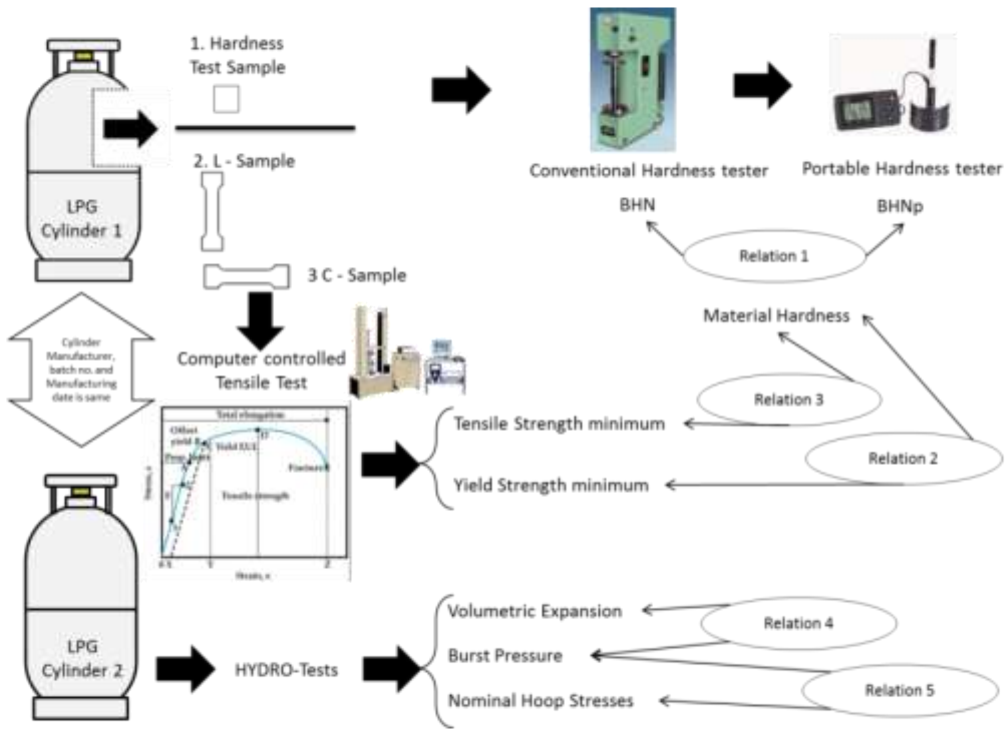


Figure 17: Few relations among various variables

Once the critical parameters are identified from acceptance test, develop major relations as per literature survey like hardness vs. yield strength and hardness vs. tensile strength. Similar relation can be established for hydro test results. The concepts of developing relations are shown in below picture. Referring to Figure 15 and Figure 17, total 37 relations can be established with 11 critical parameters.

5.6 Theoretical Framework for estimation of Critical Parameters

Cylinders are manufactured from a definitely prescribed raw material having control at the time of raw material intake for production and using standard practices for producing cylinders, all the cylinders produced under same design and manufacturing conditions exhibits similar properties. Based on this fact, it is expected that cylinder critical parameters can exhibit relations among themselves. Correlation and regression analysis can be used for identifying various relations and empirical formulas for estimating from one common independent parameter such as cylinder surface hardness. Thus, a mathematical model can be developed for estimating all critical parameters for estimation purpose. Figure18 and Figure 19 below shows the framework of mathematical model for estimating critical parameters of LPG Cylinder material using either circumferential or longitudinal values.

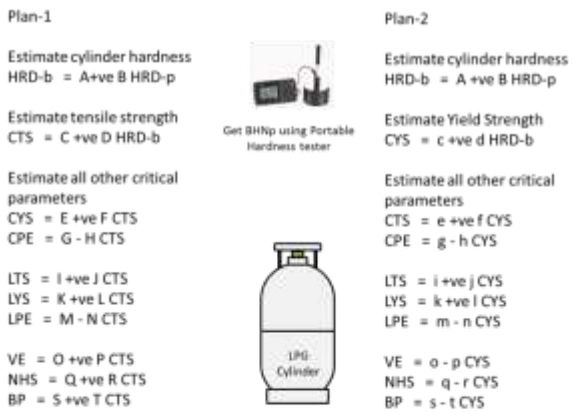


Figure 18: Estimation of critical parameters - framework

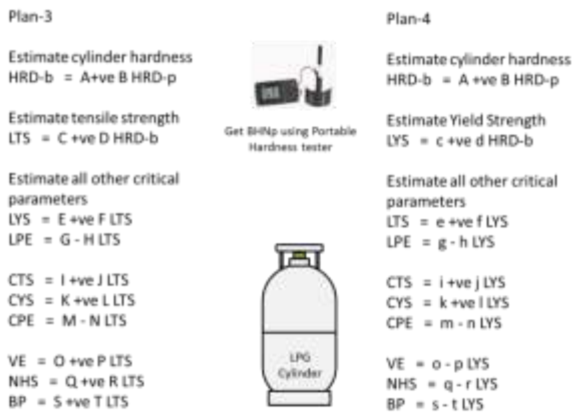


Figure 19: Estimation of critical parameters - framework

---End of Chapter 5---

Chapter-6

6. Research Methodology

Research methodology adopted for current research is discussed in detail in this chapter, which is an extension to previous chapter. The methodology adopted here is a combination of theory, analysis of primary data and experiments. The chapter also outlines various statistical methods and tools used in research to get the intended results.

6.1 Methodology - Overview

The core idea behind the research is to estimate all LPG cylinder critical properties from cylinder hardness value. Although, it is a single sentence, it is not as simple as stated. From the literature survey it is established that tensile, yield strengths can be estimated from hardness values of low carbon steel [37][88] &[84]. It means, if the cylinder hardness is known, tensile strength and yield strength can be estimated. However, conventional hardness test such as Brinells hardness test is also one kind of a destructive test and the indentation from hardness tester can causes local destruction. Such cylinder cannot be used in market as the thickness is reduced below acceptable value at testing spot . Although, conventional hardness test cannot be conducted simply on cylinders to estimate its critical properties, advanced portable hardness testers can be used to get readings of surface hardness directly in Brinells Hardness Number (BHN), which can be compared later with actual metal hardness [87]. In such case the surface hardness of cylinder can be obtained without destroying a cylinder. However, the surface hardness of cylinder is not reflecting the true hardness due to sand blasting operations involved in cylinder manufacturing process[4]. Surface hardness is expected to be higher than cylinder material due to sand blasting operations during manufacturing process for painting process. In order to examine this fact, experimental research was planned on domestic LPG cylinders to study the surface hardness and actual metal hardness values and to derive a relation among these two parameters. With this relation accurate parent metal hardness can be obtained from a portable hardness tester (surface hardness value) without destroying the cylinder.

Estimating all acceptance test and Hydro-test critical parameters of cylinder material is not so simple even though the cylinder hardness is available. In an acceptance test, all LPG Cylinders are checked for their parent metal properties in two perpendicular directions. I.e. Two tensile samples are drawn from LPG Cylinders, one in longitudinal direction and the other in circumferential direction [25]. These test specimens are tested on universal testing machine to determine yield strength, tensile strength and percentage elongation. It means 6 different properties viz. Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS), Circumferential Percentage Elongation (CPE), Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS) Longitudinal Percentage Elongation (LPE) are measured in acceptance test. Although there are two sets of properties for LPG Cylinder material (one in longitudinal direction and the other in circumferential direction), Indian standard explicitly does not state the requirements for these parameters separately [25]. Hence, it is necessary to examine the influencing or critical properties from these two sets using experimental data. This analysis reveals critical properties that can affect acceptance or rejection of new cylinder batch produced in manufacturing location. Once the influencing properties of acceptance test are known it is easy to get these values from cylinder hardness.

Indian standard specifies all LPG Cylinders are to be produced in batches from definitely prescribed raw material [25]. The standard also provides guidelines for cylinder production, inspection, testing and certifications with in set of limits. However, each batch should be produced with same raw material and with production methods. Cylinder produced with prescribed raw material, standard production and testing methods exhibits meaningful correlations among various physical properties of acceptance test. Thus, all properties of acceptance test can be correlated and empirical formulas can be developed in terms of yield strength or tensile strength. It means, if the yield strength and tensile strength is known, all acceptance test properties can be estimated with empirical formulas [11].

Similarly, in a LPG Cylinder hydro test, volumetric expansion (VE), burst pressure (BP) and nominal hoops stresses (NHS) are calculated and are considered as critical parameters [5] & [9]. These parameters are again depends on cylinder yield strength and tensile strength and percentage elongation as they are manufactured with same raw material and same manufacturing processes parameters. Thus if the correlations are established with empirical formulas, these values can also be obtained either with tensile strength and yield strength values.

The methodology works in simple way. If cylinder hardness is measured with a portable hardness tester to get the actual cylinder hardness and this is used to estimate minimum yield strength or tensile strength of cylinder material. The yield and tensile estimates are further used to estimate all acceptance test and hydro-test results of an LPG Cylinder. If a tool or software is developed to estimate these values quickly and instantaneously, 100% cylinders can be tested in a manufacturing location without destroying them for their material compliance. Also the same method can be used to estimate the cylinder properties in market in failure or accident investigations. This software can be integrated in future with a portable hardness tester itself and that can be installed online for estimating the cylinder physical properties while manufacturing as a fail-safe inspection plan.

Thus, the methodology for carrying the current research is segmented in three major categories as shown in Figure 20 and are

1. Analysis of primary data
2. Experimental research
3. Theoretical framework

6.2 Sampling

In existing practices, all LPG Cylinders are tested and certified by Bureau of Indian Standards at manufacturing locations. These cylinders are once again randomly tested in an independent 3rd party laboratory for ensuring compliance with standard. Cylinders are being the property of Indian marketing oil / Gas companies, Indian oil / gas companies are having their independent joint venture laboratory for testing the quality of these cylinders independently irrespective of the marketing company. This laboratory, LPG Equipment Research Centre is located in Bangalore and having both Bureau of Indian standards authorization and national accredited board of laboratories (NABL) accreditation for their testing practices. It is not possible to conduct experiments on LPG cylinder as they are the properties of oil companies; the primary data on acceptance test and hydro test are collected from this laboratory for analysis purpose. 55 Domestic LPG Cylinders acceptance test data and 40 cylinders hydro-test data is collected from the independent laboratory for this purpose (details are given in Annexure section). In addition to that the laboratory cooperated and helped in conducting experimental analysis on 55 domestic cylinders to get hardness values using two different test methods (brinells hardness tester and portable hardness tester). These experiments were conducted in a commercial NABL accredited commercial laboratory in Bangalore. Detailed test certificates and the NABL accreditation details (on the letter head) are in the annexure as supporting documents

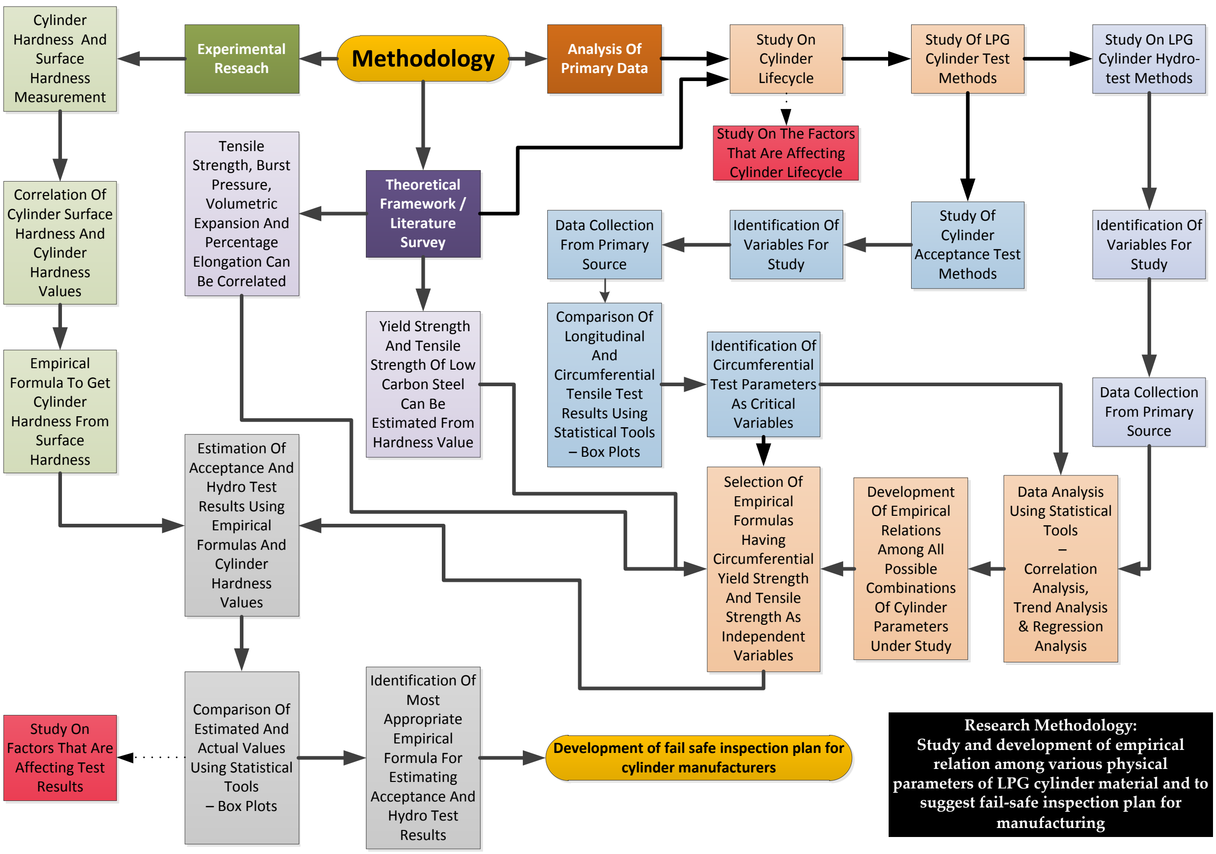


Figure 20: Methodology - Overview

6.3 Statistical Tools for Data Analysis

Minitab16, Microsoft windows based statistical software is used for statistical analysis in this research.

Surface hardness and hardness of cylinder parent metal are assumed to be linear as they are measured on a single sample with two different test methods. The results are analyzed with person correlation coefficients to establish correlation among the two variables and checked with the trend analysis whether the variables are directly proportional or inversely proportional. After establishing the correlation, a general regression analysis is carried out with the available 55 cylinders test data to get a regression equation to get cylinder material hardness from cylinder surface hardness values.

In order to get finalize the critical properties of acceptance test results viz., Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS), Circumferential Percentage Elongation (CPE), Longitudinal Tensile Strength (LTS), Longitudinal Yield strength (LYS) Longitudinal Percentage Elongation (LPE) are compared with box plots with similar groups to know the influencing properties for accepting a batch of newly manufactured cylinders in manufacturing unit. The value whichever is lesser is considered as influencing parameter, as the standard stipulates minimum parameters for these values [25].

To establish inter-relations among various parameters of LPG Cylinder material, all parameters i.e. Portable Hardness Value (BHNp), Cylinder Hardness (BHNb), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS), Circumferential Percentage Elongation (CPE), Longitudinal Tensile Strength (LTS), Longitudinal Yield strength (LYS) Longitudinal Percentage Elongation (LPE), Volumetric expansion (VE), Burst pressure (BP) and Nominal Hoops Stresses(NHS) are analyzed. Using control charts the data is validated for the analysis purpose and to ensure that the data is within the permissible limits stated in Indian standard. Once the data is validated, all possible combinations of these parameters are established. In the current study 55 possible combinations can be established. Person correlation coefficients are calculated for all these 55 combinations and trend analysis is carried out to know the dependencies of the pairs. Further regression analysis is carried out on these parameters keeping yield strength and tensile strength as independent variables and all other critical parameter to be estimated as a dependent variable to get the desired empirical formula. Thus 4 sets of empirical formulas can be obtained with longitudinal tensile strength, longitudinal yield strength, circumferential tensile strength, and circumferential yield strength as independent parameters to get all rest of the physical parameters. This leads 36 empirical formulas to get the desired parameters from LYS, LYS, CTS and CYS. At this stage if excel based software is developed; the results can be estimated quickly and instantaneously from the established empirical formulas.

Actual and estimated values of all critical parameters are compared with box plots for easy understanding and graphical illustration, to get the recommended equation for obtaining the critical values. Based on the outcome, fail safe inspection plan for manufacturers can be developed for manufacturers to check all cylinders in a manufacturing location for their material compliance. Figure 21 below gives over view of the statistical methodology adopted in the current research.

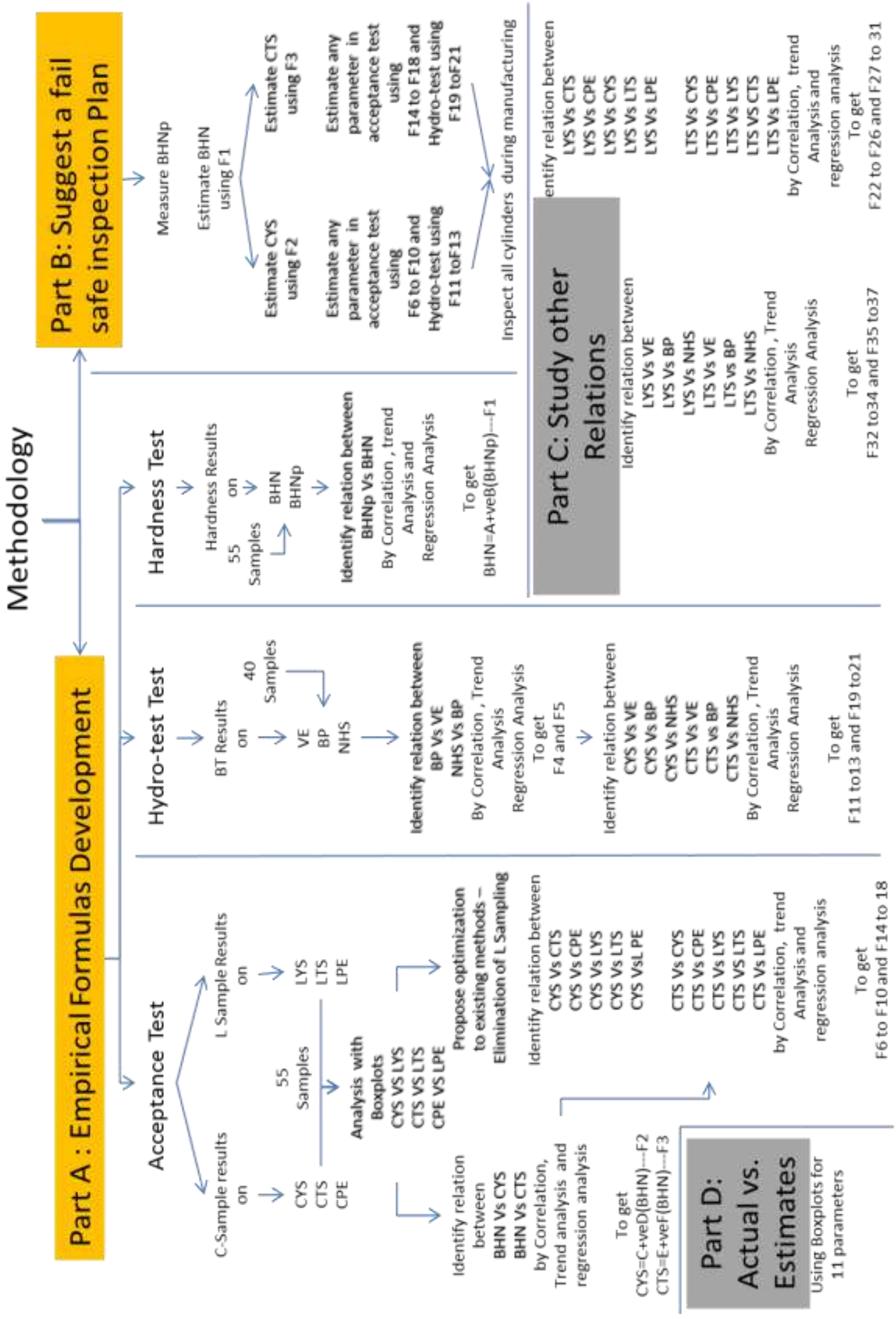


Figure 21: Research Methodology

---End of Chapter 6---

Chapter-7

7. Data Analysis, Results and Discussion

Research data collection, analysis, results and discussion are outlined in this chapter. The data was collected from an authorized laboratory and additional experiments were conducted in accredited laboratory for reliability. Minitab16 was used for analyzing results. The data was validated using control charts and box plots where ever appropriate. Correlation, trend and regression analysis was carried out to establish interrelations and empirical formulas among various critical parameters of LPG Cylinder material. All the empirical formulas are grouped in four different categories for estimating critical parameters of LPG cylinder acceptance and hydrotest results using hardness values. Data analysis was validated with appropriate reasoning and justifications.

While analysis data scholar had an opportunity to analyses LPG Cylinder life cycle and sample preparation methods for acceptance test. Detailed discussion on these topics and study outcome was given at the end.

7.1 Data Collection

Research data was collected in two phase. In the first phase, acceptance and hydro test results were collected from one of the central government based, National accredited board of testing laboratories (NABL) and Bureau of Indian Standards (BIS) approved laboratory in India. In the second phase, cylinder hardness is tested in two different methods in a NABL accredited commercial laboratory. The test certificates are attached in the annexure section for reference and the data tables are given below.

Domestic LPG Cylinders of 33.3 liter water capacity are used for this research. These cylinders are most common type of cylinders in India and are constructed in two piece construction. These cylinders are intended for domestic use in India. These cylinders are manufactured from several manufacturers in India and are tested and certified as per IS 3196.

7.1.1 Data Table for Acceptance and Hydro-Test results

Table 5: Acceptance and hydro test data

Sl NO	Acceptance Test						Burst Test		
	Longitudinal Sample			Circumferential Sample			Burst Pressure	Nominal Hoop stress	Volumetric Expansion
	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL			
SN	LYS in MPa	LTS in MPa	LPE in %	CYS in MPa	CTS in MPa	CPE in %	BP in bar	NHS in MPa	VE in %
1	283	365	42	264	362	50	93.16	609.92	27
2	314	393	28	298	387	36	0.00	N/A	N/A
3	250	361	47	250	361	47	0.00	N/A	N/A
4	260	350	41	282	353	45	98.07	642.02	35
5	260	350	41	244	356	47	88.02	576.28	29

Sl NO	Acceptance Test						Burst Test		
	Longitudinal Sample			Circumferential Sample			Burst Pressure	Nominal Hoop stress	Volumetric Expansion
	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL			
SN	LYS in MPa	LTS in MPa	LPE in %	CYS in MPa	CTS in MPa	CPE in %	BP in bar	NHS in MPa	VE in %
6	275	366	36	241	368	43	90.71	593.87	21
7	258	352	40	246	362	42	91.02	595.86	33
8	281	357	38	265	353	40	91.02	595.86	31
9	269	379	36	270	390	43	88.03	576.35	33
10	297	393	39	265	377	46	86.89	568.83	25
11	317	443	26	270	407	31	92.00	602.28	26
12	251	361	44	243	370	45	88.79	581.29	32
13	244	374	38	247	378	35	94.91	621.35	25
14	272	351	43	244	359	42	106.98	700.38	10
15	267	361	40	266	375	45	93.86	614.48	32
16	245	355	41	250	357	47	92.05	602.60	34
17	255	365	43	247	363	43	0.00	N/A	N/A
18	265	364	39	247	362	44	88.43	578.91	25
19	308	433	36	250	450	32	90.99	595.67	33
20	271	368	40	251	350	43	91.07	596.25	27
21	285	376	45	264	366	43	87.87	575.25	25
22	283	372	43	259	360	43	87.93	575.64	30
23	273	366	44	266	359	44	91.94	601.90	31
24	252	366	47	258	358	48	91.69	600.29	31
25	259	366	43	242	357	47	89.01	582.70	29
26	270	363	44	249	364	47	83.88	549.12	21

Sl NO	Acceptance Test						Burst Test		
	Longitudinal Sample			Circumferential Sample			Burst Pressure	Nominal Hoop stress	Volumetric Expansion
	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL			
SN	LYS in MPa	LTS in MPa	LPE in %	CYS in MPa	CTS in MPa	CPE in %	BP in bar	NHS in MPa	VE in %
27	268	351	42	262	359	43	0.00	N/A	N/A
28	274	354	44	256	354	48	0.00	N/A	N/A
29	268	368	46	246	376	47	94.80	620.64	32
30	264	386	32	296	370	34	87.32	571.66	25
31	244	379	38	240	375	43	93.99	615.32	35
32	261	370	39	262	365	48	89.51	585.98	34
33	251	350	42	252	351	35	89.31	584.69	27
34	258	361	33	263	351	48	91.62	599.84	31
35	271	372	44	253	363	49	91.59	599.65	29
36	310	396	39	257	352	48	0.00	N/A	N/A
37	266	380	39	261	359	40	0.00	N/A	N/A
38	259	374	38	273	363	43	98.61	645.56	18
39	245	351	48	243	351	48	89.40	585.27	29
40	243	366	29	248	367	44	0.00	N/A	N/A
41	273	351	44	273	355	45	89.08	583.21	28
42	240	374	38	261	357	43	88.06	576.54	34
43	240	391	43	256	390	34	89.73	587.45	33
44	244	375	37	252	389	35	87.79	574.74	32
45	264	392	42	259	388	42	87.75	574.48	17
46	321	392	39	280	384	35	89.89	588.48	25
47	258	369	40	243	375	36	90.28	591.05	34

Sl NO	Acceptance Test						Burst Test		
	Longitudinal Sample			Circumferential Sample			Burst Pressure	Nominal Hoop stress	Volumetric Expansion
	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL			
SN	LYS in MPa	LTS in MPa	LPE in %	CYS in MPa	CTS in MPa	CPE in %	BP in bar	NHS in MPa	VE in %
48	253	376	37	247	380	37	0.00	N/A	N/A
49	276	355	43	262	361	46	86.13	563.89	31
50	240	363	40	243	363	38	91.21	597.15	27
51	264	361	42	249	357	46	94.93	621.48	35
52	267	366	35	241	364	37	0.00	N/A	N/A
53	242	368	38	255	370	34	0.00	N/A	N/A
54	268	372	36	272	399	33	0.00	N/A	N/A
55	248	361	32	250	383	39	92.98	608.70	24

Note: N/A represents the test results are not available. This is possible if the particular batch sample is not available for conducting test at the laboratory.

As a practice, two cylinders of same batch and same manufacturer to be send for research laboratory for testing. Over years of experience, the burst pressure of LPG cylinder is typically in the range of 90 kgf/cm^2 to 130 Kgf/cm^2, which is much beyond specification in standard (approx. 56 kgf/cm^2). Hence, some of the plants while sending LPG cylinders for testing dispatch only one cylinder to avoid wastage of cylinders. This is acceptable as the cylinder is already having BSI mark on it before dispatching to the testing laboratory.

7.1.2 Data Table – Hardness Test

Table 6: Hardness test Data

Sl NO	Hardness Test	
	Brinells Hardness Test	Portable Hardness Tester
SN	HDN-B in BHN	HDN-P in BHN
1	137	131
2	149	150
3	131	138
4	131	145
5	131	129
6	121	132
7	143	164
8	131	134
9	131	146
10	137	146
11	143	146
12	143	174
13	131	132
14	137	139
15	131	148
16	143	139
17	156	150
18	143	136
19	137	147
20	137	156

Sl NO	Hardness Test	
	Brinells Hardness Test	Portable Hardness Tester
SN	HDN-B in BHN	HDN-P in BHN
21	143	157
22	131	148
23	149	141
24	131	148
25	137	145
26	131	139
27	131	163
28	143	145
29	156	146
30	149	164
31	143	142
32	137	144
33	126	152
34	143	159
35	149	163
36	143	136
37	149	160
38	143	163
39	143	162
40	137	138
41	149	131
42	137	154

Sl NO	Hardness Test	
	Brinells Hardness Test	Portable Hardness Tester
SN	HDN-B in BHN	HDN-P in BHN
43	149	128
44	131	132
45	149	129
46	163	183
47	143	145
48	137	151
49	143	146
50	137	144
51	137	116
52	131	122
53	137	152
54	126	116
55	126	128

7.2 Hardness Test Experimental Results Analysis

Hardness tests are conducted on same piece of metal using two different methods. One is with conventional brinells hardness tester (see Figure 23) and the other one is portable hardness testing machine (see Figure 24)The analysis of results were carried out by plotting box plots. It is evident from boxplots that the hardness obtained from portable hardness tester is higher than the conventional Brinell's method. This is mainly due to strain hardening of surface during manufacturing process [44]. All cylinders during manufacturing should undergo either shot blasting or grit blasting operations before they get painted. This shot blasting or grit blasting will increase the surface hardness of cylinder material and it will be in the order of 4.21% of BHN value from the experimental results [4]. Figure 22 below shows the hardness sample location and Figure 23[87] and Figure 24[103] are the two machines / apparatus for conducing the experimental research in this work. Comparisons of hardness values obtained from these two methods are given in box plot Figure 25 and individual value plots in Figure26. The correlation constant and the trend information for material hardness and surface hardness values are given in Figure 41. If the material hardness increases the surface hardness also will increase [4]. The regression analysis is carried out for the hardness values and the cylinder hardness can be estimated from surface hardness using the following formula

$$BHNb = 100.114 + 0.269094 \times BHNp$$

Where BHNb is Brinells hardness number in BHN

BHNp is Brinells hardness number obtained from portable hardness tester when tested on surface of cylinder in BHN

Details of trend analysis, regression analysis are given separately in subsequent sections.

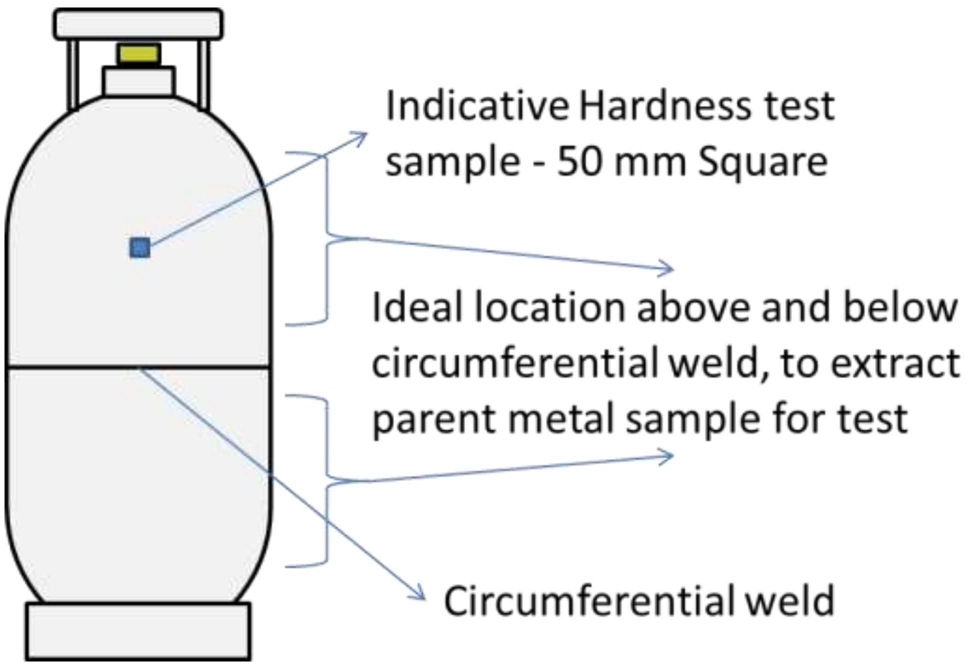


Figure 22: Hardness test sample from a domestic LPG Cylinder

Figure 23: SAROJ Make Brinell's Hardness Testing Machine

Figure 24: YAMMAYO make Portable Digital NDT Hardness tester

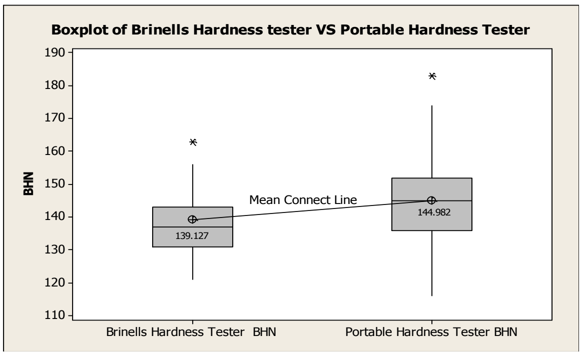


Figure 25: Box plot of Destructive and Non-destructive test results

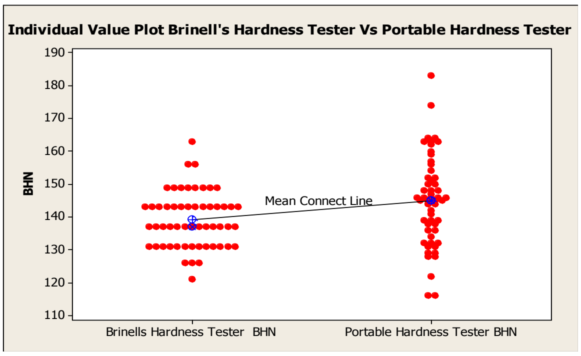


Figure 26: Individual plots of Destructive and Non-destructive test results

7.3 Acceptance And Hydro-test Results Analysis

7.3.1 Data Analysis - Overview

The data analysis is carried out in four phases. In the first phase control charts were drawn to all test results and compared with standard for its compliance. Carried out correlation studies for longitudinal and circumferential parameters and established the relation and trends for these critical variables in second phase. During third phase, empirical formulas are developed using regression analysis and in last phase, a method was developed to get all critical parameters using empirical formulas.

7.3.2 Data Validation

Acceptance and Hydro test date for Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS), Circumferential Percentage Elongation (CPE), Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS) Longitudinal Percentage Elongation (LPE), Volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoops Stresses (NHS) collected and validated with control charts. The charts are given below for reference with appropriate caption and are validated against Table.2 (see chapter 2.4.1) and Table 3 (see chapter 3.4.2). See Figure 27 to Figure 35, It is evident from charts that the data considered for the study is relevant and valid for research.

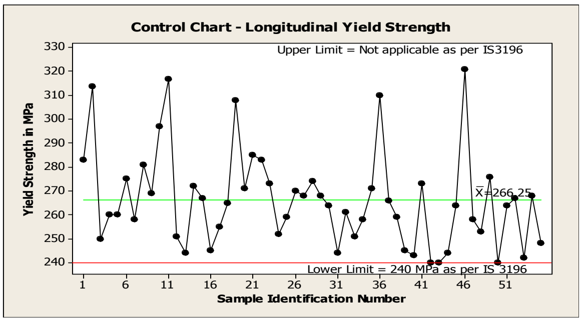


Figure 27: Yield strength values of Longitudinal Samples

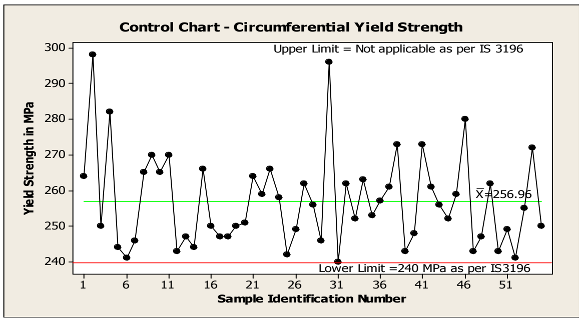


Figure 28: Yield strength values of Circumferential Samples

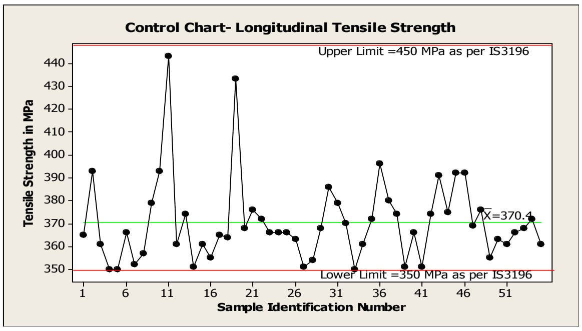


Figure 29: Tensile Strength values of Longitudinal Samples

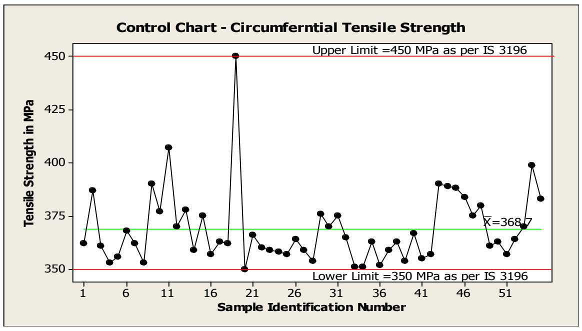
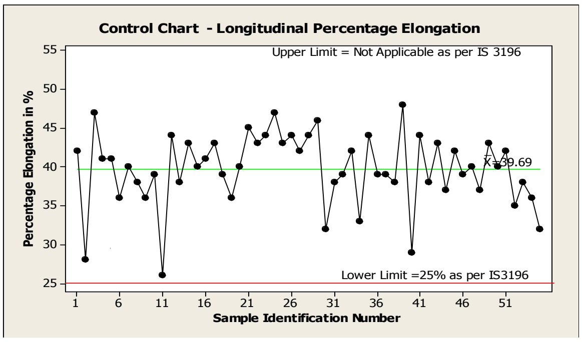


Figure 30: Tensile Strength values of Circumferential Samples



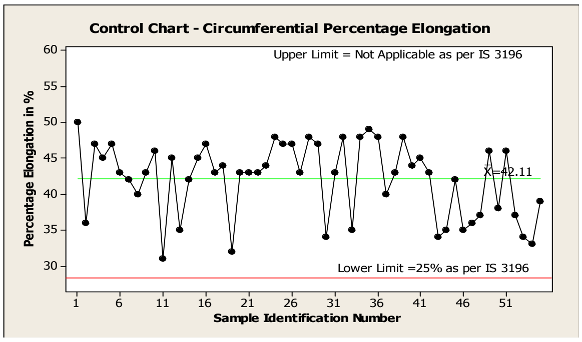
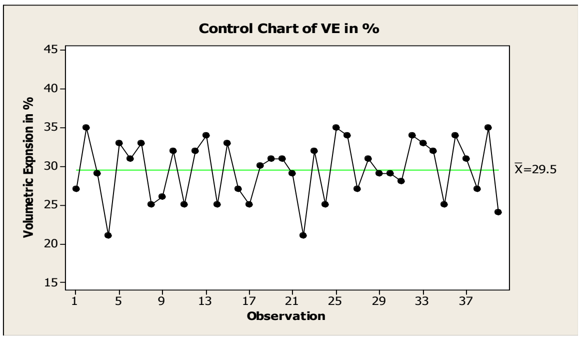


Figure 31: Percentage elongation values of Longitudinal Samples

Figure 32: Percentage Elongation values of Circumferential Samples



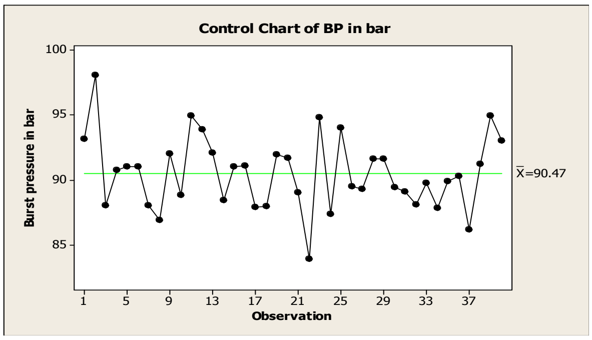


Figure 33: Control Chart for Volumetric Expansion (VE)

Figure 34: Control Chart for Burst Pressure (BP)

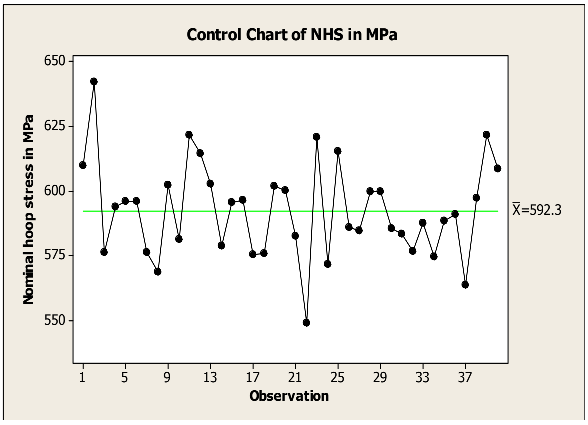


Figure 35: Control Chart for Nominal Hoop Stress (NHS)

7.3.3 Circumferential Vs. Longitudinal Test Results

In order to establish influencing parameters, box plots were generated and compared for both circumferential and longitudinal test results. From the data analysis, it is evident that the tensile and yield strength results are always lower in circumferential test specimen. See

Figure 36 and Figure 37. Whereas the percentage elongation is lower in longitudinal test specimen see Figure.38 and Figure.39. I.e. Circumferential sample test results are more critical than longitudinal sample test results and are the deciding factors to accept a lot of cylinders manufactured in a unit.

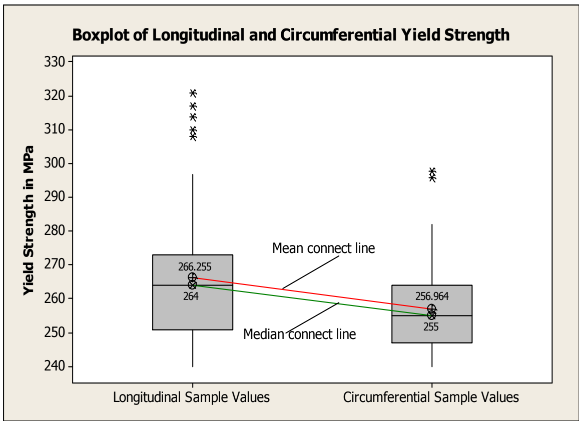


Figure 36: Comparison of Longitudinal and circumferential Yield strength values

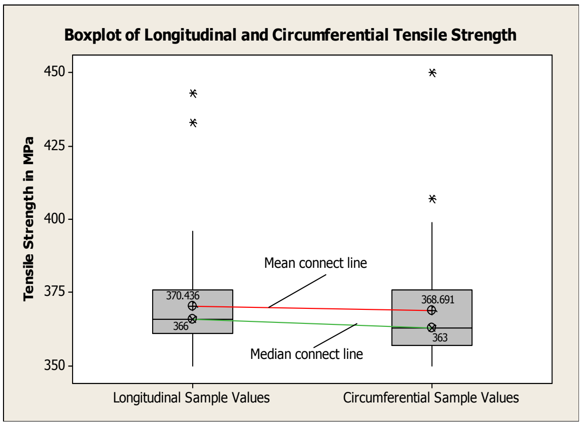


Figure 37: Comparison of Longitudinal and circumferential Tensile strength values

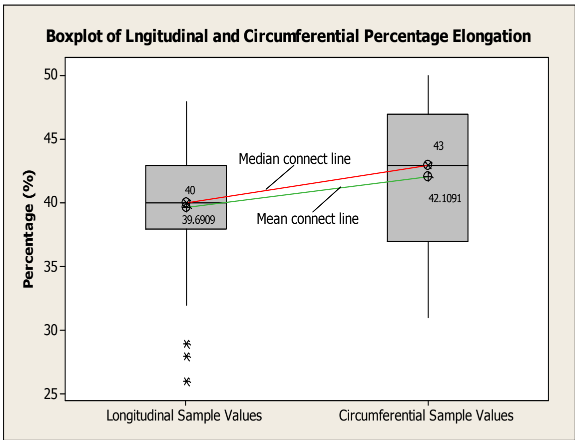


Figure 38: Comparison of Longitudinal and circumferential Percentage Elongation values

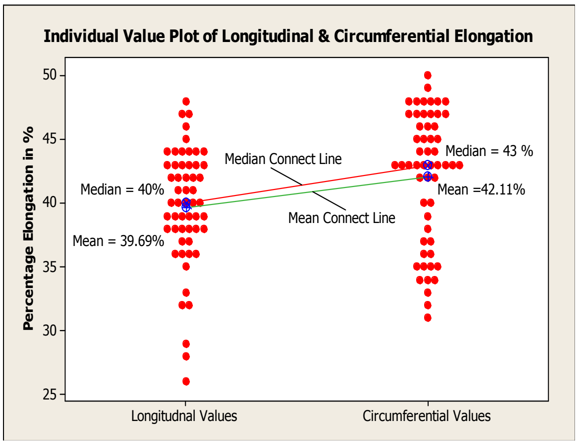


Figure 39: Comparison of longitudinal and circumferential Percentage Elongation values

If the percentage elongation limit for acceptance test in standard IS 3196 part 3 can be increased from the existing 25 % to 27%, only one circumferential test specimen testing is sufficient to determine the material parameters as per the standards and thus the testing time and efforts can be reduced drastically (up to 50%) [4]. This phenomenon can be justified with

United States, Department of transportation guidelines for 4WBA welded cylinders testing [83]. The US standard specifies tensile test in circumferential direction only to determine the yield strength and Tensile strength. The elongation requirements as per DOT standard varies with varied gauge lengths. Thus, by increasing the percentage elongation specification in standard from 25% to 27%, longitudinal sample testing can be eliminated in acceptance test of LPG Cylinder while certifying LPG Cylinder [83].

7.3.4 Correlation Study

Possible pairs among the critical parameters for correlation are listed in Figure.40. Correlation study was carried out among these identified parameters pairs using Minitab 16, a Microsoft windows based statistical analysis software and the person correlation constants are tabulated in Figure 41.Further the trend analysis is carried on all possible pairs and tabulated in the same Figure 41. Meaningful correlations can be established among tensile strength, yield strength percentage elongation, volumetric expansion burst pressure and nominal hoop stresses.

From Figure.41, LTS-LYS, LTS-CTS, LTS-CYS, LYS-CTS, LYS-CYS, LPE-CPE, LPE-VE, CTS-CYS, CTS-VE, CTS-BP, CTS-NHS, CPE-VE, CPE-BP, CPE-NHS, VE-BP, VE-NHS, BP-NHS shows relation which is directly proportion to each other. It means any one of the parameter is reported higher than typical values during the test, surely the other parameter in the pair exhibits higher values compared to the typical value. Similarly from Figure.41, LTS-LPE, LTS-CPE, LTS-VE, LTS-BP, LTS-NHS, LYS-LPE, LYS-CPE, LYS-VE, LYS-BP, LYS-NHS, LPE-CTS, LPE-CYS, LPE-BP, LPE-HS, CTS-CPE, CYS-CPE, CYS-VE, CYS-BP, CYS-NHS exhibits inversely proportional relation among these pair elements. That means any one in a pair is reported lower values then a typical value, the other parameter in the pair reports higher value than the typical value and vice-versa. Form this study, it is evident that the longitudinal and circumferential samples, the yield strength and tensile strength are proportional to each other and the percentage elongating is inversely proportional to these values. Similarly the volumetric expansion, burst pressure and nominal hoop stresses are always proportional to each other. However, the Hydro-test results are proportional to elongation values of acceptance test results and inversely proportional to tensile and yield strength. It means if the percentage elongation of a cylinder material is more than a typical value; the volumetric expansion will be report more than the typical value of a LPG cylinder. On the other hand, if the tensile strength of a cylinder material is more, the volumetric expansion will report lesser than a typical value of a cylinder. Thus acceptance test results can be used for fro estimating hydro-test results.

7.3.5 Factors affecting Correlation Study

Interestingly, in some pairs of acceptance test results, the trends exhibit contradictory relations comparative to their counterpart results of circumferential or longitudinal tests. A study was carried out on these aspects to check he factors affecting the test values. In such cases it is advised to verify person correlation constant to check whether the results are having any correlation or just scattered apart. Such kind of contradictory relations are possible due to various factors when analyzing practical test results and the this phenomenon can be attributed to various factors such raw material selection, heat treatment process parameters, cylinder manufacturing methods, welding process parameters, sample preparation methods [3]. Means, if the cylinders manufacturer from different raw materials sourced from different steel mills, produced different production methods, different welding processes and treated with different heat treatment process parameters [10]. It is also possible if the test methods and sample preparation methods adopted are different. Considering all these conditions, the test results may be varied slightly [10].

	BHN	BHNp	LTS	LYS	LPE	CTS	CYS	CPE	VE	BP	NHS
BHN		BHN vs BHNp	BHN vs LTS	BHN vs LYS	BHN vs LPE	BHN vs CTS	BHN vs CYS	BHN vs CPE	BHN vs VE	BHN vs BP	BHN vs NHS
BHNp	BHN vs BHNp		BHNp vs LTS	BHNp vs LYS	BHNp vs LPE	BHNp vs CTS	BHNp vs CYS	BHNp vs CPE	BHNp vs VE	BHNp vs BP	BHNp vs NHS
LTS	BHN vs LTS	BHNp vs LTS		LTS vs LYS	LTS vs LPE	LTS vs CTS	LTS vs CYS	LTS vs CPE	LTS vs VE	LTS vs BP	LTS vs NHS
LYS	BHN vs LYS	BHNp vs LYS	LTS vs LYS		LYS vs LPE	LYS vs CTS	LYS vs CYS	LYS vs CPE	LYS vs VE	LYS vs BP	LYS vs NHS
LPE	BHN vs LPE	BHNp vs LPE	LTS vs LPE	LYS vs LPE		LPE vs CTS	LPE vs CYS	LPE vs CPE	LPE vs VE	LPE vs BP	LPE vs NHS
CTS	BHN vs CTS	BHNp vs CTS	LTS vs CTS	LYS vs CTS	LPE vs CTS		CTS vs CYS	CTS vs CPE	CTS vs VE	CTS vs BP	CTS vs NHS
CYS	BHN vs CYS	BHNp vs CYS	LTS vs CYS	LYS vs CYS	LPE vs CYS	CTS vs CYS		CYS vs CPE	CYS vs VE	CYS vs BP	CYS vs NHS
CPE	BHN vs CPE	BHNp vs CPE	LTS vs CPE	LYS vs CPE	LPE vs CPE	CTS vs CPE	CYS vs CPE		CPE vs VE	CPE vs BP	CPE vs NHS
VE	BHN vs VE	BHNp vs VE	LTS vs VE	LYS vs VE	LPE vs VE	CTS vs VE	CYS vs VE	CPE vs VE		VE vs BP	VE vs NHS
BP	BHN vs BP	BHNp vs BP	LTS vs BP	LYS vs BP	LPE vs BP	CTS vs BP	CYS vs BP	CPE vs BP	VE vs BP		BP vs NHS
NHS	BHN vs NHS	BHNp vs NHS	LTS vs NHS	LYS vs NHS	LPE vs NHS	CTS vs NHS	CYS vs NHS	CPE vs NHS	VE vs NHS	BP vs NHS	

Figure 40: Combinations among various parameters of LPG Cylinder material

	BHN	BHNp	LTS	LYS	LPE	CTS	CYS	CPE	VE	BP	NHS
BHN		+ve Trend	+ve Trend	+ve Trend	+ve Trend	+ve Trend	+ve Trend	+ve Trend	+ve Trend	- Trend	- Trend
BHNp	0.431		+ve Trend	+ve Trend	+ve Trend	- Trend	+ve Trend	+ve Trend	- Trend	- Trend	- Trend
LTS	0.261	0.065		+ve Trend	- Trend	+ve Trend	+ve Trend	- Trend	- Trend	- Trend	- Trend
LYS	0.246	0.129	0.559		- Trend	+ve Trend	+ve Trend	- Trend	- Trend	- Trend	- Trend
LPE	0.054	0.078	-0.491	-0.232		- Trend	- Trend	+ve Trend	+ve Trend	- Trend	- Trend
CTS	0.034	-0.102	0.76	0.32	-0.434		+ve Trend	- Trend	+ve Trend	+ve Trend	+ve Trend
CYS	0.238	0.231	0.28	0.47	-0.328	0.126		- Trend	- Trend	- Trend	- Trend
CPE	0.025	0.022	-0.503	-0.101	0.541	-0.627	-0.188		+ve Trend	+ve Trend	+ve Trend
VE	0.134	-0.026	-0.093	-0.315	0.165	0.028	-0.051	0.133		+ve Trend	+ve Trend
BP	-0.009	-0.198	-0.049	-0.114	-0.08	0.02	-0.038	0.018	0.334		+ve Trend
NHS	-0.009	-0.198	-0.049	-0.114	-0.08	0.02	-0.038	0.018	0.334	1	

Figure 41: Pearson Correlation Coefficients and trend Analysis.

Note: Positive indicates, the pairs are directly proportional and negative indicates, the pairs are indirectly proportional to each other

7.4 Regression Analysis

From the literature, it is evident that the hardness, tensile strength and yield strength are in linear relation [84] & [88]. Thus with regression analysis, mathematical equations were developed for all the parameters in terms of hardness and one of the major variables like tensile strength or yield strength using Minitab 16, a statistical software. All the empirical formulas are given below and are grouped in subsequent sections.

7.4.1 Empirical Relations

Empirical formulas to calculate acceptance and hydrotest parameters using CTS, CYS, LTS & LYS are given below. Also, empirical formula for calculating BHN or BHNb is given in terms of BHN-p. Further, formulas for calculating CTS, CYS, LTS & LYS using BHNb are mentioned here under. Thus 40 different sets of formulas are given below for calculating cylinder critical parameters. Out of which 37 formulas are used for developing 4 different plans using CTS, CYS, LTS and LYS (36 formulas) and a hardness value (1 formula). Detailed plans and segmentations are given in subsequent sections and chapters.

1) BP in bar = 83.4186 + 0.23914 VE in %
2) BP in bar = 89.3691 + 0.00299424 CTS in MPa
3) BP in bar = 92.6448 - 0.00846375 CYS in MPa
4) BP in bar = 93.0812 - 0.00704432 LTS in MPa
5) BP in bar = 94.7164 - 0.0159533 LYS in MPa
6) CPE in % = 110.901 - 0.186611 CTS in MPa
7) CPE in % = 49.03 - 0.0259937 LYS in MPa
8) CPE in % = 61.0831 - 0.0738395 CYS in MPa
9) CPE in % = 95.0519 - 0.14292 LTS in MPa
10) CTS in MPa = 294.98 + 0.27664 LYS in MPa
11) CTS in MPa = 325.931 + 0.166194 CYS in MPa
12) CTS in MPa = 358.93 + 0.0697682 HRD-b in BHN
13) CTS in MPa = 100.106 + 0.724902 LTS in Mpa
14) CYS in MPa = 175.044 + 0.307674 LYS in MPa

15) CYS in MPa = 182.075 + 0.202164 LTS in MPa

16) CYS in MPa = 205.909 + 0.366962 HRD-b in BHN

17) CYS in MPa = 221.702 + 0.0956556 CTS in MPa

18) HRD-b in BHN = 100.114 + 0.269094 HRD-p in BHN

19) LPE in % = 54.0581 - 0.0539602 LYS in MPa

20) LPE in % = 69.5775 - 0.116307 CYS in MPa

21) LPE in % = 82.7526 - 0.116813 CTS in MPa

22) LPE in % = 86.3641 - 0.125995 LTS in MPa

23) LTS in MPa = 235.637 + 0.50628 LYS in MPa

24) LTS in MPa = 271.134 + 0.386446 CYS in MPa

25) LTS in MPa = 292.834 + 0.557781 HRD-b in BHN

26) LTS in MPa = 76.4299 + 0.797551 CTS in MPa

27) LYS in MPa = 129.53 + 0.370893 CTS in MPa

28) LYS in MPa = 185.675 + 0.579177 HRD-b in BHN

29) LYS in MPa = 37.7161 + 0.616944 LTS in MPa

30) LYS in MPa = 82.0919 + 0.716688 CYS in MPa

31) NHS in MPa = 0.000917823 + 6.54681 BP in bar

32) NHS in MPa = 546.126 + 1.56561 VE in %

33) NHS in MPa = 585.081 + 0.0196074 CTS in MPa

34) NHS in MPa = 606.528 - 0.0554084 CYS in MPa

35) NHS in MPa = 609.385 - 0.0461164 LTS in MPa

36) NHS in MPa = 620.091 - 0.104444 LYS in MPa

37) VE in % = 27.3037 + 0.00595615 CTS in MPa

38) VE in % = 33.5117 - 0.0156355 CYS in MPa

39) VE in % = 36.4303 - 0.0187191 LTS in MPa

40) VE in % = 45.8573 - 0.0614995 LYS in MPa

7.5 Empirical Formulas for Acceptance Test parameters

Regression analysis was carried out on acceptance test parameters and regression equations are developed based on the correlation constants and the trend analysis. The equations are given in Table.7

Table 7: Regression Analysis of Hydro-test parameters

Regression analysis plan				
Vs.	LTS	LYS	CTS	CYS
LTS		LTS = X10 + Y10 LYS	LTS = X11 + Y11 CTS	LTS = X12 + Y12 CYS
LYS	LYS = X13 + Y13 LTS		LYS = X14 + Y14 CTS	LYS = X15 + Y15 CYS
LPE	LPE = X16 + Y16 LTS	LPE = X17 + Y17 LYS	LPE = X18 + Y18 CTS	LPE = X19 + Y19 CYS
CTS	CTS = X20 + Y20 LTS	CTS = X21 + Y21 LYS		CTS = X22 + Y22 CYS
CYS	CYS = X23 + Y23 LTS	CYS = X24 + Y24 LYS	CYS= X25 + Y25 CTS	
CPE	CPE = X26 + Y26 LTS	CPE = X27 + Y27 LYS	CPE= X28 + Y28 CTS	CPE = X29 + Y29 CYS
Regression Equations / Empirical Formulas				
Vs.	LTS	LYS	CTS	CYS
LTS		LTS = 235.637+0.50628 LYS	LTS = 76.4299+0.797551 CTS	LTS = 271.134+0.386446 CYS
LYS	LYS = 37.7161+0.616944 LTS		LYS = 129.53+0.370893 CTS	LYS = 82.0919+0.716688 CYS

LPE	LPE = 86.3641-0.125995 LTS	LPE = 54.0581-0.0539602 LYS	LPE = 82.7526-0.116813 CTS	LPE = 69.5775-0.116307 CYS
CTS	CTS = 100.106+0.724902 LTS	CTS = 294.98+0.27664 LYS		CTS = 325.931+0.166194 CYS
CYS	CYS = 182.075+0.202164 LTS	CYS = 175.044+0.307674 LYS	CYS = 221.702+0.0956556 CTS	
CPE	CPE = 95.0519-0.14292 LTS	CPE = 49.03-0.0259937 LYS	CPE = 110.901-0.186611 CTS	CPE = 61.0831-0.0738395 CYS

7.6 Empirical Formulas For Hydro-test parameters

Regression analysis was carried out hydro test parameters and regression equations are developed based on the correlation constants and the trend analysis. The regression equation are given in Table.8

Table 8: Regression Analysis of Hydro-test parameters

Regression analysis plan		
Regression Analysis plan	Volumetric Expansion (VE)	Burst Pressure (BP)
Burst Pressure (BP)	BP = X1 + Y1 VE	-
Nominal Hoop Stresses (NHS)	NHS = X2 + Y2 VE	NHS = X3 + Y3 BP
Regression Equations / Empirical Formulas		
Regression Equations	Volumetric Expansion (VE)	Burst Pressure (BP)
Burst Pressure (BP)	BP=83.4186+0.23914 VE	
Nominal Hoop Stresses (NHS)	NHS=546.126+1.56561 VE	NHS=0.000917823+6.54681 BP

7.7 Study on Actual Values Vs. Estimates

7.7.1 General

Using the regression equation and the available test data (Actual) for yield strength and tensile strength all other parameters are calculated and compared with actual values. The actual and estimated values are plotted using box plots for easy understanding and comparison purpose from Figure. 42 to Figure 49.

Most of the cases the interquartile range boxes are reduced in estimates from the box plots. It means the estimates are restricted to one particular range and are not spread to the extent of the actual values [9]. The main factor affecting the interquartile range box is the test results. In the present research the data was collected only form good or passed cylinders. If failure cylinders data along with passed cylinders data is fed to the statistical analysis to develop regression equations, the interquartile range box in boxplots can be extended to the extent of the actual values. However, this is practically not possible at this stage as the failure data is not available due to the type of experiments conducted on LPG Cylinders [9]. However, an attempt can be made to simulate various manufacturing conditions and heat treatment process parameters to produce some trial batches and failure data can be generated. This could be the future scope of work, if the oil companies sought an integrated solution for their practical issues.

7.7.2 Hydrotest Parameters

Although there is some compression in interquartile range boxes in the boxplots from Figure 42 to Figure 49, the estimates are 99.2% same with any of the four estimated methods given in the research and hence a software is developed to estimate the results in any one of the manufacturers choice.

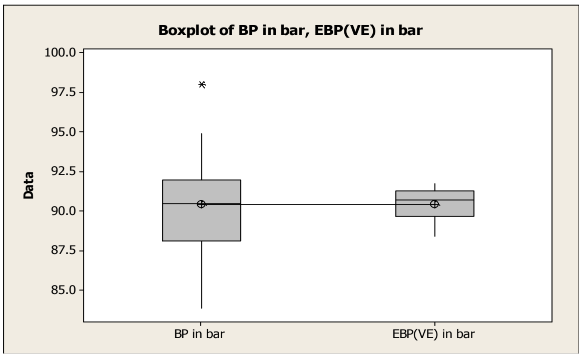


Figure 42: Comparison of Actual and estimated values of Burst Pressure

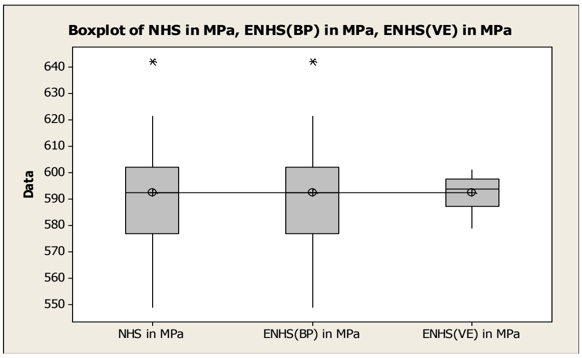


Figure 43: Comparison of actual and estimated values of Nominal Hoop Stresses with two different methods

7.7.3 Acceptance Test Parameters

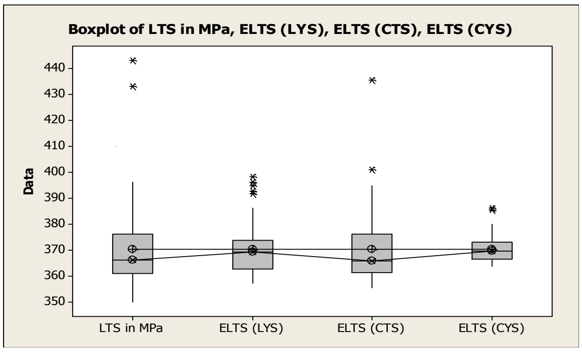


Figure 44: Comparison of actual and estimated values of Longitudinal Tensile Strength values

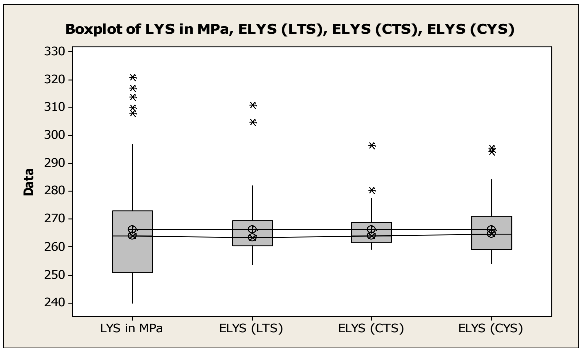


Figure 45: Comparison of actual and estimated values of Longitudinal Yield strength values

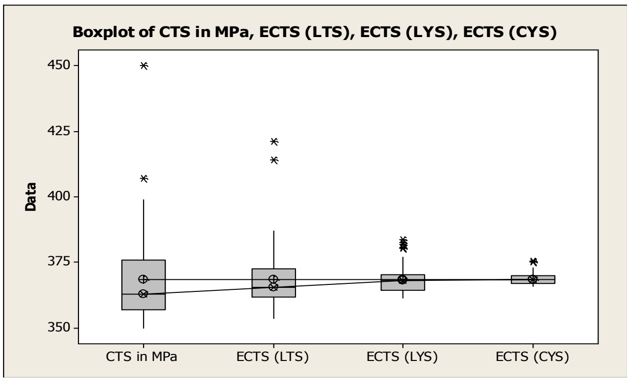


Figure 46: Comparison of actual and estimated values of Circumferential Tensile Strength values

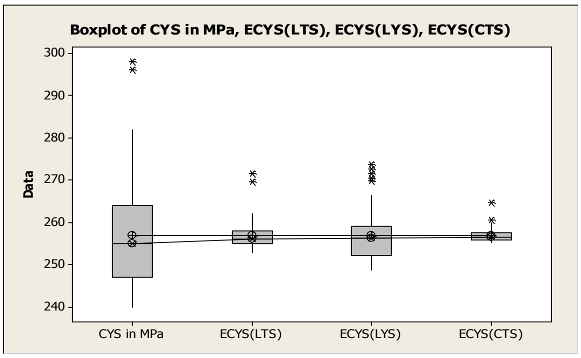


Figure 47: Comparison of actual and estimated values of Circumferential Yield Strength values

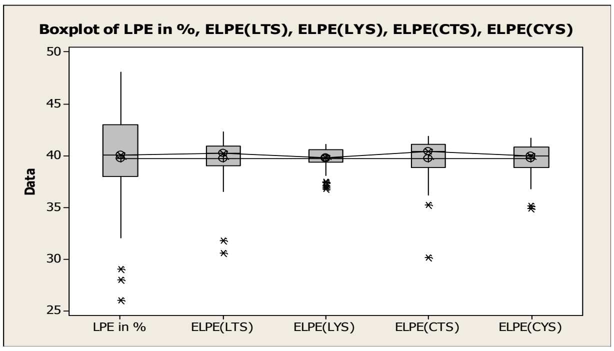


Figure 48: Comparison of actual and estimated values of Longitudinal Percentage Elongation values

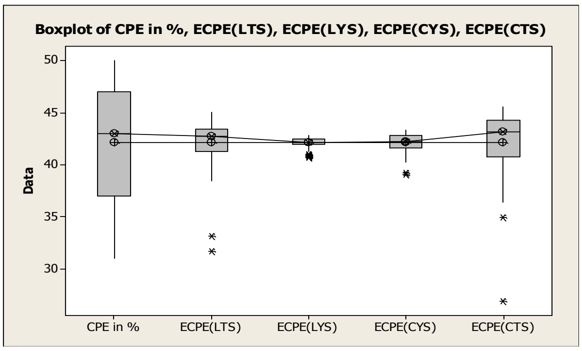


Figure 49: Comparison of actual and estimated values of Circumferential Percentage Elongation values

7.8 Discussion on Fail Safe Inspection Plan

Four methods are suggested in this study to estimate critical parameters of LPG cylinder material and are based on circumferential tensile values, circumferential yield vales, longitudinal tensile values and longitudinal yield values. These plans are given below in Figure.50 Also a separate chapter was dedicated for this section. As per the plan, the surface hardness is measured with any one of the portable hardness tester in BHN. This value is used to estimate cylinder hardness in BHN. Once the cylinder hardness is available, either yield strength or tensile strength can be estimated for either circumferential or longitudinal direction using any one of the given four equations. Once the Yield strength or circumferential values are available, all other parameters can be estimated using empirical formulas given in that particular set. Thus all the cylinder critical parameters are available for verification.

Plan-1: Estimates using Circumferential Yield Strength
Step:1
Estimate Hardness
BHN = 100.114 +ve 0.269094 BHNp
Step:2
Estimate Circumferential Yield Strength
CYS = 205.909 +ve 0.366962 BHN
Step:3
Estimate all other critical parameters
CTS = 325.931 +ve 0.166194 CYS
CPE = 61.0831 - 0.0738395 CYS
LTS = 271.134 +ve 0.386446 CYS
LYS = 82.0919 +ve 0.716688 CYS
LPE = 69.5775 - 0.116307 CYS
VE = 33.5117 - 0.0156355 CYS
NHS = 606.528 - 0.0554084 CYS
BP = 92.6448 - 0.00846375 CYS

Plan-2:Estimates using Circumferential Tensile Strength
Step:1
Estimate hardness
BHN = 100.114 +ve 0.269094 BHNp
Step:2
Estimate Circumferential tensile strength
CTS = 358.93 +ve 0.0697682 BHN
Step:3
Estimate all other critical parameters
CYS = 221.702 +ve 0.0956556 CTS
CPE = 110.901 - 0.186611 CTS
LTS = 76.4299 +ve 0.797551 CTS
LYS = 129.53 +ve 0.370893 CTS
LPE = 82.7526 - 0.116813 CTS
VE = 27.3037 +ve 0.00595615 CTS
NHS = 585.081 +ve 0.0196074 CTS
BP = 89.3691 +ve 0.00299424 CTS

Plan-3 : Estimates using Longitudinal Yield Strength
Step:1
Estimate Hardness
BHN = 100.114 +ve 0.269094 BHNp
Step:2
Estimate Longitudinal Yield Strength
LYS = 185.675 +ve 0.579177 BHN
Step:3
Estimate all other critical parameters
LTS = 235.637 +ve 0.50628 LYS
LPE = 54.0581 - 0.0539602 LYS
CTS = 294.98 +ve 0.27664 LYS
CYS = 175.044 +ve 0.307674 LYS
CPE = 49.03 - 0.0259937 LYS
VE = 45.8573 - 0.0614995 LYS
NHS = 620.091 - 0.104444 LYS
BP = 94.7164 - 0.0159533 LYS

Plan-4 : Estimates using Longitudinal Tensile Strength
Step:1
Estimate Hardness
BHN = 100.114 +ve 0.269094 BHNp
Step:2
Estimate Longitudinal Tensile strength
LTS = 292.834 +ve 0.557781 BHN
Step:3
Estimate all other critical parameters
LYS = 37.7161 +ve 0.616944 LTS
LPE = 86.3641 - 0.125995 LTS
CTS = 100.106 +ve 0.724902 LTS
CYS = 182.075 +ve 0.202164 LTS
CPE = 95.0519 - 0.14292 LTS
VE = 36.4303 - 0.0187191 LTS
NHS = 609.385 - 0.0461164 LTS
BP = 93.0812 - 0.00704432 LTS

Figure 50: Empirical formulas with four different plans

7.9 Discussion on Software Development Requirement

In order to estimate these properties quickly and easily Microsoft Excel based software was developed for estimation purpose. A separate chapter was dedicated for this software development to explain the scope and functionality of the software. The software is developed in such a way that the values can be estimated with any required plan or in all four methods instantaneously using the surface hardness values obtained from portable hardness tester in BHN. The dashboard provides all critical parameters instantaneously and from a single click after the surface hardness value fed to the software. The dash board screen shot is shown below for reference (See Figure. 51).

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Input		
Hardness Value from portable tester	**135**	in BHN
Output		
Material Hardness	136	in BHN

Parameter	**Value**	***Unit***
Plan 1 - Using Circumferential Yield Strength		
Circumferential Yield Strength	256	in MPa
Circumferential Acceptance sample estimated Values		
Circumferential Tensile Strength	368	in MPa
Circumferential percentage elongation	42.2	in %
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	370	in MPa
Longitudinal Yield Strength	266	in MPa
Longitudinal Percentage elongation	39.8	in %
Hydro-Test estimated Values		
Volumetric expansion	29.5	in %
Burst Pressure	90.5	in bar
Nominal Hoop Stresses	592	in MPa

Parameter	**Value**	***Unit***
Plan 2 - Using Circumferential Tensile Strength		
Circumferential Tensile Strength	368	in MPa
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	in MPa
Circumferential Percentage elongation	42.1	in %
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	370	in MPa
Longitudinal Yield Strength	266	in MPa
Longitudinal Percentage elongation	39.7	in %
Hydro-Test estimated Values		
Volumetric expansion	29.5	in %
Burst Pressure	90.5	in bar
Nominal Hoop Stresses	592	in MPa

Parameter	**Value**	***Unit***
Plan 3 - Using Longitudinal Yield Strength		
Longitudinal Yield Strength	265	in MPa
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	370	in MPa
Longitudinal Percentage elongation	39.8	in %
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	256	in MPa
Circumferential Tensile Strength	368	in MPa
Circumferential percentage elongation	42.1	in %
Hydro-Test estimated Values		
Volumetric expansion	29.6	in %
Burst Pressure	90.5	in bar
Nominal Hoop Stresses	592	in MPa

Parameter	**Value**	***Unit***
Plan 4 - Using Longitudinal Tensile Strength		
Longitudinal Tensile Strength	369	in MPa
Longitudinal Acceptance sample estimated Values		
Longitudinal Yield Strength	265	in MPa
Longitudinal Percentage elongation	39.9	in %
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	in MPa
Circumferential Tensile Strength	368	in MPa
Circumferential percentage elongation	42.3	in %
Hydro-Test estimated Values		
Volumetric expansion	29.5	in %
Burst Pressure	90.5	in bar
Nominal Hoop Stresses	592	in MPa

Developed as a part of PhD Dissertation

Figure 51: Screen shot of the software for empirical formulas

7.10 Discussion on factors affecting LPG Cylinder Life cycle

While studying LPG Cylinder Life cycle, an opportunity is available to study the factors affecting the cylinder life cycle and a separate study was carried out on this area. The topic was briefly described in chapter 2.4 and 2.5

7.11 Discussion on factors affecting Acceptance Test Results

While establishing the critical and influencing parameters for acceptance test, the results of longitudinal and circumferential tensile test specimens were analyzed. This led the study towards various sample preparation methods in the existing practice and studies the sample preparation process in detailed. Several factors in sample preparation can affect the test results. An optimal method was suggested with a publication on this domain. Brief extracts of the paper is given below

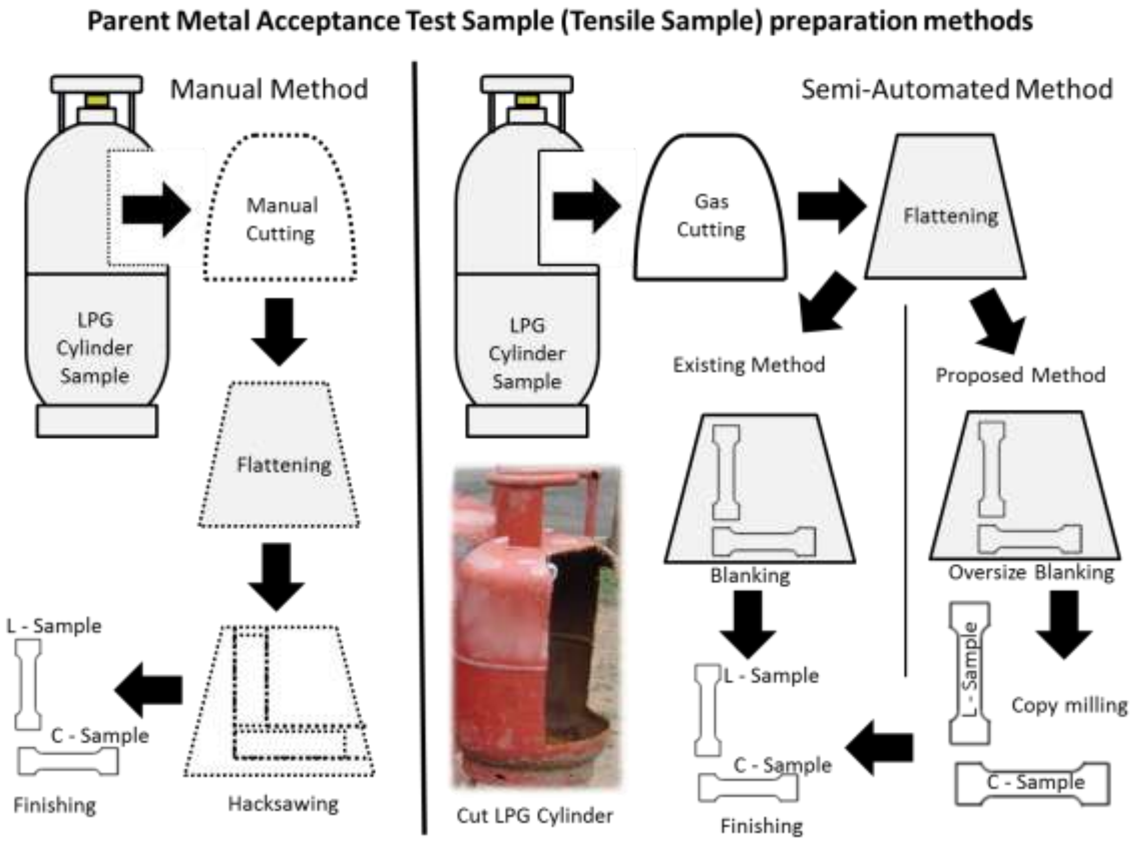


Figure 52: Pictorial Representation of LPG Cylinder Sample Preparation

Although test methods are same for tensile testing at various places like laboratories, commercial establishments, sample preparation process affects the end results. Strain or work hardening of sample during cold flattening and chiseling operations in manual sample preparation process, increases the resistance of specimen against failure at a given load condition and thus it reflects higher values of yield and tensile strength [3]. Maintaining dimensional accuracy (parallel length) between gauge lengths of specimen's is important for a tensile test. Any variation in parallel lengths leads irregular cross section of specimen and there is a change in area of cross section of the specimen at that point. In Such cases, specimen tends to fail at least cross section area in this parallel length if the specimen preparation is defective due to filing process. As a result of this effect, actual yield strength and tensile strength values reflect lower than the actual values [3].

Similarly in a semi-automated sample preparation process, the gas cutting operation changes the metal properties at heat affected zone especially near the edges of blank. It is observed that the hardness at the heat effected zone increases compared to the non-heated effected zone [98]. This phenomenon also increases tensile strength and yield strength as these two values are proportional to each other. Further, in blanking operations, due to shear force, the specimen cross section reduces near the edge reduces. This reduction cannot be measured with a veneer calipers or a screw gauge, while calculating the area of cross section for tensile strength or yield stress calculation. Thus, the sample exhibits lesser yield strength and tensile strength than the actual value .Considering these effects, the sample preparation is having an important role in tensile testing of parent metal [3].

Figure 53: Example of two cut cylinders and a tensile specimen

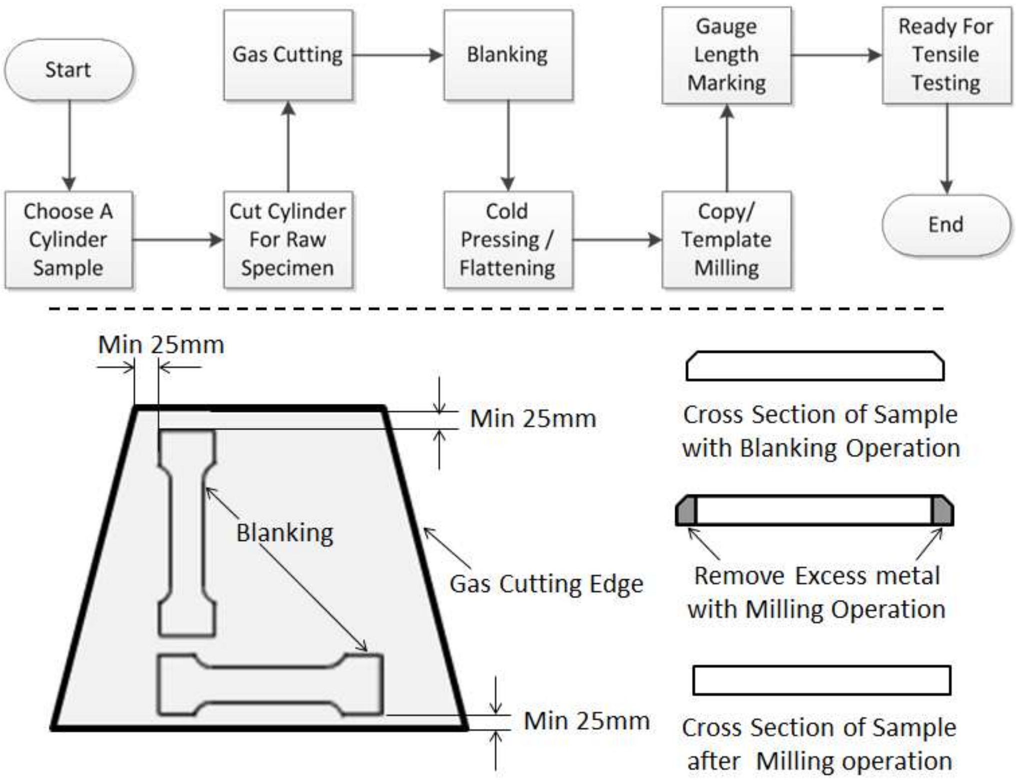


Figure 54: Optimal way of sample Preparation for uniform results

---End of Chapter 7---

Chapter-8

8. Estimation of Acceptance Test results

The chapter describes methods to estimate acceptance test results from research findings. Also, detailed discussions on various parameters to be considered while estimating critical parameters are given in this chapter. It is recommended to estimate critical values using circumferential tensile strength and the reason for the same was discussed in the chapter with justification.

8.1 Overview

Acceptance tests are mandatory certification tests as per statutory authorities, to be conducted on Liquefied Petroleum Gas (LPG) cylinders in any cylinder manufacturing plant when a new cylinder batch is produced as per Indian standard, IS 3196. For every batch of 203 or less cylinders produced in a manufacturing plant, one cylinder must undergo the acceptance test. As a part of this test, a sample cylinder is selected from a manufactured batch and two tensile specimens are cut from the body of this cylinder; one in longitudinal direction and the other in transverse direction or circumferential direction for testing purpose [11]. The tensile samples are tested on a universal testing machine to obtain physical properties of LPG Cylinder material. That is from this test; Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS) and Circumferential Percentage Elongation (CPE) of cylinder material can be measured [11]. These parameters are checked against standard requirements to pass a freshly manufactured cylinder batch in manufacturing location. LPG cylinders are produced from a definitely prescribed raw material and batch production methods are implemented for producing a specific batch. Hence it is expected that all cylinders in a batch are identical and having similar physical properties. These properties are revealed from a sample cylinder subjected to acceptance test and the values are attributed to all other cylinders in the batch. It is evident from the data analysis that these physical properties exhibit certain relations among themselves. In this chapter a method was given to estimate physical properties of cylinder material with empirical formulas derived in previous section, without destroying a cylinder or without conducting a destructive test on LPG cylinder.

8.2 Estimation of Acceptance Test Parameters

Figure 55 shows the methodology to estimate acceptance test results Critical parameters for acceptance test are given in below and are Longitudinal Tensile Strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield Strength (CYS) and Circumferential Percentage Elongation (CPE). Refer to Figure 55, Portable hardness tester is used to measure surface hardness of cylinder BHNp with the help of BHNp CTS can be estimated and from CTS all other acceptance test parameters can be calculated using the empirical formulas given in the Figure 55.

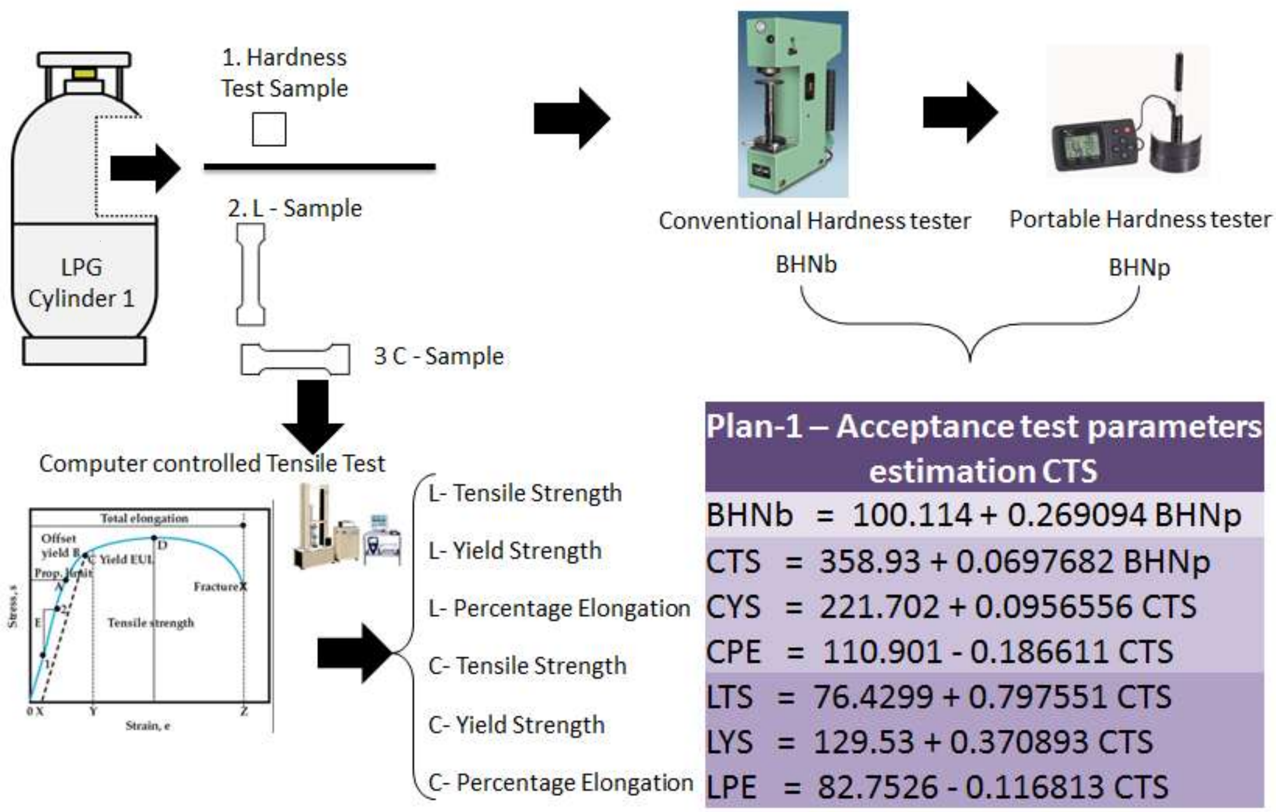


Figure 55: Estimation of Acceptance test parameters

Referring to the previous section although each parameter can be estimated in multiple ways, it is advisable to calculate the values either with circumferential tensile strength values. This is mainly because; cylinder material exhibits lower values for circumferential sample and is critical for statutory compliance. Further the formulas generated from tensile strength are derived without manual intervention while testing the sample. Hence it is advisable to calculate acceptance test results using circumferential tensile values. However in the current study was carried out using NABL accredited laboratories test data. Hence, chances of error are negligible and any formula can be used for estimates.

8.3 Discussion on Acceptance Test Data

The reasoning behind developing empirical formulas is given in this section. Referring to figure 56, Percentage elongation can be estimated from tensile strength and yield strength whereas tensile strength and yield strength is not possible to estimate using elongation values. This is mainly due to the following reason. Tensile strength and yield strength can be obtained directly from tensile test whereas the percentage elongation is calculated after the test by keeping the broken samples together [11]. It means, while calculating the tensile strength and yield strength the error due to experiment is minimal. On the other hand, the possibility is very high in case of percentage elongation [11]. In simple terms, referring to Figure.56 suppose, if LTS to be estimated, it can be calculated form LYS, CTS or CYS but no from LPE or CPE whereas, LPE can be estimated from any one of the parameters LYS, LTS, CYS, CTS and not from LPE or CPE.

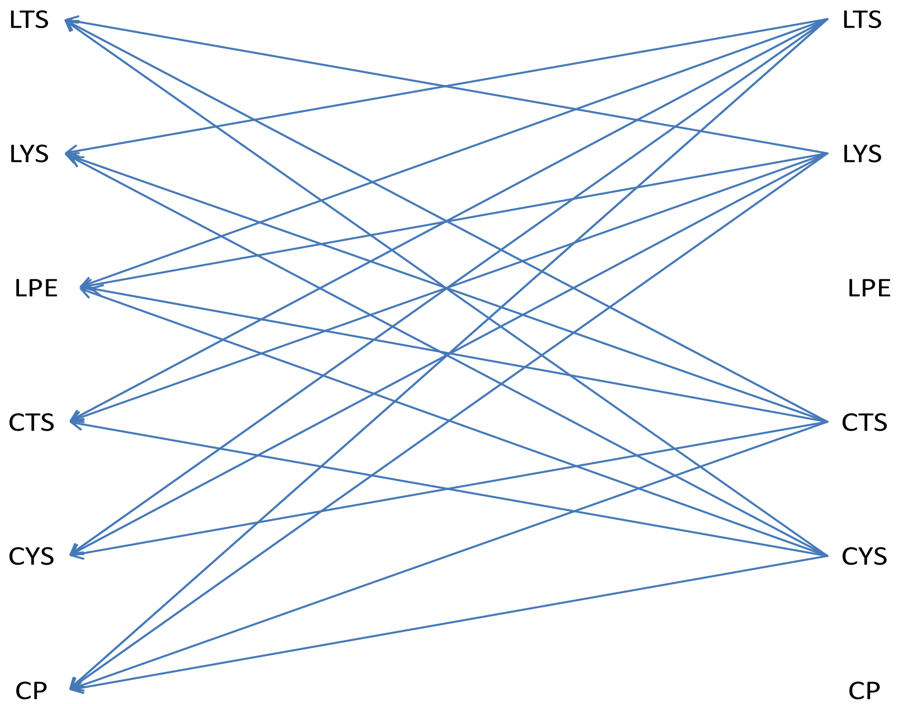


Figure 56: Possible Correlations among various acceptance test parameters of LPG Cylinder Parent metal

Further, LPG Cylinders are manufactured with low carbon steel with definitely prescribed raw material for construction. The relation between tensile strength and yield strength are proportional and the relation between tensile strength and the percentage elongation is inverse relation in low carbon steel [11]. In simple terms, higher the tensile strength, lower the percentage elongation in a low carbon steel. Also, from data analysis, it is established that a circumferential tensile sample exhibits less tensile strength and yield strength than a longitudinal sample. However, circumferential sample exhibits more percentage elongation than a longitudinal sample. Keeping all these possibilities and relations in mind, empirical formulas are generated using linear quadratic equations [11].

Values of all critical parameters are estimated using the empirical formulas and box plots were generated for comparison of actual values with estimated values. For example, referring to Figure.57, LTS was estimated using LYS, CTS, CYS and compared with LTS actual values with estimated LTS values obtained from LYS, CTS and CYS as ELTS, ECTS and ECYS [11].

Similarly for all other critical parameters, LYS, LPE, CTS, CYS, and CPE are estimated and compared with actual values using the box plots from Figure.58 to Figure.61. Although the mean connect lines are matching with both actual and estimated values in all box plots, the median connect lines are not in line with actual values because of the regression equations of the estimates. It is observed that the interquartile range boxes are more or less compressed in all estimated results in all the boxplots. Wherever such compression is observed, it indicates lean relationship among those specific pairs. For example, referring to the Figure.58 LTS can be estimated LYS, CTS and CYS. However the CTS Estimates are close to the LTS actual values and the estimate for LTS is more appropriate from CTS and least appropriate from CYS. Similarly for estimating LYS, CTS and CYS; CYS, LTS and LYS values are more appropriate whereas for estimating LPE and CPE, CTS is more appropriate [11].

This compressed interquartile range box in all boxplots also indicates that the range of estimates is limited to certain levels because of the sample data type. In case a set of failure cylinder data is considered for empirical formula generation, this range could expand to the levels of actual values. There are certain out layers observed in boxplots are due to certain values of the data are beyond the normal. Range this is possible due to sample data type, and sample preparation process. Also, the Pearson correlation constants of certain pairs are not showing very strong correlation. Weak correlations are possible due to various reasons like raw material selection, cylinder manufacturing process, welding methods adopted while fabricating cylinders, Heat treatment process parameters to relieve internal stresses in cylinders due to welding operation, Sample test methods etc. In the current study, the samples are collected from various manufacturers in India, produced their cylinders with minor variations in raw material sourced from various steel mills in India. Indian standard doesn't specify explicit manufacturing process, test method, heat treatment process parameters, sample test methods. However, it states the finished cylinder should meet certain conditions for Bureau of Indian Standards certification. This is mainly to accommodate several manufacturers in India for producing approximately 18 million cylinders in a year to meet the current Indian market demand. Also, it is practically not possible to get failed cylinder test data for analysis purpose and to develop a mathematical model. The cylinder data available in any BIS approved laboratory is only from accepted or passed cylinder segment. Thus the failure cylinder test data is not included in this study for empirical formula generation purpose. In addition to that, the test set up, sample preparation can also leads inadvertent mistakes some times, especially while calculating yield strength and percentage elongation [11].

It is evident from the work; empirical formulas can be established among the critical variables of cylinder acceptance test parameters. However, to improve the accuracy of empirical formulas, it is necessary to consider failure cylinders test data in addition to the passed cylinders test data for analysis purpose. Further, the data used for the analysis purpose should be from a controlled manufacturing and test conditions. It means very accurate the empirical formulas can be established, if the raw material, manufacturing process, heat treatment parameters and welding methods are standardized for LPG cylinder manufacturing. However, it is practically not possible, keeping in view of the existing cylinder manufacturers' population and their productions setup. Thus the empirical formulas developed in this method can be used only for estimation purpose and cannot be implemented for replacing existing testing process mentioned in Indian standards [11].

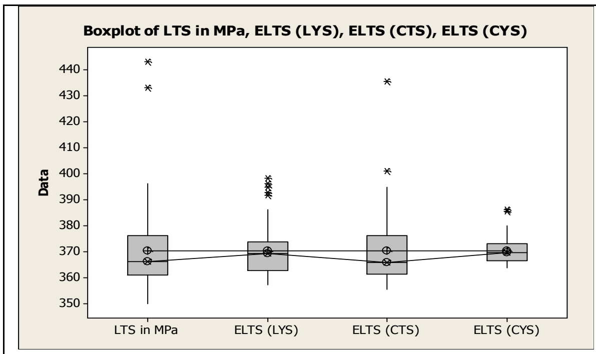


Figure 57: Comparison of actual and estimated values of Longitudinal Tensile Strength values

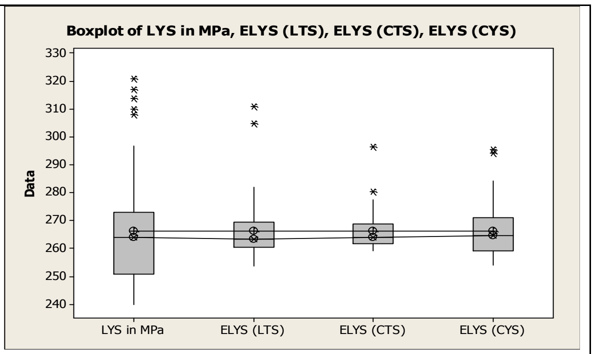


Figure 58: Comparison of actual and estimated values of Longitudinal Yield strength values

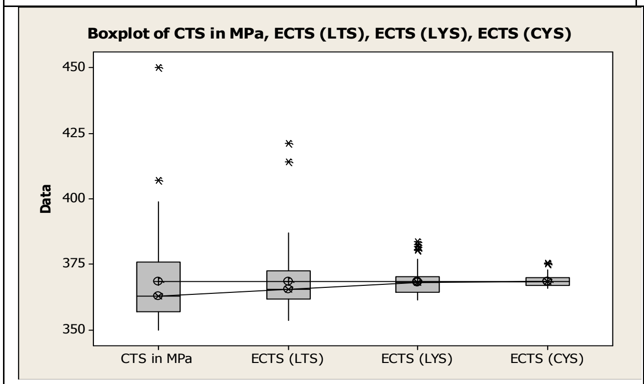


Figure 59: Comparison of actual and estimated values of Circumferential Tensile Strength values

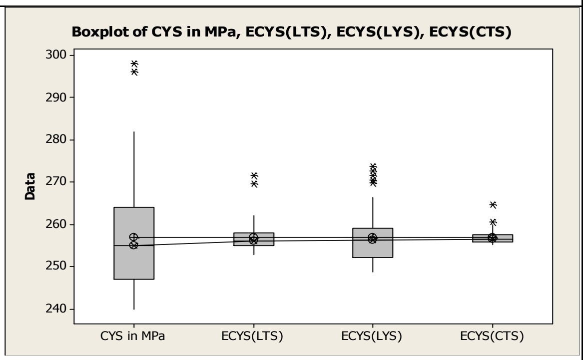


Figure 60: Comparison of actual and estimated values of Circumferential Yield Strength values

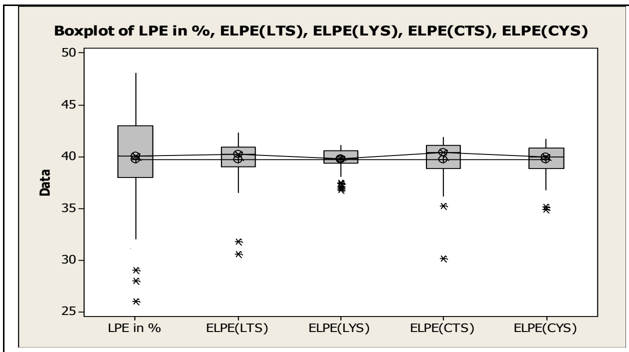


Figure 61: Comparison of actual and estimated values of Longitudinal Percentage Elongation values

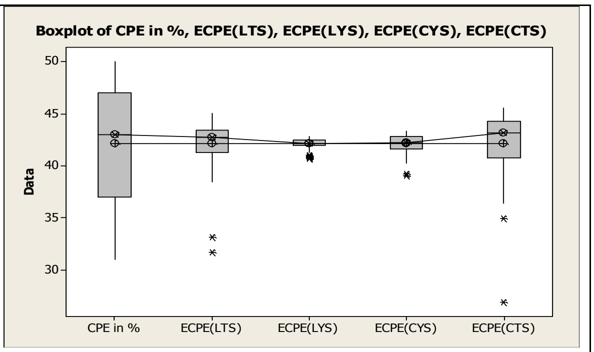


Figure 62: Comparison of actual and estimated values of Circumferential Percentage Elongation values

LPG cylinders in use are tested and approved by BIS at the time of releasing them to market. The empirical formulas given in this work can provide indicative values of such cylinder for analysis purpose, as the test data used in deriving the empirical formulas is purely from such cylinders [11].

---End of Chapter 8---

Chapter-9

9. Estimation of Hydrotest Results

The chapter describes the methodology to obtain hydrotest results using empirical formulas developed in current study. It is advisable to estimate the hydro test parameters using circumferential tensile strength values. Detailed analysis on hydrotest results was given at the end of the chapter.

9.1 Overview

One cylinder out of 403 new Liquefied Petroleum Gas cylinder batch produced in a manufacturing location should undergo hydro-tests. Hydro tests on LPG cylinders are typically conducted in a manufacturing location and are hydrostatic leak test, permanent volumetric expansion test, Burst pressure test and nominal hoop stresses calculation. These tests reveal permanent volumetric expansion (VE) at test pressure conditions, burst pressure (BP) of a cylinder and nominal hoop stresses (NHS) of cylinder at burst pressure conditions. A random new sample cylinder is subjected to internal hydro-test pressure to test pressure conditions (25kgf/cm2) and retain the pressure for not less than 30 seconds to check for any leaks. Once the cylinder is ensured leaks free, internal pressure is relieved and measured the volumetric expansion of the cylinder under test pressure condition. This cylinder is then subjected to continuous internal hydrostatic test pressure till it bursts. The pressure at which the cylinder bursts is recorded as burst pressure. Using the burst pressure, cylinder thickness and cylinder external diameter, nominal hoop stresses are calculated at burst pressure conditions. These parameters are checked against standard for their compliance. Indian standard IS 3196 provides the guidelines and the limits to these critical values... It is not possible to verify or check the cylinder in market for measuring cylinder burst pressure as a part of accident analysis or incident investigation due to the nature of tests (destructive tests) involved for measurement. This chapter describes a method to estimate hydrotest results using empirical formulas derived in this research

9.2 Estimation of Hydrotest Results

Referring to figure 63, cylinder surface hardness (BHNp) can be obtained with a portable hardness tester and the value can be used for estimating hydrotest parameters using the empirical formulas given in the figure 63. Similar to acceptance tests, it is advisable to estimate the values using circumferential tensile test due to minimal human intervention.

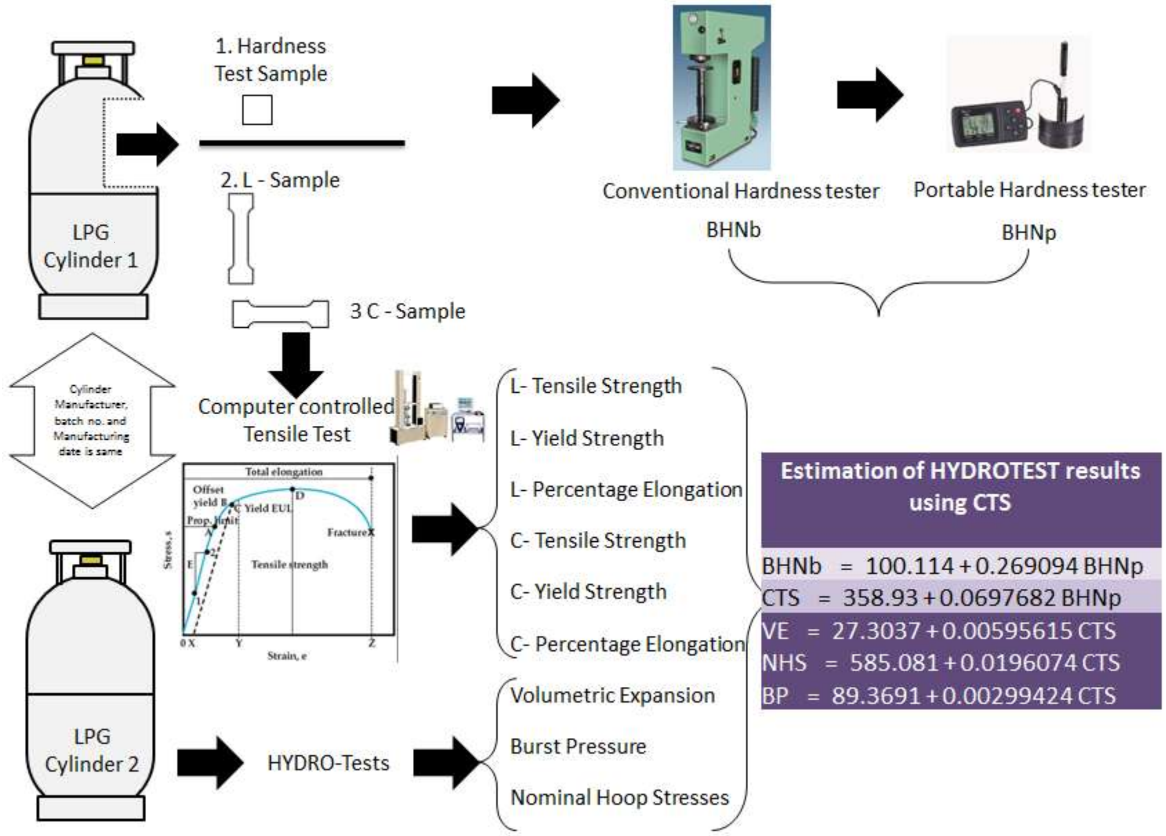


Figure 63: Estimation of Hydrotest results

9.3 Discussion on Hydrotest Results

LPG Cylinders are manufactured with low carbon steel with definitely prescribed raw material for construction. Low carbon steel exhibits inverse relation between tensile strength and the percentage. In simple terms, higher the tensile strength, lower the percentage elongation in a low carbon steel. Volumetric expansion is nothing but elongation of cylinder in longitudinal and circumferential direction and hence this can be related to material physical property of percentage elongation. Similarly, burst pressure can be correlated with tensile strength of a cylinder material. Burst pressure and volumetric expansion can be correlated with a linear relationship and is exhibited in the current study. Thus the empirical formulas are generated using linear equations. However, the Pearson correlation constant is not showing very strong correlation among volumetric expansion and burst pressure [5].

Weak correlations are possible due to various reasons like raw material selection, cylinder manufacturing process, welding methods adopted while fabricating cylinders, Heat treatment process parameters to relieve internal stresses in cylinders due to welding operation, Sample test methods etc. In the current study, the samples are collected from various manufacturers in India, produced their cylinders with minor variations in raw material sourced from various steel mills in India. Indian standard doesn't specify explicit manufacturing process, test method, heat treatment process parameters, sample test methods. However, it states the finished cylinder should meet certain conditions for Bureau of Indian Standards certification. This is mainly to accommodate several manufacturers in India for producing approximately 18 million cylinders in a year to meet the current Indian market demand. Also, it is practically not possible to get failed cylinder test data for analysis purpose and to develop a mathematical model. The cylinder data available in any BIS approved laboratory is only from accepted or passed cylinder segment. Thus the failure cylinder test data is not included in this study for empirical formula generation purpose. In addition to that, the test set up can lead also leads inadvertent mistakes some times, especially while noting down the burst pressure due to cyclic hydrostatic loads from a positive displacement pump [5].

Referring to the box plots (Figure.64 and Figure.65), although the mean connect lines are matching with both actual and estimated values, the interquartile range boxes are compressed in estimated results. This is mainly due to the lean relationship between BP-VE and NHS-VE. Whereas, the relation between NHS - BP shows a very strong correlation; because the NHS is derived from burst pressure using LPG cylinder initial diameter and thickness (, which are constant values for a specific cylinder design). Thus the box plot among BP and NHS is a replica of BP. However, if the nominal hoop stress is estimated from VE, compression of interquartile range box can be witnessed. This compressed interquartile range box indicates that the range of estimates is limited to certain levels because of the sample type. In case a set of failure cylinder data is considered for empirical formula generation, this range could expand to the levels of actual values [5].

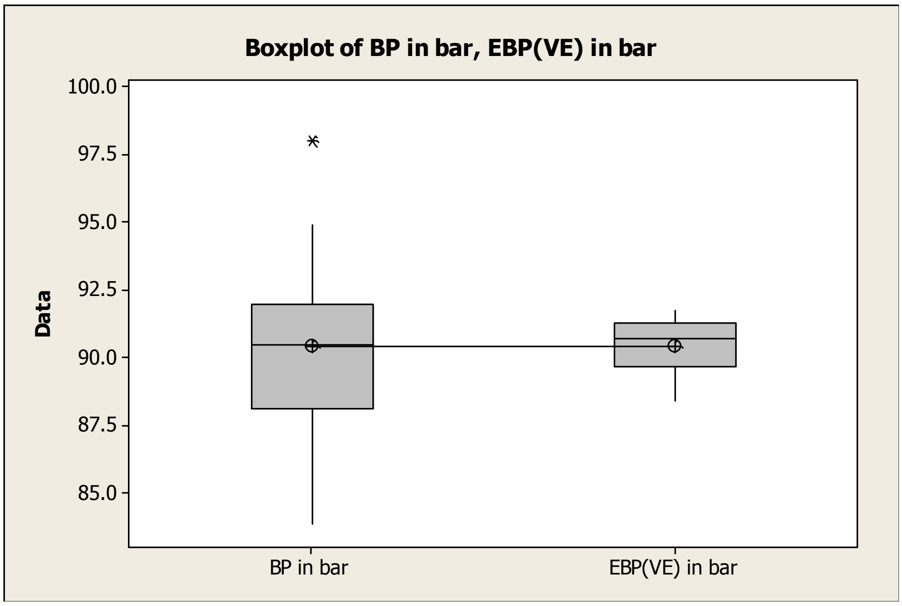


Figure 64: Comparison of Actual and estimated values of Burst Pressure

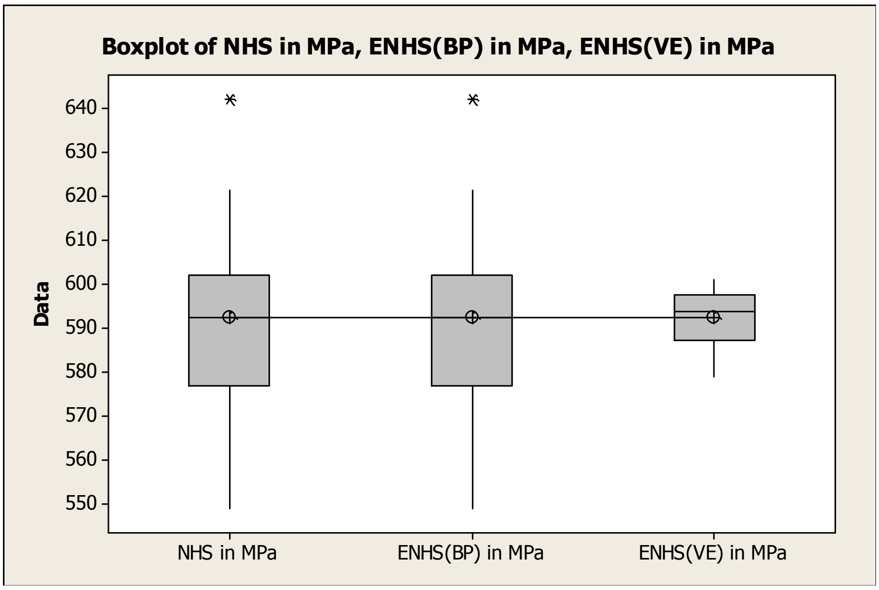


Figure 65: Comparison of actual and estimated values of Nominal Hoop Stresses with two different methods

It is evident from the work; empirical formulas can be established among the critical variables of cylinder hydro test parameters. However, to improve the accuracy of empirical formulas, it is necessary to consider failure cylinders test data in addition to the passed cylinders test data for analysis purpose. Further, the data used for the analysis purpose should be from a controlled manufacturing and test conditions. It means very accurate the empirical formulas can be established, if the raw material, manufacturing process, heat treatment parameters and welding methods are standardized for LPG cylinder manufacturing. However, it is practically not possible, keeping in view of the existing cylinder manufacturers' population and their productions setup. Thus the empirical formulas developed in this method can be used only for estimation purpose and cannot be implemented for replacing existing testing process mentioned in Indian standards [5].

LPG cylinders in use are tested and approved by BIS at the time of releasing them to market. The empirical formulas given in this work can provide indicative values of such cylinder for analysis purpose, as the test data used in deriving the empirical formulas is purely from such cylinders [5].

---End of Chapter 9---

Chapter-10

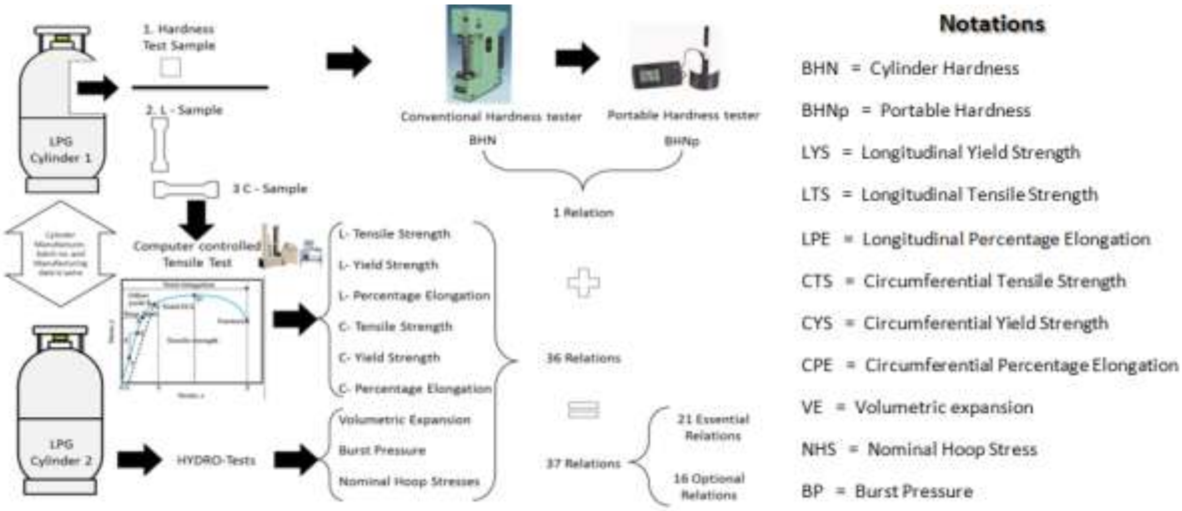
10. Software System

Microsoft excel based software was developed to calculate and analyses the critical parameters of LPG cylinder material using portable hardness test value. The software helps in selecting a specific plan and calculates values as per that specific plan. Software also visually highlights the non-complied parameters, if any. The usability and scope for future developments are discussed this chapter.

10.1 Purpose of Software Development

Current study yielded 37 empirical formulas in which 21 essential and 16 optional relations among various physical parameters of LPG Cylinder material See Figure 66. These values are based on hardness value of a cylinder. Analysis of all these empirical parameters demands time. On production line it is not possible to calculate all these values manually while inspecting a cylinder. In order to have an effective fail proof inspection system, the results should be available with least operators' efforts and should be simple to operate. This triggers the scope for developing a software system to calculate and analyses the empirical formulas obtained in this study.

Once again keeping in view of simplicity, it was decided to use Microsoft excel based software for calculating physical parameters. Most of the personal computers or laptops are available with Microsoft excel software and there is no exclusive license or training required to operate the software. Hence the software was developed in Microsoft excel.



Plan-1 - Estimates using CTS	Plan-2 Estimates using CYS	Plan-3 Estimates using LTS	Plan-4 Estimates using LYS
BHN = 100.114 + 0.269094 BHNp	BHN = 100.114 + 0.269094 BHNp	BHN = 100.114 + 0.269094 BHNp	BHN = 100.114 + 0.269094 BHNp
CTS = 358.93 + 0.0697682 BHNp	CYS = 205.909 + 0.366962 BHNp	LTS = 292.834 + 0.557781 BHNp	LYS = 185.675 + 0.579177 BHNp
CYS = 221.702 + 0.0956556 CTS	CTS = 325.931 + 0.166194 CYS	LYS = 37.7161 + 0.616944 LTS	LTS = 235.637 + 0.50628 LYS
CPE = 110.901 - 0.186611 CTS	CPE = 61.0831 - 0.0738395 CYS	LPE = 86.3641 - 0.125995 LTS	LPE = 54.0581 - 0.0539602 LYS
LTS = 76.4299 + 0.797551 CTS	LTS = 271.134 + 0.386446 CYS	CTS = 100.106 + 0.724902 LTS	CTS = 294.98 + 0.27664 LYS
LYS = 129.53 + 0.370893 CTS	LYS = 82.0919 + 0.716688 CYS	CYS = 182.075 + 0.202164 LTS	CYS = 175.044 + 0.307674 LYS
LPE = 82.7526 - 0.116813 CTS	LPE = 69.5775 - 0.116307 CYS	CPE = 95.0519 - 0.14292 LTS	CPE = 49.03 - 0.0259937 LYS
VE = 27.3037 + 0.00595615 CTS	VE = 33.5117 - 0.0156355 CYS	VE = 36.4303 - 0.0187191 LTS	VE = 45.8573 - 0.0614995 LYS
NHS = 585.081 + 0.0196074 CTS	NHS = 606.528 - 0.0554084 CYS	NHS = 609.385 - 0.0461164 LTS	NHS = 620.091 - 0.104444 LYS
BP = 89.3691 + 0.00299424 CTS	BP = 92.6448 - 0.00846375 CYS	BP = 93.0812 - 0.00704432 LTS	BP = 94.7164 - 0.0159533 LYS

Figure 66: Software development scope

10.2 Scope and Functionalities

Cylinders are subjected to hardness test using a portable hardness tester to verify hardness values. This single hardness value is used to estimate critical parameters of various cylinder parameters. The parameters can be obtained in 4 different methods. However these parameters are all having compliance requirement as per Indian standard.

Thus, the scope of software tool is to calculate various critical parameters of LPG Cylinder material using hardness value and tabulate under specific plan. Further the tool should provide visual display if any of the parameters are going out of compliance limits stated in the standard.

10.3 Software Description and Usage

An excel file “Estimation of LPG Cylinder critical parameters” can be access by clicking the file below.

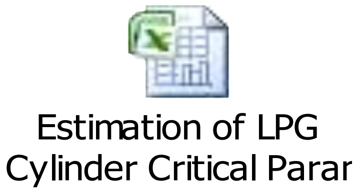


Figure 67: Software in MS Excel

Up on opening the file, one can input hardness value obtained from a portable hardness tester in the input column and choose a specific plan by pressing the button.

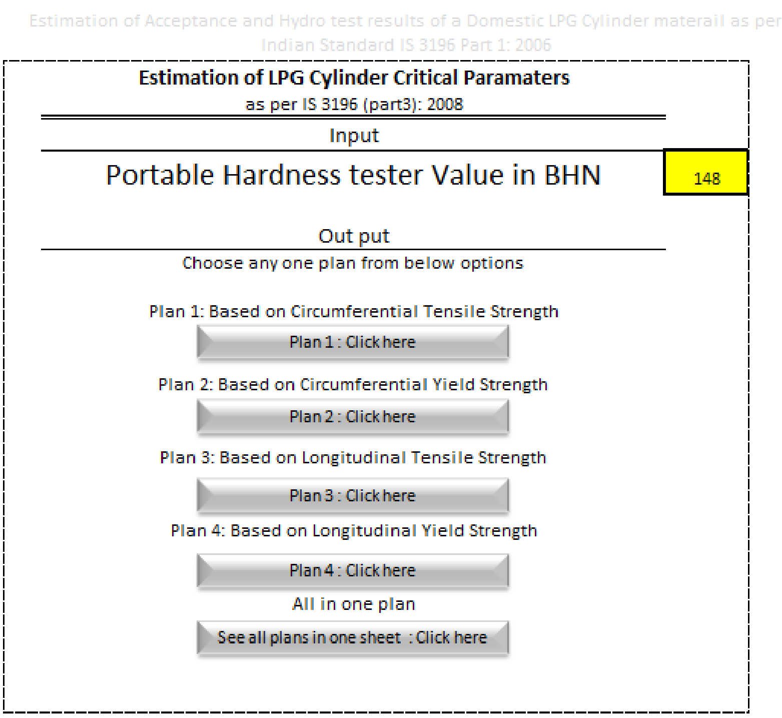


Figure 68: Software user front end

Based on the pan Microsoft excel calculates the values at backend and through critical parameters in a sheet. Figure 69 to Figure 73 refers various screens of software based on the input selection.

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Input		
Hardness Value from portable tester	**148**	in BHN
Output		
Material Hardness	140	in BHN
Parameter	**Value**	**Unit**
Plan 1 - Using Circumferential Tensile Strength		
Circumferential Tensile Strength	369	in MPa
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	in MPa
Circumferential Percentage elongation	42	in %
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	370	in MPa
Longitudinal Yield Strength	266	in MPa
Longitudinal Percentage elongation	40	in %
Hydro-Test estimated Values		
Volumetric expansion	29	in %
Burst Pressure	90	in bar
Nominal Hoop Stresses	592	in MPa

Print

Home

Figure 69: Results screen – Plan 1

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Input		
Hardness Value from portable tester	**148**	in BHN
Output		
Material Hardness	140	in BHN
Parameter	**Value**	**Unit**
Plan 2 - Using Circumferential Yield Strength		
Circumferential Yield Strength	257	in MPa
Circumferential Acceptance sample estimated Values		
Circumferential Tensile Strength	369	in MPa
Circumferential percentage elongation	42	in %
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	371	in MPa
Longitudinal Yield Strength	266	in MPa
Longitudinal Percentage elongation	40	in %
Hydro-Test estimated Values		
Volumetric expansion	29	in %
Burst Pressure	90	in bar
Nominal Hoop Stresses	592	in MPa

Print

Home

Figure 70: Results screen – Plan 2

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Plan		
Hardness Value from portable tester	148	in BHN
Output		
Material Hardness	140	in BHN
Parameter	**Value**	***Unit***
Plan 3 - Using Longitudinal Tensile Strength		
Longitudinal Tensile Strength	371	in MPa
Longitudinal Acceptance sample estimated Values		
Longitudinal Yield Strength	267	in MPa
Longitudinal Percentage elongation	40	in %
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	in MPa
Circumferential Tensile Strength	369	in MPa
Circumferential percentage elongation	42	in %
Hydro-Test estimated Values		
Volumetric expansion	29	in %
Burst Pressure	90	in bar
Nominal Hoop Stresses	592	in MPa

Print

Home

Figure 71: Results screen – Plan3

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Input		
Hardness Value from portable tester	148	in BHN
Output		
Material Hardness	140	in BHN
Parameter	**Value**	***Unit***
Plan 3 - Using Longitudinal Yield Strength		
Longitudinal Yield Strength	267	in MPa
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	371	in MPa
Longitudinal Percentage elongation	40	in %
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	in MPa
Circumferential Tensile Strength	369	in MPa
Circumferential percentage elongation	42	in %
Hydro-Test estimated Values		
Volumetric expansion	29	in %
Burst Pressure	90	in bar
Nominal Hoop Stresses	592	in MPa

Print

Home

Figure 72: Results screen – Plan4

Estimation of Acceptance and Hydro test results of a Domestic LPG Cylinder materail as per Indian Standard IS 3196 Part 1: 2006

Input			
Hardness Value from portable tester	148	[illegible]	Print
Output			Home
Material Hardness	140	[illegible]	

Parameter	Valu	Unit
Plan 1 - Using Circumferential Tensile Strength		
Circumferential Tensile Strength	369	[illegible]
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	[illegible]
Circumferential Percentage elongation	42	[illegible]
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	370	[illegible]
Longitudinal Yield Strength	266	[illegible]
Longitudinal Percentage elongation	40	[illegible]
Hydro-Test estimated Values		
Volumetric expansion	29	[illegible]
Burst Pressure	90	[illegible]
Nominal Hoop Stresses	592	[illegible]

Parameter	Valu	Unit
Plan 2 - Using Circumferential Yield Strength		
Circumferential Yield Strength	257	[illegible]
Circumferential Acceptance sample estimated Values		
Circumferential Tensile Strength	369	[illegible]
Circumferential percentage elongation	42	[illegible]
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	371	[illegible]
Longitudinal Yield Strength	266	[illegible]
Longitudinal Percentage elongation	40	[illegible]
Hydro-Test estimated Values		
Volumetric expansion	29	[illegible]
Burst Pressure	90	[illegible]
Nominal Hoop Stresses	592	[illegible]

Parameter	Valu	Unit
Plan 3 - Using Longitudinal Tensile Strength		
Longitudinal Tensile Strength	371	[illegible]
Longitudinal Acceptance sample estimated Values		
Longitudinal Yield Strength	267	[illegible]
Longitudinal Percentage elongation	40	[illegible]
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	[illegible]
Circumferential Tensile Strength	369	[illegible]
Circumferential percentage elongation	42	[illegible]
Hydro-Test estimated Values		
Volumetric expansion	29	[illegible]
Burst Pressure	90	[illegible]
Nominal Hoop Stresses	592	[illegible]

Parameter	Valu	Unit
Plan 4 - Using Longitudinal Yield Strength		
Longitudinal Yield Strength	267	[illegible]
Longitudinal Acceptance sample estimated Values		
Longitudinal Tensile Strength	371	[illegible]
Longitudinal Percentage elongation	40	[illegible]
Circumferential Acceptance sample estimated Values		
Circumferential Yield Strength	257	[illegible]
Circumferential Tensile Strength	369	[illegible]
Circumferential percentage elongation	42	[illegible]
Hydro-Test estimated Values		
Volumetric expansion	29	[illegible]
Burst Pressure	90	[illegible]
Nominal Hoop Stresses	592	[illegible]

Developed as a part of PhD Dissertation

Figure 73: Results screen – All in one plan

In case the values are going beyond the specifications, the cell and the font color will be highlighted with red.

Thus an operator can easily identify the parameter which is going beyond the specification for rejection. Once the operator decides whether to pass or fail a sample, he can take a print or can go back to main many by pressing appropriate labels.

10.4 Control and Reliability

The cells related to the formulas can be locked for with administrative rights so that no one can access or modify formulas. Thus control and reliability of the application can be ensured.

Further, with administrative rights one can choose any specific plan to their requirement and the other plans may be disabled.

10.5 Future Developments

After implementing the plan, in case production line staff is not equipped with a PC or laptop, control charts can be prepared as per Hardness vales on specific plan and may be used for line production requirement.

Further, integration of software with portable hardness tester backend application can be explored as a scope for testing instrument development. This solves the production line problems and also very convenient to use various stake holders of LPG Cylinder business including manufacturers, customers, inspection agencies, statutory authorities etc.

---End of Chapter 10---

Chapter-11

11. Fail-safe Inspection Plan

Fail safe inspection plan was suggested in this chapter. This plan not only intended for manufacturers but also it can be extended beyond manufacturing premises. The methodology is discussed with 4 different plans to estimate critical parameters of cylinder material. Also, fail safe inspection plan implementation scope in cylinder life cycle, its advantages and scope for amendments to national standards are discussed in this chapter.

11.1 General

This chapter focuses integration of entire research towards meaningful outcome for the benefit of LPG cylinder business stakeholders. Four methods are suggested in this chapter to estimate critical parameters of LPG cylinder material and are based on tensile and yield strength values of circumferential and longitudinal valves. These plans are discussed individually in subsequent sections along with fail safe inspection method for implementation in various stages of LPG Cylinder life cycle.

11.2 Methodology

Surface hardness of cylinder can be measured with any one of the portable hardness tester (micro hardness tester) and can get Brinells hardness number (BHN-p) of the material directly. This value is used to estimate cylinder material hardness in terms of BHN-b. Estimation of material hardness is common to all methods. However, to get more accurate results, the surface hardness values can be measured at several places on the cylinder and can be averaged.

Once the cylinder material hardness is available, with a given set of empirical formulas, tensile strength and yield strength in circumferential and longitudinal direction can be estimated. Using these values yield or tensile strength values, all other critical parameters of cylinder material can be estimated with a set of empirical formulas in a specific plan. Once the Yield strength or tensile strength values are available, all other cylinder critical parameters of acceptance and hydrotest can be estimated using empirical formulas given in a particular plan. Thus all the cylinder critical parameters can be obtained without destroying a cylinder.

11.2.1 Methodology based on Circumferential Tensile Strength

Once the cylinder material hardness is BHN-b obtained as mentioned in section 11.2, using a set of empirical formulas given in Figure 74, are required to use for obtaining critical parameters of acceptance and hydrotest parameters of LPG Cylinder material. Referring to the formulas, all the parameters in this plan are in terms of circumferential tensile strength (CTS) values. Thus the critical values viz. Yield strength, tensile strength and percentage elongation, volumetric expansion, burst pressure and nominal hoop stress of a cylinder material can be estimated

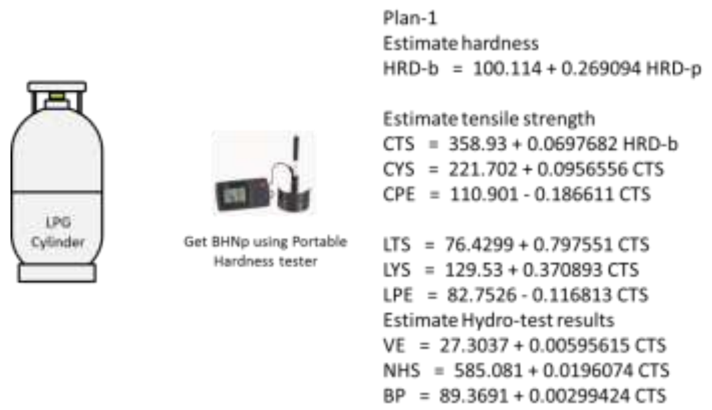


Figure 74: Fail Safe Inspection Plan 1

11.2.2 Methodology based on Circumferential Yield Strength

Once the cylinder material hardness is BHN-b obtained as mentioned in section 11.2, using a set of empirical formulas given in Figure 75, are required to use for obtaining critical parameters of acceptance and hydrotest parameters of LPG Cylinder material. Referring to the formulas, all the parameters in this plan are in terms of circumferential yield strength (CYS) values. Thus the critical values viz. Yield strength, tensile strength and percentage elongation, volumetric expansion, burst pressure and nominal hoop stress of a cylinder material can be estimated

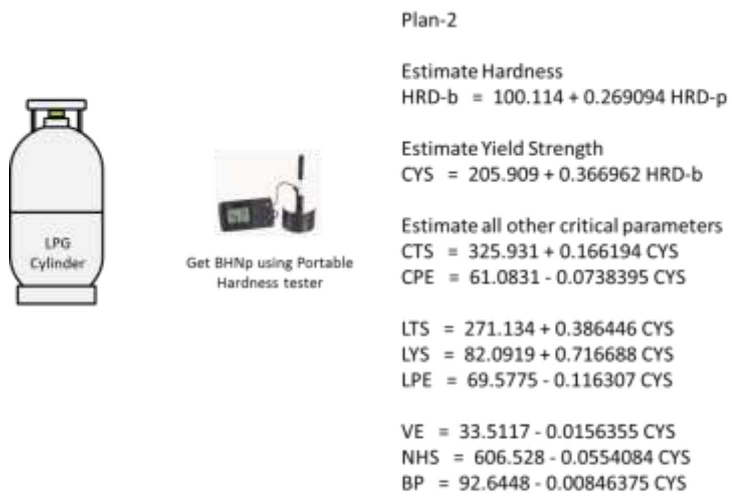


Figure 75: Fail Safe Inspection Plan 2

11.2.3 Methodology based on Longitudinal Tensile Strength

Once the cylinder material hardness is BHN-b obtained as mentioned in section 11.2, using a set of empirical formulas given in Figure 76, are required to use for obtaining critical parameters of acceptance and hydrotest parameters of LPG Cylinder material. Referring to the formulas, all the parameters in this plan are in terms of longitudinal tensile strength (LTS) values. Thus the critical values viz. Yield strength, tensile strength and percentage elongation, volumetric expansion, burst pressure and nominal hoop stress of a cylinder material can be estimated

Plan-3 : Optional from Longitudinal Values

Estimate Hardness

HRD-b = 100.114 + 0.269094 HRD-p

Estimate tensile strength - Longitudinal

LTS = 292.834 + 0.557781 HRD-b

LYS = 37.7161 + 0.616944 LTS

LPE = 86.3641 - 0.125995 LTS

CTS = 100.106 + 0.724902 LTS

CYS = 182.075 + 0.202164 LTS

CPE = 95.0519 - 0.14292 LTS

VE = 36.4303 - 0.0187191 LTS

NHS = 609.385 - 0.0461164 LTS

BP = 93.0812 - 0.00704432 LTS

Figure 76: Fail Safe Inspection Plan 3

11.2.4 Methodology based on Longitudinal Yield Strength

Once the cylinder material hardness is BHN-b obtained as mentioned in section 11.2, using a set of empirical formulas given in Figure 77, are required to use for obtaining critical parameters of acceptance and hydrotest parameters of LPG Cylinder material. Referring to the formulas, all the parameters in this plan are in terms of longitudinal yield strength (LYS) values. Thus the critical values viz. Yield strength, tensile strength and percentage elongation, volumetric expansion, burst pressure and nominal hoop stress of a cylinder material can be estimated

Plan-4 : Optional
Estimate Hardness
HRD-b = 100.114 + 0.269094 HRD-p
Estimate Yield Strength - longitudinal
LYS = 185.675 + 0.579177 HRD-b
LTS = 235.637 + 0.50628 LYS
LPE = 54.0581 - 0.0539602 LYS

CTS = 294.98 + 0.27664 LYS
CYS = 175.044 + 0.307674 LYS
CPE = 49.03 - 0.0259937 LYS

VE = 45.8573 - 0.0614995 LYS
NHS = 620.091 - 0.104444 LYS
BP = 94.7164 - 0.0159533 LYS

Figure 77: Fail Safe Inspection Plan 4

11.2.5 Analysis of proposed Fail-Safe Inspection Plans

It is evident from research findings that the circumferential values of a cylinder material are always lower than longitudinal values and hence they are critical. Further, among tensile and yield strength values, tensile strength can be obtained directly from a universal tensile testing machine while conducting the test. Contrary, yield strength is obtained after identification of yield point manually on the graph. In view of this manual intervention, it is recommended to estimate cylinder critical values using tensile strength values. However, in the current study the tests are conducted in more accurate manner in an NABL accredited laboratory. Thus the variations in estimates are almost zero.

11.3 Fail-Safe Inspection for Cylinder Manufacturer

Defects can be identified and eliminated at the originating location and hence the primary focus of this study is on cylinder manufacturer premises for suggesting a Fail proof inspection plan. Fail proof inspection plans are possible only when there is 100% inspection on production lines. In the existing state of art technology, 100% inspection is not possible in a cylinder manufacturing plant due to involvement of destructive tests to obtain critical material parameter values. In the current research methods are suggested to obtain these values without destroying a cylinder. Thus, implementation of fail proof inspection plan is feasible in manufacturing location. Further, in a continuous production environment, inspection time should be minimal to avoid piling up of stocks on production line for processing. To address this issue, methods suggested in this plan consume minimal time and the values can be obtained almost instantaneous.

Using the set of different plans mentioned in this chapter, anyone can estimate cylinder critical parameters with ease and with accuracy. The time to get a hardness value from a portable hardness tester is almost instantaneous and hence, cylinder hardness can be obtained during manufacturing process itself. i.e. immediately after heat treatment process before painting the cylinder. At this stage the cylinder parent metal hardness can be obtained from cylinder surface (BHN-b) itself as these cylinders are yet to be shot blasted for painting operation. 100% cylinders can be tested at this stage during manufacturing. However, if a manufacturer wishes to test the cylinder after paining, a small amount of paint to be peeled off and BHN-p can be measured at this stage which can be later translated to BHN-b for estimating the critical values. Software given in the system can be used for obtaining critical values quickly from hardness values. Scope for developing a tool was discussed in section

11.6. However, control charts can be prepared based on hardness values, using excel based software for segregation of cylinders intended for rework. For additional caution, existing practices of destructive tests can be carried out on cylinder for certification. I.e. In existing system, acceptance test and hydrotests are conducted after completion of batch production and before certifying for BIS marking. At this stage two cylinders are picked randomly from a manufacturing lot; among them one goes for acceptance test and the other for hydrotest. Based on these two cylinders results, a batch is decided for certification.

Thus, 100% cylinders can be ensured for material safety from a manufacturing plant and at the same time existing inspection systems can also be continued to reinforce safety in using an LPG Cylinder.

11.4 Implementation of plan in LPG Cylinder Life cycle

The system can be implemented during cylinder life cycle to ensure material safety at various stages of it its life cycle and to check the material safety compliance requirements. This is possible mainly due to the involvement of simple tools and nondestructive inspections.

11.4.1 At the time of new LPG Cylinder receipts in LPG bottling plants

In the existing practices, marketing oil companies' doesn't have facilities to check material compliance requirement of an LPG cylinder in their bottling plants. Hence new cylinder inspection is limited to visual only in plant premises before dispatching to customers. Often, plants send their cylinders to their in-house laboratories for verification of cylinder material compliance requirements but this is not mandatory obligation. In other words, new cylinders cannot be inspected for material compliance requirements before dispatching to consumer.

The proposed method can be used for inspecting randomly at LPG bottling plants can curb entry of non-complied cylinders to market.

While receiving new cylinders, every LPG bottling plant conducts statistical quality control checks (visual and few no destructive inspections). In addition to these checks, if an LPG bottling plant is equipped with a portable hardness tester, cylinders can be randomly checked for material quality also at this stage. A small amount of cylinder paint can be peeled off to check cylinder surface hardness (BHN-p). Using the set of formulas given in this chapter all other material properties can be verified and in case of any deviation, it can be notified to appropriate authorities for corrective action.

11.4.2 At the time of verification of used LPG Cylinders during Refilling

Each and every used cylinder, before refilling should undergo certain visual inspections viz. Verification of dents, cuts, fire marks, mandatory testing dates, etc. Among these, if a cylinder is observed with fire marks, the same needs to be discarded from its service. This is mainly due to safety reason. Suppose a cylinder is subjected to fire, cylinder material properties can change considerably and the cylinder many not be safe to use. However in the existing state of art technology, there is no method to verify cylinder material properties at this stage and hence, the cylinders are discarded from their service. Cylinder material properties can be verified at this stage using the method mentioned in this chapter 11.2.

11.4.3 At the time of verification of used LPG Cylinders during Requalification Tests

LPG Cylinders need to be periodically re-qualified during their usage in market. Requalification means, cylinders are tested and certified for safe use. Generally requalification tests are carried out in first 10 years and subsequently every five years. It means, once the cylinder is requalified, it is safe to use for next five years. The periodic requalification is guided by Indian standard IS 13258:1991, 'welded low carbon steel cylinders exceeding 5 liter water capacity for low pressure liquefiable gas - Code of practice for inspection and reconditioning of used LPG cylinders' the standard does not states the requirements for material inspection. Suppose a cylinder is subjected to fire incident and came with painted or cleaned condition, it is not possible to identify the cylinder in its life cycle. Such cylinders can be identified using the methods mentioned in this chapter (11.2)

11.4.4 Verification of Cylinders after Hot Repairs

Cylinders are often sent for hot repairs to repair their damaged foot rings and valve protection rings [96]. These are damaged due to wrong handling and dropping from height. Such cylinders are sent to manufacturer premises for repairs. Foot rings and valve protection rings are removed from cylinder body and new rings are welded to these cylinder. It is mandatory to relieve stresses in cylinder body after such repair. However, in the existing system, there is no method to verify whether stress relieving is carried out or not. Majority of cylinders in their life cycle at least once they for hot repairs. Method proposed in this chapter can be used to verify material properties after hot repairs.

11.4.5 At the time of verification of LPG Cylinders during Incident Analysis

In the existing practices, if a cylinder is met with an accident or fire incident; appropriate authorities conduct incident investigation, which is mostly limited to visual inspection. Normally cylinder material properties are not checked at this stage due to involvement of destructive test. The evidence (Cylinder) cannot be destroyed as it may need to submit in court of law. Thus, most of the incident investigations are limited to visual inspection. Using the method mentioned in this chapter, cylinders can be investigated thoroughly and accurate feedback can be given to law enforcing authorities.

11.4.6 Verification Tool for enforcing Authorities

Bureau of Indian standards authorities can use the method as a tool for enforcing the compliance requirement. The authorities need not depend on manufacturers' facilities for inspecting cylinders. Using the methods described in the chapter, a simple hand held portable hardness tester is more than sufficient to verify material compliance requirements. Also cylinders can be verified at any point in their life cycle.

11.5 Scope for Steel Cylinder Standards Amendments

Indian standard, IS 3196 can be amended to incorporate the methods mentioned in this chapter for fail safe inspection plan for steel cylinders. In addition to that IS 13258:1991, 'welded low carbon steel cylinders exceeding 5 litre water capacity for low pressure liquefiable gas - Code of practice for inspection and reconditioning of used LPG cylinders' can be amended keeping in view of consumer safety.

11.6 Advantages of Fail-safe Inspection Method

In this method, critical parameters of any cylinder can be checked with in few seconds without destroying a cylinder. Alternately, based on the hardness values obtained from a portable hardness tester, cylinders can be segregated whether they are complied with the requirements or not. Such verification system can be implemented online as the time required for verification is in seconds (maximum 10 seconds) and can be installed just before the painting operation to avoid surface preparation in a cylinder manufacturing location.

In addition to this, the proposed method can be used for inspection of cylinders during re-qualification test. In existing standards, there are no such requirements. Implementation of this method at this stage helps in identifying cylinders that are subjected to adverse conditions during their life cycle like fire incident. Also, if the method can be implemented after hot repair carried out on LPG Cylinder, to ensure proper heat treatment after hot repair of cylinders. Hot repair replaces foot ring or valve protection ring of LPG Cylinder hot repaired cylinders should undergo heat treatment to relieve internal stresses due to welding operation involved in it. Further, this method can be used for failure, accident and incident investigations at any point in cylinder life cycle.

---End of Chapter 11---

Chapter-12

12. Summary and Conclusions

The chapter concludes current research work and noticeable contributions are mentioned in this section. Recommendations of the research and the benefits in implementing research finding to all stakeholders of LPG Cylinder business are given in this section. Also, scope for future research was outlined at the end of this chapter.

12.1 Summary

Although LPG cylinder specifications and test methods are well established and defined in Indian standards, clauses related to LPG Cylinder material compliance is not sound. This is identified as a gap in this study and considered as basis for the current research. Detailed study on LPG Cylinders life cycle from raw material to scrapping was carried out with emphasis on LPG Cylinder testing at manufacturing plant and aimed the study to improve the existing test practices.

Acceptance and hydro testing are the two critical tests for certifying a batch of cylinder in manufacturing plant and are studies in depth. Set of empirical formulas were developed to estimate these values with the help of cylinder hardness. Fail-safe methods were suggested to test cylinders (100%) in manufacturing plant to ensure all cylinders from a manufacturing location are meeting standards requirements. Microsoft excel based software was developed with 4 different options to estimate cylinder parent metal critical values and to estimate critical parameters of acceptance test and hydrotest.

12.2 Conclusions and Noticeable Contributions

Research contributions are segmented under the three broad categories, viz.

1. Study on LPG Cylinder
2. Relations among various critical parameters of LPG Cylinder
3. Fail-Safe inspection plan

and are summarized below.

12.2.1 In-depth study on LPG cylinder

1. The state of art LPG Cylinder life cycle is documented. Various factors affecting cylinder life cycle were described in details with appropriate justifications.

   Papers published [6] & [7] and attached in publication section

2. Acceptance testing and hydro testing processes of LPG Cylinder at manufacturing premises were described in detail and highlighted possible areas, where the national standard can be interpreted wrongly against the interests of consumer.

   Papers published [9] & [10] and attached in publication section

3. Various factors that can affect LPG Cylinder testing process are outlined with necessary reasoning and appropriate clauses of Indian Standard.

   Paper published [3] and attached in publication section

4. Carried out an in-depth study on LPG Cylinder parent metal tensile test and proposed a method for preparing tensile specimen from LPG Cylinder.

Papers published [3] &[10] and attached in publication section

5. The process dealing with non-compliant cylinder in market was pronounced with all supporting documents, which is the basis for this work.

Refer Chapter.1 and attached in Appendix section

12.2.2 Relations among various critical parameters of LPG Cylinder material

1. Detailed study was carried out on LPG Cylinder longitudinal and circumferential tensile samples and proved that the circumferential samples exhibits lower yield and tensile values than longitudinal samples all the time. Hence, there exists a chance to discard longitudinal sample testing in existing acceptance testing practices.

Paper published [8] and attached in publication section

2. Carried out a study on LPG Cylinder material hardness by measuring the hardness with two different methods. It was proved that the surface hardness of cylinder is higher than the actual material hardness. The reasons for this phenomenon was outlines in the current research

Paper Published [4] and attached in publication section

3. Correlation analysis was carried out for 55 combinations of 11 parameters of LPG Cylinders material properties. Trends between 55 combinations were established the reasons for correlation values that are deviating from the expected values were outlined with justifications.

Paper Published [11] and attached in publication section

4. 37 Empirical formulas were developed with 4 different plans to estimate all 9 critical parameters. Compared the actual and estimated values and suggested the best formulas for estimating critical parameters.

Paper Published [5] and attached in publication section.

1 paper is in press

5. Reasons for compression in inter-quartile range boxes in box plots of actual and estimated values are described with appropriate justifications. As a result of this the empirical values can be used for indicative purpose only and not for replacing the existing test practices.

Paper Published [5] and attached in publication section.

1 paper is in press

12.2.3 Fail-Safe Inspection

1. Microsoft excel based software was developed to estimate critical parameters quickly with four different plans to estimate critical values quickly. This can be used as a basis for modifying existing portable testers to get the critical parameters directly at the time of testing hardness.

Presented in an international conference [1]

2. Suggested a fail-safe inspection plan for cylinder manufacturers for estimating cylinder critical parameters quickly and effectively. With this methods cylinder manufacturers can ensure all cylinders produced in their plant are complying the requirements of Indian Standard.

Presented in an international conference [1]

1 paper is in press

12.3 Recommendations

1. Longitudinal tensile sample testing in acceptance testing of LPG Cylinder parent metal tensile test can be eliminated and approximately 50% of testing cycle time can be saved.

2. Fail-safe cylinder inspection plan can be implemented in manufacturing locations using empirical formulas and hand held hardness tester, besides the existing destructive test methods, besides the existing test methods to avoid entry of non-complied cylinders into market

12.4 Advantages

Implementation of recommendations of the current research can benefit all stakeholders in LPG cylinder business viz. end users (customers), cylinder manufacturers, statutory authorities, marketing oil companies and accident investigation agencies.

1. Implementation of fail-safe inspection plan can ensure elimination of non-complied cylinders in to market (to consumer)
2. If acceptance test sample failed twice in cylinder manufacturer location, they can segregate the cylinders and only non-complied cylinders can be sent for heat treatment process instead of the entire lot. This saves fuel cost to the cylinder manufacturer and also the implementation of fail-safe method can protect manufacturers from unwarranted suspensions from enforcement bodies and oil companies. The cylinder manufacturers can prove their point with valid and scientific data.
3. Statutory authorities need not depend on cylinder manufacturers for compliance testing. Simple hardness tester is sufficient to check the cylinder parameters at any point of time in its life cycle.

4. Oil companies being the owners of cylinders, they can assure safe cylinders to their customers and can verify cylinder properties at any point of time especially after hot repairs and after statutory requalification of cylinders.
5. Investigation agencies can verify the accident and incident analysis without destroying the sample.

12.5 Scope For Future Work

Although current research itself an exhaustive work, there is definite possibility to extend current research to below areas.

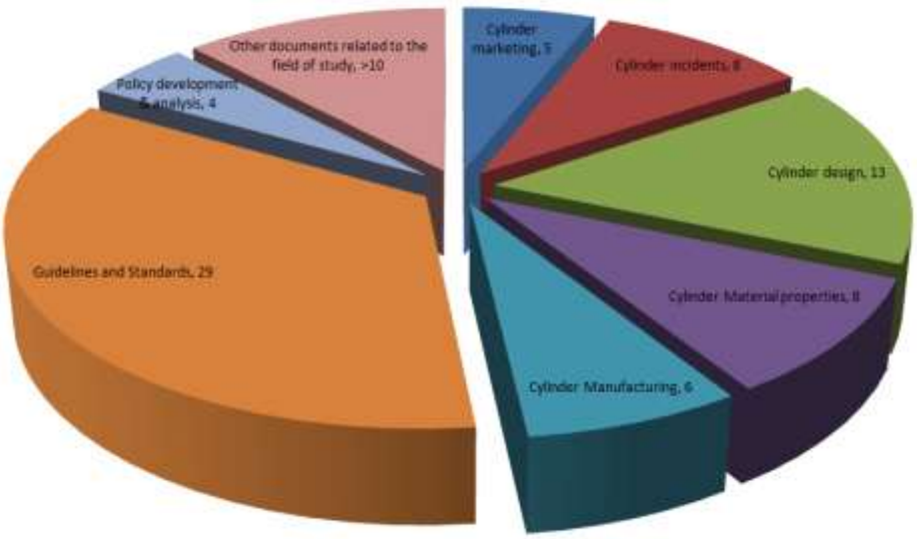
- Conducting an exhaustive research in association with cylinder manufacturer to know the effects of various heat treatment process parameters on final cylinder.
- Simulate various manufacturing conditions and heat treatment process parameters to establish failure data for generating empirical formulas with which the existing destructive test methods can be eliminated completely
- Impact of welding methods and processes on LPG cylinder hydro test results can be studied.
- Estimation of cylinder critical parameters using cylinder material composition can be explored

---End of Chapter 12---

Chapter-13

13. References

The references are segmented primarily under Cylinder Marketing, cylinder incidents, cylinder design, cylinder material properties, cylinder manufacturing, national and international standards and policy development as per below segmentation. Detailed references are given in this section.



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---End of References Section---

Appendix

Supporting Documents

In this chapter, additional material that supports current research is given for cross reference. Experimental data and primary data are given for ready references to the data tables.

In addition to that, Oil company tender clauses for suspension of cylinder manufacturer are given to outline oil companies are aware of issues in LPG Cylinder business. BIS authorized list for suspension of a manufactures under unsatisfactory performance are given to brief the actions of BIS on cylinder manufacture. Oil companies and BIS are silent on cylinder batches in market having issues. This show as an evidence to show gaps in existing systems and procedure that are required to be addressed in view of public safety.

At the end clauses related to IS 3196 on sampling and interpretation of results are given for supporting the gaps in the existing standards / literature in terms of low sample size and interpretation of existing standards.

Primary Cylinder Test data from NABL accredited lab

UNIVERSITY OF PETROLEUM & ENERGY STUDIES
(ISO 9001:2000 Certified)

Date: 04th May 2012

To
Chief Executive officer
M/s. LPG Equipment Research Centre
Doorvani Nagar, Bangalore
Karnataka, India

Dear Sir,

Sub: Cylinder Test Data Request for pure academic work - Reg.

On behalf our University of Petroleum and Energy Studies (UPES, Dehradun), we humbly request your help in providing access to your experimental data for pure academic purpose.

Our PhD research scholar, Mr. Akula Ramakrishna (SAP ID 500018375) is working on a research project title 'Study and development of empirical relation among various physical parameters of LPG cylinder material and suggest fail-safe inspection plan for manufacturing'. He is working on a novel approach for LPG cylinder testing. He requires LPG cylinders experimental test data (Yield strength, ultimate tensile strength and percentage elongation values) for developing empirical formulas. I am glad if you can provide access to your experimental data. You may mask vital information, if any in identifying the cylinders from the data

I assure the data will be used purely for academic purpose and will not be used for any other motive.
I request you to do the needful and extend your cooperation. Kindly allow the candidate for the experimental data collection from your testing lab. Please let me know if you have any quarries in the regard.

Thank you

Sincerely

Dr. Nihal Anwar Siddiqui
Head- Environment Research Institute
University of Petroleum and Energy Studies
Dehradun, India
Mobile: +919634525401

एल पी जी इक्युपमेन्ट रीसर्च सेन्टर
विपरीत आई. टी. आई. मेन गेट, पि. बि. न. १६१८,
दूरवाणी नगर, बैंगलूर - ५६००१६
दूरभाष : 91-80-25613345, 25612257, 25614035
ईमेल :

LPG Equipment Research Centre
Opp. ITI Main Gate, P.B. No. 1618,
Dooravaninagar, Bangalore - 560 016
Tel : 91-80-25613345, 25612257, 25614035
E-mail :

IS / ISO 9001
QMS

(NABL ACCREDITED LABORATORY)

LERC/ 259/1

Date: 23rd Jul 2012

To

Dr. Nihal Anwar Siddiqui

Head Environmental Research Institute

University of Petroleum and Energy Studies

Dehradun, India

Sub: Cylinder Test Data for academic work

Your letter reference Nil Dt: 04th May 2012

Dear Sir,

One of your PhD Research Scholars, Mr. Akula Ramakrishna (SAP ID 500018375) approached us with your recommendation letter (Reference: Nil Dt: 04th May 2012), seeking LPG Cylinder test data for his academic research work.

Based on our discussion had with your research scholar, we understand that he is developing empirical formulae to estimate the LPG Cylinder material properties. We are pleased to provide necessary support for his academic work, keeping in view of his subject. Please ensure that the data which we share with you shall be used purely for academic work and shall not be used for any other purpose.

Thank you

Yours Faithfully

C N Rajendrakumar

DGM (LERC)

Encl: n/a

Cc: Akula Ramakrishna, Research Scholar

Sl NO	JC No	Acceptance Test							Burst test results					Material Composition						
		Longitudinal Sample			Circumferential Sample			Weld Tensile Strength	Burst Pressure	Nominal Hoopp stress	Type of fracture	Position	Vol Exp	C	Si	Mn	P	S	Al	N
		Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL													
18	4121	265	364	39	247	362	44	442	90.17	578.913	YES	C" weld leak	26	0.1	0.09	0.41	0.01	0.004	0.023	0.007
19	4123	308	433	36	250	450	32	480	92.78	595.67	YES	Initiation on lower shell	33	0.11	0.15	0.38	0.016	<0.001	0.056	0.007
20	4124	271	368	40	251	350	43	425	92.87	596.247	YES	C" weld leak	27	<0.003	0.11	0.4	0.009	0.012	0.07	0.008
21	4125	285	378	45	264	386	43	427	89.6	575.253	YES	C" weld leak	25	<0.003	0.1	0.36	0.012	0.01	0.066	0.008
22	4126	283	372	43	259	360	43	440	89.66	575.638	YES	Initiation on lower shell	30	<0.003	0.04	0.52	0.009	0.013	0.062	0.008
23	4127	273	386	44	266	359	44	431	93.75	601.897	YES	Initiation on upper shell	31	<0.003	0.09	0.45	0.009	<0.001	0.027	0.008
24	4128	252	366	47	258	358	48	455	93.5	600.292	YES	c' weld leak	31	<0.003	0.04	0.52	0.013	0.008	0.049	0.008
25	4129	259	366	43	242	357	47	442	90.76	582.701	YES	c" weld leak	29	<0.003	0.04	0.53	0.01	0.013	0.061	0.009
26	4131	270	363	44	249	364	47	437	85.53	549.123	YES	c" weld leak	21	<0.003	0.05	0.54	0.014	0.003	0.049	0.008
27	4134	268	351	42	262	359	43	416						0.03	0.11	0.37	0.016	0.003	0.047	0.008
28	4135	274	354	44	256	354	48	442						0.03	0.11	0.37	0.016	0.003	0.047	0.008
29	4138	268	368	46	246	376	47	441	96.67	620.644	YES	Initiation on upper shell	32	0.02	0.08	0.41	0.023	0.001	0.023	0.007
30	4139	264	386	32	296	370	34	493	89.04	571.658	YES	C' weld leak	25	0.03	0.09	0.36	0.017	0.003	0.055	0.008
31	4142	244	379	38	240	375	43	494	95.84	615.315	YES	Leak from lower shell	35	0.02	0.12	0.36	0.021	0.007	0.038	0.008
32	4143	261	370	39	262	365	48	445	91.27	585.975	YES	C' weld leak	34	0.02	0.05	0.53	0.013	0.002	0.046	0.007
33	4144	251	350	42	252	351	35	440	91.07	584.691	YES	C' weld leak	27	0.02	0.03	0.53	0.01	0.003	0.058	0.007
34	4145	258	361	33	263	351	48	440	93.43	599.843	YES	C' weld leak	31	0.02	0.02	0.51	0.017	0.005	0.053	0.008

		Acceptance Test							Burst test results					Material Composition						
		Longitudinal Sample			Circumferential Sample															
Sl NO	JC No	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL	Weld Tensile Strength	Burst Pressure	Nominal Hoopp stress	Type of fracture	Position	Vol Exp	C	Si	Mn	P	S	Al	N
35	4146	271	372	44	253	363	49	440	93.4	599.65	YES	Initiation on lower shell	29	0.01	0.09	0.58	0.01	0.005	0.037	0.007
36	4148	310	396	39	257	352	48	456						<0.003	0.12	0.38	0.095	<0.001	0.064	0.008
37	4149	266	380	39	261	359	40	441						<0.003	0.12	0.38	0.095	<0.001	0.066	0.007
38	4150	259	374	38	273	363	43	415	100.55	645.556	YES	Leak at C-Weld	18	<0.003	0.11	0.36	0.013	0.008	0.052	0.007
39	4151	245	351	48	243	344	48	391	91.16	585.269	YES	Leak in upper shell	29	<0.003	0.08	0.42	0.015	0.001	0.021	0.008
40	4152	243	366	29	248	367	44	380						<0.003	0.04	0.39	0.017	0.009	0.072	0.008
41	4156	273	351	44	273	355	45	484	90.84	583.214	YES	Leak at C-Weld	28	<0.003	0.04	0.53	0.009	0.006	0.044	0.007
42	4157	240	374	38	261	357	43	423	89.8	576.537	YES	Leak at lower shell	34	<0.003	0.11	0.37	0.015	0.01	0.043	0.008
43	4161	240	391	43	256	390	34	482	91.5	587.452	YES	Leak at Upper Shell	33	0.14	<0.01	0.48	0.008	0.003	0.041	0.008
44	4169	244	375	37	252	389	35	478	89.52	574.74	YES	Leak on lower shell	32	0.1	0.14	0.4	0.01	0.004	0.048	0.009
45	4170	264	392	42	259	388	42	455	89.48	574.483	YES	C' weld leak	17	0.09	0.13	0.4	0.033	0.015	0.016	0.006
46	4171	321	392	39	280	384	35	466	91.66	588.479	YES	Initiation in upper shell	25	0.13	0.07	0.4	0.013	0.002	0.021	0.007
47	4178	258	369	40	243	375	36	438	92.06	591.047	YES	Initiation in lower shell	34	0.12	0.12	0.36	0.015	0.002	0.042	0.007
48	4180	253	376	37	247	380	37	401						0.12	0.12	0.38	0.024	0.003	0.028	0.007
49	4182	276	355	43	262	361	46	439	87.83	563.889	YES	Initiation in lower shell	31	0.1	0.04	0.51	0.018	0.007	0.044	0.007
50	4183	240	363	40	243	363	36	427	93.01	597.146	YES	C' weld leak	27	0.13	0.03	0.63	0.016	0.007	0.049	0.006
51	4184	254	361	42	249	357	46	363	96.8	621.479	YES	Initiation in upper shell	35	0.14	0.1	0.35	0.02	0.007	0.036	0.007

		Acceptance Test							Burst test results					Material Composition						
		Longitudinal Sample			Circumferential Sample															
Sl NO	JC No	Yield Strength	Tensile Strength	%EL	Yield Strength	Tensile Strength	%EL	Weld Tensile Strength	Burst Pressure	Nominal Hoopp stress	Type of fracture	Position	Vol Exp	C	Si	Mn	P	S	Al	N
52	4186	287	366	35	241	364	37	448						0.05	0.08	0.3	0.012	0.0025	0.028	0.007
53	4187	242	388	38	255	370	34	426						0.02	0.08	0.41	0.013	0.002	0.029	0.007
54	4198	268	372	36	272	399	33	450						0.08	0.13	0.43	0.01	<0.001	0.032	0.002
55	4202	248	361	32	250	383	39	422	94.81	608.703	YES	Initiation in lower shell	24	0.16	0.07	0.41	0.009	<0.001	0.023	0.008

Experimental data From NABL accredited lab

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TEST REPORT

Customer	BARC Reference	
Akula Ramakrishna	Report No	1207/MTD 149
Research Scholar	Date of Receipt	23/07/2012
SAP ID 500018375	Date of Analysis	23/07/2012
University Of Petroleum and Energy Studies	Date of Report	23/07/2012
	Job Order No	MTD/2012/07/241
Dehradun, India	Page No	Page 2 of 4

HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	INDENTATION DIAMETER IN mm	BHN
5	4101	5.4	121
6	4184	5.1	137
7	4186	5.2	131
8	4187	5.1	137
9	4198	5.3	126
10	4202	5.3	126
11	4118	5.2	131
12	4119	5.0	143
13	4115	5.1	137
14	4106	5.2	131
15	4128	5.2	131
16	4126	5.2	131
17	4129	5.1	137
18	4127	4.9	149
19	4151	5.0	143
20	4152	5.1	137
21	4150	5.0	143
22	4148	5.0	143
23	4149	4.9	149
24	4110	5.0	143
25	4157	5.1	137

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Anantha Narayana. A.R.
Mechanical-Manager
Authorised Signatory

Tested by

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Studies	Job Order No	MTD/2012/07/241
Dehradun, India	Page No	Page 3 of 4

HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	INDENTATION DIAMETER IN mm	BHN
26	4156	4.9	149
27	4161	4.9	149
28	4135	5.0	143
29	4112	5.2	131
30	4099	5.2	131
31	4134	5.2	131
32	4139	4.9	149
33	4131	5.2	131
34	4138	4.8	156
35	4104	5.0	143
36	4108	5.1	137
37	4107	5.2	131
38	4169	5.2	131
39	4171	4.7	163
40	4170	4.9	149
41	4178	5.0	143
42	4183	5.1	137
43	4182	5.0	143
44	4180	5.1	137
45	4092	5.1	137
46	4121	5.0	143

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HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	INDENTATION DIAMETER IN mm	BHN
47	4124	5.1	137
48	4123	5.1	137
49	4125	5.0	143
50	4120	4.8	156
51	4143	5.1	137
52	4144	5.3	126
53	4142	5.0	143
54	4145	5.0	143
55	4146	4.9	149

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	Job Order No	MTD/2012/07/241
Dehradun, India	Page No	Page 1 of 4

HARDNESS TEST REPORT

Test Equipment Details:	Sample Details
Equipment: Portable Digital Hardness Tester Model: Bliss TH 270 Make: YAMMAYO Portable Metal Hardness Tester	Size, 2" X 2" Flat steel sample extracted from LPG Cylinder Quantity : 55 numbers Identification: User defined identification on each sample Number of tests carried out on each sample : 5

Equipment Calibration Details

Verification with standard test block provided with the equipment

The portable hardness tester was verified with standard test block before carrying out the test and ensured that the deviations are well within permissible limits as per respective reference standards specifications

The test has been carried out with hand held hardness tester and the results are tabulated below

SL NO	SAMPLE IDENTIFICATION	BHN
1	4095	150
2	4096	138
3	4098	145
4	4109	146
5	4101	132
6	4184	116
7	4186	122

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Dehradun, India	Page No	Page 2 of 4

HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	BHN
8	4187	152
9	4198	116
10	4202	128
11	4118	148
12	4119	139
13	4115	139
14	4106	134
15	4128	148
16	4126	148
17	4129	145
18	4127	141
19	4151	162
20	4152	138
21	4150	163
22	4148	136
23	4149	160
24	4110	174
25	4157	154
26	4156	131
27	4161	128

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HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	BHN
28	4135	145
29	4112	132
30	4099	129
31	4134	163
32	4139	164
33	4131	139
34	4138	146
35	4104	164
36	4108	146
37	4107	146
38	4169	132
39	4171	183
40	4170	129
41	4178	145
42	4183	144
43	4182	146
44	4180	151
45	4092	131
46	4121	136
47	4124	156

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HARDNESS TEST REPORT

SL NO	SAMPLE IDENTIFICATION	BHN
48	4123	147
49	4125	157
50	4120	150
51	4143	144
52	4144	152
53	4142	142
54	4145	159
55	4146	163

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Cylinder Manufacturer suspension procedure

THE Quality control and suspension procedures are given in the following scanned documents of Indian oil cylinders tender document

CRFQ No. 1000186706 ANNEXURE VI
TERMS & CONDITIONS OF AGREEMENT

Parties shall have to produce Gazette notification, proof showing that duty charged is totally on account of excise rate and/or Sales Tax and/or VAT revision and not due to any change in assessable value or otherwise, and invoice us accordingly. Same principle will be observed for de-escalation also.

However, any increase in the rate of Sales tax or VAT or Excise Duty on LPG cylinders due to change in the annual Turn-over or full/partial withdrawal of sales tax or VAT or excise duty concession to the successful tenderer shall not be reimbursed.

6. PAYMENT

The following documents should be submitted along with the invoice:

(a) Face Sheet
(b) Invoice, mentioning the actual date of receipt of consignment at the destination.
(c) Copy of delivery challan (that includes photocopy, scanned copy sent by email and/or fax copy) duly acknowledged by the location
(d) Lorry Receipt
(e) Central Excise Gate Pass –Invoice
(f) Packing list
(g) **Proof of the application along with the payment made to PESO for obtaining filling permission**
(h) Octroi Receipt, if applicable

Payment terms shall be 15-days which implies that payment shall be released by BPCL within 15 (fifteen) days, on 'best-effort' basis after 15 days of receipt of invoice along with all enclosures as mentioned above. The payment shall be done through National electronic fund transfer (NEFT).

7. QUALITY CONTROL / SUSPENSION

(a) The successful tenderer is required to strictly adhere to the quality control/inspection procedures stipulated by Bureau of Indian Standards (BIS) and Petroleum and Explosive Safety Organisation (PESO), and advice given by the Corporation and Oil Industry Technical Committee (OITC) from time to time.

Stage-wise inspection should be carried out as per scheme of testing of BIS. Manufacturer should employ manpower required at each stage of inspection such that they at least have minimum specified skills/qualifications.

The in-charge of quality control & production department and quality supervisors should possess minimum qualification of diploma in Engineering. Information should be promptly forwarded to BIS and PESO in case these key persons looking after critical aspects of production and quality control of LPG Cylinders are changed. Any change in the Plant & Machinery should be with prior approval of BIS and PESO.

Page 5 of 20

(b) Without prejudice to the other provisions of the Contract, BPCL reserves the right to order suspension of production and supplies of the Cylinders by the successful tenderer in case any lapse in quality is detected by members of OITC or by officers/ representatives of BPCL (like first fill leak), or if any lapse is reported by any statutory authority, quality complaint from any source, malpractice detected by any authority etc. at any time during the currency of the Agreement.

(c) Such suspension orders will be intimated in writing by fax and/or Registered Post either by the Corporation or by OITC to successful tenderer. On receipt of suspension order, successful tenderer shall carry out detailed root-cause analysis for failure of the cylinder/quality problem.

Corrective and preventive actions to be taken for a particular type of failure should be identified and implemented by the successful tenderer. The successful tenderer shall submit an action-taken report, duly verified by BIS, to BPCL. BPCL shall revoke the suspension based on the adequacy of this action-taken report.

The successful tenderer will be required to complete all actions necessary to obtain clearance from Corporation/OITC for resumption of production and despatch at the earliest but not later than 20 days from the date of suspension.

If request for the clearance from Corporation/ OITC is not applied for within the said period of 20 days, the Corporation shall have the rights solely at its discretion to cancel the remaining order quantity and forfeit the supply and performance guarantee amount without prejudice to any other right as may be available to the Corporation both under law and the contract terms contained in this agreement for the recovery of the damages.

(d) Despite the order of suspension, if the successful tenderer produces and/or despatches any LPG Cylinders, the Corporation shall be entitled to refuse taking delivery of such consignments and the successful tenderer shall not be entitled to claim any damage or compensation for any loss that may occur to him, from BPCL on account of refusal to accept such consignment. In such cases BPCL shall take necessary action which may be deemed fit against the successful tenderer.

(e) Whenever the successful tenderer is under suspension, the call-off/ allocation for the suspended party may be pruned to the extent of undelivered quantity against that call off/allocation at the sole discretion of BPCL. **Extra cost, if any, borne by BPCL while procuring (from other suppliers) and/or placing such shortfall quantity to the short-supplied plant, as outlined above, shall be recovered from the defaulting successful tenderer as per clause 11 below.**

(f) If the successful tenderer is under suspension at the start of a month/time of placing call-off or PO and the suspension is not revoked till 7th of the month, then the notional allocation based on the requirement of the plant/plants as the case may be to a maximum of 130% of the

Bureau of Indian Standards list of cancelled licenses (IS 3196)

BUREAU OF INDIAN STANDARDS

Licences Cancelled

Total No of Records 5

Date 11/03/2013 Data for IS 3196 : Part 1 : 2006

S.No	Licence No	Name & Address	Date of Cancellation	Reason for Cancellation
Jharkhand				
IS 3196 : Part 1 : 1992		Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity for Low Pressure Liquefiable Gases - Part 1 Cylinders for liquefied Petroleum Gases (LPG) - Specification		
1	5117147	Chandawat Udyog (Cylinders) Ltd.,, Village : Lalgarh, PO : Madhupur., PIN : 815353. City : Deoghar	08/06/2006	Non Payment of Dues,
Maharashtra				
IS 3196 : Part 1 : 1992		Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity for Low Pressure Liquefiable Gases - Part 1 Cylinders for liquefied Petroleum Gases (LPG) - Specification		
2	7484588	KHARA GAS EQUIPMENTS PVT. LTD.,, KHASARA NO 60 & 61, GRAM BURUJWADA, TALUKA SAONER,	19/12/2005	Unsatisfactory Periodic Inspection,Unsatisfactory performance visit dated 29/04/2005
Punjab				
IS 3196 : Part 1 : 1992		Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity for Low Pressure Liquefiable Gases - Part 1 Cylinders for liquefied Petroleum Gases (LPG) - Specification		
3	1175545	INOX AIR PROUDCT LTD., G.T. ROAD MANDIGOBINGARH City : MANDIGOBINGARH	04/06/2007	firm had surrended the licence vide letter dated 28-5-2007.
Tamil nadu				
IS 3196 : Part 1 : 1992		Welded Low Carbon Steel Cylinders Exceeding 5 Litre Water Capacity for Low Pressure Liquefiable Gases - Part 1 Cylinders for liquefied Petroleum Gases (LPG) - Specification		
4	6289181	SRI MAHA VISHNU CYLINDERS, SURVEY NO.195/1,2 & 3, SHOLINGANALLUR VILLAGE Dist : Chennai	14/01/2008	Shifting of Premises,Due to non-co-operation for carrying out inspection and resorted to threatening.
West Bengal				

Extracts of clause 5.1 in IS3196 Part3: 2012 on Acceptance Test Sampling

1 SCOPE

This standard lays down methods of test for welded low carbon steel cylinders intended for storage and transportation of low pressure liquefiable gases, of nominal water capacity exceeding 5 litre and up to and including 250 litre nominal water capacity. This standard also lays down various tests carried out in the plant and laboratory and details of carrying out these tests.

2 REFERENCES

The standards listed in Annex A contain provisions, which through reference in this text, constitute provisions of this standard. At the time of publication, the editions indicted were valid. All standards are subject to revision and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated in Annex A.

3 TERMINOLOGY

For the purpose of this standard, the definitions given in IS 7241 shall apply.

4 TESTS

The details of the following tests specified in IS 3196 (Part 1), IS 3196 (Part 2), IS 3196 (Part 4) and IS 13258 have been stipulated in this standard:

a) Acceptance tests;
b) Burst and volumetric expansion test;
c) Hydrostatic stretch test;
d) Hydrostatic test;
e) Pneumatic leakage test;
f) Radiographic examination; and
g) Fatigue test/cycle test.

5 ACCEPTANCE TESTS

5.1 Number of Test Specimen

For every batch of 202 or less heat-treated cylinders, one cylinder shall be selected at random for these tests. The following test specimen shall be prepared from this cylinder as shown in Fig. 1.

a) *Test specimen for parent metal (P) tensile testing*:
   1) For two-piece cylinders, one tensile test specimen in the longitudinal direction and one tensile test specimen in the transverse direction shall be cut from the cylindrical portion of the cylinder. Alternatively, if sufficient cylindrical length is not available to permit cutting the cylindrical portion, then one tensile test specimen may be taken from the dished end (*see* Fig. 1A).
   2) For three-piece cylinders, one tensile test specimen in the longitudinal direction and one tensile test specimen in the transverse direction from the cylindrical portion and one tensile test specimen from one of the dished ends may be taken (*see* Fig. 1B).

b) *Test specimens from welds (W)*:
   1) For two-piece cylinders, one tensile test, one root bend test and one face bend test specimen may be taken across the circumferential weld (*see* Fig. 1A).
   2) For three-piece cylinders, one tensile test, one root bend test and one face bend test specimen may be taken across the longitudinal weld. In addition one tensile test, one root bend test and one face bend test specimen may be taken across one of the circumferential weld (*see* Fig. 1B). The specimen shall be taken alternately from the top and bottom circumferential welds on successive cylinders selected for the test.

c) Test specimen for minimum thickness test from knuckle radius portion for both two-piece and three-piece cylinders.

Extracts of clause 5.7 in IS3196 Part3: 2012 on interpretation of test results

5.7 Results

5.7.1 If the sample fails in any of the tests given in **5.2** to **5.4** and if the inspecting authority considers that the failure was due to an error in carrying out the test, a fresh test shall be done on a test piece taken from the same cylinder. The defective test shall be ignored and one of the following procedures shall be adopted:

a) Test in which the failure occurred shall be repeated on the cylinder and in addition, all the tests given in **5** shall be carried out on another cylinder from the same batch manufactured from the same welding machine. If both the cylinders satisfy the test requirements, the batch shall be accepted. If the sample fails in any of the test carried out as per this clause, the method given in **5.7.1** (b) or **5.7.2** as applicable shall be adopted depending on the nature of failure.

b) Batch may be re-heat-treated and all the tests specified in **5** shall be carried out on two cylinders. If both the cylinders satisfy the test requirements, the batch may be accepted. If any of the tests specified in this clause fail, the batch may be re-heat-treated and offered for retest.

Extracts of clause 6 in IS 3196 Part3: 2012 on Hydrotest sampling

6 HYDROSTATIC STRETCH TEST

One cylinder taken at random from each batch of 403 or less shall be subjected to a hydrostatic stretch test by any of the following methods:

NOTE — This test method is based on IS 5844 which may be referred in case further references are required.

hydrostatic pressure till it bursts. The initial original volume and the expansion shall be noted by weight method, with provision for peak pressure and peak load indication facility, proper arrangement shall be provided to avoid pressure fluctuation during, the test. A typical sketch of such an arrangement is given in Fig. 9.

9.1.2 The nominal hoop stress corresponding to the pressure at which destruction occurs shall be calculated from the formula:

$$f_b = \frac{P_b \times D_i}{2\,t'}$$

where

- f_b = nominal hoop stress at which destruction occurs, in MPa (N/mm^2);
- P_b = internal hydrostatic pressure at which cylinder bursts, in MPa (N/mm^2);
- D_i = nominal original internal dia of the cylinder, in mm; and
- t' = minimum agreed finished thickness as specified on the drawing, in mm.

9.1.3 The value of 'f_b' shall be calculated and the fracture examined.

9.1.4 During burst test; in case leakage starts from any welding, the specimen shall be discarded. The cause of leakage to be identified and fresh test specimen shall be taken from the same welding machine to which the earlier sample belong.

9.2 Failure in Burst Test

If a cylinder fails due to non-compliance of the requirements of this test, the following procedure shall be adopted:

a) If failure can be attributed to a cause which is discernible even before the test, all cylinders with such defects shall be segregated and re-processed and considered as a new batch. After repair the procedure stated in (c) shall be adopted.

b) From the entire original batch or the rest of the sound cylinders after segregation as per (a), as the case may be, two more cylinders shall be selected at random and tested. If both cylinders meet the test requirement this batch shall be accepted. In case of failure of any one of the samples the procedure stated in (c) shall be adopted.

c) The re-processed new batch of cylinders as per (a) above or the failed batch after being tested as per (b) shall be re-heat treated and shall be tested in accordance with all the tests specified in **5**. Two cylinders shall be selected at random thereafter and subjected to burst test. In case of any failure the entire batch shall be rejected.

9.3 Fatigue/Cycle Test

9.3.1 For the purpose of this test, three cylinders which are guaranteed by the manufacturer to be representatives of the minimum end(s) thickness set by design and which shall include all markings, shall be filled with non-corrosive liquid and subjected to successive reversals of hydraulic pressure. This test shall be considered as type test.

9.3.2 The test shall be carried out at an upper cycle pressure, either,

a) equal to two-thirds of the test pressure in which case the cylinder shall be subjected to 80 000 cycles without failure; or

b) equal to the test pressure in which case the cylinder shall be subjected to 10 000 cycles without failure.

The values of the lower cyclic pressure shall not exceed 10 percent of the upper cycle pressure. The frequency of the reversal of pressure shall not exceed 0.25 Hz (15 cycles/min). In case of an interruption during the test, after rectification of the cause of interruption, the test shall be resumed from the point the interruption had occurred.

The temperature measured shall not exceed 50°C during the test. If the measured surface temperature of the cylinder exceeds the maximum permitted, the test shall be stopped and resumed after the temperature drops. External forced cooling is permitted.

9.3.3 During fatigue test; in case leakage starts from any welding the specimen shall be discarded and fresh test specimen shall be taken and subjected to the required cycles for fatigue test.

9.3.4 The cylinders subject to fatigue test, shall be burst tested and shall meet the requirement of burst test.

9.3.5 Failure in burst test of cylinders subjected to fatigue test will be treated at par with failure in burst test and the retesting shall be in accordance with **9.2**.

10 RADIOGRAPHIC EXAMINATION

10.1 On each cylinder selected for radiographic examination, each weld intersection, 100 mm of the adjacent longitudinal weld and 50 mm (25 mm on each side of the intersection) of the adjacent circumferential weld shall be radiographed (*see* Fig. 10).

---End of Appendix Section---

Publications based on research work

Based on the research the author published 9 research papers in 5 international journals. Also, one Technical paper and an e-poster were presented in an international safety conference held at Kuwait. In addition to these confirmed works, 4 additional research papers are in the process of publication in international journals.

Published In International Journals

1. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review of Liquefied Petroleum Gas (LPG) Cylinder Life cycle." *International Journal of Advanced Enginering Technology* IV, no. III (July-Sept 2013): 37-41.

   [6] See References Section

2. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review of Liquefied Petroleum Gas Cylinder Design and Manufacturing Process as per Indian Standard, IS 3196 (Part 1): 2006." *International Journal of Advanced Engineering Technology* IV, no. II (April-June 2013): 124-127.

   [7] See References Section

3. Akula, Ramakrishna, Siddiqui A Nihal, and Sojan Lal P. "Review on Liquefied Petroleum Gas cylinder acceptance test as per Indian Standard, IS 3196 (Part 3): 2012." *International Journal of Advanced Engineering Technology* IV, no. II (April-June 2013): 119-123.

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[4] See References Section

International Conference Presentation - Technical Paper

1. Akula Ramakrishna (2013). A METHOD TO ENSURE REGULATORY COMPLIANCE IN TESTING LP GAS CYLINDER AS PER INDIAN STANDARD IS 3196 PART 3:2006. *In: 7th International HSSE and Loss prevention Professional Development Conference and Exhibition*, 26-28 Nov 2013, Kuwait.

[1] See References Section

International Conference Presentation – ePoster

1. Akula Ramakrishna (2013). A METHOD TO ENSURE REGULATORY COMPLIANCE IN TESTING LP GAS CYLINDER AS PER INDIAN STANDARD IS 3196 PART 3:2006. *In: 7th International HSSE and Loss prevention Professional Development Conference and Exhibition*, 26-28 Nov 2013, Kuwait.

In Press

1. Akula Ramakrishna, Nihal A Siddiqui and P Sojan Lal (2014). DEVELOPMENT OF EMPIRICAL FORMULAS FOR LPG ACCEPTANCE TEST PARAMETERS. *Processing for publication*. **In press**, pp.Nil.

2. Akula Ramakrishna, Nihal A Siddiqui and P Sojan Lal (2014). ESTIMATION OF LPG CYLINDER PARENT METAL YIELD STRENGTH AD TENSILE STRENGTH FROM HARDNESS VALUES. *Processing for publication*. **In press**, pp.Nil.

3. Akula Ramakrishna, Nihal A Siddiqui and P Sojan Lal (2014). ESTIMATION OF ACCEPTANCE AND HYDROTEST RESULTS OF LPG CYLINDER MATERIAL USING EMPIRICAL FORMULAS. *Processing for publication*. **In press**, pp.Nil.

4. Akula Ramakrishna, Nihal A Siddiqui and P Sojan Lal (2014). ALTERNATE METHOD TO ENSURE CYLINDER MATERIAL COMPLIANCE REQUIREMENT AS PER INDIAN STANDARD IS 3196. *Processing for publication*. **In press**, pp.Nil.

---Attached hard copies of published papers---

Review Article

REVIEW ON LIQUEFIED PETROLEUM GAS (LPG) CYLINDER LIFE CYCLE

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ABSTRACT:

Liquefied Petroleum Gas (LPG) cylinders are produced from low carbon steel. These cylinders are termed as compressed gas cylinders and are necessary to meet national specifications for manufacturing, testing, inspection and re-qualification. Manufacturers ensure Bureau of Indian Standards certification for each and every cylinder produced from their units. Raw material selection, design, manufacturing, bottling, usage, repairs, requalification and scrapping are the major phases in LPG cylinder's life cycle. An attempt has been made in this paper to describe these phases in brief from raw material selection to scrapping a cylinder. Also the paper discusses various reasons for scrapping a cylinder in early stages of its life cycle.

KEYWORDS: LPG Cylinder, LPG Cylinder life Cycle, Phases in LPG Cylinder lifecycle.

INTRODUCTION

Liquefied Petroleum Gas (LPG) cylinders in India are produced as per Indian standard IS 3196 part1: 2006, *Welded low carbon steel cylinders exceeding 5 liere water capacities for low pressure liquefiable gases – Specification* [11]. These cylinders undergo stringent norms and procedures from manufacturing to withdrawal of cylinders from service [3],[4],[11], [12], [13]&[14]. Indian standard IS 3196 part 3 states the guidelines for testing of new cylinders for Bureau of Indian Standards (BIS) certification [12] and BIS logo is punched on every cylinders. This mark ensures that the cylinder underwent stringent norms and tested as per the code of practice [11]&[12]. In India, state-owned oil companies market different type of cylinders, intended for variety of business segments like domestic, commercial and industrial. Technically, all these cylinders are identified with volume of cylinder in water capacity. For example the domestic LPG cylinder marketed by state owned oil companies is 33.3 liters water capacity and are fabricated in two piece constructions [11]. All the government oil companies market same kind of cylinder for domestic segment. An attempt has been made in this paper to describe the life cycle of a domestic LPG cylinder in India for general understand. Further, LPG cylinders are ill-treated in market. The effects of this ill-treatment affects cylinder life cycle. At the end, an attempt has been made to review cylinder ill-treatment effects on its life cycle.

LPG CYLINDE LIFE CYCLE - REVIIEW

General

LPG Cylinder life cycle is described with a flow chart in Fig.1. In India government oil companies estimate their new cylinder requirements and procure through tendering process. These cylinders should be designed, manufactured and tested as per IS 3196 [11] & [12]. The manufacturers supplies cylinders as per the requirements of the oil companies and are the property of respective oil company. The consumer is only the owner for the gas in it. Oil companies take ownership for the cylinder and they do all repairs and statutory requalification of cylinder at later stages of its life cycle as a mandatory requirement from statutory authorities. This cost will not be passed on to consumer. Once the cylinder reaches a stage, where it is not fit for reuse, the cylinder is discarded from market and scrapped. Below text describes various critical stages in LPG cylinder life cycle.

Cylinders are generally fabricated either in two piece or three piece construction as shown in Fig.2 [1]. In a two-piece construction, two domes of either tori-spherical or semi-ellipsoidal are welded together to form a cylinder body [11]. In a three piece cylinder the domes of tori-spherical or semi ellipsoidal or hemi spherical domes are connected to a cylindrical portion as shown in Fig.2 [11]

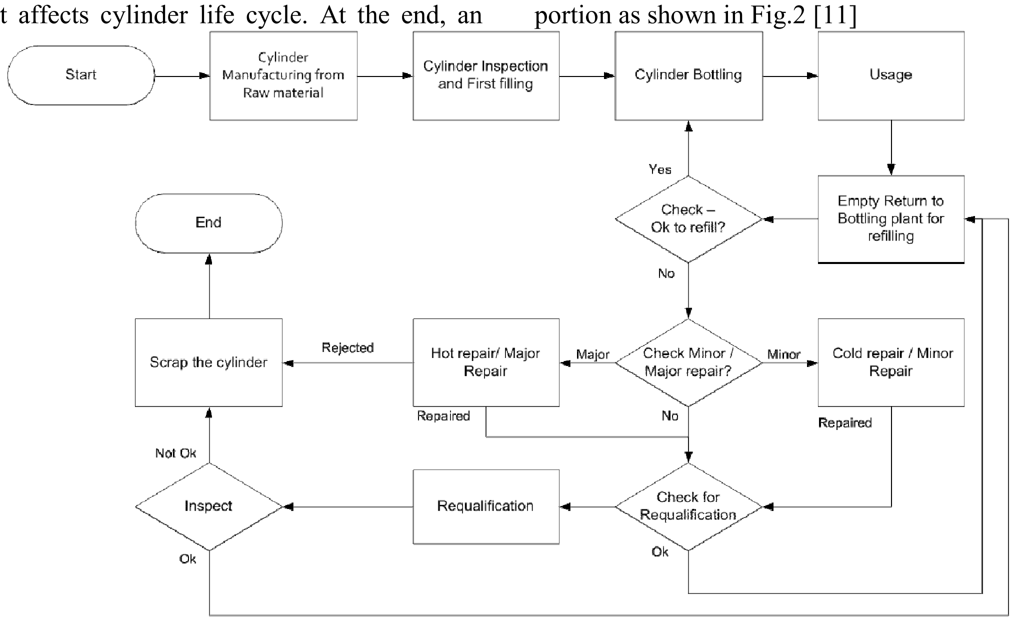

Fig.1 Typical stages in LPG cylinder life cycle

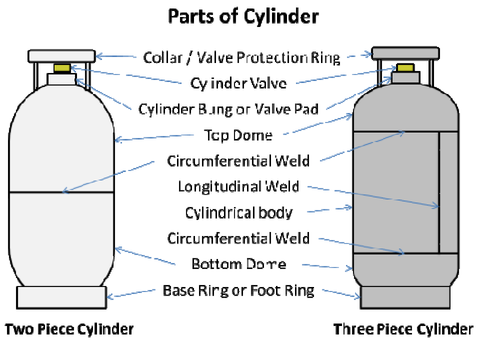

Fig.2: Cylinder parts and type of construction

Raw Material

Raw material is the most critical thing in cylinder life cycle. In India, low carbon steel confirms to Indian standards IS 6240 [9] or equivalent is used for manufacturing cylinder bodies [11]. In addition to that, the standard IS3196 part1 specifies, the bung/ valve pad (See Fig.2) material shall be hot forged from rolled steel bars either confirming to class 1A or class 2 of Indian standard IS 1875 or IS 2062 [11]. Also the standard states, the material for foot ring, valve protection ring shall confirms to Grade 0 of IS1079 or IS 2062 or IS 6240[11]. Further, if the cylinder is manufactured with a butt weld, the backing strip for the butt weld should confirm to IS2062[11]. Majority of cylinder manufacturers are fabricating cylinders with joggling joint, where backing strip is not required for welding.

In case the manufacturer uses an equivalent raw material for cylinder construction, the finished cylinder should guarantee 240 MPa yield stress, 350MPa to 450 MPa tensile strength and the percentage of permanent elongation of parent metal should not be less than 25% when it is subjected to parent metal tensile test as per IS 3196 part3[6],[9],[10],[11]&[12].

Design

Cylinder design calculations are intended to determine thickness[15][16]. The thickness is derived based on type of construction and the dome shape. Thickness for cylindrical portion and the domes shapes are calculated separately and the higher thickness among these two values are considered as calculated cylinder thickness [11]. Two piece and three piece cylinder construction design calculations and calculations for tori-spherical, semi ellipsoidal and hemi spherical domes are given in IS 3196 part1 [11]. Test pressure is considered as 25kgf/cm^2 and the weld joint factor is considered based on the weld examination method adopted during manufacturing process for design calculations purpose [11]. Once the design is completed, the manufacturer should produce one or more prototype cylinder and test to ensure the cylinders are meeting the requirements mentioned in the standard [11]. Bureau of Indian Standards authorities verifies and accept the design and allows the manufacturer to start production.

Manufacturing

Cylinder manufacturer process flow diagram is shown in Fig.3[5],[16]. Normally cylinders are produced in batches of 203 and above [11]. The process starts from raw material. The diagram shows both three piece and two piece cylinder manufacturing process [2]. Steel plates are cut to the required dimensions to produce cylindrical body by rolling operation [9]. This is only for a three piece cylinders manufacturing. Indian domestic LPG Cylinders are in two piece construction. Valve protection rings (or collars) are fabricated by blanking, rolling and forming operations as shown in the figure. There are no specific guidelines for the shape of valve protection rings. Hence, the shape can be differed from different marketing companies. Valve protection ring for Indian domestic LPG cylinder (marketed by government oil companies) is fabricated with a circular steel pipe with three stay plates attached to it. The domes are manufactured by blanking and deep drawing process. The top dome undergoes trimming and piercing operations for attaching bung. The bottom dome undergoes only trimming operation as shown in Fig.3. The base plates (also known as foot rings) are manufactured by blanking, rolling, welding and forming operations. Similar to valve protection ring, the base ring or foot ring shape is not specified in standard. It can be manufactured as per the requirements of marketing company. The foot rings design for Indian domestic oil company cylinders are slightly differ from these base rings shown in picture.

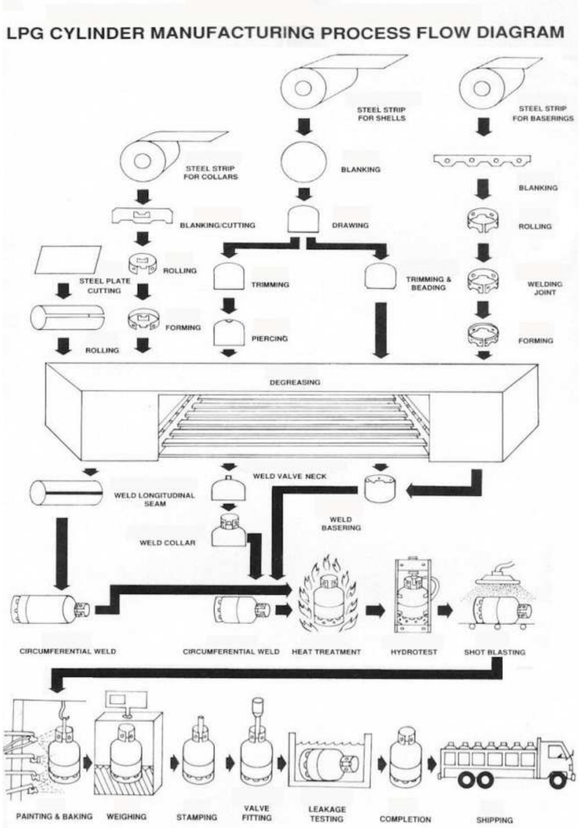

Fig.3: LPG cylinder manufacturing process flow diagram

All these components undergo degreasing operation and then welded together as shown in Fig.3 to form either a two piece or three piece cylinders. The complete cylinder then subjected to heat treatment to relieve the internal strain developed due to welding operation. Welding and Heat treatment are critical operation in cylinder manufacturing. The welding methods and welder qualifications are prescribed in IS 3196 [11]. Similarly the heat treatment process parameters are particularly important to get required mechanical properties of finished cylinder [11]. Cylinder should be heat treated correctly as per the recommendations of raw material suppliers [11]. Otherwise, the finished cylinder may exhibit tensile strength values above or below stated specifications.

After the heat treatment process, every cylinder is subjected to hydro-test [11]. This test reveals leaks in finished cylinders, if any. All cylinders in manufacturing location should undergo this test. Hydro test passed cylinders are sent for painting. Before painting the cylinder surface is prepared either by shot blasting or grit blasting. Once the surface is prepared, cylinders are powder coated and baked to achieve smooth paint thickness all over cylinder body. The cylinders are then weighed and stamped tare weight on their collars or valve protection rings. Also other details of cylinder like serial number, manufacturing date are punched on cylinder body. The cylinders are then fitted with a valve and tested for leaks once again. Once the cylinder crosses all these stages successfully, it is ready for dispatch and allowed to use in market.

In addition to the above, manufacturer should test few sample cylinders from each lot for certification purpose [5]&[12]. Those tests are Acceptance tests, Burst test, volumetric expansion test, hydrostatic stretch test, hydrostatic test, pneumatic leak test, radiographic examination, and fatigue /cycle test [12]&[15]. The acceptance test reveals the parent metal mechanical properties and weld mechanical properties. As per the requirement, test tensile samples are cut from cylinder and tested for measuring yield strength, tensile strength, percentage elongation, weld tensile strength [10]&[12]. One cylinder should undergo this test for every batch of 202 or above cylinders [11]. Volumetric expansion test indicated permanent volumetric expansion of cylinder under test pressure conditions. One cylinder should undergo this test for every batch of 403 cylinders [11]. The same cylinder can be subjected to burst test to measure burst pressure and nominal hoop stress in cylinder at burst pressure conditions. Radiographic examination is intended to check the weld quality and the depth of penetration [11] &[12]. Fatigue test is a type test to check the cylinder under cyclic internal pressures [11]&[12]. Leak tests are intended to check visible leaks in cylinders. All these tests to be conducted on sample cylinders as per Indian standard IS 3196 part3. Once the batch is accepted by bureau of Indian standards, certified cylinders are released to market for use.

Cylinder Life cycle

Typical process flow diagram of an LPG Cylinder movement in a bottling plant is shown in Fig. 4.

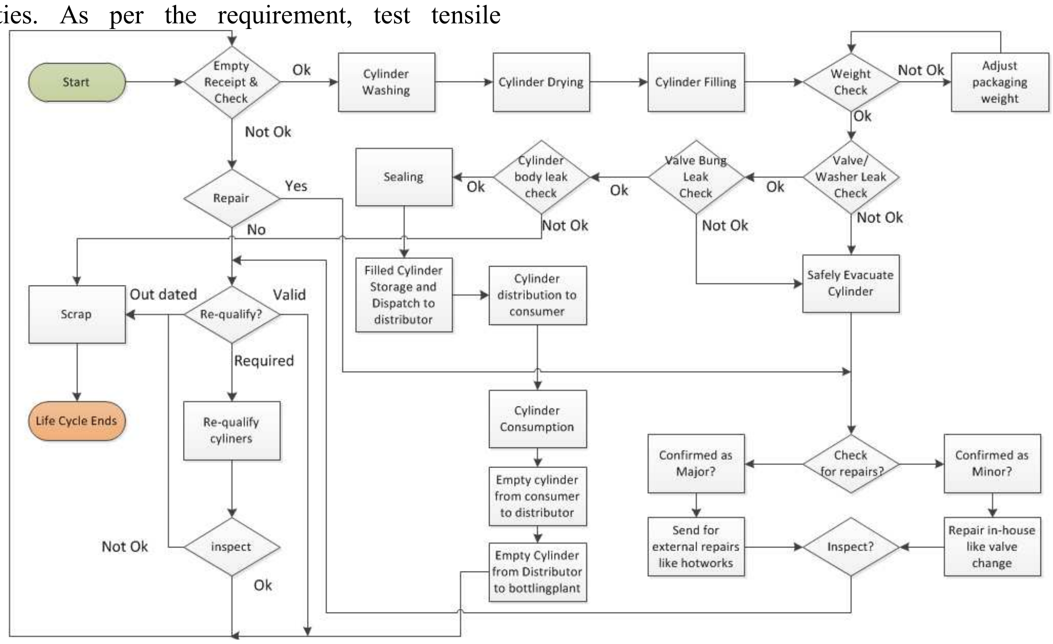

Fig.4: Flow diagram of an LPG cylinder from first filling to scrap

Empty cylinders received in plant for filling are initially checked for body damage, repairs or requalification requirements [14]. Once the cylinder passes this stage, cylinders are washed and dried to remove loose particles on their bodies. The dried cylinders are sent for filling. The filling process may be either automated system on a carrousel or through standalone manual scales, depending on the bottling plant size, demand, type of product etc. Filled Cylinders undergo weight check to ensure the cylinders are filled with correct quantity. In case of any deviation observed in weight, the quantity is adjusted on correction scale and then sent back for weight check. The filled cylinders are then sent for valve leak check, internal washer leak check and body leak checks. If the cylinder is found to be alright, the cylinder finally goes for sealing and will be dispatched to dealer or customer from bottling plant [3]. An empty cylinder from customer / dealer comes back to plant and follows the empty cylinder check and subsequent process in a cycle.

Suppose if any cylinder is found to be valve or internal washer or bung leak during filling, such cylinders are segregated and sent for evacuation. The product from LPG cylinder is evacuated in evacuation process. The evacuated cylinders are subjected to repairs and finally sent back to system for filling. If the cylinder found to be body leak during filling or any other stages, the cylinder needs to be scrapped, irrespective of the gravity of the leak. Similarly, if a cylinder is identified that it caught fire in its usage, it should be scrapped and no repair is allowed on such cylinders. In case cylinders are found to be severely damaged and needs replacement of foot ring or valve protection ring, such cylinders are treated as hot repair cylinders and they are transported to cylinder manufacturer or authorized hot repairer. Hot repair is a process in which the cylinder foot rings and valve protection rings are replaced with new ones. This is performed by cutting the damaged component from cylinder body and replaces with a new one by welding operation. Due to involvement of welding operation, the cylinders needs to be heat treated after the hot repair process to relieve stresses in cylinders developed due to the welding operations [14]. These cylinders need to be checked for hydrostatic tests [14]. Once the cylinders are repaired and tested, they are inducted back to the system as empty cylinders for filling.

As per the statutory guidelines, all used cylinders needs to be requalified at periodic intervals to ensure the cylinders are safe to withstand test pressures during its operation [13]. Presently in India, new cylinders are to be first re-qualified after 7 years and there after the subsequent re-qualifications to be done once in 5 years [13]. That means a new cylinder is subjected to hydrostatic test pressure after 7 years of manufacturing. At this stage, it is checked for various tests [14] including visual inspection, internal inspection, bottom pitting, corrosion and hydrostatic test at test pressure conditions. The cylinder requalification date needs to be punched permanently on cylinder body for future reference. In case the cylinder is not meeting the test criteria, the cylinder needs to be scrapped. The cylinder scrapping is process, in which the cylinders are crushed after degassing the cylinder with the help of a hydraulic press to approximately to 300 mm blanks. These blanks cannot be used in any way except steel scrap. Scrapping is the end of cylinder life cycle.

DISCUSSION

Although, at every stages of LPG Cylinder life cycle from manufacturing to bottling are regulated or controlled with several statutory regulations, guidelines and best practices, they are ill-treated in market place i.e. from dispatch of filled cylinder to receipt of empty cylinder in bottling plant. This ill-treatment is mainly in the form of body rolling, dropping cylinders from heights on hard surface, usage of wrong adaptor for extracting gas from cylinders, using hot water baths for generating more vapours from cylinders, illegal transfers of liquid from one cylinder to another cylinder, wet and humid kitchen condition, usage of cylinder close to hotplate etc. this kind of abuse to cylinder affects cylinder life cycle and adoption of such practices on continues basis reduces the life of cylinder.

Body rolling of cylinder in horizontal position on roads or on any hard surfaces like cemented or concrete floors, causes erosion of circumferential weld. This erosion leads LPG leaks from weld joint and may cause safety hazard while using a cylinder. Also this erosion causes leaks during hydro testing of cylinders. Any kid of leak from hydro-testing needs to be scrapped. Cylinders are recommended to handle only in upright positing. In such case, even foot ring is eroded; it can be replaced during its life cycle.

Dropping of cylinders from heights is a common concern in Indian market. Due to heavy weight of cylinder or insufficient infrastructure to carry cylinder, both filled and empty cylinders are dropped from trucks and from different heights at customer premises and cylinder distribution godowns. This ill-treatment damages foot rings, valve protection rings and cylinder body. Frequent replacement of foot ring and subsequent heat treatment process causes changes in metallurgical properties of parent metal. Such cylinders cannot withstand hydro test and needs to be scrapped much in advance in their life cycle.

Usages of illegal adaptors on cylinders are common in India, especially when the cylinders are connected to commercial burners while cooking large volumes of food. This practice can lead cylinder valve damage and requires valve replacement in plant. Further, Illegal product transfer from domestic cylinders to commercial cylinders or auto gas cylinders (due to duel pricing in India) is having an impact on cylinder life cycle. These transfers are performed in crude and unsafe manner. Cylinder valves are damaged severely in such crude operations and require replacement of valves in plant. Cylinder bung is having gas thread, which is a taper thread. The valve bungs are cleaned with appropriate National Gas thread (NGT) tap at the time of valve replacement. Frequent replacement of valve causes excessive wear of bung threat due to the tapping operation. This wear causes bung leaks and also regulators cannot fit on Cylinders due to insufficient gap between regulator base and the cylinder bung. Although, the cylinder body is in good shape, such cylinders cannot be used and should be scrapped.

Cylinder is having a limitation in LPG vapour generation in ambient conditions depending on the liquid level in cylinder. If the vapour consumption is excessive than vapour generation, sweating observed on the body of cylinder. Sweating is a phenomenon, in which the moisture from atmosphere accumulates on cylinder body due to low surface temperatures of cylinder body. This is possible if the ambient conditions are extremely cold when the cylinder is in use or the cylinder is connected to multiple appliances and the vapour consumption is more than the generation. In such cases, often hot water bath is given to cylinders by placing a cylinder in hot water tub for producing more vapours. This practice is not advisable at all. Sweating and hot water bath leads body corrosion to cylinder. Excessive body corrosion leads erosion of cylinder body and weakens parent metal as the thickness reduces. Such cylinders cannot pass hydro test during requalification and needs to be scrapped. Appropriate cylinder manifold design, avoiding usage of domestic cylinder for commercial purposes, avoiding usage of commercial non-standard adaptors is a remedial solution to this problem. Also a system that comprises combination of cylinder with liquid withdrawal valve and a vaporizer can be used for safe and reliable operation, in case several systems are connected to a single cylinder.

Most of Indian kitchens conditions are wet and humid. Cylinder foot rings can be damaged as a result of corrosion caused due to prolonged exposure to moisture in kitchens. This leads damage to foot ring or bottom pitting and reduction of thickness in bottom dome. Such cylinders are not fit for use. Also, in some kitchens the hotplates in kitchens are kept very close to the cylinders due to limitation in space. Cylinders are heated and the pressures inside the cylinder can increase drastically. In such condition and a cylinder can fail due to internal fatigue loads and bulges its shape. This condition also ultimately leads withdrawal of cylinder from market.

Although, LPG Cylinder confirms to standard and statutory requirements majority of its life is outside the cylinder manufacturer or bottling plant premises, where there is a chance to wrong handling of cylinder. This wrong handling definitely affects cylinder life cycle.

ACKNOWLEDGEMENTS

The authors wish to thanks all officers and staff in LPG Equipment Research Centre, Bangalore for their technical help and material support.

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Review Article

REVIEW ON LIQUEFIED PETROLEUM GAS CYLINDER DESIGN AND MANUFACTURING PROCESS AS PER INDIAN STANDARD, IS 3196 (PART1): 2006

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ABSTRACT:

Liquefied Petroleum Gas (LPG) Cylinders are manufactured and tested under stringent norms before they get certified by Bureau of Indian Standards (BIS) for market use. These LPG cylinders are designed and manufactured as per Indian standard. Normally, cylinders are produced in batches from raw material specified in Indian standards and tested before dispatching to market. As a part of design, cylinder thickness is calculated, that is based on the shape of the cylinder dome and cylindrical portion of the dome. Cylinders are then produced through various stages and tested before BIS Certifies a lot. An attempt has been made in this paper to explain the process behind manufacturing LPG Cylinder. The paper outlines the possible issues during cylinder manufacturing process and the deficiencies in the current Indian standard.

KEYWORDS: Liquefied Petroleum Gas Cylinders, Cylinder Design Specifications, LPG Cylinder testing, and LPG Cylinder Manufacturing.

INTRODUCTION

Liquefied Petroleum Gas (also known as LPG or LP Gas) Cylinders in India are produced as per Indian standard, *Welded low carbon steel cylinders exceeding 5 liter water capacity for low pressure liquefiable gases, IS 3196 (part 1):2006* [1]. India is the third largest LPG consumer of in domestic sector in the world [2]. Approximately 3 million LP Gas cylinders are delivered to Indian homes every day [2]. All these cylinders in India are manufactured, tested under stringent norms and certified by Bureau of Indian standards before they released for market use. An attempt has been made in this paper to review the cylinder manufacturing process from design stage to finished cylinder.

REVIEW OF CYLINDER MANUFACTURING PROCESS

General

LPG cylinders are manufactured either in two piece or three piece construction as shown in Fig.1. Body parts of a cylinder are explained in this figure [1]. In two piece construction, cylinders are fabricated by welding two domed ends directly together. A three piece cylinder is fabricated by joining two domed ends to a cylindrical body as shown in Fig.1. The domed ends can be tori-Spherical, Semi ellipsoidal or Hemi-spherical in shape as shown in Fig.2[1].

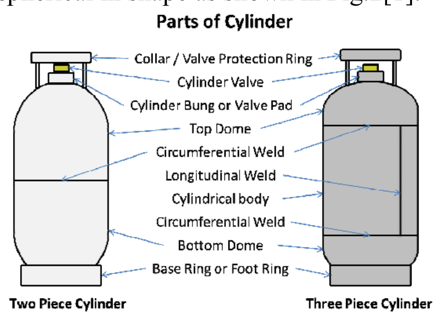

Fig.1 Parts of Cylinder

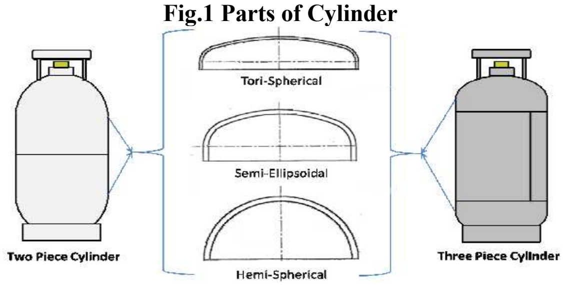

Fig.2 Types of dooms in two and three piece cylinders

Cylinder design

Wall thickness is primary factor to be arrived while designing a cylinder. Thickness depends on several factors such as cylinder test pressure, outer diameter of cylinder, shape of cylinder dome, yield strength of material, weld joint factor, ratio of domed end diameter to height, dishing radius, knuckle radius and length of straight flange. In order to design the thickness, a test pressure of 23.53 bar, and a minimum yield strength is 240 MPa [1] is considered as per Indian standard IS3196 part1. Further, weld joint factor to be considered as 1.0, 0.9 and 0.7 depends on type of radiographic examination adopted to check the welds during and after manufacturing[1]. Design calculations of any cylinder are based on cylinder dome shape. Figure 2 shows the shapes of cylinder domes in two and three piece cylinders and are, Tori spherical, Semi- Ellipsoidal and Hemi Spherical. Higher thickness among dome shapes and cylindrical portion of a cylinder is considered as a final thickness. Generally hemispherical domes are not used for two pieces [1].

The thickness of cylindrical portion is calculated using the following formulas and the highest thickness is considered as the cylindrical portion thickness [1].

$$t = \frac{PhDo}{200 \times 0.8\,J\,Re + Ph}$$

Or

$$t = \frac{PhDi}{200 \times 0.8\,J\,Re - Ph}$$

And

$$t = 0.136 \times \sqrt{Do}$$

Where

t = calculated minimum wall thickness, in mm
t_e = calculated wall thickness of doom, in mm
P_h = Test pressure, in Kgf/cm^2
D_i = inner diameter, in mm
D_o = outer diameter in mm
h_o = external height of domes end in mm
h_i = internal height of domed ends in mm
R_e = yield strength in MPa
J = weld joint factor
= 1.0 fully radio graphed welds
= 0.9 for two piece cylinder
= 0.9 where every 50 cylinders in batch are spot radio graphed as per standard
= 0.7 all other cases
K = ratio $D_o / h_o \geq 0.192$
R_i = dishing radius $\leq D_o$, in mm
r_i = knuckel radius $\geq D_o$
S_f = length of straight flange in mm
$\geq 0.3\sqrt{Dote}$

$$z = \frac{\frac{20ri}{Ri} + 3}{\frac{20ri}{20Ri} + 1}$$

Further, the thickness of a tori-Spherical cylinder dome is calculated from the following formula [1]$te = \frac{PhDo}{200\times 0.8\,J\,Re+Ph} \times \frac{KZ}{5}$

and the thickness of a semi ellipsoidal cylinder dome is calculated with the following formula[1]

$$te = \frac{PhDo}{200 \times 0.8\,J\,Re + Ph} \times \frac{K(0.65 + 0.1K)}{4}$$

In addition to the above, the Indian Standard IS 3196 stipulates minimum cylinder thickness should be 2.4 mm [1] for cylinders up to and including 13 litre water capacity and 2.4 mm for cylinders above 13 litre water capacity. Once the design is finalized, a prototype cylinder to be produced and to be subjected to various tests to ensure deemed fit [1].

Raw material

Special grade steel complies with Indian standard IS 6240, *Hot rolled steel plate (up to 6 mm) sheet and strip for the manufacture of low pressure liquefiable gas cylinders* or equivalent is used for cylinder body[3]. Standard IS 3196 specifies critical parameters of material viz. yield strength, tensile strength, percentage elongation and the material composition[1]. The bung or valve pad should confirms to class 1A or Class2 of IS 1875, *carbon steel billets, blooms, slabs and bars for forging* or IS 2062, *Steel for general structural purposes* Valve protection ring, Foot ring should confirm to Grade 0 of IS 1079, *Hot rolled carbon steel sheets and strip* [7]or IS 2062 or IS 6240.

Manufacturing

Cylinders are generally manufactured in lots. Each cylinder lot consists of 202 cylinders or less[4].

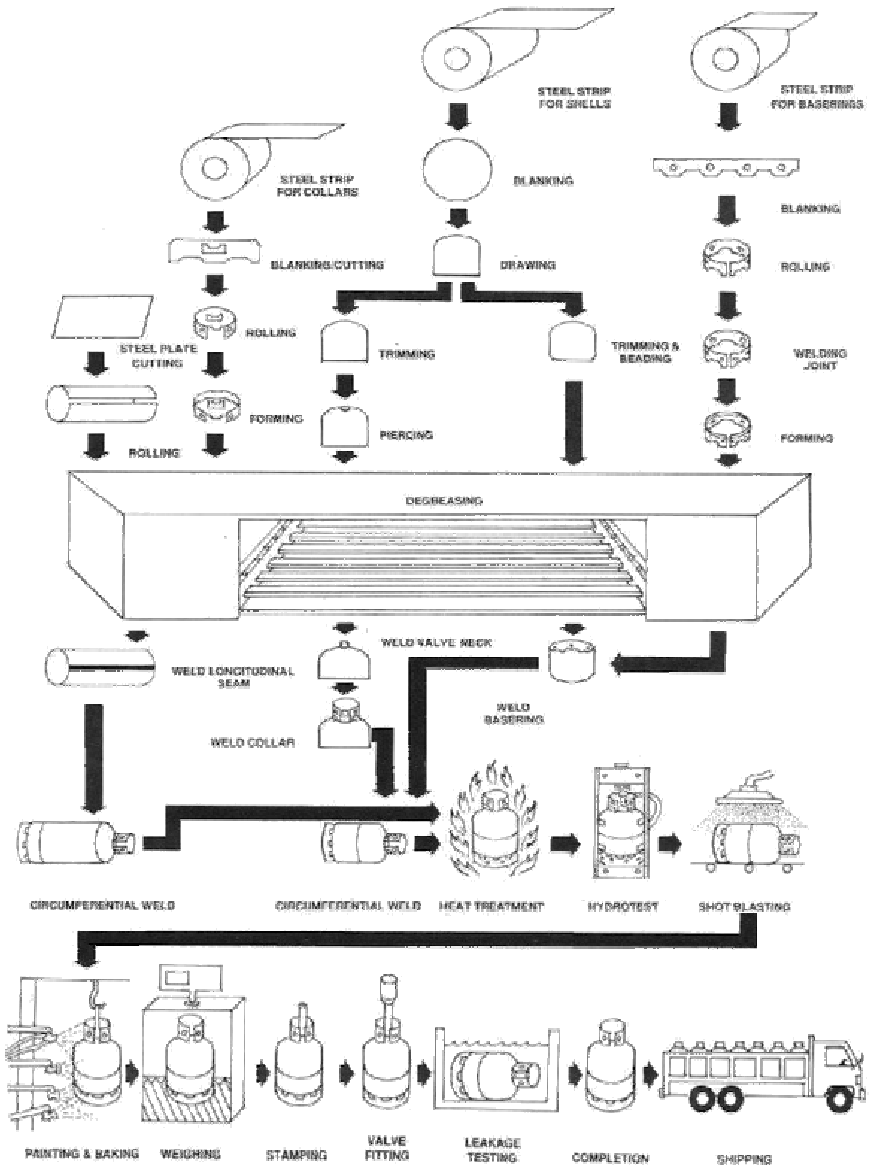

Fig.3: LPG Cylinder Manufacturing Process flow diagram

Fig.3 shows the cylinder manufacturing process from raw material to finished product for both two piece and three piece cylinders[5]. Raw material as per IS 6240 [3] or equivalent either in coil or sheet form may be used for producing cylinders. For a two piece cylinder, circular blanks are cut from sheet to produce top and bottom domes. Top dome further undergoes piercing operation to accommodate bung. Valve protection ring and foot rings are produced by blanking, rolling, joining and forming operations from raw material. For a three piece cylinder, cylindrical body piece is produced by rolling operation. All these components are degreased for efficient and defect free welding operation. Any fusion welding method can be used to join cylinder parts. However Welding procedure and the welder performance requirements should meet either IS 2825, *Code for unfired pressure vessels* [6] or IS 817, *code of practice for training and testing of metal arc* *welders* for welding depends on full and partial radiographic examination.

The welding process starts with joining of valve pad, which is welded to top dome. Valve protection ring and foot rings are also welded to domes before they weld together, for a two piece cylinder. In case of a three piece cylinder, both these domes are welded to a cylindrical body to form a complete cylinder. The welding process can create heat affected zone on parent metal near the weld areas. This can cause internal stresses in the cylinder body. Such stresses are relieved in a heat treatment process during manufacturing. Depending on the raw material and the final cylinder material specifications the heat treatment can be either stress relieving or normalizing. Heat treatment time and temperature are maintained in such a way that the end product should meet the testing parameters mentioned in IS 3196 part3 [4].

All cylinders are subjected to hydro test after heat treatment to ensure that there are no leaks in the cylinders. The cylinders are then subjected to painting. The painting process includes short-basting powder coating and baking. The cylinders are then sent for markings. Cylinder unique serial number and test dates are marked on cylinder at this stage. Further, all cylinders are individually weighed and tare weight is stamped on stay plate. After this process, the valves are fitted to cylinders and tested for leaks in a leak test bath. This completes the cylinder manufacturing process.

Testing of cylinders

Normally one cylinder in a lot of 202 or less is subjected to acceptance test. Similarly out of 403 or less lot size one cylinder is subjected to hydrostatic test as per IS 3196 part3 [4]. In addition to that, cylinders are subjected to various non-destructive and destructive tests, to get Bureau of Indian certification for marketing. The following are the essential tests to be conducted on cylinders before they get certified by Bureau of Indian standards [4].

- Acceptance test
- Burst and volumetric expansion test
- Hydrostatic stretch test and burst test
- Hydrostatic test
- Pneumatic leak test
- Radiographic examination and
- Fatigue test/ Cycle test

Acceptance tests reveals yield, tensile strength and percentage elongation of parent metal and weld tensile strength. Further the acceptance test reveals weld quality through bend tests and macro examination of weld samples. Cylinder thickness is also measured in this test to verify the design compliance[4].

Hydrostatic stretch test reveals the permanent stretch retained in a cylinder under 80% of test pressure conditions to check whether the cylinder is meeting the required conditions or not. It may conducted wither water jacket method or non-jacket method. After this the cylinder is subjected to burst test to measure nominal hoop stresses in cylinder material [4].

Hydrostatic test is conducted to check the leaks in cylinders from pin holes, blow holes, undercuts in welding at test pressure conditions. This test is conducted on a cylinder with no valve attached to it. Once the valve is attached pneumatic test is conducted on cylinder to check for leaks, if any[4].

Radiographic examination is conducted on a cylinder to check weld penetration at weld overlaps and also to check the weld defects in cylinder [4].

Fatigue or cycle test is type test conducted on cylinders to check the behaviour of cylinder under cyclic loads. Cylinders are subjected to test pressure or two third of test pressures for a specified number of cycles and then subjected to burst pressure to check the burst test compliance [4].

The cylinders are also checked for circularity, surface defects, profile regularity, straightness and verticality during manufacturing, to ensure there are no manufacturing defects [1].

Various test methods and their requirements for LPG Cylinders are mentioned in a separately Indian Standard, welded low carbon steel cylinders exceeding 5 litre water capacity for low pressure liquefiable gases part3 Methods of test , IS 3196 Part3 [4]. On passing these requirements, the cylinders are certified by Bureau of Indian standards with a BIS mark for market use.

DISCUSSION

The stresses developed in parent metal due to welding of cylinders during manufacturing can be relieved only by heat treatment process. The heat treatment process parameter varies depending on the raw material composition. Typically the heat treatment for a domestic LPG cylinder of 33.3 water capacity is around 850^{O}Cto 900^{O}C for 10 to 15 minutes time. This process incurs huge cost to manufacturer for maintaining the furnace. On the other hand after completion of a lot of 403 cylinders only 3 cylinders undergoes testing as per IS 3196 part3. Based on the results of these three cylinders rest of the 400 cylinders are certified by Bureau of Indian standards for issuing BIS certification. It is almost impossible to any certifying agency like BIS to monitor the cylinder manufacturer on continues basis. In case, if manufacturer bypasses or adopt short cut methods for heat treatment process and manage to pass three cylinders in a batch, improperly heat-treated cylinders may enter into market. This type of scenario cannot be ruled out in India, keeping in view of consumer safety. In order to address this either, the sampling size of acceptance testing should be increased or there should be some provision to test all cylinders at manufacturing premises through non-destructive methods to ensure material quality compliance, which is not existence in the current Indian standard.

CONCLUSION

In this paper cylinder manufacturing process was described from design stage to finished cylinder. Cylinder design calculations are aimed to find thickness, which is calculated separately for cylindrical and domes portions and finalize whichever is greater. Once the design is finalized, cylinders are produced from a specified raw material through various processes. Internal stresses in cylinders are relieved in a heat treatment process. Cylinders are marked with unique serial numbers and tare weight. Various tests are conducted on cylinders to get certification from bureau of Indian standards for market circulation. Although LPG Cylinders are manufactured under stringent norms, with the existing standard there is a possibility to enter non complied cylinder into market. This was explained briefly at the end of the paper.

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Study on Hydro Testing of LPG Cylinders

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Abstract*— Liquefied petroleum Gas (LPG) cylinders are designed and manufactured in India as per Indian standard IS 3196 part 1. Several tests mentioned in IS 3196 part 3 need to be conducted on LPG Cylinders for introducing them to market. Among these tests, acceptance and hydro-tests are major tests to be conducted on LPG Cylinders to get Bureau of Indian certification. Hydro-tests on LPG cylinders reveals permanent volumetric expansion of cylinder, nominal hoop stresses at the time of destruction and the internal pressure at which a cylinder bursts. These values are important to ensure that the design and construction of cylinders are safe and compiled to standards. These hydro-test results depend on cylinder raw material selection, manufacturing processes and the heat treatment process parameters adopted during manufacturing process. An attempt has been made in this paper to study experimental test data of 40 Domestic LPG cylinders Hydro test results to understand correlations among these parameters.

***Index Terms*— Hydrostatic testing of LPG Cylinder, Burst testing of LPG Cylinder, Volumetric expansion tests of LPG Cylinders, Hydro-testing of LPG Cylinders.**

I. INTRODUCTION

LPG Cylinders are manufactured in India as per Indian standard IS 3196[2][3][4]. Cylinder manufacturers design, manufacture and test these cylinders as per this standard and get certified by Bureau of Indian Standards (BIS) for marketing. It is mandatory to get certification for every cylinder released from manufacturing location to market. Two cylinders from each manufactured lot are subjected to destructive test for verification of cylinder material properties, as a part of certification process [3]. For every manufactured lot of 203 and below one cylinder is tested for acceptance test [3]. Parent metal physical properties like yield strength, tensile strength, percentage elongation of parent metal, weld tensile strength, weld joint strength etc. are revealed in acceptance test [2]. Similarly for every manufactured lot of 403 cylinders and below one cylinder is subjected to various hydro-tests [3]. Hydro-test on cylinder reveals cylinder water capacity, leaks, volumetric expansion, burst pressure and nominal hoop stress at which a cylinder bursts [3]. Requirements of various hydro-tests for LPG cylinders are mentioned in Indian standard IS 3196 part 1 and various test methods are described in Indian Standard, IS 3196 part 3. There are few factors that can influence these results during manufacturing process and are cylinder raw material selection, cylinder manufacturing process, heat treatment process parameters [5][11][12]. An attempt has been made in this paper to study permanent volumetric expansion, burst pressure and nominal hoop stresses by analyzing 40 domestic LPG cylinders burst test results. These results are correlated and analyzed using Minitab 16, a Microsoft windows based statistical software.

II. MATERIALS AND METHODS

A. General

Burst test results of domestic LPG cylinders of 33.3 liter capacity are selected for this study. These cylinders are most common type of cylinders used in Indian houses and are designed and manufactured as per IS 3196 and certified by Bureau of Indian Standard for market use [2]. In addition to this certification, Indian government oil companies verify cylinder quality in their own independent laboratory for quality compliance.

B. Material

Forty domestic LPG cylinders of 33.3 liters capacity received from various locations across India are tested in Bureau of Indian Standards approved lab for analysis. All these domestic cylinders are produced from raw material meeting IS 6240 standard [1]. Physical properties and hydro-test requirements of these cylinders are meeting the Table.1 [1][2][3].

Table.1 Requirement of LPG cylinder parent metal physical properties

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Strength (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Hydro-test	Burst Pressure	Minimum 54.92 bar	Clause 9.1.2 of IS 3196 Part3: 2012
	Nominal Hoop stress	Minimum 332.5 MPa	Clause 17.3.3 of IS 3196 Part1: 2006
	Volumetric Expansion	≥ 20% (for Tensile strength ≤410 MPa)	Clause 17.3.3.e of IS 3196 Part1: 2006

C. Types of Hydro-tests on LPG Cylinders

General

Table.1 shows the critical parameters of hydro-tests and their acceptable limits with cross reference to Indian standard. Manufacturers should conduct the following hydro-tests on every cylinders lot produced in their units. These hydro-tests reveal Volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoop Stresses (NHS). These VE, BP and NHS values are considered as critical parameters in hydro-testing of LPG Cylinders [6][7][8]. These values can be correlated

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with tensile strength and yield strength of material [10].

Water capacity test

In a water capacity test, cylinder water capacity is measured and checked whether they are within acceptable limits are not. Domestic LPG Cylinders in India are of 33.3 liter water capacity and its acceptable limit is within 33.30 liters to 33.95 liters as per Indian standard, IS 3196 part 1[2] [3].

Hydrostatic test

Every cylinder produced in a manufacturing location should undergo hydrostatic test. In this test, cylinders are subjected to hydrostatic test pressure of 25 kgf/cm^2 and retain this pressure up to 30 seconds to check any pressure drop [2] [3]. Once the cylinder external surface is dried, they are checked for visual external leaks and pressure drop. If there is any pressure drop or any visible external leaks observed on cylinder body or on welds, the cylinder is considered as failed cylinder for usage [2] & [3].

Hydrostatic stretch test

One cylinder from every manufactured lot of 403 and below should undergo hydrostatic stretch test [3]. This test can be performed either with water jacket method or non-water jacket method described in IS 3196 part 3. The test cylinder is submerged in a water bath for conducting the test, in a water jacket method [3]. In the other hand, the cylinder is tested openly in a non-water jacket method [3]. In both cases there is a provision to control and measure the water pumped to cylinder. Initially a cylinder is filled with measured quantity of water say, C1. This filled cylinder is gradually pressurized with water till it reaches hydrostatic test pressure of 25 kgf/cm^2 through an apparatus that can measure the pumped water quantity in a precise manner. Once the pressure reaches, the test pressure, the pressure is retained for not less than 60 sec and measures the water contained in the cylinder as C2. The water capacity of cylinder is measured once again after releasing the test pressure and recorded as C3. Based on the records, the volumetric expansion is calculated as; the difference between C1 and C2 represents the total volumetric expansion and the difference between C1 and C3 represents the permanent expansion. This value should be within 1/5000 of the original volume of the cylinder [3] to pass the test.

Burst test and nominal hoop stresses

One cylinder from every manufactured lot of 403 and below should test for measuring burst pressure and nominal hoop stresses [2] & [3]. Generally the cylinder tested for volumetric expansion test can be used for this purpose. In this test, cylinders are subjected to continuous hydrostatic internal pressure till it bursts. The internal pressure of cylinder at which it bursts is noted and recorded as burst pressure. Based on this burst pressure nominal hoop stresses are calculated using below formula

$$fb=(Pb \times Di)/2t$$

Where, *fb*-nominal hoop stress at which destruction occurs; *Pb*-Internal hydrostatic pressure at which cylinder bursts in MPa; *Di* -Nominal original internal diameter of the cylinder in mm and *t*-minimum agreed finishing thickness of the cylinder in mm [3].

III. EXPERIMENTAL DATA VALIDATION AND ANALYSIS

Forty domestic LPG cylinders results of volumetric expansion (VE), burst pressure (BP), and nominal hoop stress (NHS) are collected and checked the relation among these parameters by correlation analysis. 40 observations of cylinders are shown in control charts of volumetric expansion (VE), burst pressure (BP) and normal hoop stresses (NHS) in Fig. 1, 2 and 3 respectively. Person correlation constants were calculated among the possible pairs of VE, BP and NHS. The correlation pairs, constants and the trends are tabulated in Table 2.

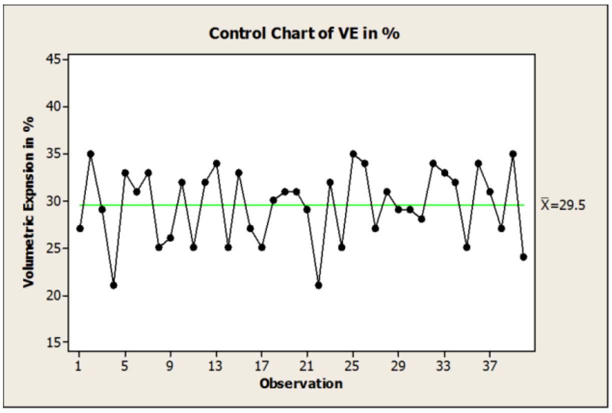

Fig.1 Control Chart for Volumetric Expansion (VE)

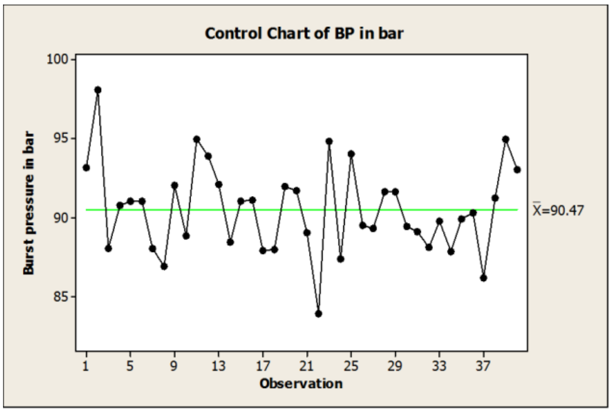

Fig.2 Control Chart for Burst Pressure (BP)

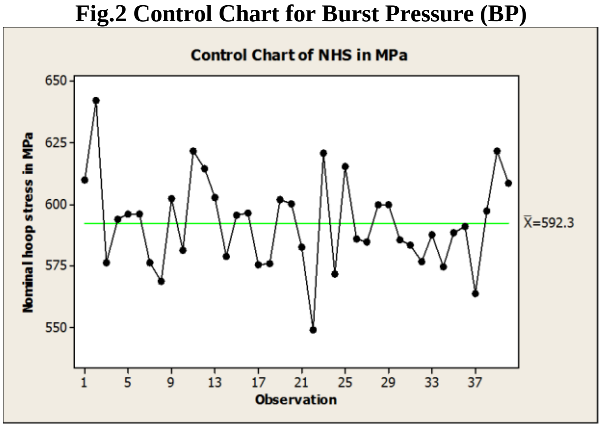

Fig.3 Control Chart for Nominal Hoop Stress (NHS)

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Table.2 Hydro-Test Parameters Relations, Pearson Correlation Coefficients and Trends

Correlation Study among variables			
Parameter	VE	BP	NHS
VE			
BP	BP Vs. VE		
NHS	NHS Vs. VE	NHS Vs, BP	

Pearson Correlation Constants			
Parameter	VE	BP	NHS
VE			
BP	0.334		
NHS	0.334	1	

Trend Analysis			
Parameter	VE	BP	NHS
VE			
BP	Positive		
NHS	Positive	Positive	

IV. DISCUSSION

Referring to the Table.1 and control harts of VE, BP and NHS (Fig. 1, 2 and 3), the test results are validated as per Indian standard, IS 3196. It is evident from Pearson correlation constants mentioned in Table.2, relations can be established among BP vs. VE, NHS vs. VE and BP vs. NHS. The relationship among BP vs. VE and NHS vs. VE shows positive trend. That means, if the volumetric expansion of LPG cylinder is observed relatively more, the burst pressure and nominal hoop stresses will also report relatively high. Similarly if the volumetric expansion is low, the burst pressure and the nominal hoop stress reports relatively low values. The relation among BPVs NHS is showing a strong positive relation of one because the NHS is derived from BP with the formula given above. Although the correlation exists strongly among these variables, it is not fully evident through Pearson correlation studies. This is mainly because of few parameters like raw material selection, manufacturing process parameters and testing conditions can change the end results [11][12]. This can be justified as under. In the current study, samples are taken from different manufacturing locations across [9] India and are compiled to IS 6240 [1]. Although raw material is compiled to Indian standards, it is sources from various steel manufacturers in India. Standard stipulates only minimum specification for the raw material (see Table.1) not the best quality or highest possible specifications. Suppose, if a manufacturer is left with no option but to use high quality in terms of logistics or transportation cost or high demand for the product at the time of production, they may use raw material having quality mentioned beyond minimum specification for cylinder manufacturing, which can affect hydro-test results. All cylinders while manufacturing need to pass heat treatment process to get desired physical properties of finished cylinder and to relieve internal pressures generated due to welding process. The Indian standard once again stipulates minimum requirements of material physical properties (see Table1). The manufacturer can even go beyond the stated specifications due to lack of options mentioned above such as logistics, timelines and to meet the demand requirements. Further, the heat treatment process parameters like soaking time in furnace and cooling times after heat treatment are set based on raw material mill certificate and furnace manufacturer's recommendation [5]. Although the end products are meeting the minimum specifications, these parameters can slightly vary in commercial environments and thus the end product quality can meet and go beyond the stated requirement. Further, the welding process and weld methods are can also influence the burst test results and volumetric expansion [7] as these weld methods, welding procedures; weld electrodes are different from one cylinder manufacturer to another. Thus varying heat treatment process parameters and welding methods have a definite impact on Hydro-test results of LPG Cylinders. The testing conditions can also influence hydro-test results. Manufacturing locations are commercial establishments and are predominantly work in commercial framework. These establishments are different from testing laboratories or research and development institutes. Standard provides flexibility in testing through various options like water jacket method and non-water jacket method etc. to accommodate different manufacturing setups. Also they do not suggest a specific test setup for a specific test. Chances always exist to vary test results within acceptable limits when they are subjected to two different test methods and setups. This will affect the repeatability of the test results within acceptable limits. Also, individual equipment used in test setup can some time leads inadvertent mistakes. For example, while subjecting a cylinder for burst test, the pressure can be increased with a positive displacement pump (Piston pump). The output from positive displacement pump is pulsating. The gauges attached to such test setup should take care of such fluctuations while reading the dial gauge with appropriate dampening medium. Otherwise there could be an error in reading accurate pressure especially while reading burst pressure. Such phenomenon can affect the hydro-test results.

V. CONCLUSION

In this work, forty domestic LPG Cylinders hydro test data was analyzed to establish correlations among volumetric expansion, burst pressure, and nominal hoop stresses. It is evident from the correlation study that a relation can be established among these variables. Although, it is clearly evident that there is a relation exists among various parameters, few factors like raw material, heat treatment process parameters, welding processes, test setups can affect test results in typical commercial environments.

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Research Paper

STUDY ON LPG CYLIDNER PARENT METAL MECHANICAL PROPERTIES

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ABSTRACT:

Liquefied petroleum Gas (LPG) cylinders undergo various tests before they certified by Bureau of Indian Standards for market use. Acceptance test is one among those tests, in which the cylinder mechanical properties of parent metal are checked against specification for compliance. Acceptance test is a destructive test, in which tensile samples are carefully drawn from LPG cylinder in both longitudinal and circumferential directions and tested on a tensile testing machine to measure Tensile strength, Yield stress and Percentage Elongation. These resulted mechanical properties depend on several factors such as raw material selection, manufacturing process, heat treatment process parameters. An attempt has been made in this paper to study and understand correlations among these properties.

KEYWORDS Acceptance testing of LPG Cylinder, Correlation study, Mechanical properties, tensile strength, Yield stress and Percentage of permanent elongation.

INTRODUCTION

Indian standards, IS 3196 Part 3: 2012 (*Welded low carbon steel cylinders exceeding 5 liter water capacity for low pressure liquefiable gases Part 3: methods of test*) states, one random cylinder from every batch of 202 or less heat treated cylinders should undergo acceptance test [6]. Acceptance test comprises of 4 individual tests and are parent metal tensile test, tensile test on weld joint, bend test across weld and Macro examination [6]. Among these tests, except parent metal tensile test, all other tests are related to weld and weld joint. In parent metal tensile test, a tensile specimen is prepared from a sample cylinder and tested on universal tensile testing machine to measure parent metal mechanical properties viz. Tensile Strength, Yield strength or yield stress and percentage permanent elongation in both longitudinal and circumferential direction (see Fig.1) [5].

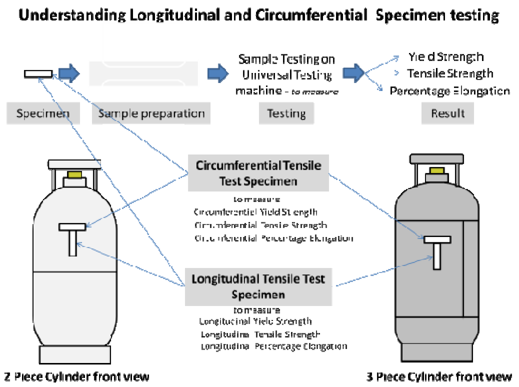

Fig.1 Tensile test on Parent metal

Table.1 Requirement of LPG cylinder parent metal physical properties

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Stress (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

Indian standard IS 3196 part1: 2006 specified the minimum mechanical properties for these parameters are given in Table.1 with cross references from Indian standards [5] & [4]. From literature study, it was established that the Tensile strength and yield stress of longitudinal sample exhibits higher values than circumferential sample [8]. Similarly, the percentage elongation of circumferential sample is higher than the longitudinal sample [8]. The scope of this work is limited to the parent metal tensile test only. An attempt has been made in this work to study the relation among tensile strength, yield stress and percentage elongation of both longitudinal and circumferential samples with the help of windows based statistical software, Minitab 16.

MATERIALS AND METHODS

Material - LPG Cylinder Samples

Fifty five samples of 33.3 liter capacity Domestic LPG Cylinders were selected for experimental analysis purpose. These cylinders are produced from raw material specified in Indian standard IS 6240:2008 [4] and are heat treated to ensure that the finished cylinder parent metal is meeting specifications mentioned in Table.1 [4] & [5]. The test samples were received from state owned oil companies in India and experiments were conducted in one of the central government based and National accredited board laboratories (NABL) certified testing laboratory in Bangalore, India. All these cylinders are certified by Bureau of Indian standards for market use.

Sample Preparation

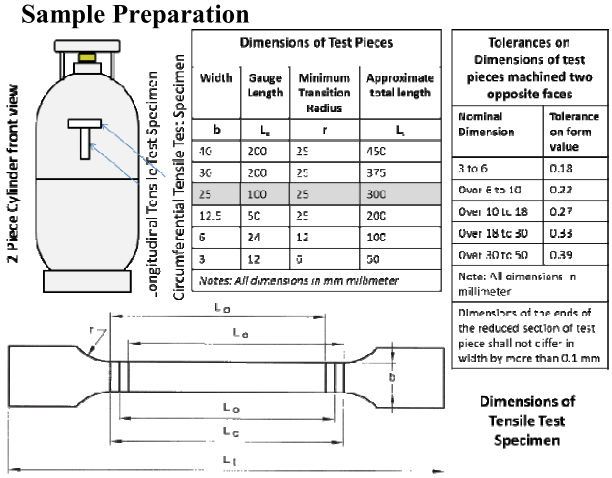

Fig.2: Tensile Test Sample Preparation

Indian standard IS 3196 Part3, provide guidelines for sample preparation and test procedure for parent metal tensile test [6]. Two tensile samples were carefully cut from cylinders as per the dimensions highlighted in Fig.2 in both longitudinal and circumferential direction for testing purpose. Gauge length for all these 55 samples is considered as $5.65\sqrt{S_o}$, where S_o is original cross section area [6].

Tensile Test

Computer controlled FIE make universal testing machine is used for conducting tensile tests for this study. The machine is having a valid calibration in accordance with Indian standard IS 1828 (part1) at the time of testing. It is ensured that the rate of strain during plastic deformation not exceeding 0.15/min for yield strength measurement and also the rate of stressing is maintained between 20 to 30 $mm^{-2}S^{-1}$ in the elastic region to avoid errors due to inertia effect. All 55 Cylinder samples are tested as per tensile test methods prescribed in Indian standard IS 3196 Part3 and IS 1608.

Methodology

Tests were conducted on 55 LPG Cylinder samples both in longitudinal and circumferential direction and ensured that the cylinders are qualified for the analysis as per Table.1 by generating individual plots. Pearson's correlation coefficients were calculated to various pairs of physical properties as per the Table. 2 and analysed the coefficients

Table.2 LPG Cylinder Material Specifications

Correlation analysis of Longitudinal Tensile test results	Tensile Strength, LTS	Yield Stress, LYS
Tensile Strength, LTS		
Yield Stress, LYS	LTS Vs LYS	
Percentage Elongation, L%EL	LTS Vs L%EL	LYS VS L%EL

Correlation analysis of Circumferential Tensile test results	Tensile Strength, CTS	Yield Stress, CYS
Tensile Strength, CTS		
Yield Stress, CYS	CTS Vs CYS	
Percentage Elongation, C%EL	CTS Vs C%EL	CYS VS C%EL

RESULTS

Individual plots of tensile strength, yield stress and percentage elongation for both longitudinal and circumferential test results are generated and are given in Fig.3 and Fig.4. In these two figures longitudinal tensile strength, longitudinal yield strength and longitudinal percentage elongation are termed as LTS, LYS & L%EL respectively. Similarly, circumferential tensile strength, circumferential yield strength and circumferential percentage elongation are termed as CTS, CYS and C%EL respectively. The numbers in the figures with blue colour indicates mean values and in red colour indicates median value. Pearson correlation coefficients were calculated using Minitab 16 software for all pairs shown in Table.2 and results are tabulated Table.3 along with trends.

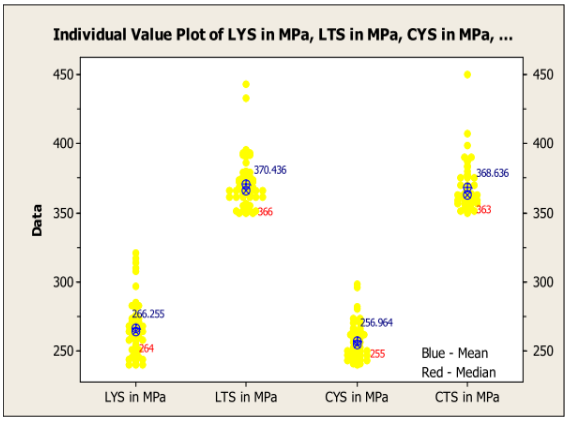

Fig.3: Individual plots of yield stress and tensile strength

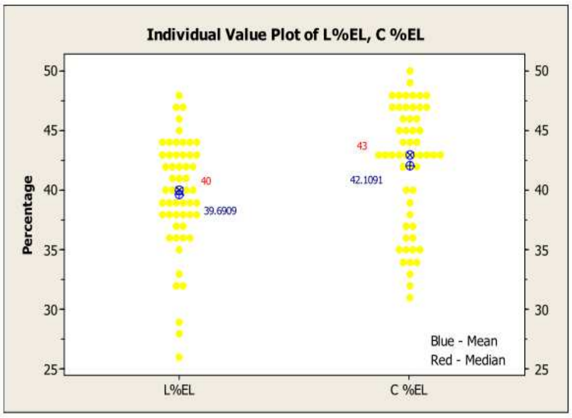

Fig.4: Individual plots of percentage elongation

Table.3 Pearson correlation coefficient values and trends

Correlation analysis of Longitudinal Tensile test results	Tensile Strength, LTS	Yield Stress, LYS
Tensile Strength, LTS		
Yield Stress, LYS	0.559 / Positive trend	
Percentage Elongation, L%EL	-0.491 / Negative trend	-0.232 / Negative trend

Correlation analysis of Circumferential Tensile test results	Tensile Strength, CTS	Yield Stress, CYS
Tensile Strength, CTS		
Yield Stress, CYS	0.133 / Positive trend	
Percentage Elongation, C%EL	-0.629 / Negative trend	-0.188 / Negative trend

DISCUSSION

It is evident from Fig.3 that the yield strength and tensile strength values are within the permissible limits mentioned in Table.1 and are qualified for the analysis. The mean values of the both tensile strength and yield stress of longitudinal samples are higher than the circumferential samples. This is also established with existing literature on LPG Cylinders [8]. Similarly, Fig.4 qualifies all samples for analysis by meeting the specification mentioned in Table.1. It also proves that the circumferential sample exhibits higher percentage elongation value than the longitudinal sample [8]. It means, under severe internal pressures, the cylinder expands more rapidly in circumferential direction due to higher elongation values and lesser tensile strength. This phenomenon is evident in all volumetric expansion and burst tests conducted in laboratories as per IS 3196 part3: 2012 [6]. The same phenomenon allows cylinders to burst with a crack observed in longitudinal direction during burst testing of cylinder [6].

Pearson's correlation coefficients in Table.3 indicate moderate relation exists between longitudinal tensile strength (LTS) vs longitudinal yield strength (LYS), longitudinal tensile strength (LTS) vs longitudinal percentage elongation (L%EL) and circumferential tensile strength (CTS) vs circumferential percentage elongation(C%EL). However from the same table it is evident that the relation cannot be clearly defined between longitudinal yield strength (LYS) vs longitudinal percentage elongation (L%EL), circumferential tensile strength (CTS) vs circumferential yield strength (CYS) and circumferential yield strength (CYS) vs circumferential percentage elongation (C%EL) as the correlation coefficient values are very low. However the trend between LTS vs LYS and CTS vs CYS is positive and LTS vs L%EL, LYS vs L%El, CTS vs C%EL and CYS vs C%EL are negative. That means, if the yield strength is relatively high in cylinder testing, the tensile strength also exhibits relatively higher value in in both longitudinal and circumferential samples. Similarly, if the tensile strength is relatively high, the material exhibits relatively lower percentage elongation values in both circumferential and longitudinal samples. Also, if the yield strength is high the percentage elongation is low in both circumferential and longitudinal samples as the yield strength and tensile strength exhibits positive trend in their results. Although it is a general phenomenon for any steel sample, the trends and correlations are not reflecting strongly in the current correlation study with LPG cylinder samples. This is mainly due to the following reasons.

Tensile strength and yield strength are generally follow strong positive correlation. However, low Pearson's coefficient values as obtained in current study are possible mainly because of problem in identifying the actual yield point and there by calculating yield stress. Normally for domestic cylinders identification of definite yield point is not possible [10]. Indian Standard IS 3196 part3 recognises this fact and a provision is given in standard to identify yield point in such cases. As per the standard, yield point can be identified by drawing a straight line along stress strain curve in elastic zone and allows assuming the yield point, where the origin of curve starts deflecting from the straight line [6]. Established literature states, cylinders produced from deep drawing process don't exhibit definite yield point [10]. Thus, in LPG cylinder testing process, the yield point should be identified manually and this identification is purely depends on the lab technicians skill. Whereas ultimate tensile strength can be obtain directly from testing equipment without any manual intervention. Although both yield strength and tensile strength follow definite positive trend, because of manual intervention in calculating the yield strength, true correlation may not reflect in cylinder testing process.

Manual intervention requires keeping the broken test pieces together for measuring the final gauge length [6], while calculating percentage elongation. This manual intervention is also to some extent affects the final elongation results and there by Pearson's correlation coefficients. Such results may not reflect true conditions and the relations.

Sample preparation methods in production units such as cylinder cutting (Gas cutting or cold cutting methods), drawing, chiselling, blanking, flattening operation while preparing tensile sample, and accuracy of sample preparation; maintain parallel lengths and final sample finishing effects deviations in test result considerably.

Raw material, manufacturing conditions, manufacturing processes, heat treatment process parameters varies from manufacturer to manufacturer and hence there exists a chance to get low Pearson's correlation coefficients although the cylinders are manufactured with definitely prescribed raw material.

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Research Article

IMPACT OF SAMPLE PREPARATION METHODS ON LIQUEFIED PETROLEUM GAS CYLINDER PARENT METAL TENSILE TEST

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ABSTRACT:

Liquefied Petroleum Gas (LPG) cylinders in India are designed, manufactured, tested and certified at manufacturing location to ensure cylinder are manufactured as per Indian Standard, IS 3196. Several tests are conducted on LPG Cylinders, in which acceptance test is one of the important tests to reveal cylinder parent metal mechanical properties. Two tensile specimens are prepared from finished cylinder batch for this test and tested on a universal testing machine to determine, yield strength, percentage elongation and ultimate tensile strength of parent metal. Values of these test results are compared against standard values prescribed in Indian standards to decide acceptance of cylinder batch for market release. There are various ways of preparing tensile sample for acceptance test, depending on the accuracy of test results and sample production requirements. An attempt has been made in this paper to review existing sample preparation practices for 33.3 litre water capacity domestic LPG Cylinders and suggested a feasible option for optimal sample preparation method in which both sample preparation timelines and dimensional accuracy can be achieved for accurate test results.

KEYWORDS: Acceptance test sample, Tensile Sample preparation, LPG Cylinder sample, LPG Cylinder testing

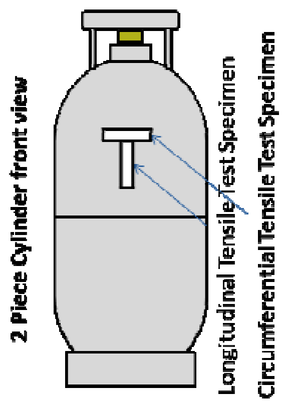
INTRODUCTION

Liquefied Petroleum Gas (LPG) cylinders in India are produced as per Indian standard IS 3196 part1: 2006, *Welded low carbon steel cylinders exceeding 5 litre water capacities for low pressure liquefiable gases – Specification* [7]. Indian standard IS 3196 part 3[8] states the guidelines for testing of new cylinders for Bureau of Indian Standards (BIS) certification. BIS logo is punched on every certified cylinder for market use. Acceptance test is one of the important tests to be conducted on LPG Cylinder to know parent metal properties of a finished cylinder batch [7][8]. A random cylinder is picked from a batch of 203 or less [8] cylinders for acceptance test during manufacturing. This test reveals parent metal mechanical properties viz. yield stress, percentage elongation and tensile strength [8]. In order to carry out a tensile test, two tensile samples are cut from finished sample cylinder from a lot or batch; one in longitudinal and the other in circumferential directions [7] and tested on a universal testing machine. Although, dimensions of tensile test sample and test methods are given in the Indian standard, IS 3196 part3, sample preparation methods are not clearly stated in it. It is evident that the sample preparation in terms of dimensional accuracy affects the tensile test results [17]. There are various ways to prepare a sample depending on the accuracy and sample preparation cycle time requirement. An attempt has been made in this paper to discuss various sample preparation methods from a domestic 33.3 litre capacity LPG cylinder. Impact of sample preparation methods on test results are discussed with a feasible solution for optimal sample preparation method to get accurate test results.

LPG CYLINDE SAMPLE PREPARATION - REVIIEW

General

Domestic LPG Cylinder of 33.3 litre water capacity is constructed in two piece construction [2]. Two deep drawn domes are welded together with a circumferential seam to form the body of a two piece LPG cylinders as shown in Fig.1.



Dimensions of Test Pieces

Width	Gauge Length	Minimum Transition Radius	Approximate total length
b	L_o	r	L_t
40	200	25	450
30	200	25	375
25	100	25	300
12.5	50	25	200
6	24	12	100
3	12	6	50

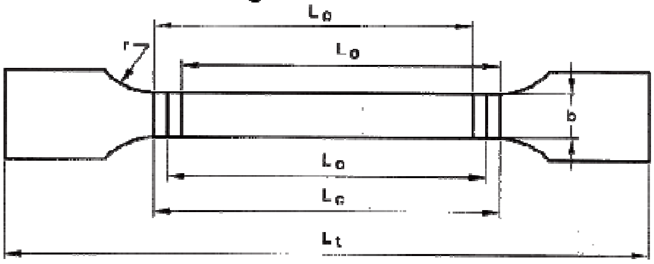
Notes: All dimensions in mm millimeter

Tolerances on Dimensions of test pieces machined two opposite faces

Nominal Dimension	Tolerance on form value
3 to 6	0.18
Over 6 to 10	0.22
Over 10 to 18	0.27
Over 18 to 30	0.33
Over 30 to 50	0.39

Note: All dimensions in millimeter

Dimensions of the ends of the reduced section of test piece shall not differ in width by more than 0.1 mm



Dimensions of Tensile Test Specimen

Fig.1: Dimensions of LPG Cylinder Acceptance sample

These cylinders are tested per batch to ensure their parent metal properties are within specified limits [5]. One random sample cylinder is selected from a batch of 203 or less manufactured cylinders lot for testing tensile properties of parent metal. In order to test, two tensile specimens, one in longitudinal direction and the other in circumferential direction to be cut from sample LPG cylinder. Acceptable dimensions, its tolerances and gauge length details of tensile specimen as per Indian standard, IS3196 Part3 are given in Figure.1 [7][8]. There are currently 133 license holders for producing cylinders in India as per Indian Code IS 3196 part1 [14] and they test several thousand cylinders in a year for accepting cylinder batches from their manufacturing plants. The cylinders are tested in all manufacturing locations before they get certified by BIS. Keeping in view of the large volumes, tensile sample dimensions (marked in the Fig.1 with 25 mm width) and preparation methods are mostly standardised as an industrial practice.

Sample Preparation

There are several ways to prepare a tensile sample. Keeping in view of the intended requirements, these samples are prepared either manual methods or semi-automated methods. Semi-automated methods are used for routine laboratory testing purpose at manufacturing locations. Manual methods are deployed for quality assurance purpose in standalone certifying bodies or laboratory. Both these methods are having their own advantages and disadvantages. Fig. 2 show process flow chart of these sample preparation methods and Figure.3 shows existing and proposed methods in pictorial form.

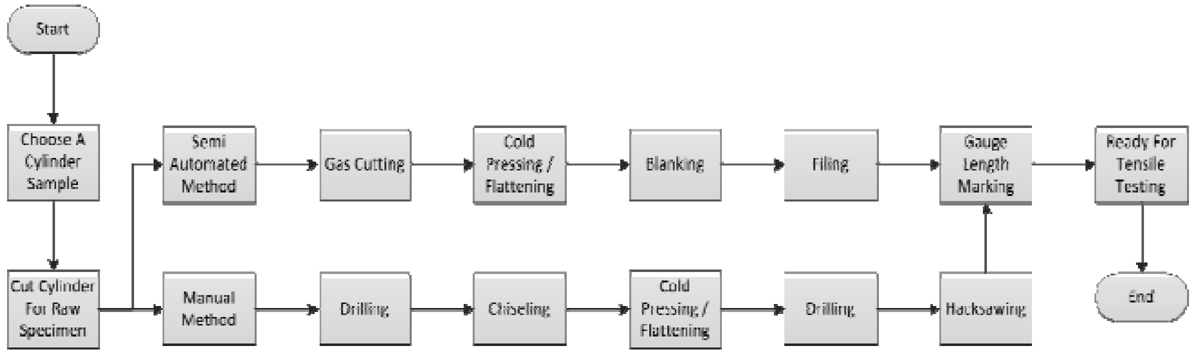


Fig.2Flow chart - Sample Preparation

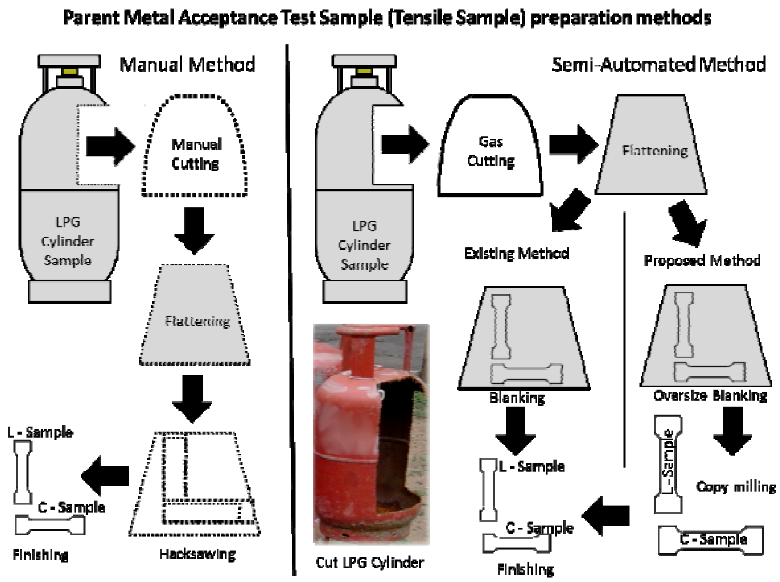


Fig.3: Pictorial Representation of LPG Cylinder Sample Preparation

Manual sample preparation

Manual preparation methods are adopted for quality assurance purpose in certifying agencies or statutory agencies, where few samples are tested occasionally for quality assurance purpose. In this method, cylinders are drilled and chiselled to take a blank piece from cylinders (see Fig.3). This blank piece is then straightened in a press by cold pressing operation. Once the blank piece is ensured flat, tensile samples are cut from this blank on a metallic band saw or hacksaw. Sample is finished by either milling or filing operation. With this method test piece of any size shown in Figure.1 can be prepared. However, sample preparation takes considerable amount of time and is purely depending on the skill of the sample preparation worker. This method can be adopted where there is less demands for sample preparation.

Semi-automated preparation

Tensile samples are produced in manufacturing locations for routine laboratory tests are produced by deploying semi-automated methods. In this method, a blank piece is cut from cylinder by gas cutting operation (see Fig.3). The cut blank is straightened using cold pressing operation. The straight blank is then placed in a blanking press and tensile sample is punched by blanking operation. The specimen is then finished by filing operation. This method is quick and uniform samples can be produced with least sample preparation cycle time. This method can be deployed where huge numbers of samples are required to prepare in less time. However, this method is best for a single type of sample instead of variety of sizes, as it requires different sizes of blanking dies.

Impact of mechanical operations on sample

Manual preparation does not attract any stresses in cylinder cutting with drilling operation. However, the drilling operation should be coupled with coolant water circulation system to remove heat generated during cutting process [7]. Chiselling and cold pressing operations increase work hardening or strain hardening in metal [17]. Further, finishing operation that involves manual filing operations, can lead irregular parallel lengths of tensile specimen. This irregular parallels length leads sample failure at least cross section areas within the parallel lengths [17].

In a semi-automated process, the gas cutting operation leads excessive heating of cutting zone and results heat affected zones at edges of the cut piece [1][16]. Further, blanking operations causes strain hardening or work hardening at edges of parallel lengths in test specimen [15]. Also, the blanking process causes minor variation in cross section at the edges of the specimen due to shear forces of blanking dies [15]. Specimens finished with manual filing at the end leads irregular parallel lengths, similar to manual preparation process.

DISCUSSION

Although test methods adopted are same for tensile testing, different sample preparation process affects the end results. Strain or work hardening of sample during cold flattening and chiselling operations in manual sample preparation process, increases the resistance of specimen against failure at a given load condition and thus it reflects higher values of yield and tensile strength of test specimen [17]. Maintaining dimensional accuracy (parallel length) between gauge lengths of specimen's is important for a tensile test [6]. Any variation in parallel lengths leads irregular cross section of specimen and there is a change in area of cross section of the specimen at that point. In Such cases, specimen tends to fail at least cross section area in this parallel length, if the specimen preparation is defective due to filing process. As a result of this effect, actual yield strength and tensile strength values reflects lower than the actual values of the metal under test [17].

Similarly in a semi-automated process, the gas cutting operation changes the metal properties at heat affected zone especially near the edges of blank [16]. It is observed that the hardness at the heat effected zone increases [16] compared to the non-heated effected zone. This phenomenon also increases tensile strength and yield strength as these two values are proportional [3][9][11][12][13] to each other. Further, in blanking operations, due to shear force, the specimen cross section reduces near the edge [15] as shown in figure.4. This reduction cannot be measured with a vernier callipers or a screw gauge, while calculating the area of cross section for tensile strength or yield stress calculation. Thus, the sample exhibits lesser yield strength and tensile strength than the actual value [17]. Considering these effects, the sample preparation is having an important role in tensile testing of parent metal.

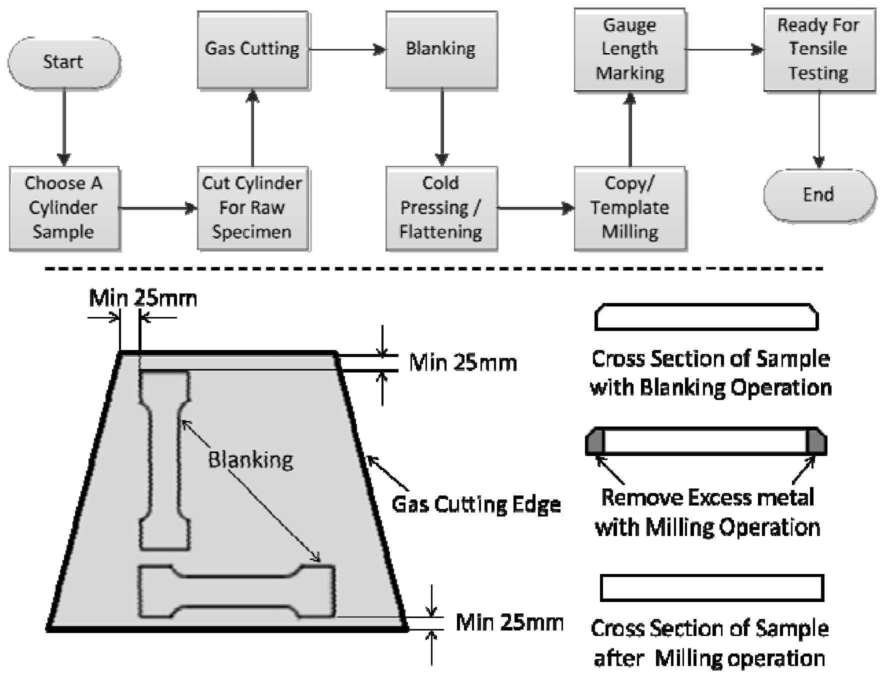


Fig.4: Proposed method for tensile sample preparation

It is necessary to strike a balance between the accuracy of sample preparation and the sample preparation cycle time in cylinder manufacturing plants. In order to do so, it is suggested to follow the process described in Figure. 4 for sample preparation. From the literature, it is evident that the heat effected zones during gas cutting operation affects up to 25mm distance from its edge [16]. Hence, while blanking a specimen from the cut portion of cylinder, the specimen should be cut in such a way that it is at is positioned at least 25 mm away from the edge of the gas cut blank. Also, specimen blanking die should be designed in such a way that the width between the parallel lengths of the semi-finished specimen should at least increase two times of the specimen thickness at the time of blanking (see Fig.4). Milling or copy milling operation should be performed on test specimen for finishing instead of manual filing. This ensures perfect parallel lengths and at the same time eliminates work hardening and straining hardening zones in the specimen while preparation [17]. Always ensure the heat generation from milling operation is removed with proper coolant while finishing the test specimen. Cold flattening of blank before preparation can lead strain hardening of sample and increases its fracture resistance [17]. This could be one of the reasons for increased longitudinal sample test results over circumferential sample test results [18]. As per American Standard (DOT), for a domestic cylinder testing, only circumferential sample testing is sufficient for accepting a batch and there is no need to test the longitudinal sample for passing a cylinder batch [4]. Cold flattening of cut blank is not avoidable due to the shape of the cylinder. However; if a small specimen can be selected such as 12.5 mm width sample (Fig.4) [8] for laboratory tests, this cold flattening operation can be avoided totally and sufficient space is available to prepare tensile sample from domestic LPG cylinder.

CONCLUSIONS

It is evident from literature that sample preparation method affects tensile test results. Accuracy and cycle time are the two important things to be kept in mind while preparing tensile samples for routine laboratory tests in cylinder manufacturing locations. A feasible solution was discussed for this issue and suggested a new method of sample preparation with appropriate justifications. Also, it is suggested to go for a lower sample size specified in IS 3196 part 3 for routine laboratory tests to avoid strain hardening of metal due to cold pressing operation involved in existing sample preparation method.

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Review Article

REVIEW ON LIQUEFIED PETROLEUM GAS CYLINDER ACCEPTANCE TEST AS PER INDIAN STANDARD, IS 3196 (PART 3):2012

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ABSTRACT:

Domestic Liquefied Petroleum Gas Cylinders in India are manufactured and tested as per Indian Standard, *Welded low carbon steel cylinders exceeding 5 liter water capacity for low pressure liquefiable gases (IS 3196),* before they get certified by Bureau of Indian standards for usage. Acceptance test is one of the important tests conducted on a random cylinder sample to determine the material properties and to ensure they are confirming to IS 3196. Two tensile specimens are drawn, one in longitudinal and the other in circumferential direction from a sample cylinder for testing. The test results are verified with standard requirements for accepting a batch for Bureau of Indian Standards certification and market use. In this research, experimental data related to 55 domestic LPG cylinders was collected from an approved laboratory and analysed longitudinal and circumferential tensile test results. It was observed that the circumferential samples exhibits lower tensile and yield strength values than the longitudinal tensile specimen at all times. However, the percentage elongation for a circumferential sample is higher than the longitudinal sample. The relation between longitudinal and circumferential sample in terms of ratio was established and proposed to eliminate longitudinal sample testing in acceptance test by increasing the percentage elongation value from 25% to 27%.

KEYWORDS: Liquefied Petroleum Gas Cylinders, Acceptance testing, Domestic LPG Cylinder testing, IS 3196, Longitudinal and Circumferential tensile test.

INTRODUCTION

India is the third largest consumer of Liquefied Petroleum Gas (also known as LPG or LP Gas) in domestic sector in the world after china and USA [1]. Approximately 3 million LP Gas Cylinders are delivered to Indian homes every day [1]. LPG Cylinders in India are produced as per Indian standard, *Welded low carbon steel cylinders exceeding 5 liter water capacity for low pressure liquefiable gases,* IS 3196 (part 1):2006 [2]. The domestic cylinders supplied by state owned oil companies are usually referred as 33.3 litres water capacity cylinders. These cylinders are fabricated in two piece bodies as shown in **Fig** 1.

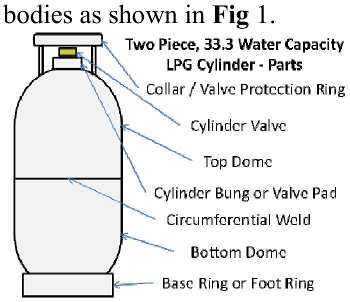

Fig.1 Parts of Cylinder

LPG cylinders are produced in batches and one random cylinder out 202 cylinder batch undergoes this acceptance test for material quality verification as per Indian standard IS 3196 (part 3): 2012 [3]. Acceptance test is a destructive tests conducted on a random LPG cylinder sample for accepting and certifying a cylinder batch at manufacturer premises. This test reveals all critical material parameters such as Yield Strength (YS), Tensile Strength (TS) and Percentage Elongation (PE) of cylinder material [3]. The yield strength and tensile strength is also referred as yield stress or tensile stress. In order to measure the critical parameters, two tensile specimens are carefully drawn from a sample cylinder, one in circumferential (also referred as transverse) direction and the other in longitudinal direction as shown in Fig.2 for acceptance test. Incase sufficient length is not available for tensile sample preparation, an alternate specimen can be drwn from bottom dome of the cylinder as shown in the same Fig. 2 for testing purpose [3].

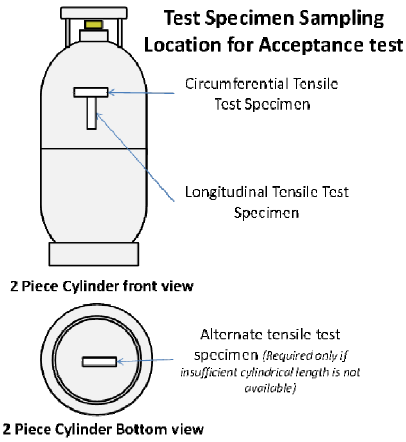

Fig. 2: Sampling location in Two Piece cylinders

However, in practice no cylinder manufacturer prepares a sample from this portion due to limitation of space for cutting a sample. Once longitudinal and circumferential tensile test specimens are prepared, they are subjected to tensile test on a universal testing machine to determine yield strength, tensile strength and percentage elongation in both curcumferential and longitudianl directions as shown in Fig. 3 and ensured that the results are complied to the requirements in standards as per table 1[2],[3],[4].

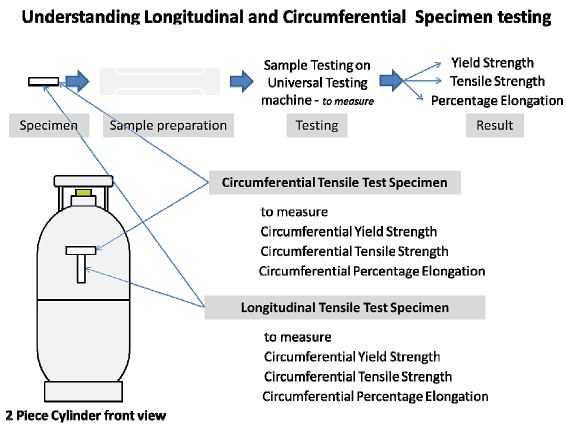

Fig. 3: Sampling location in a two piece cylinders

These values are determined based on design specifications of cylinder mentioned in IS 3196 for domestic two piece LPG Cylinder [2]. Table.1 also provides cross reference to these specifications from interlinked Indian national standards. Either IS 3196 or IS 6240 (i.e. *Hot rolled steel plate (upto 6mm) sheet and strip for the manufacture of low pressure liquefiable gas cylinders*) doesnot specify separate values for critical parameters of longitudinal and circumferential specimens. However, both sample should meet the minimum requirements mentioned in IS 6240, for acceptance [2]. Although the samples are drwan from same cylinder, material properties slightly differ in these two specimens as they were drawn in perpindicular directions to each other. The specimen having lower critical values determines the acceptance of cylinder batch out of these two specimens as the values are not explecitly defined for longitudinal and circumferential samples. An attempt has been made in this paper to compare longitudinal and circumferential tensile test samples with an aim to check the relation among these samples.

MATERIALS AND METHODS

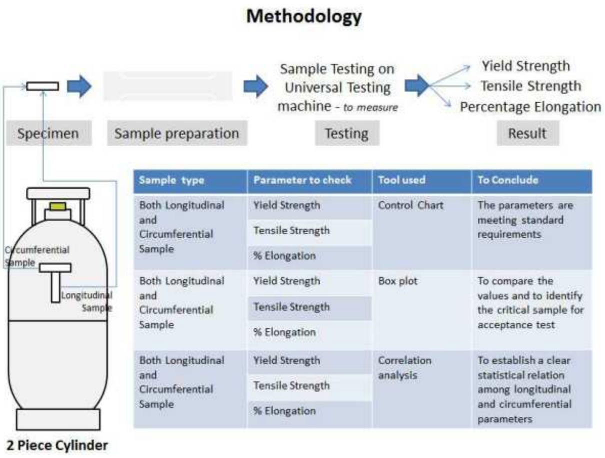

Fig. 4: Methodology adopted for data analysis

Two pieces domestic LPG Cylinder sampling method and the sampling location for tensile test specimen were given in IS 3196 Part3: 2012[3]. To accept a batch and get certification from Bureau of Indian Standards, the sample needs to be prepared as per this standard [3]. BIS approves certain laboratories for sample testing including the cylinder manufacturer's own test facility. All cylinder manufacturers test laboratories, tests one cylinder for every 202 cylinder batch produced in their manufacturing unit as per Indian standard IS 3196[3]. In addition to that few independent test laboratories are approved to test LPG cylinders for their quality conformance. Experimental data of 55 domestic two piece LPG cylinders were collected from one of such independent central government based organisation having both Bureau of Indian Standards (BIS) recognition and National accreditation board (NABL) accredited for LPG Cylinder testing in India.

The experimental data was collected from domestic LPG cylinder (33.3 litres capacity) samples designed and manufactured as per IS 3196 (part 1):2006 from various BIS approevd cylinder manufacturers in India. Prior testing in this independent laboratory, All these cylinders were tested under controlled conditions as per IS 3196 (part 3):2012 at individual cylinder manufacturer premises and got approval from Bureau of Indian standards for their material quality confirmance as per standard.

The data analysis was carried out using Minitab16; Microsoft windows based statistical software application. Control charts were drawn for all critical parameters to ensure data is meeting the requirements of table.1 and valid for analysis purpose. Further, box plots were drawn to compare longitudinal and circumferential test results. Also, correlation analysis was carried out to establish a statistical relation among yield strength, tensile strength and percentage elongation of longitudinal and circumferential test results.

Table 1: Acceptance test limits to pass a sample

Parameter	Requirements as per IS 3196 Part1: 2006 for acceptance test	Reference Clauses in Indian Standards
Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
Yield Strength (YS)	240 MPa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
Percentage Elongation (PE)	25%	Clause 4.1.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008

RESULTS

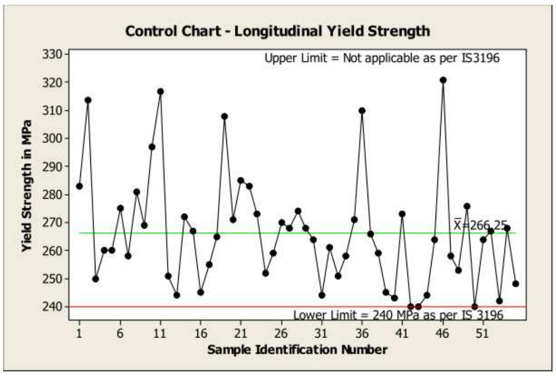

Fig.5 : Yield strength values of Longitudinal Samples

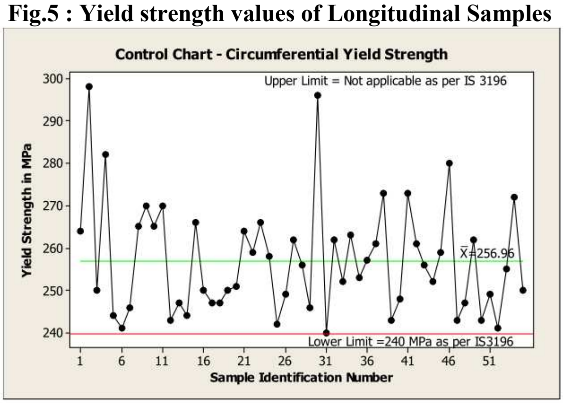

Fig.6 : Yield strength values of Circumferential Samples

Control charts (see Fig. 5 and Fig.6) indicates that all longitudinal and circumferential sample test values are either 240 MPa or above value and are meeting the minimum requirement to pass the criteria mention in that table 1 for yield strength. There is no upper limit mentioned in IS 3196 for yield strength thus all 55 samples are considered as valid pass samples for analysis.

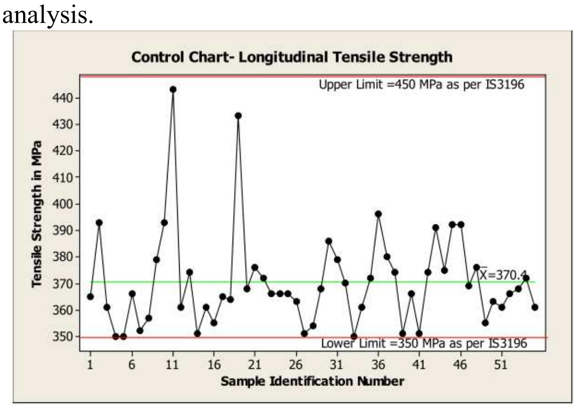

Fig.7 : Tensile Strength values of Longitudianl Samples

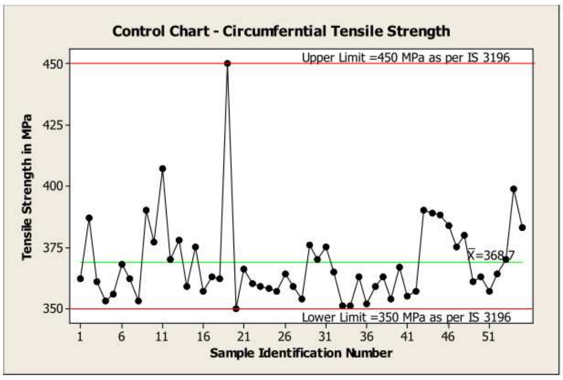

Fig.8 : Tensile Strength values of Circumferential Samples

Also, Control charts (see Fig.7 and Fig.8) indicate that all longitudinal and circumferential sample test values are lying between 350 MPa and 450 MPa. It means that they meet the desired requirement to pass the criteria mention in that table 1 for tensile strength and all 55 samples are considered as valid pass samples as per IS 3196.

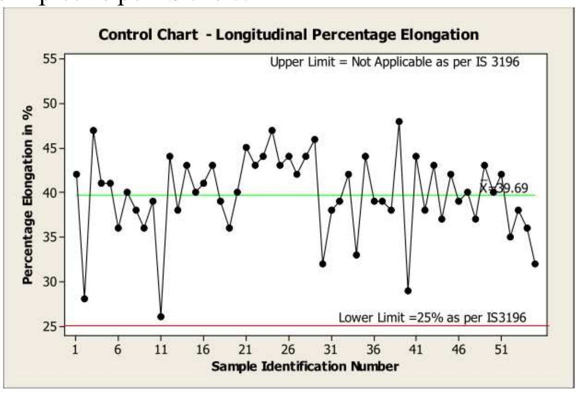

Fig.9 : Percentage elongation values of Longitudianl Samples

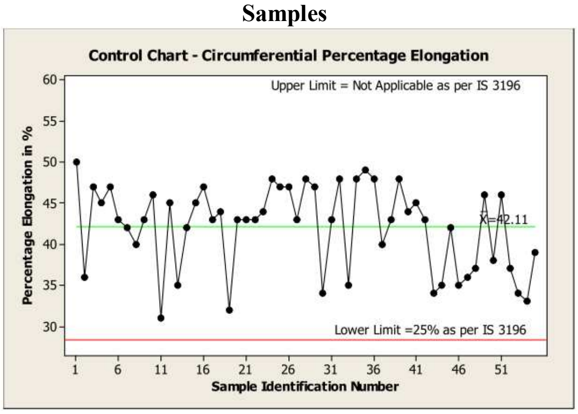

Fig.10 : Percentage Elongation values of Circumferential Samples

Similarly, Control charts (see Fig. 9 and Fig.10) indicates that all longitudinal and circumferential sample percentage elongation values are either 25% or above and are meeting the desired requirement to pass the criteria mention in that table 1 for percentage elongation and all 55 samples are considered as valid pass samples for the analysis purpose.

It is established that the data is valid for analysis through control charts. Now, To compare Longitudinal and circumferential specimen values of yield strength, tensile strength and percentage elongation, correlation study was carried out on the sample data. Further, separate box plots were generated to establish the relation among these variables.

The correlation study revealed a supportive relation between longitudinal and circumferential tensile strength with a Pearson correlation value of 0.759. The positive value indicates that the circumferential and longitudinal tensile results are directly proportional. Further, the Pearson correlation coefficients for Yield strength and percentage elongation are 0.470 and 0.541 respectively. These values also indicate that the parameters of Longitudinal and circumferential results are directly proportional. The Pearson correlation values for percentage elongation and yield strength are low mainly because, the yield strength and percentage elongation has to calculate manually during the test.

It is evident that tensile specimen drawn from deep drawn steel shells will not exhibit definite yield point in tensile test and hence IS3196 (Part 3) states a method to estimate the yield strength.

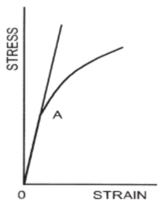

Fig.11: Determination of Yield Strength or Yield Stress

According to this, a straight line shall be drawn on the stress strain curve as shown in fig.11 and take the yield stress or strength at the point ‘A’ from where the curve starts deflecting from straight line, In case yield point is not clear.

The standard also states, testing person should take care while placing the broken parts of the test piece while determining the elongation. There is always a chance exist for minor manual error, while calculating both yield strength and percentage elongation. As a result, lower values of Pearson’s correlation coefficients are justified, although both samples are drawn from same test cylinder. To know the relation in a pictorial form for comparison purpose, separate box plots were generated for yield strength, tensile strength and percentage elongation.

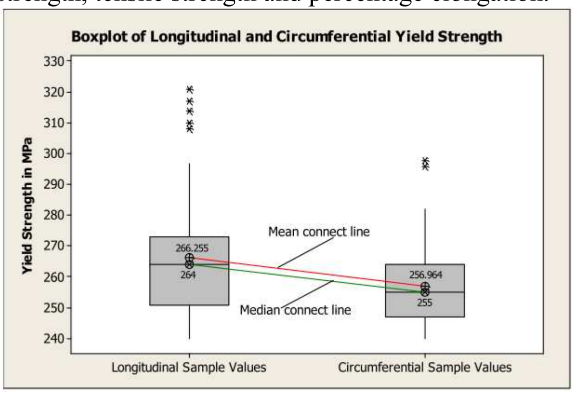

Fig.12: Comparison of Longitudinal and circumferential Yield strength values

Box plot (See Fig.12) compares both yield strength values of longitudinal and circumferential test results. Referring to the mean and median values in the plot, it is clearly evident from Fig.12 that the yield strength of a cylinder in circumferential direction is lesser than the yield strength in longitudinal direction of a cylinder. It indicates, if the circumferential specimen test values of any cylinder meets the required yield strength criteria mentioned in Table 1, longitudinal specimen test values will either at least meet or above the specifications mentioned in Table1.

Referring to Fig.12, it is observed that there are 5 out layers in longitudinal and 2 out layers circumferential test values. Although these are outlays in box plot, all these samples are meeting minimum required criteria as per the table 1 and is confirmed in Fig.5 and Fig.6. Due to manual intervention during testing occurrence of such out layers are possible and are justified with control charts.

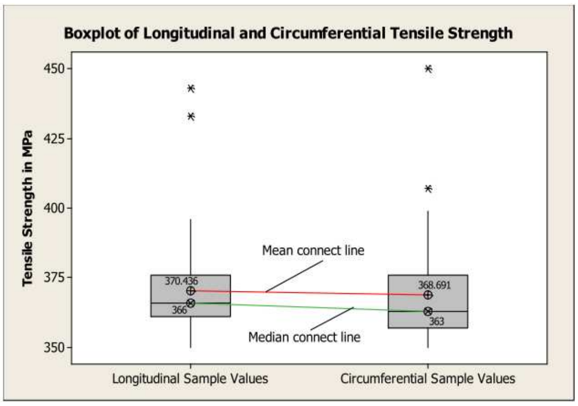

Fig.13: Comparison of Longitudinal and circumferential Tensile strength values

Fig.13 is a box plot that compares both Tensile strength test results of longitudinal and circumferential specimens. Referring to the mean and median values in fig.13, it is clearly evident that the tensile strength of a cylinder in circumferential direction is lesser than the tensile strength in longitudinal direction. It means, if the circumferential specimen meets the required tensile strength criteria mentioned in table 1, longitudinal sample values will either meet or above the specifications for any cylinder.

In the above box plot, there are 2 out layers observed in each longitudinal and circumferential specimen respectively. Although the tensile strength is calculated automatically by the machine, occurrences of out layers are possible due to minor variation in tensile sample preparation. However the control charts indicates these samples are valid and meet the standard requirements.

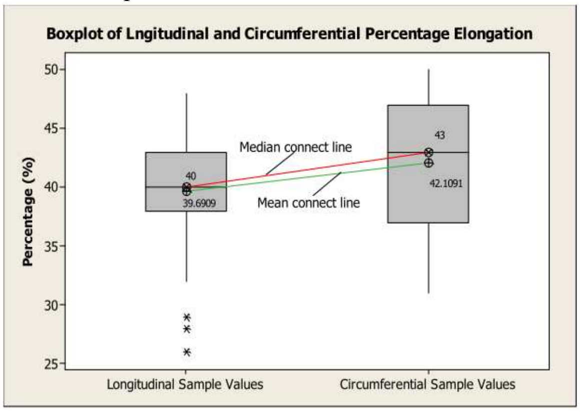

Fig.14: Comparison of Longitudinal and circumferential Percentage Elongation values

Fig.14 is a box plot that compares both percentage elongation values of longitudinal and circumferential specimen. Referring to the mean and median values in the plot, it is clearly evident from the box plot that the percentage elongation of a cylinder in longitudinal direction is lesser than the percentage elongation in circumferential direction. It means, if the longitudinal specimen meets the required percentage elongation criteria mentioned in table 1, circumferential sample values will either meet or exceed the specifications.

In the Fig. 14, there are 3 out layers observed in longitudinal specimens. Although there are certain outlays in box plot, all the 55 samples are meeting minimum required criteria as per the table 1 and as per the control charts (See Fig.9 and Fig.10).

DISCUSSION:

From the experimental data analysis, it is evident that the tensile and yield strength results are always lower in circumferential specimen. Whereas the percentage elongation is lower in longitudinal specimen. I.e. If circumferential sample complies to yield and tensile strength requirements, longitudinal sample will obviously complies tensile and yield strength requirements of material. However circumferential sample percentage elongation alone may not satisfy standards requirements at all times.

Under standard manufacturing conditions, If the percentage elongation of longitudinal sample can be estimated with circumferential sample, Testing of longitudinal sample can be eliminated in acceptance testing of LPG Cylinder. An attempt has been made in this work to develop a relation among these two parameters Individual data plots were drawn (see Fig.15) to the longitudinal and circumferential percentage elongation values and calculated mean and median values.

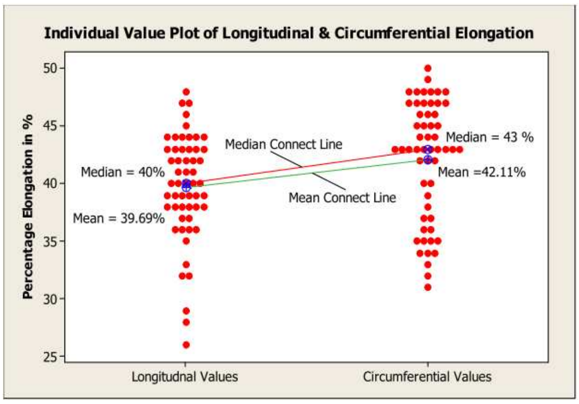

Fig.15: Comparison of longitudinal and circumferential Percentage Elongation values

From this, the mean value of longitudinal percentage elongation is 1.061 times of circumferential percentage elongation. That means, if the percentage elongation for longitudinal sample is 25% the circumferential percentage elongation could be 26.525%. It can be treated as 27% as per Indian standard IS3196 part 3 due to practical limitations and manual calculations. IS 3196 states that the elongation after fracture shall be expressed to the nearest one percentage. If the percentage elongation limit for acceptance test in standard IS 3196 part 3 can be increased from the existing 25 % [2] to 27%, only one circumferential test specimen testing is sufficient to determine the material parameters as per the standards and thus the testing time and efforts can be reduced drastically (up to 50%). This can be justified with United States, Department of transportation guidelines for 4BA welded cylinders testing. The US standard specifies tensile test in circumferential direction only to determine the yield strength and Tensile strength. The elongation requirements as per DOT standard varies with varied gauge lengths[5]. Thus, by increasing the percentage elongation specification in standard from 25% to 27%, longitudinal sample testing can be eliminated in acceptance test of LPG Cylinder while certifying LPG Cylinder.

ACKNOWLEDGEMENTS

The authors wish to thanks all officers and staff in LPG Equipment Research Centre, Bangalore for their technical help and material support.

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Research Paper

COMPARATIVE ANALYSIS OF LPG CYLINDER HARDNESS VALUES OBTAINED FROM BRINELL HARDNESS TEST AND PORTABLE HARDNESS TESTER

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ABSTRACT:

Liquefied Petroleum Gas (LPG) cylinders are designed and tested as per Indian standard IS 3196. Several tests need to be conducted on LPG Cylinder in manufacturing location for Bureau of Indian standards (BIS) certification. Among these tests, acceptance tests are intended to know the material critical parameters like yield stress, percentage elongation and tensile strength. Few experiments were conducted in this work to measure hardness of LPG cylinder material using both Brinell hardness testing machine and a non-destructive portable digital hardness tester (Yammayo Bliss TH 270). An attempt has been made in this paper to compare these test results with an aim to differentiate hardness values obtained from these test methods on LPG Cylinder material.

KEYWORDS: Liquefied Petroleum Gas Cylinders, LPG Cylinder hardness testing, Micro-hardness of LPG Cylinders, Surface hardness of LPG Cylinders.

INTRODUCTION

Liquefied Petroleum Gas (also known as LPG or LP Gas) Cylinders in India are produced and tested as per Indian standard, *IS 3196* [7]&[8]. These cylinders are produced from low carbon steel with a composition specified in Indian Standard IS 6240 or equivalent [6]. All these LPG cylinders are tested and certified by Bureau of Indian standards for market use [8]. Sample cylinders need to undergo several tests as per Indian standards IS 3196 Part3:2012 and comply all the requirements mentioned in the standard as a part of certification process [8]. Among these tests, acceptance tests are aimed to check material critical parameters like tensile strength, yield stress and percentage elongation. Several studies were carried out on steel to establish relation among hardness, tensile strength and yield stress [2],[9]&[12]. However as per the current Indian standard IS 3196 Part3: 2012 [8], there is no clause for hardness test on LPG Cylinder. Keeping in view of the established research [2],[9]&[12], if LPG cylinder hardness is known, the critical parameters like tensile strength and yield stress can be estimated without destroying the cylinders for acceptance testing. Thus an attempt has been made in this work to measure cylinder hardness using two different methods and compared the results for meaningful conclusions.

MATERIALS AND METHODS

Material - LPG Cylinder Samples

Domestic LPG Cylinders of 33.3 liter capacity were selected for experimental analysis. These cylinders are produced from low carbon steel specified in Table.1 [6]&[7] and are heat treated to ensure that the finished cylinder parent metal is meeting specifications mentioned in Table.2 [6]. Fifty five such domestic cylinders are tested to measure their hardness

Table.1 LPG Cylinder Raw Material chemical Composition

Constituent	Unit %	Permissible Variation Over max and under min. specified limit in %
Carbon (C)	0.16 max	0.02%
Silicon (Si)	0.25 max	0.03%
Manganese (Mn)	0.30 min	0.03%
Phosphorous (P)	0.025 max	0.005%
Sulphur (S)	0.025 max	0.005%
Aluminium (Al)	0.020 min	--
Nitrogen (N)	0.009 max	--

Table.2 LPG Cylinder Material Specifications

Mechanical Properties			
Tensile strength MPa	Yield Stress MPa	Percentage Elongation	Internal diameter of bend
Between	*Minimum*	*Minimum*	*Maximum*
350-450	240	25	t
Note: where 't' is the thickness of test piece			

Method

50mm square sample was cut from the body (see Fig.1) of a finished LPG cylinder and removed paint for hardness test. 55 numbers of such LPG cylinder samples were tested on Brinell hardness testing machine and Yammayo make Digital NDT hardness tester for obtaining Hardness values of cylinder material. All these experiments were carried out in a National Accredited Board of Laboratories (NABL) certified laboratory for accuracy and reliability of tests. The BHN values obtained from both these experimental methods were analysed using Minitab 16, a Microsoft windows based statistical software. Box plots and individual plots were generated based on test results and analysed.

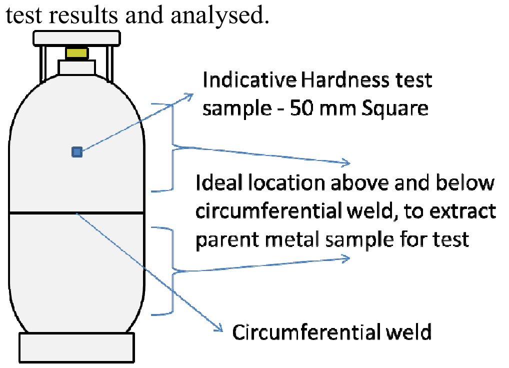

Fig.1 Hardness test sample from a domestic LPG Cylinder

Brinell Hardness Tester

Fig.2: SAROJ Make Brinell's Hardness Testing Machine [13]

Destructive test was carried out on LPG Cylinder samples using a Saroj make, B 3000 H model, Brinell hardness tester (See Fig.2) with 10mm dia ball to measuring hardness. The indentation was measured with Brinell microscope and obtained the Brinell hardness number (BHN) from standard tables. It is ensured that the machine is having a valid calibration status from an NABL accredited laboratory at the time of testing.

Portable Digital NDT hardness tester

Non-destructive test was carried out on LPG Samples using Yammayo make, Bliss TH 270 model, digital NDT portable hardness tester (See Fig.3). The tester is supplied with standard test block for verification purpose. This hand held equipment is having an option of measuring the hardness directly in terms of Brinell hardness number (BHN) and can be read on digital display instantaneously at the time of testing. The tester was verified with standard test block before carrying out each test to ensure that there is no error. Each sample was tested at 8 places and average BHN of these eight readings was considered for reporting purpose. All 55 cylinder samples were tested in similar way.

Fig.3: YAMMAYO make Portable Digital NDT Hardness tester [14]

RESULTS

Destructive and non-destructive test results of LPG cylinder were analysed using Minitab16 software.

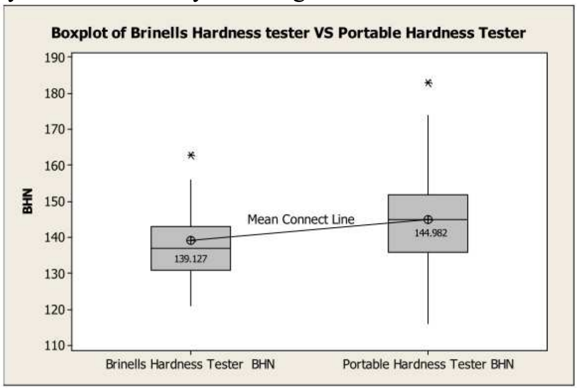

Fig.4: Box plot of Destructive and Non-destructive test results

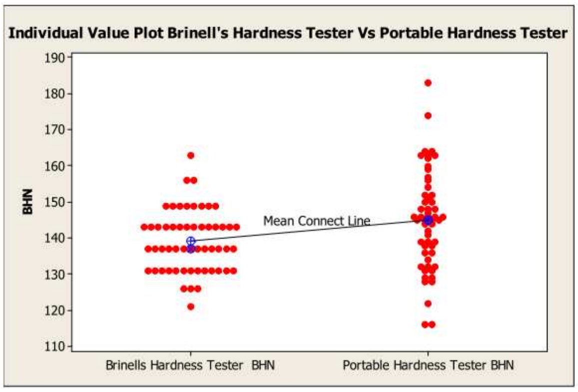

Fig.5: Individual plots of Destructive and Non-destructive test results DISCUSSION

Box plots (Fig.4) and individual plots (Fig.5) were drawn and are shown here. From the box plot it is evident that the BHN values from portable digital NDT based hardness tester is higher competed to conventional Brinell hardness tester. Further, from the individual plot (Fig.5), it is evident that the values of portable hardness tester are scattered compared to the conventional Brinell hardness methods.

It is evident from the plots that the hardness obtained from portable hardness tester is higher than the conventional Brinell's method. This is mainly due to strain hardening of surface during manufacturing process. All cylinders during manufacturing should undergo either shot blasting or grit blasting operations before they get painted [15]. This shot blasting or grit blasting will increase the surface hardness of cylinder material and it will be in the order of 4.21% of BHN value from the experimental results. Portable hardness testers can only verify the surface hardness due to the inherent features and hence it will not reflect the true hardness of the material. The portable harness always shows approximately 4.21% higher BHN value than the actual material hardness. Further, the test repeatability in portable hardness tester is purely based on skills of the testing person, sample preparation and sample placement for measurement. Hence, sufficient care should be taken and follow all manufacturers recommendations while measuring hardness values using NDT methods.

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The authors wish to thanks all officers and staff in LPG Equipment Research Centre, Bangalore for their technical help and material support.

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Research Paper

STUDY ON CORRELATIONS AMONG VARIOUS CRITICAL PARAMETERS OF LPG CYLINDER MATERIAL

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ABSTRACT

Liquefied Petroleum Gas (LPG) cylinders in India are designed, manufactured, tested and certified as per Indian Standard, IS 3196. These cylinders undergo various tests to get mandatory Bureau of Indian standards (BIS) certification for use in market. Acceptance and hydro-tests are two important destructive tests on newly manufactured cylinder lot to know various critical parameters of LPG Cylinder material viz. yield strength, tensile strength percentage elongation, nominal hoop stresses, burst pressure and volumetric expansion. All these critical parameters are related and correlations can be established among these parameters. An attempt has been made in this paper to study 40 domestic LPG cylinders acceptance and hydro-test data to establish correlations among these critical parameters and observed meaningful relations can be established among these variables. However, few factors like raw material selection, heat treatment process parameters, cylinder manufacturing methods, welding process parameters, sample preparation methods can affect the end results of these critical parameters.

KEYWORDS: Acceptance test sample, Hydro-testing of LPG Cylinder, LPG Cylinder material, interrelations of critical components

INTRODUCTION

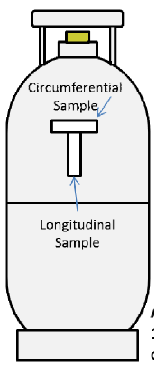
Indian standard IS 3196 part 3 specifies various tests to be conducted on finished Liquefied Petroleum Gas (LPG) cylinders in a manufacturing location to get certification from Bureau of Indian Standards [2][3]. There tests include both destructive and non-destructive tests. Among the non-destructive tests, acceptance test and hydro-test are the important tests to be conducted on every cylinder batch produced in a manufacturing location [2][3]. These tests reveal critical properties of cylinder as a whole and cylinder material. One sample cylinder out of every 203 cylinders produced in a manufacturing location is subjected to acceptance test [2][3]. For the acceptance test, two tensile specimens are cut from cylinder body one in longitudinal and the other in transverse or circumferential direction to check material physical properties viz. Circumferential Tensile Strength (CTS), Longitudinal Tensile Strength (LTS), Circumferential Yield strength (CYS), Longitudinal Yield Strength (LYS), Circumferential Percentage Elongation (CPE) and Longitudinal Percentage Elongation (LPE)[2]. The values of these tests should complying standard requirements shown in Fig.1[1][2][3]. Similarly, one cylinder out of 403 cylinder batch is subjected for hydro-tests in which volumetric expansion (VE), burst pressure (BP) and nominal hoop stresses (NHS) of cylinder are revealed [3]. IS-3196 states specifications for these parameters and are given in Fig.1. These acceptance and hydro-tests contributes significant role in cylinder batch acceptance in a production unit. Thus, the parameters viz. CYS, CTS, CPE, LTS, LYS, LPE, BP, VE and NHS are the critical parameters in new LPG cylinder testing process [5][7][9].

An attempt has been made in this paper to check the relations among these parameters with experimental results and established various correlations among these parameters. Also an attempt has been made to justify the weak relations among some of these critical parameters with appropriate justifications.

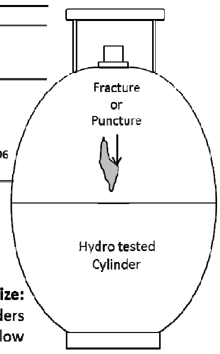
Critical parameters and their requirements of Acceptance and Hydro tests of LPG Cylinders

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Acceptance Test	Tensile Strength (TS)	350MPa to 450 MPa	Clause 4.1 of IS 3196 Part1: 2006 and Table 3 of IS6240:2008
	Yield Strength (YS)	240 Mpa	Clause 4.1 of IS 3196 Part1: 2006 Table 3 of IS6240:2008
	Percentage Elongation (PE)	25%	Clause 4.1.1 of S 3196 Part1: 2006 Table 3 of IS6240:2008

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Hydro-test	Burst Pressure	Minimum 54.92 bar	Clause 9.1.2 of IS 3196 Part3: 2012
	Nominal Hoop stress	Minimum 332.5 MPa	Clause 17.3.3 of IS 3196 Part1: 2006
	Volumetric Expansion	≥ 20% (for Tensile strength ≤410 MPa)	Clause 17.3.3.e of IS 3196 Part1: 2006



Acceptance test sample Size: 1 cylinder out of 203 cylinders or below



Hydro-test Sample Size: 1 cylinder out of 403 cylinders or below

Fig.1: Critical parameters of LPG Cylinder Material

LPG CYLINDER TESTING

Acceptance test

One random sample out of 203 or below new cylinder batch produced in a manufacturing location should undergo this test [3]. Two tensile samples one in longitudinal direction and the other in circumferential direction are carefully cut from cylinder and tested on a universal testing machine to get LYS, LTS, LPE, CYS, CTS and CPE [2]. These results are verified against standard values and decide whether the batch to be accepted or rejected [2][3].

Hydro-test

One random sample out of 403 or below new cylinder batch produced in a manufacturing location should undergo this test [3]. The cylinder is subjected to hydrostatic test pressure and checked for permanent volumetric expansion (VE) of cylinder under test pressure conditions. Further the same cylinder is subjected to hydrostatic internal pressures till it bursts and records the burst pressure (BP). Based on the burst pressure, calculated thickness, and cylinder diameter, Nominal hoop stresses (NHS) are calculated at burst pressure conditions. The values of VE, BP and NHS are checked against standard values to decide whether to accept the cylinder batch or not [3].

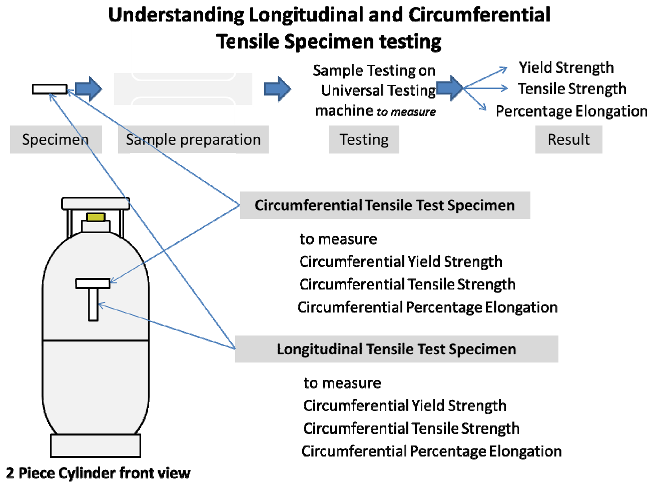


Fig.2 Acceptance test of LPG Cylinders

METHODOLOGY

Data Collection

Domestic LPG Cylinders of 33.3 litre water capacity are selected for to check the correlations among the critical parameters of cylinder material. These cylinders are most common type of cylinders in India and are constructed in two piece construction [6]. 40 such random cylinders Acceptance and hydro test data from Bureau of Indian Standards (BIS) approved and National Accreditation Board of Laboratories (NABL) accredited laboratory is collected for analysis. These cylinders are manufactured from several manufacturers in India and are tested and certified as per IS 3196. For correlations study purpose, Hydro-test and acceptance test samples are selected in such a way that both the samples are manufactured from same manufacturer with same batch number, manufacturing date.

Analysis and Results

Minitab16, Microsoft windows based a statistical analysis software is used for analysis purpose. Acceptance and hydro-test results are tabulated in terms of CTS, CYS, CPE, LTS, LYS, LPE, BP, VE and NHS and validated the data using control charts. All possible pairs among the identified parameters are listed in the Table.1.

Table.1: Various combinations of LPG Cylinder material

Bottom and top half shows possible combinations for correlation and trend analysis									
	LTS	LYS	LPE	CTS	CYS	CPE	VE	BP	NHS
LTS		LTS vs. LYS	LTS vs. LPE	LTS vs. CTS	LTS vs. CYS	LTS vs. CPE	LTS vs. VE	LTS vs. BP	LTS vs. NHS
LYS	LTS vs. LYS		LYS vs. LPE	LYS vs. CTS	LYS vs. CYS	LYS vs. CPE	LYS vs. VE	LYS vs. BP	LYS vs. NHS
LPE	LTS vs. LPE	LYS vs. LPE		LPE vs. CTS	LPE vs. CYS	LPE vs. CPE	LPE vs. VE	LPE vs. BP	LPE vs. NHS
CTS	LTS vs. CTS	LYS vs. CTS	LPE vs. CTS		CTS vs. CYS	CTS vs. CPE	CTS vs. VE	CTS vs. BP	CTS vs. NHS
CYS	LTS vs. CYS	LYS vs. CYS	LPE vs. CYS	CTS vs. CYS		CYS vs. CPE	CYS vs. VE	CYS vs. BP	CYS vs. NHS
CPE	LTS vs. CPE	LYS vs. CPE	LPE vs. CPE	CTS vs. CPE	CYS vs. CPE		CPE vs. VE	CPE vs. BP	CPE vs. NHS
VE	LTS vs. VE	LYS vs. VE	LPE vs. VE	CTS vs. VE	CYS vs. VE	CPE vs. VE		VE vs. BP	VE vs. NHS
BP	LTS vs. BP	LYS vs. BP	LPE vs. BP	CTS vs. BP	CYS vs. BP	CPE vs. BP	VE vs. BP		BP vs. NHS
NHS	LTS vs. NHS	LYS vs. NHS	LPE vs. NHS	CTS vs. NHS	CYS vs. NHS	CPE vs. NHS	VE vs. NHS	BP vs. NHS	

Table.2: Pearson Correlation Constants and Trend Analysis

Bottom half refers correlation constants and top half refers trends between two parameters identified parameters									
	LTS	LYS	LPE	CTS	CYS	CPE	VE	BP	NHS
LTS		+ve Trend	-ve Trend	+ve Trend	+ve Trend	-ve Trend	-ve Trend	-ve Trend	-ve Trend
LYS	0.559		-ve Trend	+ve Trend	+ve Trend	-ve Trend	-ve Trend	-ve Trend	-ve Trend
LPE	-0.491	-0.232		-ve Trend	-ve Trend	+ve Trend	+ve Trend	-ve Trend	-ve Trend
CTS	0.76	0.32	-0.434		+ve Trend	-ve Trend	+ve Trend	+ve Trend	+ve Trend
CYS	0.28	0.47	-0.328	0.126		-ve Trend	-ve Trend	-ve Trend	-ve Trend
CPE	-0.503	-0.101	0.541	-0.627	-0.188		+ve Trend	+ve Trend	+ve Trend
VE	-0.093	-0.315	0.165	0.028	-0.051	0.133		+ve Trend	+ve Trend
BP	-0.049	-0.114	-0.08	0.02	-0.038	0.018	0.334		+ve Trend
NHS	-0.049	-0.114	-0.08	0.02	-0.038	0.018	0.334	1	

Pearson correlation constants were calculated among the possible relations using Minitab 16 and the values are tabulated in Table.2. Trend analysis is also carried out on each identified pair to establish trends among these parameters. These trends are reported in Table.2. Referring to the Table.2, Positive trend indicates, the slope of the trend is directly proportional and negative means, the slope of the trend is indirectly proportional. From the person correlation constants, correlations can be established among Tensile strength, Yield strength, percentage elongation, volumetric expansion, Burst pressure and nominal hoop stresses. Further the interrelations among these parameters are given in terms of directly proportional or inversely proportional in Fig.3

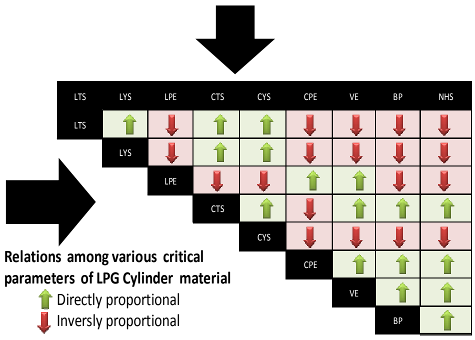


Fig.3: Relations among various critical parameters of LPG Cylinder material

DISCUSSION

Form the correlation constants, meaningful correlations can be established among tensile strength, yield strength percentage elongation, volumetric expansion burst pressure and nominal hoop stresses. However, in some pairs, the correlation constant is not really showing strong relations. This is possible because, of variety of reasons. Few possible reasons are raw material, heat treatment process parameters, welding parameters, test methods, and test setup, sample preparation etc.

From Fig. 3, LTS-LYS, LTS-CTS, LTS-CYS, LYS-CTS, LYS-CYS, LPE-CPE, LPE-VE, CTS-CYS, CTS-VE, CTS-BP, CTS-NHS, CPE-VE, CPE-BP, CPE-NHS, VE-BP, VE-NHS, BP-NHS shows relation which is directly proportion to each other. It means any one of the parameter is reported higher than typical values during the test, surely the other parameter in the pair exhibits higher values compared to the typical value. For example, referring to LTS-LYS; in a cylinder material if a longitudinal tensile strength (LTS) values is reported higher than a typical value or routinely observed value, the longitudinal yield strength (LYS) will also report higher values in parent metal testing. On the other hand, if LTS reports low LYS will also report low. This phenomenon is clearly evident in a low carbon steel stress strain curve [4].

Similarly, from Fig.3, LTS-LPE, LTS-CPE, LTS-VE, LTS-BP, LTS-NHS, LYS-LPE, LYS-CPE, LYS-VE, LYS-BP, LYS-NHS, LPE-CTS, LPE-CYS, LPE-BP, LPE-HS, CTS-CPE, CYS-CPE, CYS-VE, CYS-BP, CYS-NHS exhibits inversely proportional relation among these pair elements. That means any one in a pair is reported lower values then a typical value, the other parameter in the pair reports higher value than the typical value and vice-versa. In simple terms, in LTS-LPE relation, if longitudinal tensile strength (LTS) is reported higher than the typical values, the percentage elongation will report lower than its typical value of a cylinder material. This phenomenon can be justified again with a low carbon steel stress strain curve i.e. lower carbon steel reports, higher the tensile strength, lower the percentage elongation [4].

Form this study, it is evident that the longitudinal and circumferential samples, the yield strength and tensile strength are proportional to each other and the percentage elongating is inversely proportional to these values. Similarly the volumetric expansion, burst pressure and nominal hoop stresses are always proportional to each other. However, the Hydro-test results are proportional to elongation values of acceptance test results and inversely proportional to tensile and yield strength. It means, if the percentage elongation of a cylinder material is more than a typical value, the volumetric expansion will be report more than the typical value of a LPG cylinder. On the other hand, if the tensile strength of a cylinder material is more, the volumetric expansion will report lesser than a typical value of a cylinder. Similarly, all other correlations can be established among all possible pairs of acceptance and hydro-test results using the Table.1 and Table.2

Interestingly, in some pairs of acceptance test results, the trends exhibit contradictory relations comparative to their counterpart results of circumferential or longitudinal tests. In such cases it is advised to verify person correlation constant to check whether the results are having any correlation or just scattered apart. Such kind of contradictory relations are possible due to various factors when analysing practical test results and the this phenomenon can be attributed to various factors such raw material selection, heat treatment process parameters, cylinder manufacturing methods, welding process parameters, sample preparation methods [5][7][8][9]. Means, if the cylinders manufacturer from different raw materials sourced from different steel mills, produced different production methods, different welding processes and treated with different heat treatment process parameters[6][7][8]. It is also possible if the test methods and sample preparation methods adopted are different [9]. Considering all these conditions, the test results may be varied slightly.

CONCLUSION

It is possible to establish relation among acceptance and hydro test parameters of a cylinder material. Tensile and yield strength are in proportional to each other in both longitudinal and circumferential samples. On the other hand, percentage elongation is inversely proportional to both tensile and yield strength. The values of volumetric expansion, burst pressure and nominal hoop stress are always proportional to each other. Further these values are proportional to percentage elongation of both circumferential and longitudinal acceptance samples. However, the hydro test parameters are inversely proportional to yield and tensile strength. Although, various relations can be established among various parameters, the results may vary due to various manufacturing and testing parameters.

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Research Paper

DEVELOPMENT OF EMPIRICAL FORMULAS FOR LPG CYLINDER HYDRO TEST PARAMETERS

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ABSTRACT:

Hydro-tests are critical mandatory tests to be conducted on Liquefied Petroleum Gas Cylinders to ensuring its design and statutory compliance. Volumetric expansion, burst pressure and nominal hoop stresses are measured from hydro-tests. Indian standard IS3196 provides general guidelines to conduct these tests and also provides the compliance requirement as per statutory authorities. These tests are destructive in nature and hence this test is conducted on random sample cylinders in a manufacturing location while manufacturing new cylinders. There is no method to judge or estimate these critical parameters, once the cylinders are released to market for usage. An attempt has been made in this paper to develop empirical formulas for estimating these hydro-test parameters. 40 domestic LPG Cylinders hydro-test data was collected analysed and developed empirical relations among these critical variables. Estimated values of these critical parameters from empirical formulas are analysed with appropriate reasoning and these formulas can be used for indicative estimates.

KEYWORDS: Empirical formulas for Hydro-test , Hydro-testing of LPG Cylinder, Burst pressure of LPG Cylinder, Volumetric Expansion of LPG Cylinder, Nominal Hoop Stresses of LPG Cylinder

INTRODUCTION

One cylinder out of 403 new Liquefied Petroleum Gas (LPG) cylinder batch produced in a manufacturing location should undergo hydro-tests [2][3]. Hydro tests on LPG cylinders are typically conducted in a manufacturing location and are hydrostatic leak test, permanent volumetric expansion test, Burst pressure test and nominal hoop stresses calculation [3]. These tests reveal permanent volumetric expansion (VE) at test pressure conditions, burst pressure (BP) of a cylinder and nominal hoop stresses (NHS) of cylinder at burst pressure conditions [2]. A random new sample cylinder is subjected to internal hydro-test pressure to test pressure conditions (25kgf/cm2) and retain the pressure for not less than 30 seconds to check for any leaks [3]. Once the cylinder is ensured leaks free, internal pressure is relieved and measured the volumetric expansion of the cylinder under test pressure condition [3]. This cylinder is then subjected to continuous internal hydrostatic test pressure till it bursts [3]. The pressure at which the cylinder bursts is recorded as burst pressure. Using the burst pressure, cylinder thickness and cylinder external diameter, nominal hoop stresses are calculated at burst pressure conditions [3]. These parameters are checked against standard for their compliance. Indian standard IS 3196 provides the guidelines and the limits to these critical values. The values are given in Fig.1 for reference [1][2][3]. It is not possible to verify or check the cylinder in market for measuring cylinder burst pressure as a part of accident analysis or incident investigation due to the nature of tests (destructive tests) involved for measurement. In this paper an attempt has been made to develop empirical relations among various critical parameters of hydro-test using 40 domestic LPG cylinders hydro-test data.

Type of Test	Parameter	Requirements as per Indian Standard, IS 3196 Part1: 2006	Clause / Cross Reference
Hydro-test	Burst Pressure	Minimum 54.92 bar	Clause 9.1.2 of IS 3196 Part3: 2012
	Nominal Hoop stress	Minimum 332.5 MPa	Clause 17.3.3 of IS 3196 Part1: 2006
	Volumetric Expansion	≥ 20% (for Tensile strength ≤410 MPa)	Clause 17.3.3.e of IS 3196 Part1: 2006

Hydro-test Sample Size: 1 cylinder out of 403 cylinders or below

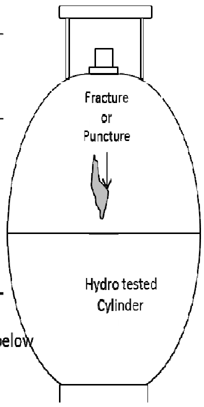

Fig.1: Hydro tests of LPG Cylinders - Critical parameters and their requirements as per Indian Standards

METHODOLOGY

Data Collection

Domestic LPG Cylinders of 33.3 litre water capacity are selected to check the correlations among the critical parameters of cylinder material. These cylinders are most common type of cylinders in India and are constructed in two piece construction [2]. 40 such random cylinders hydro test data from a Bureau of Indian Standards (BIS) approved and National Accreditation Board of Laboratories (NABL) accredited laboratories is collected for analysis purpose. These cylinders are manufactured from several manufacturers in India and are tested and certified as per IS 3196.

Analysis and Results

Minitab16, Microsoft windows based a statistical analysis software is used for analysis purpose in this study. Hydro-test results are tabulated in terms of Volumetric Expansion (VE), Burst Pressure (BP) and Nominal Hoop Stresses (NHS) and correlation study was carried out between pairs shown in Table.1. Pearson correlation constants were calculated using Minitab16 and tabulated in the same table (Table.1). Trends among these pairs were checked by establishing trend lines among VE vs. BP, VE vs. NHS and BP vs. NHS. All trends are observed to be linear among these variables. Based on linear trend lines, regression analysis was carried out to establish linear equations among the critical variables mentioned in Table.2. The table also shows the linear equations among these critical variables. These linear equations are nothing but the empirical formulas for estimating the hydro test parameters and are;

1. Burst Pressure = 83.4186 + 0.23914 x Volumetric Expansion.

2. Nominal Hoop stress = 546.126 +1.56561 x Volumetric Expansion
3. Nominal Hoop Stress= 0.000917823 + 6.54681 x Burst Pressure.

Where, Burst pressure is in bar; Nominal Hoop stress is in MPa and Volumetric Expansion is in %.

Volumetric expansion is measured by applying test pressure conditions to cylinders. The cylinder slightly expands under this test conditions, which is acceptable as per IS 3196 [3]and IS 13258 [4]. Based on volumetric expansion results burst pressure and the nominal hoop stresses can be estimated using the empirical formulas provide in the Table.2.

Table.1: Correlation Study on Hydro test parameters

Correlation Study Plan	Volumetric Expansion (VE)	Burst Pressure (BP)
Burst Pressure (BP)	BP vs. VE	
Nominal Hoop Stresses (NHS)	NHS vs. VE	NHS Vs. BP
Correlation Constants	**Volumetric Expansion (VE)**	**Burst Pressure (BP)**
Burst Pressure (BP)	0.334	
Nominal Hoop Stresses (NHS)	0.334	1

Table.2: Regression Analysis of Hydro-test parameters

Regression Analysis plan	Volumetric Expansion (VE)	Burst Pressure (BP)
Burst Pressure (BP)	$BP = X_1 + Y_1 VE$	-
Nominal Hoop Stresses (NHS)	$NHS = X_2 + Y_2 VE$	$NHS = X_3 + Y_3 BP$
Regression Equations	**Volumetric Expansion (VE)**	**Burst Pressure (BP)**
Burst Pressure (BP)	BP=83.4186+0.23914 VE	
Nominal Hoop Stresses (NHS)	NHS=546.126+1.56561 VE	NHS=0.000917823+6.54681 BP

In order to validate empirical formulas, BP and NHS values are estimated using VE actual test data and compared the actual values of test data with the estimated values. For a clear graphical representation, box plots are generated using minitab16 for comparing actual and estimated values. Fig.2 shows the box plot of actual burst pressure (BP) and the estimated burst pressure (EBP). Similarly Fig.3 shows the box plot of actual nominal hoop stress (NHS) and the estimated nominal hoop stress with two different methods; i.e. one derived as a function of volumetric expansion, ENHS (VE) and the other as a function of burst pressure, ENHS (BP).

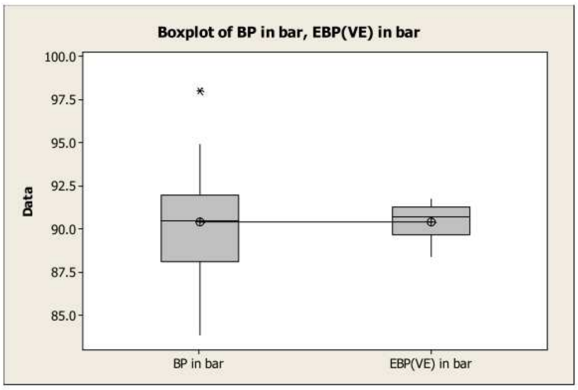

Fig.2: Comparison of Actual and estimated values of Burst Pressure

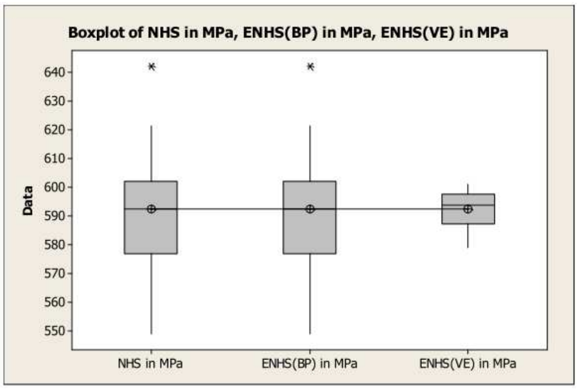

Fig.3 Comparison of actual and estimated values of Nominal Hoop Stresses with two different methods

DISCUSSION

LPG Cylinders are manufactured with low carbon steel with definitely prescribed raw material for construction [2]. Low carbon steel exhibits inverse relation between tensile strength and the percentage [5]. In simple terms, higher the tensile strength, lower the percentage elongation in a low carbon steel. Volumetric expansion is nothing but elongation of cylinder in longitudinal and circumferential direction and hence this can be related to material physical property of percentage elongation. Similarly, burst pressure can be correlated with tensile strength of a cylinder material. Burst pressure and volumetric expansion can be correlated with a linear relationship and is exhibited in the current study. Thus the empirical formulas are generated using linear equations. However, the Pearson correlation constant is not showing very strong correlation among volumetric expansion and burst pressure.

Weak correlations are possible due to various reasons like raw material selection, cylinder manufacturing process, welding methods adopted while fabricating cylinders, Heat treatment process parameters to relieve internal stresses in cylinders due to welding operation, Sample test methods etc[6][7][8][9]. In the current study, the samples are collected from various manufacturers in India, produced their cylinders with minor variations in raw material sourced from various steel mills in India. Indian standard doesn't specify explicit manufacturing process, test method, heat treatment process parameters, sample test methods [2][3]. However, it states the finished cylinder should meet certain conditions for Bureau of Indian Standards certification [2]. This is mainly to accommodate several manufacturers in India for producing approximately 18 million cylinders in a year to meet the current Indian market demand [10]. Also, it is practically not possible to get failed cylinder test data for analysis purpose and to develop a mathematical model. The cylinder data available in any BIS approved laboratory is only from accepted or passed cylinder segment. Thus the failure cylinder test data is not included in this study for empirical formula generation purpose. In addition to that, the test set up can lead also leads inadvertent mistakes some times, especially while noting down the burst pressure due to cyclic hydrostatic loads from a positive displacement pump[7][9].

Referring to the box plots (Fig.2 and Fig.3), although the mean connect lines are matching with both actual and estimated values, the interquartile range boxes are compressed in estimated results. This is mainly due to the lean relationship between BP-VE and NHS-VE. Whereas, the relation between NHS - BP shows a very strong correlation; because the NHS is derived from burst pressure using LPG cylinder initial diameter and thickness (, which are constant values for a specific cylinder design)[3]. Thus the box plot among BP and NHS is a replica of BP. However, if the nominal hoop stress is estimated from VE, compression of interquartile range box can be witnessed. This compressed interquartile range box indicates that the range of estimates is limited to certain levels because of the sample type. In case a set of failure cylinder data is considered for empirical formula generation, this range could expand to the levels of actual values.

It is evident from the work; empirical formulas can be established among the critical variables of cylinder hydro test parameters. However, to improve the accuracy of empirical formulas, it is necessary to consider failure cylinders test data in addition to the passed cylinders test data for analysis purpose. Further, the data used for the analysis purpose should be from a controlled manufacturing and test conditions. It means very accurate the empirical formulas can be established, if the raw material, manufacturing process, heat treatment parameters and welding methods are standardised for LPG cylinder manufacturing. However, it is practically not possible, keeping in view of the existing cylinder manufacturers' population and their productions setup [11]. Thus the empirical formulas developed in this method can be used only for estimation purpose and cannot be implemented for replacing existing testing process mentioned in Indian standards.

LPG cylinders in use are tested and approved by BIS at the time of releasing them to market. The empirical formulas given in this work can provide indicative values of such cylinder for analysis purpose, as the test data used in deriving the empirical formulas is purely from such cylinders.

CONCLUSION

40 domestic LPG cylinder test results are fed to Minitab 16 and developed empirical formulas to estimate hydro-test parameters. Estimated and actual test values are analysed in the study using correlation study, trend analysis, regression analysis and by generating box plots. It is evident form the study, that the empirical formulas can be established among various LPG Cylinders hydro tests parameters. However, the accuracy of these empirical formulas are grossly depends on raw material selection, manufacturing methods, heat treatment process parameters, test methods etc. While developing empirical formulas, it is necessary to include failure test data for accurate empirical formulas to increase the range of estimated values. The empirical formulas given in this paper can be used for indicative purpose and not intended for replacing the existing test methods prescribed in Indian standards.

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A METHOD TO ENSURE REGULATORY COMPLIANCE FOR LP GAS CYLINDER TESTING AS PER IS 3196 (PART3):2012

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ABSTRACT[1]

Domestic LPG cylinders in India are tested as per Indian Standard, IS3196 part3:2012 and certified by Bureau of Indian standards (BIS) before releasing them to market for use. Retesting clause in standard is favoring cylinder manufacturers. Also, due to low sampling size of cylinder batch for testing, non-complied cylinders can enter in to market. There is always a chance existing to enter non complied cylinders into market and it is practically impossible to be segregated in vast cylinder market in India for any corrective action. A fail-safe system is missing in existing system for verification of cylinders material properties without destroying them. A system is necessary to verify all cylinders at manufacturer premises quickly and effectively, before releasing them into market to reduce the risk associated with usage of LPG in a cylinder.
A novel method is proposed in this paper to estimate cylinder material properties with the combination of simple non-destructive test method and a few empirical formulas. Experiments were conducted on 55 domestic cylinders and established several relations among various critical parameters of cylinder material. Further, empirical formulas were developed among various critical material parameters and suggested two plans for estimation of cylinder critical parameters. With this method, cylinder regulatory compliance can be ensured for all cylinders produced in manufacturing plant. Also this method is useful to statutory authorities, inspection agencies for verification of cylinder material compliance at any stages in its life cycle.

KEYWORDS

IS 3196 Part 1, IS 3196 Part 3, LPG Cylinder and Cylinder testing,

INTRODUCTION

Liquefied Petroleum Gas (LPG) cylinders in India are manufactured as per Indian standard IS 3196 Part1:2006 [14] and tested as per IS3196 part3: 2012 [15]. These cylinders are produced in batches with definitely prescribed raw material [13]. LPG Cylinder material plays very crucial role in containing and transporting hazardous LPG [18]. Existing LPG Cylinder testing practices are destructive in nature and only two cylinders are tested for their material safety or material compliance [15] requirements. If the cylinder sampling is biased at manufacturing plant, non-compliant cylinders can enter into consumer homes, which cannot be retrieved from market till cylinder life cycle ends [5]. Currently, there is no procedure in place to identify or trace non-compliant LPG cylinders in market. These cylinders can be a potential safety hazard to consumer, if they are subjected to adverse conditions and wrong handling [5]. If there is a method exists, in which LPG cylinder material properties can be checked easily and quickly, without destroying; entry of such non-complied LPG cylinders into consumer homes can be restricted. However, such method should be inexpensive and would not demand skilled operators to conduct

[1] No of words in Abstract- 241
No of words in manuscript - 2253

inspection on cylinders. In this research an attempt has been made to solve this issue by develop a fail-safe inspection method to LPG cylinder manufacturer to test all cylinders in their plant easily and quickly without destroying or damaging cylinders. Further, LPG cylinders material properties can be verified effortlessly at any point time in their lifecycle, which is not possible in current state of the art technology.

GAPS IN LPG CYLINDER TESTING

Once a cylinder batch or lot is produced in a manufacturing plant, random sample cylinders are subjected to acceptance test and hydro-test tested to measure cylinder material properties [6]. In the existing sampling process, one cylinder in every 203 cylinders batch undergoes acceptance test and one cylinder in 403 cylinders batch is tested for hydro-test [7][8]. The tests reveals all critical parameters for acceptance test and hydro test and are Longitudinal Tensile strength (LTS), Longitudinal Yield Strength (LYS), Longitudinal Percentage Elongation (LPE), Circumferential Tensile Strength (CTS), Circumferential Yield strength (CYS), Circumferential Percentage Elongation (CPE), Burst Pressure (BP), Volumetric Expansion (VE) and Nominal Hoop Stresses (NHS)[9]. The sampling process doesn't fit into any of the statistical sampling processes.

Further, There are two possible scenarios in cylinder production at a manufacturing location as shown in Fig.1. There are cylinders produced with fulfilment of all necessary guidelines and standards and cylinder produced without fulfilling necessary guidelines or standards. There are no issues foreseen in the former case. However, if the sampling process is biased non complied cylinders may enter into market. Further, standard doesn't explicitly discard any cylinder batch produced in a manufacturing location [15]. Instead a provision is given to manufacturer to re-heat-treat a non complied batch till it passes the acceptance test [15]. This provision can be interpreted as a favour towards cylinder manufacturer by neglecting the consumer.

If a cylinder fails during its first filling or initial entry in market, Indian state owned oil company tender specifications provides guidelines [1] to handle such failures (also see Fig.1). Also, there are certain grey areas in LPG business. One can refer Bureau of Indian standards web site for Cylinder Manufacturer suspension cases[2][3][4], Oil company tender documents[1] for defined actions against restricted practices on cylinder manufacturer, Competition commission of India website [21] for judgements on restricted practices etc. The scope of the research is not to expose the grey areas in the business but to provide a meaningful solution to address gaps that are acceptable to all stakeholders of LPG Cylinder business.

INFERENCES FROM LITERATURE REVIEW

It was understood that the 17.5 % of Indian homes are equipped with LPG as a cooking fuel and it is equivalent to 33.6 million numbers [18]. This huge number makes almost impossible to trace and retrieve non-compliant cylinders from market [5]. LPG cylinder specifications states, the thickness is based on yield strength and test pressure, weld joint factor and the diameter of cylinder [14][17]. Among these parameters the yield strength can be obtained only with tensile testing of cylinder material [15]. Yield strength and tensile strength are considered as independent variables for the current study. Studies revealed linear relation between yield strength and hardness on low carbon steel [16][19][20]. Also, It is evident that correlations are possible among hardness, tensile strength and yield strength [16][19][20]. it was observed that there is no clause for rejection of a cylinder batch in Indian standard if the sample is not qualified in acceptance test [15].

METHODOLOGY

The core idea behind the research is to estimate all LPG cylinder critical properties from its hardness value [12][16][19][20]. From the literature survey it is known that tensile, yield strengths can be estimated from hardness values for low carbon steel (LPG cylinder material). Conventional hardness test cannot be conducted on cylinders due to the associated indentation. However, advanced portable hardness testers can be used to get readings of surface hardness directly in Brinells Hardness Number (BHN). Surface hardness is always higher than cylinder parent metal hardness due to sand blasting operations involved in cylinder manufacturing process [5][10][12]. Sand blasting operation causes strain hardening of LPG Cylinder surface. Thus to check the relation among surface hardness and actual material hardness, hardness tests were conducted on 55 domestic LPG cylinders in both the ways and analysed the results to establish some relation. Correlation study, trend analysis and regression analysis was carried on these 55 cylinders and established a relation among these parameters in such a way that with surface hardness values cylinder actual material hardness can be estimated [12].

Indian standard specifies all LPG Cylinders are to be produced in batches from definitely prescribed raw material [14]. The standard also provides guidelines for cylinder production, inspection, testing and certifications. However, each batch should be produced with same raw material and with production methods [14]. Thus LPG cylinder produced in a single batch or lot from prescribed raw material, standard production and testing methods exhibits meaningful correlations among various physical properties [10].

In an acceptance test, all LPG Cylinders are checked for their parent metal properties in two perpendicular directions. i.e. Two tensile samples are drawn from LPG Cylinders one in longitudinal direction and the other in circumferential direction and are tested on universal testing machine to determine Yield strength, tensile strength and percentage elongation [15]. It means 6 different properties viz. circumferential tensile strength (CTS), Circumferential Yield Strength (CYS), Circumferential Percentage Elongation (CPE), longitudinal tensile Strength (LTS), Longitudinal Yield strength (LYS) Longitudinal Percentage Elongation (LPE). Indian standard explicitly does not state the requirements of these two groups separately and hence it is necessary to examine the influencing or critical properties from experimental (Primary) data that can affect acceptance or rejection of new cylinder batch produced in manufacturing location [15]. Once the influencing properties of acceptance (either longitudinal or circumferential) are known it is easy to get these values from cylinder hardness. 55 domestic LPG Cylinder acceptance test data and 40 cylinder hydro test data was collected from one of the Bureau of Indian standards authorised laboratory for analysis purpose.

RESULTS AND DISCUSSION

Hardness test experimental results analysis

It is evident from individual boxplots that the hardness obtained from portable hardness tester is higher than the conventional Brinell's method (see Fig.2). This is in the order of 4.21% of BHN value of actual cylinder hardness. Correlation study, trend analysis and regression analysis are carried out and an empirical formula was developed to estimate cylinder hardness from surface hardness. The formula is given below.

$$BHN = 100.114 + 0.269094 \times BHNp$$

Where BHN is Brinells hardness number of cylinder material in BHN
BHNp is Surface hardness of cylinder material in BHN

Primary Data Analysis

From experimental data analysis, it is evident that the yield and tensile strength results are always lower in circumferential test specimen (see Fig.3 and Fig.4). Whereas the percentage elongation is lower in longitudinal test specimen (See Fig.5) i.e. circumferential sample test results are more critical than longitudinal sample test results for accepting a lot of LPG cylinders manufactured in a plant.

Possible pairs among the critical parameters for correlation are identified. Correlation study was carried out among these identified parameters pairs using Minitab 16, a Microsoft windows based statistical analysis software. Further the trend analysis was carried on all possible pairs and tabulated in Fig.6. Meaningful correlations can be established among tensile strength, yield strength percentage elongation, volumetric expansion burst pressure and nominal hoop stresses. From Fig. 6, LTS-LYS, LTS-CTS, LTS-CYS, LYS-CTS, LYS-CYS, LPE-CPE, LPE-VE, CTS-CYS, CTS-VE, CTS-BP, CTS-NHS, CPE-VE, CPE-BP, CPE-NHS, VE-BP, VE-NHS, BP-NHS shows relation which is directly proportion to each other and LTS-LPE, LTS-CPE, LTS-VE, LTS-BP, LTS-NHS, LYS-LPE, LYS-CPE, LYS-VE, LYS-BP, LYS-NHS, LPE-CTS, LPE-CYS, LPE-BP, LPE-HS, CTS-CPE, CYS-CPE, CYS-VE, CYS-BP, CYS-NHS exhibits inversely proportional relation among these pair elements.

Development of Empirical Formulas for critical Parameters

The trend analysis among various pairs of critical parameters shown linear trend and hence empirical formulas are developed using regression analysis. While developing regression analysis, circumferential yield strength (CYS) and circumferential tensile strength (CTS) are considered as independent variables for obtaining all other critical parameters. Thus two different methods are suggested in this work for estimating the critical parameters with regression analysis (see Table.1). Similarly LYS and LYS also can be used for estimating all parameters.

Study on Actual Vs. Estimated Values

Using the regression equation and the available test data (actual) for yield strength and tensile strength all other parameters are calculated and compared with actual values. The actual and estimated values are plotted using box plots for easy understanding and comparison purpose. Most of the cases the interquartile range boxes are reduced in estimates from the box plots. It means the estimates are restricted to one particular range and are not spread to the extent of the actual values. Thus, the method suggested in this work can be used as indicative purpose to ensure regulatory compliance but not to replace the existing test methods mentioned in IS 3196 part3 2012 [15]. Although there is some compression in interquartile range boxes in the boxplots, the estimates are 99.2% accurate.

METHOD TO ENSURE REGULATORY COMPLIANCE

Two methods are suggested in this study to estimate critical parameters of LPG cylinder material and are based on circumferential tensile values, circumferential yield vales, these plans are given below in Table.1. As per the plan, surface hardness is measured with any one of the portable hardness tester in BHN. This value is used to estimate cylinder hardness in BHN. Once the cylinder hardness is available, either circumferential yield strength or circumferential tensile strength can be estimated. Once the Yield strength or tensile strength values are available, all other parameters can be estimated using empirical formulas given in a particular group in Table.1. Thus all the cylinder critical parameters are available for verification.

Software needs to be developed and integrated with a portable hardness tester to get critical parameters directly while checking the hardness. In this method, critical parameters of any cylinder can be checked with in few seconds without destroying a cylinder. Alternately, based on the hardness values obtained from a portable hardness tester, cylinders can be segregated whether they are complied with the requirements or not. Such verification system can be implemented online as the time required for verification is in seconds (maximum 10 seconds) and can be installed just before the painting operation to avoid surface preparation in a cylinder manufacturing location.

In addition to this, the proposed method can be used for inspection of cylinders during re-qualification test. In existing standards, there are no such requirements. Implementation of this method at this stage helps in identifying cylinders that are subjected to adverse conditions during their life cycle like fire incident. Also, if the method can be implemented after hot repair carried out on LPG Cylinder, to ensure proper heat treatment after hot repair of cylinders. Hot repair replaces foot ring or valve protection ring of LPG Cylinder hot repaired cylinders should undergo heat treatment to relieve internal stresses due to welding operation involved in it. Further, this method can be used for failure, accident and incident investigations at any point in cylinder life cycle.

ADVANTAGES

- Implementation of fail-safe inspection method can ensure elimination of non-complied cylinders in to market and efficient implementation of regulatory compliance.
- If acceptance test sample failed twice in cylinder manufacturer location, manufacturer can segregate non complied cylinders separately for heat treatment instead of the entire lot. This saves fuel cost to the cylinder manufacturer and also implementation of fail-safe method can protect manufacturers from unwarranted suspensions from enforcement authorities.
- Statutory authorities need not depend on cylinder manufacturers for compliance testing. A simple hand held or portable hardness tester is sufficient to check the cylinder parameters at any point of time in its life cycle.
- Oil companies being the owners of cylinders, they can assure safe cylinders to their customers and can verify material properties at any point of time
- Investigation agencies can verify the accident and incident analysis without destroying the sample and can produce the sample as evidence in court of law.

CONCLUSIONS

Although Indian standard for LPG cylinder specifications and test methods are well established few clauses in standard are not in favour of consumers. Acceptance and hydro testing of LPG Cylinders are studied in depth and developed empirical formulas for estimating these values using cylinder surface hardness. A fail-safe method was suggested to test all cylinders in manufacturing plant to ensure all cylinders from a manufacturing location are meeting the standards requirements. Fail-safe cylinder inspection plan can be implemented in manufacturing locations using empirical formulas and hand held hardness tester, besides the existing destructive test methods, to avoid entry of non-complied cylinders into market.

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Table 1: Empirical formulas using circumferential yield and tensile stress

Plan-1: Estimates using Circumferential Yield Strength	Plan-2:Estimates using Circumferential Tensile Strength
Step:1	Step:1
Estimate Hardness	Estimate hardness
BHN = 100.114 +ve 0.269094 BHNp	BHN = 100.114 +ve 0.269094 BHNp
Step:2	Step:2
Estimate Circumferential Yield Strength	Estimate Circumferential tensile strength
CYS = 205.909 +ve 0.366962 BHN	CTS = 358.93 +ve 0.0697682 BHN
Step:3	Step:3
Estimate all other critical parameters	Estimate all other critical parameters
CTS = 325.931 +ve 0.166194 CYS	CYS = 221.702 +ve 0.0956556 CTS
CPE = 61.0831 - 0.0738395 CYS	CPE = 110.901 - 0.186611 CTS
LTS = 271.134 +ve 0.386446 CYS	LTS = 76.4299 +ve 0.797551 CTS
LYS = 82.0919 +ve 0.716688 CYS	LYS = 129.53 +ve 0.370893 CTS
LPE = 69.5775 - 0.116307 CYS	LPE = 82.7526 - 0.116813 CTS
VE = 33.5117 - 0.0156355 CYS	VE = 27.3037 +ve 0.00595615 CTS
NHS = 606.528 - 0.0554084 CYS	NHS = 585.081 +ve 0.0196074 CTS
BP = 92.6448 - 0.00846375 CYS	BP = 89.3691 +ve 0.00299424 CTS

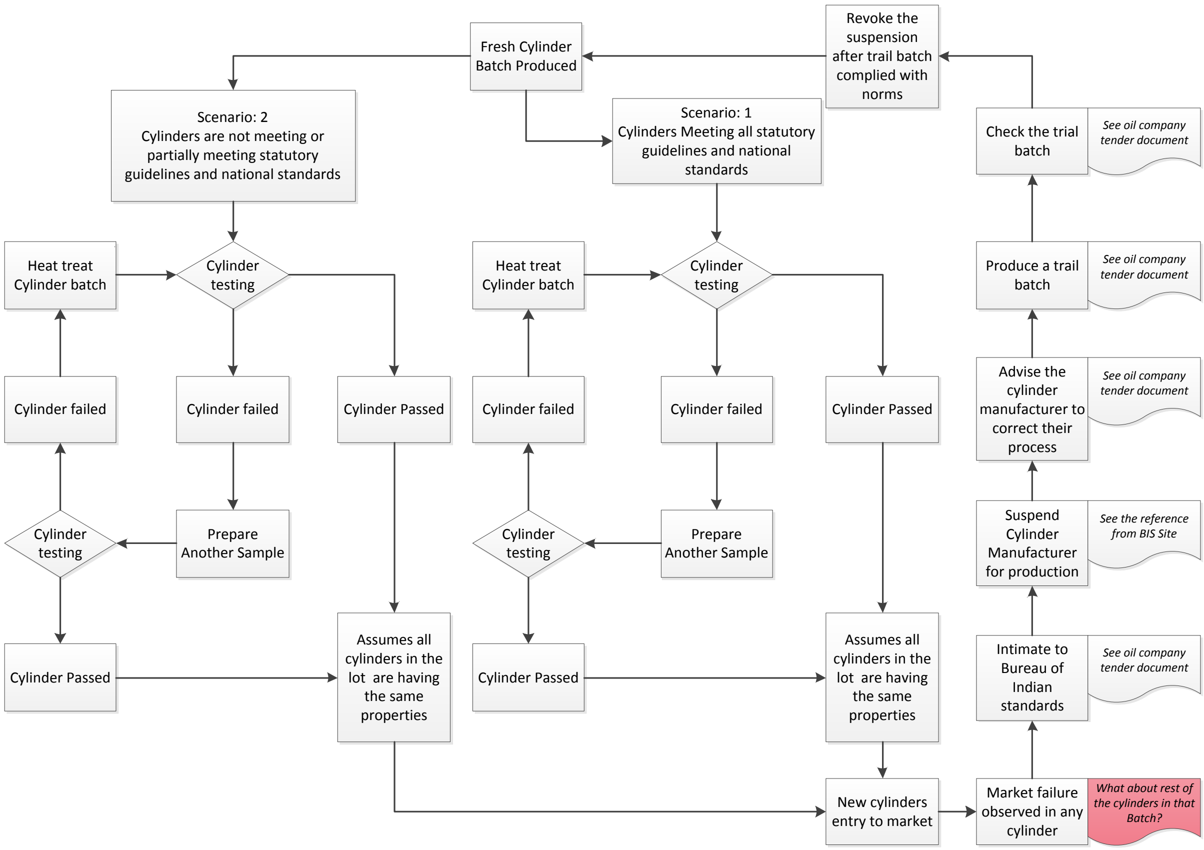

Figure 1: Flow diagram of Cylinder batch production in a manufacturing unit

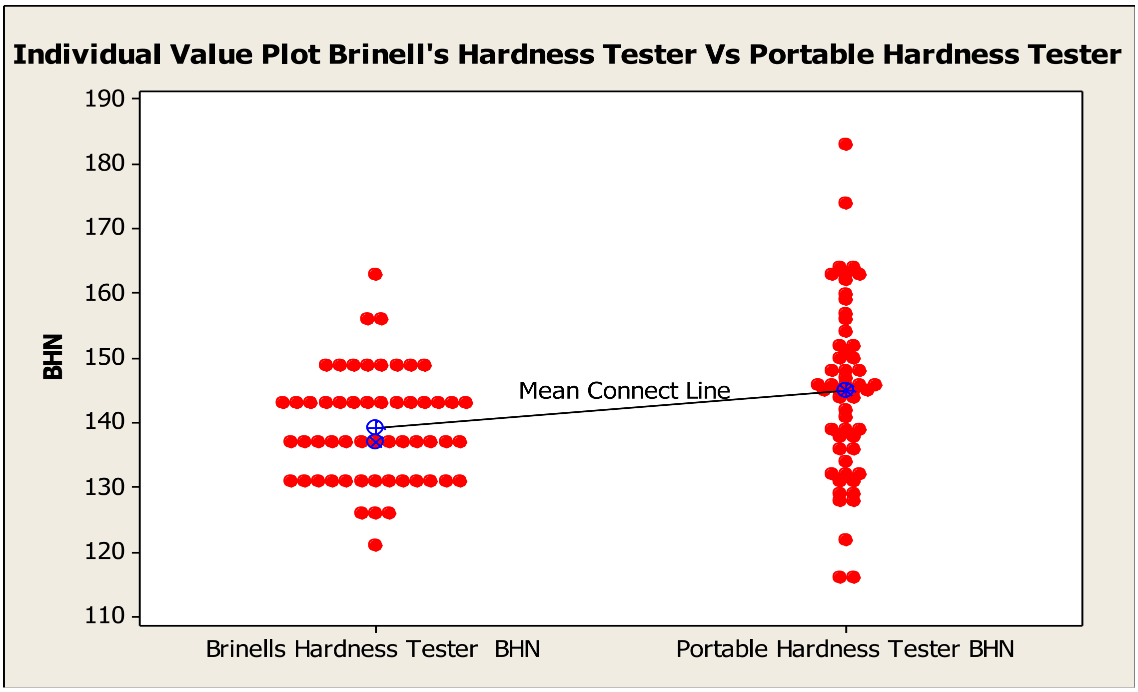

Figure 2: Individual plots of Destructive and Non-destructive hardness test results

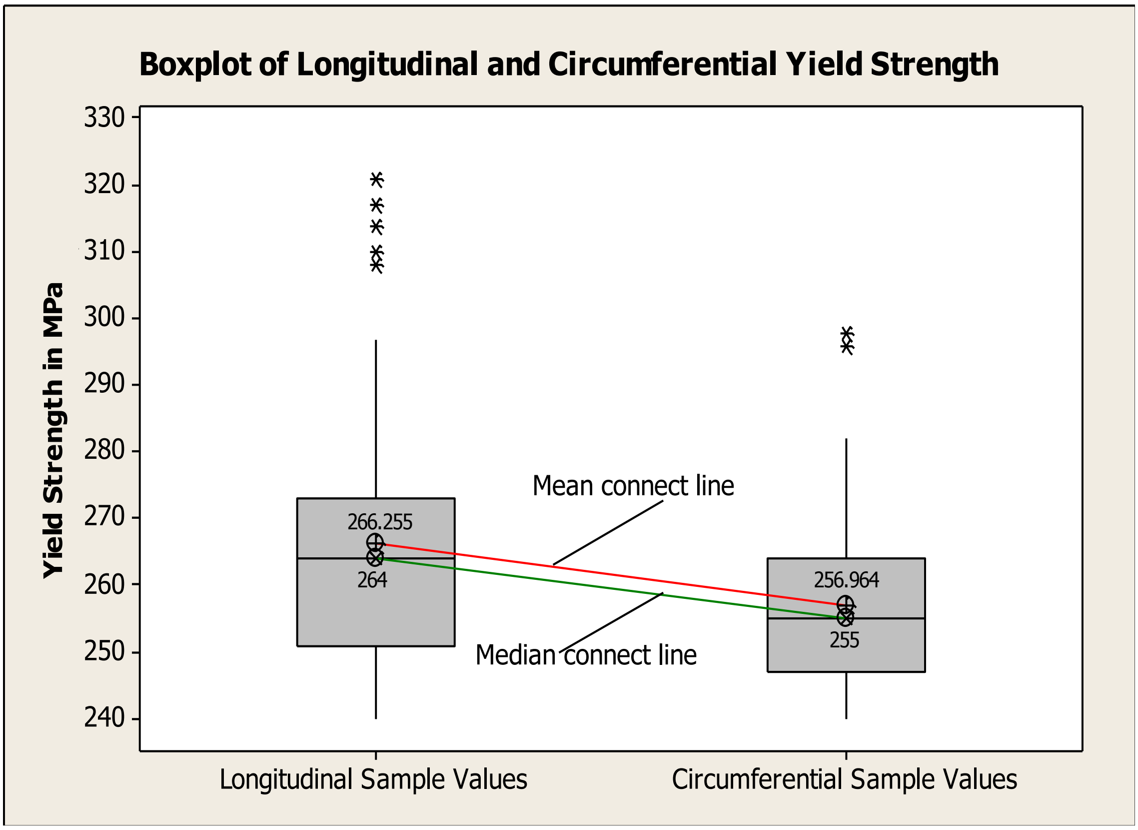

Figure 3: Comparison of Longitudinal and circumferential Yield strength values

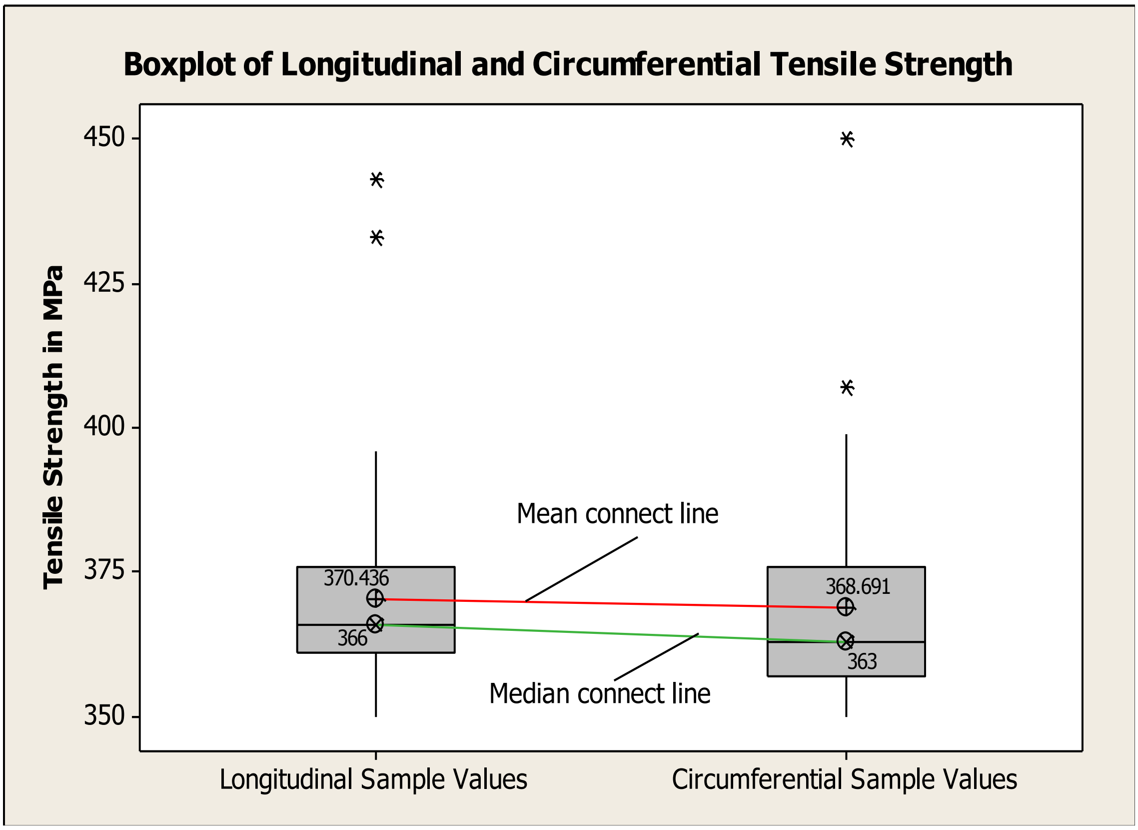

Figure 4: Comparison of Longitudinal and circumferential Tensile strength values

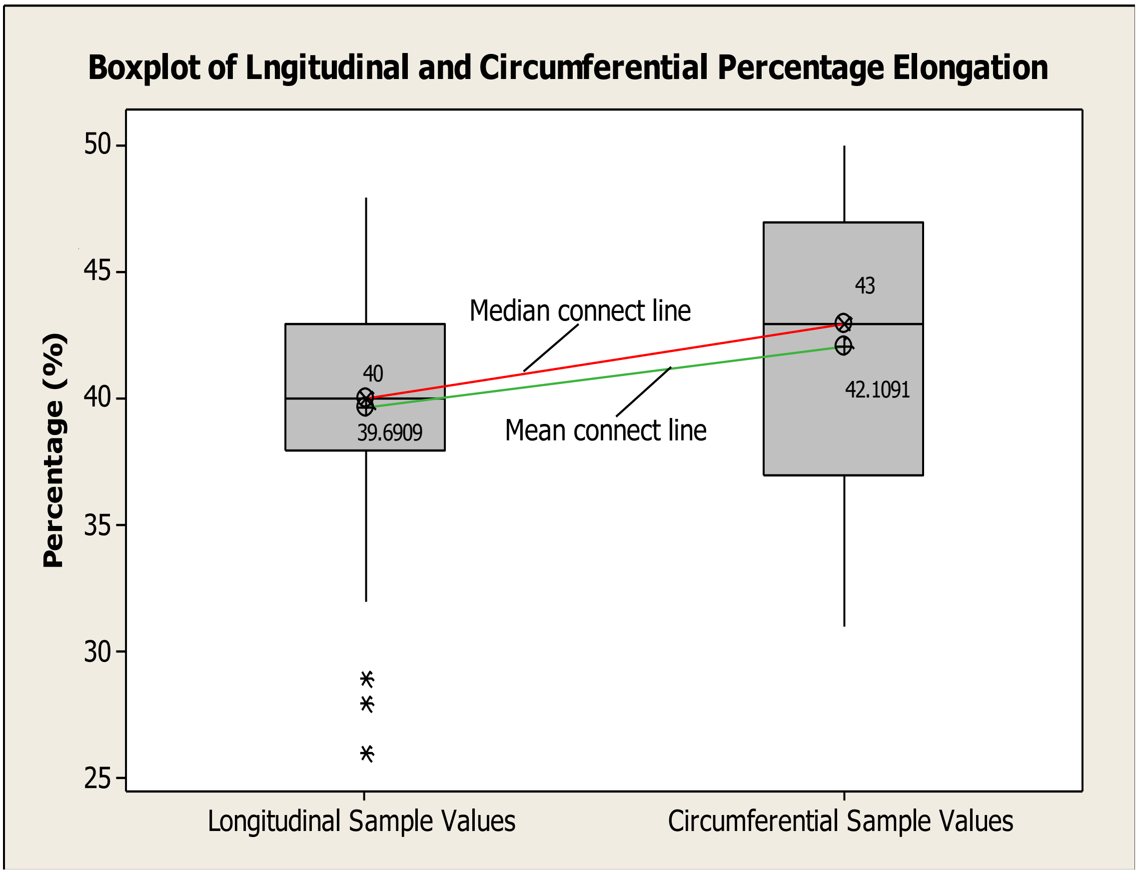

Figure 5: Comparison of Longitudinal and circumferential Percentage Elongation values

	BHN	BHNp	LTS	LYS	LPE	CTS	CYS	CPE	VE	BP	NHS
BHN		↑	↑	↑	↑	↑	↑	↑	↑	↓	↓
BHNp			↑	↑	↑	↓	↑	↑	↓	↓	↓
LTS				↑	↓	↑	↑	↓	↓	↓	↓
LYS					↓	↑	↑	↓	↓	↓	↓
LPE						↓	↓	↑	↑	↓	↓
CTS							↑	↓	↑	↑	↑
CYS								↓	↓	↓	↓
CPE									↑	↑	↑
VE										↑	↑
BP											↑
NHS											

55 Relations among various critical parameters of LPG Cylinder material

↑ Directly proportional

↓ Inversely proportional

Figure 6: Trend analysis among various critical parameters of LPG cylinder material

About Author

Scholar Profile

Akula Ramakrishna completed his B.Tech – Mechanical from National Institute of technology, Warangal (India) and finished his MBA in operations management. He is also holding Post Graduate Diploma in Health Safety and Environment. He is a chartered Engineer (India) and a Graduate member in IOSH (GradIOSH).

Akula Ramakrishna is currently associated with Emirates Gas LLC, Dubai as a Plant Manager since 2009. He is currently handling LPG bottling and bulk distribution operations, operational safety of bottling plants, business excellence initiatives, Department performance monitoring Lean *and 5S initiatives. He is serving as a member of several in-house committees in Emirates gas. He is having more than 14 years of Liquefied Petroleum Gas industry experience. He won prestigious Emirates National Oil Company (ENOC) CEO Excellence award as a distinguished professional employee in 2011.*

He started his professional career in oil and gas domain with Hindustan Petroleum Corporation (India) as a management trainee in 1999. He exhibited outstanding performance throughout his professional career in HPCL. He was exclusively picked up and deputed a senior officer/ Dy. Manager (Research) in LPG Equipment Research Centre (LERC), Bangalore (2003-2007) to look after mechanical lab. He led several R&D projects and investigated several LPG equipment failure and accident investigations at LERC.

Later, he moved to an engineering consultancy, M/s. Infotech Enterprises to support Mi-Swaco for their rig equipment safety compliance projects and served as a project leader from 2007-2009. He was exclusively nominated for prestigious international assignments (design compliance audits) in Aberdeen (Scotland) and Berra (Italy) and successfully completed those projects with outstanding customer satisfaction ratings.

Bio-Data

AKULA RAMAKRISHNA

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Skills

- Gas plant operations, maintenance and EHSQ
- Business strategies development and implementation
- Implementation of Business excellence initiatives, Balanced Scorecard, Lean and 5S Systems
- Internal and external audits as per ISO, IMS, EFQM, DQA, CE Compliance
- Development & review of Policies, Procedures, Standard Operating Practices & Technical specification
- Training and e-learning modules development; Imparting Trainings to internal (Staff) and external stakeholders (like customers & Govt. Officials)
- In-house publications like poster, newsletters, campaigns, presentations
- Tendering and Contract administration; Project Management and documentation
- Technical report writing, Computer proficiency and Multicultural People management

Oil and Gas domain experience

Duration	Organization	Core Business	Location	Position	Responsibilities	Team Size
Since 21st Mar 2013	**Emirates Gas** LLC (ENOC Group Company)	Gas Marketing	Dubai, UAE (Ajman, Fujairah, Al-Qusais, Um-Al-Quwain on need basis)	Plant Manager - Operations	Gas plant Operations, Plant Operational Safety (EHSQ), Performance monitoring and Business Excellence initiatives	Direct reports 13 members Indirect reports 130 members
From 12th Jul 2007 to 20th Feb	**Infotech** Enterprises Limited / MI-Swaco	Engineering Consultancy – Oil and Gas domain	Hyderabad, India Aberdeen, Scotland	Project Leader and Compliance support	Oil and Gas Equipment Safety audits, Technical	Direct reports 2 members Global

Duration	Organization	Core Business	Location	Position	Responsibilities	Team Size
2009			(UK) Berra, Italy	engineer on deputation	Documentation and Safety Training to Engineers	team constitutes 6 members located in 5 countries
From 08th Sep 2003 to 10th Jul 2007	**LPG Equipment Research Centre** (JV to Hindustan Petroleum)	Gas equipment safety testing, certification, Research and Development	Bangalore, India	Executive operations officer (Research) on deputation from HPCL	LPG Equipment safety testing, certification, R&D and Training	Direct reports-3 no.
From 08th Aug 1999 to 07th Sep 2003	**Hindustan Petroleum Corporation Limited** (HPCL)	Oil and Gas refining and Marketing	Madurai LPG Bottling plant	Operations Officer	Gas plant projects, Operations, Maintenance, quality and safety	Direct reports-15 no. Indirect reports 45 members

Accolades

Some of the remarkable achievements are:

- ENOC **CEO Excellence Award** (2011) - for the outstanding contribution to Emirates Gas – This award is open for all ENOC group companies (36 organisations).
- Rendering services as an **assessor for Dubai Quality Award** (Department of Economic development, Govt. of Dubai) to assess business excellence (as per EFQM) in DQA applicant organisations - My team won 2nd best team award in 2012 DQA award cycle
- **Visionary Leader** (2003) – for outstanding contribution in formulating gas business strategies for Hindustan Petroleum Corporation Limited – Silver Medal was received from Chairman and Managing director of HPCL in 2003
- **Most innovative design Award** (1998) – for conceptualizing and developing innovative windmill in a prestigious design contest held in Indian Institute of Technology, Bombay (India) in 1998

Educational Qualifications

Degree	Specialization	Institute / University	Rank and Year
Doctor of Philosophy - **PhD (HSE)**	Health Safety and Environment. (Pursuing research	University of Petroleum and Energy Studies, Dehradun, India	Thesis submitted for review. Degree is expected to award in **May 2014**

	on LPG Cylinder safety)		
Post Graduate Diploma in Health Safety and Environment **(PGDHSE)**	Health Safety and Environment	Annamalai University, Chennai, India	First division (72% marks) **- May 2010**
Master of Business Administration **(MBA)**	Operations Management	Indira Gandhi national Open university, New Delhi, India	First division in 3.62 / 5 Point grade – **June 2002**
Bachelor of Technology **(B.Tech)**	Mechanical	National Institute of Technology, Warangal, India Formerly known as Regional Engineering College	First class with distinction (73% of Marks) – **May 1999**

Professional Memberships

- IOSH
- ASSE
- All India Management Association
- Project Management Institute
- Indian Science Congress Association
- Institute of Engineers (India)

Significant Trainings and Certifications

- ISO Lead Auditor
- IMS Internal Auditor
- Project Management Professional
- Accident incident investigator
- Disaster Management Professional
- Hazardous Material Incident Management Professional

Note: All logos in this document were sourced from official websites of respective organizations/ institutes

---End of Authors' Profile---