ANALYSIS AND EXPERIMENTAL STUDY OF ZINC-NICKEL-CHROMIUM (Zn-Ni-Cr) COATING ON PIPELINE MATERIAL

By Anagm Dhanunjaya
M-Tech (Pipeline Engineering)
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College of Engineering
University of Petroleum & Energy Studies
Dehradun
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Submitted by:

Angam Dhanunjaya

SAP ID: 500025297

Under the Guidance of

Mr. Ramesh M

Assistant Professor Senior Scale

Department of Mechanical Engineering

University of Petroleum & Energy Studies

Dehradun – 248007

Approved

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Dean

College of Engineering

University of Petroleum & Energy Studies

Dehradun

April, 2015

CERTIFICATE

This is to certify that the work contained in this thesis titled "**Analysis and Experimental study of zinc-nickel-chromium (zn-ni-cr) coating on pipeline material**" has been carried out by Angam Dhanunjaya under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Coating is a covering that can be applied to the surface of an object, normally called as substrate. The purpose of application of coating is the value enhancement of the substrate by improving its appearance, corrosion resistant property, wear resistance, etc. Process of coating involves application of thin film of functional material to a substrate. The functional material may be metallic or non-metallic; organic or inorganic; solid, liquid or gas. This can be genuine criteria of classification of coatings.

The offshore oil and gas industry is growing at an unprecedented rate as multinational companies scramble to explore new energy sources from deep sea. Offshore drilling platforms and subsea pipelines are often located in the world's harshest marine environments, where long term asset protection is essential to overall planning.

Metal coatings are used to prevent ferrous metals from corroding and also to improve the appearance of all metals.

The project is to select a suitable subsea material and improve its corrosion resistance, operating life and mechanical properties with the help of Zn-Ni-Cr coating. The specimens are modeled in SolidWorks as per ASTM E8 for tensile test and ASTM E23 for Impact test. The modeled specimen is then tested for its yield strength, percentage elongation, Von-Misses Stress, Etc.

The specimens are then manufactured as per the theoretical model created in SolidWorks and electroplated with Zn-Ni-Cr. The specimens are then practically tested for mechanical properties and later on compared with the theoretical results obtained.

The last phase of the project involves in performing corrosion tests in 3 % NaCl solution and in ASTM D1141 solution. Later on SEM analysis will be done on the specimens.

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LIST OF ABBREVIATIONS

NaCl - Sodium Chloride

Cr - Corrosion Rate

US - United States

UTM – Universal Testing Machine

SEM – Scanning Electron Microscope

SAE – Society of Automotive Engineers

MIL – Military Standard

MIC – Microbiologically Induced Corrosion

AISI - American Iron and Steel Institute

ASTM - American Society of Testing Materials

ASME - American Society of Mechanical Engineers

EN - English Nomenclature

Zn - Zinc

1. INTRODUCTION

Pipelines acknowledge to a phenomenal degree segregating part all through the world for transporting gasses and fluids. All things considered, these pipelines are laid under secured circumstances over long partitions from source to destination. The making interest and vitality for pipelines in everywhere all through the world warrants incredible adroitness as for shield it from the deteriorating impacts, for occasion, disintegration, external forces, corrosion and others. Among these impacts, disintegration contributes an expansive bit of the channel dissatisfaction cases. A substantial illustration, a late audit shows that corrosion of metals and blends costs high expenses every year to the companies. The investigators at Battelle Establishment and the National Association of Standards and Advancement accepted that roughly 33% of the aggregate expenses ($ 100 billion reliably) could be all around decreased or executed by the utilization of best accessible erosion aversion systems and material scrambling hatred systems and materials .

The two principle portrayals of pipeline operation dissatisfaction are outside forces and disintegration (corrosion). The outside qualities are a direct after effect of pipeline directors, catastrophes like shudders and others. The pipeline dissatisfaction in light of disintegration merges both internal and outside utilization. External qualities and disintegration identify with more than 60 percent of all pipeline disillusionments. Utilization is named colossal clarification behind pipeline frustrations with its both sorts (inside and outside). Utilization is the phenomena of electrochemical response between the material and its surroundings. In the bigger piece of the cases, the pipe including environment is soil. For this situation, utilization will be affected by different segments inside the earth.

Chiefly physical, creation and common properties of the earth will expect the certified part for pipeline utilization. Getting directly to the point, temperature, pH, dampness, salts and other compound variables continually influence the pipelines disintegration under soil. Inside and out that truly matters all pipeline disintegration in soil is electrochemical in nature; that is, the utilization is an electrochemical response where electrons move from anode to cathode inside the devouring metal. The metal eats up at one spot at first look while the soil soaked quality is responding at a near to site or even at some incredibly distant site. Utilization happens at the anode site where metal particles leave the surface to crumble in the soil soaked quality. This electrochemical disintegration can be effected by unmistakable parts, for case, momentous soil, 2 differential air course, distinctive metals, new and old steel pipe, soil, stickiness substance, and position of water table, soil resistivity, dissolvable particles substance, soil pH, oxidation lessening potential and the district of life structures in soil. Of course, the utilization issue can be successfully managed by utilizing best open movements of disintegration affirmation. Covering of pipeline expect a gigantic part in disintegration control of pipelines particularly in soil. Covering is connected with minimize the obliged force use in cathodic security frameworks.

The fundamental methods used to associate outside disintegration with pipelines are coatings and cathodic affirmation. Periodically, soil conditions can trade off the execution of cathodic protection. A substantial case, the electrical conductivity of the soil is a key figure the course of action of a suitable cathodic confirmation structure. Poor outline or an astounding increase in soil resistivity can understand a loss of useful insurance at secured steel surfaces. High temperatures or over the top cathodic security potential results can invigorate covering disbondment. Covering materials including polyvinyl chloride, dim top or coal tar can tolerate a loss of dependability in association through clearing of covering pieces by water filtering, oxidation, or biodegradation. High temperatures can again invigorate covering separating.

The following growth in covering penetrability gifts water access to the basic steel surfaces. In this recommendation AISI 1040 oil smothered uncovered steel secured with 20 microns combination of zinc-nickel-chromium (Zn-Ni-Cr) is changed over to UTM tractable specimen of 300mm length with 56 mm gauge length (ASTM standard) to check for the yield quality complexity amidst secured and uncoated steel in an UTM machine. V-notch Charpy test samples with the same covering are attempted to center the qualification in the measure of imperativeness devoured by the material in the midst of break. The same material (uncovered and secured with 20 microns Zn-Ni-Cr) is weighed for hardness refinement in Rockwell hardness scale in perspective of space hardness of a material. The Rockwell test chooses the hardness by measuring the significance of passage of an indenter under a far reaching weight stood out from the penetration made by a preload. The illustration of 20 microns of zinc-nickel-chromium covering of both UTM and Charpy V notch test are kept in 5% NaCl solution for 96 hours. After that the expended sample are striven for occurring yield quality and the imperativeness held. The differentiation between the corroded zinc-nickel-chromium and non-corroded zinc-nickel-chromium illustration of both UTM and Charpy V notch test are plotted in charts. Scanning Electron Microscope lens (SEM) will be used to study the surface morphology, the topography and the surface devotee properties of the coatings. These tests will be driven on 2 uncovered metal with and without corrosion as well as coated metal with and without corrosion and the results will be taken a gander at. The practicality of the covering will be shut in like way.

1.1 Corrosion

Corrosion is a natural process, which converts refined metal to their more stable oxide. It is the gradual destruction of materials (usually metals) by chemical reaction with their environment. In the most common use of the word, this means electrochemical oxidation of metals in reaction with an oxidant such as oxygen.

1.1.1 Types of Corrosion

Corrosion is a characteristic procedure, which changes over refined metal to their more steady oxide. It is the progressive annihilation of materials (normally metals) by compound response with their surroundings. The major types of corrosion are:-

1.1.2 Galvanic Corrosion

Galvanic erosion happens when two separate metals have physical or electrical contact with one another and are drenched in a typical electrolyte, or when the same metal is presented to electrolyte with distinctive focuses. In a galvanic couple, the more dynamic metal (the anode) consumes at a quickened rate and the more honorable metal (the cathode) erodes at a slower rate. At the point when submerged independently, every metal erodes at its own particular rate. Galvanic erosion is of significant enthusiasm to the marine business furthermore anyplace water (containing salts) contacts pipes or metal structures. Variables, for example, relative size of the anode, sorts of metal, and working conditions (temperature, stickiness, saltiness, and so on.) influence galvanic corrosion. The surface range degree of the anode and cathode straightforwardly influences the erosion rates of the materials. Galvanic erosion is frequently averted by the utilization of conciliatory anodes.

1.1.3 Pitting corrosion

Low amassing of oxygen or high convergence of species, for example, chloride which finish as anions, can meddle with a given combination's capacity to re-frame a passivizing film. In the most pessimistic scenario, the majority of the surface will stay secure, however, little nearby changes will corrupt the oxide film in a couple of basic focuses. Corrosion at these focuses will be extraordinarily intensified, and can bring about corrosion pits of a few sorts, contingent on conditions. While the corrosion pits just nucleate under genuinely amazing circumstances, they can keep on growing notwithstanding when conditions come back to typical, since the inside of a pit is characteristically denied of oxygen and mainly the pH reductions to low values and the corrosion rate increments because of an autocatalytic procedure. In compelling cases, the sharp tips of to a great degree long and slender corrosion pits can bring about anxiety focus to the point that overall intense combinations can break; a meager film penetrated by an imperceptibly little gap can conceal a thumb measured pit from perspective. These issues are particularly unsafe on the grounds that they are hard to distinguish from a part or structure comes up short. Setting stays among the most well-known and harming manifestations of corrosion in passivated combinations.

1.1.4 Crevice corrosion

Crevice corrosion is a restricted manifestation of corrosion happening inbound spaces (fissure), to which the entrance of the working liquid from nature is constrained. The arrangement of a differential air circulation cell prompts corrosion inside the cleft. Samples of the fissure are holes and contact zones between parts, under gaskets or seals, inside splits and creases, spaces loaded with stores and under ooze heaps. Fissure corrosion is impacted by the cleft sort (metal-metal, metal-non-metal), hole geometry (size, surface completion), and metallurgical and natural elements. The defencelessness to fissure corrosion can be assessed with ASTM standard methods. A basic cleft corrosion temperature is usually used to rank a material's imperviousness to fissure corrosion.

1.1.5 Microbial corrosion

Microbial corrosion, or normally known as microbiologically impacted corrosion (MIC), is a corrosion brought about or advanced by microorganisms, for the most part chemoautotrophs. It can apply to both metallic and non-metallic materials, in the vicinity or nonappearance of oxygen. Sulphate-diminishing microbes are dynamic without oxygen (anaerobic); they create hydrogen sulphide, bringing on sulphide anxiety splitting. In the vicinity of oxygen (vigorous), some microbes might straightforwardly oxidize iron to iron oxides and hydroxides, other microscopic organisms oxidize sulphur and produce sulphuric corrosive bringing on biogenic sulphide corrosion. Fixation cells can shape in the stores of corrosion items, prompting restricted corrosion.

1.1.6 High-Temperature Corrosion

High-temperature corrosion is compound crumbling of a material (commonly a metal) as a consequence of warming. This non-galvanic manifestation of corrosion can happen when a metal is subjected to a hot environment containing oxygen, sulphur or different mixes fit for oxidizing (or helping the oxidation of) the material concerned. Case in point, materials utilized as a part of aviation, force era and even in auto motors need to oppose supported periods at high temperature in which they may be presented to an environment containing possibly exceptionally destructive results of ignition. The results of high-temperature corrosion can conceivably be swung to the preference of the specialist. The development of oxides on stainless steels, for instance, can give a defensive layer anticipating further environmental assault, taking into consideration a material to be utilized for managed periods at both room and high temperatures in threatening conditions. Such high temperature corrosion items, as compacted oxide layer coatings, anticipate or diminish wear amid high-temperature sliding contact of metallic (or metallic and clay) surfaces.

1.1.7 Metal dusting

Metal dusting is a cataclysmic type of corrosion that happens when defenceless materials are presented to situations with high carbon exercises, for example, combination gas and other high CO situations. The corrosion shows itself as a separation of mass metal to metal powder. The associated instrument is firstly the testimony with a graphite layer on the surface of the metal, normally from carbon monoxide (CO) in the vapour stage. This graphite layer is then thought to frame metastable M3C species (where M is the metal), which relocate far from the metal surface. Nonetheless, in a few administrations no M3C species is watched showing a direct exchange of metal iotas into the graphite layer.

1.2 Electroplating

Electroplating is the utilization of a metal covering to metallic or other directing surfaces by an electrochemical methodology. The article to be plated (the work) is made the cathode (negative anode) of an electrolysis cell through which a direct electric current is passed. The article is inundated in a watery arrangement (the shower) containing the obliged metal in an oxidized structure, either as an equated activity or as a complex particle. The anode is generally a bar of the metal being plated. Electroplating is generally utilized as a part of commercial ventures, for example, vehicles, planes, hardware, adornments, and toys. The general methodology of electroplating uses an electrolytic cell, which comprises of putting a negative charge on the metal and dunking it into an answer that contains metal salt (electrolytes) which contain decidedly charged metal particles. At that point, because of the negative and positive charges, the two metals are pulled in to one another.

1.2.1 Preparing the Surface

The reason for setting up the surface before starting to plate another metal onto it is to guarantee that it is clean and free of contaminants, which may meddle with the holding. Tainting frequently forestalls statement and absence of attachment. Typically this is done in three stages: cleaning, treatment and flushing. Cleaning generally comprises of utilizing certain solvents, for example, antacid cleaners, water, or corrosive cleaners so as to evacuate layers of oil at first glance. Treatment incorporates surface alteration which is the solidifying of the parts and applying metal layers. Washing prompts the last item and is the last touch to electroplating. Two certain techniques for setting up the surface are physical cleaning and synthetic cleaning. Concoction cleaning comprises of utilizing solvents that are either surface-dynamic chemicals or chemicals which respond with the metal/surface. In physical, cleaning there is mechanical vitality being connected so as to evacuate contaminants. Physical cleaning incorporates brush scraped area and ultrasonic fomentation.

1.2.2 Galvanic Series

The galvanic series is a diagram demonstrating the connections and an aide for selecting metals that can be joined, with a point of aiding in the choice making methodology. This is finished by showing which materials have a negligible inclination to a galvanic communication, or the need or even level of assurance that can be connected to lessen the normal plausible cooperation The galvanic series characterizes the respectability of metals and in addition semi-metals. This procedure happens when two metals are submerged in an electrolyte when electronically associated, before letting the base experience galvanic consumption. The consumption rate will be impacted by the electrolyte and also the distinction in honorability. Batteries frame the essential rule of metal consumption potential in the galvanic response. Every combination or metal has a particular consumption potential. The more negative a metal or composite is in the galvanic series, the more probable it is to endure galvanic consumption while the positive shows resistivity to erosion when subjected to reasonable conditions to erosion. The closer a metal or a compound is in the series, the less are the impacts of galvanic consumption contrasted with those metals far separated in the series with more noteworthy erosion. Then again, the series can be controlled by the anode and cathode reactivity to the metals' electrons. Those metals with high quantities of electron responses at the anode are found lower in the galvanic series contrasted with those with higher responses, with the inverse valid in the cathode

The principle targets of the present work are:

1. To diminish the consumption rate of the pipeline material utilizing metallic zinc covering.
2. The weigh for the increment in Elasticity and Yield Quality of the material utilizing Universal Testing Machine.
3. To weigh for the increment in Impact Energy and Modulus of Rigidity of the coated material utilizing Charpy Test Machine.
4. To weigh for the increment in Space hardness of the covered material utilizing Rockwell Hardness Machine.

2. LITERATURE REVIEW

Research work is carried out in the field of zinc Alloy coatings for ferrous substrates which can be either done by electrode-plating or by hot-dip galvanization. A summary of the previous research work carried out in this field of work is summarized below. G.D. Wilcox, et al; in 1993 studied and examined the range of zinc alloy electro deposited coatings that are available as finishes for continuous steel strip. It suggested zinc alloy electrodeposited coatings as superior replacements to zinc for the protection of steel substrates. Of the more common systems, zinc-nickel appears to be finding the most widespread use, particularly in strip applications. Zinc-cobalt coatings are confined to non-strip products, whilst zinc-iron's share of the market seems smaller than the aforementioned systems. Zinc-manganese has not, in all probability, become available on the market, although potentially it has very good corrosion resistance.

W. Zhang et al. in 2008 studied the electrochemical corrosion behavior of nano-crystalline zinc coatings in 3.5% NaCl solutions. The study was about the corrosion behavior of electrodeposited nano-crystalline (NC) zinc coatings with an average grain size of 43 nm. It was investigated in 3.5% NaCl solutions in comparison with conventional polycrystalline (PC) zinc coatings by using electrochemical measurement and surface analysis techniques. Both polarization curve and electrochemical impedance spectroscopy (EIS) results indicate that NC and PC coatings are in active state at the corrosion potentials, and NC coatings have much higher corrosion resistance than PC ones.

The EIS characteristics and corrosion processes of PC and NC zinc coatings during 330 h of immersion were discussed in detail. They concluded that in 3.5% NaCl solutions open to air at 25±2 °C, both NC and PC zinc coatings electrodeposited from acidic sulfate solutions are in active state at the corrosion potentials. During 330 h of immersion, NC zinc coatings show much higher corrosion resistance than the PC ones. The porous corrosion product layers can form on both coating surfaces, which seem to play an important role in the corrosion processes. In comparison with the PC zinc coatings, the enhanced corrosion resistance of NC zinc coatings is mainly due to the better protection of the corrosion product layer.

O.S.I Fayomi and A.P.I Popoola in 2012 did an investigation of the Properties of Zn Coated Mild Steel. Here the mechanical (wear and hardness) and corrosion behaviors of Zn Coated Mild Steel in 3.65% NaCl are described. A thin film of Zn on steel substrates was prepared by electro deposition technique using Zn particles to form a bath plating solution. Scanning electron microscope and Atomic force microscope were used to study the surface morphology, the topography and the surface adherent properties of the coatings. The crystal particles present were observed by X-ray diffraction pattern (XRD) and energy dispersive X-ray diffraction spectrometer (EDS). The micro hardness of deposited plate, the electrochemical behavior and the corrosion properties of the deposits were investigated by means of Vickers micro hardness and polarization measurements. The uniform deposits of Zn showed fine grains and good protection against corrosion as appreciated 75% hardness value was achieved.

John Milne and Roger Giler suggest in their book of Nickel chromium Alloys for Electric Resistance Heating as In reviewing the four major alloys in the nickel-chromium family, please compare their basic characteristics shown in Table 3. Additional information on all heating alloys may be found in Volume 3 of the American Society for Metals (ASM) Handbook.(') All of these heating alloys have good life if the heating element is properly designed with the correct alloy, wire size and coil configuration (for coiled wire elements). Resistance alloy wire and strip product forms are generally supplied in the annealed condition, unless specifically re-quested otherwise. In the annealed condition, they are easily fabricated by coiling or bending. Satisfactory life as a heating element begins with the manufacture of the alloy, and further results from the proper care of the alloy wire, ribbon or strip — while it is being fabricated into an element and installed into the end-use device. The nickel-chromium alloys are inherently corrosion-resisting (like stainless steels), but they can be detrimentally affected by certain circumstances and reasonable precautions must be taken to keep the elements clean. This aspect is covered in greater detail further on.

3. THEORITCAL DEVELOPMENT

3.1 CARBON STEEL

Carbon steel (plain carbon steel) is steel which contain main alloying elements is carbon. Here we find maximum up to 1.5% carbon and other alloying elements like copper, manganese, silicon. Most of the steel produced now-a-days is plain carbon steel. It is divided into the following types depending upon the carbon content.

- Dead or mild steel (up to 0.15% carbon)
- Low carbon steel (0.15%-0.45% carbon)
- Medium carbon steel (0.45%-0.8% carbon)
- High carbon steel (0.8%-1.5% carbon)

Steel with low carbon content has properties similar to iron. As the carbon content increases the metal becomes harder and stronger but less ductile and more difficult to weld. Higher carbon content lowers the melting point and its temperature resistance carbon content cannot alter yield strength of material.

3.1.1 LOW CARBON STEEL

Low carbon steel has carbon content of 1.5% to 4.5%. Low carbon steel is the most common type of steel as its price is relatively low while it provides material properties that are acceptable for many applications. It is neither externally brittle nor ductile due to its low carbon content. It has lower tensile strength and malleable.

3.2 ZINC ELECTROPLATING

This is also called zinc coating, but applied in a cold, electrolytic bath rather than a molten zinc bath. Traditionally the plating/coatings are thinner than hot dipped and not suitable for extended outdoor exposure. In this process a layer of pure zinc is applied. The thickness of plating ranges from a few microns on cheap hardware components to 15 microns or more on good-quality fasteners. Technical and cost issues prevent the economical plating of components with heavier coatings.

3.3 NICKLE ELECTROPLATING

Low stress can be achieved by adding stress-reducing additives to Watts or sulphamate nickel solutions. However, a low tensile stress can also be maintained without the use of organic additives, using sulphamate baths with low chloride levels. It is important to carefully maintain the solutions and to continuously treat for impurities. Nodular build-up or treeing at edges may be troublesome. Fitting of shields is often helpful. In other cases the mandrel may be extended so that the treeing occurs on parts of the electroform that can be machined off at a later stage.

In some cases, it may be necessary to machine off the trees part way through the electroforming operation and then return to the bath for further build-up. In such cases it is essential to re-activate the nickel to insure good nickel-nickel adhesion. Agitation by air, eductors or mechanical, is important to minimize high current density burning or pitting. The choice of electroforming solution can also influence the degree of treeing. Certain addition agents similar to leveling agents can suppress the treeing tendency. Also, high chloride solutions are superior to Watts solutions in this respect.

3.4 ELECTRODEPOSITED ZINC-NICKEL-CHROMIUM TECHNICAL DATA

Characteristics

Smoothness	High
Brightness	High
Retention of Brightness	Low
Thermal Conductivity	Medium
Heat Resistance	Low
Solderability	Medium
Electrical Resistance	Medium
Contact Resistance	High
Adhesion	High
Elastic Modulus	Medium
Tensile Strength	Low
Ductility	Medium
Hardness	Low
Friction Coefficient	High
Abrasion Resistance	Low
Sliding Wear Resistance	Medium
Fatigue Life Reduction	Low
Hydrogen Embrittlement Risk	High

Fitness for Food Contact	Low
Uniformity of Thickness	Medium
Cost	Low
Corrosion	**Protection**
Severe Atmosphere	Medium
High Temperature	Low
Water	Medium
Sea Water	Medium
Acids	Low
Alkalis	Low
Salt Solutions	Low

3.4.1 COATING THICKNESS VS. COATING WEIGHT

The usual criterion for determining the expected service life of zn-ni-cr coatings is thickness: the thicker the coating, the longer the service life. This is an acceptable criterion when comparing zn-ni-cr coatings produced by the same process. When comparing zn-ni-cr coatings produced by different processes, the thickness criterion cannot be used without considering the amount of available zn-ni-cr per unit volume. While the coating densities for some of the different types of zn-ni-cr coatings are nearly identical, others differ considerably. Each of these thicknesses, representing the same weight per unit area of zn-ni-cr, would be expected to provide equivalent service life. It is also important to remember that for all continuous galvanized sheet materials, including electro galvanized, the coating weight is given for the total zn-ni-cr weight for both sides of the sheet.

3.4.2 ECONOMIC CONSIDERATIONS

Selection from the wide range of coatings available for steel will normally depend on the suitability of the coating for the intended use and the economics of the protective system. Factors that affect the economics for a particular application include:

- Initial cost of the coating;
- Coating life to first maintenance;
- Cost of maintenance;

Hidden costs, such as accessibility of the site, production loss due to maintenance recoating, and rising wages for labor-intensive coatings, such as metal spraying and painting must also be considered. The choice of the most economical system is not precise, because neither the timing nor the cost of future maintenance can be accurately predicted.

3.4.3 COATING PROPERTIES

In general, the coating microstructure consists of the substrate, the interfacial alloy layer and the overlay cast structure. Depending upon the type of coating, the microstructure and composition of these constituents will control the desired properties. The substrate must meet the design requirements of the component and therefore is usually selected based on mechanical properties such as strength, ductility, formability, etc. However, the substrate composition can play a major role in the type of coating obtained and can affect the growth kinetics of the phases formed in the coating. Alloy additions to the steel to improve sheet formability. The important properties that concern the use of zn-ni-cr coatings are primarily corrosion and formability and other properties involve weldability and paintability. However, it should be noted that the corrosion resistance of any zn-ni-cr coating can drastically change depending upon the specific corrosion environment and whether the coating is welded, contains a paint system or is deformed, and the extent to which galvanic protection is required for nearby uncoated areas.

3.4.3.1 Corrosion Resistance

zn-ni-cr coatings add corrosion resistance to steel in several ways. As a barrier layer, a continuous zn-ni-cr coating separates the steel from the corrosive environment. By galvanic protection, zn acts as a sacrificial anode to protect the underlying steel at voids, scratches and cut edges of the coating. The sacrificial properties of zn be seen in a galvanic series where the potential of zn is less noble than steel in most environments at ambient temperatures. A porous zn oxide superficial layer forms on the surface by a mechanism of dissolution/reprecipitation, leading to preferential corrosion pathways across the high porosity areas, which accounts for the linear corrosion rate. In addition, after dissolution of the zn-ni-cr metal, zn hydroxide can precipitate at the cathodic areas of the exposed steel, forming a secondary barrier layer. Thus, the zn-ni-cr coating will corrode at a slower rate than the steel substrate, although the corrosion rate of zn-ni-cr will vary depending upon the exposure.

3.4.3.2 Formability

The deformation and fracture behavior of zn-ni-cr-based coatings on sheet steel can alter the performance of steels in stamping operation. During deformation, increased frictional conditions at the sheet/tool steel interface and the substrate mechanical properties can change the formability response of the material. Coating ductility depends on factors such as grain size, crystallographic orientation, temperature, coating thickness and phase composition of the intermetallic layer. Coating particulate buildup on die surfaces can lead to changes in frictional behavior as well as poor appearance on surfaces of formed parts. Proper lubrication is essential in the design of any forming process, especially when forming zn-ni-cr coated parts. zn-ni-cr coatings fail as a result of particle removal during forming.

3.4.3.3 Weldability

Weldability of zn-ni-cr coatings is an important property of the coating, since most galvanized product is joined in this manner. Arc welding of galvanized steel sheet produces defects such as gas cavities (blowholes) and spatters. Recent research has shown that the formation mechanism of gas cavities was due to vaporization of the zn-ni-cr, and methods for the reduction of blowholes were developed to improve welding quality. In spot weldability zn-ni-cr coatings reduce the life of welding electrodes due to alloying of the copper electrode with zn-ni-cr. In the case of galvanized steel, the electrode life may be as little as 1500±2000 welds, compared to a tip life for bare steel of 10,000 welds. This effect leads to higher resistance, localized heating and increased pitting and erosion of the electrode tip. As a result, manufacturing costs increase because lower tip-life reduces productivity due to frequent down time in the welding operation to redress tips.

3.5 AISI 1040 STEEL

3.5.1 INTRODUCTION

AISI 1040 carbon steel has high carbon content and can be hardened by heat treatment followed by quenching and tempering to achieve 150 to 250 ksi tensile strength. The following datasheet gives an overview of AISI 1040 carbon steel. [12]

3.5.2 CHEMICAL COMPOSITION

The following table shows the chemical composition of AISI 1040 carbon steel.

Element	Content (%)
Iron, Fe	98.699
Manganese, Mn	0.60-0.90
Carbon, C	0.370-0.440
Sulfur, S	≤ 0.050
Phosphorous, P	≤ 0.040

Table 1: Chemical Composition of AISI 1040 Carbon Steel

3.5.3 PHYSICAL PROPERTIES

The physical properties of AISI 1040 carbon steel are tabulated below.

Properties	Metric	Imperial
Density (chemical composition of 0.435% C, 0.69% Mn, 0.20% Si, annealed at 860°C (1580°F))	7.845 g/cc	0.2834 lb./in³
Melting point	1521°C	2770°C

Table 2: Physical Properties of AISI 1040 Carbon Steel

3.5.4 MECHANICAL PROPERTIES

Properties	Metric	Imperial
Tensile strength	620 MPa	89900 psi
Yield strength	415 MPa	60200 psi
Bulk modulus (typical for steels)	140 GPa	20300 ksi
Shear modulus (typical for steels)	80 GPa	11600 ksi
Elastic Modulus	190-210 GPa	27557-30458 ksi
Poisson's ratio	0.27-0.30	0.27-0.30
Elongation at break (in 50 mm)	25%	25%
Reduction of area	50%	50%
Hardness, Brinell	201	201
Hardness, Knoop (converted from Brinell hardness)	223	223
Hardness, Rockwell B (converted from Brinell hardness)	93	93

Izod impact (annealed at 790°C (1450°F))	45 J	33.2 ftlb
Izod impact (as rolled)	49 J	36.1 ftlb
Izod impact (normalized at 900°C (1650°F)	65 J	47.9 ftlb

Table 3: Mechanical Properties of AISI 1040 Carbon Steel

3.5.5 OTHER DESIGNATIONS

Other designations that are equivalent to AISI 1040 carbon steel include:

ASTM A29 (1040)	ASTM A510 (1040)	ASTM A513
ASTM A519 (1040)	ASTM A546 (1040)	ASTM A576 (1040)
ASTM A682 (1040)	ASTM A827	ASTM A830
MIL S11310 (CS 1040)	MIL S16788	MIL S46070
SAE J1397 (1040)	SAE J403 (1040)	SAE J412 (1040

Table 4: Other Designations that are equivalent to AISI 1040 Carbon Steel

3.5.6 FABRICATION AND HEAT TREATMENT

3.5.6.1 MACHINABILITY

The machinability rating of AISI 1040 carbon steel is 60.

3.5.6.2 FORMING

AISI 1040 carbon steel can be formed in the annealed condition.

3.5.6.3 WELDING

AISI 1040 carbon steel can be welded using all welding techniques. It can be pre-heated at 149 to 260°C (300 to 500°F) and post-heated at 594 to 649°C (1100 to 1200°F) due to its high carbon content.

3.5.6.4 HEAT TREATMENT

AISI 1040 carbon steel can be heat treated at 844 to 899°C (1550 to 1650°F) followed by quenching in water and tempering.

3.5.6.5 FORGING

AISI 1040 carbon steel can be forged at 982 to 1260°C (1800 to 2300°F).

3.5.6.6 HOT WORKING

AISI 1040 carbon steel can be hot worked from 94 to 483°C (200 to 900°F).

3.5.6.7 COLD WORKING

AISI 1040 carbon steel can be cold worked in the annealed state using conventional methods.

3.5.6.8 ANNEALING

AISI 1040 carbon steel can be annealed at temperatures ranging from 872 to 983°C (1600 to 1800°F). It can be then slowly cooled in the furnace. Stress relief annealing process can be performed at a temperature of about 594°C (1100°F). Normalizing treatment can also be performed at 899°C (1650°F) followed by cooling slowly.

3.5.6.9 TEMPERING

AISI 1040 carbon steel can be tempered at 316 to 705°C (600 to 1300°F) based on the desired strength.

3.5.6.10 HARDENING

AISI 1040 carbon steel can be hardened by performing cold working process.

3.5.7 APPLICATIONS

AISI 1040 carbon steel can be used in couplings, crankshafts, and cold headed parts.

3.6 TENSILE TEST

A tensile test is most likely the most major kind of mechanical test you can perform on material. Tensile tests are straightforward, moderately reasonable, and completely institutionalized. By pulling on something, you will rapidly decide how the material will respond to powers being connected in strain. As the material is being pulled, you will think that its quality alongside the amount it will stretch.

The tensile test or strain test includes applying a continually expanding burden to a test example up to the point of disappointment. The procedure makes an anxiety/strain bend indicating how the material responds all through the tensile test. The information created amid tensile testing is utilized to focus mechanical properties of materials and gives the accompanying quantitative estimations:

Tensile strength, otherwise called Ultimate Tensile Strength (UTS), is the greatest tensile anxiety conveyed by the example, characterized as the most extreme burden isolated by the first cross-sectional territory of the test specimen. Yield strength is the stress at which time permanent (plastic) deformation or yielding is observed to begin.

Ductility measurements are typically elongation, defined as the strain at, or after, the point of fracture and reduction of area of the fracture of the test sample.

The test specimen is safely held by top and base holds joined to the tensile or widespread testing machine. Amid the strain test, the holds are moved separated at a consistent rate to extend the example. The power on the example and its relocation is constantly observed and plotted on an 33 anxiety strain bend until disappointment. The estimations, tensile quality, yield quality and flexibility are computed by the professional after the test example has broken. The test example is assembled back to gauge the last length, then this estimation is contrasted and the pre-test or unique length to acquire stretching. The first cross area estimation is likewise contrasted with the last cross segment to get the diminishment in region.

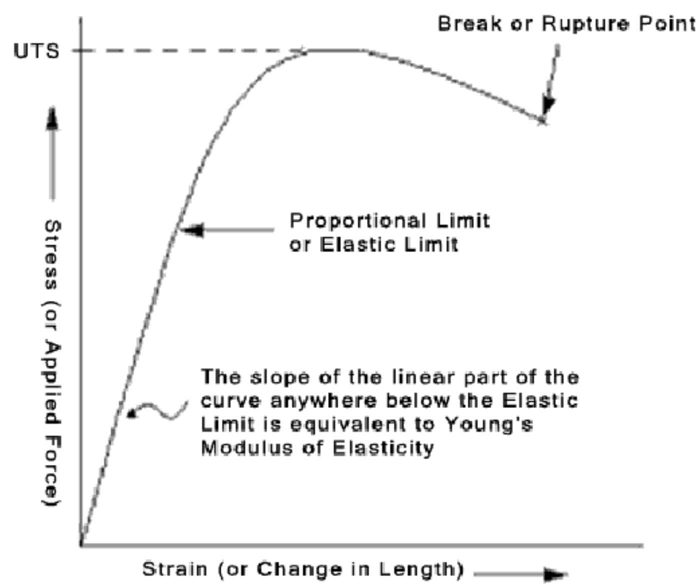


Fig 1: Stress Strain Graph

3.6.1 MODULUS OF ELASTICITY

The modulus of elasticity is a measure of the firmness of the material; however it just applies to the straight locale of the bend. On the off chance that an example is stacked inside this direct district, the material will come back to its same condition if the heap is uprooted. At the point that the bend is no straighter and digresses from the straight-line relationship, Hooke's Law no more applies and some changeless twisting happens in the example. This point is known 34 as the "versatile or relative utmost". Starting here on in the tensile test, the material responds plastically to any further increment in burden or anxiety. It won't come back to its unique, unstressed condition if the heap were uprooted.

3.6.2 YIELD STRENGTH

"Yield strength" of a material is characterized as the anxiety connected to the material at which plastic disfigurement begins to happen while the material is stacked.

3.6.3 STRAIN

Strain is a standardized measure of disfigurement speaking to the uprooting between particles in the body in respect to a reference length. The condition of strain at a material purpose of a continuum body is characterized as the totality of every last one of changes long of material lines or strands, the ordinary strain, which go through that point furthermore the totality of every last one of changes in the edge between sets of lines at first opposite to one another, the shear strain, emanating starting here. Nonetheless, it is sufficient to know the ordinary and shear segments of strain on an arrangement of three commonly opposite bearings.

3.6.4 STRESS

Stress is a physical amount that communicates the inside powers that neighboring particles of a ceaseless material apply on one another, while strain is the measure of the distortion of the material. Strain inside a material may emerge by different systems, for example, stress as connected by outer strengths to the mass material (like gravity) or to its surface (like contact powers, outside weight, or grating). Any strain (distortion) of a strong material produces an inward flexible stress, closely resembling the response power of a spring that has a tendency to restore the material to its unique non-twisted state. In fluids and gasses, just misshapenness that changes the volume produces persevering flexible stress. In any case, if the distortion is progressively changing with time, even in liquids there will ordinarily be a few gooey stresses, contradicting that change. Versatile and thick stresses are typically joined with the name mechanical stress.

3.6.5 ULTIMATE TENSILE STRENGTH

One of the properties you can focus on a material is its ultimate tensile strength (UTS). This is the greatest burden the example supports amid the test. The UTS might compare to the strength at break. This all relies on upon what sort of material you are trying . . . fragile, malleable or a substance that even shows both properties. Furthermore, here and there a material may be flexible when tried in a lab, be that as it may, when set in administration and presented to amazing icy temperatures, it may move to fragile conduct

3.7 IMPACT CHARPY TESTING

The Charpy impact test is an institutionalized high strain-rate test which decides the measure of vitality consumed by a material amid break. This ingested vitality is a measure of a given material's indent strength and goes about as a device to study temperature-subordinate bendable fragile move. The mechanical assembly comprises of a pendulum of known mass and length that is dropped from a known stature to impact an indented example of material. The vitality exchanged to the material can be surmised by contrasting the distinction in the stature of the mallet prior and then afterward the break (vitality consumed by the crack occasion). The score in the example influences the consequences of the impact test; hence it is important for the intent to be of consistent measurements and geometry. The span of the example can likewise influence results following the measurements figure out if or not the material are in plane strain. This distinction can incredibly influence conclusions made.

The Charpy Impact Test is ordinarily utilized on metals but, on the other hand, is connected to composites, earthenware production, and polymers. With the Charpy impact test one most regularly assesses the relative durability of a material, in that capacity; it is utilized as a fast and temperate quality control gadget. The Charpy Impact Test comprise of hitting a suitable example with a mallet on a pendulum arm while the example is held safely at every end. The sled strikes inverse the score. The vitality consumed by the example is dictated by definitely measuring the decline in the movement of the pendulum arm [15].

Vital variables that include the strength of a material incorporate low temperatures, high strain rates (by impact or pressurization), and anxiety concentrators, for example, indents breaks and voids. By applying the Charpy Impact Test to indistinguishable examples at distinctive temperatures, and after that plotting the impact vitality as a component of temperature, the bendable weak move gets to be evident. This is fundamental data to acquire when deciding the base administration temperature for a material. Impact testing decides a material's strength or impact quality in the vicinity of a blemish or score and quick stacking conditions. This damaging test includes cracking an indented example and measuring the measure of vitality consumed by the material amid break.

This impact test demonstrates the relationship of flexible to weak move in consumed vitality at a progression of temperatures. Since iron and all other body-focused cubic metals experience a move from bendable conduct at higher temperatures to fragile conduct at lower temperatures, this test is obliged today for various imperative steel items including steel structure plate for boats, atomic plant weight vessels, forgings for electric force plant generator rotors, and so forth. The test is performed utilizing a few machined bar examples 1cm x 1cm x 5.5cm with a 2mm profound indent at the center of a predetermined level surface – normally a "V" score. The examples are tested at a progression of indicated temperatures (e.g. -20ºC, -10ºC, 0ºC, +10ºC, +20ºC). When an example achieves the exact temperature, it is immediately set into a unique holder with the score arranged vertically and toward the birthplace of impact. The example is struck by a "tup" appended to a swinging pendulum of particular outline and weight. The example breaks at its scored cross-segment upon impact, and the upward swing of the pendulum is utilized to focus the measure of vitality consumed (indent sturdiness) simultaneously. It is still an inquiry if Charpy and others thought about the flexible to fragile move that happens with temperature in steel amid these early years of impact tests. The extent that it is known, the majority of Charpy's tests were led at room temperature.

Charpy test specimens normally measure 55x10x10mm and have a notch machined across one of the larger faces. The notches may be:

- V-notch – A V-shaped notch, 2mm deep, with 45° angle and 0.25mm radius along the base.
- U-notch or keyhole notch – A 5mm deep notch with 1mm radius at the base of the notch.

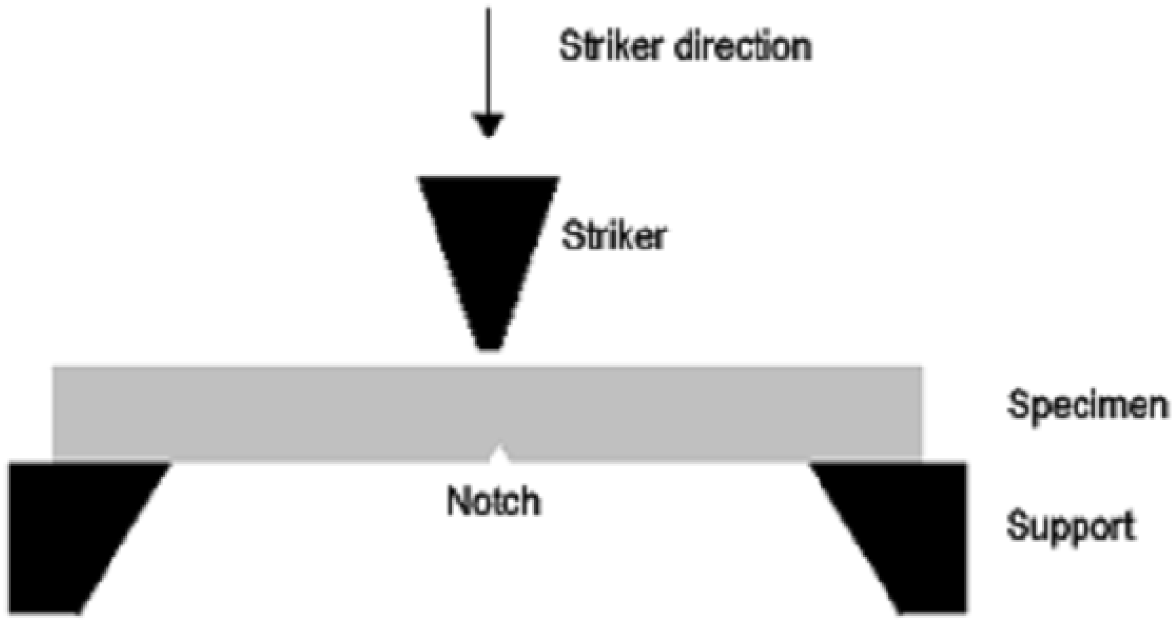


Fig 2: Impact Charpy Concept

3.7.1 TOUGHNESS

Toughness is the capacity of a material to ingest vitality and plastically misshape without fracturing. One meaning of material toughness is the measure of vitality every unit volume that a material can assimilate before bursting. It is additionally characterized as a material's imperviousness to break when focused.

3.7.2 FRACTURE

A fracture is the detachment of an item or material into two or more pieces under the activity of anxiety. The fracture of a strong as a rule happens because of the improvement of certain relocation intermittence surfaces inside the strong.

4. EXPERIMENTAL CALCULATIONS

4.1 TENSILE SPECIMEN

Length	300 mm
Gauge Length	56 mm
Radius	10 mm
Diameter of hole in gauge length	1 mm
Depth of hole in gauge length	0.5 mm

Table 5: Tensile Specimen Dimensions

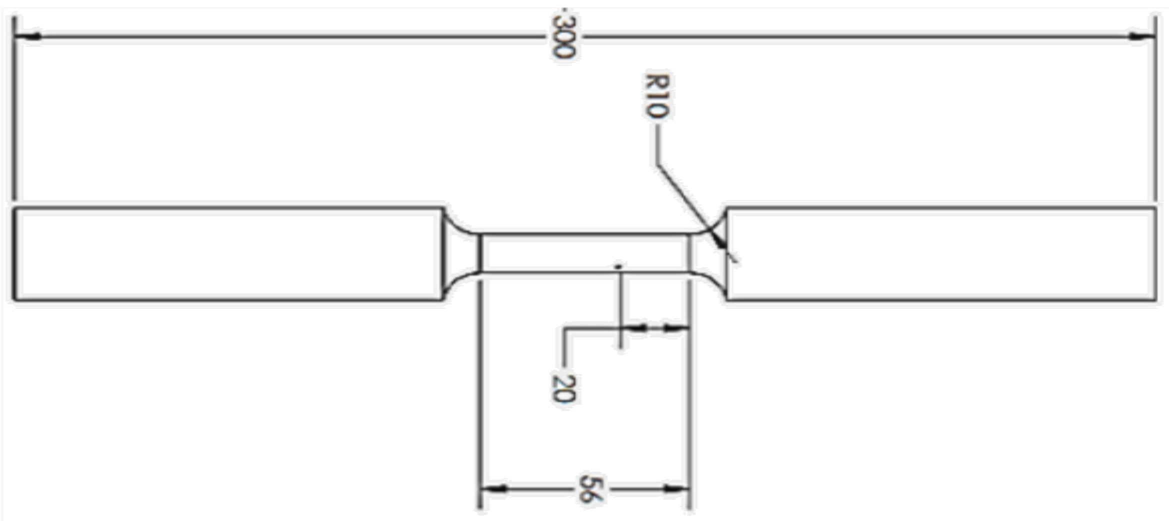


Fig 3: Tensile Specimen Dimensions

4.2 IMPACT CHARPY TEST SPECIMENS

The standard Charpy Impact Test specimen comprise of a bar of metal or other material, 55x10x10mm having a score machined over one of the bigger measurements.

Length of Specimen	55mm
Angle of V Notch	90^0
Width of Specimen	10mm
Height of Specimen	10mm

Table 6: Charpy Test Specimen Dimensions

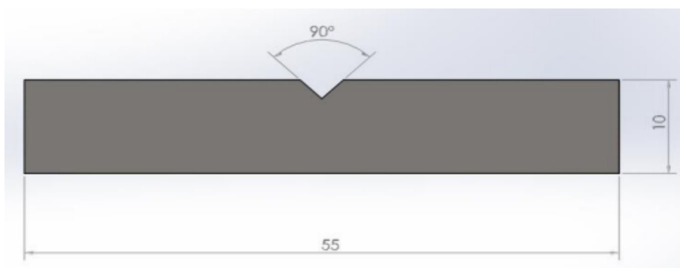


Fig 4: Charpy Test Specimen Dimensions

4.3 FORMULAE USED

4.3.1 FORMULAS USED FOR TENSILE TEST

$$Utlimate\ Tensile\ Strength = \frac{\text{Ultimate Load}}{\text{Original Cross Sectional Area}}$$

$$Percentage\ Elongation = \frac{\text{Extended Gauge Length} - \text{Original Gauge Length}}{\text{Original Gauge length}} \text{X100}$$

$$Yeild\ Strength = \frac{\text{Load on Yeild Point}}{\text{Original Cross Sectional Area}} \quad (N/mm2)$$

4.3.2 FORMULAS USED FOR CHARPY IMPACT TEST

$$Impact\ Energy\ (U) = \text{Final Reading} - \text{Initial Reading} \quad (Joules)$$

$$Notch\ Impact\ Strength\ (I) = \frac{\text{Impact Energy}}{\text{Effective Area of Specimen}} \quad (N/m)$$

$$Modulus\ of\ rapture = \frac{\text{Impact Energy}}{\text{Effective Volume}} \quad (Joule/mm3)$$

4.3.3 FORMULAS USED FOR CORROSION RATE

$$CR(mm/year) = \frac{Weight\ loss\ in\ grams\ X\ 8.74\ X\ 10\text{^}4}{Density\ X\ Cross\ sectional\ Area\ X\ Time\ (hrs)}$$

$$CR(mills/year) = \frac{\text{Weight loss in grams X 3.45 X 10^6}}{Density\ X\ Cross\ sectional\ Area\ X\ Time\ (hrs)}$$

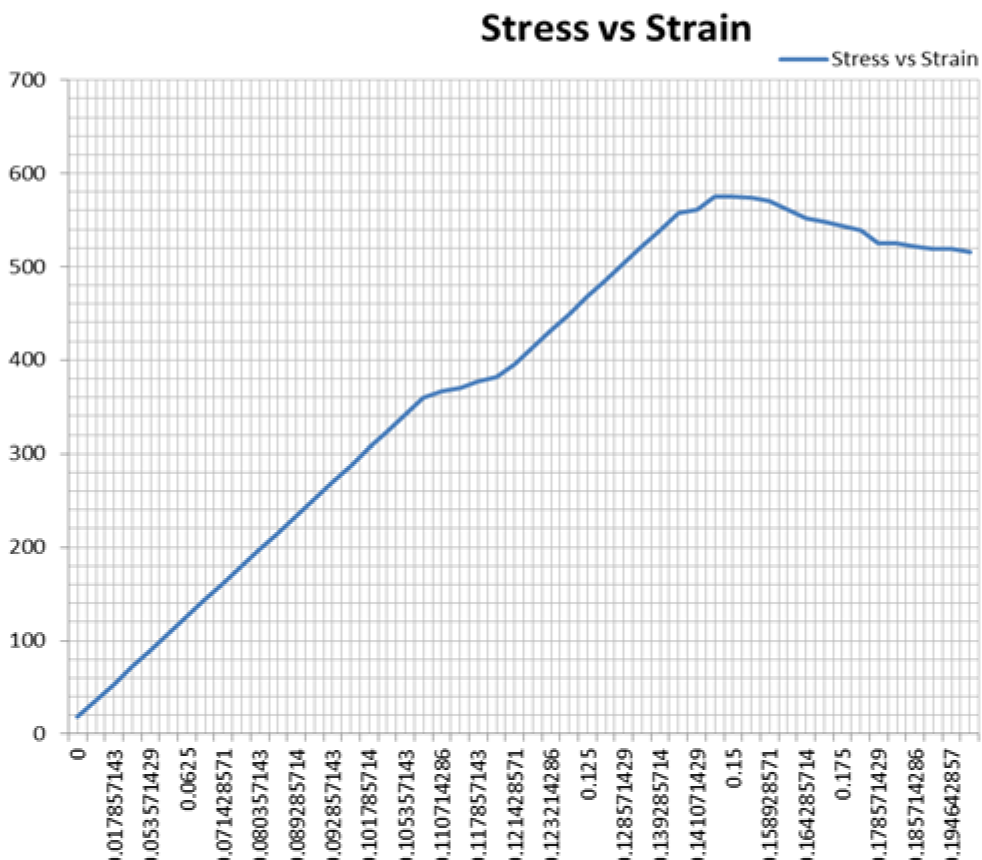
- Density = Density of the Bare Metal (gram/cc)
- Cross Sectional Area = Cross Sectional Area of the Gauge (mm^2)
- Time = Duration immersed in Saltwater Solution (hours)
- Weight Loss = Weight of specimen before immersed in saltwater – Weight of specimen after immersed in water

4.4 STRESS AND STRAIN VALUES OF BARE METAL

Load(KN)	Elongation(mm)	Stress	Strain
2	0	17.98237727	0
4	0	35.96475454	0
6	1	53.94713181	0.017857143
8	2	71.92950908	0.035714286
10	3	89.91188635	0.053571429
12	3.5	107.8942636	0.0625
14	3.5	125.8766409	0.0625
16	4	143.8590182	0.071428571
18	4	161.8413954	0.071428571
20	4.2	179.8237727	0.075
22	4.5	197.80615	0.080357143
24	4.8	215.7885272	0.085714286
26	5	233.7709045	0.089285714
28	5	251.7532818	0.089285714
30	5.2	269.7356591	0.092857143
32	5.5	287.7180363	0.098214286
34	5.7	305.7004136	0.101785714
36	5.7	323.6827909	0.101785714
38	5.9	341.6651681	0.105357143
40	6	359.6475454	0.107142857
40.8	6.2	366.8404963	0.110714286
41.2	6.4	370.4369718	0.114285714
42	6.6	377.6299227	0.117857143
42.4	6.8	381.2263981	0.121428571
44	6.8	395.6122999	0.121428571
46	6.9	413.5946772	0.123214286
48	6.9	431.5770545	0.123214286
50	6.95	449.5594318	0.124107143
52	7	467.541809	0.125
54	7	485.5241863	0.125
56	7.2	503.5065636	0.128571429
58	7.4	521.4889408	0.132142857
60	7.8	539.4713181	0.139285714
62	7.85	557.4536954	0.140178571
62.4	7.9	561.0501708	0.141071429
64	8	575.4360726	0.142857143

64	8.4	575.4360726	0.15
63.8	8.8	573.6378349	0.157142857
63.4	8.9	570.0413595	0.158928571
62.4	9	561.0501708	0.160714286
61.4	9.2	552.0589822	0.164285714
61	9.4	548.4625067	0.167857143
60.4	9.8	543.0677936	0.175
60	9.9	539.4713181	0.176785714
58.4	10	525.0854163	0.178571429
58.4	10.2	525.0854163	0.182142857
58	10.4	521.4889408	0.185714286
57.8	10.85	519.6907031	0.19375
57.8	10.9	519.6907031	0.194642857
57.4	11	516.0942277	0.196428571

- Table 7: Stress And Strain Values of Bare Material



- Graph 1: Stress vs. Strain Graph of Bare Material

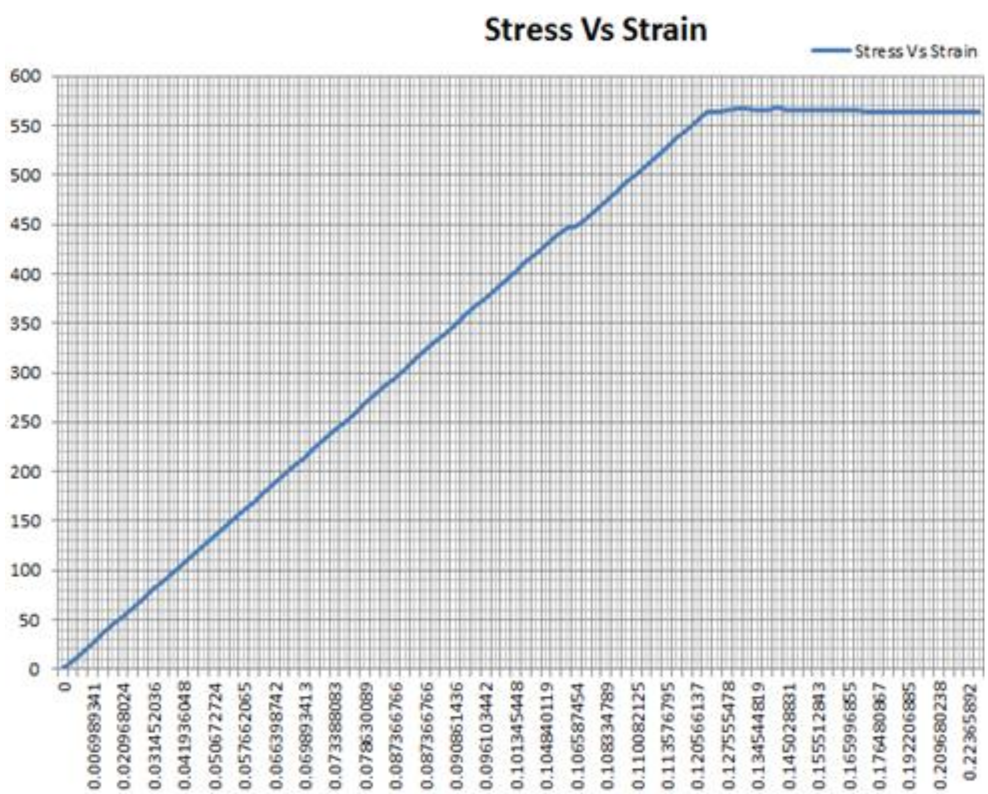
4.5 STRESS AND STRAIN VALUES OF CORRODED BARE METAL

Load(KN)	Elongation(mm)	Stress	Strain
0	0	0	0
1	0	8.946144212	0
2	0.1	17.89228842	0.001747335
3	0.4	26.83843264	0.006989341
4	0.6	35.78457685	0.010484012
5	1	44.73072106	0.017473353
6	1.2	53.67686527	0.020968024
7	1.6	62.62300948	0.027957365
8	1.8	71.56915369	0.031452036
9	1.8	80.51529791	0.031452036
10	2	89.46144212	0.034946706
11	2.1	98.40758633	0.036694042
12	2.4	107.3537305	0.041936048
13	2.6	116.2998748	0.045430718
14	2.8	125.246019	0.048925389
15	2.9	134.1921632	0.050672724
16	3	143.1383074	0.052420059
17	3.2	152.0844516	0.05591473
18	3.3	161.0305958	0.057662065
19	3.5	169.97674	0.061156736
20	3.7	178.9228842	0.064651407
21	3.8	187.8690284	0.066398742
22	3.9	196.8151727	0.068146077
23	4	205.7613169	0.069893413
24	4	214.7074611	0.069893413
25	4	223.6536053	0.069893413
26	4.1	232.5997495	0.071640748
27	4.2	241.5458937	0.073388083
28	4.2	250.4920379	0.073388083
29	4.3	259.4381821	0.075135418
30	4.5	268.3843264	0.078630089
31	4.7	277.3304706	0.08212476
32	4.9	286.2766148	0.08561943
33	5	295.222759	0.087366766
34	5	304.1689032	0.087366766
35	5	313.1150474	0.087366766

36	5	322.0611916	0.087366766
37	5	331.0073358	0.087366766
38	5.1	339.9534801	0.089114101
39	5.2	348.8996243	0.090861436
40	5.2	357.8457685	0.090861436
41	5.3	366.7919127	0.092608772
42	5.5	375.7380569	0.096103442
43	5.5	384.6842011	0.096103442
44	5.6	393.6303453	0.097850778
45	5.8	402.5764895	0.101345448
46	5.9	411.5226337	0.103092784
47	5.9	420.468778	0.103092784
48	6	429.4149222	0.104840119
49	6	438.3610664	0.104840119
49.9	6	446.4125962	0.104840119
50	6.1	447.3072106	0.106587454
51	6.1	456.2533548	0.106587454
52	6.2	465.199499	0.108334789
53	6.2	474.1456432	0.108334789
54	6.2	483.0917874	0.108334789
55	6.3	492.0379317	0.110082125
56	6.3	500.9840759	0.110082125
57	6.3	509.9302201	0.110082125
58	6.4	518.8763643	0.11182946
59	6.5	527.8225085	0.113576795
60	6.7	536.7686527	0.117071466
61	6.8	545.7147969	0.118818801
62	6.9	554.6609411	0.120566137
63	7	563.6070853	0.122313472
63.1	7.1	564.5016998	0.124060807
63.2	7.3	565.3963142	0.127555478
63.4	7.7	567.185543	0.134544819
63.3	7.3	566.2909286	0.127555478
63.2	7.7	565.3963142	0.134544819
63.11	8	564.5911612	0.139786825
63.5	8.2	568.0801575	0.143281496
63.2	8.3	565.3963142	0.145028831
63.2	8.5	565.3963142	0.148523502
63.2	8.8	565.3963142	0.153765508

63.2	8.9	565.3963142	0.155512843
63.2	9	565.3963142	0.157260178
63.2	9.1	565.3963142	0.159007514
63.2	9.5	565.3963142	0.165996855
63.2	9.9	565.3963142	0.172986196
63.1	10	564.5016998	0.174733531
63.1	10.1	564.5016998	0.176480867
63.1	10.5	564.5016998	0.183470208
63.1	10.9	564.5016998	0.190459549
63.1	11	564.5016998	0.192206885
63.1	11.1	564.5016998	0.19395422
63.1	11.6	564.5016998	0.202690896
63	12	563.6070853	0.209680238
63	12.1	563.6070853	0.211427573
63	12.3	563.6070853	0.214922244
63	12.8	563.6070853	0.22365892
63	13	563.6070853	0.227153591

- Table 8: Stress vs. Strain Values of Corroded Bare Material



- Graph 2: Stress vs. Strain Graph of Corroded Bare Material

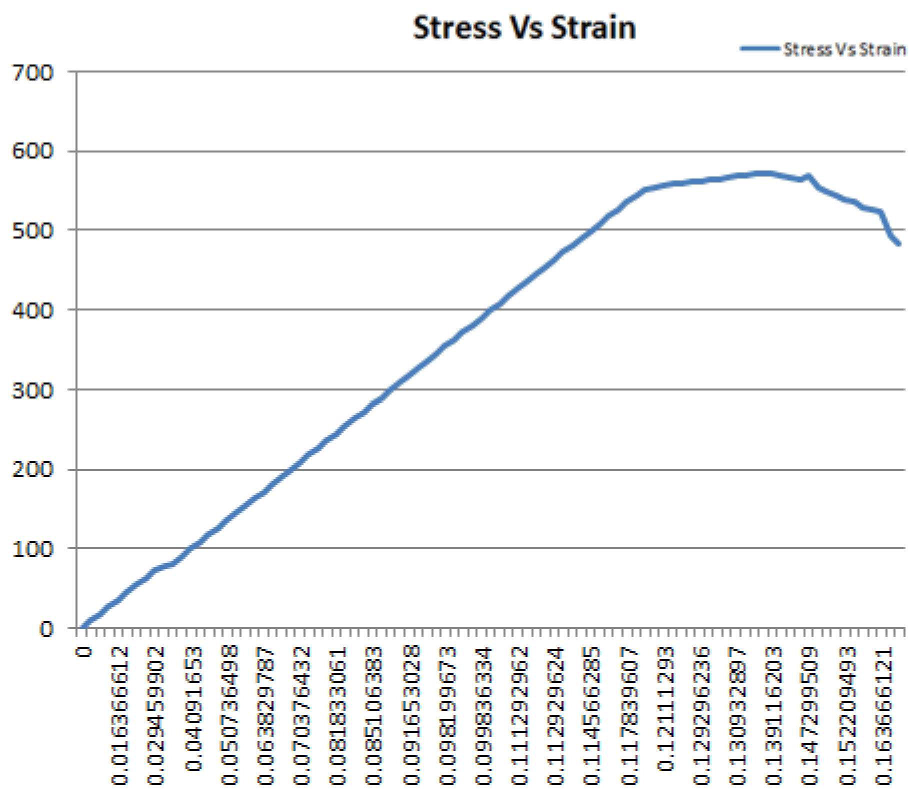
4.6 STRESS AND STRAIN VALUES OF COATED SPECIMEN

Load(KN)	Elongation(mm)	Stress	Strain
0	0	0	0
1	0.2	9.082652134	0.003273322
2	0.4	18.16530427	0.006546645
3	0.4	27.2479564	0.006546645
4	1	36.33060854	0.016366612
5	1	45.41326067	0.016366612
6	1.2	54.49591281	0.019639935
7	1.5	63.57856494	0.024549918
8	1.8	72.66121708	0.029459902
8.7	2	79.01907357	0.032733224
9	2.2	81.74386921	0.036006547
10	2.5	90.82652134	0.04091653
11	2.5	99.90917348	0.04091653
12	2.7	108.9918256	0.044189853
13	3	118.0744777	0.049099836
14	3	127.1571299	0.049099836
15	3.1	136.239782	0.050736498
16	3.2	145.3224342	0.052373159
17	3.3	154.4050863	0.05400982
18	3.8	163.4877384	0.062193126
19	3.9	172.5703906	0.063829787
20	4	181.6530427	0.065466448
21	4.1	190.7356948	0.06710311
22	4.2	199.818347	0.068739771
23	4.3	208.9009991	0.070376432
24	4.4	217.9836512	0.072013093
25	4.5	227.0663034	0.073649755
26	4.8	236.1489555	0.078559738
27	5	245.2316076	0.081833061
28	5	254.3142598	0.081833061
29	5	263.3969119	0.081833061
30	5.1	272.479564	0.083469722
31	5.2	281.5622162	0.085106383
32	5.3	290.6448683	0.086743044
33	5.5	299.7275204	0.090016367
34	5.5	308.8101726	0.090016367

35	5.6	317.8928247	0.091653028
36	5.7	326.9754768	0.093289689
37	5.8	336.058129	0.09492635
38	5.9	345.1407811	0.096563011
39	6	354.2234332	0.098199673
40	6	363.3060854	0.098199673
41	6	372.3887375	0.098199673
42	6	381.4713896	0.098199673
43	6.1	390.5540418	0.099836334
44	6.1	399.6366939	0.099836334
45	6.2	408.719346	0.101472995
46	6.7	417.8019982	0.109656301
47	6.8	426.8846503	0.111292962
48	6.9	435.9673025	0.112929624
49	6.9	445.0499546	0.112929624
50	6.9	454.1326067	0.112929624
51	6.9	463.2152589	0.112929624
52	6.9	472.297911	0.112929624
53	6.9	481.3805631	0.112929624
54	7	490.4632153	0.114566285
55	7	499.5458674	0.114566285
56	7.1	508.6285195	0.116202946
57	7.1	517.7111717	0.116202946
58	7.1	526.7938238	0.116202946
59	7.2	535.8764759	0.117839607
60	7.3	544.9591281	0.119476268
60.7	7.3	551.3169846	0.119476268
61	7.4	554.0417802	0.12111293
61.3	7.4	556.7665758	0.12111293
61.5	7.5	558.5831063	0.122749591
61.6	7.6	559.4913715	0.124386252
61.8	7.8	561.3079019	0.127659574
61.9	7.9	562.2161671	0.129296236
62	7.9	563.1244323	0.129296236
62.2	8	564.9409628	0.130932897
62.4	8	566.7574932	0.130932897
62.6	8	568.5740236	0.130932897
62.7	8.1	569.4822888	0.132569558
62.9	8.2	571.2988193	0.134206219

63	8.2	572.2070845	0.134206219
62.9	8.5	571.2988193	0.139116203
62.7	9	569.4822888	0.147299509
62.3	9	565.849228	0.147299509
62	9	563.1244323	0.147299509
62.6	9	568.5740236	0.147299509
61	9	554.0417802	0.147299509
60.5	9.1	549.5004541	0.14893617
60	9.2	544.9591281	0.150572831
59.4	9.3	539.5095368	0.152209493
59	9.4	535.8764759	0.153846154
58.2	9.5	528.6103542	0.155482815
58	10	526.7938238	0.163666121
57.7	10	524.0690282	0.163666121
54.3	10.1	493.1880109	0.165302782
53.3	10.5	484.1053588	0.171849427

- Table 9: Stress vs. Strain Values of Coated Material



- Graph 3: Stress vs. Strain Graph of Coated Material

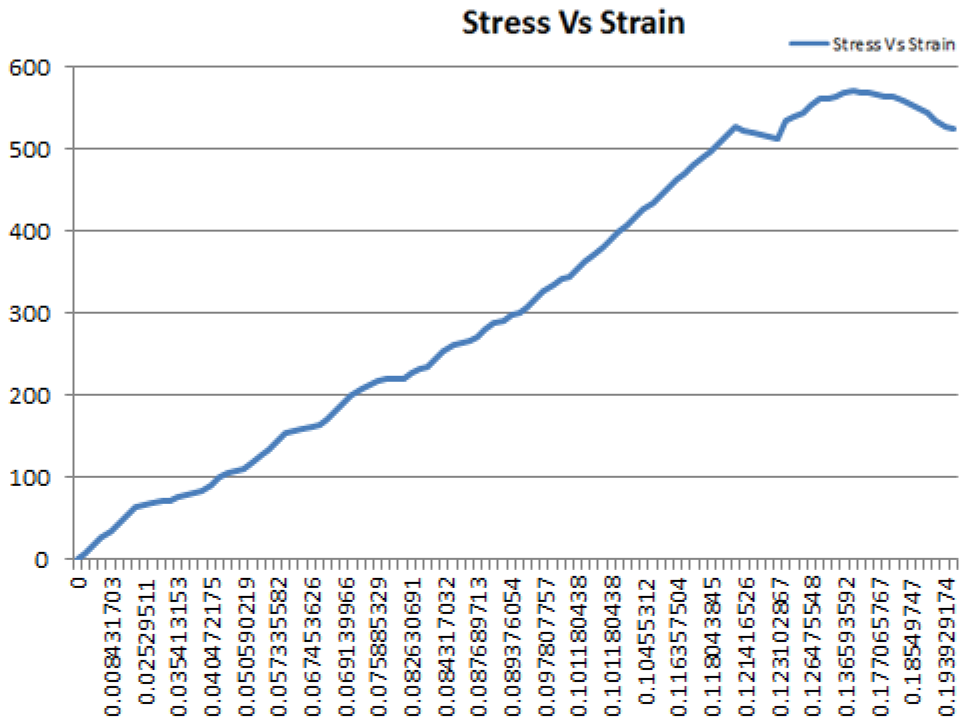
4.7 STRESS AND STRAIN VALUES OF CORRODED COATED SPECIMEN

Load (KN)	Elongation (mm)	Stress	Strain
0	0	0	0
1	0	0.009082652	0
2	0	0.018165304	0
3	0.1	0.027247956	0.001686341
4	0.5	0.036330609	0.008431703
5	1	0.045413261	0.016863406
6	1.1	0.054495913	0.018549747
7	1.4	0.063578565	0.023608769
7.3	1.5	0.066303361	0.02529511
7.7	1.8	0.069936421	0.030354132
7.9	1.9	0.071752952	0.032040472
8	2	0.072661217	0.033726813
8.3	2.1	0.075386013	0.035413153
8.8	2.1	0.079927339	0.035413153
9	2.1	0.081743869	0.035413153
9.3	2.2	0.084468665	0.037099494
10	2.4	0.090826521	0.040472175
11	2.5	0.099909173	0.042158516
11.7	2.8	0.10626703	0.047217538
12	2.9	0.108991826	0.048903879
12.3	3	0.111716621	0.050590219
13	3.1	0.118074478	0.05227656
14	3.2	0.12715713	0.053962901
15	3.3	0.136239782	0.055649241
16	3.4	0.145322434	0.057335582
17	3.6	0.154405086	0.060708263
17.3	3.8	0.157129882	0.064080944
17.6	3.9	0.159854678	0.065767285
17.8	4	0.161671208	0.067453626
18	4	0.163487738	0.067453626
19	4	0.172570391	0.067453626
20	4	0.181653043	0.067453626
21	4.1	0.190735695	0.069139966
22	4.2	0.199818347	0.070826307
23	4.3	0.208900999	0.072512648
23.4	4.5	0.21253406	0.075885329

24	4.5	0.217983651	0.075885329
24.2	4.5	0.219800182	0.075885329
24.4	4.8	0.221616712	0.080944351
24.4	4.9	0.221616712	0.082630691
25	4.9	0.227066303	0.082630691
25.7	4.9	0.23342416	0.082630691
26	4.9	0.236148955	0.082630691
27	4.9	0.245231608	0.082630691
28	5	0.25431426	0.084317032
28.9	5.1	0.262488647	0.086003373
29	5.1	0.263396912	0.086003373
29.4	5.2	0.267029973	0.087689713
30	5.2	0.272479564	0.087689713
31	5.2	0.281562216	0.087689713
31.7	5.3	0.287920073	0.089376054
32	5.3	0.290644868	0.089376054
32.8	5.3	0.29791099	0.089376054
33	5.5	0.29972752	0.092748735
34	5.5	0.308810173	0.092748735
35	5.6	0.317892825	0.094435076
36	5.8	0.326975477	0.097807757
37	5.9	0.336058129	0.099494098
37.8	6	0.343324251	0.101180438
38	6	0.345140781	0.101180438
39	6	0.354223433	0.101180438
40	6	0.363306085	0.101180438
41	6	0.372388738	0.101180438
42	6	0.38147139	0.101180438
43	6	0.390554042	0.101180438
44	6.1	0.399636694	0.102866779
45	6.1	0.408719346	0.102866779
46	6.2	0.417801998	0.10455312
47	6.2	0.42688465	0.10455312
48	6.2	0.435967302	0.10455312
49	6.5	0.445049955	0.109612142
50	6.8	0.454132607	0.114671164
51	6.9	0.463215259	0.116357504
52	6.9	0.472297911	0.116357504
53	6.9	0.481380563	0.116357504

54	7	0.490463215	0.118043845
55	7	0.499545867	0.118043845
56	7	0.50862852	0.118043845
57	7.1	0.517711172	0.119730185
58	7.2	0.526793824	0.121416526
57.6	7.2	0.523160763	0.121416526
57.4	7.2	0.521344233	0.121416526
57	7.3	0.517711172	0.123102867
56.8	7.3	0.515894641	0.123102867
56.4	7.3	0.51226158	0.123102867
59	7.3	0.535876476	0.123102867
59.4	7.5	0.539509537	0.126475548
60	7.5	0.544959128	0.126475548
61	7.5	0.55404178	0.126475548
61.8	7.8	0.561307902	0.13153457
61.8	8	0.561307902	0.134907251
62	8	0.563124432	0.134907251
62.7	8.1	0.569482289	0.136593592
62.8	8.5	0.570390554	0.143338954
62.7	9	0.569482289	0.151770658
62.6	10	0.568574024	0.168634064
62.4	10.5	0.566757493	0.177065767
62.2	11	0.564940963	0.18549747
62	11	0.563124432	0.18549747
61.7	11	0.560399637	0.18549747
61	11	0.55404178	0.18549747
60.4	11.1	0.548592189	0.187183811
60	11.2	0.544959128	0.188870152
59	11.4	0.535876476	0.192242833
58	11.5	0.526793824	0.193929174
57.9	12	0.525885559	0.202360877

- Table 10: Stress vs. Strain Values of Corroded Coated Material



- Graph 4: Stress vs. Strain Graph of Corroded Coated Material

5. RESULTS AND DISCUSSION

5.1 CORROSION RATE

5.1.1 CORROSION RATE OF BARE METAL

Surface Area of Bare Metal = 180.57 cm^2

$$CR\ (mm/year) = \frac{4 \text{ x } 8.74 \text{ x } 10^4}{7.847 \text{ x } 180.57 \text{ x } 96} = 2.5707\ mm/year$$

$$CR\ (mils/year) = \frac{4 \text{ x } 3.45 \text{ x } 10^6}{7.845 \text{ x } 180.57 \text{ x } 96} = 101.477\ mils/year$$

5.1.2 CORROSION RATE OF COATED METAL WITH ZINC – NICKEL - CHROME

Surface Area of Zn- Ni- Cr Metal = 180.57 x 4 = 722.28 cm^2

Density of Zn-Ni-Cr = 7.30 g/cc

$$CR\ (mm/year) = \frac{2 \text{ x } 8.74 \text{ x } 10^4}{7.30 \text{ x } 722.28 \text{ x } 96} = 0.34533\ mm/year$$

$$CR\ (mils/year) = \frac{2 \text{ x } 3.45 \text{ x } 10^6}{7.30 \text{ x } 722.28 \text{ x } 96} = 13.63168 mils/year$$

5.1.3 PERCENTAGE DECREASE IN CORROSION

$$\%\ decrease\ in\ corrosion = \frac{0.730 - 2.570}{2.570}\ x\ 100 = -71.59\%$$

The corrosion of bare metal with Zn-Ni-Cr electroplated coating has reduced the corrosion rate by 71.59 %

5.2 IMPACT ENERGY AND MODULUS OF RAPTURE

5.2.1 IMPACT ENERGY AND MODULUS OF RAPTURE OF BARE METAL

Material	Length (mm)	Breadth (mm)	Height (mm)	Depth of Notch (mm)	Initial Reading (Joules) (X)	Final Reading (Joules) (Y)	Effective Area (m^2)	Impact Energy (N/m)	Modulus of Rupture Joule/mm^3
Bare	54.74	9.47	9.47	0.9	2	37.5	8.96809 E-05	395847.9	0.007231
Corroded Bare	55.52	9.43	9.43	1.21	2	33.8	8.89249 E-05	357605.1	0.006441

Table 11: Impact Energy and Modulus of Rapture of Bare Metal

5.2.2 IMPACT ENERGY AND MODULUS OF RAPTURE OF COATED METAL

Material	Length (mm)	Breadth (mm)	Height (mm)	Depth of Notch (mm)	Initial Reading (Joules) (X)	Final Reading (Joules) (Y)	Effective Area	Impact Energy (N/mm)	Modulus of Rupture (Joule/mm^3)
Bare Zn-Ni-Cr	56.20	9.5	9.5	1.3	2	48.2	0.00009025	511911.3	0.00910874
Corroded Zn-Ni-Cr	55.42	9.43	9.43	1.13	2	30	0.00008892	314889.7	0.00568156

Table 12: Impact Energy and Modulus of Rapture of Coated Metal

$1mm^2 = 10^{-6}\ m^2$

Impact Energy = U/A_e

A_e = Effective Area

Impact Strength (U) = Y-X

Modulus of Rapture = U/V_e

V_e = Effective Volume

5.3 RESULTS OF MECHANICAL TESTING

Readings	Tensile Strength (N/mm^2)	Yield Strength (N/mm^2)	Impact Energy (KN)	Hardness
Bare Metal	574.01	360	400.912	33.166
Corroded Bare Metal	568.01	352	357.605	29.667
Zn-Ni-Cr	574.438	385.2	511.911	35.63
Corroded Zn-Ni-Cr	570.51	367.5	314.889	31.92

Table 13: Results of Mechanical Testing

6. CONCLUSIONS AND RECOMMENDATIONS

1. The results show that the ultimate tensile strength is increasing for zn-ni-cr coating, also yield strength is increasing for the coating. It is showing the same consequences for both corroded and non-corroded specimens.
2. For a given tempering time, the ultimate tensile strength and the yield strength decrease, whereas the elongation and hence the ductility i.e. elongation increases by increasing the tempering temperature.
3. Ultimate tensile strength decreases continuously by increasing tempering temperature and time. The ductility of the specimen is measured by the tensile test. The elongation increases with the increase in tempering temperature and time.
4. The higher is the tempering temperature, the lower is the hardness or the more is softness (ductility) induced in the previously quenched specimen.
5. The longer is the tempering time (keeping the temperature constant), the higher is the ductility induced in the specimen as a result of the grain re-arrangement.

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APPENDIX

A1. ARTIFICIAL SALT WATER SOLUTION

This substitute sea water may be utilized for research center testing where a reproducible arrangement reenacting ocean water is needed. Cases are for tests for oil sullying, detergency assessment, and erosion testing. The need natural matter, suspended matter, and marine life in this arrangement does not allow unfit acknowledgement of test results as speaking to execution in genuine sea water. Where erosion is included, the outcomes got from research facility tests may not estimate those secured under regular testing conditions that contrast extraordinarily from those of the lab, and particularly where impacts of speed, salt environments, or natural constituents are included. Additionally, the fast exhaustion of responding components introduce in low fixations recommends alert in the direct utilization of results [16].

A1.1 "THE CORROSION BEHAVIOR OF LOW CARBON STEEL IN NATURAL AND SYNTHETIC SEAWATERS" BY H. MOLLER, E.T. BOSHOFF, AND H. FRONEMAN

Drenching tests were performed in consistently circulated air through arrangements utilizing two examples every arrangement. The volume of the arrangement was 1000 ml. Air circulation was attained to by utilizing a little vacuum apparatus, which additionally added to uniform test conditions by blending. All trials were directed at room temperature (25°C). The specimens were drenched in the different answers for 3, 10 or 21 days. The water in the test cells was invigorated at regular intervals for the most extended introduction times. Before examination in an examining electron magnifying lens (SEM), the examples were covered with a sputtered layer of gold keeping in mind the end goal to lessen charging impacts. Erosion items in the examples utilized for the weight reduction investigations were uprooted with Clarke's answer preceding weighing. A without scale test was additionally tried in Clarke's answer for confirm that negligible metal misfortune happened amid this treatment.

A2. UNIAXIAL TENSILE TESTING

Uniaxial tensile test is known as a basic and universal engineering test to achieve material parameters such as ultimate strength, yield strength, % elongation, % area of reduction and

Young's modulus. These important parameters obtained from the standard tensile testing are useful for the selection of engineering materials for any applications required [17].

The tensile testing is carried out by applying longitudinal or axial load at a specific extension rate to a standard tensile specimen with known dimensions (gauge length and cross sectional area perpendicular to the load direction) till failure. The applied tensile load and extension are recorded during the test for the calculation of stress and strain. A range of universal standards provided by Professional societies such as American Society of Testing and Materials (ASTM), British standard, JIS standard and DIN standard provides testing are selected based on preferential uses. Each standard may contain a variety of test standards suitable for different materials, dimensions and fabrication history. For instance, ASTM E8: is a standard test method for tension testing of metallic materials and ASTM B557 is standard test methods of tension testing wrought and cast aluminum and magnesium alloy products.

A standard specimen is prepared in a round or a square section along the gauge length, depending on the standard used. Both ends of the specimens should have sufficient length and a surface condition such that they are firmly gripped during testing. The initial gauge length Lo is standardized (in several countries) and varies with the diameter (Do) or the cross-sectional area (Ao) of the specimen. This is because if the gauge length is too long, the % elongation might be underestimated in this case. Any heat treatments should be applied on to the specimen prior to machining to produce the final specimen readily for testing. This has been done to prevent surface oxide scales that might act as stress concentration which might subsequently affect the final tensile properties due to premature failure. There might be some exceptions, for examples, surface hardening or surface coating on the materials. These processes should be employed after specimen machining in order to obtain the tensile properties results which include the actual specimen surface conditions.

General techniques utilized for measuring loads and displacements employs sensors providing electrical signals. Load cells are used for measuring the load applied while strain gauges are used for strain measurement. A Change in a linear dimension is proportional to the change in electrical voltage of the strain gauge attached on to the specimen

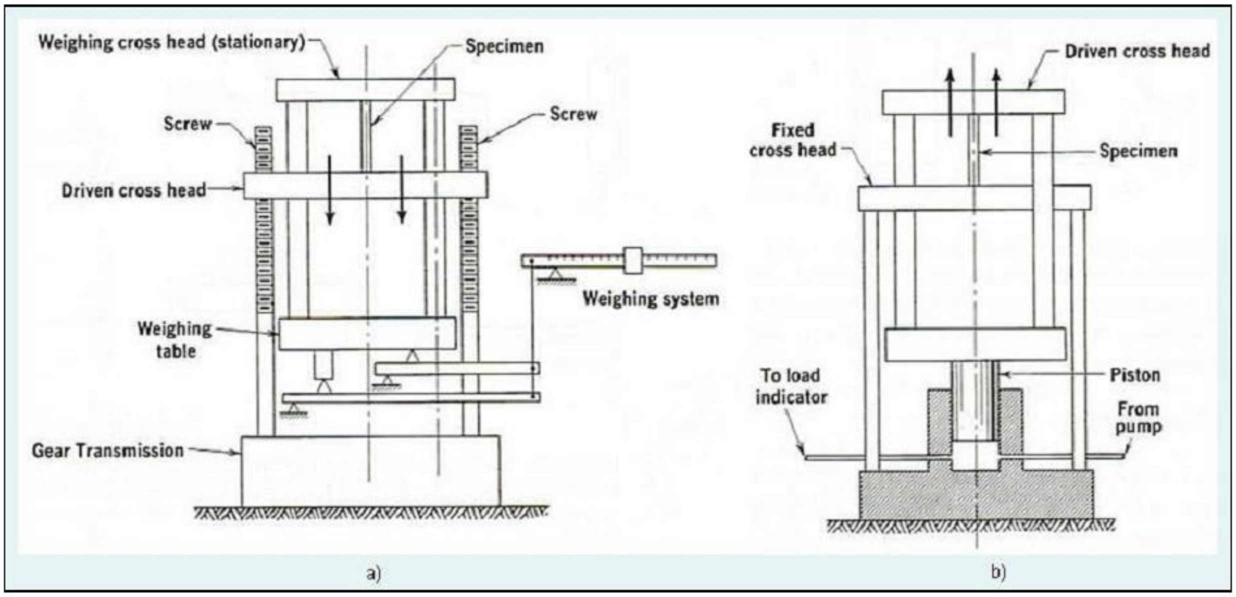

Fig 5: Schematics showing a) A screw driven machine and b) A hydraulic testing machine.

A3. CHARPY IMPACT TEST

The Charpy Impact Test, also known as the Charpy V-notch test, is a standardized high strain-rate test which determines the amount of energy absorbed by a material during fracture. This absorbed energy is a measure of a given material's notch toughness and acts as a tool to study temperature-dependent ductile-brittle transition. It is widely applied in industry, since it is easy to prepare and conduct and results can be obtained quickly and cheaply. A disadvantage is that some results are only comparative.

The test was developed around 1900 by S. B. Russell (1898, American) and G. Charpy (1901, French). The test became known as the Charpy test in the early 1900s due to the technical contributions and standardization efforts by Georges Charpy. The test was pivotal in understanding the fracture problems of ships during WWII.

Today it is utilized in many industries for testing materials, for example the construction of pressure vessels and bridges to determine how storms will affect the materials used.

A3.1 DEFINITION

The apparatus consists of a pendulum of known mass and length that is dropped from a known height to impact a notched specimen of material. The energy transferred to the material can be inferred by comparing the difference in the height of the hammer before and after the fracture (energy absorbed by the fracture event).

The notch in the sample affects the results of the impact test, thus it is necessary for the notch to be of regular dimensions and geometry. The size of the sample can also affect results, since the dimensions determine whether or not the material is in plane strain. This difference can greatly affect conclusions made.

The "Standard methods for Notched Bar Impact Testing of Metallic Materials" can be found in ASTM E23, ISO 148-1 or EN 10045-1, where all the aspects of the test and equipment used are described in detail.

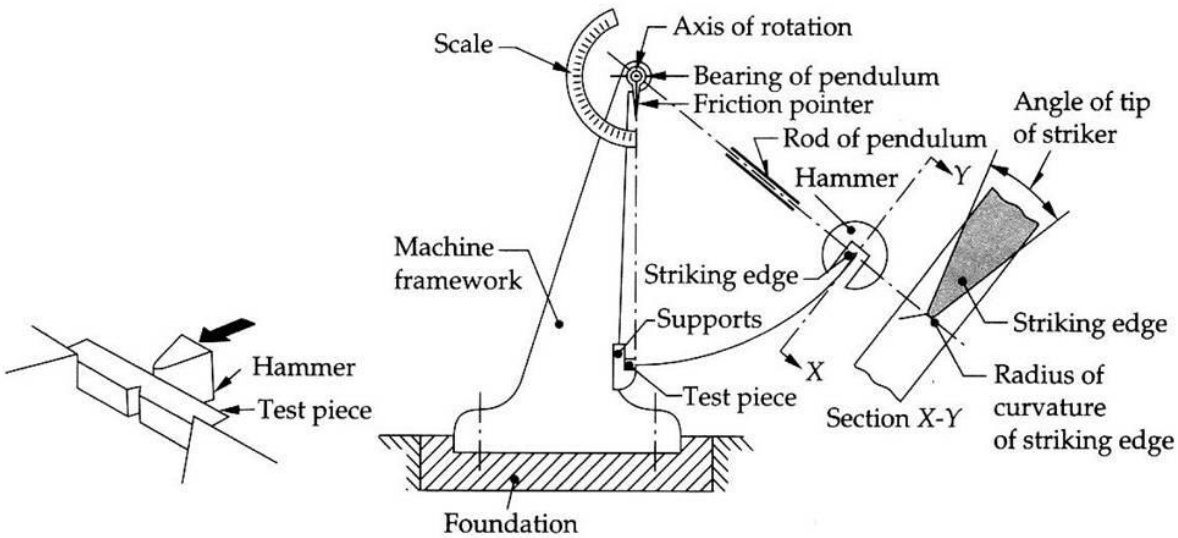

Fig 6: Schematics showing an example of Charpy Impact Test

SPECIMEN USED IN EXPERIMENTAL WORK

A4. UTM TENSILE TEST BROKEN SPECIMENS

Fig 7: Bare UTM Test Specimen

Fig 8: Bare Corroded UTM Test Specimen

Fig 9: Corrosion on Coated Specimen

Fig 10: Corroded Coated UTM Specimen

Fig 11: Coated UTM Specimen