

# EXPERIMENTAL STUDIES AND ANALYSIS OF (ZINC) COATING ON PIPELINE MATERIAL

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# EXPERIMENTAL STUDIES AND ANALYSIS OF (ZINC) COATING ON PIPELINE MATERIAL

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**CERTIFICATE**

This is to certify that the work contained in this thesis titled “**Experimental Studies and Analysis of (Zinc) Coating on Pipeline Material**” has been carried out by Mintu Choudhury under my supervision and has not been submitted elsewhere for a degree.

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## **ABSTRACT**

The generation of zinc and zinc alloy coatings on steel is one of the commercially most important processing techniques used to protect steel components exposed to corrosive environments. From a technological standpoint, the principles of galvanizing have remained unchanged since this coating came into use over 200 years ago. However, because of new applications in the automotive and construction industry, a considerable amount of research has recently occurred on all aspects of the galvanizing process and on new types of Zn coatings. This review will discuss the metallurgy of zinc-coated steel from a scientific standpoint to develop relationships to practical applications. Researches in the area of zinc coatings on steel are rather unending because of the unique properties and the very low cost that it offers. This project involves the experimental studies of the metallic coating (Zinc) on AISI 1040 oil quenched steel. It includes checking the fatigue loads that the material can withstand, tensile strength using Universal Testing Machine, V-Notch Charpy test to check the toughness of the material and dipping the specimens in 5% NaCl solution for determining the corrosion rate. Scanning Electron Microscope (SEM) will be used to study the surface morphology, the topography and the surface adherent properties of the coatings. These tests will be conducted on bare metal and the coated metal and the results will be compared. The effectiveness of the coating will be concluded accordingly.

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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 assume a to a great degree critical part all through the world for transporting gases and fluids. Generally, these pipelines are laid under buried situations over long distances from source to destination. In the United States there are around 2 million km of covered gas pipelines and 280,000 km of petroleum pipelines [1]. In Canada there is around 580,000 km of buried pipelines, which contributes billions of dollars to the economy. The developing interest and significance for pipelines in everywhere throughout the world warrants uncommon thoughtfulness regarding shield it from the crumbling impacts, for example, corrosion, external forces and others. Among these impacts, corrosion contributes most of the pipe failure cases. Case in point, a late audit shows that corrosion of metals and compounds costs U.S organizations a sum of more or less \$300 billion every year [2]. The researchers at Battelle Institute and the National Institute of Standards and Technology presumed that roughly 33% of the aggregate expenses (\$ 100 billion every year) could be altogether decreased or killed by the utilization of best accessible erosion aversion systems and materials [2].

The two principle classifications of pipe failure are external forces and corrosion. The external forces are because of pipeline operators, mishaps like earthquakes and others. The pipeline failure because of corrosion incorporates both inner and outside corrosion. External forces and corrosion represent more than 60 percent of all pipeline failures [3]. Corrosion is named significant reason for pipeline failures with its both sorts (interior and outer). Corrosion is the phenomena of electrochemical response between the material and its surroundings. In the vast majority of the cases, the pipe surrounding environment is soil. For this situation, corrosion will be affected by numerous elements inside the soil. Primarily physical, chemical and organic attributes of the soil will assume the real part for pipeline corrosion. Truth be told, temperature, pH, dampness, salts and other chemical factors frequently impact the pipelines corrosion under soil. For all intents and purposes all pipeline corrosion in soil is electrochemical in nature; that is, the corrosion is an electrochemical response where electrons move from anode to cathode inside the corroding metal. The metal consumes at one spot at first glance while the soil dampness is responding at a nearby site or even at some extremely distant site. Corrosion happens at the anode site where metal particles leave the surface to disintegrate in the soil dampness. This electrochemical corrosion can be effected by distinctive elements, for example, unique soil,

differential air circulation, disparate metals, new and old steel pipe, soil, dampness substance, and position of water table, soil resistivity, dissolvable particles substance, soil pH, oxidation-lessening potential and the vicinity of organisms in soil. On the other hand, the corrosion issue can be successfully overseen by utilizing best accessible advancements of corrosion protection. Covering of pipeline assumes a significant part in corrosion control of pipelines particularly in soil. Covering is connected to minimize the obliged force utilization in cathodic protection frameworks. The vital techniques used to anticipate outer corrosion of pipelines are coatings and cathodic protection. Infrequently, soil conditions can trade off the execution of cathodic protection. Case in point, the electrical conductivity of the soil is a key figure the configuration of a suitable cathodic protection framework. Poor configuration or a surprising increment in soil resistivity can bring about a loss of viable insurance at covered steel surfaces. High temperatures or exorbitant cathodic security possibilities can quicken covering disbondment. Covering materials including polyvinyl chloride, black-top or coal tar can endure a loss of trustworthiness in administration through evacuation of covering segments by water filtering, oxidation, or biodegradation. High temperatures can again quicken covering disintegration. The subsequent increment in covering porousness permits water access to the basic steel surfaces [4].

In this thesis AISI 1040 oil quenched bare steel coated with 20 microns pure zinc (Zn) is converted to UTM tensile specimen of 300mm length with 56 mm gauge length (ASTM standard) to check for the yield strength difference between coated and uncoated steel in a UTM machine. V-notch Charpy test specimens with the same coating are tested to determine the difference in the amount of energy absorbed by the material during fracture. The same material (bare and coated with 20 microns zinc) is checked for hardness difference in Rockwell hardness scale based on indentation hardness of a material. The Rockwell test determines the hardness by measuring the depth of penetration of an indenter under a large load compared to the penetration made by a preload [5]. The specimen of 20 microns of zinc coating of both UTM and Charpy V notch test are kept in 5% NaCl solution for 96 hours. After that the corroded specimen are tested for resulting yield strength and the energy absorbed. The difference between the corroded zinc and non-corroded zinc specimen of both UTM and Charpy V notch test are plotted in graphs. Scanning Electron Microscope (SEM) will be used to study the surface morphology, the topography and the surface adherent properties of the coatings. These tests will be conducted on

bare metal and the coated metal and the results will be compared. The effectiveness of the coating will be concluded accordingly.

The main objectives of the present work are:

1. To reduce the corrosion rate of the pipeline material using metallic zinc coating.
2. The check for the increase in Tensile Strength and Yield Strength of the material using Universal Testing Machine.
3. To check for the increase in Impact Energy and Modulus of Rapture of the coated material using Charpy Test Machine.
4. To check for the increase in Indentation hardness of the coated material using Rockwell Hardness Machine.
5. To study the surface morphologies of both bare and zinc coated specimen which will be immersed in 5% NaCl solution and compare the results accordingly.

## **2. LITERATURE REVIEW**

Many researchers have carried out research in the field of zinc 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 [6] studied and examined the range of zinc alloy electrodeposited 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 [7] 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  $25\pm 2$  °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.

H B Muralidhara and Y Arthoba Naik in 2008 [8] conducted Studies on nano-crystalline zinc coating. They made solutions from AR grade chemicals and double-distilled water. To judge the

quality and nature of the zinc deposits from the zincate electrolytes at various current density, pH and temperature, plating was carried out on polished mild steel sheets using standard 267-ml Hull cell for 10 min. The optimum concentration of condensation product was also determined by using Hull cell tests at various concentrations while keeping the other parameters constant in each case. The concluded that electrodeposition is a versatile technique for producing nano-crystalline zinc deposition. The deposition of zinc from sulphate baths showed higher conductivity, low cost and non-polluting nature. The use of additives in an electrolytic bath changes the morphology of zinc coating surface by refining in the microstructure. Electrochemical measurements and SEM analysis confirmed that bright deposits showed higher corrosion resistance than dull zinc coatings. XRD and TEM analysis confirmed the formation of nano-crystalline zinc deposition.

S. Moshood et al. in 2011 [9] studied the influence of seawater environment in zinc plated mild steel. Mild steel samples were zinc electroplated at voltage varied (0.6, 0.8, 1.0, 1.5 V) and for plating time also varied (20, 30, 40, 50, 60 minutes). Focused ion-beam scanning electron microscopy was used to observe the surface morphology of the plated surface. The visual observation of plated samples revealed that samples plated at 0.6 V for 20 and 60 minutes; 0.8 V for 30 minutes and 1.0 V for 40 minutes showed the best physical properties such as color, brightness, fineness, streak and strong adhesion. The plated samples were then subjected to seawater environment for 30 days. The electropotentials mV (SCE) was measured daily. Weight loss was determined at intervals of five days for the duration of the exposure period. Experimental result showed little corrosion attack on the zinc-plated samples on the fifteenth and twenty-fifth day's exposure. The severity of attack decreases with increasing weight of zinc coated on substrate. Significant increases in the corrosion resistance were achieved for the plated samples compared with that of the substrate. The pH of the seawater became more alkaline at the end of the thirty days test. The conclusion was that improved mechanical and physical properties were obtained from zinc coated mild steel in the presence of aggressive chloride containing seawater element from sea water. Uncoated mild steel has been found to be unsuitable for use in seawater environment due to its relatively high corrosion rate. However, electroplated zinc sample was able to protect mild steel in seawater or chloride environment with the use of zinc as protection material to retard corrosion attack. Thick zinc coating was also observed to offer protection in seawater environment at a moderate plating voltage.

E. Almeida & D. Pereira & O. Figueiredo in 1988 [10] studied the degradation of zinc coatings in salty atmospheres. Several zinc coatings (hot dip galvanized, zinc metallized, organic and inorganic zinc-rich primers) were exposed in a salt spray cabinet and in a natural marine atmosphere. No correlation could be found between the behaviors of coatings exposed to these environments. In the work carried out by them, the origin of this discrepancy was critically evaluated. The surface degradation of zinc coatings was studied by scanning electron microscopy (SEM) and energy-dispersive X-ray spectrometry (EDS). Corrosion products were investigated using X-ray diffraction. The kinetics of formation and the morphological characteristics of the corrosion product layers were seen to differ in the environments considered. It was concluded that laboratory salt spray testing is not a reliable method for the selection of protective zinc coatings.

O.S.I Fayomi and A.P.I Popoola in 2012 [11] 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 electrodeposition 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 microhardness of deposited plate, the electrochemical behavior and the corrosion properties of the deposits were investigated by means of Vickers microhardness and polarization measurements. The uniform deposits of Zn showed fine grains and good protection against corrosion as appreciated 75% hardness value was achieved.

### **3. THEORETICAL DEVELOPMENT**

#### **3.1 CARBON STEEL**

Carbon steel (plain carbon steel) is steel which contain main alloying element 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.

### 3.2.1 ELECTROPLATING PROCESS

This is a plating process that uses electrical current to reduce cations of a desired material from a solution and coat a conductive object with a thin layer of the material, such as a metal. Electroplating is primarily used for depositing a layer of material to bestow a desired property like corrosion protection. The process used in electroplating is called electrodepositing; the process is analogous to a galvanic cell acting in reverse.

The part to be plated is the cathode of the circuit. In one technique, the anode is made of the metal to be plated on the part. Both components are immersed in a solution called an electrolyte containing one or more dissolved metal salts as well as other ions that permit the flow of electricity. A rectifier supplies a direct current to the anode, oxidizing the metal molecules that comprise it and allowing them to dissolve in the solution [13].

At the cathode, the dissolved metal ions in the electrolyte solution are reduced at the interface between the solution and the cathode, such that they "plate out" onto the cathode. The rate at which the anode is dissolved is equal to the rate at which the cathode is plated, vis-a-vis the current flowing through the circuit. In this manner, the ions in the electrolyte bath are continuously replenished by the anode [14].

Zinc metal has a number of characteristics that make it well-suited for use as a coating for protecting iron and steel products from corrosion. Its excellent corrosion resistance in most environments accounts for its successful use as a protective coating on a variety of products and in many exposure conditions. The excellent field performance of zinc coatings results from their ability to form dense, adherent corrosion product films and a rate of corrosion considerably below that of ferrous materials, some 10 to 100 times slower, depending upon the environment. While a fresh zinc surface is quite reactive when exposed to the atmosphere, a thin film of corrosion products develops rapidly, greatly reducing the rate of further corrosion. The following figure shows the expected service life to first maintenance (5% red rust) of iron and steel, based on the zinc coating thickness and the environment.

### **3.2.2 ASTM B633 - 07**

This specification establishes the requirements for electro-deposited zinc coatings applied to iron or steel articles for corrosion-protection purposes. The coating is provided in four standard thickness classes in the as-plated condition or with one of three types of supplementary finishes. The surface of the article is cleaned as pre-plating basis metal, pre- and post-coating treatment is given to reduce the risk of hydrogen embrittlement. Coating is sampled, prepared, tested and conform accordingly to this specification the general criteria is the appearance (luster and workmanship), thickness, adhesion, corrosion resistance, and hydrogen embrittlement.

High-strength metals, unless otherwise specified, including high-strength steels having a tensile strength greater than 247 ksi or hardness  $\geq$  RC 46 are not electroplated. Stress relieving of all parts with ultimate tensile strength  $\geq$ 145, 000 psi at minimum 375°F for three hours or more is recommended. If these facts are considered and adhered to in specifying and ensuring that the vendor complies with the process and follows with the test results, the desired level of corrosion protection can be achieved.

### **3.3 ZINC COATINGS**

Zinc metal has a number of characteristics that make it well suited for use as a protective coating for ferrous substrates and as a result Zinc coatings are widely used for corrosion control. Their performance results from their ability to react with the atmospheric compounds (O<sub>2</sub>, CO<sub>2</sub> and H<sub>2</sub>O) which form over the coating surface dense, adherent films, whose rate of corrosion is considerably below that of ferrous materials (barrier protection). Additionally, Zinc is anodic to iron and steel and consequently offers cathodic protection

Zinc is a bluish white metal, which, if mechanically polished, or electrodeposited with appropriate brighteners, somewhat resembles chromium in appearance. However, the reflectivity of the polished surface is soon lost in most atmospheres. This quick tarnishing and corroding, is the property that makes zinc plating work so well in providing “sacrificial” protection for steel. The relatively low cost, protective nature and attractive appearance of zinc plating make it a popular coating for nuts, bolts, washers, metal stampings, and automotive components, fabricated parts for industrial applications, and also serves as an effective undercoat for paints.

Zinc coatings are predominantly used to improve the aqueous corrosion of steel by two methods, barrier protection and galvanic protection. In barrier protection, the zinc coating, which separates the steel from the corrosion environment, will first corrode before the corrosive environment reaches the steel. In galvanic protection, zinc is less noble or anodic to iron at ambient conditions, and will sacrificially corrode to protect the substrate steel, even if some of the steel is exposed as cut edges or scratches in the coating. Typical processing methods used in producing zinc coatings include hot-dip galvanizing, thermal spraying and electrodeposition. This review will be limited to hot-dip galvanizing, i.e. the immersion of a steel article in a liquid bath of zinc or a zinc alloy, by batch or continuous processing. The continuous process is more advantageous for coiled products such as sheet, wire and tube, whereas the batch process is normally used for bulk products.

In general, prior to immersion in the liquid zinc bath, the steel article to be galvanized is first cleaned to eliminate any surface oxide that may react in the zinc bath. After hot-dipping, in which the steel reacts with the bath forming the coating, the article is withdrawn, cooled and sometimes subsequently heat treated. The anatomy of a zinc coated steel part consists of the overlay or coating alloy, an interfacial layer between the overlay and the substrate steel containing a series of intermetallic compounds, and the substrate steel. Each of these regions can be affected by the bath time and temperature, as well as the chemistry of both the bath and the substrate steel.

### **3.3.1 ELECTRODEPOSITED ZINC 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

### **Basic Data for Zinc**

Atomic Number	30
Atomic Weight	65.38
Crystal Structure	Close packed Hexagonal
Color	Bluish White
Density	7100 kg/m <sup>3</sup>
Melting Point	419.5°C
Boiling Point	907°C
Specific Heat Capacity	389.8J/kg°C
Thermal Conductivity	112.2 W/m°C
Coefficient of Linear Expansion	31.2 x 10 <sup>6</sup> /°C

Specific Electrical Resistance	59 $\mu\Omega\text{mm}$
Magnetic Susceptibility	0.157 x 10 <sup>6</sup>
Young's Modulus of Elasticity	96.5 GPa
Tensile Strength	37 MPA (cast)
Hardness	30 HV
Coefficient of Friction (on Zn in air)	0.75
Coefficient of Friction (on Fe in air)	0.55

### **3.3.2 SELECTION OF ZINC COATINGS**

After deciding to use a zinc coating for corrosion protection, some factors must be considered to ensure the proper coating is selected for the intended application and service environment. Obviously, zinc coating processes which are limited to small parts, and operations limited to continuous lines in steel mills (i.e. continuous galvanizing and electro galvanizing) cannot be considered for the protective coating of structural steel members. Each zinc coating reviewed provides various degrees of corrosion protection. When selecting a coating, it is important to investigate the corrosiveness of the exposure environment to ensure the zinc coating selected will provide adequate service life for the cost.

### **3.3.3 COATING THICKNESS VS. COATING WEIGHT**

The usual criterion for determining the expected service life of zinc coatings is thickness: the thicker the coating, the longer the service life. This is an acceptable criterion when comparing zinc coatings produced by the same process. When comparing zinc coatings produced by different processes, the thickness criterion cannot be used without considering the amount of available zinc per unit volume. While the coating densities for some of the different types of zinc coatings are nearly identical, others differ considerably. Each of these thicknesses, representing the same weight per unit area of zinc, 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 zinc weight for both sides of the sheet.

### **3.3.4 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.

### **3.3.5 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 zinc coatings are primarily corrosion and formability and other properties involve weldability and paintability. However, it should be noted that the corrosion resistance of any zinc 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.

#### **3.3.5.1 Corrosion Resistance**

Zinc coatings add corrosion resistance to steel in several ways. As a barrier layer, a continuous zinc coating separates the steel from the corrosive environment. By galvanic protection, zinc acts as a sacrificial anode to protect the underlying steel at voids, scratches and cut edges of the

coating. The sacrificial properties of zinc can be seen in a galvanic series where the potential of zinc is less noble than steel in most environments at ambient temperatures. A porous zinc 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 zinc metal, zinc hydroxide can precipitate at the cathodic areas of the exposed steel, forming a secondary barrier layer. Thus, the zinc coating will corrode at a slower rate than the steel substrate, although the corrosion rate of zinc will vary depending upon the exposure.

### **3.3.5.2 Formability**

The deformation and fracture behavior of Zn-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 zinc coated parts. Zinc coatings fail as a result of particle removal during forming.

### **3.3.5.3 Weldability**

Weldability of zinc 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 zinc, and methods for the reduction of blowholes were developed to improve welding quality. In spot weldability zinc coatings reduce the life of welding electrodes due to alloying of the copper electrode with zinc. In the case of galvanized steel, the electrode life may be as little as  $1500 \pm 2000$  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.

### 3.4 AISI 1040 STEEL

#### 3.4.1 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]

#### 3.4.2 CHEMICAL COMPOSITION

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

<b>Element</b>	<b>Content (%)</b>
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

#### 3.4.3 PHYSICAL PROPERTIES

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

<b>Properties</b>	<b>Metric</b>	<b>Imperial</b>
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./in <sup>3</sup>
Melting point	1521°C	2770°C

Table 2: Physical Properties of AISI 1040 Carbon Steel

### 3.4.4 MECHANICAL PROPERTIES

The mechanical properties of AISI 1040 carbon steel are outlined in the following table.

<b>Properties</b>	<b>Metric</b>	<b>Imperial</b>
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

### 3.4.5 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

## **3.4.6 FABRICATION AND HEAT TREATMENT**

### **3.4.6.1 MACHINABILITY**

The machinability rating of AISI 1040 carbon steel is 60.

### **3.4.6.2 FORMING**

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

### **3.4.6.3 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.

### **3.4.6.4 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.

### **3.4.6.5 FORGING**

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

### **3.4.6.6 HOT WORKING**

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

### **3.4.6.7 COLD WORKING**

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

### **3.4.6.8 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.

### **3.4.6.9 TEMPERING**

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

#### **3.4.6.10 HARDENING**

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

#### **3.4.7 APPLICATIONS**

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

### **3.5 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:

#### **3.5.1 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.

#### **3.5.2 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 off 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 passivized combinations.

### **3.5.3 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 defenselessness 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.

### **3.5.4 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.

### **3.5.5 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.

### **3.5.6 METAL DUSTING**

Metal dusting is a cataclysmic type of corrosion that happens when defenseless 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 vapor stage. This graphite layer is then thought to frame metastable M<sub>3</sub>C species (where M is the metal), which relocate far from the metal surface. Nonetheless, in a few administrations no M<sub>3</sub>C species is watched showing a direct exchange of metal iotas into the graphite layer.

### 3.6 PROCESS FLOW DIAGRAM

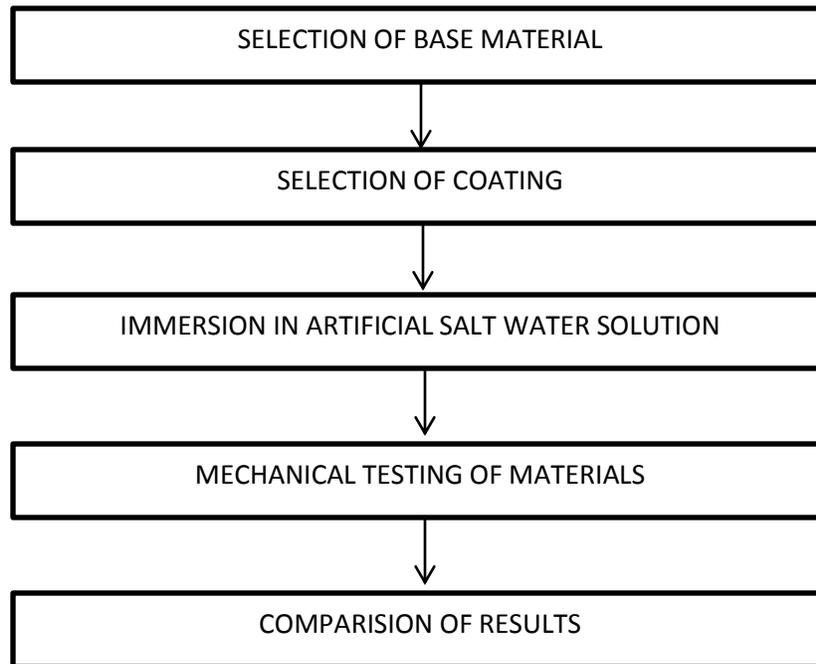


Fig 1: Process Flow Diagram

### 3.7 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.

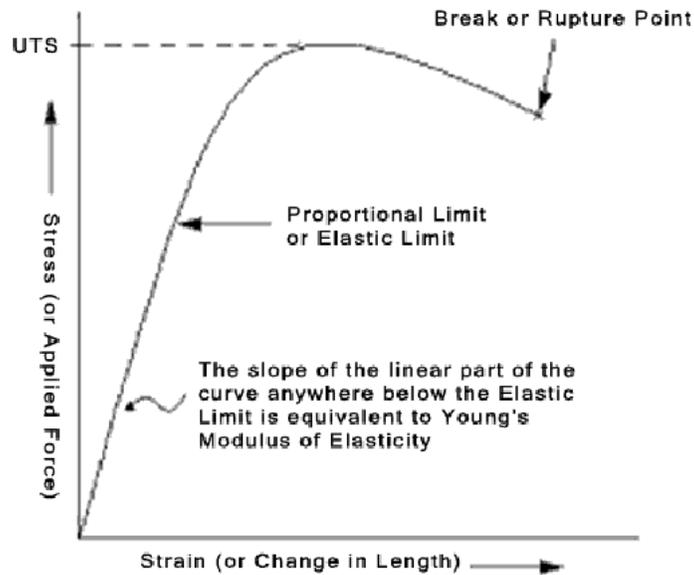


Fig 2: Stress Strain Graph

### **3.7.1 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 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.

### **3.7.2 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.

### **3.7.3 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.

### **3.7.4 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 misshapeness 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.

### **3.7.5 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

### **3.8 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. -20°C, -10°C, 0°C, +10°C, +20°C). 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.

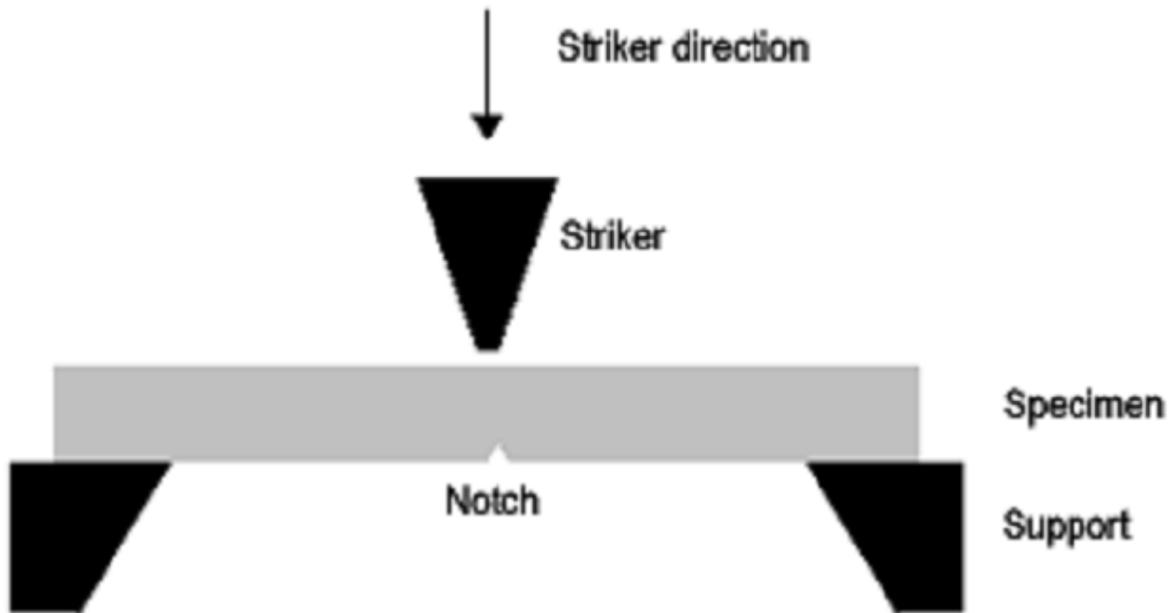


Fig 3: Impact Charpy Concept

### 3.8.1 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.

### 3.8.2 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/ COMPUTATIONAL

### 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

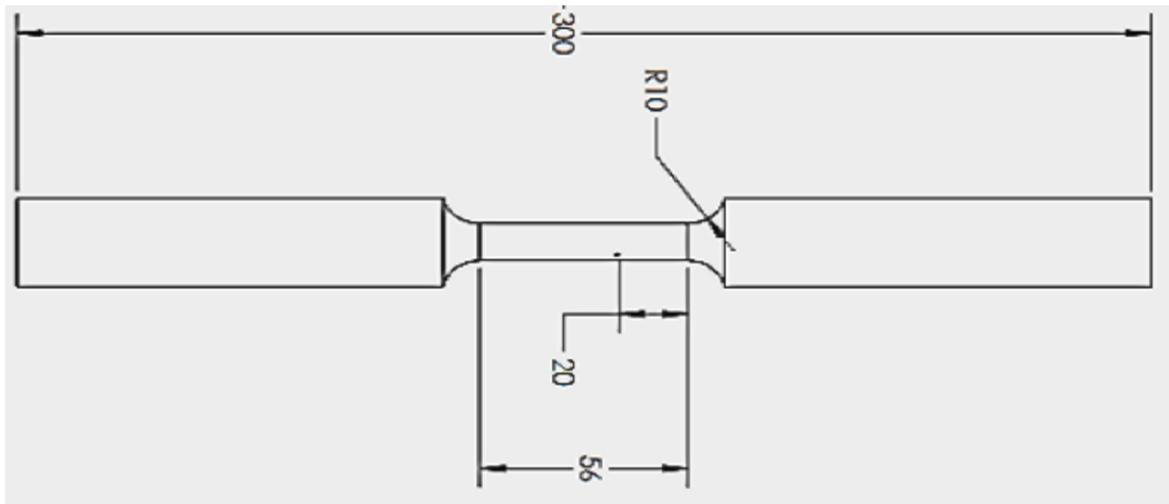


Fig 3: Tensile Specimen Dimensions

### 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 <sup>0</sup>
Width of Specimen	10mm
Height of Specimen	10mm

Table 6: Charpy Test Specimen Dimensions

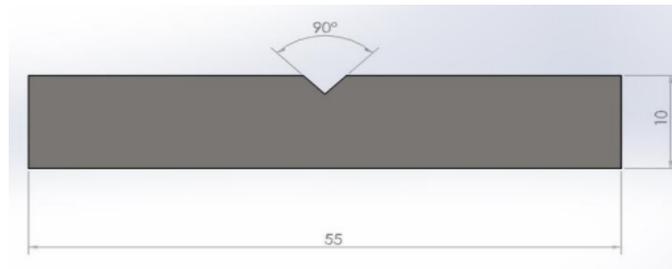


Fig 4: Charpy Test Specimen Dimensions

#### 4.3 FORMULAS USED

##### 4.3.1 FORMULAS USED FOR TENSILE TEST

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

$$\text{Percentage Elongation} = \frac{\text{Extended Gauge Length} - \text{Original Gauge Length}}{\text{Original Gauge length}} \times 100$$

$$\text{Yeild Strength} = \frac{\text{Load on Yeild Point}}{\text{Original Cross Sectional Area}} \quad (\text{N/mm}^2)$$

##### 4.3.2 FORMULAS USED FOR CHARPY IMPACT TEST

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

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

$$\text{Modulus of rapture} = \frac{\text{Impact Energy}}{\text{Effective Volume}} \quad (\text{Joule/mm}^3)$$

### 4.3.3 FORMULAS USED FOR CORROSION RATE

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

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

- Density = Density of the Bare Metal (gram/cc)
- Cross Sectional Area = Cross Sectional Area of the Gauge (mm<sup>2</sup>)
- 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

Stress	Strain
17.98238	0
35.96475	0
53.94713	0.017857
71.92951	0.035714
89.91189	0.053571
107.8943	0.0625
125.8766	0.0625
143.859	0.071429
161.8414	0.071429
179.8238	0.075
197.8061	0.080357
215.7885	0.085714
233.7709	0.089286
251.7533	0.089286
269.7357	0.092857
287.718	0.098214
305.7004	0.101786
323.6828	0.101786
341.6652	0.105357
359.6475	0.107143
366.8405	0.110714
370.437	0.114286
377.6299	0.117857
381.2264	0.121429
395.6123	0.121429
413.5947	0.123214
431.5771	0.123214
449.5594	0.124107
467.5418	0.125
485.5242	0.125
503.5066	0.128571
521.4889	0.132143
539.4713	0.139286
557.4537	0.140179
561.0502	0.141071
575.4361	0.142857
575.4361	0.15
573.6378	0.157143

570.0414	0.158929
561.0502	0.160714
552.059	0.164286
548.4625	0.167857
543.0678	0.175
539.4713	0.176786
525.0854	0.178571
525.0854	0.182143
521.4889	0.185714
519.6907	0.19375
519.6907	0.194643
516.0942	0.196429

Table 7: Stress And Strain Values of Bare Material

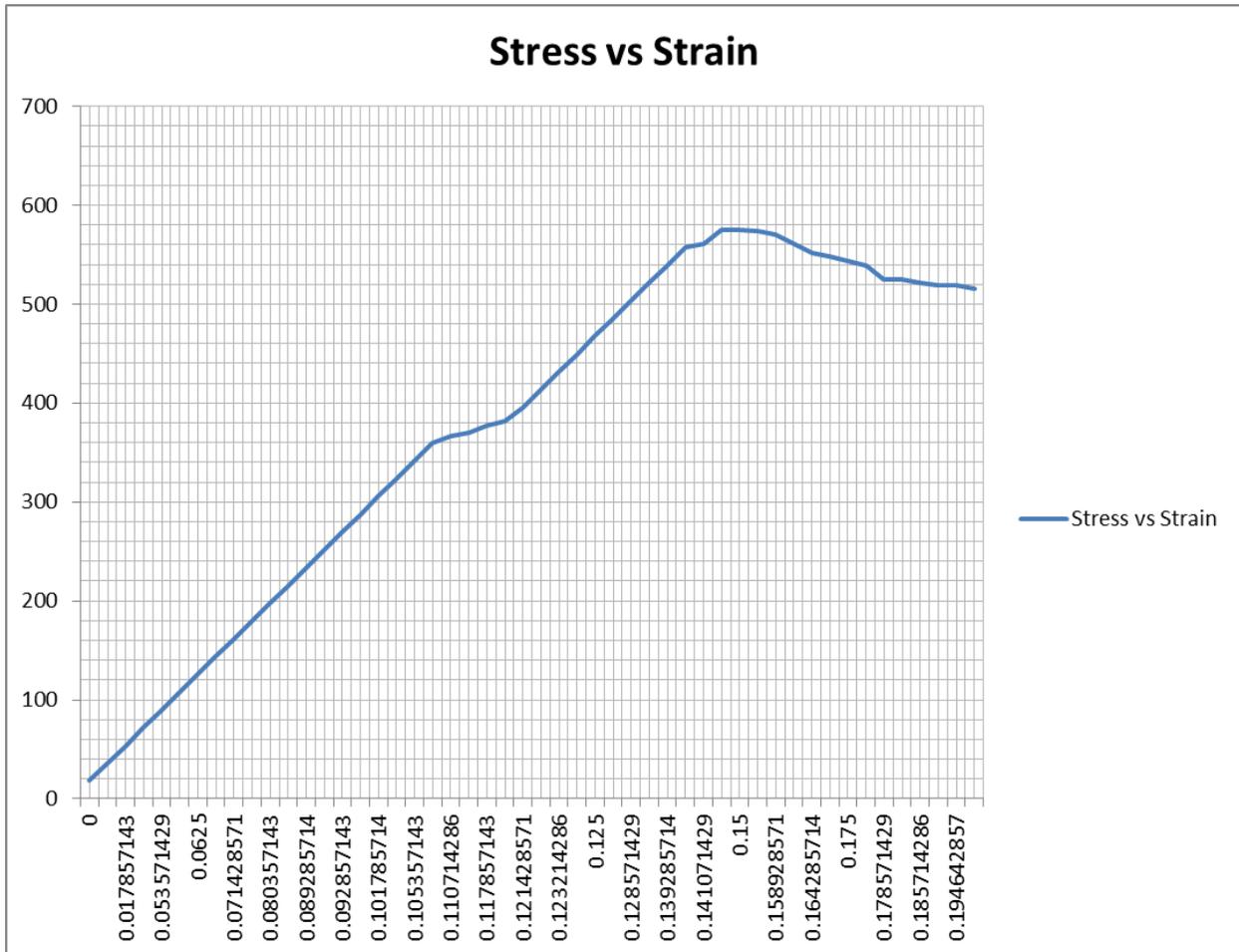


Fig 5: Stress vs. Strain Graph of Bare Material

#### 4.5 STRESS AND STRAIN VALUES OF CORRODED BARE SPECIMEN

Stress	Strain
0	0
8.946144212	0
17.89228842	0.001747
26.83843264	0.006989
35.78457685	0.010484
44.73072106	0.017473
53.67686527	0.020968
62.62300948	0.027957
71.56915369	0.031452
80.51529791	0.031452
89.46144212	0.034947
98.40758633	0.036694
107.3537305	0.041936
116.2998748	0.045431
125.246019	0.048925
134.1921632	0.050673
143.1383074	0.05242
152.0844516	0.055915
161.0305958	0.057662
169.97674	0.061157
178.9228842	0.064651
187.8690284	0.066399
196.8151727	0.068146
205.7613169	0.069893
214.7074611	0.069893
223.6536053	0.069893
232.5997495	0.071641
241.5458937	0.073388
250.4920379	0.073388
259.4381821	0.075135
268.3843264	0.07863
277.3304706	0.082125
286.2766148	0.085619
295.222759	0.087367
304.1689032	0.087367
313.1150474	0.087367
322.0611916	0.087367
331.0073358	0.087367

339.9534801	0.089114
348.8996243	0.090861
357.8457685	0.090861
366.7919127	0.092609
375.7380569	0.096103
384.6842011	0.096103
393.6303453	0.097851
402.5764895	0.101345
411.5226337	0.103093
420.468778	0.103093
429.4149222	0.10484
438.3610664	0.10484
446.4125962	0.10484
447.3072106	0.106587
456.2533548	0.106587
465.199499	0.108335
474.1456432	0.108335
483.0917874	0.108335
492.0379317	0.110082
500.9840759	0.110082
509.9302201	0.110082
518.8763643	0.111829
527.8225085	0.113577
536.7686527	0.117071
545.7147969	0.118819
554.6609411	0.120566
563.6070853	0.122313
564.5016998	0.124061
565.3963142	0.127555
567.185543	0.134545
566.2909286	0.127555
565.3963142	0.134545
564.5911612	0.139787
568.0801575	0.143281
565.3963142	0.145029
565.3963142	0.148524
565.3963142	0.153766
565.3963142	0.155513
565.3963142	0.15726
565.3963142	0.159008
565.3963142	0.165997

565.3963142	0.172986
564.5016998	0.174734
564.5016998	0.176481
564.5016998	0.18347
564.5016998	0.19046
564.5016998	0.192207
564.5016998	0.193954
564.5016998	0.202691
563.6070853	0.20968
563.6070853	0.211428
563.6070853	0.214922
563.6070853	0.223659
563.6070853	0.227154

Table 8: Stress And Strain Values of Bare Corroded Material

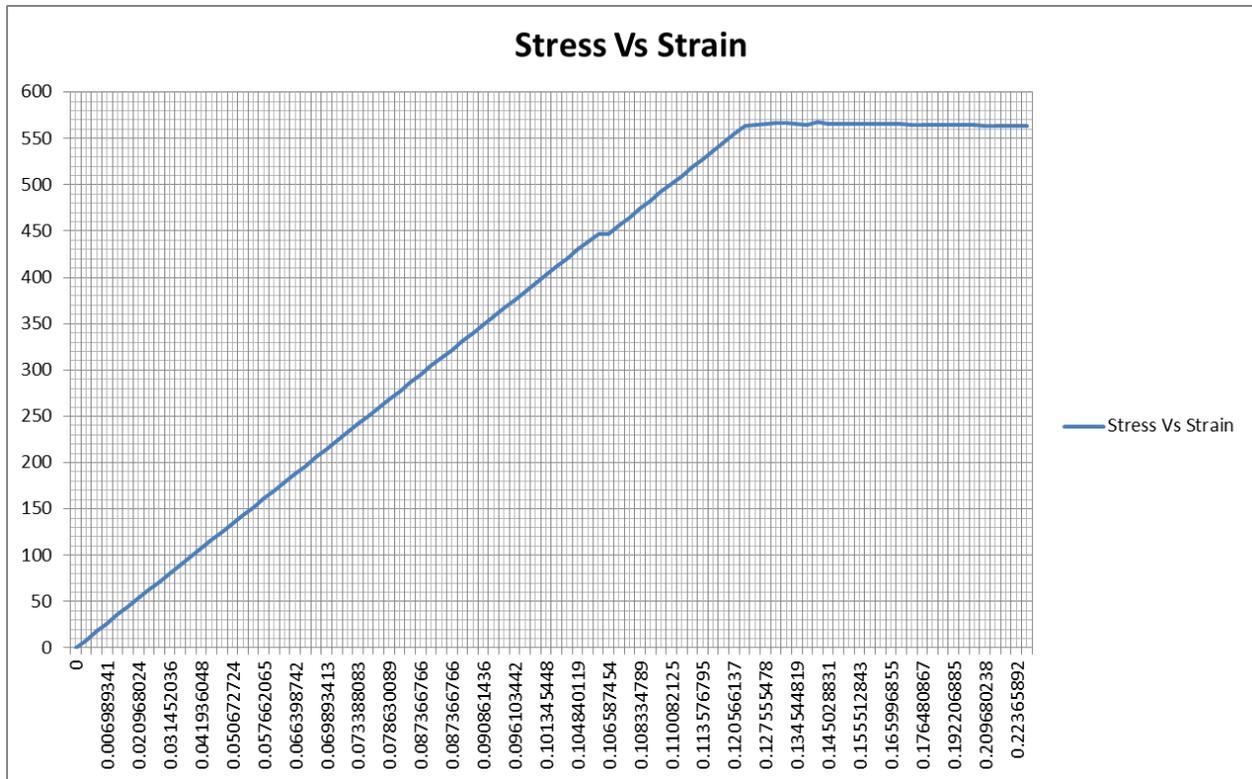


Fig 6: Stress And Strain Graph of Bare Corroded Material

#### 4.6 STRESS AND STRAIN VALUES OF COATED SPECIMEN

Stress	Strain	Stress (Mpa)
<b>0</b>	0	0
<b>0.009238</b>	0	9.237875289
<b>0.018476</b>	0	18.47575058
<b>0.027714</b>	0	27.71362587
<b>0.036952</b>	0	36.95150115
<b>0.046189</b>	0.01616	46.18937644
<b>0.055427</b>	0.096962	55.42725173
<b>0.064665</b>	0.113122	64.66512702
<b>0.073903</b>	0.129282	73.90300231
<b>0.083141</b>	0.145443	83.1408776
<b>0.092379</b>	0.145443	92.37875289
<b>0.101617</b>	0.161603	101.6166282
<b>0.110855</b>	0.161603	110.8545035
<b>0.120092</b>	0.177763	120.0923788
<b>0.12933</b>	0.177763	129.330254
<b>0.138568</b>	0.177763	138.5681293
<b>0.147806</b>	0.185844	147.8060046
<b>0.157044</b>	0.185844	157.0438799
<b>0.166282</b>	0.185844	166.2817552
<b>0.17552</b>	0.193924	175.5196305
<b>0.184758</b>	0.193924	184.7575058
<b>0.193995</b>	0.202004	193.9953811
<b>0.203233</b>	0.202004	203.2332564
<b>0.212471</b>	0.202004	212.4711316
<b>0.221709</b>	0.202004	221.7090069
<b>0.230947</b>	0.210084	230.9468822
<b>0.240185</b>	0.210084	240.1847575
<b>0.249423</b>	0.210084	249.4226328
<b>0.258661</b>	0.210084	258.6605081
<b>0.267898</b>	0.210084	267.8983834
<b>0.277136</b>	0.218164	277.1362587
<b>0.286374</b>	0.218164	286.3741339
<b>0.295612</b>	0.218164	295.6120092
<b>0.30485</b>	0.226244	304.8498845
<b>0.314088</b>	0.226244	314.0877598
<b>0.323326</b>	0.226244	323.3256351
<b>0.332564</b>	0.226244	332.5635104
<b>0.341801</b>	0.234324	341.8013857

<b>0.351039</b>	0.234324	351.039261
<b>0.360277</b>	0.234324	360.2771363
<b>0.369515</b>	0.234324	369.5150115
<b>0.378753</b>	0.234324	378.7528868
<b>0.387991</b>	0.234324	387.9907621
<b>0.39261</b>	0.242405	392.6096998
<b>0.397229</b>	0.242405	397.2286374
<b>0.401848</b>	0.242405	401.8475751
<b>0.406467</b>	0.242405	406.4665127
<b>0.413395</b>	0.242405	413.3949192
<b>0.415704</b>	0.242405	415.704388
<b>0.420323</b>	0.242405	420.3233256
<b>0.422633</b>	0.242405	422.6327945
<b>0.424942</b>	0.242405	424.9422633
<b>0.43418</b>	0.242405	434.1801386
<b>0.443418</b>	0.250485	443.4180139
<b>0.452656</b>	0.250485	452.6558891
<b>0.461894</b>	0.250485	461.8937644
<b>0.471132</b>	0.250485	471.1316397
<b>0.48037</b>	0.250485	480.369515
<b>0.489607</b>	0.250485	489.6073903
<b>0.498845</b>	0.258565	498.8452656
<b>0.508083</b>	0.258565	508.0831409
<b>0.517321</b>	0.258565	517.3210162
<b>0.526559</b>	0.258565	526.5588915
<b>0.535797</b>	0.258565	535.7967667
<b>0.545035</b>	0.266645	545.034642
<b>0.554273</b>	0.266645	554.2725173
<b>0.56351</b>	0.266645	563.5103926
<b>0.568129</b>	0.274725	568.1293303
<b>0.570439</b>	0.282805	570.4387991
<b>0.568129</b>	0.290886	568.1293303
<b>0.56351</b>	0.290886	563.5103926
<b>0.554273</b>	0.298966	554.2725173
<b>0.545035</b>	0.298966	545.034642
<b>0.535797</b>	0.307046	535.7967667
<b>0.545035</b>	0.315126	545.034642
<b>0.517321</b>	0.315126	517.3210162
<b>0.508083</b>	0.323206	508.0831409
<b>0.498845</b>	0.323206	498.8452656
<b>0.489607</b>	0.331286	489.6073903

<b>0.48037</b>	0.339367	480.369515
<b>0.471132</b>	0.339367	471.1316397
<b>0.461894</b>	0.339367	461.8937644
<b>0.452656</b>	0.339367	452.6558891
<b>0.443418</b>	0.347447	443.4180139
<b>0.43418</b>	0.347447	434.1801386
<b>0.424942</b>	0.355527	424.9422633
<b>0.415704</b>	0.363607	415.704388
<b>0.401848</b>	0.371687	401.8475751

Table 9: Stress And Strain Values of Coated Material

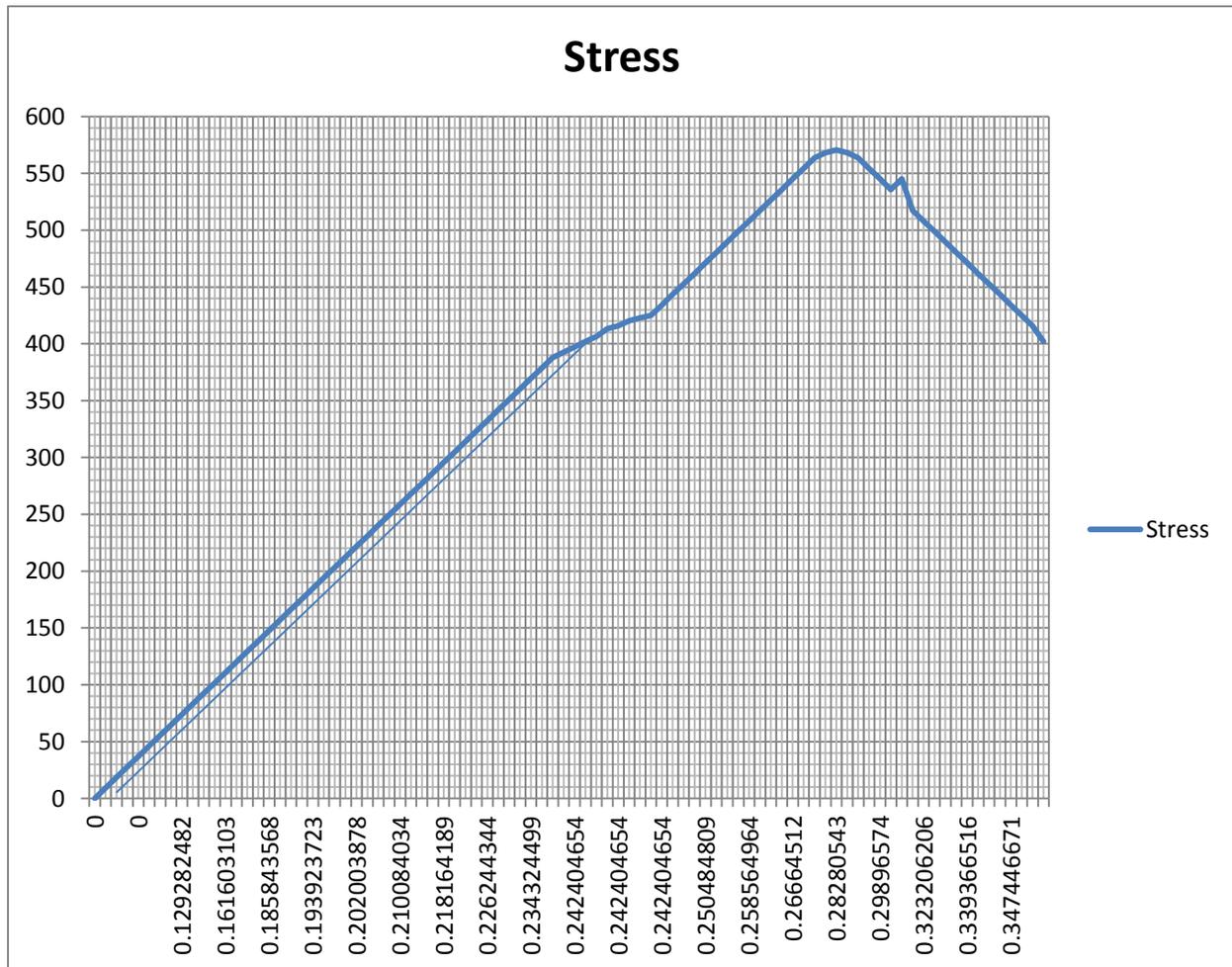


Fig 7: Stress vs. Strain Graph of Coated Material

#### 4.7 STRESS AND STRAIN VALUES OF CORRODED COATED SPECIMEN

Stress	Strain	Stress (Mpa)
<b>0</b>	0	0
<b>0.009238</b>	0	9.237875289
<b>0.018476</b>	0	18.47575058
<b>0.027714</b>	0	27.71362587
<b>0.036952</b>	0	36.95150115
<b>0.04388</b>	0.00808	43.87990762
<b>0.046189</b>	0.00808	46.18937644
<b>0.053118</b>	0.064641	53.11778291
<b>0.055427</b>	0.080802	55.42725173
<b>0.064665</b>	0.113122	64.66512702
<b>0.073903</b>	0.129282	73.90300231
<b>0.083141</b>	0.145443	83.1408776
<b>0.092379</b>	0.145443	92.37875289
<b>0.101617</b>	0.161603	101.6166282
<b>0.110855</b>	0.161603	110.8545035
<b>0.120092</b>	0.161603	120.0923788
<b>0.12933</b>	0.161603	129.330254
<b>0.138568</b>	0.161603	138.5681293
<b>0.147806</b>	0.161603	147.8060046
<b>0.157044</b>	0.169683	157.0438799
<b>0.166282</b>	0.169683	166.2817552
<b>0.17552</b>	0.169683	175.5196305
<b>0.184758</b>	0.169683	184.7575058
<b>0.193995</b>	0.177763	193.9953811
<b>0.203233</b>	0.177763	203.2332564
<b>0.212471</b>	0.185844	212.4711316
<b>0.221709</b>	0.185844	221.7090069
<b>0.230947</b>	0.185844	230.9468822
<b>0.240185</b>	0.185844	240.1847575
<b>0.249423</b>	0.185844	249.4226328
<b>0.258661</b>	0.185844	258.6605081
<b>0.267898</b>	0.193924	267.8983834
<b>0.277136</b>	0.193924	277.1362587
<b>0.286374</b>	0.202004	286.3741339
<b>0.295612</b>	0.202004	295.6120092
<b>0.30485</b>	0.202004	304.8498845
<b>0.314088</b>	0.202004	314.0877598
<b>0.323326</b>	0.210084	323.3256351
<b>0.332564</b>	0.210084	332.5635104
<b>0.341801</b>	0.210084	341.8013857

<b>0.351039</b>	0.210084	351.039261
<b>0.353349</b>	0.218164	353.3487298
<b>0.360277</b>	0.218164	360.2771363
<b>0.369515</b>	0.218164	369.5150115
<b>0.378753</b>	0.226244	378.7528868
<b>0.387991</b>	0.226244	387.9907621
<b>0.397229</b>	0.226244	397.2286374
<b>0.406467</b>	0.226244	406.4665127
<b>0.415704</b>	0.234324	415.704388
<b>0.424942</b>	0.234324	424.9422633
<b>0.43418</b>	0.234324	434.1801386
<b>0.443418</b>	0.234324	443.4180139
<b>0.452656</b>	0.242405	452.6558891
<b>0.461894</b>	0.242405	461.8937644
<b>0.471132</b>	0.242405	471.1316397
<b>0.48037</b>	0.242405	480.369515
<b>0.489607</b>	0.242405	489.6073903
<b>0.498845</b>	0.250485	498.8452656
<b>0.508083</b>	0.250485	508.0831409
<b>0.517321</b>	0.250485	517.3210162
<b>0.526559</b>	0.250485	526.5588915
<b>0.535797</b>	0.250485	535.7967667
<b>0.545035</b>	0.258565	545.034642
<b>0.554273</b>	0.274725	554.2725173
<b>0.545035</b>	0.274725	545.034642
<b>0.535797</b>	0.290886	535.7967667
<b>0.526559</b>	0.298966	526.5588915
<b>0.517321</b>	0.307046	517.3210162
<b>0.508083</b>	0.315126	508.0831409
<b>0.498845</b>	0.315126	498.8452656
<b>0.489607</b>	0.323206	489.6073903
<b>0.48037</b>	0.331286	480.369515
<b>0.461894</b>	0.339367	461.8937644
<b>0.452656</b>	0.347447	452.6558891
<b>0.443418</b>	0.355527	443.4180139
<b>0.43418</b>	0.355527	434.1801386
<b>0.413395</b>	0.363607	413.3949192

Table 10: Stress And Strain Values of Corroded Coated Material

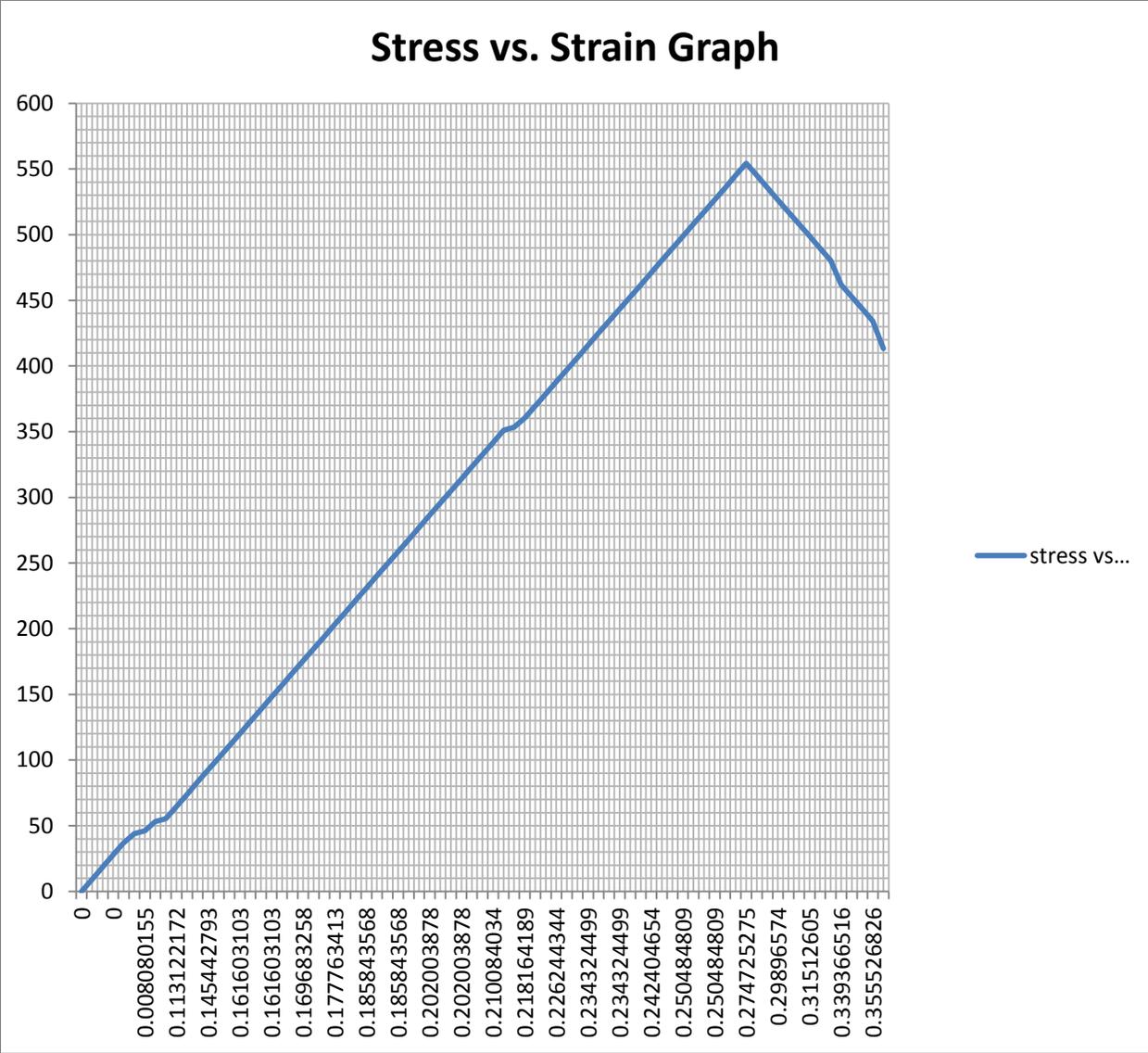


Fig 8: Stress vs. Strain Graph of Corroded Coated Material

## 5. RESULTS AND DISCUSSION

### 5.1 CORROSION RATE

#### 5.1.1 CORROSION RATE OF BARE METAL

Surface Area of Bare Metal = 180.57 cm<sup>2</sup>

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

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

#### 5.1.2 CORROSION RATE OF COATED METAL WITH ZINC

Surface Area of Zinc Metal = 180.57 x 2 = 361.14 cm<sup>2</sup>

Density of Zinc = 7.10 g/cc

$$CR (mm/year) = \frac{2 \times 8.74 \times 10^4}{7.10 \times 361.14 \times 96} = 0.710 \text{ mm/year}$$

$$CR (mils/year) = \frac{2 \times 3.45 \times 10^6}{7.10 \times 361.14 \times 96} = 27.952 \text{ mils/year}$$

### 5.1.3 PERCENTAGE DECREASE IN CORROSION

$$\% \text{ decrease in corrosion} = \frac{0.710 - 2.570}{2.570} \times 100 = -72.37\%$$

The corrosion of bare metal with Zinc electroplated coating has reduced the corrosion rate by 72.37 %

## 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 <sup>2</sup> )	Impact Energy (N/m)	Modulus of Rupture Joule/mm <sup>3</sup>
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 <sup>3</sup> )
Bare Zinc	55.8	9.5	9.5	0.8	2	41	0.00009025	432133	0.007744
Corroded Zinc	51.69	9.44	9.44	1.04	2	30	0.00008911	314205.7	0.006079

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

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

$$\text{Impact Energy} = U/A_e$$

$A_e$  = Effective Area

$$\text{Impact Strength (U)} = Y-X$$

$$\text{Modulus of Rapture} = U/V_e$$

$V_e$  = Effective Volume

### 5.3 RESULTS OF MECHANICAL TESTING

Readings	Tensile Strength (N/ mm <sup>2</sup> )	Yield Strength (N/ mm <sup>2</sup> )	Impact Energy (KN)	Hardness
Bare Metal	574.01	360	400.912	33.166
Corroded Bare Metal	568.01	352	357.605	29.667
Zinc	570.438	385.2	432.133	34.63
Corroded Zinc	563.51	367.5	314.205	29.92

Table 13: Results of Mechanical Testing

### 5.4 SEM (SCANNING ELECTRON MICROSCOPE) COMPARISION

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. SEM can achieve resolution better than 1 nanometer. Specimens can be observed in high vacuum, in low vacuum, in wet conditions (in environmental SEM), and at a wide range of cryogenic or elevated temperatures.

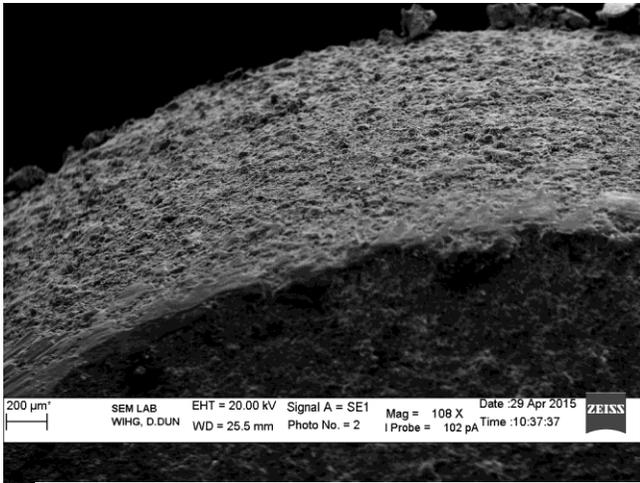


Fig 9a: Bare Corroded Specimen

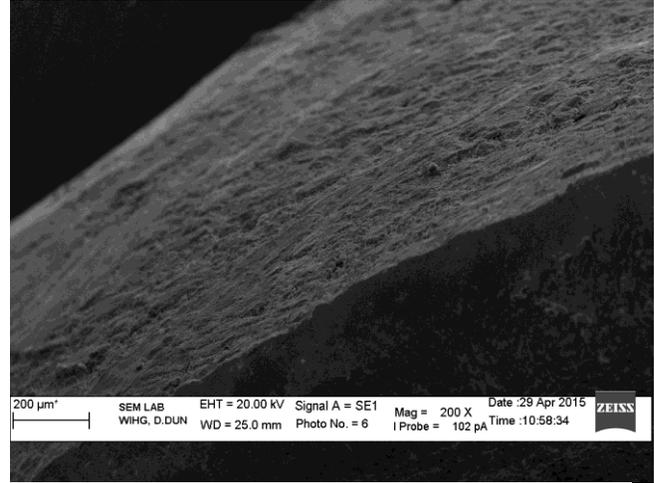


Fig 9b: Bare Non Corroded Specimen

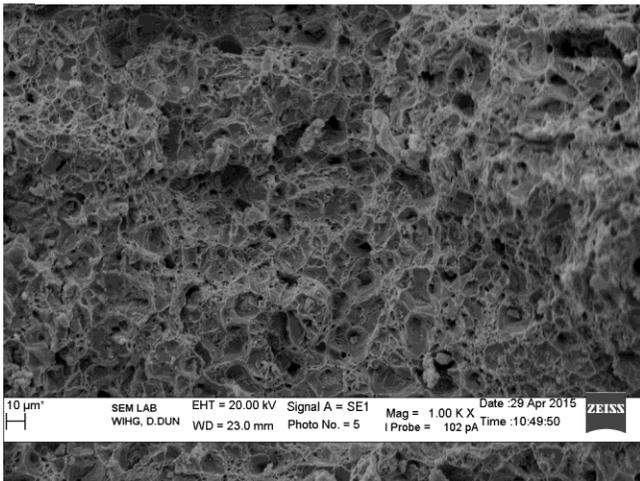


Fig 10a: Bare Corroded Specimen

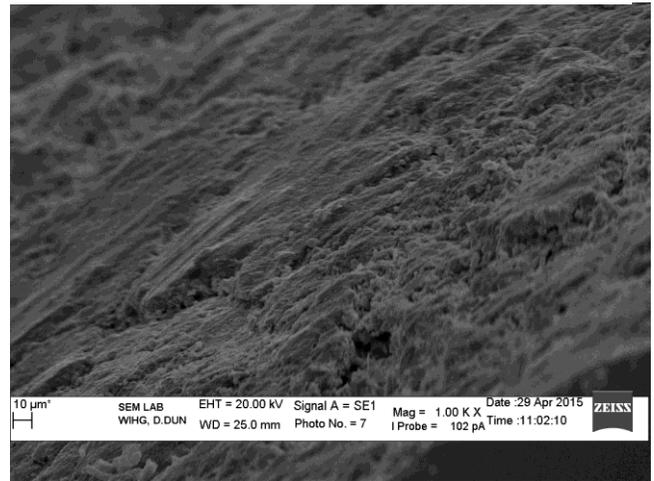


Fig 10b: Bare Non Corroded Specimen

SEM is used to examine the surface of bare metal not immersed in corrosion solution and the bare metal immersed in 5% NaCl solution and it is compared as shown in figure 9(a), 9(b) and 10(a), 10 (b). The surface morphologies of both the immersed and non-immersed bare metal are scanned at the fractured part and the study suggests that the non-corroded specimen has more smooth surfaces than the corroded specimen.

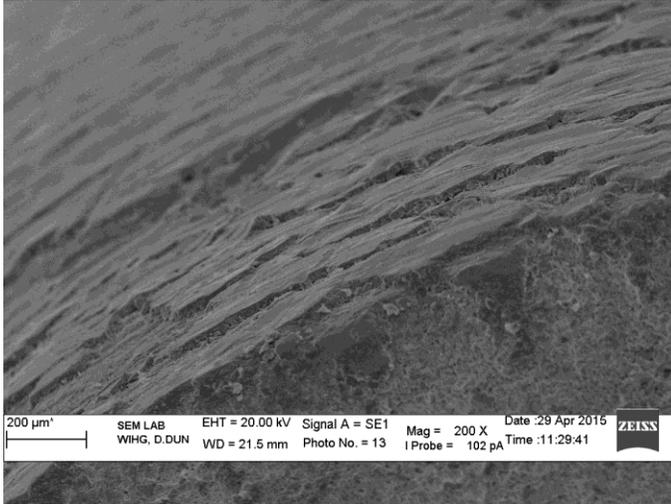


Fig 11a: Zinc Coated Corroded Specimen

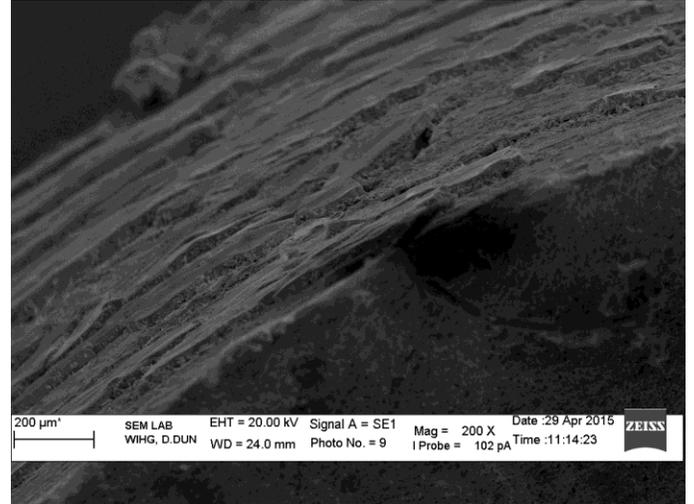


Fig 11b: Zinc Coated Specimen

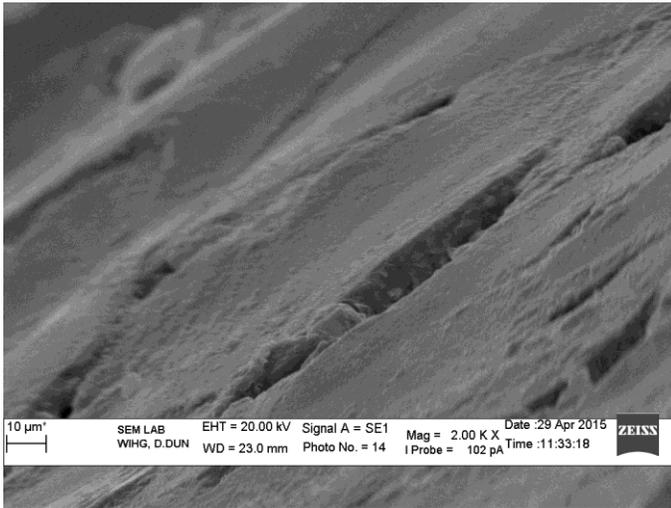


Fig 12a: Zinc Coated Corroded Specimen

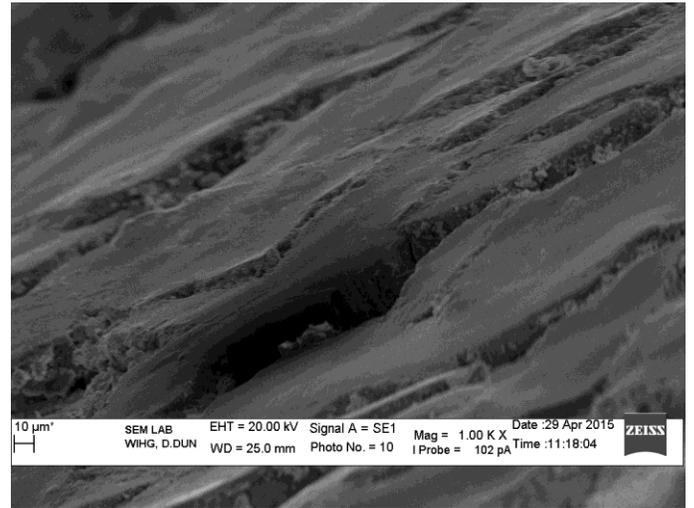


Fig 12b: Zinc Coated Specimen

## **6. CONCLUSIONS AND RECOMMENDATIONS**

1. The results show that the ultimate tensile strength is decreasing for zinc coating, whereas the yield strength is increasing for the same. It is showing the same consequences for both corroded and non-corroded specimens.
2. For a given room temperature, the Impact Energy is increasing for Zinc coated specimen.
3. The Rockwell indentation hardness has slightly increased for Zinc coated steel but when it's corroded, the Rockwell hardness decreases.
4. The corrosion of bare metal with Zinc electroplated coating has reduced the corrosion rate by 72.37 %.
5. Zinc phosphate can be used as anticorrosive pigments. This pigment is slightly soluble and can form a corrosion inhibiting molecular layer at the steel surface.
6. The uses of metallic zinc as a sacrificial pigment, in essence the development of an "in situ" cathodic protection system.
7. Zinc coating has been proved as chemical element which helps in reducing microbial and crevice corrosion.
8. Zinc coating has proved to be the most cost effective metallic coating.
9. It has been proved that Zinc aluminum alloy has increased the operating life by 15 years
10. In the oil and gas transmission industry, several materials are specified to be zinc-coated or zinc-electroplated to protect them from environmental corrosion. The materials that are commonly specified to be zinc-coated or zinc-electroplated vary from structural members at the stations to some low-pressure pipelines and fittings within plants [19].
11. The most common metallic coating is galvanized zinc coating applied to the surface of a carbon steel pipe, to protect the pipeline against atmospheric corrosion. It may be alloyed with aluminum for further corrosion resistance [20].
12. The surface morphologies of both the immersed and non-immersed bare metal and zinc coated specimens are scanned at the fractured part and the study suggests that the non-corroded specimen has more smooth surfaces than the corroded specimen.

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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 sullyng, 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  $L_0$  is standardized (in several countries) and varies with the diameter ( $D_0$ ) or the cross-sectional area ( $A_0$ ) 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

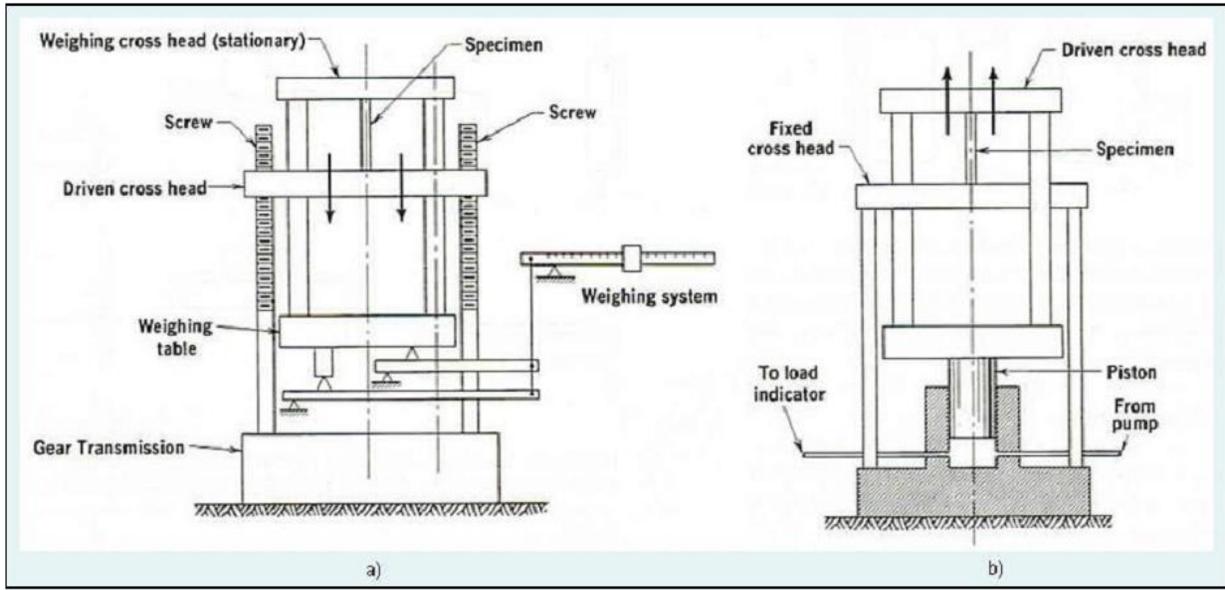


Fig 13: Schematics showing a) A screw driven machine and b) A hydraulic testing machine [18].

### 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.

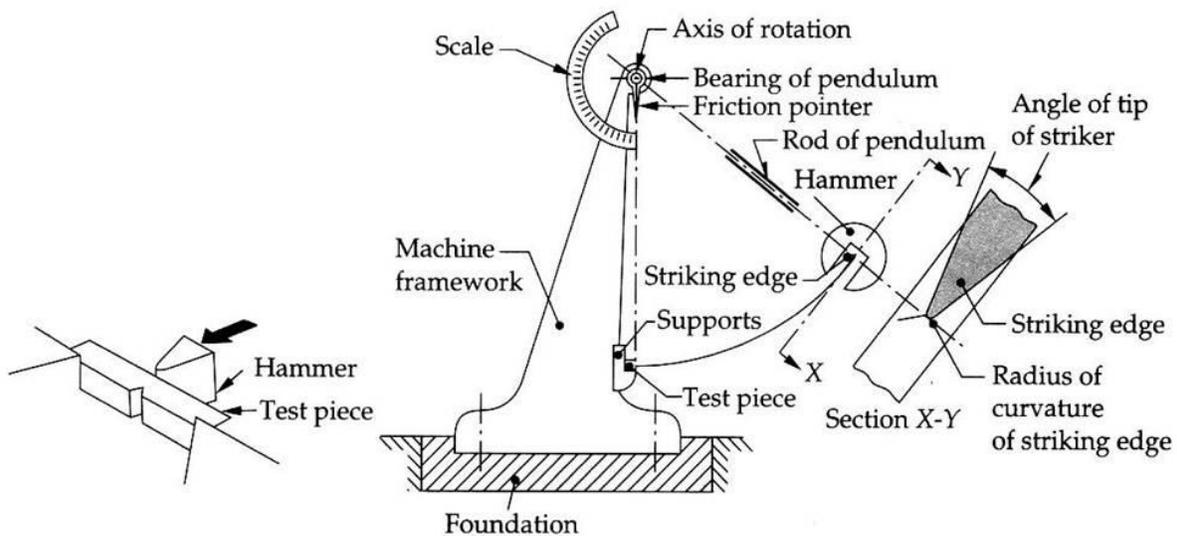


Fig 14: Schematics showing an example of Charpy Impact Test

#### A4. UTM TENSILE TEST BROKEN SPECIMENS



Fig 14: Bare UTM Test Specimen



Fig 15: Bare Corroded UTM Test Specimen



Fig 16: Zinc Coated UTM Test Specimen



Fig 17: Zinc Coated Corroded UTM Test Specimen