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# PROPERTY ENHANCEMENT IN SUPER DUPLEX STAINLESS STEEL (UNS S32760)

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## ABSTRACT

This project work is concentrated on defining the best method to enhance the mechanical properties of metal. In this project, the study metal is Super Duplex Stainless Steel (UNS S32760). This metal which posses equal ratio of austenite and ferrite content. Using about three methods to compare the properties as well the economic consideration on improving the material property. For this study, tensile strength, hardness and the micro structure of the metal is recorded. The methodologies engaged in this study are Case hardening, Zinc overlay surface stratifying process. This study will provoke a better method to get a improvised properties of metal. Considering the metal with its internal layer hardened, treating the surface of the metal with stratified zinc treatment and a bare metal to categorize the monitored property and to summarize with a consolidated report.

## INTRODUCTION

According to the industrial sectors, metals plays an important in production, processing, improvement and distribution of the products. In this project work, study is carried out to improve the properties of the metal which will meet all the requirement of industry to increase quality with low cost. The metal considered for the study is Super Duplex Stainless Steel (UNS S32760).Super duplex stainless steels are generally more complex, more highly alloyed materials with PREN (Pitting Resistance Equivalent number) is less than or equal to 40.0 and offer even higher strength and corrosion resistance making them suitable for very demanding applications such as offshore marine engineering. A range of duplex and super duplex stainless steels are stocked and released to various specifications (including NORSOK) in a variety of forms. Bar (stocked from ½” to 10” diameter), Forgings (blocks, rings and stepped forgings), Sheet, Plate, Pipe, Tube, Closed die forgings, Castings, Flanges, Bolting, Welding Consumables. Super duplex wire, strand and wire rope are also available in the market. Super Duplex Stainless steels were developed during the first decades of the twentieth century in the United Kingdom and Germany. Stainless steel is the term for iron-based alloys that contain at least 10.5% of chromium. The earliest grades of stainless steels were martensitic and ferritic (Fe-Cr) steels. Later austenitic stainless steel (Fe-Cr-Ni) became the largest group and was used extensively due to its ease of production and fabrication Addition of Ni to ferritic stainless

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steels changes the structure to a duplex microstructure which, as its name implies, contains two-phases in significant quantities (both ferrite and austenite). It has typical contents of 18 - 28% Cr and 4 - 7% Ni, but both the phases should be in equal proportion of (50% - 50%) to exhibit the best performance. Duplex steels have much in common with austenitic and ferritic stainless steels, but they have several unique advantages. They have better stress corrosion crack (SCC) resistance than most austenitic grades, are tougher than most ferritic grades and have a higher strength than most grades of either type. They also have the advantage of lower nickel content than comparable austenitic alloys while providing similar corrosion resistance in many environments. Higher strength stainless steels with lower nickel content makes duplex steels an attractive alternative to austenitic grades, especially when the cost of nickel is high.Life assessment of structures, equipment, machinery, etc., in all industrial and commercial fields is an essential element for the continuous improvement of a safer environment.

LITERATURE SURVEY

PROPERTIES OF SUPERDUPLEX STAINLESS STEEL

Super Duplex Stainless steels are notable for their corrosion resistance, which increases with increasing chromium content. Molybdenum additions increase corrosion resistance in reducing acids and against pitting attack in chloride solutions. Thus, there are numerous grades of stainless steel with varying chromium and molybdenum contents to suit the environment the alloy must endure. Thus stainless steels are used where both the strength of steel and corrosion resistance are required. Stainless steel is resistance to corrosion and staining, low maintenance, and familiar lustre make it an ideal material for many applications.

Table2.1 Chemical composition of super duplex stainless steel

| **CHEMICAL COMPOSITION OF SUPERDUPLEX STAINLESS STEEL** | | | |
|---|---|---|---|
| Carbon | 0.03% Max. | Chromium | 24 - 26% |
| Silicon | 1% | Nickel | 6 - 8% |
| Manganese | 1% | Molybdenum | 3 - 4% |
| Phosphorous | 0.035% | Copper | 0.5% |
| Sulphur | 0.015% | Tungsten | 0.5 - 1% |
| Pitting Resistance Equivalent PREn>40(Cr% + 3.3Mo% + 16N%) | | | |

Forging temperature for this material should be 1100 – 1250oC Reheat as often as necessary and **cool** in still air. F55 is readily weld able using many of the standard electric arc welding processes but oxyacetylene welding is not recommended because carbon pickup in the weld metal may occur. Using Duplex 2507 must be restricted to applications below 600° F (316° C). Extended elevated temperature exposure can reduce both the toughness and corrosion resistance of alloy 2507.

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Duplex 2507 has good mechanical properties. Often a light gauge of 2507 material can be used to achieve the same design strength of a thicker nickel alloy. The resulting weight savings can considerably reduce the overall cost of fabrication.

DEVELOPMENT IN DUPLEX STEEL

The higher production cost of the 2205 alloys, resulting primarily from the costs associated with the alloying elements, has limited the applications as an alternative to the commercial grades of austenitic stainless steel such as 304, 316, and 317 especially when its high strength and corrosion resistance exceed the requirement of its application. Thus, it was recommended to provide new weldable grades of duplex stainless steel with a higher corrosion resistance than those commonly used in lieu of austenitic stainless steel grades, and lower production cost than the 2205 alloy. New grades of duplex stainless steel have been introduced in the market based on their economic benefits, ease of fabrication: welding, casting, and machining; improvement in design properties. The success of duplex stainless steels has contributed to the development of an entire family of duplex alloys which can be divided based on their chemical composition and PREN number into essentially four groups:

a. Lean Alloy:

Lean alloys are Mo free duplex stainless steels with relatively reduced Ni content with respect to the standard 22% Cr stainless steel. The reduction in the content of theseexpensive alloying elements has been compensated by increasing the quantity of cheaper alloying elements such Mn and nitrogen for maintaining the correct ferrite/austenite balance. These alloys have seen a significant development over the last years due to their lower cost with respect to its strength and corrosion resistance. The low cost grades of DSS provide alternatives to AISI 304 and 316 in many applications such as structural supports for the onshore and offshore oil and gas industry, architectural and building, waste water treatment facility, automotive, and transportation.

b. Standard 22%Cr:

This is the most popular group in the duplex stainless steel family with PREN values ranging from 30-36 include SAF 2205 duplex stainless steel. In general, this group of stainless steels has higher corrosion resistance than the commercial austenitic stainless steel (e.g., 304, 310, and 316)

c. 25% Cr High Alloy:

This category of stainless steel with variable content of a wide range of alloying elements such as Mo, N, Cu, and W has a PREN ranging from 32 to 40. This includes Ferralim 255 and cast ASTM A890-1B.

PITTING CORROSION

Pitting resistance of stainless steels in chloride environments is essentially controlled by the steel composition particularly levels of chromium, molybdenum and nitrogen present .Endeavors have been made to develop a mathematical formula describing the relationship between the quantity of these elements and the pitting corrosion potential. The most commonly used expression is the so-called Pitting Resistance Equivalent Number PREN , which has been calculated from the bulk alloy composition [6]. This method may be accurate for duplex stainless steel alloys because they contain austenite and ferrite phases that are different in composition. Austenite is enriched with N whereas ferrite is richer in Cr and Mo. It has been found that, in general, austenite has a lower PREN than ferrite in the base material, whereas austenite has higher PREN than ferrite in the weld metal. PREN = Cr + 3.3 Mo + 16 N Equation 2 proposed, introducing Tungsten as an active alloying element: PREW = Cr + 3.3 Mo + 1.15 W + 16 N .

To achieve the best pitting corrosion resistance, the physical metallurgy and welding metallurgy of duplex stainless steels must be understood

- Balance of ferrite and austenite: too much ferrite can cause the formation of Cr2
- Control Ni content: Ni only should be used for controlling phase balance. High Ni will result in too much austenite and not enough Ni will promote the formation of too much ferrite. Higher Ni content also stabilizes sigma phase. N or other intermetallic phases and too much austenite will not only reduce the nitrogen concentration in austenite but also will result in greater segregation of Cr and Mo in the austenite .
- Select proper heat treatment temperature: unlike the solution heat treatment of fully austenitic stainless steels, solution annealing temperature.

## EXPERIMENT

HARDENING

Hardening The duplex stainless steel material was heated to 800 c by the muffle furrnace and is kept at this temperature for soaking for 3 different timings. The soaking was varied from 30minutes, 45minutes, and 60minutes. The material after heating was cooled very fast . The material after heating was cooled by oil cooling. The oil used for cooling is SAE 20-40 oil which is used mostly for automobiles.after hardening the hardness increases as the soaking time increases. Similarly the normalising heat treatment increases wear strength, and also the compressive yield strength of the Duplex stainless steel with the increasing soaking time. But the impact strength of Duplex stainless steel is reduced. Hence hardening heat treatment can be used to improve the hardness of Duplex stainless steel. The tempering is used for increasing the impact strength, of materials after tempering. From the result obtained after tempering it is found that impact strength of the Duplex stainless steel also increases with increase in soaking time. But it is found that hardness of Duplex stainless steelsteel reduces after tempering. The normalising heat treatment is carried out mainly to improve strength with some ductility.

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Fig 3.1 Before Hardening

Fig 3.2 after Hardening

The high surface hardness just results from a super saturation of the microstructure, and not from the precipitation of hard nitrides and carbides, such as in classical nitro carburizing, the hardened zone is very ductile. . The temperature maintained inside the furnace is 800 c. and left the specimen for about another 30minute to get it tempered.

ELECTRO GALVANIZING:

Electro galvanizing is a process in which a layer of zinc is bonded to steel in order to protect against corrosion. The process involves electroplating, running a current of electricity through a saline/zinc solution with a zinc anode and steel conductor. Zinc electroplating maintains a dominant position among other electroplating process options, based upon electroplated tonnage per annum. According to the International Zinc Association, more than 5 million tons are used yearly for both Hot Dip galvanizing and electroplating. The Plating of Zinc was developed at the beginning of the 20th century. At that time, the electrolyte was cyanide based. A significant innovation occurred in the 1960s, with the introduction of the first acid chloride-based electrolyte. The 1980s saw a return to alkaline electrolytes, only this time, without the use of cyanide. The most commonly used electro galvanized cold rolled steel is SECC steel. Compared to hot dip galvanizing, electroplated zinc offers these significant advantages:

- Lower thickness deposits to achieve comparable performance
- Broader conversion coating availability for increased performance and color options
- Brighter, more aesthetically appealing, deposits

The corrosion protection afforded by the electrodeposited zinc layer is primarily due to the anodic potential dissolution of zinc versus iron (the substrate in most cases). Zinc acts as a sacrificial anode for protecting the iron (steel). While steel is close to $E_{SCE}$= -400 mV (the potential refers to the standard Saturated calomel electrode (SCE), depending on the alloy composition, electroplated zinc is much more anodic with $E_{SCE}$= -980 mV. Steel is preserved from corrosion by cathodic protection. Conversion coatings (hexavalent chromium (CrVI) or trivalent chromium (CrIII) depending upon OEM requirements) are applied to drastically enhance the corrosion protection by building an additional inhibiting layer of Chromium and Zinc hydroxides. These oxide films range in thickness from 10nm for the thinnest blue/clear passivity to 4nm for the thickest black chromates.

**Galvanization** (or galvanizing as it is most commonly called in that industry) is the process of applying a protective zinc coating to steel or iron, to prevent rusting. The most common method is hot-dip **galvanizing**, in which parts are submerged in a bath of molten zinc. **Galvanising** is a method of rust prevention. The iron or steel object is coated in a thin layer of **zinc**. any pitting rust on the surface of the specimen.


Fig 3.3 Before Galvanizing

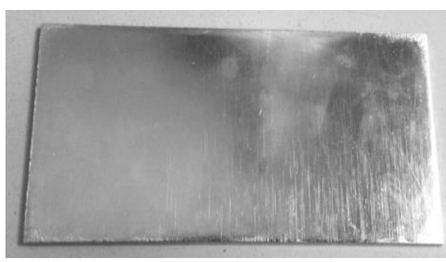

Fig 3.4 After Galvanizing

The purpose of Electro galvanizing is to safeguard the articles from the weather factors' corrosive action. It occurs through electro-deposition; the steel's surface is protected by applying a metal layer that technically resembles more a cataphoresis paint than a galvanizing process.

## I. MATERIAL TESTING

VICKERS HARDNESS TEST

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Vickers hardness is determined similarly to Brinnell hardness. It is classified as a micro hardness determination method and is the more common, compared to Knoop micro hardness. It is measured by forcing an indenter into the surface of the sample. It differs in that it uses a 136angle square pyramid indenter, which produces a square indentation in the specimen, rather than a spherical or conical indenter, which Rockwell and Brinnell hardness techniques use. The square indenter is advantageous over the round indentations as the square indentations are easier to measure than the round impressions from spherical and conical indenters.

### *Measuring Vickers Hardness*

The Vickers hardness tester is equipped with an adjustable height stage, which is wound up to close to the indenter prior to the test. The test is executed with a lever or button, with all the rest of the test parameters being controlled automatically. Indenter loads vary between 1 and 120 kg. The indentation is then measured with a microscope across the diagonals of the square indentation.

### *Calculating Vickers Hardness*

The hardness is calculated by dividing the load by the surface area of the indentation, such that Vickers hardness is determined using the following formula:

$$H_v = \frac{F}{A}$$

where Hv = Vickers hardness (in MPa), F = load and A = surface area of the impression.


Fig4.1 Vickers hardness tester

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Table 4.2 Result for Hardness test

| SPECIMEN NAME | HV value for all specimen | | | Con solidated HV Value |
|---|---|---|---|---|
| | Test 1 | Test 2 | Test 3 | |
| Bare Specimen | 287 | 303 | 303 | 298 |
| Hardened Specimen | 369 | 372 | 370 | 371 |
| Galvanised specimen | 302 | 304 | 305 | 304 |

After doing this testing process on every metals, an intendation will be formed. According to that intendation size, a calculation is done and result is formulated

TENSILE TEST

Tensile testing, also known as tension testing is a fundamental materials science and engineering test in which a sample is subjected to a controlled tension until failure. Properties that are directly measured via a tensile test are ultimate tensile strength, breaking strength, maximum elongation and reduction in area. From these measurements the following properties can also be determined: Young's modulus, Poisson's ratio, yield strength, and strain-hardening characteristic. Tensile testing might have a variety of purposes, such as:

Select a material or item for an application

Predict how a material will perform in use: normal and extreme forces.

Determine if, or verify that, the requirements of a specification, regulation, or contract are met

Decide if a new product development program is on track: Demonstrate proof of concept

Demonstrate the utility of a proposed patent

Provide standard data for other scientific, engineering, and quality assurance functions

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Provide a basis for Technical communication

Provide a technical means of comparison of several options

Provide evidence in legal proceedings

TEST SPECIMEN

A tensile specimens is a standardized sample cross-section. It has two shoulders and a gage (section) in between. The shoulders are large so they can be readily gripped, whereas the gauge section has a smaller cross-section so that the deformation and failure can occur in this area. In large castings and forgings it is common to add extra material, which is designed to be removed from the casting so that test specimens can be made from it.

OBTAINED RESULT

Using the Universal Testing Machine (UTM), the observed data is three different graphs. They are Stress vs Strain graph, Load vs displacement and Strain vs Displacement. With additional observations of maximum displacement, force, Reduction in area, Tensile strength.When the conditions for the environment have been identified and the test has been created, this should be conducted again several times to verify whether this test meets the acceptable reproducibility standard.

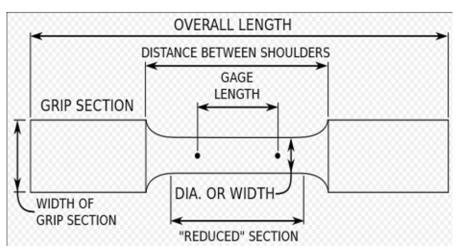


Fig 4.2 Tensile flat specimen

Fig 4.3 Tensile Test Specimen

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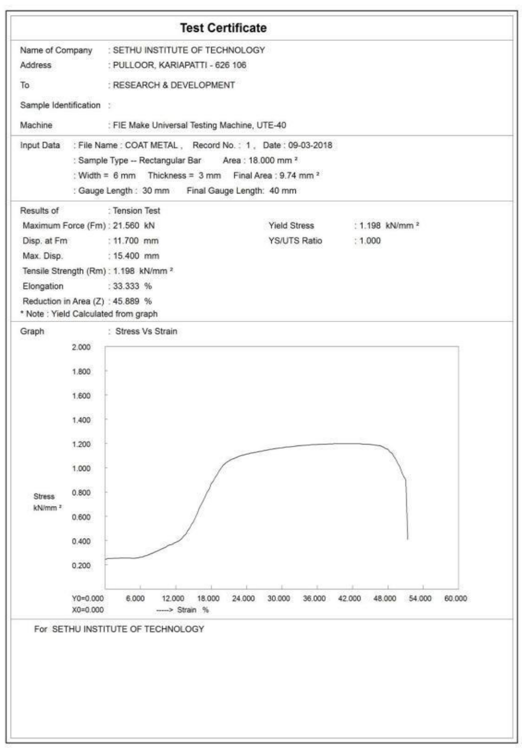
Tensile testing is most often carried out at a material testing laboratory. The ASTM D638 is among the most common tensile testing protocols. The ASTM D638 measures plastics tensile properties including ultimate tensile strength, yield strength, elongation and Poisson's ratio.

Tab 4.3 Report of Tensile test

| SPECIMEN Data | Tensil-e Streng-th (kN/mm2) | Displacement (Max) (mm) | Elongation (%) | Force (Max) (kN) |
|---|---|---|---|---|
| Bare metal | 0.75 | 13.5 | 25 | 21.34 |
| Hardened metal | 1.252 | 9.7 | 10.01 | 22.54 |
| Galvanized Metal | 1.198 | 15.4 | 33.33 | 21.56 |


Test Certificate

Name of Company : SETHU INSTITUTE OF TECHNOLOGY
Address : PULLOOR, KARIAPATTI - 626 106
To : RESEARCH & DEVELOPMENT
Sample Identification :
Machine : FIE Make Universal Testing Machine, UTE-40

Input Data : File Name : COAT METAL , Record No. : 1 , Date : 09-03-2018
: Sample Type -- Rectangular Bar Area : 18.000 mm ²
: Width = 6 mm Thickness = 3 mm Final Area : 9.74 mm ²
: Gauge Length : 30 mm Final Gauge Length: 40 mm

Results of : Tension Test
Maximum Force (Fm) : 21.560 kN | Yield Stress : 1.198 kN/mm ²
Disp. at Fm : 11.700 mm | YS/UTS Ratio : 1.000
Max. Disp. : 15.400 mm
Tensile Strength (Rm) : 1.198 kN/mm ²
Elongation : 33.333 %
Reduction in Area (Z) : 45.889 %
* Note : Yield Calculated from graph

Graph : Stress Vs Strain


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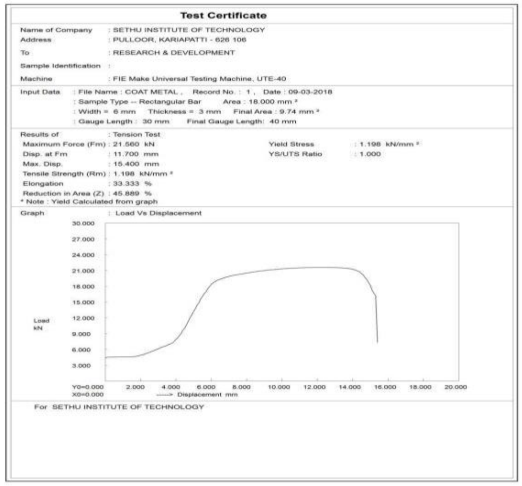
Fig 4.4 Stress Vs Strain graph of Coated Metal



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Yield Stress : 1.198 kN/mm ²
YS/UTS Ratio : 1.000
* Note : Yield Calculated from graph

Graph : Load Vs Displacement



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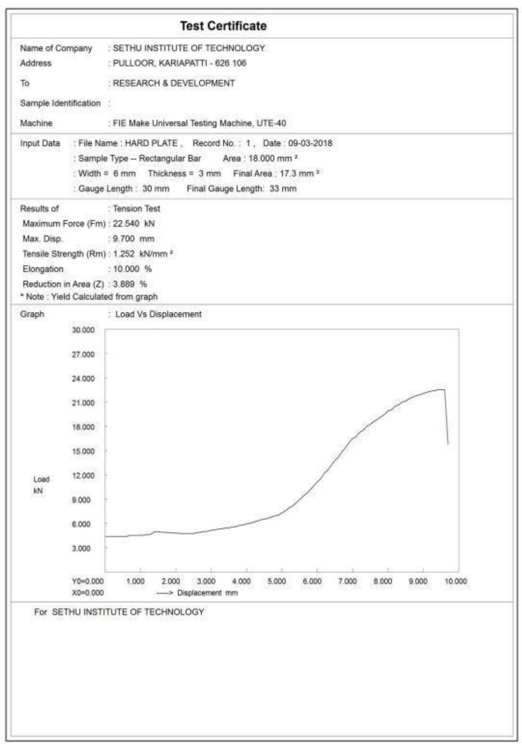
Fig 4.5 Load Vs Displacement graph of Coated Metal



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: Width = 6 mm Thickness = 3 mm Final Area : 17.3 mm ²
: Gauge Length : 30 mm Final Gauge Length: 33 mm

Results of : Tension Test
Maximum Force (Fm) : 22.540 kN
Max. Disp. : 9.700 mm
Tensile Strength (Rm) : 1.252 kN/mm ²
Elongation : 10.000 %
Reduction in Area (Z) : 3.889 %
* Note : Yield Calculated from graph

Graph : Load Vs Displacement



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Fig 4.6 Load Vs Displacement graph of Hardened metal

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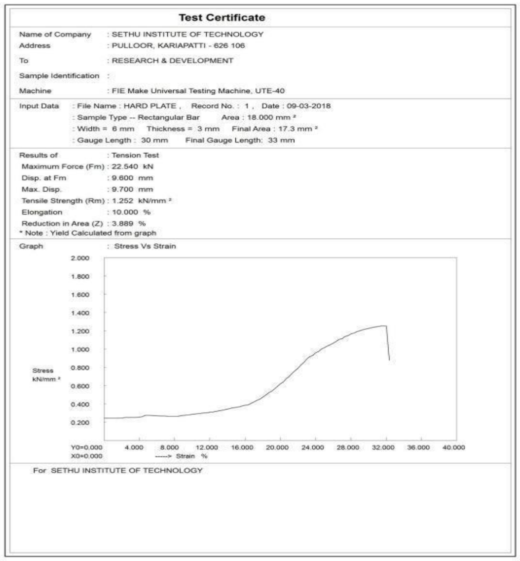

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Results of : Tension Test
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Disp. at Fm : 9.600 mm
Max. Disp. : 9.700 mm
Tensile Strength (Rm) : 1.252 kN/mm ²
Elongation : 10.000 %
Reduction in Area (Z) : 3.889 %
* Note : Yield Calculated from graph

Graph : Stress Vs Strain



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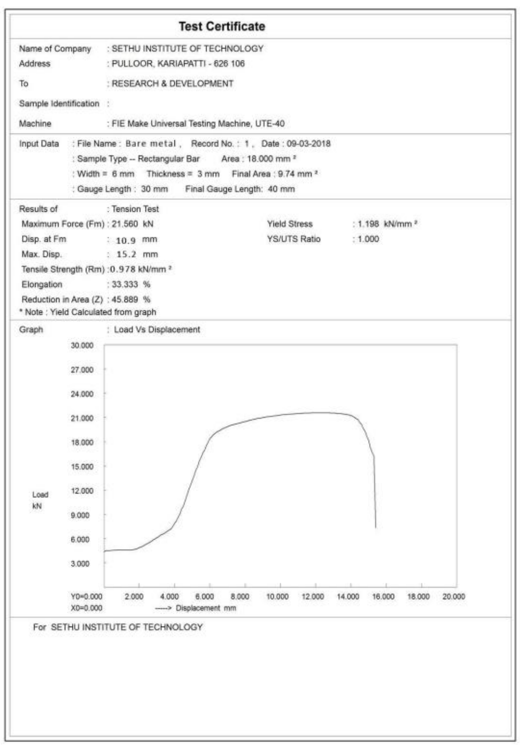
Fig 4.7 Stress Vs Strain graph of Hardened Metal



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Disp. at Fm : 10.9 mm YS/UTS Ratio : 1.000
Max. Disp. : 15.2 mm
Tensile Strength (Rm) :0.978 kN/mm ²
Elongation : 33.333 %
Reduction in Area (Z) : 45.889 %
* Note : Yield Calculated from graph

Graph : Load Vs Displacement



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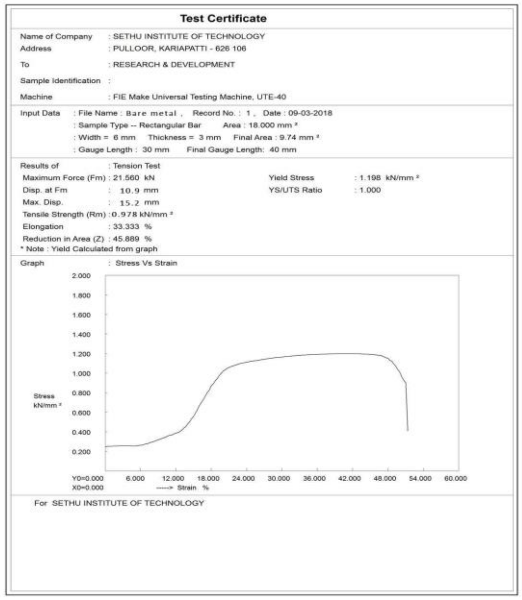
Fig 4.8 Load vs Displacement graph of Bare metal



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* Note : Yield Calculated from graph

Graph : Stress Vs Strain



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Fig 4.9 Stress vs Strain graph of Bare metal

CORROSION TEST

BEFORE IMMERSION TEST:

Fig 4.10 Coated metal before test

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Fig 4.11 Bare Metal before test

Fig 4.12 Hardened Metal before test

AFTER IMMERSION TEST:

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Fig 4.13 Coated Metal after test

Fig 4.14 Bare Metal after test

Fig 4.15 Hardened Metal after test

Immersion testing in Sodium Chloride solution with Hydrogen Sulphide solution allows an assessment of pitting corrosion resistance of Duplex stainless steels. The environment within a corrosion pit that may develop during service in chloride solutions, eg seawater. Hence, this test has become accepted as a quality control or ranking test for stainless alloys and metals.

This test method provides a procedure for determining the ability of metal specimen to withstand immersion or splash exposure by fresh or seawater as might be encountered when installed in a marine environment. This is one of several tests, including environmental cycling exposure and exposure to a

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corrosive environment, that are intended to provide an accelerated basis for evaluating the aging effects of a marine environment on module materials and construction specific to marine applications.

Immersion tests measure the progress of corrosion damage obtained from the immersion length within a corrosive environment, as well as other factors that can accelerate the corrosion process. These tests can involve alternative drying or immersions, such as in cases of cyclical tests. Moreover, test instrumentations may be included throughout immersion like electrochemical instrumentation connections in order to facilitate the measurements. Immersion tests are capable of generating uniform data for alloy corrosion and are utilized in industries subjected to immersion conditions.

- Simple immersion test - In this test, small batches of the material are subjected to the medium under testing, while loss of weight is being gaged for a particular period.

The immersion test remains the most reliable method in terms of screening. It also serves as the most simple and economical way to determine the most suitable material to protect against corrosion in certain environments.

## OBSERVED RESULT:

As per the study, the corrosion resistant property of the material is monitored. By conducting a simple immersion test, we observed which material is resisting to get rust at natural environment conditions.

## RESULT &DISCUSSION

As declared earlier this experiment has been conducted to find the economic and best way to enhance the property of a material. In this project work, the property enhancement is carried out on a Super Duplex Stainless Steel material. To identify the property enhancement, three different experiment has been made on the study material. To observe the changes in the material, three different tests has been taken using the experimented material. The three different experimented metals which have been undertaken to three different tests are bare material, hardened material, and galvanized material. These three differently treated metals have been undertaken some tests to observe the property enhancement in the materials. In first test, all the metals are exposed to the Vickers hardness test. Specifically, as mentioned in the above experiment chapter this test is to find the hardness of the material. The hardness property is very much important for metal to resist plastic deformation induced by the mechanical indentation or abrasion. If a material possesses good hardness value, then it means the material has strong intermolecular bonds. At the result of the test, it is found that the hardened metal is harder than the rest. Even though, the galvanized metal occupies the next place to a hardened metal. So, this is considerable. In second test, all the metals are again taken a tensile test in a universal testing machine. This tensile test is taken on all metal to find out the tensile strength of the metal. It is the property of the metal to withstand stress while being stretched without breaking.

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As a result, the work proved that the galvanized metal possesses good tensile strength and other property. Thus, in this test the galvanized metal is durable and reliable. In third test, all the metals are treated with immersion corrosion test to find rust resisting behavior of the specimens. Corrosion is a factor which is destructing the refined property of the metal into a corroded surface. If a material has corrosion resistance property then it can be exposed to all environmental conditions. At the end of this test, it is found that the galvanized metal does not possessed any rust, except the other two metals.

## CONCLUSION

Discussing about the properties of the metals, we can barely notice that the property of the galvanized metal has the enhanced characteristics. When compared to the bare and hardened metal. This project can prove the property differences which has been observed during the test. Considering the tensile test of all metals, the result obtained as the hardened metal has high tensile strength compared to all three metals. In this test, the hardened metal has a tensile strength of 1.252kN/mm2, galvanized metal has 1.198kN/mm2, the bare metal has 0.978kN/mm2. Evaluating the values, the galvanized metal specimen is establishing a considerable result.

According to all test reports, the experimented material which is coated with zinc- overlay galvanization is very much effective and efficient than all other tested metals. It is also contributing the most economic treatment among these methods. So, this project work concluded that zinc- overlay galvanization is the appropriate method to enhance the property of the Super Duplex Stainless Steel.

According to the environmental and safety aspects, this project enhances the property of the metal and makes it so durable even at the extreme weather conditions. If the metal exposed to the corrosive environment, it won't corrode for decades. Due to this property, it is been used in offshore oil and gas piping to ensure ultimate safety to prevent catastrophic disasters.

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