



## **Addis Ababa University**

Addis Ababa Institute of Technology School  
of Mechanical and Industrial Engineering

**Manufacturing Engineering**

### **Investigating the effect of coating material, thickness and joint configuration on mechanical property of welded mild steel**

A Thesis Submitted to the Graduate School of Addis Ababa University in  
Partial Fulfillment of Requirements Degree of Masters of Science in  
Mechanical Engineering (Manufacturing Engineering)

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Submission Date: May 20/2024

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## List of Abbreviation

AAIT	Addis Ababa Institute of Technology
AISI	American iron and steel institution
ASME	American society of mechanical engineers
ASTM	American society of testing material
AWS	American welding society
CGHAZ	Coarse grain heat affected zone
DOE	Design of experiment
FGHAZ	Fine grain heat affected zone
FZ	Fusion zone
HAZ	Heat affected zone
HV	Hardness value
MMAW	Manual metal arc welding
$\mu\text{m}$	Micrometer
mm	Millimeter
MINCNT	Multi walled-carbon-nanotube
NDT	Nondestructive testing
SAW	Submerge arc welding
SMAW	Shielded metal arc welding
WM	Weld metal
UTM	Universal testing machine
CT	Coating thickness
CM	Coating material
JC	Joint configuration

## Abstract

The influence of coating material, thickness and joint configuration on mechanical property of SMAW welded joint for SAE1020 mild steel was assessed in this study. The coating material has 2 levels zinc and copper with 4 different coating thickness levels 85-95, 100-110, 115-125 and 130-140 with 2 welding configuration butt and lap joint. The design of experiment (DOE) was done using taguchi orthogonal array then for the mixed level taguchi design array L16 ( $4^1 2^2$ ) experimental runs were conducted. During welding coated mild steel there is a trapping of zinc and copper in molten pool of steel causing mechanical property reduction and welding defect on microstructural analysis.

This work investigates mechanical properties namely hardness, tensile and flexural strength of welded joint under different coating material, thickness and joint configuration. In addition to this the micro structure analysis of welding zone of uncoated and coated with 85-95 and 130-140 coating thickness was analyzed using an optical microscope with 100\* magnification.

The result of the investigation indicates that significant decrease in hardness with increase in coating thickness. From the experiment with increasing the coating thickness from 85 micro meter to 130 micro meter the hardness value decrease with 15.55% and in joint configuration butt joint configuration reduced with 1.605% compared to lap joint. The tensile strength and flexural strength is lower with 9.21% and 8.9% with increasing coating thickness from 85 micro meter to 130 micro meter. The optimal parameter set are 85-95 coating thickness, copper coating material and butt joint configuration this was analyzed using grey relation analysis. The signal-to-noise ratio rank conclude that Varying the coating thickness found to cause more significant changes on mechanical properties than varying coating material and joint configuration. The micro structural investigation of uncoated and coated mild steel was done using an optical microscope. The result of the investigation indicates that a welding defect was seen in microstructure of zinc coated mild steel as coating thickness increase. In addition to this in the fusion zone of the welding there is a small increase in grain size then this will reduce the strength of material. Finally uncoated mild steel shows better mechanical property than the coated one but for some critical reasons if coated mild steel is used this work recommend to use a mild steel with coating thickness of 85-95 for safe and quality structural construction.

**Key words:** Mild steel, Coating thickness, Coating material, Small scale copper and zinc coating technique, mechanical properties.

## Acknowledgment

First I would like to thank the almighty GOD for give me the strength to finalize this study, beside, I would like to give my deep gratitude to my advisor Dr. Mesfin Gizaw for his motivational and thoughtful supervision, patience and his valuable advice from the start to the end of the study. I am immensely grateful for your kindness, patience, time and professional contribution to the success of my study.

My appreciation also goes to my university wolkite university for give me the great opportunity to join the MSc program. I am also grateful for standard institute, Adam Science and Technology University and Ethiopia Technical University (Ethio china) for allowing me to use their testing facility to conduct my experiments. I would also like to thank all my families and friends for their valuable prized support.

## Chapter one

### Introduction

#### Background of the study

Most commonly corrosion is considered to be most predominant cause for failure of structural material a relation between mechanical property deterioration and corrosion of metal was directly related [1] and researchers conclude that the metal corrodes more readily in environments with higher acidity levels. and this will reduce both tensile strength and fracture toughness of the metal [2]. So in order to reduce corrosion formation coating of metal is important.

Metal coating is a process of covering a metal with metal or other surface finish to protect the surface from rust and other corrosion caused by different environmental exposures such as air, chemical exposure and water. This technique mostly used by many manufacturing companies to protect their finished products from getting damaged or corroded [3]. There are different coating and coating techniques that can be used but the issue that determine The type of coating, the substrate material, the coating's thickness range, the part's size, shape, and the equipment cost all influence which method is best for a particular paint or coating measurement [4]. But to weld coated steel specific precaution should be taken; the zinc coating in the weld area evaporates when galvanized steel is arc welded due to the heat of the welding arc. This is due to the coating's boiling point being lower than the melting point of steel. For instance during zinc coating The zinc volatilized and leaves the base metal adjacent to weld. When resistance welding galvanized sheet, heat disrupts the zinc coating less than arc processes do. [5]. Then Coating thickness is a significant variable that affects cost control measurement and process control for product quality. Then inspection of coating thickness is the most important step in determining the quality of galvanized coating. The process can be classified in to two groups; destructive techniques and non-destructive techniques. Non-destructive dry film methods like magnetic, eddy current, ultrasonic, or micrometer measurement are frequently used methods of measurement. [6].

On the whole there are several research works that investigate the metal coating and coating thickness difference will result a change on mechanical property of base metal. Most of the research works doesn't investigate the coating effect on weldability of metal but this research was investigated the mechanical properties like tensile, hardness, bending strength and microstructural of coated and welded mild steel was examined by using different coating thickness.

## 1.2 Statement of the problem

Galvanized steel is one of the most common kind of steel in today market because of its extended durability and used as a protective material from rust the standard thickness of galvanized coating thickness should be 35-100 micro meter [7] but for structural steel work the minimum average coating thickness is 85 micrometer up to 140 micro meter. Even if it has so many importance ride off the galvanized material across the welding area before welding is significant activity in most welding industries (American welding society standard 19 give specification about welding galvanized steel and the standard advices preparing the zinc coated metal from welding by grinding off the galvanized layer 1-4 inch on either side of the welding line and both side) because the most significant challenge for using the coated( galvanized) steel as a structural material is that during welding this can be during maintenance or new construction) if welding takes place with out riding of the coating then the coating will melt and mix the molten metal. So using this galvanized steel by removing the coating at the welded area for welding fabrication of items will not be economical and time consuming activity especially for bulky fabrication of items in addition to this in some maintenance construction there are some unreachable areas to remove the coated material. So the importance of working on this research area is that to investigate the effect of coating material and coating thickness on weldability mild steel without removing the coating material.

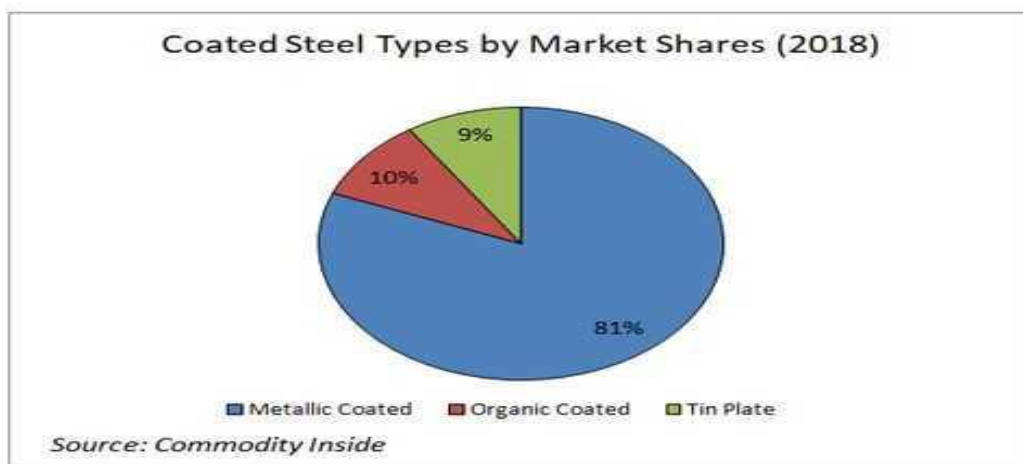


Figure 1: Coating steel types

Now a day's corrosion is considered to be most predominant cause for failure of structural material construction [8] beam and key structural element that play a crucial part in supporting the building weight and creating a safe load path from the slab to the structural foundation [9]. So in order to reduce the accelerated failure rate a protective coating must be used as a barrier of corrosion and erosion. The biggest obstacle to use coated steel as a structural component is that during welding coating material (this can be during maintenance or new construction) the coating will melt and mix with the molten

metal then this will change the chemical composition of the welded metal then this will result a change on mechanical property (hardness, tensile, bending and microstructural test) of the metal. So the importance of working on this research area is that to identify the mechanical property changes during different coating material, coating thickness and joint configuration. Then by comparing the mechanical property experimental tests the appropriate and best coating material, coating thickness and joint configuration will be selected.

**Okafor, Ignatius C., et al.** Studies the impact of zinc galvanization on low- and medium-carbon structural steel's microstructure and fracture behavior. The microstructure and fracture behavior of ASTM 572 grade 65 steel, intended for use in wind towers, were examined in this study. The three-point bending test was used to examine the fracture toughness of steels in samples that were coated with zinc and those that were no. to examine the microstructural change a scanning electro microscope was used. Finally, after zinc galvanization, the study finds that low carbon steel exhibited a higher resistance to fracture than medium carbon steel [10]. However this paper doesn't consider the coating thickness variation. So in this research mild steels SAE1020 will be examined at different coatings thickness and identify mechanical property during different joint configuration. The application of mild steel is to manufacture products in many industries and markets. It is one of the most popularly steel types It can be utilized in the construction of buildings, pipelines, vehicles, machinery, building gates and fencing, and cookware.[10]

### 1.3 Objective of the study

#### 1.3.1 General objective

**The study aim is to investigate the effect of coating material, thickness and joint configuration on mechanical property of welded mild steel.**

#### 1.3.2 Specific objective

- ✓ To study mechanical properties of the welded mild steel during zinc and copper coating material.
- ✓ To study the effect of coating thickness on mechanical properties of welded mild steel.
- ✓ To study the effect of welding joint configuration on mechanical properties.
- ✓ To study microstructure of the welding during zinc and copper coating with thickness 85-100,130-140 and uncoated metal.
- ✓ To identify the optimal experimental parameter
- ✓ Comparing the uncoated mildsteel mechanical property result with the coated optimal parameter

### 1.4 Significance of research

In most welding industries ride off the galvanized material across the welding area is significant activity but using this galvanized steel by removing the coating at the welded area for welding fabrication of items will not be economical and time consuming activity especially for bulky fabrication of items in addition to this in some maintenance constructions there are some unreachable areas to remove the coated material. So this study investigates the effect of coating material and its thickness on mechanical property of welded joint. Then the main aim of this study is to investigate the optimal experimental set up for safe construction design.

### 1.5 Scope of the research

This study experimentally explores the effect of zinc and copper coating on mild steel weld ability with a coating thickness 85-95,100-110,115-125 and 130-140 micro meter join with shield metal arc welding. The mechanical properties like tensile strength, bending strength and hardness test was tested for prepared sample. In addition to this the microstructure for lap welding zinc coating with thickness of 85-95, 115-130 and uncoated mild steel was analyzed.

### 1.6 Limitation of the study

Among many obstacles face while conducting this work the major one's are;

First, it is hard to find enough journals and books that discuss about coating thickness and weldability relation. In addition to this there was a limitation to get experiment materials like coating thickness gauge.

Second, the electroplating process was time taking since the process was done at small scale at home.

Third, Obtaining the right testing equipment and experimental setup for the mechanical property test was difficult.

### 1.7 Research questions

- ✓ What effect can be noticed on lap joint/butt joint configuration of mild steel when coated with pure zinc at a thickness range of 85-95, 100-110,115-125 and 130-140 micro meters?
- ✓ What effect can be noticed on lap joint/butt joint configuration of mild steel when coated with copper at a thickness range of 85-95, 100-110, 115-125 and 130-140 micro meter?

- ✓ Which coating type and coating thickness is more dominant parameter? For maintaining required quality.

### 1.8 Organization of the thesis

**Chapter one:** - This section provides an overview of the study's history, metal coating, and corrosion effect. It also includes a description of the study's scope, main and specific objectives, problem justification, and limitation.

**Chapter two:** - Describe literature written on coating, coating type, effect of corrosion on mechanical property of steel and effect of coating on different metal.

**Chapter three:** - This section explores materials and methods that are used to conduct the experiment. In addition the coating type, coating thickness and welding type are included in this chapter.

**Chapter four:** - Explains the outcome and discusses about the experimental findings.

**Chapter five:** - Provides a conclusion, recommendation and future work of the thesis depending on the conducted result.

## Chapter two

### Literature review

#### 2.1 Introduction to coating

Metal coatings are applied to metal to prevent rust and minimize metal deterioration. When exposed to the environment, an uncoated metal will rust and corrode. By coating metal, external protection is provided[11]. Polymers like epoxy, polyurethane, and moisture-cured urethane are used to make metal coatings. Metal can be coated with a variety of coatings; the type of coating to use depends on how the metal product will be used in the end. Some metal coatings are intended to shield the metal from debris, rust, and dirt. This is applicable for outdoor equipment, like boats, heavy equipment, automobiles, trains, and airplanes. These products come into contact with various potentially hazardous working environments, such as fuel, oil, lubricants, and dirt [12]. The metal coatings keep rust and oxidation. A train or car's uncoated metal would quickly corrode from the liquids and chemicals it is frequently exposed to. Coating the metal makes it resistant to these impurities, making the final product more robust and long-lasting. [2]. Furthermore, metal coatings are employed as torque agents or lubricants. For instance, metal objects like screws, bolts, and fasteners are frequently coated with metal to facilitate tightening or unscrewing [13]. Metal coatings in all material need to fulfill international standards like ISO12944 which is a global corrosion protection standard for different environments C2,C3,C4, and C5 this is originally released in 1998 the standard is put together by representatives from key countries and components involved in the protection of steel structure to build a mutual beneficial standard[14]

##### 2.1.1 Coating type

There are numerous methods of metal coating with their limitations and benefits [12].

1. Anodizing- is performed by submerging the aluminum component and cathode in a tank that is filled with electrolytic solution. Aluminum is exposed to an electrical current, which causes it to oxidize and create a barrier of protection. The limitation of this process is that it is only useful on a handful of metal that means it is unsuitable for ferrous metals.
2. Galvanization- this is a process of immersing a metal in a molten zinc bath, it is highly stable and adherent to the metal. The biggest disadvantage of the galvanization process is its cost.
3. Electroplating- is also known as electro deposition during this process both the metal to be coated and the coating metal are placed in an electrolytic solution. The metal to be coated acts as an anode while the coating metal acts as a cathode. The electric current causes metal ions to move from the cathode to the anode and form a coating. The drawback of this process is that it can produce non-uniform coating thickness.

4. Paint coating- is the application of liquid paint, which is the most widely available and reasonably priced type of coating. However, because liquid paint ages, peels, and flakes more quickly than other coating methods, it is less durable than other coating methods.
5. Power coating- is coating an object with powder-based substance the coating particles will be electrically change with polarity that is opposite to the part to be coated the difference change caused the powder particles to adhere to the metal's surface while power coatings may be cost effective in long term the initial start-up cost can be significant and it is also difficult or impossible to achieve thin coating layers.

### 2.1.2 Coating characteristics

A corrosion resistance coating needs to have a number of crucial characteristics. These could change based on how the coating is specifically used. However, a few fundamental qualities are needed for any coating material [15].

#### 1. Water Resistance

Since all coatings will come into contact with moisture and water is the universal solvent that causes both iron and steel to oxidize even in standard basic water conditions, resistance to water is the most important coating characteristic. No single coating can function well in every water situation. The various types of water only serve to exacerbate these mechanical issues by causing swamp water, which leads to server pitting. Excellent water resistance is a requirement for high-performance corrosion-resistant coatings. This means that they must be able to endure repeated submersion in fresh or salt water without blistering, cracking, softening, swelling, or losing their adhesive properties. Additionally, because these coatings are typically exposed to a condensing atmosphere, it must be able to endure repeated cycles of wet and dry conditions.

#### 2. Chemical resistance

The ability of a coating to withstand the disintegration of chemical reactions resulting from said resistance is known as chemical resistance, and it is contingent upon the resins used in the coating's production as well as the formulation of the coating itself. A coating intended for use in a chemical atmosphere for corrosion resistance should typically be resistant to a wide range of PH values of salt, acid, and alkalis. It ought to be impervious to organic substances like gasoline, lubricant, diesel oil, and the like.

#### 3. Proper adhesion

Since adhesion is crucial to preventing both the effects of water on the coating's life and problems caused by temperature gradients across the coating, a corrosion-resistant coating must have a high level of adhesion.

#### 4. Abrasion resistance

The best organic coatings for abrasion resistance are poly urethane ones, which offer remarkable protection against impact, scouring, and abrasion. Inorganic zinc coatings, on the other hand, are more expensive, but they stick to steel surfaces well and perform exceptionally well when used on ship and barge decks due to their silicate and zinc content.

#### 5. Ability of expands and contract

Every coating material has a unique coefficient of expansion; therefore, for a coating to be resistant to corrosion, it must also be able to expand and contract. Temperature fluctuations must be tolerated by a suitable corrosion-resistant coating without causing it to check or crack. The outstanding resistance of inorganic zinc coating to such temperature changes has been demonstrated.

#### 6. Weather resistance

A protective coating that is weather-resistant must withstand sunlight, rain, snow, freezing and thawing, expansion and contraction of the substrate's chemical fumes, dusts, and continuous wet-dry cycling. Generally, weather resistance combines almost all of the properties needed for a coating into one property for everyday use, but for more specialized applications, a coating must withstand the above conditions without excessive checking.

#### 7. Resistance to bacteria and fungus

Fungi and bacteria can impact a coating in two different ways. Initially, they tend to live and flourish on any dirt that has accumulated on the coating's surface. They establish colonies after attacking the coating. These fungal colonies can eventually cause the coating to permanently break down because they are living on one or more of the coating's ingredients.

#### 8. Pleasing appearance

While protecting the basic structure and preventing corrosion are the main purposes of a coating. It should also retain its color and be aesthetically pleasing.

#### 9. Easy application

Application is crucial for coating, particularly when working with multi-cornered structures. These areas are the first to deteriorate in a corrosion atmosphere and suffer if a coating is difficult to apply.

#### 10. Friction resistance

Certain coatings experience friction, especially when they serve as a faying surface for metal sections that are bolted or riveted together to create friction joints. Under these circumstances, inorganic coatings have shown to be incredibly satisfactory, whereas the majority of organic coatings are not.

## 2.2 Factors to consider when choosing coating

There are a number of ways used for coating and each technique is different. To pick the most suitable one for particular application, there are three factors that need to be considered to determine the right coating process what is metal coating [16]

### 1. Objective

The first factor to consider is the specific goal for using a metal coating and how it helps achieve the desired outcome. Some metal coating techniques are designed specifically to protect the surface from rust, corrosion, dirt and debris example include outdoor equipment, automobiles, trains and airplanes by using the right metal coating technique, it help prevent oxidation and rust on the surface and provides durability and long-lasting product[17].

### 2. Time required

The second factor is to consider the amount of time needed for coating process to be completed. It depends on the choice of technique being used for the metal coating to be the surface. The time varies from one process to another, and in a manufacturing environment it can be important to ensure that the right technique is being used to fit with the production schedule.

### 3. Cost

The third factor to be consider is cost the different techniques vary in cost depending on a number of factors. Decisions are made based on the quantity of parts, capital required, the expense of material and labor, time savings and product quality. The importance of finished coating and product use typically guide the decision.

#### 2.2.1 Coating thickness

Coating thickness refers to the thickness of coating. The thickness of this layer can be investigated using a variety of approaches. There are two categories into which this process can be divided: destructive and non-destructive techniques [18] Direct thickness measurement is made possible by a destructive technique. The sample cannot be used after analysis because it needs to be changed at the macroscopic or microscopic level. and must be disposed of on the other hand, A non-destructive method makes it easier to measure the sample without causing any damage to it [19]. Direct measurements are classified as non-destructive methods since they require certain assumptions and computations to produce a numerical thickness value [20]. The method most frequently employed in the industrial field for thickness measurement and quality control is the X-ray fluorescence spectroscopy. Because it enables quick, non-destructive analysis that requires little sample preparation [21]. Other non-destructive methods, like ellipsometry, are more frequently employed for research purposes; nevertheless, they are rarely applicable to metallic coating and X-ray reflectivity. [18]. The thickness of organic coatings can be determined using a number of accepted techniques. The type of coating and substrate, the coating's thickness range, the part's size and shape, and economics are the factors that typically dictate the method used [22]. Non-destructive dry film methods like magnetic, eddy current, ultrasonic, or micrometer measurement; destructive dry-film methods like cross-sectioning or gravimetric measurement; and

wet-film measurement are frequently utilized measuring techniques [16].

## 2.3 Grey relation analysis

GRA is technique adopted for the calculation of grey relational degree and for the determination of contributing measure of the influencing parameters in process that governs overall behavior the system following are the detailed step involved in this process[23].

### 2.3.1 Normalization of the response

This stage involves pre-processing or normalization of data with respect to objective function defined equation (1) is used if larger –the-better is chosen for normalization and equation (2) is used for smaller-the-better function. This stage is performed for reduction of variation in the experiment data to make the Analysis easier [23]

$$Xi(k) = \frac{xi(k) - \min xi(k)}{\max xi(k) - \min xi(k)} \quad (1)$$

$$Xi(k) = \frac{\max xi(k) - xi(k)}{\max xi(k) - \min xi(k)} \quad (2)$$

In the above equations,  $i = 1, \dots, m$ ;  $k = 1, \dots, n$ ,  $m$  represents number of experimental runs  $n$  is the responses.

$Xi(k)$  - value post data pre-processing

$xi(k)$  - the original sequence data

$\max xi(k)$  - largest value of  $xi(k)$

$\min xi(k)$  - minimal value.

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### 2.3.2 Computation of deviation sequence

The deviation is computed based on the nature of response and its objective function in the case of ra smaller-the-better criteria is opted as the outcome needed to minimized whereas for larger-the-better option is considered for maximizing the response outcome. This stage involves calculation of deviation f from the normalization values. The deviation is computed based on higher normalization value attained from the experiment [23]

### 2.3.3 Computation of grey relation coefficient (GRC)

Equation(3) as shown below is applied for the computation of GRC

$$\xi_i(k) = \frac{\Delta \min + \psi \Delta \max}{\Delta o_i(k) + \psi \Delta \max} \quad (3)$$

### 2.3.4 Computation of grey relation grade ( GRD)

The correlative level between the reference and comparability sequence is represented by GRD. This stage involves conversation of multi-objective function in to single objective function. The governing equation followed for determining GRD is given in equation (4)

$$\gamma^i = 1/n \sum_n^{k=1} \xi_i(k) \quad (4)$$

### 2.3.5 Optimal parameter

This stage involves identification of rank for each value/ the rank thus identified provides the sequence of run resulting in optimum solution.

## 2.4 Influence of coating on material property

### 2.4.1 Effect of coating on different metals

This section of the study reviews the findings of earlier investigations that were conducted on effect of coating on different metals the materials used in the review are mainly published works found relevant to this investigation which are useful in pointing out the direction to adopt for this thesis and clearly revealing the gap in knowledge which this research will fill for the advancement

**Okafor, Ignatius et al.** investigates the impact of zinc galvanization on the low- and medium-carbon structural steel's microstructure and fracture behavior. ASTM 572 grade 65 steel for wind tower application was used for this study's microstructure and fracture behavior. The three-point bending test was used to examine the fracture toughness of steels in samples that were coated with zinc and those that were not. to examine the microstructural change a scanning electro microscope were used. Finally the research concludes that the low carbon steel showed high resistance to fracture than medium carbon steel after zinc galvanization [24]. **Manjunatha, S. S., and S. Basavarajappa et al.** Also stated that the properties of the MO coating deposited by plasma spraying were affected by the thickness of the coating. On a steel substrate, molybdenum coatings with varying coating thicknesses (100, 200, 300, and 400  $\mu\text{m}$ ) were deposited using plasma spraying. Investigations were conducted into the differences in the properties and microstructural characteristics of coatings with different thicknesses. A Vickers indenter was used to measure the micro hardness. Porosity is investigated quantitatively with the aid of a computerized image analyzer. Using a pin-on-disc wear test rig, the impact of coating thickness on wear resistance was calculated. According to the experimental findings, coating porosity increased as coating thickness increased. Additionally, decreased micro hardness and decreased wear resistance were the outcomes of the increased coating thickness [25]. **Ravi Kumar et al.** Studied on effect of metal coating on mechanical property of aluminum alloy The primary goal of this investigation was to examine the tensile and hardness characteristics of Al 7075 with various metal coatings, including nickel, zinc, and cadmium. The time-dependent electroplating method is effective in coating these metals on Al 7075 at varying thicknesses of 10, 15, and 20 microns. Tensile and hardness tests were performed on these metal-coated Al-7075 specimens in accordance with ASTM guidelines. When compared to zinc and cadmium coated alloys, nickel-coated alloy show excellent hardness and tensile property [26].

**Zhang, Chao, et al.** Investigate the effect of Cu coating on microstructure and properties of Al/steel in the study. 6082 Al alloy and Q235B steel were chosen as a base metal with dimension of 150mm\*100mm\*2mm. electroplating process was used to coat the sample with the coating thickness 0-20 micro meter and cold metal transfer welding- brazing was used to realize the reliable connection of Al/steel with a Cu coatings. Then the sample macro-morphology was observed by ZEISS optical microscope. Finally, it can be concluded that the wettability and spreadability of AlSi12 on the surface of steel could be enhanced by a Cu coating applied at the proper thickness [27]. **Marder, Arnold Robert et al.** Studies the characterization analysis of zinc and aluminum coating for steel. The coating method used for this research was electroplating which is coating of metal or conducting surface by using electrochemical process. The properties of metals and alloys can be controlled and improved by modifying their microstructure when using their pulse current. The first part of the paper identifies the materials and experiment conditions of coating. And finally conclude that Aluminum is not suitable for the process of electroplating hence it can not be used, the zinc is perfectly suitable for electro plating process and to perfectly coated [28]. **Chen, Xiang, et al.** Studied impact of magnesium, aluminum, and zinc coating on spot welding joints. The material used for this experiment was HC340LAD+ZM steel (sheet thickness=1.4 micro meter). Painting coating type was used to coat the sample. The welding process involved 10Ka of welding current, 14 cycles of welding time, and 2.6 KN of electrode loading. On this foundation, the study looked at the microstructure, corrosion characteristics, and formation mechanism of two steel plates that were either coated in magnesium, aluminum, or zinc and were welded at different welding times. With a tensile speed of 2 mm/min, the SANS microcomputer servo-controlled hydraulic universal testing machine was used to measure the tensile shear force of the spot welding sample. The HXS-1000AKY hardness meter was used to measure the micro hardness value. and come to the conclusion that the mechanical characteristics of the welding joint are marginally impacted by the Zn-Al-Mg coating. However the corrosion current of the body material containing Zn-Al-Mg plating was 7.17 times that of the uncoated plate[29]. **Geldermann, Jutta, et al.** Studies the effect of coating steel on mechanical properties Different protective coatings are frequently employed in practice to guarantee the necessary durability of parts under a high load operation. however most of them have significant disadvantages for example, in the complexity of the technological process, high porosity of coating and low mechanical properties which is restrict the scope of their application. The paper present the analysis of existing production method for applying a metal coatings. The most popular way to protect ferrous metals against corrosion is galvanization however there is no data on the optimal value of coating thickness[30].

**Abdulrahaman, Mahmud Abdulmalik.** Studies how mild steel's mechanical characteristics and corrosion behavior would change if coated with carbon nanotubes in an acidic environment. The mechanical characteristics and corrosion behavior of mild steel coated with carbon nanotubes under various coating conditions were examined in the study. The mild steel samples were coated with a network of dispersed MWCNTs (Multi walled Carbon Nanotubes), and the coating thickness decreased with an increase in coating temperature and holding time. As the coating temperature and holding time were increased, the mechanical properties (tensile strength, yield strength, and hardness value) of the coated steel samples also increased. When the various coating conditions were compared, coated mild steels with a temperature of 950 °C and a holding time of 90 minutes showed higher values for hardness, yield strength, and tensile strength. As the holding time and coating temperature increased, the mild steel samples coated experienced a decrease in both corrosion current and corrosion rate. The sample coated for 90 minutes at 950 °C showed the lowest rate of corrosion [31].

#### 2.4.2 Metallurgical and mechanical property of coated metal

The mechanical properties and joint performance of the coated and welded metals are directly influenced by their metallurgical characteristics, so this makes them extremely significant. It is well known that the micro structure of the uncoated and coated metal are somewhat different because the coated material will melt and mix with molten metal then this will change the chemical composition of welded metal and will also bring a mechanical properties change( hardness, tensile, bending...)[32]. The reason why coating is used is that according to reports, 20% of the world's energy was lost due to corrosion [33] It was discovered that corrosion, along with other factors like erosion, wear, and hoop stress, was the main cause of failure [34]. Corrosion along with erosion, lead to a volumetric reduction of component, reducing their life time and thereby increasing their maintenance and replacement cost [35]. In order to counteract the accelerated failure rate, this protective coating serves as a barrier against erosion and corrosion. The coating process is divided based on the method of coat as follow vapor depositing, galvanic thermal spraying, metal coating and high density beam and ion implantation [36]. Subsequently, steel is an iron alloy that has been utilized for a variety of purposes since 2000 BC [37]. Due to its greater abundance on Earth than other metals, steel is more vital in applications such as building, manufacturing, transportation, oil and gas turbines, piping, and household appliances.

#### 2.5 Manual metal arc welding

One of the most widely used fabrication techniques is welding, which is also used extensively to produce high-quality weld joints for a variety of structural components. In certain countries,

shielded metal arc welding accounts for over half of all welding because of its simplicity and versatility; it is also largely utilized in the maintenance and repair sector, heavily utilized in the building of steel structures, and in industrial fabrication. But now a days Its application in the construction business has declined and gas metal arc welding become popular in industrial environment. [38]

The first manual metal arc welding process was invented in Russia in 1888. Stick welding, flux shielded arc welding, and shielded metal arc welding are other names for manual metal arc welding (MMAW). The kjellberg process in Sweden and the quasi-arc method in the UK were introduced in the early 1900s, which marked the beginning of the development of coated electrodes [39]. It is inconsequential that the expensive cost of coated electrodes delayed their adoption. But as the need for quality welds increased, coated electrodes and manual metal arc would inevitably become synonymous.

By heating metals with an arc formed between the metals and stick-like covered electrodes, manual metal arc welding melts and joins metals. A common name for it is stick welding. A welding cable is used to connect the electrode holder to one power source terminal, and a second cable is used to connect the work piece to the other terminal. Filler metal for the joint is provided by the core wire of the covered electrode, which also conducts electricity to the arc. The electrode holder holds the top 1.5 cm of the core wire, which serves as the electrical contact. The electrode holder is basically a metal clamp that has an outer shell that is electrically insulated so that the welder can [40].

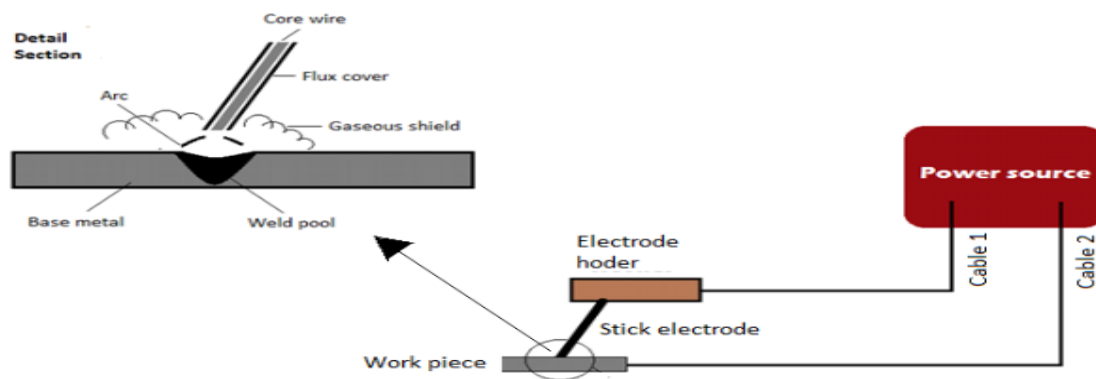


Figure 3: Manual Welding process

The metal rod (electrode) and the work piece both melt to generate a pool of weld when an arc is struck between them. The flux layer on the rod will simultaneously melt, forming gas and slag that will shield the weld spot from the environment. The slag will cool and solidify.

Welding has improved the operating efficiency, productivity, and service life of plants and related equipment, which has had a substantial impact on many industries. In order to achieve a

high production rate, automation of welding operations is currently popular in the fabrication sectors. One of the most crucial production processes for uniting structural elements for a variety of applications is shielded (manual) metal arc welding. These applications include, to guide ways for trains, ships, bridges, building structures, cars and nuclear reactors.[41]

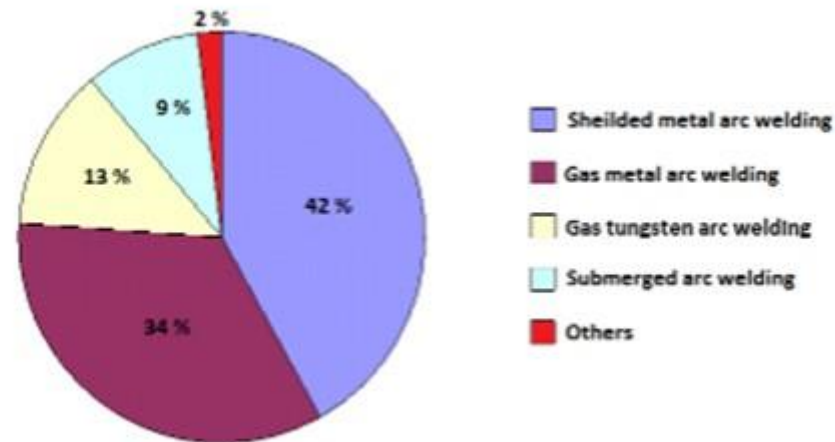


Figure 4: Application range for various types of welding

For MMAW to produce an electric arc that produces enough heat to melt the metal and make a weld, it needs a constant supply of either direct or alternating electric current. Extremely high temperatures and intricate operations are required for the arc welding process, which results in significant deformities and substantial residual stress. The strength of the structure is often weakened by these severe occurrences, making it more susceptible to failures including buckling corrosion and fracture. Although hardness is a crucial mechanical attribute of a material, during welding, high temperatures and quick cooling have an impact on both the weld's hardness and the heat-affected zone (HAZ). [42]

### 2.5.1 Chemical aspect of manual metal arc welding

A manual metal arc (MMA) electrode is made up of an alloying additive, an organic mineral, a clay-like coating, and a metal core rod. Other powdered minerals include fluoride carbonate, oxide, and organic minerals. [43] An aid for extruding the flux component into the metal core rod is a silicate binder. The heat produced by the arc during welding melts both the base metal and the electrode. Several parameters determine the MMA welding transfer mode. The primary ones include the electrode's temperature, coating thickness, melting temperature of the core material, voltage, current, and electrode diameter. Studies have shown that increased silicone oxide content in flux leads to increased penetration. According to reports, components like sodium and potassium salts as well as others that enhanced arc stability and decreased cathodes' spot wandering often increased penetration. [44]

## Summarizing related previous research

Table 1: Summary of previous research

Author	Sample	Coating thickness	Welding type	Conducted test	Finding
(RaviKumar,2017)[27]	Aluminum alloy(AI7075) coated with nickel, zinc,cadmium	10,15 and 20 microns	-	Hardness and tensile test	Comparing nickel-coated alloy to zinc and cadmium, it is discovered that the former shows excellent tensile and hardness properties.
(Amraei M,2019)[45]	S690,S1100 and S700	-	gas metal arc welding	Tensile test Micro hardness test Micro structure of heat affected zone	The joint ductility is highly dependent on heat input values over the range of 0.3-1.4kj/mm for each welding pass
(ManjunathaSS,2020)[26]	Steel coated with plasma sprayed molybdenum	100,200,300 and 400	-	Micro hardness test Micro structural test	Result indicate that porosity of the coating was increased with increasing coating thickness.
(Zhang C, 2022)[28]	6082 Al alloy/Q235B steel coated with cu with coating thickness( 0-20)	0-20 micro meter	cold metal transfer welding-brazing	Macro-morphology	Result conclude that coating with appropriate thickness could improve the wettability and spreadbility of AlSi12 on surface of steel
(MidawiAR,2021)[46]	CP800 AND 980HF coated	85 micro meter	gas metal arc	Tensile test Hardness	Zinc coated CP800 weld show 8% reduction in

	with zinc	130 micro meter	welding	test Microstruct ure in heat affected zone	strength compared to uncoated material and in case of 980HF 2% drop was seen
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### Research gap

There are several research works that investigate the effect of metal coating and its thickness on mechanical property of base metal. In addition to this some researchers work on effect of coating on weldability of material but not considering the coating thickness variation. So since coating thickness variation cause mechanical and microstructural change the main aim of this paper is to identify the effect of coating material and coating thickness on mechanical property of welded joint and finally recommending the optimum values of coating thickness and coating material which is important to construct safe and quality structure.

## Chapter Three

### Material and method

#### 3.1 Introduction

This thesis paper was used a combination of qualitative and quantitative data collection techniques. The methods for gathering data include reading books, analyzing software, conducting experiments, observing, and examining articles. Some of the techniques used in this study were coating the mild steel, measuring the coating thickness, welding the coated mild steel and finally preparing a testing sample for tensile strength, vicker hardness, bending test and micro structural analysis.

#### 3.1 Materials

This section provides a brief discussion of the experimental materials used to make samples. The selection of these materials, coatings, and welding procedures was based on their availability and broad variety of applications in Ethiopian and international medium- and small-scale metal fabrication factories.[45]

##### 3.1.1 Tested metal

The material used for this study is mild steel. Specifically SAE1020 was used which is purchased from local market in Addis Ababa Ethiopia and they are not corrosion resistant and rust will occur easily. So to prevent this coating (galvanization) takes place. While mild steel has numerous advantages the use of this mild steel in manufacturing and fabrication can make welding these materials challenging. To ensure a successful weld, it's crucial to take into account factors like filler metal selection [46]. In an increasing number of applications, mild steel offers advantages in terms of toughness and durability; however, there are a few things to keep in mind when welding these materials. High strength welds can be produced by selecting the correct filler material, applying the appropriate heat treatment, and following the correct welding procedures. These elements are crucial for reducing rework and maintaining high productivity [47].

The test piece's mechanical, chemical, and physical characteristics are listed in tables 1 and 2, respectively, below. A spectrometer test was conducted to determine the test piece's chemical make-up and from the comparative table the chemical makeup of the specimen is equivalent to SAE1020.

Table 2: Chemical composition of test sample

Material	Carbon	Manganese	Iron	Phosphorus	Sulfur	Chromium
SAE1020	0.20	0.40	99.09	0.040	0.050	0.015

Table 3: Mechanical and physical property of the sample

Material	Tensile strength ultimate	Tensile strength yield	Elongation before fracture	Poisson ratio	Shear modulus	Density
SAE1020	394.72	294.74	36.5%	0.29	81GPa	7.87g/c

### 3.3 Coating method

Copper and zinc are most commonly used coating materials the benefit of using these coating material is that because both zinc and copper coating offers excellent protection against corrosion with low cost when it is compared with galvanized steel. In addition two coating types can be coated in small scale at home using electro plating. Electro plating is the electrochemical process of applying a metal coating to a conducting surface, such as metallic which is cheap process that can be done at home by using a container with containing vinger and salt which used to increase the conductivity. And inserting the copper/zinc within the solution with connecting the work piece to be plated with positive charge and the coating plate with the negative charge then the coating will start. So since this is cost effective method of coating for this research this method was used.



Figure 5: Extracted zinc plate from electric equipment's



Figure 6: Extracted copper from electric wire



Figure 7: Small Scale Electroplating (coating) at home

The Electroplating is generally preferred because of the ability to control

- The bath
- Thickness of deposits
- Other properties of deposits

When electroplating the thickness of the metal coating is going to be entirely depend on the length of time the part spend in solution. However electroplating is influenced by many variables such as the solution temperature, and current [48].

### 3.4 Measuring coating thickness

Coating or painting thickness gauges are used for measuring the paint thickness of surface coating. Inspection of coating thickness is the most important step in determining the quality of galvanized coating. The process can be classified in to two different categories, destructive and non-destructive techniques. Commonly used measuring techniques are non-destructive dry film methods such as magnetic, eddy current, ultrasonic or micrometer measurement [49]. For this study a magnetic principle technique was used because it complies with recognized international standard including ASTM D7091, CSAG164-M and ISO2808.

The coating thickness standard required specified in ASTM B695 range from 0.2 to 4.3 mils (5-110 micrometer)



Figure 2: Measuring coating thickness

- The thickness of the coating depend on the thickness of the base metal and its chemical composition
- The typical minimum average coating thickness for structural steelwork is **85  $\mu\text{m}$** . Thick steel parts and steels which have been abrasive blast cleaned tend to produce relatively thick coatings up to 140  $\mu\text{m}$ . [50]

Table 4: Structural steel coating standard [53]

articles and its thickness	local coating (minimum)		mean coating (minimum)	
	$\text{g/m}^2$	$\mu\text{m}$	$\text{g/m}^2$	$\mu\text{m}$
steel > 6mm	505	70	610	85
steel > 3mm to $\leq$ 6mm	395	55	505	70
steel $\geq$ 1.5mm to $\leq$ 3mm	325	45	395	55
steel < 1.5mm	250	35	325	45
castings $\geq$ 6mm	505	70	575	80
castings < 6mm	430	60	505	70

### 3.5 Welding method

The chemical makeup of steels is perhaps the most significant element affecting their weldability. There is no consensus definition of what weld ability is and the meaning attributed to the phrase varies greatly depending on one's perspective. As per the American Welding Society, weldability refers to a metal's capacity to fuse together into a specific, well-designed structure under the given fabrication conditions and perform satisfactorily in the intended purpose. The mild steel that was chosen has several uses in the fabrication sector. The type of welding used for this research was manual metal arc welding (MMAW) this welding type was selected by conceding thickness of the sheets used and efficient and economical method. Manual metal arc welding is the most flexible and most widely used arc welding process. A BODA ZX7-200 welding machine with the following specifications was used for this particular task.



Figure 9: Welding machine used for the experiment(Boda zx7 250 dual voltage 220v/380v manual metal welding machine inverter dc)

BODA ZXY-200 power source rectifiers for welding with MMA coated electrodes. They perform admirably in both outdoor and workshop environments. They are professional and intensive application, and they are simple to use with shunt modification.

Specification of welding machine

Table 5: Specification of welding machine

Input power	50/60 HZ
Maximum input current	57A-30A
Rated Input voltage	220±15%
Effective factor	0.85

Welding current range	20A-140A
Connector size	13mm

### 3.5.1 Electrode

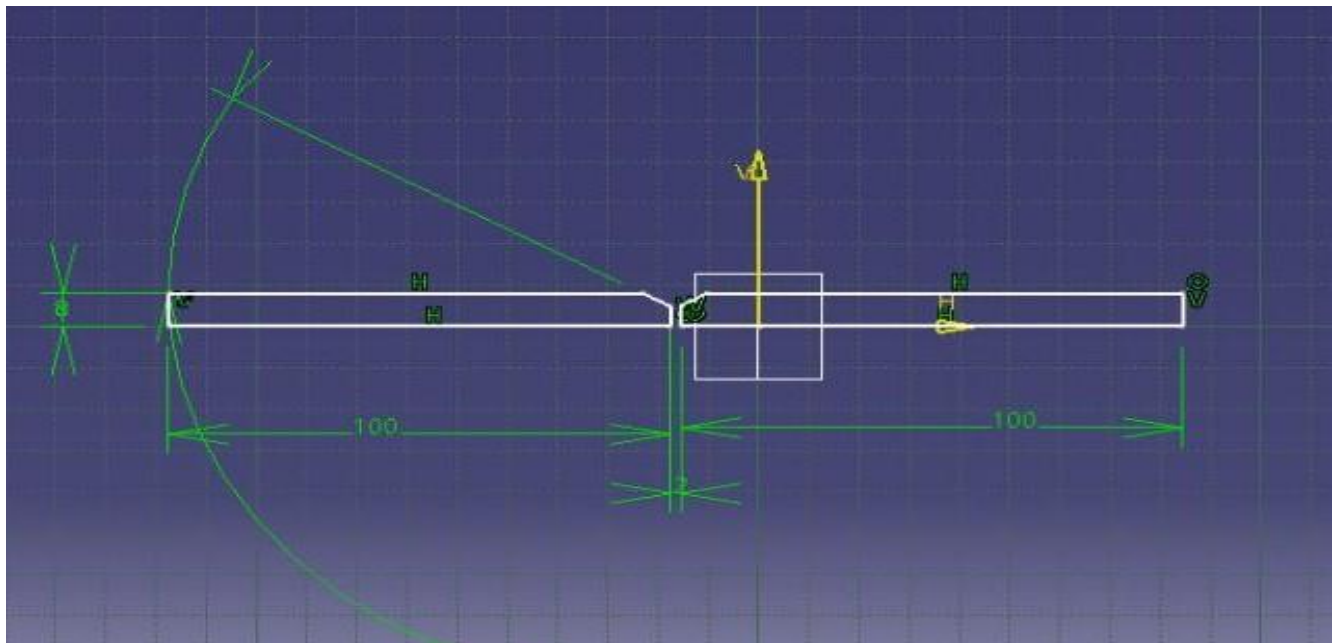
The excellent welding technological qualities, stable arc, minimal splash, and nice shape of carbon steel welding electrode make it appropriate for use in all positions. Because of this characteristic, low strength welding wire E6011 was chosen.

Table 6: electrode condition

Electrode type	E6011
Electrode diameter	3.2mm
Electrode extension	20mm
Electrode feed rate	5-15 m/min
Work angle	30 degree
Type of welding	All type

### 3.5.2 Sample dimension

Cut 100×110 pieces using shearing machine. Avoid using thermal cutting devices to prevent test results from being interrupted by the heat produced during the cutting operation.



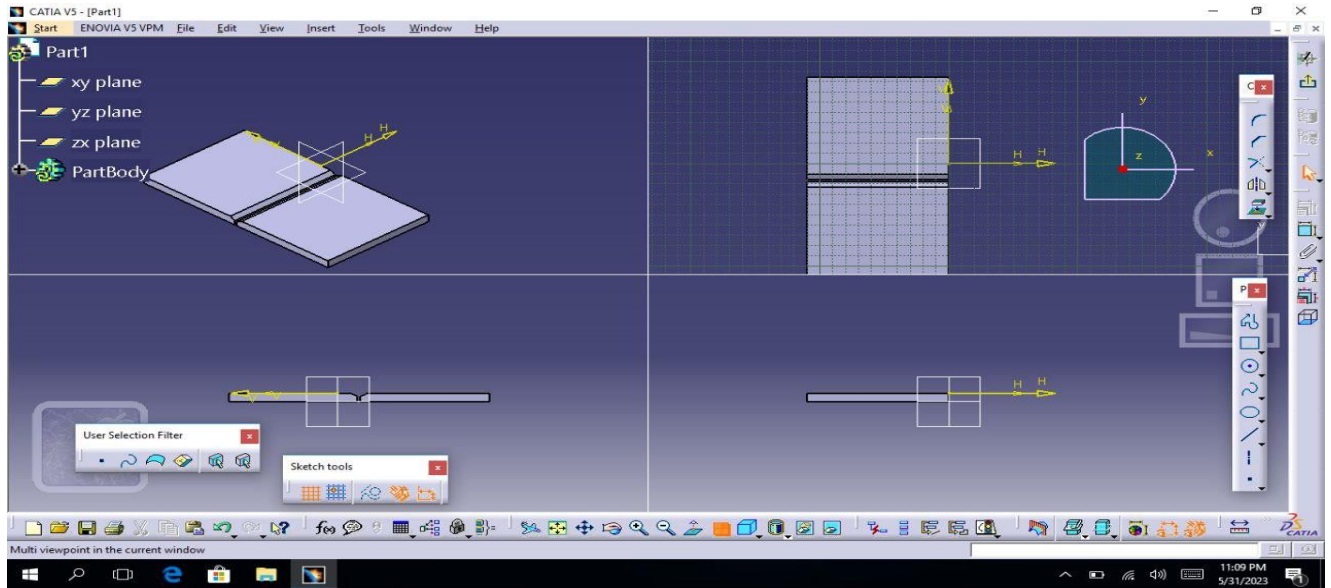


Figure 10: sample for microstructural and hardness test

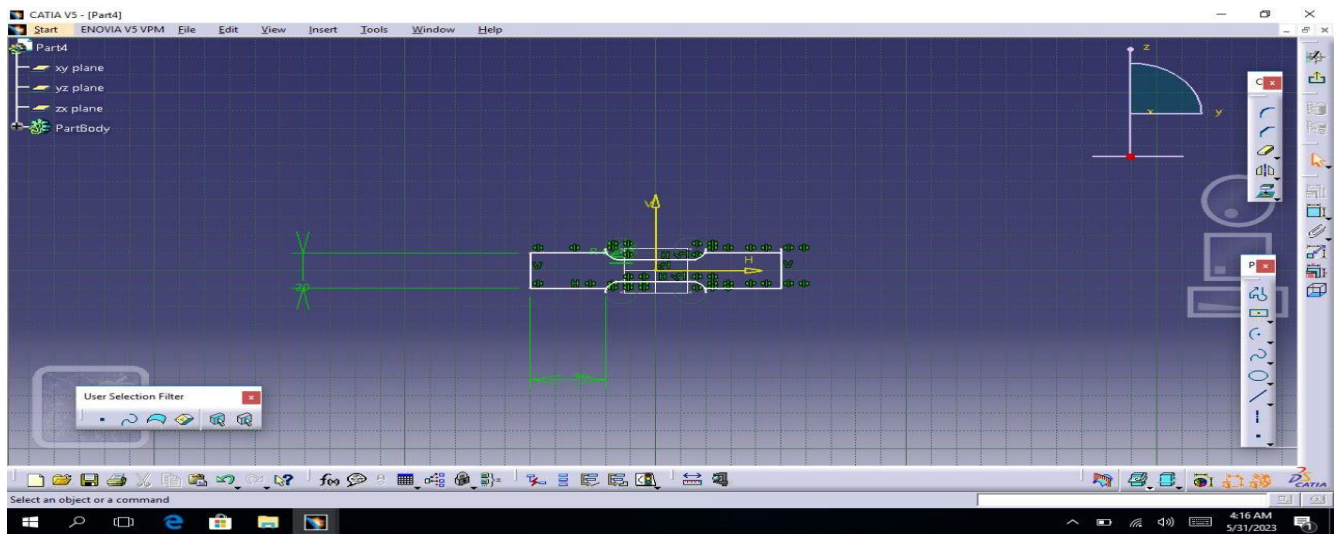
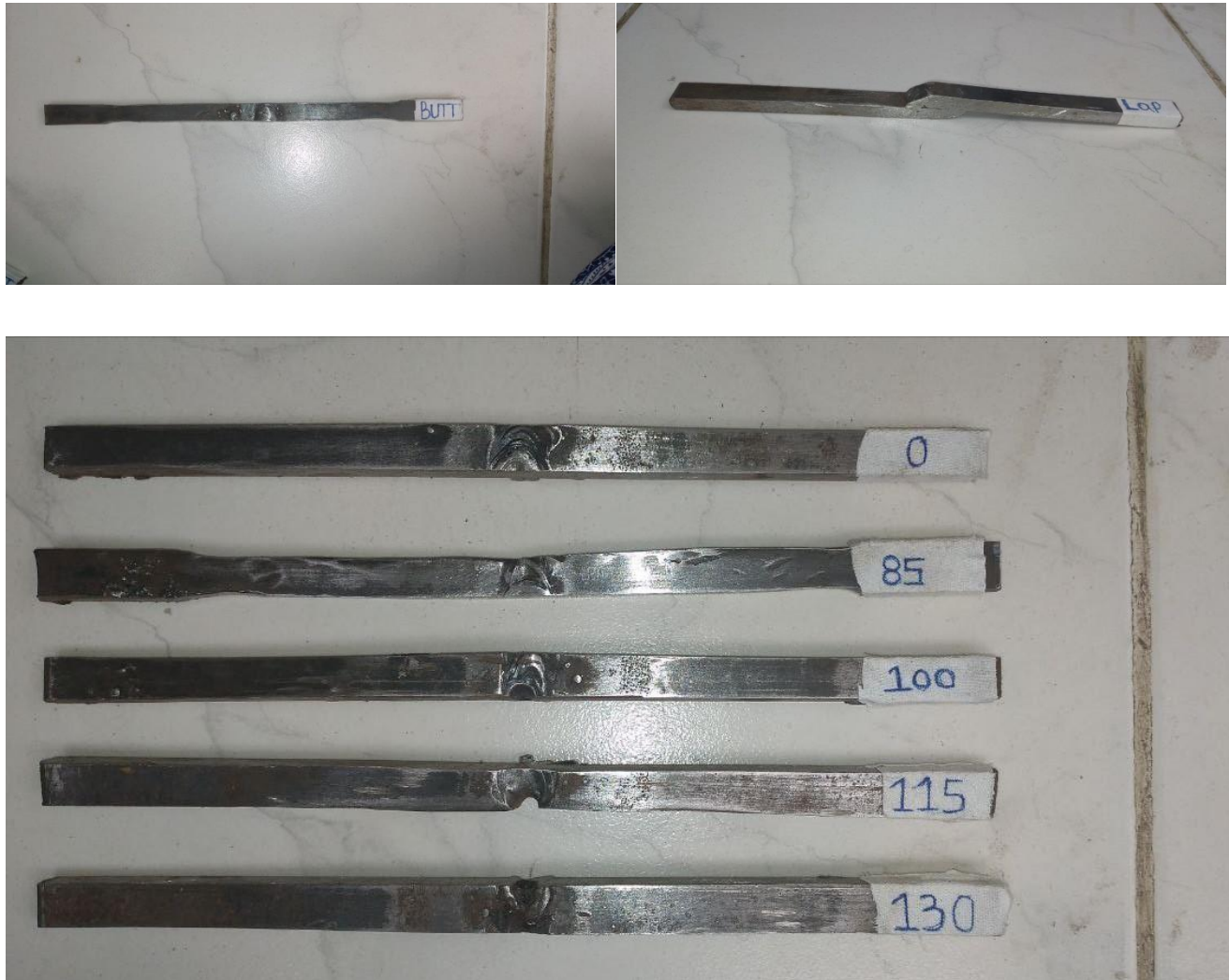


Figure 11: Sample for tensile test





### 3.6 Mechanical properties

#### I. Micro hardness measurement

Vickers micro hardness test was used in this study to test the sample and this was indication of local hardening effect in various part of the weld zone. It also helps in corroborating the presence of a particular phase. The Vickers micro-hardness test was performed at the cross section of all the coated and heat treated sample with Vickers hardness test standard of ASTM A370-14.

#### II. Tensile test measurement

Tensile strength of the weld joint was crucial property for this study. So by using ASTM A370-14 standard the tensile strength of the sample was conduct. 3 set of sample was tested at room temperature to ensure the consistence of the result. Then finally the average value was considered for analysis for tensile test.

#### III. Bending strength measurement

The bending strength or flexural strength of material is defined as ability to resist deformation under load during bending test described in ASTM E370 the maximum achieved flexural stress value noted as flexural strength. Three point bending test was used for this research experiment.

### Experimental method

The flow chart in the figure illustrates how this investigation was organized methodically. To investigate the effect of coating thickness on weldability of mild steel it is important to come up with coating standards of mild steel and factors affecting coating. For this research there are three influential experimental parameters namely coating material, coating thickness and welding configuration. Straight welding was accomplished by manual arc welding, where identical electrode and machine are utilized for every sample.

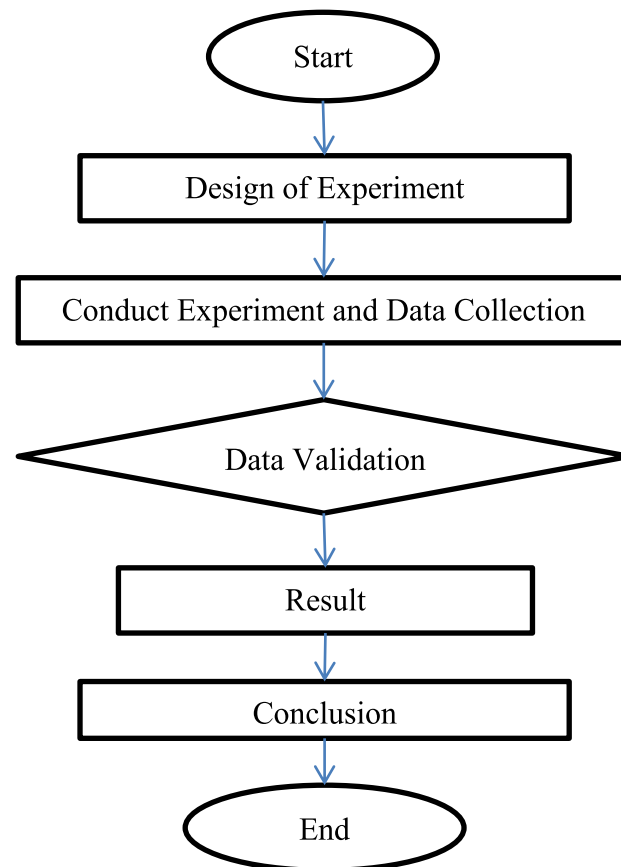


Figure 12: Methodology flow chart

### 3.7 Design of experiment

Design of experiment (DOE) is systematic method to determine the relationship between factor affecting a process and the out of that process. DOE is powerful data collection and analysis tool that can be used in variety of experimental situation. The experiment design in this research takes

into account the impact of multiple factor interactions. Taguchi technique is applied to plan the experiment to decide optimum coating parameters for making experiment sample. the taguchi method provide good improvement productivity during the experimental work. So that high quality experiment can be produced quickly and with low cost. The DOE using taguchi approach can significantly reduce time required for experimental investigation. In this investigation, the first stage is taguchi's orthogonal arrays were used to conduct experiments. Analysis using taguchi design L16( $4^1 2^2$ ).

Factors 3

Runs 16

The three factors are

1. Coating material
2. Coating thickness
3. Welding configuration

A mixed level taguchi design was used to design the taguchi design of experiment.

- For coating material 2 levels were used zinc and copper
- For coating thickness 4 levels were used 85-95,100-110,115-125 and 130-140.
- For welding configuration 2 levels were used lap and butt joint.

Description of variables

The dependent variable in this research is tensile strength, bending strength and material hardness property.

Taguchi design problem (P4L2)

Table 7: Taguchi design problem

Material	Coating material	Coating thickness	joint type
Mild steel	Zinc	85-95	<i>Lap</i>
		100-110	
		115-125	
		130-140	
Mild steel	Copper	85-95	<i>Butt</i>
		100-110	
		115-125	
		130-140	

P= the number of parameter

L= the number of level

Taguchi design array

**Table 8: Taguchi design array**

<b>Material</b>	<b>Coating material</b>	<b>Coating thickness</b>	<b>Joint type</b>
Mild steel	Zinc	85-95	Lap joint
Mild steel	Copper	85-95	Lap joint
Mild steel	Zinc	85-95	Butt joint
Mild steel	Copper	85-95	Butt joint
Mild steel	Zinc	100-110	Lap joint
Mild steel	Copper	100-110	Lap joint
Mild steel	Zinc	100-110	Butt joint
Mild steel	Copper	100-110	Butt joint
Mild steel	Zinc	115-125	Lap joint
Mild steel	Copper	115-125	Lap joint
Mild steel	Zinc	115-125	Butt joint
Mild steel	Copper	115-125	Butt joint
Mild steel	Zinc	130-140	Lap joint
Mild steel	Copper	130-140	Lap joint
Mild steel	Zinc	130-140	Butt joint
Mild steel	Copper	130-140	Butt joint

### 3.8 Sample preparation

To produce a valid result, appropriate sample design and preparation are essential. The sample preparation process was illustrated in general in the accompanying figure(13); details are covered in the section.

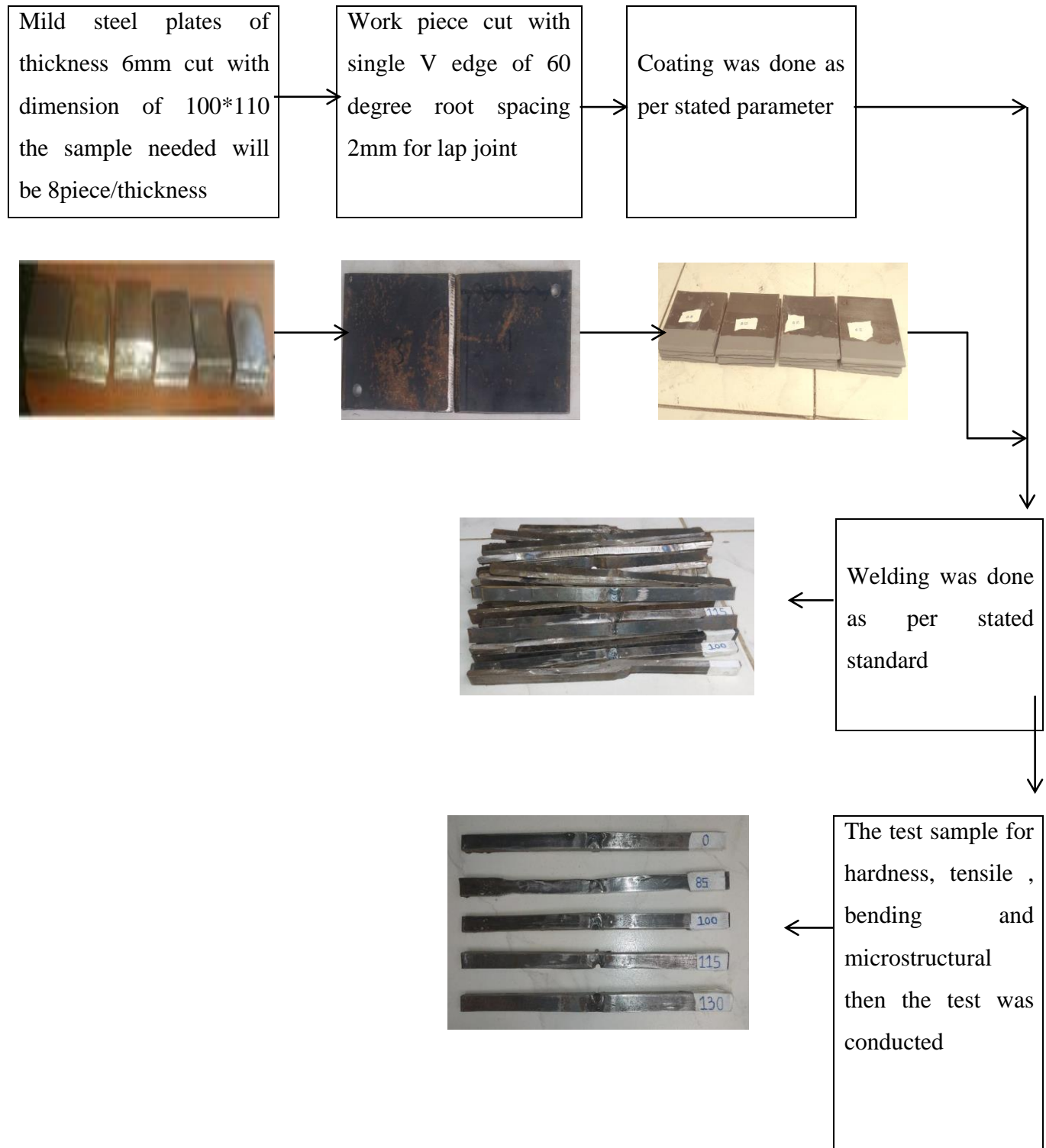


Figure 13: Process flow chart for test piece preparation

### 3.8.1 Welding work piece

#### 3.8.1.2 Preparing weld surface cleaning

The work piece edges and surfaces are appropriately prepared by using a wire brush and polisher to remove surface impurities such as moisture, oil, and grease paint.

#### Edge preparation

Preparation the edge before welding will improve joint strength. So in this work for butt joint single v groove joint are selected with broad root spacing as per ISO9692 joint preparation recommendations. Here the work item was cut with groove angle of 60 degree and the distance between the samples was 2mm.

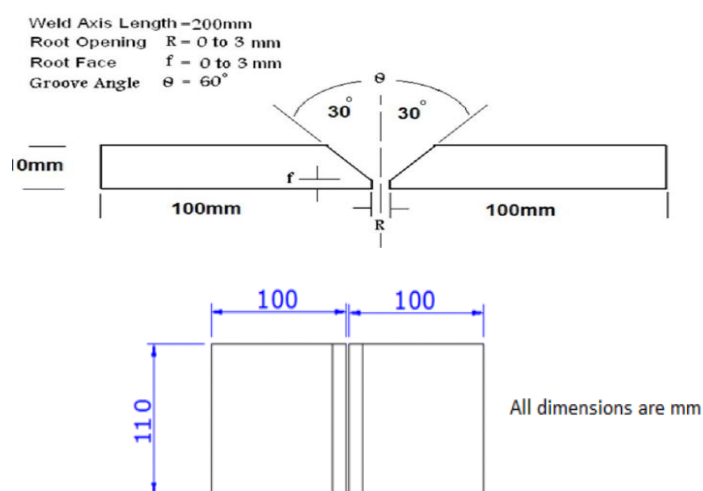


Figure 14: Edge preparation

As the name suggests, a lap joint is formed by the base metals overlapping one another. The selected lap joint was both sided weld in order to make the welding strong.

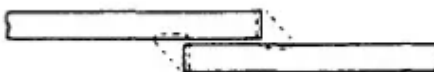


Figure 15: lap joint welding

#### 3.8.1.3 Coating sample

Once the edge preparation was done then the work pieces was coated using small scale zinc and copper coating technique (home electro plating). test pieces coating thickness, coating material and welding configuration are shown in table (9).

Table 9: 85-95 coating thickness with different coating material and welding configuration

Sample number	Coating thickness	Coating material	Welding configuration
1	85-95	Zinc	Lap
2	85-95	Zinc	Lap
3	85-95	Copper	Butt
4	85-95	Copper	Butt

Table 10: 100-110 coating thickness with different coating material and welding configuration

Sample number	Coating thickness	Coating material	welding configuration
1	100-110	Zinc	Lap
2	100-110	Zinc	Lap
3	100-110	Copper	Butt
4	100-110	Copper	Butt

Table 11: 115-125 coating thickness with different coating material and welding configuration

Sample number	Coating thickness	Coating material	Welding configuration
1	115-125	Zinc	Lap
2	115-125	Zinc	Lap
3	115-125	Copper	Butt
4	115-125	Copper	Butt

Table 12: 130-140 coating thickness with different coating material and welding configuration

Sample number	Coating thickness	Coating material	Welding configuration
1	130-140	Zinc	Lap
2	130-140	Zinc	Lap
3	130-140	Copper	Butt
4	130-140	Copper	Butt

#### 3.8.1.4 Welding samples

Once the coating process was done on each work pieces then the samples were welded using manual metal arc welding with the suggested welding parameters for mild steel with low carbon content.

Then during welding the coated metal in terms of welding simplicity the uncoated metal is simple during welding and doesn't show that much exaggerated defect and incase of the coated metal welding with

increasing the thickness of the coating the visually inspected defects were seen in the welding for example mostly observed welding defects were spatter, undercut and porosity. The 32 work samples are welded in to 16 test samples then by cutting this welded sample 48 testing samples were prepared.

### 3.8.1.5 Welding defects

During welding a coated metal spatter is one of the most common defect that occur during manual metal arc welding. Then this spatter leads to gaping holes in the welds and corresponding poor strength. In addition to this the thicker the coating thickness the amount of fume generated was increased and with increased in the amount of spatter in most welding samples big holes were observed with the result of zinc entrapment in the weld. These problems result in higher post-weld cleaning expenses, lower quality, more rework, and this general decrease in output.



A



B

Figure 16: A welding of uncoated mild steel, B welding of coated mild steel

### 3.8.2 Preparing sample and conducting test

After the welding process was completed, each work piece was cut with standard dimension using a power hack. Then the test pieces for hardness testing, microstructural testing, tensile testing and bending testing become ready. The preparation process of each test pieces and test procedures are discussed below

#### 3.8.2.1 Hardness testing

The ability of a metallic material to withstand plastic deformation caused by force applied through an indenter is known as its hardness. In actual use, hardness is determined by the size of the impression an indenter of a particular shape leaves on a specimen. When a given force is applied for a given amount of time the indenter being measured after the removal of force[51]. There are various hardness testing technique Rockwell hardness test, vicker hardness test, brinell hardness test, scleroscope test, knop hardness test and durometer test [52]. The sample for hardness testing was performed in accordance to ASTM A370-14 standard using vicker's hardness testing machine.

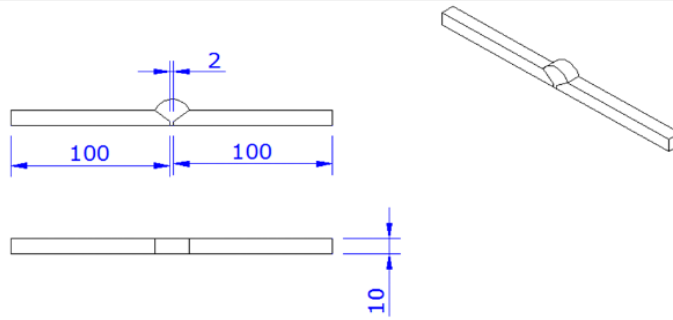


Figure 17: Hardness test sample

The surface to be tested for hardness was ground down to make it fit flat on the testing machine's base because the weld bead did not flash with the remaining material. By applying a load ranging from 1 to 1000 grams to a test specimen, a square-shaped diamond indenter is used to measure the specimen's microhardness. and measuring the diagonals formed by the square-shaped indenter and finding their average[53]. The specimen's surface should be prepared such that the ends of the indentation diagonals are clearly visible. For this research There is one main parameter that needs to be examined for the hardness test. That is examining the weld's change in hardness that came due to different coating thicknesses.



Figure 18: Vicker hardness testing machine

The hardness testing machine's reference manual suggested utilizing a load period of ten to fifteen seconds and the loading speed is still approximately 70 micrometers per second with a constant weight of 10kg Every test conducted on this machine was performed with the same loading speed and duration in order to reduce test variability and facilitate cross-test comparisons of hardness tests. The indenter on the vicker hardness machine is diamond cone ground at 120 degrees for testing hardened steels and

carbides.



Figure 19: Butt welding sample



Figure 20: Lap welding sample

### 3.8.2.2 Tensile testing

Tensile testing is a destructive testing method used to determine a metallic material's tensile strength, yield strength, and ductility. Tensile strength is the highest stress a material can withstand when under tension, or alternatively, the greatest applied load per cross section area that a material can withstand before failing. It can matimatically determined as the highest tensile force that may pass through sectional area – most commonly used way to test material strength is tensile testing. tensile test sample was as per ASTME8/E8M with prepared machined specimen dimensioned 100\*10\*2mm. the tensile standard sample was prepared by milling machine as shown in finger(21)

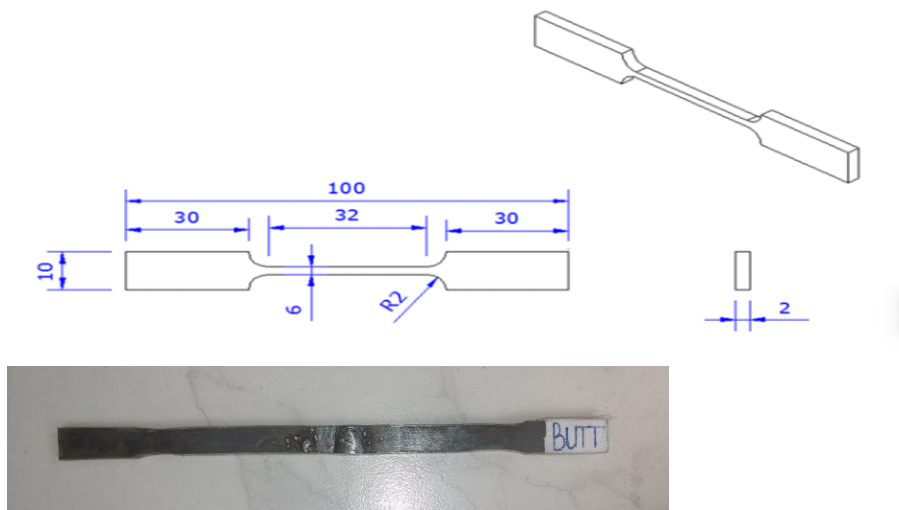


Figure 21: Butt Tensile test sample

The maximum testing strength of machined items determined using a controllably calibrated testing machine. The transverse tensile test, a destructive test on welds in metallic materials, was performed in accordance with ASTM/A30-14 standard. A material is gripped at both ends by an apparatus which slowly pulls length wise on the piece until it fractures.



Figure 22: tensile test process

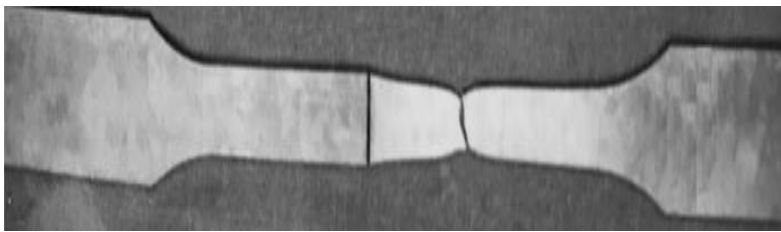


Figure 23: tensile test after destructive testing

Here the elongation of the welded joints decrease with the increase in hardness of the welds it was observed that the fracture occurred in the thinner/weaker material but not in the weld.

For tensile testing the force was applied slowly the loading rate was 5Mpa/s. This was done because if the applying load is too fast this may result in skewed result. Once all parameter have been set the test starts and the lower head starts to drop steadily. Then after the specimens breaks the test is stopped and the digital screen displays the load in KN and elongation in mm.

### 3.8.2.3 Bending test

The bending test is a technique used to measure a material's yield and stiffness. In addition to this we can also define that bend test can determines the quality of a weld at the face and root of welding joint. Mathematically bending of steel is calculated as

$$\text{Bend allowance} = [0.017453 * \text{inside radius}] + [(0.0078 * \text{material thickness})] * \text{bend angle} [54]$$

One of the most common and important mechanical property of a metal is bending. There are three common tests for bending. The three point bend test, four point bend test, and cantilever beam bend test are these. For this research paper the 3 point bending test was used. the welding bend test was performed on universal testing machine by placing a specimen on two support anvils and bending it through

applied force to measure its properties. The sub size sample created in accordance with ASTM A23 for the butt joint to conduct the bending test. The sample were prepared by using lath machine then finally the bending test was conducted by using ASTM A370 standard.

#### **3.8.2.4 Metallographic examination**

The sample was prepared in accordance with ASTM E23 then grinding, polishing, etching and metallographic examination of the lap and butt joint. Then the test were carried out on a 10 micrometer scale using an optical microscope with a magnification of \*100. Before the microstructure test, a few procedures must be completed which includes etching with composition of ethanol nitric acid (nital) 50ml concentration, polishing, grinding, and sectioning then at the end of the process scratches free and bright mirror surface was there. Then finally the sample become ready to view and images begins scanned using an attached camera on a digital imaging system.

## Chapter 4

### Result and discussion

#### 4.1 Mechanical property

Hardness is dependent on a number of factors, such as phase composition and microstructure. most commonly dislocation density is also measured by a material's hardness.

Then the heat-affected zone hardness values on average are 200.5HV, 190.1HV, 172.0HV and 160.1HV for coating thickness of 85-95,100-110,115-125 and 130-140 micro meter respectively for zinc coating for butt joint. 192.0HV, 185.2HV, 178.2HV and 168.3HV for coating thickness of 85-95,100-110,115-125 and 130-140 micro meter zinc coating for lap joint respectively. 196.2HV,176.2HV,179.0HV and 159.5HV for coating thickness of 85-95,100-110,115-125 and 130-140 micro meter respectively for copper coating for butt joint. 180HV,175.0HV,170.1HV and 162.1HV for coating thickness of 85-95,100-110,115-125 and 130-140 micro meter respectively for copper coating for lap joint. From the experiment in general the hardness of the material decreases by increase the coating thickness but in case of coating type different zinc coating hardness is higher than copper coating. In other case the metal in butt joint configuration shows an improved hardness property than lap joint.

#### Signal-to-noise ratio

Larger is better  $S/N = -10 \cdot \log (\Sigma (1/Y^2)/n)$

Nominal is best  $S/N = -10 \cdot \log (\sigma^2)$

Smaller is better  $S/N = -10 \cdot \log (\Sigma (Y^2)/n))$  [55]

Estimating the Best experiment

Table 13

#### Step: 1 Develop experimental layout using L16 orthogonal array and performance result

Runs	CM	CT	JC	Hardness	Tensile	Bending
1	Zinc	85-95	Lap	192	33.3	14642
2	Copper	85-95	Lap	180	35	14639
3	Zinc	85-95	Butt	200.5	35.7	14008
4	Copper	85-95	Butt	196.2	36.3	14000
5	zinc	100-110	Lap	185.2	32.8	13731
6	Copper	100-110	Lap	175	32.7	13729

7	Zinc	100-110	Butt	190.1	33.6	13312
8	Copper	100-110	Butt	176.2	33.4	13311
9	Zinc	115-125	Lap	178.2	28.2	13215
10	Copper	115-125	Lap	170.1	28.5	13210
11	Zinc	115-125	Butt	172	30.5	12917
12	Copper	115-125	Butt	179	30	12914
13	Zinc	130-140	Lap	160.1	24.2	12845
14	Copper	130-140	Lap	159.5	24	12830
15	Zinc	130-140	butt	168.3	25.5	12713
16	Copper	130-140	Butt	162.1	25.4	12710

### Step 2: Transformation of experimental data obtain from test result in S/N ratio

**Table 14**

	Hardness	Tensile	Bending
	45.66602	30.95549	83.31201
	45.10545	30.88136	82.92256
	45.85398	31.19813	82.92752
	46.04229	31.05336	83.31023
	45.35282	30.31748	82.75404
	44.86076	30.29096	82.75278
	45.57964	30.52679	82.48487
	44.92012	30.47493	82.48421
	45.01815	29.00498	82.42134
	44.61409	29.0969	82.41806
	44.71057	29.686	82.22323
	45.05706	29.54243	82.22122
	44.08783	27.67631	82.17468
	44.05521	27.60422	82.16453
	44.52168	28.1308	82.08496
	44.19566	28.09667	82.08291

**Step 3: Normalization of S/N ratio was performed****Table 15**

	hardness	Tensile	Bending
	0.810645	0.932486	1
	0.471466	0.088141	0.001448
1	1	1	0.687181
	0.094766	0.040282	0.316856
	0.653023	0.147155	-0.01862
	0.025662	0.342106	-0.79732
	0.767173	0.813199	0.327033
	0.435265	0.79877	0.326502
	0.484602	0.389759	0.27535
	0.281254	0.415334	0.272676
	0.329809	0.57925	0.114167
	0.504182	0.539302	0.112525
	0.016413	0.020057	0.074666
	0	0	0.066408
	0.234752	0.14652	0.001668
	0.07068	0.137023	0

**Step 4: Determine deviation sequence****Table 16**

	hardness	Tensile	Bending
	0.189355	0.067514	0
	0.528534	0.911859	0.998552
	0	0	0.312819
	0.905234	0.959718	0.683144
	0.346977	0.852845	1.018622
	0.974338	0.657894	1.797321
	0.232827	0.186801	0.672967
	0.564735	0.20123	0.673498
	0.515398	0.610241	0.72465

	0.718746	0.584666	0.727324
	0.670191	0.42075	0.885833
	0.495818	0.460698	0.887475
	0.983587	0.979943	0.925334
	1	1	0.933592
	0.765248	0.85348	0.998332
	0.92932	0.862977	1

**Step 5: Determine grey relation coefficient****Table 17**

	hardness	Tensile	Bending
	0.725315	0.881036	1
	1.892025	1.096661	1.00145
	1	1	0.615143
	1.104687	1.041972	1.463821
	0.590335	0.369591	0.329246
	1.026338	1.520001	0.556384
	0.682289	0.728013	0.426269
	1.770743	4.96943	1.484785
	0.492418	0.450353	0.40828
	1.391312	1.710378	1.374903
	0.427281	0.543036	0.360794
	2.016869	2.170618	1.126793
	0.337021	0.337851	0.350795
	1	1	1.071132
	0.395179	0.369418	0.333704
	1.076056	1.15878	1

**Step 6: Determine grey relation coefficient grade and rank****Table 18**

	CM	CT	JT	Hardness	Tensile	Bending	Grade	Rank
	Zinc	85-95	lap	192	35.3	14642	0.869267	8
	copper	85-95	lap	180	35	14639	1.201276	3

	Zinc	85-95	butt	200.5	36.3	14008	1.154607	4
	copper	85-95	butt	196.2	35.7	14000	2.382818	1
	zinc	100-110	lap	185.2	32.8	13731	0.505437	16
	copper	100-110	lap	175	32.7	13729	0.990869	6
	Zinc	100-110	butt	190.1	33.6	13312	0.965029	7
	copper	100-110	butt	176.2	33.4	13311	0.825302	9
	Zinc	115-125	lap	178.2	28.2	13215	0.772558	11
	copper	115-125	lap	170.1	28.5	13210	1.154161	5
	Zinc	115-125	butt	172	30.5	12917	0.699036	13
	copper	115-125	butt	179	30	12914	1.512761	2
	Zinc	130-140	lap	160.1	24.2	12845	0.582001	15
	copper	130-140	lap	159.5	24	12830	0.777901	10
	Zinc	130-140	butt	168.3	25.5	12713	0.588199	14
	copper	130-140	butt	162.1	25.4	12710	0.744945	12

### Response table for mean

Table 19

Level	Coating thickness	Coating material	Joint configuration
1	1.2110	0.7670	0.8890
2	1.0126	1.1988	1.0768
3	1.0346	-	-
4	0.6733	-	-
Delta	0.5378	0.4317	0.1878
Rank	1	2	3

Here delta is the difference between highest and lowest grey relation grade of each parameter as described in taguchi method. The value of delta signifies the influence of parameter on the process. Higher the delta value higher will influence so this case coating thickness will highly influence the mechanical property.

- ❖ **Therefore** the table clearly indicate that the optimal parameter set are A1,B2,C2 this means 85-95 coating thickness, copper coating material, butt joint configuration

Taguchi analysis: hardness versus coating thickness, coating material and joint configuration.

Table 20: Response table for signal to noise ratio

Level	Coating thickness	Coating material	Joint configuration
1	45.66	45.12	44.91
2	45.17	44.83	45.03
3	44.85	-	-
4	44.21	-	-
Delta	1.46	0.29	0.12
Rank	1	2	3

- The signal to noise ratio rank for hardness test show that from the parameters coating thickness, coating material and joint configuration. Coating thickness cause more significant change in hardness test.

Regression analysis: hardness versus coating thickness

Regression equation:-

$$\text{Hardness} = 246.49 - 0.6400 \text{coating thickness}$$

Coefficients

Table 21: coefficient VS coating thickness

Terms	Coef	SEcoef	T-Value	P-Value	VIP
Constant	246.49	9.83	25.06	0.000	-
Coating thickness	-0.6400	0.0904	-7.08	0.000	1.00

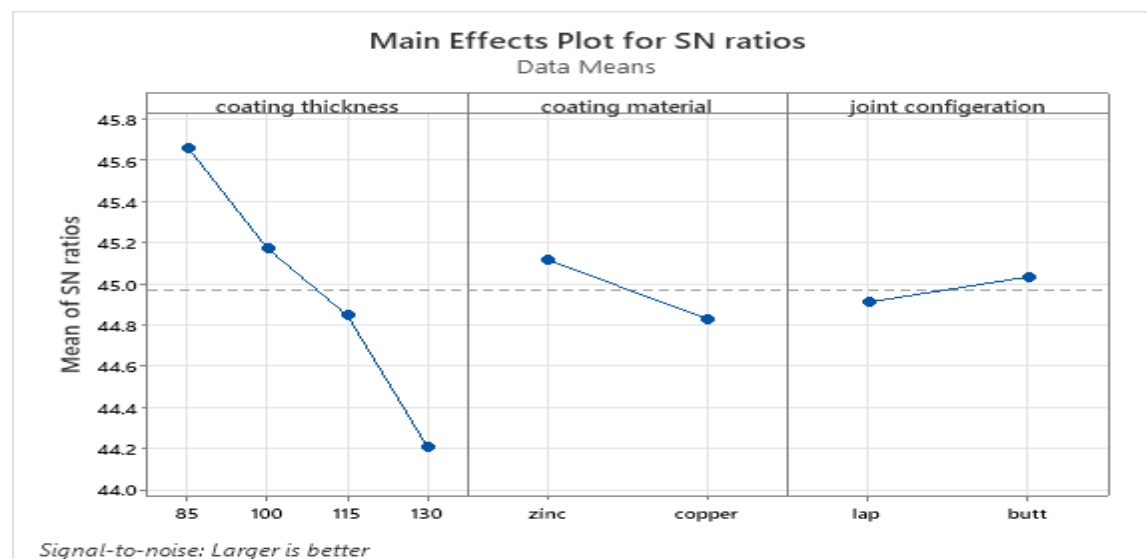


Figure 24: Hardness analysis using taguchi

## 4.2 Joint configuration effect

The strength of joints welded in a butt joint configuration was higher than that of joints welded in a lap joint configuration. The lap joint configuration showed 1.605% reduction in strength compared to butt joint configuration.

In other case of coating material the welding strength increases with 3.31% when it is coated with zinc than copper.

## 4.3 Tensile strength

The effects of coating thickness on ultimate tensile strength of the weld heat affected zone. The average heat affected zone strength value are 33.3,33.6,30.5 and 25.5 for coating thickness of 85,100,115 and 130 micro meter for zinc butt joint respectively. The average heat affected zone tensile strength value are 35.3,32.8,28.2 and 24.2 for coating thickness of 85-95,100-110,115-125 and 130-140 micro meter for zinc lap joint respectively. The average heat affected zone tensile strength for 85-95,100-110,115-125 and 130-140 micro meter for copper butt joint respectively are 35.7,33.4,30.0 and 25.4. The average heat affected zone tensile strength of 85,100,115 and 130 micro meter for copper lap joint respectively are 35.0, 32.7, 28.5 and 24.0. Then from this a significant reduce in strength may be associated with the existence of void and other defects occurring as a result of increasing coating. Excessive grain growth could also lead to reduce in tensile properties [56].

Taguchi analysis: UTS versus coating thickness, coating material and joint configuration

Table 22: Response table for signal to noise ratios for UTS

Level	Coating thickness	Coating material	Joint configuration
1	31.55	31.21	30.96
2	31.22	31.09	31.34
3	31.12	-	-
4	30.76	-	-
Delta	0.74	0.12	0.38
Rank	1	3	2

- From the signal to noise ratio rank for tensile test show that coating thickness affect the tensile test value at 1<sup>st</sup> level and joint configuration 2<sup>nd</sup> level and coating material 3<sup>rd</sup> level

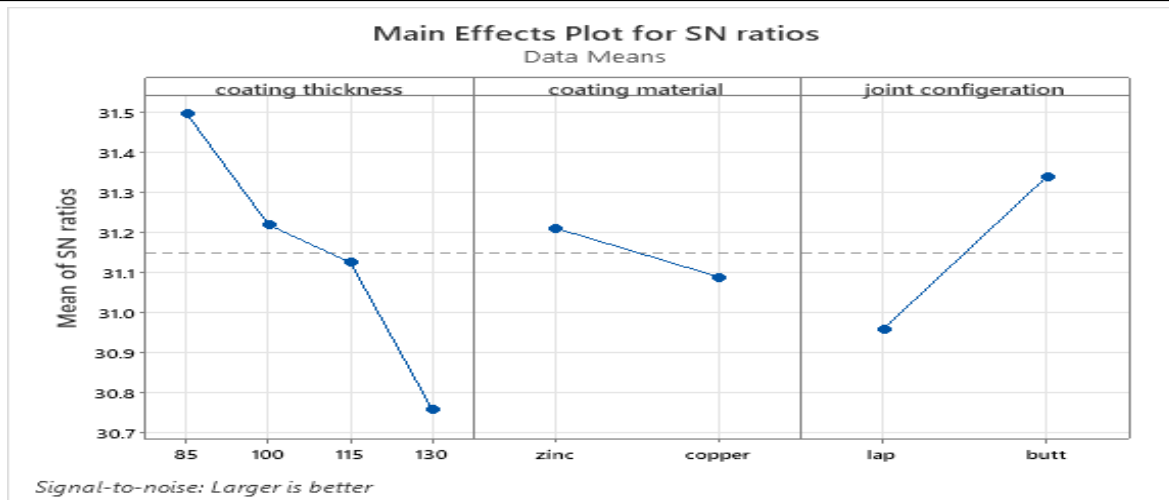


Figure 25: tensile test analysis using taguchi

Regression analysis UTS versus coating thickness

Regression equation

$$UTS = 42.97 - 0.0637 \text{ coating thickness}$$

Coefficient

Table 23: coefficient VS coating thickness

Terms	Coef	SECoef	T-Value	P-Value	VIP
Constant	42.97	1.58	27.23	0.000	-
Coating thickness	-0.0637	0.0145	-47.39	0.001	1.00

### 4.4 Bending test

Bending test experiment was implemented mainly to test the behavior of the weld and evaluate the effect of coating thickness, coating material and joint configuration of bending strength.

Effect of coating thickness on bending strength

The result of the investigation indicates insignificant change in bending strength across different coating thickness from similar heat input value. The smaller the coating thickness has quit bigger bending strength value than the thicker coated sample.

Table 24: Response table for signal to noise ratio for bending analysis

Level	Coating thickness	Coating material	Joint configuration
1	83.22	82.70	82.80
2	82.80	82.70	82.60
3	82.62	-	-
4	82.15	-	-
Delta	1.07	0.00	0.21
Rank	1	3	2

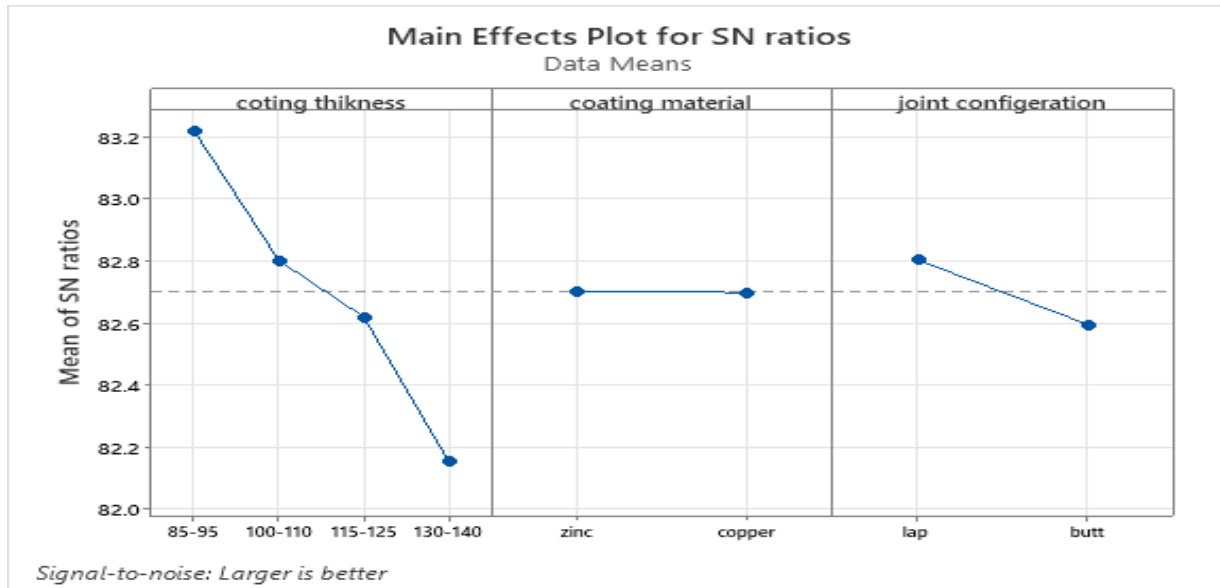


Figure 26: bending test analysis using taguchi

#### Effect of coating material on bending strength

From the experimental test result bending test of zinc and copper is most probably the same it doesn't show any change.

#### 4.4 Uncoated test result

The uncoated mild steel result shows that 24.03% increase in hardness, 35.124% increase in tensile test 3% increase in bending test than that of the 85-95 coated one. So from this result especially for beam and column application it is preferable using the uncoated one. But if it is mandatory to use the coated one due to some environmental conditions the coating thickness should be 85-95 for safe and quality construction.

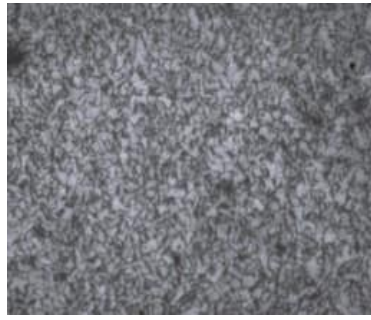
#### 4.5 Micro structure

The microstructure analysis of uncoated and coated mild steel was done using an optical microscope. The micrograph of uncoated mild steel was taken in longitudinal direction at 100\* magnification are shown in figure (27). The microstructure of mild steel plate welded using a manual metal arc welding technique. Every specimen's microstructure at the parent metal, heat-affected zone, and weld is examined. The investigation's findings show a welding defect( porosity) in the microstructure of zinc coated mild steel as the coating thickness increase the defect in fusion zone(FZ) increase. In addition to this In the heat affected zone, there was a significant coarsening of the grain . From the experiment we can see that in the fusion zone of the weld in there is an increase in the grain size of the metal coating increase then this will reduce the mechanical property of the weld. As the average grain size decrease the metal become strong but As the grain size increase the opposite effect on strength occurs (57).

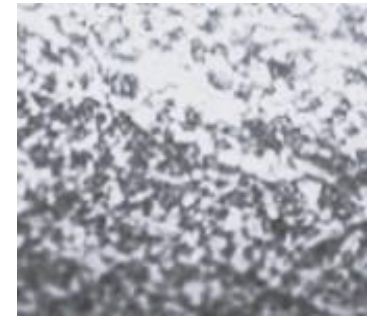
## Uncoated mild steel lap joint microstructure



Base material (BM)



Fusion zone (FZ)

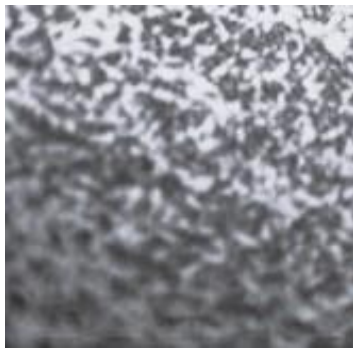


Heat affected zone (HAZ)

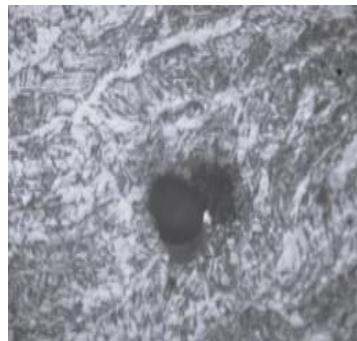
Figure 27: microstructure of uncoated mild steel

## Welded defect

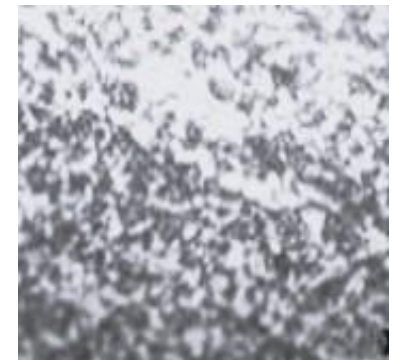
## Copper Coated 130-140 for lap joint



Base material (BM)



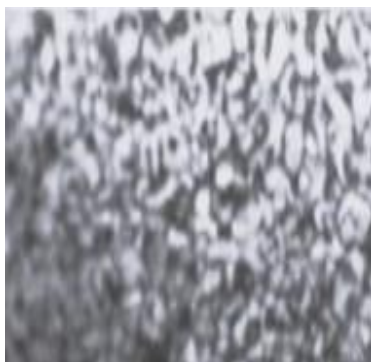
Fusion zone (FZ)



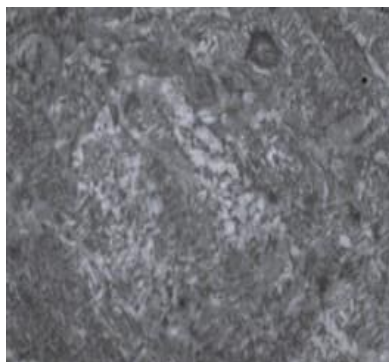
Heat affected zone (HAZ)

Figure 28: microstructure of zinc coated mild steel from 130-140 coating thickness

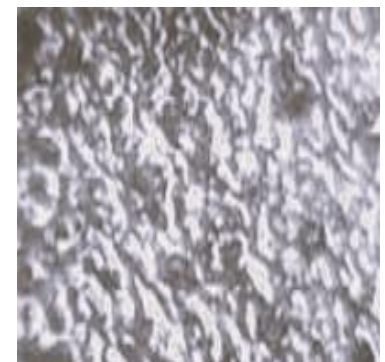
## Copper coated 85-100 for lap joint



Base material (BM)



Fusion zone (FZ)



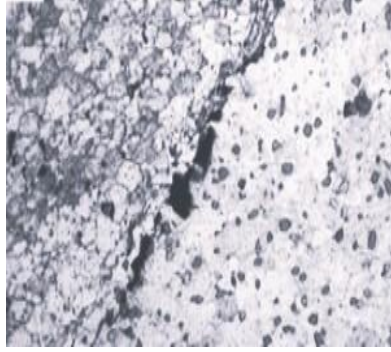
Heat affected zone

Figure 29: Microstructure of zinc coated mild steel from 85-100 coating thickness

Zinc coated 130-140 for lap joint



Base material



Fusion zone (FZ)



Heat affected zone

Zinc coated 85-100 for lap joint



Base material



Fusion zone (FZ)



Heat affected zone

## Chapter 5

### Conclusion and recommendation

#### 5.1 Conclusion

The mechanical properties and microstructure of a low carbon mild steel plate welded by manual metal arc welding process has been evaluated and it has been observed that,

- A significant decrease in hardness of metal was recorded that as the coating thickness increased. Depending on the difference in coating material the hardness of the weld in zinc coating recorded an improved hardness value than copper coating. In addition to this in case of joint configuration butt joint will record an improved hardness value than lap joint configuration.
- A significant decrease in ultimate tensile strength value was recorded as the coating thickness increased. Depending on the difference in coating material the tensile strength of the weld in zinc coating recorded an improved tensile strength value than copper coating. In case of joint configuration butt joint will record an improved tensile strength value than lap joint.
- The result of the investigation indicate that significant grain coarsening was observed in the heat affected zone of all joints and it was found that the extent of grain coarsening in heat affected zone increased with increase in the coating thickness. Excessive grain growth could also lead to decrease in the tensile properties.
- The result from signal-to-noise ratio rank indicate that varying the coating thickness found to cause more significant change on mechanical properties than varying coating material and joint configuration.

Challenges face during the experiment

It is known that Coated mild steels are highly utilized in various construction and manufacturing industries for structural and non-structural applications due to their good corrosion resistant property. However they have this importance for construction industry there is always a risk of galvanize poisoning during welding of coated metal. Galvanize poisoning is caused when a person is over exposed to zinc oxide which is formed when the galvanized coating on steel evaporates at a very high temperature such as the temperature needed from welding. Then these gases will cause long term health problems such as lung and brain cancer but this can be solved by using appropriate protective equipment's such as respirator and welding in well-ventilated area. So this research recommends that to prevent galvanized poisoning and use proper personal protections, respirator as a main protection devise. This device uses to avoid inhaling the potentially deadly zinc oxide fumes that are produced even when using a respirator you should also weld in well-ventilated area.

## 5.2 Recommendation

This researcher puts forward the following recommendation, accordingly, the need for:

- More laboratory investigation and test ought to be performed to study on other mechanical characterization of welded zinc/copper coated mild steel.
- It is highly recommended to conduct different researches on small scale coating techniques and there result on coating thickness and quality of coating.
- It is important to conduct a microstructural test to every coating thickness value in order to fulfill the research result.
- Using small scale electroplating (coating) do have some problems like not getting the exact coating thickness and quality. To resolve these problems it is strongly recommended to enhance new coating techniques which resolve the above problems.

## REFERENCE

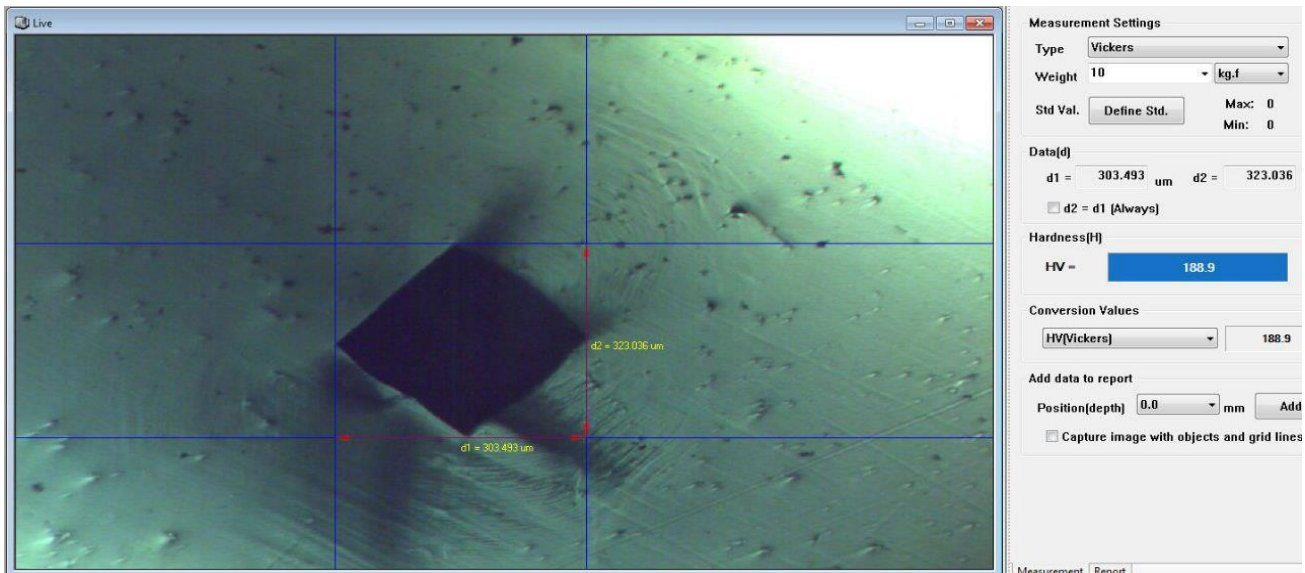
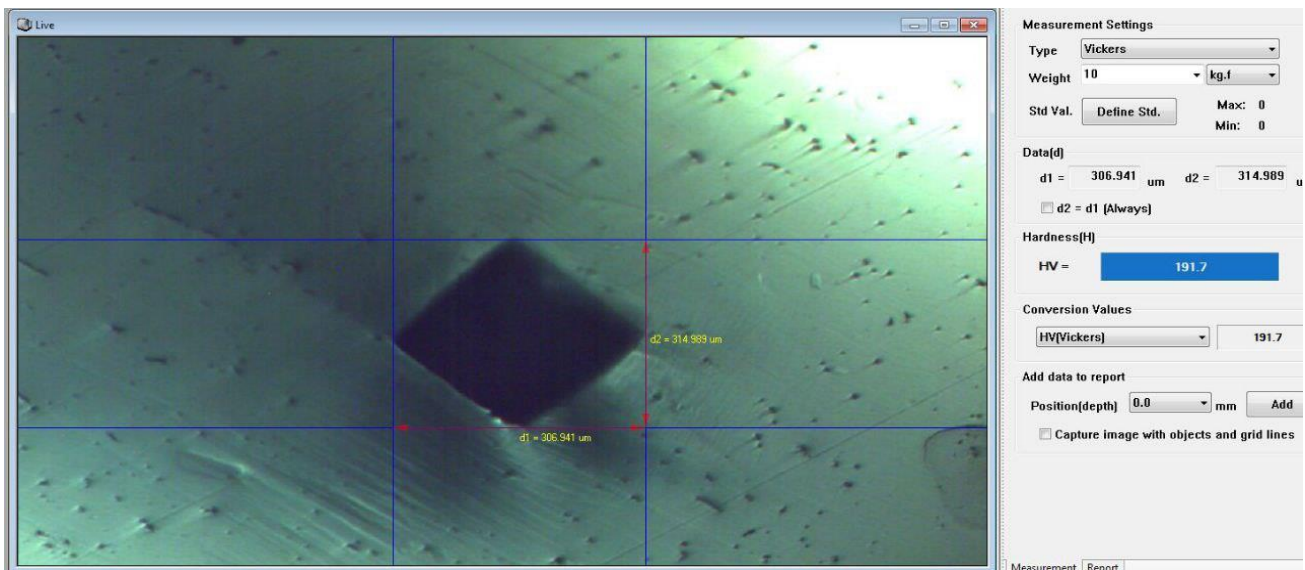
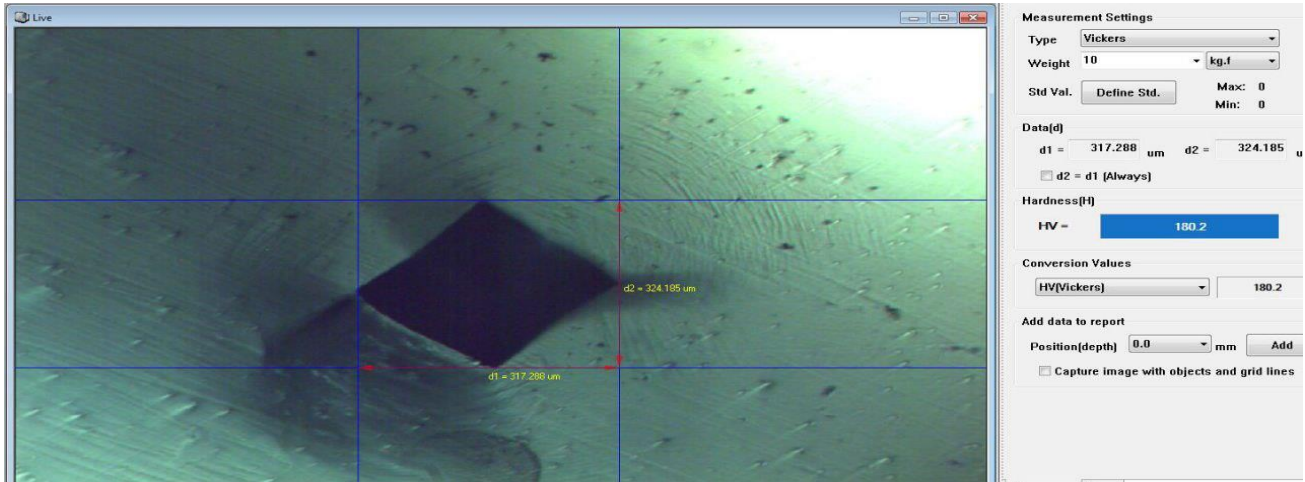
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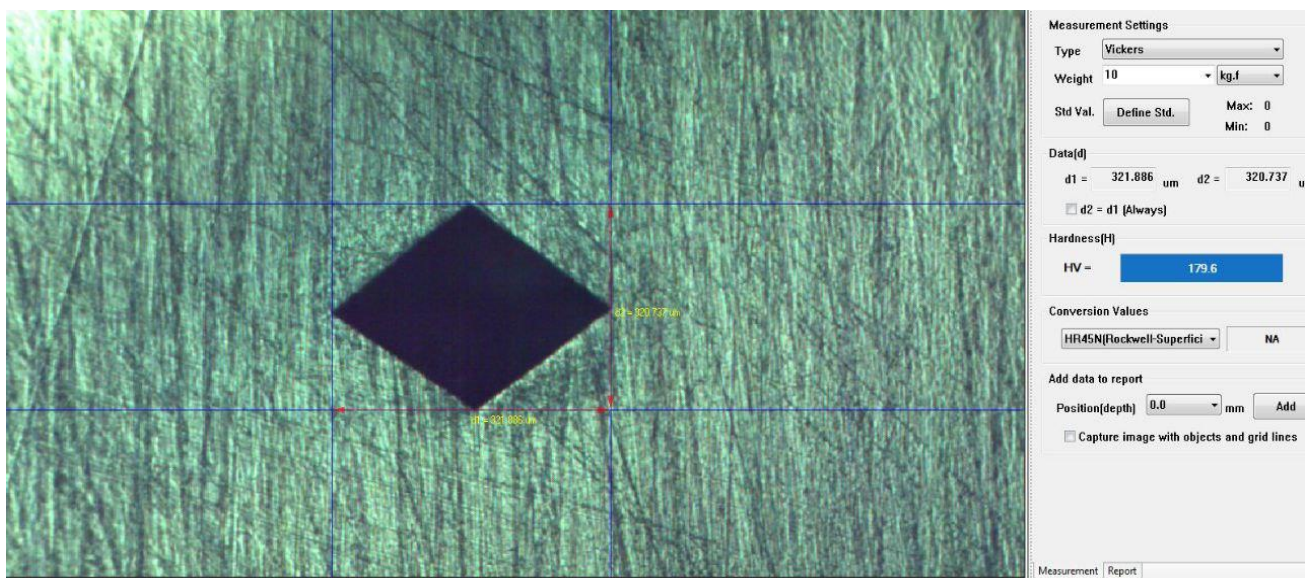
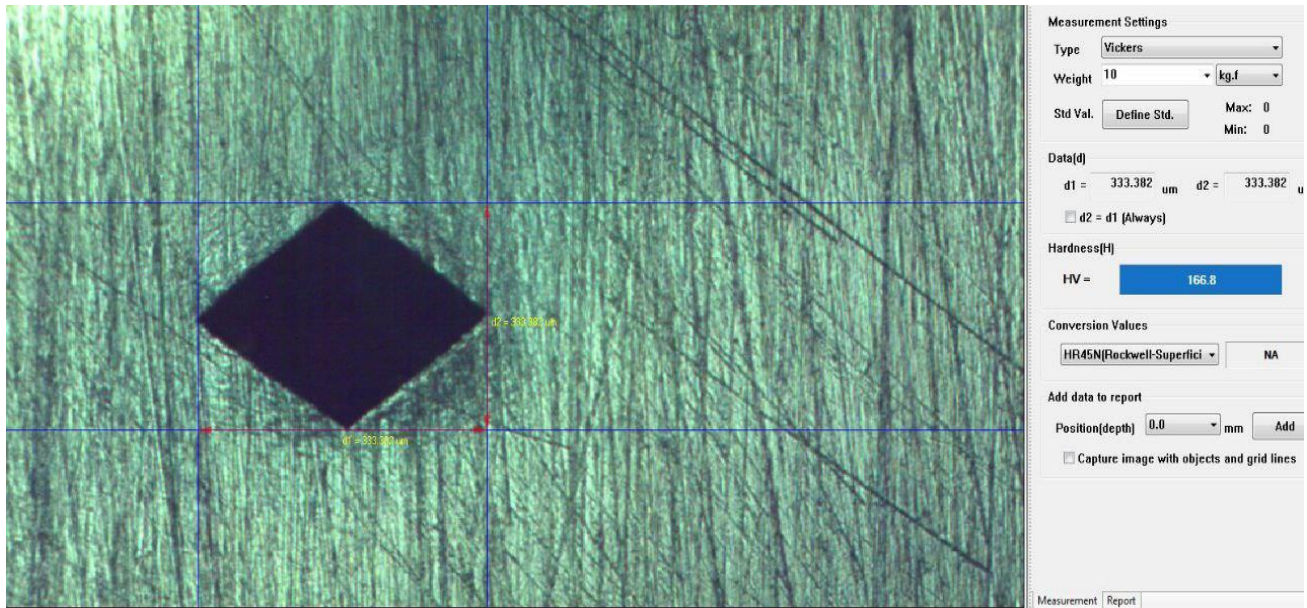
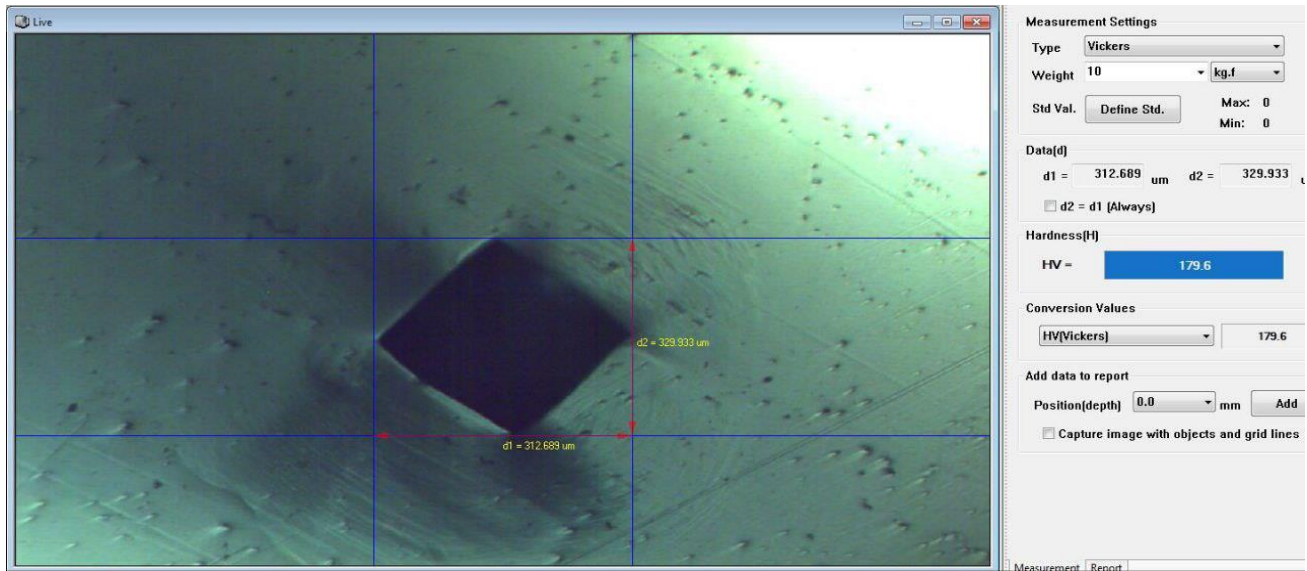
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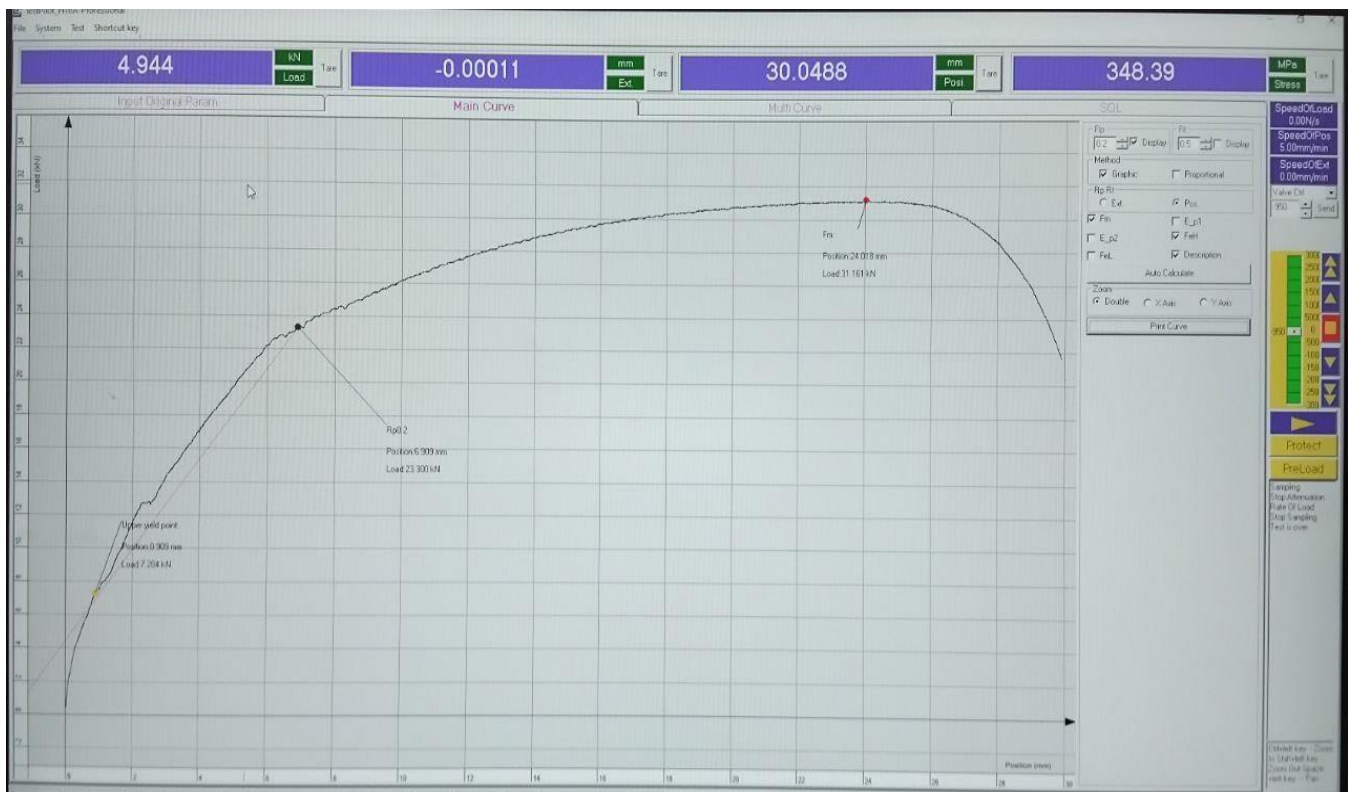
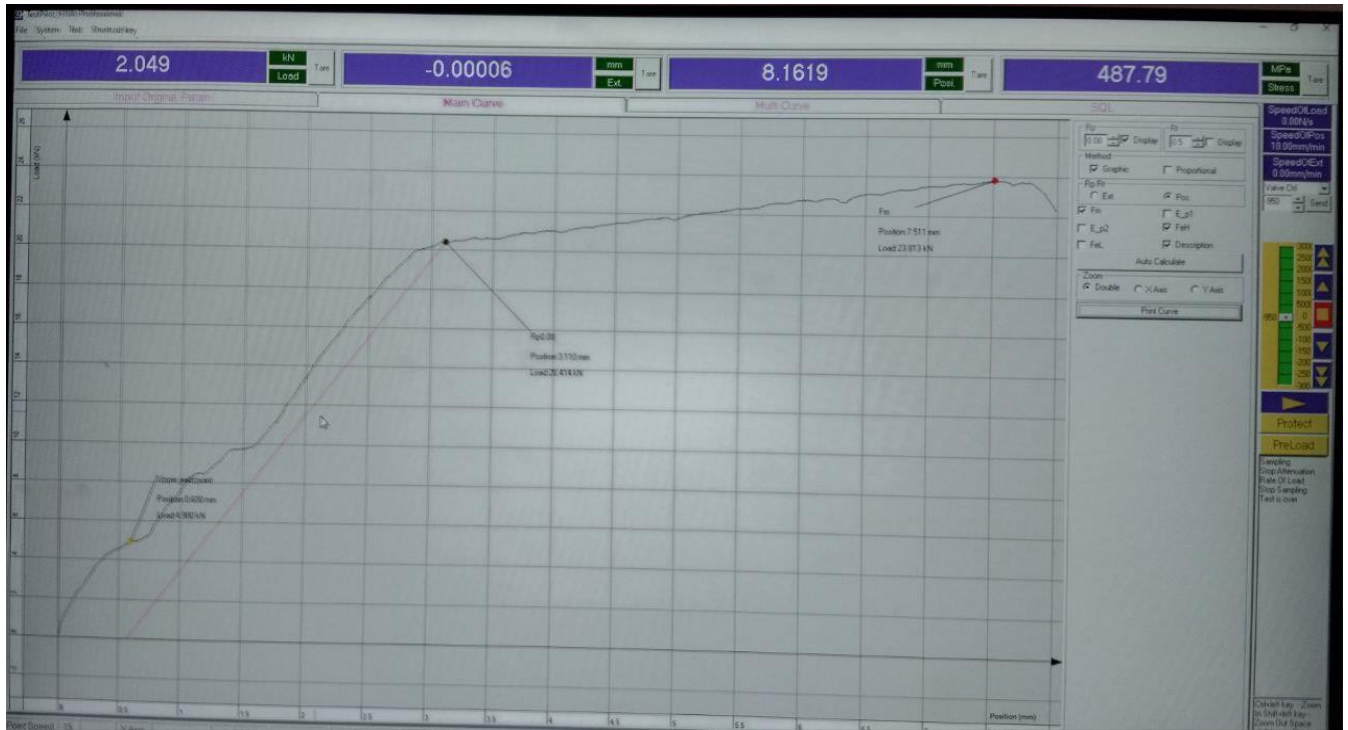
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**Annex: 1** Hardness test value





Annex 2: tensile test value



**Annex 2: Welding processes**

Joint preparations recommended in this part of ISO 9692 are suitable for welding carried out in accordance with the following processes as specified in Tables 1 to 4 (combinations of different processes

are possible):

a) (3) gas welding; oxyfuel gas welding;

b) (111) manual metal arc welding (metal arc welding with covered electrode); shielded metal arc welding;

c) (13) gas-shielded metal arc welding; gas metal arc welding includes:

— (131) MIG welding with solid wire electrode; gas metal arc welding using inert gas and solid wire electrode;

— (132) MIG welding with flux cored electrode; flux cored arc welding;

— (133) MIG welding with metal cored electrode; gas metal arc welding using inert gas and metal cored wire;

— (135) MAG welding with solid wire electrode; gas metal arc welding using active gas and solid wire electrode;

— (136) MAG welding with flux cored electrode; gas metal arc welding using active gas and flux cored electrode;

— (138) MAG welding with metal cored electrode; gas metal arc welding using active gas and metal cored electrode;

d) (141) TIG welding with solid filler material (wire/rod); gas tungsten arc welding using inert gas and solid filler material (wire/rod);

e) (5) beam welding:

— (51) electron beam welding;

— (512) electron beam welding in atmosphere;

— (52) laser welding; laser beam welding.

NOTE The numbers in parentheses refer to the reference number of the welding process specified in ISO4063.

**Finish**

The longitudinal edges of the root face should be de-burred and may be chamfered (up to 2 mm).

**Type of joint preparation**

The recommended types of joint preparation and dimensions are specified in Tables 1 to 4.

Ref. No.	Material thickness $t$ mm	Type of preparation	Symbol (in accordance with ISO 2553[2])	Cross-section	Dimensions				Recommended welding process (reference No. in accordance with ISO 4063[2])	Weld illustration	Remarks
					Angle <sup>a</sup> $\alpha, \beta$	Gap <sup>b</sup> $b$ mm	Thickness of root face $c$ mm	Depth of preparation $h$ mm			
1.1	$\leq 2$	Raised edges			—	—	—	—	3 111 141 512		Usually without filler metal
1.2.1	$\leq 4$	Square preparation			—	$6 \leq b \leq 8$	—	—	3 111 141		Where applicable with backing strip
1.2.2	$3 < t \leq 8$								13		
	$\leq 15$								141 <sup>c</sup>		
									52		
1.2.3	$\leq 100$	Square preparation with backing		—	—	—	—	51		—	
1.2.4		Square preparation with centering lip		—	—	—	—	51		—	
1.3	$3 < t \leq 10$	Single-V preparation	V		$40^\circ \leq \alpha \leq 60^\circ$	$\leq 4$	$\leq 2$	—	3 111 13 141		Where applicable with backing strip
	$8 < t \leq 12$				$6^\circ \leq \alpha \leq 8^\circ$	—			52 <sup>d</sup>		

Table 1 (continued)

Ref. No.	Material thickness $t$ mm	Type of preparation	Symbol (in accordance with ISO 2553(4))	Cross-section	Dimensions				Recommended welding process (reference No. in accordance with ISO 4063(2))	Weld illustration	Remarks
					Angle <sup>a</sup> $\alpha, \beta$	Gap <sup>b</sup> $b$ mm	Thickness of root face $c$ mm	Depth of preparation $h$ mm			
L.4	$>16$	Steep-flanked single-V preparation			$5^\circ < \beta < 20^\circ$	$5 < b < 15$	—	—	111 13		With backing strip
L.5	$5 < t < 40$	Single-V preparation with broad root face			$\alpha = 60^\circ$	$1 < b < 4$	$2 < c < 4$	—	111 13 141		—
L.6	$>12$	Single-U preparation with V root			$60^\circ < \alpha < 90^\circ$ $8^\circ < \beta < 12^\circ$	$1 < b < 3$	—	$\sim 4$	111 13 141		$6 < R < 9$
L.7	$>12$	Single-V preparation with V root			$60^\circ < \alpha < 90^\circ$ $10^\circ < \beta < 15^\circ$	$2 < b < 4$	$\leq 2$	—	111 13 141		—

**Annex 3:** Spectrometer test result***Spectrometer test***

Sample result name: - Low carbon steel

Measure date: - 25/11/2015 at 5:15

Recalculation date: - 25/11/2015 at 5:20

Method name: - Fe-100


Check type: - none

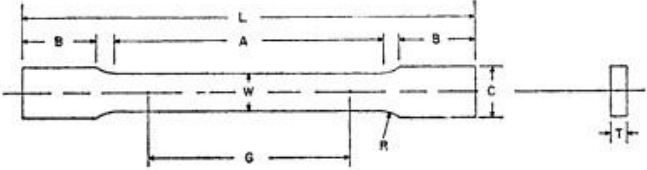
Concentration	C	Mn	Fe	P	S	Cr	Mo	Ni	Al
	0.20	0.40	99.09	0.040	0.050	0.015	0.030	<0.0050	<0.020

Concentration	Co	Cu	Nb	Ti	V	W	
	<0.020	<0.020	<0.020	0.0612	0.0225	0.400	



## Annex 4: standard test method for tensile testing of metallic material

 E8/E8M - 09



	Dimensions		
	Standard Specimens		Subsize Specimen
	Plate-Type, 40 mm [1.500 in.] Wide	Sheet-Type, 12.5 mm [0.500 in.] Wide	6 mm [0.250 in.] Wide
	mm [in.]	mm [in.]	mm [in.]
G—Gage length (Note 1 and Note 2)	200.0 ± 0.2 [8.00 ± 0.01]	50.0 ± 0.1 [2.000 ± 0.005]	25.0 ± 0.1 [1.000 ± 0.003]
W—Width (Note 3 and Note 4)	40.0 ± 2.0 [1.500 ± 0.125, -0.250]	12.5 ± 0.2 [0.500 ± 0.010]	6.0 ± 0.1 [0.250 ± 0.005]
T—Thickness (Note 5)		thickness of material 12.5 [0.500]	6 [0.250]
R—Radius of fillet, min (Note 6)	25 [1]	12.5 [0.500]	6 [0.250]
L—Overall length, (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	450 [18]	200 [8]	100 [4]
G—Gage length, min (Note 2, Note 7, and Note 8)	450 [18]	200 [8]	100 [4]
A—Length of reduced section, min	225 [9]	57 [2.25]	32 [1.25]
B—Length of grip section (Note 9)	76 [3]	50 [2]	30 [1.25]
B—Length of grip section, min (Note 9)	75 [3]	50 [2]	30 [1.25]
C—Width of grip section, approximate (Note 4 and Note 9)	50 [2]	20 [0.750]	10 [0.375]

NOTE 1—For the 40 mm [1.500 in.] wide specimen, punch marks for measuring elongation after fracture shall be made on the flat or on the edge of the specimen and within the reduced section. Either a set of nine or more punch marks 25 mm [1 in.] apart, or one or more pairs of punch marks 200 mm [8 in.] apart may be used.

NOTE 2—When elongation measurements of 40 mm [1.500 in.] wide specimens are not required, a minimum length of reduced section (A) of 75 mm [2.25 in.] may be used with all other dimensions similar to those of the plate-type specimen.

NOTE 3—For the three sizes of specimens, the ends of the reduced section shall not differ in width by more than 0.10, 0.05 or 0.02 mm [0.004, 0.002 or 0.001 in.], respectively. Also, there may be a gradual decrease in width from the ends to the center, but the width at each end shall not be more than 1 % larger than the width at the center.

NOTE 4—For each of the three sizes of specimens, narrower widths (W and C) may be used when necessary. In such cases the width of the reduced section should be as large as the width of the material being tested permits; however, unless stated specifically, the requirements for elongation in a product specification shall not apply when these narrower specimens are used.

NOTE 5—The dimension T is the thickness of the test specimen as provided for in the applicable material specifications. Minimum thickness of 40 mm [1.500 in.] wide specimens shall be 5 mm [0.188 in.]. Maximum thickness of 12.5 and 6 mm [0.500 and 0.250 in.] wide specimens shall be 19 and 6 mm [0.750 and 0.250 in.], respectively.

NOTE 6—For the 40 mm [1.500 in.] wide specimen, a 13 mm [0.500 in.] minimum radius at the ends of the reduced section is permitted for steel specimens under 690 MPa [100 000 psi] in tensile strength when a profile cutter is used to machine the reduced section.

NOTE 7—The dimension shown is suggested as a minimum. In determining the minimum length, the grips must not extend into the transition section between Dimensions A and B, see Note 9.

NOTE 8—To aid in obtaining axial force application during testing of 6-mm [0.250-in.] wide specimens, the overall length should be as large as the material will permit, up to 200 mm [8.00 in.].

NOTE 9—It is desirable, if possible, to make the length of the grip section large enough to allow the specimen to extend into the grips a distance equal to two thirds or more of the length of the grips. If the thickness of 12.5 mm [0.500-in.] wide specimens is over 10 mm [0.375 in.], longer grips and correspondingly longer grip sections of the specimen may be necessary to prevent failure in the grip section.

NOTE 10—For the three sizes of specimens, the ends of the specimen shall be symmetrical in width with the center line of the reduced section within 2.5, 0.25 and 0.13 mm [0.10, 0.01 and 0.005 in.], respectively. However, for referee testing and when required by product specifications, the ends of the 12.5 mm [0.500 in.] wide specimen shall be symmetrical within 0.2 mm [0.01 in.].

NOTE 11—For each specimen type, the radii of all fillets shall be equal to each other within a tolerance of 1.25 mm [0.05 in.], and the centers of curvature of the two fillets at a particular end shall be located across from each other (on a line perpendicular to the centerline) within a tolerance of 0.2 mm [0.01 in.].

NOTE 12—Specimens with sides parallel throughout their length are permitted, except for referee testing, provided: (a) the above tolerances are used; (b) an adequate number of marks are provided for determination of elongation; and (c) when yield strength is determined, a suitable extensometer is used. If the fracture occurs at a distance of less than 2 W from the edge of the gripping device, the tensile properties determined may not be representative of the material. In acceptance testing, if the properties meet the minimum requirements specified, no further testing is required, but if they are less than the minimum requirements, discard the test and retest.

FIG. 1 Rectangular Tension Test Specimens

**Annex 5:** Average hardness value for zinc coating

Sample No	Average HV for 0.085 coating thickness	Average HV for 0.10 coating thickness	Average HV for 0.15 Coating thickness	Average HV for 0.13 coating thickness
1	200.5	190.1	172.0	160.1
2	199.3	191.2	171.6	159.7
3	200.2	189.6	172.3	160.2
4	192.0	185.2	178.2	168.3
5	192.4	185.4	177.8	168.0
6	191.8	184.3	177.5	167.9

**Annex 6:** Average hardness value for copper coating

Sample No	Average HV for 0.085 coating thickness	Average HV for 0.10 coating thickness	Average HV for 0.15 Coating thickness	Average HV for 0.13 coating thickness
1	196.2	176.2	179.0	159.5
2	195.8	175.8	178.8	158.7
3	196.3	176.0	179.2	159.3
4	180.0	175.0	170.1	162.1
5	179.7	174.5	170.4	162.3
6	180.2	175.2	169.5	161.7

**Annex 7:** Ultimate tensile test result value for zinc coating(KN/cm<sup>2</sup>)

Sample No	Tensile test for 0.085 coating thickness	Tensile test for 0.10 coating thickness	Tensile test for 0.15 Coating thickness	Tensile test for 0.13 coating thickness
1	33.3	33.6	30.5	25.5
2	36.1	32.4	29.7	24.8
3	33.7	33.3	29.9	25.3
4	35.3	32.8	28.2	24.2
5	33.6	32.9	27.9	24.7
6	35.1	31.9	28.4	23.8

**Annex 8:** Ultimate tensile load value for copper coating(KN/cm<sup>2</sup>)

Sample No	Ultimate tensile load for 0.085 coating thickness	Ultimate tensile load for 0.10 coating thickness	Ultimate tensile load for 0.15 Coating thickness	Ultimate tensile load for 0.13 coating thickness
1	35.7	33.4	30.0	25.4
2	36.2	33.0	29.5	25.0
3	36.5	33.1	30.2	24.9
4	35.0	32.7	28.5	24.0
5	35.5	31.9	27.8	24.2
6	34.9	32.3	28.2	23.9

**Annex 9:** Average Bending test value for zinc coating

Sample No	Bending test for 0.085 coating thickness	Bending test for 0.10 coating thickness	Bending test for 0.15 Coating thickness	Bending test for 0.13 coating thickness
1	14642	13731	13215	12845
2	14621	13613	13205	12821
3	14341	13415	13195	12792
4	14008	13312	12917	12713
5	13917	13299	12961	12687
6	13815	13265	12831	12710

**Annex 10:** Average Bending test for copper coating

Sample No	Bending test for 0.085 coating thickness	Bending test for 0.10 coating thickness	Bending test for 0.15 Coating thickness	Bending test for 0.13 coating thickness
1	14643	13730	13214	12844
2	14620	13612	13204	12820
3	14340	13414	13194	12791
4	14007	13311	12914	12712
5	13916	13298	12960	12686
6	13814	13264	12830	12709

**Annex 11:** uncoated mild steel hardness, tensile and bending values

Uncoated mild steel	Average Hardness	Average tensile	Average bending
1	235.5	34.83	14729
2	248.7	48.78	14998
3	231.2	35.2	14821
4	242.1	47.62	15080
5	233.3	34.2	14752
6	240.8	47.9	14812

**Annex 11:** Features of welding machine used for this test

## YARD SV 263 / SV 333 SV 403 / SV 443

YARD power sources are rectifiers for MMA coated electrode welding. They are well suited for both workshop and outdoor working conditions. Easy to use with adjustment using the shunt, they are for professional and intensive applications.

**Features and product advantages :**

- **Input voltage:** bi-tension 230 V - 400 V three-phase
- **Simple:** power adjustment by shunt.
- **Easy to set:** linear control.
- **Cooling:** forced air cooling fan.
- **Practical:** due to the large diameter wheels and handle.
- **Versatile:** able to weld all types of electrodes (including cellulotics)




- Switch on/off and primary voltage selection.
- Current adjustment.
- Welding current indicator.
- Welding cables connectors

### Technical Characteristics:

	YARD SV 263	YARD SV 333	YARD SV 403	YARD SV 443
Three phase input voltage	230 - 400 V 3phase			
Input power	14.5 kVA - 8 kW	16.9 kVA - 10 kW	22.8 kVA - 13 kW	31.2 kVA - 18 kW
Max input current	36 A - 21 A	43 A - 26 A	57 A - 33 A	78 A - 45 A
Effective input current	21.5 A - 12.5 A	26 A - 15.5 A	34 A - 19.5 A	52 A - 30 A
Open circuit voltage	62 V - 66 V	61 V - 66 V	63 V - 70 V	71 V - 79 V

Annex 12: Welding certification of welder

