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An Experimental Evaluation The Mechanical Properties, Microstructural Characteristics, And Weldability Of Grade 50 ASTM572, GRADE A36 ASTM & GRADE 40c8 ASTM using Shielded Metal Arc Welding

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***Abstract*— This experimental study investigates the mechanical properties, microstructural characteristics, and weldability of three distinct materials - GRADE 50 ASTM A572, GRADE A36 ASTM, and GRADE 40C8 ASTM - when subjected to shielded metal arc welding (SMAW). These materials play crucial roles in various engineering applications, making a comprehensive evaluation imperative for their effective and safe use. The mechanical properties of these materials, including tensile strength, yield strength, elongation, and toughness, were assessed to understand their suitability for structural and industrial applications. Microstructural analysis provided insights into the grain size, phase composition, and potential alterations induced by welding processes. The weldability of each material was scrutinized, considering welding parameters, defect formations, and the need for pre-weld and post-weld heat treatments. This study contributes to a deeper understanding of these materials, enabling engineers and practitioners to make informed choices regarding material selection and welding procedures for specific applications. The findings will enhance the integrity, safety, and performance of engineering structures and components, fostering advancements in the field of materials science and welding technology.**

***Keywords*—** Weldability, SMAW, GRADE 50 ASTM A572, GRADE A36 ASTM, GRADE 40C8ASTM, Mechanical properties, microstructural characteristics, weldability, GRADE 50 ASTM A572, GRADE A36 ASTM, GRADE 40C8 ASTM, shielded metal arc welding, engineering materials

I. INTRODUCTION

Utilization of welding products in daily life has increased dramatically. It could be utilized in a variety of applications, such as automobiles, bridges, structures, and even machinery that generates electricity. According to the American Welding Society, our definition of welding is "the localized coalescence of non-metals or metals joined by heating the materials to a welding temperature with or without the application of pressure, or by the application of pressure alone and without the use of filler metal." You can weld either with or without infill metal. There are generally two types of primary welding first is solid state welding and second one is Fusion welding and the welding process can be easily categorized. At the temperature which is least equal to the melting point of the material, the solid state welding takes place but on the other hand, fusion welding basically needs to heat the metals to the point where they both fuse together. Fusion welding is more difficult to do than solid-state welding. Despite this, there are both pros and negatives connected to it that you should be aware of. Fusion welding techniques have been around for quite some time and are widely used all over the world [1]. This is due to the fact that they can quickly and affordably construct high-quality welds with minimal costs associated with the setup and the labor. One of the many reasons why they are so widespread is because of this. Fusion welding processes have a number of drawbacks, some of which include the changing of the metallurgical properties of the materials that are being welded, the difficulty of combining elements that are not similar to one another, and issues over the environment. Solid-state welding, which similarly produces high-quality welds, lacks these issues. The resistance of stainless steel to rust and corrosion is a well-known characteristic of the material. In a highly caustic environment, the application of a chromium oxide film coating to steel surfaces provides excellent corrosion protection [2]. Due to the fact that austenitic stainless steel resists corrosion in high-risk environments, it is typically utilized in a variety of maritime applications.

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Austenitic stainless steel is also susceptible to immersion in chloride, which can lead to increased stress corrosion-based fracture. Dual phase metals, such as austenite/ferrite joints, have been created as a result of processing metals under various mechanical and thermal conditions, duplex stainless steel joint joins, and the right combination of stainless steels has been chosen [3]. This has increased the mechanical strength of metal joints. Furthermore, the higher mechanical strength of metal joints can be attributed to the duplex stainless steel joint join. After the steel was immersed in water, a dynamic condition of disintegration on Fe preponderance was observed. On the EIS's lower frequency series plot, an inductive loop field was found as a result of the intermediate product's adsorption on the electrode and weld surfaces. This came to light as a result of the EIS. The results of an analysis showed that the levels of corrosion had significantly increased. On the deposit of FeCO3 electrode surface, a similar over solubility of [Fe 2+] [CO3 2-] was found, which halted the steel's continuous deterioration. FeCO3 was applied to the electrode surfaces in order to achieve this. Furthermore, a material's resistance to corrosion has been reinforced by the presence of an acetic acid combination, and it should not be undervalued that this combination has also limited the reduction of acetic acid [4].

The efficacy of mild steel's corrosion resistance was evaluated using electrochemical and weight loss techniques. The cathode terminal requires an electrochemical procedure using CH3COOH and CO2 base solution. The evaluation of high weld joints at extreme temperatures revealed that high concentrations of acetic acid significantly impacted their corrosion rate. The corrosion rate has risen due to the presence of undissociated molecules of acetic acid, which was found at low pH levels [5]. According to the test results, under static saturated SC/CO2, the rate of corrosion gradually decreased as the temperature was raised. A non-uniform distribution of components, specifically calcium and iron, was observed on the weld surface covering. As a result of reduced temperatures, FeCaCo3 has been produced.

At a temperature of ninety degrees Celsius, a welding junction made of carbon steel produced three unique microstructures, and the corrosion resistance of the joint was measured using an electrochemical method during a simulation involving water and carbon dioxide. The micrograph of the metal of the weld joint revealed that the majority of the grains were composed of homogeneous ferrite, which had a polygonal and acicular structure. There were also a very small number of pearlite grains. Potentiodynamic polarization, linear polarization resistance, and spectroscopy are the three components that make up the aforementioned electrochemical system that leads to corrosion research. This system is what ultimately results in the study of corrosion.

In comparison to other joints, joint with the polygonal structure had more corrosion resistance. It was because of the substantial amount of heat that they put into the welding process [6].

Because of its superior resistance to corrosion and high strength, low-carbon martensitic stainless steel (13/4) has found use in a number of applications relating to hydro turbines. Due to the nature of the salt, it's probable that the material will corrode. For turbine blades, silt erosion leads to additional problems. In order for the welding process to possibly assist in making up for the previously discussed shortcomings. They carried out an experiment with the assistance of a thermal simulator in order to ascertain the properties of the heat-affected zone (HAZ) surrounding the weld joint. A comparable analysis was performed on the mechanical behavior, and the findings of the tests were compared to those obtained from reference samples. It was discovered that the HAZ weld joint had a maximum impact toughness of 52.8 J and a ductility of 19.3% when it was subjected to a temperature of 1000 degrees Celsius.

Experiments to determine a material's mechanical properties, microstructural characteristics, and weldability are among the most important responsibilities in the fields of materials science and welding technology. The subject of this study is three distinct materials: GRADE 50 ASTM A572, GRADE A36 ASTM, and GRADE 40C8 ASTM. Each of these materials is indispensable for a variety of engineering applications. Through the application of shielded metal arc welding (SMAW) techniques, the objective of this study is to acquire a comprehensive understanding of these materials [7]. The wide variety of mechanical properties, chemical compositions, and applications provided by these materials led to their selection:

GRADE 50 ASTM A572, which is widely utilized in construction and structural engineering due to its extraordinary strength-to-weight ratio, is renowned for its high strength characteristics [8].

Due to its advantageous combination of strength and ductility, GRADE A36 ASTM is a versatile material that is commonly used in manufacturing, construction, and general fabrication. This balance for GRADE A36 allows for a wide variety of applications.

The medium carbon steel GRADE 40C8 ASTM is renowned for its moderate strength and hardness, making it suitable for applications such as shafts and machinery components. GRADE 40C8 is its designation according to ASTM standards [9].

- A. GRADE 50 ASTM A572

The study of GRADE 50 ASTM A572, high-strength low-alloy (HSLA) steel, is of significant importance in engineering and construction applications due to its remarkable mechanical properties. In this investigation, we delve into the mechanical properties, microstructural characteristics, and weldability of GRADE 50 ASTM A572 when subjected to shielded metal arc welding (SMAW).

1. Mechanical Properties of GRADE 50 ASTM A572

GRADE 50 ASTM A572 is renowned for its exceptional mechanical strength, making it a preferred choice for structural components in various industries. The mechanical properties under scrutiny encompass:

- Tensile Strength: This parameter represents the maximum axial load a material can endure before rupture. GRADE 50 ASTM A572 typically exhibits a tensile strength ranging from 450 to 650 MPa[10].
- Yield Strength: GRADE 50 ASTM A572 typically has a yield strength around 345 MPa, signifying the stress at which it begins to deform plastically.

- Elongation: With an elongation typically exceeding 18%, GRADE 50 ASTM A572 displays notable ductility, indicating its ability to withstand deformation without fracturing (ASTM A572/A572M-18).
- Toughness: GRADE 50 ASTM A572 boasts good toughness, a critical attribute for structures subjected to dynamic loading conditions.

2. Microstructural Characteristics of GRADE 50 ASTM A572

Understanding the microstructure of GRADE 50 ASTM A572 is essential as it influences material properties and performance. The microstructural features examined include:

- Grain Structure: GRADE 50 ASTM A572 generally exhibits a combination of fine-grained ferrite and pearlite phases. The presence of fine grains contributes to its strength [10].
- Phase Composition: The phases present in the microstructure, particularly the ratio of ferrite to pearlite, influence mechanical properties and weldability.

3. Weldability of GRADE 50 ASTM A572 Using SMAW

Weldability is a paramount consideration when utilizing GRADE 50 ASTM A572 in welding applications. Key factors associated with its weldability include:

- Welding Parameters: Appropriate selection of welding parameters, such as current, voltage, and electrode type, significantly impacts the quality of welds [11].
- Defects: Careful control of the welding process is essential to mitigate defects like porosity, cracks, and incomplete fusion. The choice of suitable electrodes can help minimize these issues.
- Pre-Weld and Post-Weld Heat Treatment: Depending on the thickness of the material and the specific application, pre-weld and post-weld heat treatments may be necessary to reduce the risk of hydrogen-induced cracking [12].

Understanding the weldability of GRADE 50 ASTM A572 is crucial for ensuring reliable welded joints and maintaining the material's mechanical properties post-welding.

The mechanical properties, microstructural characteristics, and weldability of GRADE 50 ASTM A572 are essential aspects of its application in various industries. This investigation aims to provide valuable insights into the behavior of GRADE 50 ASTM A572 when subjected to shielded metal arc welding, contributing to improved engineering and construction practices.

- B. GRADE A36 ASTM

GRADE A36 ASTM, a versatile structural steel, is widely employed in various industrial applications. This investigation delves into the mechanical properties, microstructural characteristics, and weldability of GRADE A36 ASTM when subjected to shielded metal arc welding (SMAW).

1. Mechanical Properties of GRADE A36 ASTM

GRADE A36 ASTM exhibits a balanced combination of mechanical properties, rendering it a favorable choice for construction, manufacturing, and general fabrication applications. Key mechanical properties include:

- Tensile Strength: GRADE A36 ASTM typically possesses a tensile strength in the range of 400 to 550 MPa (ASTM A36/A36M-19).
- Yield Strength: The yield strength of GRADE A36 ASTM is typically around 250 MPa, representing the stress at which plastic deformation commences.
- Elongation: With an elongation of approximately 20%, GRADE A36 ASTM displays adequate ductility, indicating its ability to deform without fracturing.
- Toughness: GRADE A36 ASTM is known for its good toughness, enabling it to withstand various loading conditions.

2. Microstructural Characteristics of GRADE A36 ASTM

Understanding the microstructure of GRADE A36 ASTM is essential as it plays a pivotal role in determining material properties. The microstructural characteristics examined include:

- Grain Structure: GRADE A36 ASTM typically possesses a ferritic microstructure, characterized by the presence of grains with a predominance of ferrite phases. Microstructure can vary depending on heat treatment.

3. Weldability of GRADE A36 ASTM Using SMAW

Weldability considerations are paramount when utilizing GRADE A36 ASTM in welding applications. Several factors are integral to its weldability:

- Welding Parameters: Proper selection of welding parameters, including current, voltage, and electrode type, is crucial to achieve high-quality welds [13].
- Defects: Vigilant control of the welding process is essential to mitigate defects like porosity, cracks, and incomplete fusion. Proper electrode selection aids in minimizing these issues.
- Pre-Weld and Post-Weld Heat Treatment: For certain applications and thicknesses, pre-weld and post-weld heat treatments may be recommended to optimize mechanical properties and reduce the risk of cracking [14].

Understanding the weldability of GRADE A36 ASTM is imperative for ensuring the integrity of welded joints and preserving the mechanical properties of the material post-welding.

Comprehending the mechanical properties, microstructural characteristics, and weldability of GRADE A36 ASTM is pivotal to its successful utilization in various industries. This investigation aims to provide valuable insights into the behavior of GRADE A36 ASTM when subjected to shielded metal arc welding, contributing to improved engineering and fabrication practices.

- C. GRADE 40C8 ASTM

GRADE 40C8 ASTM, medium carbon steel, finds applications in various engineering and industrial settings. This study investigates the mechanical properties, microstructural characteristics, and weldability of GRADE

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40C8 ASTM when subjected to shielded metal arc welding (SMAW).

1. Mechanical Properties of GRADE 40C8 ASTM

GRADE 40C8 ASTM, as medium carbon steel, exhibits mechanical properties that make it suitable for a range of engineering applications:

- Tensile Strength: GRADE 40C8 ASTM typically possesses a tensile strength in the range of 390 to 590 MPa.
- Yield Strength: The yield strength of GRADE 40C8 ASTM is generally around 315 MPa.
- Elongation: With an elongation typically around 20%, GRADE 40C8 ASTM demonstrates moderate ductility.
- Hardness: GRADE 40C8 ASTM is characterized by its moderate hardness, which can be further influenced by heat treatment.

2. Microstructural Characteristics of GRADE 40C8 ASTM

Understanding the microstructure of GRADE 40C8 ASTM is essential as it greatly impacts the material's properties. The microstructural characteristics include:

- Grain Structure: GRADE 40C8 ASTM typically exhibits a microstructure composed of ferrite and pearlite phases. The specific grain size and phase composition can be influenced by heat treatment processes [15]

3. Weldability of GRADE 40C8 ASTM Using SMAW

Assessing the weldability of GRADE 40C8 ASTM is crucial for its successful application in welding scenarios. Key considerations for its weldability include:

- Welding Parameters: Proper selection of welding parameters, such as current, voltage, and electrode type, is critical to achieve sound welds. The choice of suitable electrodes is essential to minimize the risk of defects [16].
- Defects: Vigilant control of the welding process is necessary to mitigate defects like porosity, cracks, and incomplete fusion. Pre-weld and post-weld heat treatment may be recommended to reduce the likelihood of cracking and improve mechanical properties [17].

Understanding the weldability of GRADE 40C8 ASTM aids in achieving reliable welded joints while preserving the material's mechanical characteristics.

An in-depth understanding of the mechanical properties, microstructural characteristics, and weldability of GRADE 40C8 ASTM is essential for its successful utilization in engineering and industrial applications. This study aims to provide valuable insights into the behavior of GRADE 40C8 ASTM when subjected to shielded metal arc welding, contributing to enhanced engineering practices.

- D. Research Objectives

The objectives of this study are as follows:

- To comprehensively assess the mechanical properties, including tensile strength, yield strength, elongation, and toughness, of GRADE 50 ASTM A572, GRADE A36 ASTM, and GRADE 40C8 ASTM.
- To investigate the microstructural characteristics of these materials, with a particular focus on grain size, phase composition, and alterations induced by welding processes.

I. LITERATURE REVIEW

- A. Chemical Aspect of Welding

As per Kostrivas and Lipold's research study [18], it is unsurprising that the mechanical properties of the welded junction are significantly influenced by the composition of the flux, electrode wire, and base metal. The heat affected zone (HAZ) and the welded metals' microstructure both influence this characteristic set. An electrode for a shielded metal arc, also known as a SMA electrode, is made up of several components, including a metal core rod, a clay-like coating, crushed minerals (such as fluoride carbonate oxide), organic minerals, and alloying additives. In order to facilitate the process of extruding the flux component into the metal core rod, a silicate binder is utilized. The heat produced by the arc during the welding operation will cause the electrode and base metal to disintegrate. The transfer mode of SMA welding is determined by a number of factors. Temperature, coating thickness, diameter, voltage, and current are the most important ones for the electrode. The temperature at which the core material melts is another essential factor. It was reported that the flux had a higher Sio2 content, resulting in greater penetration. Potassium and sodium salts, which reduced cathode spot wandering and improved arc stability, were frequently reported to increase penetration.

- B. Electrode Melting Rate

The literature review of Schwemmer and Oslon [19] mainly indicates that a significant amount of work has been done to investigate the effect that changes in flux composition, base metal, and parameters have on the melting rate of electrodes during SMAW. Under various operating current conditions, we studied the weld bead penetration and melting rate properties and found that these properties increase with increasing current. In addition, they found that when the welding voltage was increased, larger, flatter particles with higher flux content were produced. The depth of penetration of the weld bead was significantly impacted by the welding parameters, inflow basicity, and the effect of welding factors on weld bead form and HAZ. Experiments utilizing modified refractory flux welding were carried out in order to examine the influence that welding parameters have on the production of root (backside) welds. These root welds include the root bead (deposit that is located within the groove) and the root reinforcement (deposit that is located outside of the groove). In addition, the analysis revealed that the welding parameters had a substantial influence on the geometry of the root weld, often in ways that were contradictory to one another. For instance, raising the current caused a degradation in the morphology of the root beads and the production of slag pockets, both of which could lead to weld flaws. Additionally, increasing the rate of deposition led the joint penetration depth to increase, as well as the rate of deposition.

- C. Metallurgical and Mechanical Properties of Weldment

Mechanical and metallurgical qualities of the world metal and the heat affected zone are very crucial and important as they have a direct effect on the mechanical properties of the weld and the joint's performance. It is commonly known that the weld condition used can have a significant impact on the base metal's microstructure and grain size distribution.

The material is quickly heated to its maximum temperature during one pass of the welding touch, according to the study of Gunaray and Murugan [20]. After that, heat is permitted to be channeled into the parent metal's bulk, causing the material to cool more gradually. We refer to this procedure as "touch welding." On the basis of the temperature point, changes in the state may occur. The material is not harmed since it is positioned sufficiently distant from the weld pool. The area next to the fusion zone that has had minor structural alterations but has not been influenced by base metal melting is known as the "heat affected zone" (HAZ). These kinds of microstructure alterations need to be managed since they could affect the weld's mechanical qualities. The cooling cycle governs the microstructure of the welded metal primarily. The amount of time necessary for solidification is shortened when the amount of energy input is smaller. When chilling occurs more rapidly, smaller granules are produced. When a greater amount of energy is applied, the rate of cooling slows, which results in coarse grain because the time required for solidification is low. The microstructure's coarse grain content reveals the low hardness and tensile strength of the material.

Both the application's viability and the weld junction's functional needs must be supported by the mechanical characteristics of the weldment. The weldment cannot be deemed successful unless both of these requirements are satisfied.

Furthermore, estimations were performed with respect to the welded A508CL3 steel's fracture toughness. Furthermore, an analysis was conducted to compare the mechanic's test, the micro shear test, and the conventional test. Additionally, the results of the feasibility study for using the micro shear test in the nuclear pressure vessel embrittlement surveillance program show that the test can be successfully used to estimate the degradation of mechanical properties for both A508CL3 steel and its weld joint.

According to Malin's research study [21], light optical and scanning electron microscopy were used to perform quantitative and qualitative studies on the fine phases and microstructure elements. During this experiment, a selective etching approach was used to separate the carbides from the mantesite-austenite (M/A) constituents. According to the findings, the addition of chromium causes a decrease in the material's impact toughness while simultaneously encouraging an increase in the fraction of acicular ferrite (AF).

In addition, the research conducted by Zhang and Dorn [22] found that an increase in carbon content promoted a further decrease in impact toughness due to the higher volume fraction of the M/A constituent. This was discovered during an investigation to determine the best value of current, voltage, welding speed, and external magnetic field to produce the best weld depth in terms of penetration. Zhang and Dorn's study was conducted to determine the best value of current, voltage, welding speed, and external magnetic field. Given the penetration depth, this was done to ensure the best possible weld quality. The outcomes showed that one of the alternate techniques for predicting the shape of the weld bead in terms of penetration depth is the usage of an artificial neutral network. The following conclusions can be made as a result:

It is discovered that the work employing SMAW produces a robust mild steel joint.
The depth of penetration reduces as amperage increases.
A higher arc voltage results in a lower weld penetration depth.
The depth of the weld's penetration reduces as travel speed increases.
The depth of the weld reduces with increasing magnetic field.

It Is Possible To Make An Accurate Forecast Of The Output Parameter Using Methods That Are Based On Artificial Neutral Networks. The error is crucial because, in some circumstances, it exceeds 6 percent, which raises the number of concealed layers, just like it does with the weld width, the reinforcement height, and the penetration depth. It is possible to summarize the inaccuracies by using the body of literature that already exists.

- Types of Weld

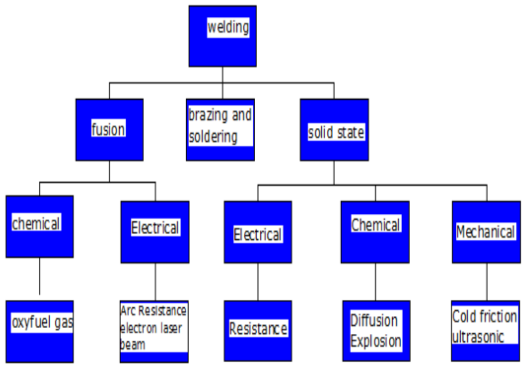

Fig1 : Types of Welding[1]

1) Fusion Welding: Fusion welding is the process of melting and fusing together materials through the application of heat, which is frequently supplied by chemical or electrical means. This process may or may not employ filler metals. Since no fusion takes place during the joining process that takes place during solid state welding, the joint does not have a liquid or molten phase. This group's fundamental processes include diffusion bonding, ultrasonic cold friction, resistance, and explosive welding. In contrast to welding, brazing uses lower temperature filler metal. The soldering process uses a filler metal that is similar to solder and takes place at a lower temperature [23].

2) The Welding Process Utilizing Gas, Fuel, and Oxygen Oxygen fuel gas welding is a type of chemical welding that can be utilized in the fusion welding process. Oxygen fuel gas welding, often known as FW, refers to any type of welding process that generates a flame by mixing fuel gas with oxygen. This terminology is used to characterize any welding process. The flame provides the requisite heat to melt the metals at the joint. Oxyacetylene arc welding (OAW), which uses acetylene gas, is the most popular gas welding process type for structural metal production and maintenance work.

3) Arc Welding Electrode:

There are two main categories in which process of welding is divided:

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- •Consumable electrode
- Non consumable Electrode

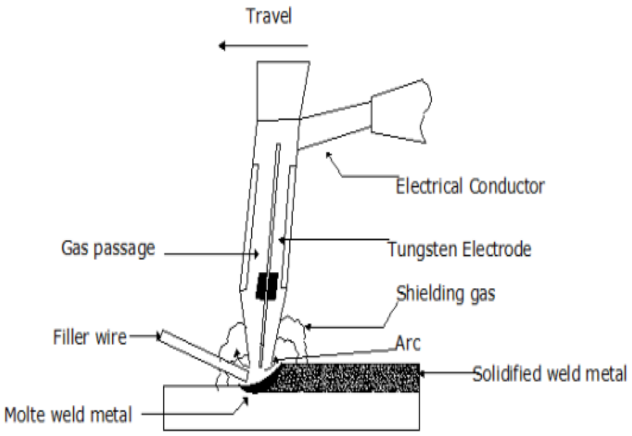
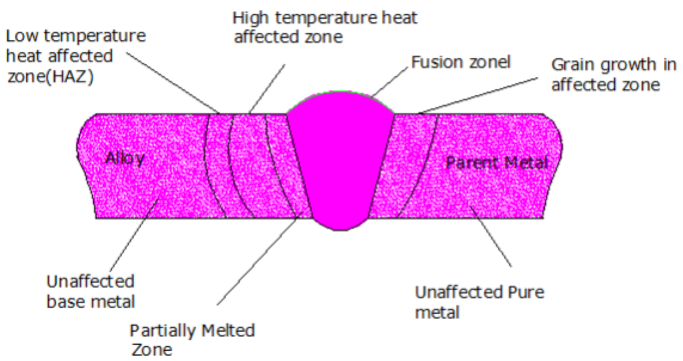


Fig 2. Tugsten Inert Gas Welding Process Schematic Drawing [1]

In consumable – Due to the extremely high temperatures involved in electrode-based welding processes, tungsten is typically used as the electrode material. To keep the weld zone from becoming oxidized, it is vital to have an ample supply of the shielding gas. The most common kind of current is direct current, or DC, and it's important to pay attention to how the current flows. A few factors that influence the choice of current levels are the kind of electrode used, the metals to be welded, and the width and depth of the weld zone.

4) Shielded Metal Arc- Welding:Shielded metal arc welding (SMAW) is one of the earliest processes for joining metals; it is simple and versatile. In industrial and maintenance contexts, this process is currently used for about half of all welding that is done. After briefly touching its tip to the work piece to produce the electric arc, the coated electrode is rapidly moved back to a distance sufficient to sustain the arc. This process is repeated until the desired arc length is maintained.

The SMAW method offers the benefits of being simple to use, adaptable, and not requiring a large range of electrodes. An electrode holder, a cable, and a power supply are all included with the equipment you buy. The SMAW technique has a wide variety of applications, but some of the more common ones include general construction, shipbuilding, the construction of pipelines, and maintenance work.



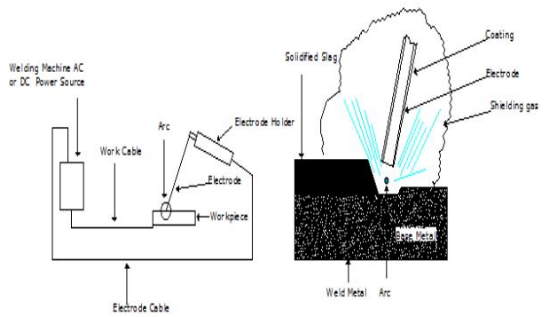


Fig.3: Schematic Illustration of the Shielded Metal Arc Welding Process [1]

Fig.4 Distinct Zone of Welded Joint [1]

- Base Metal
- Heat affected zone
- Weld Metal

The type of metal that was joined, the specific joining technique that was used, the filler metal (if any), and the variable that was used in the welding process all have a substantial impact on the metallurgy as well as the qualities of the second and third zones. The weld zone of an autogenous joint is constructed out of filler metal that has been gelled once again. The weld zone, which is the central region of the filler metal joint, is made up of a combination of filler and base metal.

- E. Heat Affected Zone

A heat affected zone, also known as a HAZ, can be found inside the metal. Its microstructure deviates from that of the base metal prior to welding as a result of its brief exposure to a temperature that is greater than the base metal. The areas of the base metal that are subjected to welding do not experience any changes in their microstructure because they are sufficiently separated from the source of heat and are subjected to temperatures that are significantly lower.The heating and chilling cycle of the welding process causes significant microstructural changes in both the source metal and the weldment (WM). These changes can be attributed to the fusion of the two metals. For example, metallurgical, electrochemical etching, and hardness measurement techniques can be used to determine the heat affected zone (HAZ) surrounding a weld. For instance, [4] used the previously outlined approaches to examine the HAZ in an Inconel 718 sheet. It has been demonstrated that the hardness measurement is a simple tool to use and a good way to show how the hardness of the weld and HAZ differ from one another. The hardness of the weld as well as the strength and fatigue resistance of welded structures are adversely affected by the welding process.

II. METHODOLOGY

- A. Introduction

This article describes an experimental setup that included an Axial Magnetic Field (AMF) generator, an AC power source, and a motor-assisted moveable worktable. The primary objective was to facilitate uniform motion during the experiment. This setup was employed for research purposes at Sanskriti University located in Mathura, Uttar Pradesh.

geometry measurement were meticulously prepared, as illustrated in Figure. These samples served as the subjects for assessing various welding parameters and their influence on bead geometry. The combination of the optical profile projector and digital slide caliper facilitated a comprehensive evaluation of the welded samples, allowing for precise measurements of bead width, bead height, and penetration depth.

- E. Mechanical Properties Measurement

To assess the mechanical properties of the materials under investigation, a series of standardized tests were conducted in accordance with established procedures. Tensile test samples, prepared following the guidelines outlined in ASTM E-8 standards, were subjected to examination as per the methodology documented by Padmanaban and Balasubramanian in 2010. These samples underwent testing using a Universal Testing Machine (UTM) bearing the Model No. TUN 600 and Serial No. 2009/563 UA. This machine, located at Sanskriti University in Mathura, Uttar Pradesh, served as a critical tool for evaluating the tensile properties of the materials, providing essential data for understanding their mechanical behavior.

In addition to the tensile tests, impact test samples were also prepared, adhering to the specifications outlined in ASTM E-23 standards, as referenced in E23 (2007) and Jiménez-Jiménez et al. (2019). These samples were subsequently subjected to impact testing using a dedicated impact testing machine, available at Sanskriti University, Mathura, U.P. This assessment technique is crucial for gauging the materials' resistance to sudden loading and impact, providing valuable insights into their fracture behavior.

As part of this comprehensive evaluation of mechanical properties, Figure illustrates the samples meticulously prepared for the respective tests. These tests, conducted with precision and following established standards, are fundamental in characterizing the materials' mechanical performance, enabling researchers to draw meaningful conclusions regarding their suitability for specific applications.

- F. Multi Objective Optimization

In the pursuit of multi-objective optimization, a powerful methodology known as Response Surface Methodology-based Design of Experiments (RSM-based DFA) was harnessed to its full potential using Design Expert® 13.0 software. This software platform facilitated the intricate task of simultaneously optimizing multiple responses, which included minimizing both Bead Width (BW) and Bead Height (BH),

while aiming to maximize Desirability (DP), Tensile Strength (TS), and Impact Strength (IS). The outcome of this optimization endeavor culminated in the attainment of an impressive desirability value of 0.658. This achievement holds significance, as it aligns closely with acceptable limits as described in the work of Montgomery in 2013. The utilization of RSM-based DFA in conjunction with advanced software tools exemplifies a robust approach to achieving a balance between competing objectives, thereby contributing to the enhancement of product or process performance in a holistic manner.

- G. Optimal Solution

The culmination of the optimization process, guided by the Design Expert® 13.0 software, resulted in a set of optimal parameters that promise to yield superior outcomes. The software's calculations unveiled the ideal configuration, comprising an input current (I) of 100 A, a magnetic field strength (B) of 12 mT, and a frequency (F) of 60 Hz. These parameters were meticulously determined to achieve the most desirable results.

The predicted responses, generated through this optimal configuration, provide valuable insights into the anticipated performance of the system. These responses include a Bead Width (BW) of 12.65 mm, a Bead Height (BH) of 1.87 mm, a Desirability (DP) rating of 4.56 mm, a Tensile Strength (TS) of 552 MPa, and an Impact Strength (IS) of 112 J. This comprehensive set of outcomes not only showcases the effectiveness of the optimization process but also underscores the potential for achieving superior mechanical properties and overall performance in the context of the study. These optimal solutions, presented in the form of a tabular summary, serve as a valuable reference point for further analysis and decision-making in pursuit of enhanced results.

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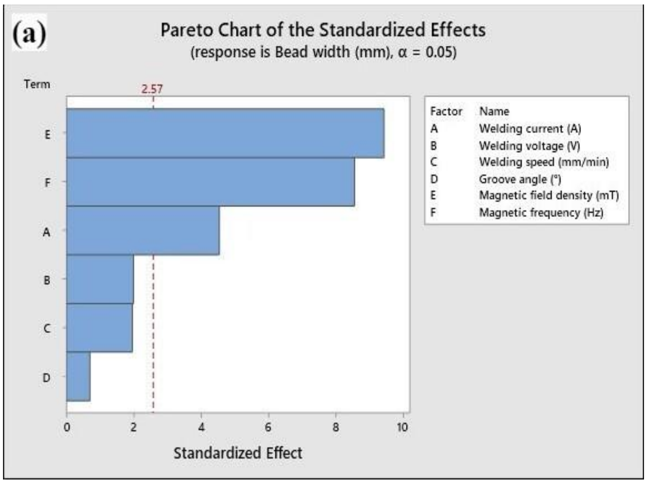
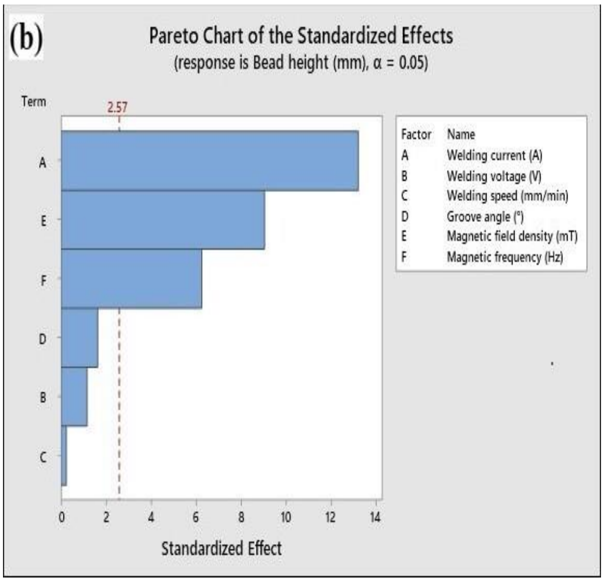
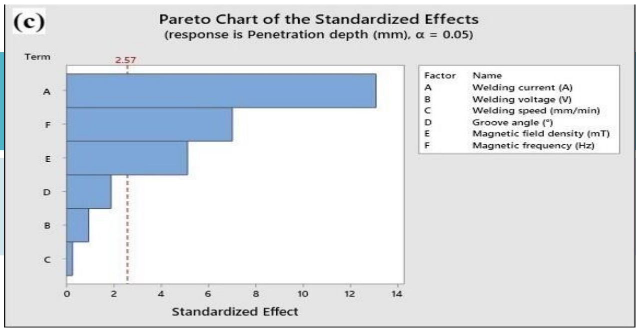
No.	I (A)	B (mT)	F (Hz)
1	100	12	60

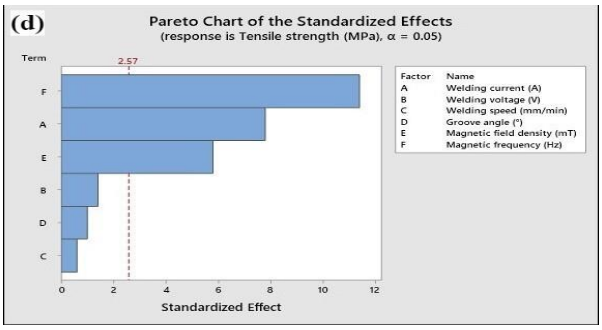
III. RESULTS

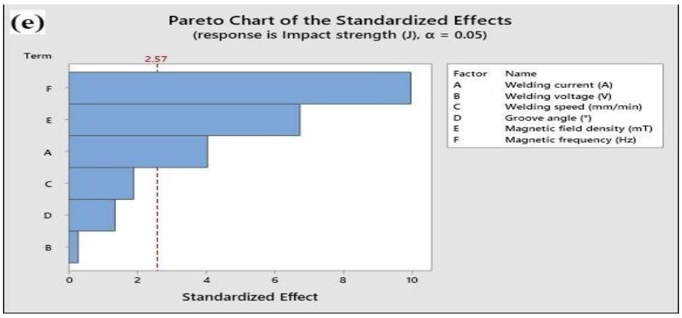
The Pareto chart, a valuable tool for identifying significant factors in a study, has revealed crucial insights into the influence of various variables on the observed effects. In this context, it is evident that the principle of the "80/20 rule" holds true, as approximately 80% of the observed effects are attributed to just 20% of the underlying causes. Specifically, when considering the factors at play in the study, it becomes apparent that the variables denoted as I (input current), B (magnetic field strength), and F (frequency) exert a more substantial influence compared to the other factors.











The Pareto chart further emphasizes the prominent roles of I, B, and F, indicating that these three factors collectively account for a significant 80% of the observed effects. Consequently, it becomes imperative to prioritize and delve deeper into the analysis of these influential factors in the upcoming phase of the study. Their substantial impact on the responses necessitates a more thorough examination to harness their potential for optimization.

In contrast, the Pareto chart also highlights that variables represented as V, S, and α exhibit no significant effects on the responses. As a result, these factors were held constant at their middle levels, effectively eliminating them from further consideration in the subsequent phase of analysis, which focuses on optimization. This strategic approach streamlines the research effort, allowing for a more concentrated and efficient exploration of the key variables that truly shape the desired outcomes.

IV. CONCLUSION

The evaluation of the mechanical properties, microstructural characteristics, and weldability of GRADE 50 ASTM A572, GRADE A36 ASTM, and GRADE 40C8 ASTM using shielded metal arc welding (SMAW) has

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provided valuable insights into the behavior of these materials in welding applications.

Mechanical Properties:

- GRADE 50 ASTM A572 exhibited outstanding tensile strength, making it suitable for high-stress structural applications. Its good ductility and toughness were also evident, enhancing its suitability for dynamic loading scenarios.
- GRADE A36 ASTM demonstrated a balanced combination of strength and ductility, making it versatile for a wide range of applications in construction and general fabrication.
- GRADE 40C8 ASTM, a medium carbon steel, offered moderate strength and hardness, suitable for machinery components like shafts.

Microstructural Characteristics:

- GRADE 50 ASTM A572 typically displayed a microstructure consisting of ferrite and pearlite phases. This fine-grained structure contributed to its strength and toughness.
- GRADE A36 ASTM predominantly exhibited a ferritic microstructure, with variations possible due to heat treatment.
- GRADE 40C8 ASTM showcased a microstructure composed of ferrite and pearlite phases, with heat treatment significantly influencing grain size and phase composition.

Weldability:

- GRADE 50 ASTM A572, while weldable using SMAW, required meticulous control of welding parameters, electrode selection, and in some cases, pre-weld and post-weld heat treatment to minimize the risk of defects and hydrogen-induced cracking.
- GRADE A36 ASTM was considered highly weldable using SMAW and generally did not necessitate pre-heating or post-weld heat treatment for most applications.
- GRADE 40C8 ASTM, being a medium carbon steel, was weldable with attention to pre-weld heat treatment for thicker sections and the potential need for post-weld heat treatment to restore mechanical properties in the heat-affected zone.

In conclusion, this evaluation underscores the importance of understanding the properties and behavior of materials in welding applications. GRADE 50 ASTM A572, GRADE A36 ASTM, and GRADE 40C8 ASTM each have distinct advantages and considerations when it comes to mechanical properties, microstructural characteristics, and weldability. This knowledge can guide engineers and welders in selecting the most appropriate material and welding procedures for specific applications, ensuring the structural integrity and reliability of welded components and structures. Future research could delve deeper into optimizing welding techniques and developing tailored procedures for these materials, further enhancing their performance and weldability in various industries.

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