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OPTIMIZING SHIELDED METAL ARC WELDING (SMAW) PARAMETERS WITH A COMPARATIVE SIMULATION APPROACH

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ABSTRACT: In the Shielded Metal Arc Welding (SMAW) process, how the parameters- electrode diameter and current affect metal deposition for weld production has been studied in this study. By altering these two characteristics on mild steel, diverse outcomes concerning efficiency have been achieved. An investigation utilizing various simulation software - ANSYS, has been performed, and the findings of similar stresses have been compared. The data acquired from the experimental inquiry has been examined utilizing comparison data tables and graphs, employing software such as ORIGIN. An optimal current value for a certain electrode diameter has been established. The data reveal that an optimal value of 250A is established for a 2.5mm electrode diameter, whereas a 4mm electrode diameter has an optimal parameter of 260A. This indicates that weld efficiency is superior for these specific values. The greatest efficiency values have been computed as follows:

Empirical Investigation: For 2.5mm electrode diameter and current of 250A, the efficiency values found to be 47.64% & for 4mm electrode diameter and current of 260A,the efficiency values is found to be 43.72% whereas in Simulation Study (ANSYS):For 2.5mm electrode diameter and current of 250A,the efficiency values found to be 43.64% & for 4mm electrode diameter and current of 260A ,the efficiency is found to be 54.39%.

Index Terms- Shielded Metal Arc Welding, ANSYS, ORIGIN. Optimal Value, Simulation

INTRODUCTION:

Welding is a fundamental joining process widely used across various industries to connect different materials such as metals, alloys, and plastics through the application of heat and/or pressure. During the welding process, the workpieces to be joined are melted at the interface, and upon solidification, a permanent joint is achieved. In many cases, a filler material is added to create a weld pool of molten metal, which, after solidification, establishes a strong bond between the materials. The weldability of a material is influenced by several factors, including metallurgical changes during welding, variations in hardness within the weld zone due to rapid solidification, oxidation resulting from interactions with atmospheric oxygen, and the tendency for crack formation at the joint. The efficiency of a weld is typically evaluated using parameters such as current, voltage, and electrode diameter.

Amongst all the methods of welding, Arc welding is the most widely used due to its versatility and applicability to different types of materials. Shielded Metal Arc Welding (SMAW), Gas Metal Arc Welding (GMAW) and Gas Tungsten Arc Welding (GTAW or TIG) are the most commonly employed arc welding techniques. SMAW, also known as Manual Metal Arc Welding, utilizes a flux-coated consumable electrode that generates shielding gas upon disintegration, protecting the weld area from atmospheric contamination. GMAW employs a continuous consumable wire electrode with an inert or active gas shielding the weld zone. GTAW, on the other hand, uses a non-consumable tungsten electrode and an inert shielding gas such as argon or helium to protect the weld area, making it suitable for welding materials like aluminum, magnesium, and stainless steel.

The effectiveness of arc welding, particularly SMAW, is influenced by the electrode covering, which stabilizes the arc, shields the weld metal, and introduces alloying elements to achieve desired mechanical properties. SMAW remains a preferred welding technique due to its simplicity, affordability, and adaptability to various applications. However, limitations such as lower deposition rates, sensitivity to certain metals, and reduced operator efficiency compared to continuous electrode processes like GMAW and FCAW must be considered when selecting the appropriate welding method.

This study aims to explore the fundamentals of SMAW welding, its process mechanisms, electrode characteristics, shielding techniques, and its advantages and limitations. By examining the critical factors influencing weld quality and efficiency, this study contributes to a deeper understanding of arc welding processes and their industrial applications.

2. LITERATURE REVIEW

O. Osayi et al. [1] improved SMAW parameters on AISI 1020 mild steel using Taguchi. According to the report, welding current affects UTS the greatest, followed by speed, root gap, and electrode angle.

K. E. K. Vimal et al. [2] used neural network model and fuzzy-based gray relational analysis to optimize SMAW process parameters for sustainability. The report found that welding speed is unimportant, while voltage and current are important.

P.G. Ahire et al. [3] enhanced mild steel MMAW process parameters using genetic algorithms. This study found that genetic algorithms can optimize parameters.

Abhijit Saha et al. [4] adjusted MMAW multi-response parameters for nano-structured hard facing material deposited on 12 mm thick AISI 1018 low carbon steel plates and found that welding current affects bead hardness and reinforcing the most.

P. Deb et al. [5] used transmission electron microscopy to compare preheated and non-preheated SMAW welded HY-80 steel joints and found that preheated weldments are harder.

K. Bhaduri et al. [6] enhanced SMAW-welded 17-4PH stainless steel joint PWHT methods and heat input.

M S Ali et al. [7] used artificial neural networks to model how SMAW process parameters and preheating affect weld qualities.

J. O. Olawale et al. [8] examined SMAW parameters and post-weld heat treatment on low-carbon steel. They found that welding current increases hardness and UTS but decreases impact strength. Normalizing temperature enhances impact strength and decreases hardness and UTS.

P. K. Ghosh et al. [9] examined how pre and post weld heat treatment affected mechanical characteristics and microstructure of modified 9Cr-1Mo (V-Nb) steel pipe joints in SMAW and TIG welding. In both welding procedures, pre and post weld heat treatment considerably alter weld area and HAZ microstructures.

Munawar et al. [10] examined the mechanical characteristics of S45c steel with and without heat treatment after SMAW. The analysis found that heating material to 150°C, 250°C, and 300°C increases its strength and mechanical qualities.

A. Shukla et al. [11] used Response Surface Methodology to study how polarity, current, and electrode angle affect SMAW penetration depth. For optimum penetration, this research recommended direct current electrode negative polarity with electrode angle 90 and current of 120 A.

Weiwei Yu et al. [12] examined the fracture toughness of SMAW and GTAW weldments of Z3CN20.09M primary coolant pipes at base metal, weld metal, HAZs, and fusion zones. They found that SMAW welds had broader metal and more asymmetrical micro hardness than GTAW welds.

In SMAW, Jagesvar Verma et al. [13] examined mechanical behavior of duplex stainless steel 2025 and austenitic stainless steel 316L welds. Low heat input yields increased hardness and ultimate strength, according to the paper.

SMAW-welded AISI 1020 low carbon steel joints were tested for mechanical qualities by Abdullah Mohd Tahir et al. [14] using varied electrodes and current levels. The report confirmed that heat input decreases hardness and tensile strength.

Using scanning and optical electron microscopy in SMAW, Aman Gupta et al. [15] examined how heat input affects UNS S32750 super duplex stainless steel microstructure and corrosion. The report found that heat input little affects weld behavior.

G. Magudeeswaran et al. [16] examined how welding electrodes affect tensile and impact parameters of SMAW weldments of quenched and tempered AISI 4340 steel.

H. Vashishtha et al. [17] examined how filler electrodes affect SMAW-welded ULNASS joint microstructure and mechanical qualities.

G. Srinivasan et al. [18] examined how aging at three temperatures affected 316 stainless steel SMAW weldments' microstructure and impact toughness.

Reeves et al. [19] employed expert systems for weld process management and sensor fusion output with a rule base to balance cost, quality, and productivity for effective arc-on-time decisions. Their expert technique is ideal for shipyards. They found that an expert system can extract welder expertise for control when they grow scarcer. Same for process planning and inexperienced welder training.

Singh [20] and Goel et al. [21] proposed an expert system technique for shielded metal arc welding and examined process planners' SMAW planning challenges.

DuPont et al. [22] examined how welding factors and process type affect arc and melting efficiency.

3. RESEARCH METHODOLOGY:

Shielded Metal Arc Welding is a prevalent welding technique utilised in both industrial settings and small-scale workshops. Therefore, a primary purpose is to enhance the efficiency of the weld, namely its tensile strength. This mostly relies on the quantity of molten metal deposited during the welding process, which is indirectly influenced by factors such as current and electrode diameter. The Universal Testing Machine has been utilized to examine the strain and determine the tensile stress. The experimentally determined tensile strength is theoretically confirmed using simulation software, specifically ANSYS. Consequently, the primary objectives of the investigation are outlined below.

i. The variation in current corresponding to changes in diameter with different welded materials clearly indicates that weld efficiency can be enhanced in this study. Taguchi method have been employed specifically to optimize the results.

ii. Theoretical validation has been conducted using ANSYS software.

iii. The data obtained from experimentation and the simulation results from ANSYS are analyzed which are illustrated in Fig.4.4 to 4.9 below illustrating the trends in the graph.

3.1 Materials used:

The raw material used for the practical analysis of the weld structure is the commonly used mild steel that has properties similar to the specification of S275JR.Category: Low-carbon, unalloyed structural steel. It complies with the EN 10025-2 standard criteria. Application: Appropriate for various general engineering and structural uses, encompassing construction, maintenance, and manufacture. Form: Typically provided as hot-rolled plates. Welding: Recognized for its excellent weldability. Machinability: S275JR exhibits favorable machinability and exhibits commendable impact resistance. Heat Treatment: Although not optimally designed for hardening, it can undergo restricted heat treatment methods such as case hardening. JR mark: The "JR" mark signifies that the steel has been subjected to a longitudinal Charpy V-Notch impact test at 27 Joules at ambient temperature and having a minimum yield strength of 275 MPa. The chemical composition of the S275JR plate, as reported by MetalOre, comprises 0.25% carbon, 0.4% silicon, 1.5% manganese, 0.03% phosphorus, 0.03% sulfur, and 0.012% nickel. Mechanical qualities: S275JR, as a hot-rolled steel, demonstrates mechanical qualities including tensile strength and yield strength. S275JR plates are composed of mild steel and carbon steel and are utilized in structural construction, plant manufacturing, machinery fabrication, and mining operations.

Its Mechanical properties are as follows - Yield Strength 275 N/mm² Tensile Strength 370 - 530 N/mm² Shear Modulus 80 GPa Hardness Vickers 115 - 154 Vickers - HV Elongation (in 200mm) 20%

4. RESULTS AND DISCUSSION:

The sample as shown in Fig.1 are subjected with two separate testing as follows: a) Experimental analysis and b) Theoretical Analysis using ANSYS Simulation

4.1 EXPERIMENTAL ANLYSIS:

The experimental investigation involved the preparation of eight samples, which underwent tensile testing using UTM following post-welding, as detailed in Table 1 along with their corresponding parameters. The results are derived from the experimental analysis of tensile tests conducted post-welding with a 2.5mm electrode and then again using a 4 mm electrode on the work pieces, while the current ratings are maintained at controlled magnitudes of 240 Amps, 250 Amps, 260 Amps, and 270 Amps.
All the Work pieces are shown after performing tensile test using a 2.5mm electrode and currents of (a) 240 Amps, (b) 250 Amps, (c) 260 Amps and (d) 270 Amps and presented in Fig. 2(a),

2 (b), 2 (c) and 2 (d) as mentioned below and the respective parameters of Experimental Investigation are presented in Table 1. The Fig. 3(a), 3 (b),3 (c) and 3(d) represent work pieces after performing tensile test using a 4 mm electrode and currents of (a)240 Amps, (b)250 Amps, (c)260 Amps and (d)270 Amps respectively. The following table is made from the experimental investigation: -

Table 1. Experimental Investigation with sample size 8

Sample Number	C/S area (mm^2)	Electrode diameter (mm)	Current (amps)	Load at Yield (kN)	Yield Stress (MPa)	Tensile stress (MPa)	Weld Efficiency (%)
Original	161.905	-	-	53.48	332.07	430.5	-
1	194.495	2.5	240	23.78	122.288	154.891	35.97
2	179.895	2.5	**250**	28.64	159.204	205.12	**47.64**
3	177.356	2.5	260	22.18	125.059	159.904	37.14
4	186.12	2.5	270	23.24	124.87	189.34	43.98
5	190.271	4	240	22.66	119.093	149.471	34.72
6	173.925	4	250	18.36	105.563	133.736	31.06
7	169.138	4	**260**	23.92	141.423	188.248	**43.72**
8	181.119	4	270	23.7	130.85	142.227	33.03

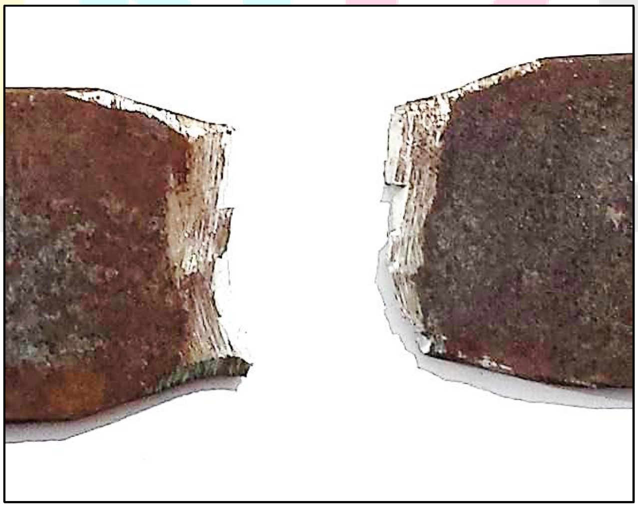


Fig. 1: *Original Test piece after tensile testing*

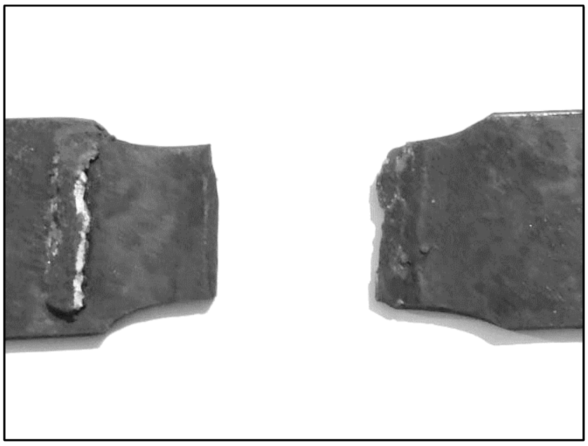
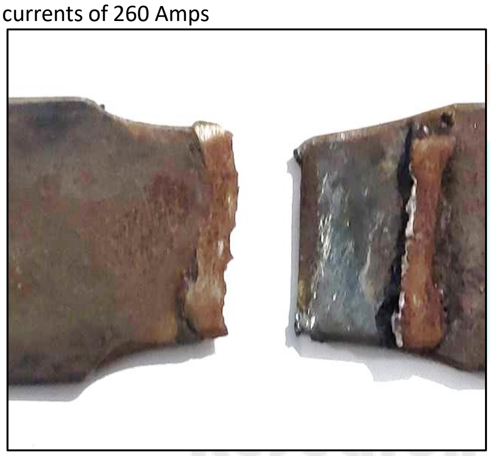


Fig 2(a). Sample- 1 post tensile test with 2.5m electrode, currents of 240 Amps

Fig 2 (b). Sample- 2 post tensile test with 2.5mm electrode currents of 250 Amps

Fig2(c) Sample -3 post tensile test with 2.5 - mm electrode, currents of 260 Amps

Fig2(d). Sample -4 post tensile test with 2.5- mm electrode 2.5mm electrode, currents of 270 Amps



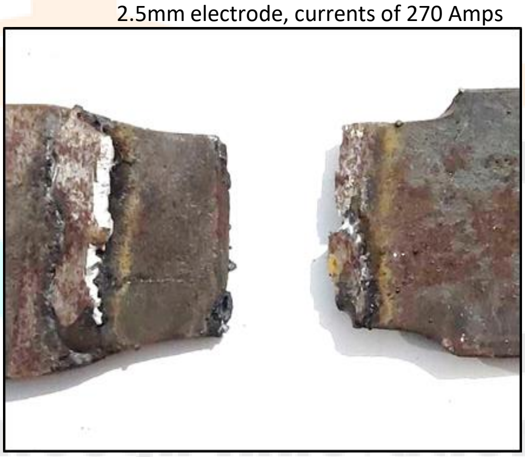


Fig3(a). Sample- 5 post tensile test with 4- mm electrode, currents of 240 Amps

Fig3(b). Sample- 6post tensile test with 4- mm electrode, currents of 250 Amps

Fig3(c). Sample- 7 post tensile test with 4- mm electrode, currents of 260 Amps

Fig 3(d). Sample- 8 post tensile test with 4 -mm electrode, currents of 260 Amps

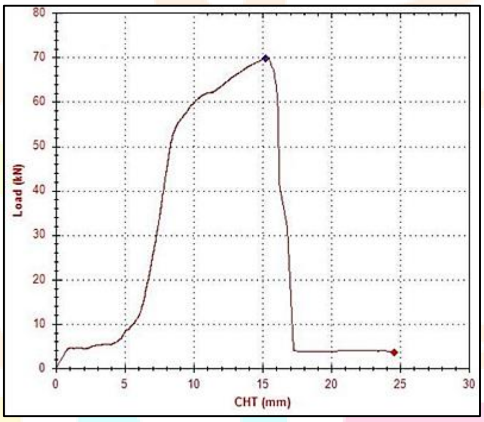


Fig. 4. Load vs cross head travel (CHT) as obtained from the UTM for the original work piece

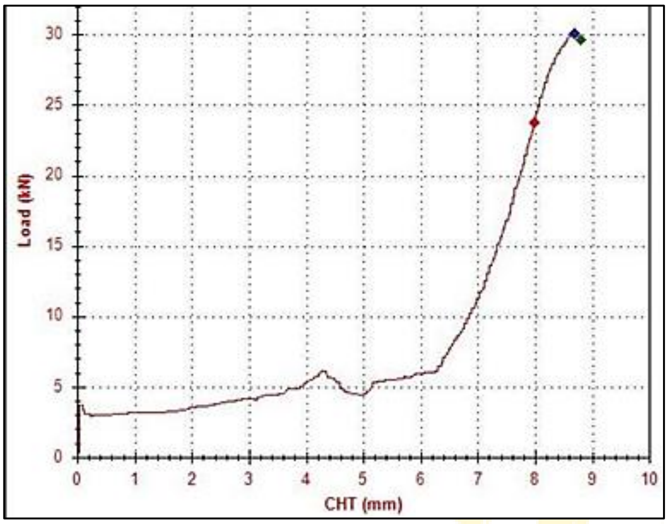


Fig 5(a). Load vs CHT varying currents of 240 amps with 2.5mm electrode

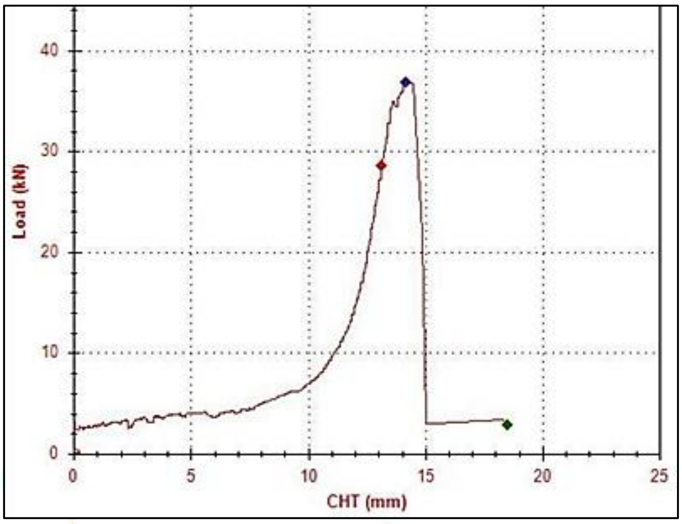


Fig 5(b). Load vs CHT varying currents of 250 amps with 2.5mm electrode

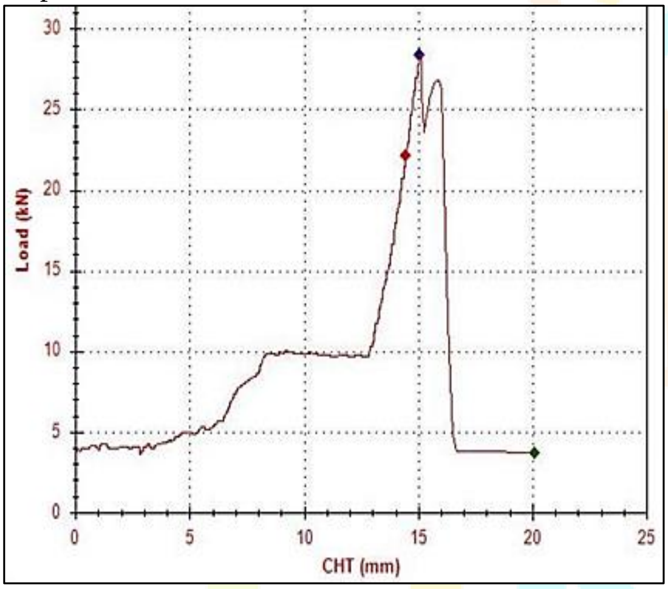


Fig 5(c). Load vs CHT varying currents of 260 amps with 2.5mm electrode

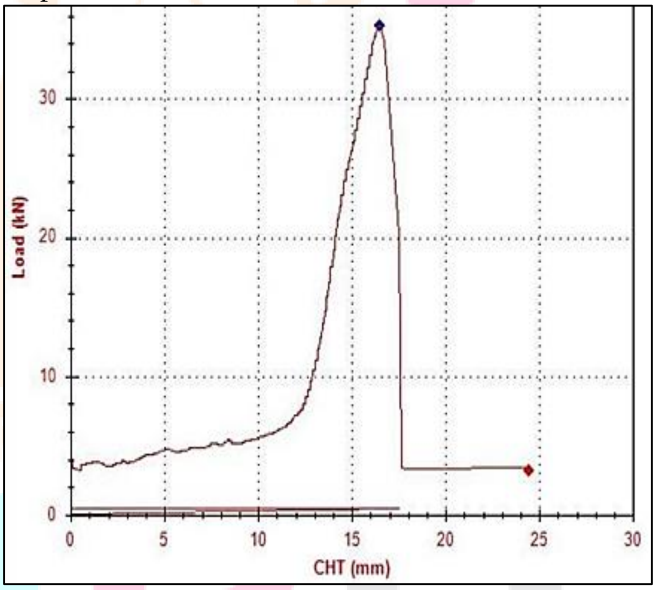


Fig 5(d). Load vs CHT varying currents of 270 amps with 2.5mm electrode

The Loads versus cross head travel / displacements (CHT) measured in Universal Testing Machine (UTM) are plotted and presented in the Fig. 4 above using the original work piece and the Fig 5(a), 5(b), 5(c), 5(d) represent the Load vs CHT with varying currents of 240,250,260 and 270 amps using 2.5mm electrode.

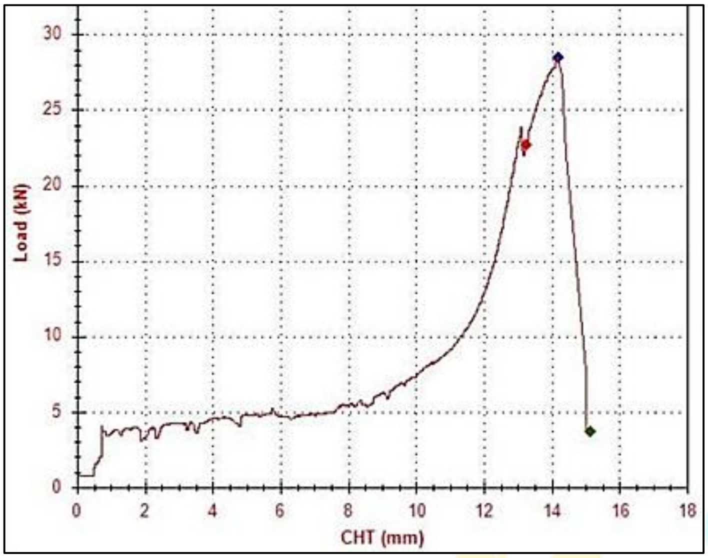


Fig 6(a). Load vs CHT varying currents of 240 amps with 4 mm electrode

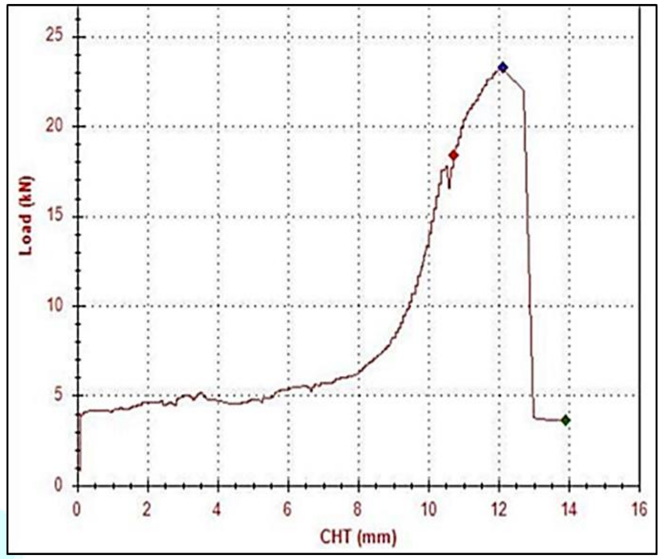


Fig 6(b). Load vs CHT varying currents of 250 amps with 4 mm electrode

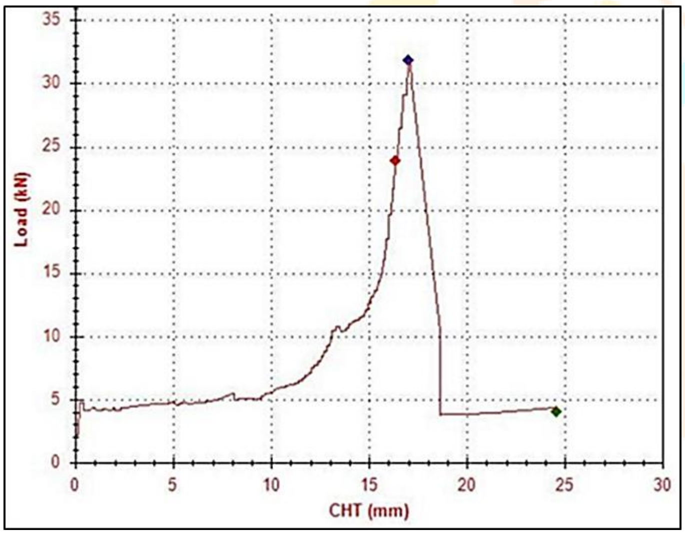


Fig 6(c). Load vs CHT varying currents of 260 amps with 4 mm electrode

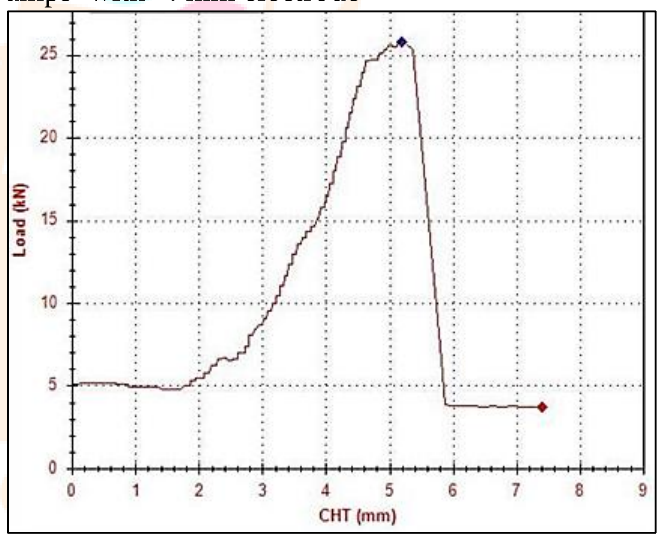


Fig 6(d). Load vs CHT varying currents of 270 amps with 4 mm electrode

The Loads versus cross head travel / displacements (CHT) measured in Universal Testing Machine (UTM) are plotted in the Fig 6(a), 6(b), 6(c), 6(d) which represent the Load vs CHT with varying currents of 240,250,260 and 270 amps and using 4 mm electrode.

The graph illustrates the relationship between load and displacement of mild steel during a mechanical tensile test. Initially, the material has elastic behavior, characterized by a progressive rise in load with movement, and reversible deformation. This is succeeded by a definitive yield point, where mild steel shifts from elastic to plastic deformation, signified by a marked alteration in the slope of the curve. Beyond the yield point, the material experiences strain hardening, resisting further deformation as the load increases sharply until it attains the ultimate tensile strength – the highest load the material can endure. Upon attaining this peak, the material undergoes necking and subsequently fractures, resulting in a precipitous decline in the load. Following the fracture, despite additional displacement, the load remains minimal, signifying total failure. The graph precisely illustrates the standard ductile behavior of mild steel, marked by a distinct yield point, significant strain hardening, and abrupt failure following ultimate strength.

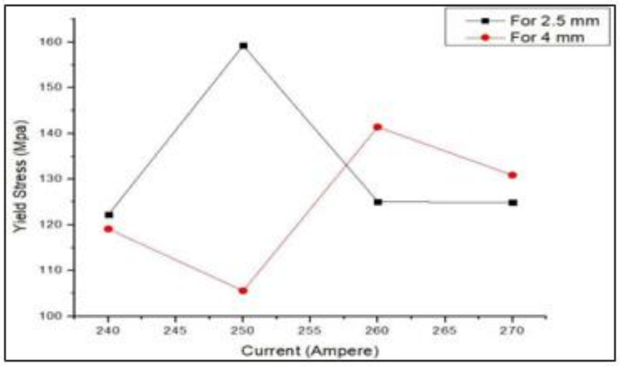


Fig 7(a). Plot between Yield Stress and Current

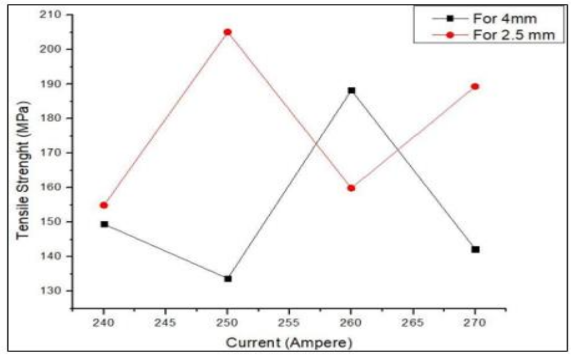


Fig 7(b). Tensile Strength vs Currents

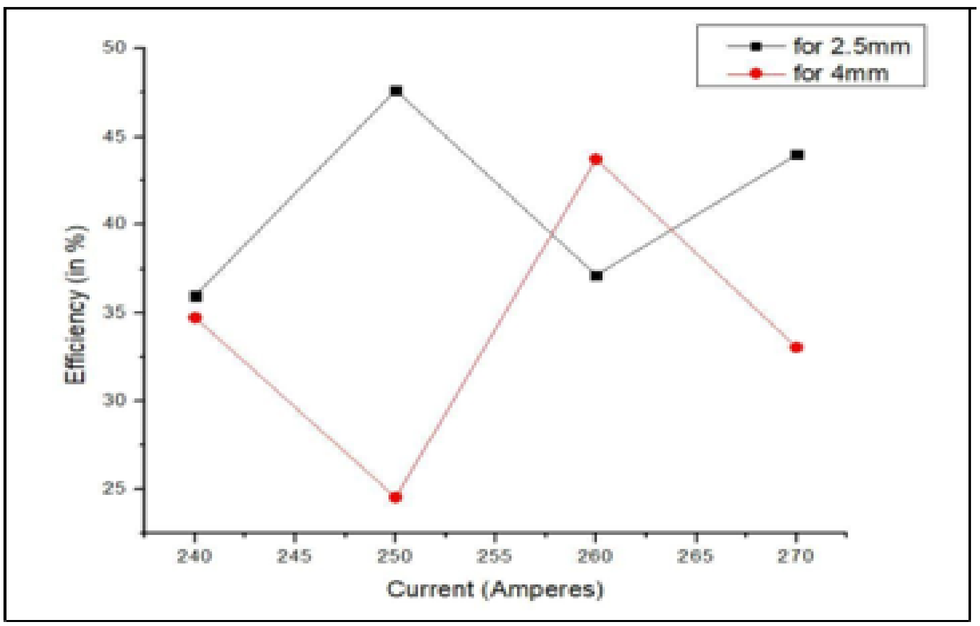


Fig.8. Efficiency vs Current Curve

The graphs in Fig. 7(a) and 7(b) illustrate the fluctuation of yield stress and tensile strength respectively in relation to welding current for two distinct material thicknesses, 2.5 mm and 4 mm, across a current spectrum of 240 to 270 amperes. For a thickness of 2.5 mm, the yield stress first rises with increasing current, peaking at around 250 amperes, before subsequently declining with further current increments. Conversely, at a thickness of 4 mm, the yield stress exhibits a rather stable trend with minimal variation, although a tiny peak is observed at approximately 260 amperes. The behavior indicates that optimal mechanical qualities are attained at particular current values, and exceeding these may result in a decline in yield strength, presumably due to overheating, grain coarsening, or inadequate fusing during welding.

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The experimental investigation of mild steel utilizing 2.5 mm and 4 mm electrodes within a current range of 240–270 A closely aligns with the previously described computational outcomes. The initial mild steel specimen demonstrated a yield stress of 332.07 MPa and a tensile strength of 430.5 MPa. The 2.5 mm electrode exhibited the maximum yield stress (159.20 MPa) and tensile strength (205.12 MPa) at 250 A, aligning with the simulation trend that indicated superior mechanical performance for 2.5 mm electrodes, culminating at approximately 250 A. The maximum weld efficiency for 2.5 mm electrodes was 47.64%, recorded at 250 A, consistent with the modelling graph indicating peak efficiency at this current. In contrast, the 4 mm electrode exhibited diminished and more variable characteristics. Despite the 4 mm electrode attaining its peak tensile strength (188.25 MPa) and efficiency (43.72%) at 260 A, it exhibited greater inconsistency and was inferior to the 2.5 mm electrode, as evidenced by both experimental and simulation outcomes. Both experimental and modelling results indicate that the 2.5 mm electrode, functioning at about 250 A, provides enhanced yield stress, tensile strength, and welding efficiency, rendering it the ideal selection for welding mild steel under the specified conditions. Similarly, the Theoretical research through simulation, assessed the mechanical performance and efficiency of mild steel welded with 2.5 mm and 4 mm electrodes within a current range of 240–270 Amperes. The results indicated that 2.5 mm electrodes consistently demonstrated superior yield stress, tensile strength, and efficiency compared to 4 mm electrodes at equivalent currents. The yield stress and tensile strength for 2.5 mm electrodes reached a maximum at 250 A and 255 A, respectively, but the 4 mm electrodes exhibited more variable behaviour. The efficiency investigation indicated that the 2.5 mm electrodes attained peak efficiency (~47%) at 250 A, whereas the 4 mm electrodes reached a maximum of approximately 43% at 260 A as depicted from the simulation graph in Fig. 8 above, albeit with increased instability. The 2.5 mm electrode demonstrates superior mechanical qualities and welding efficiency over the examined current range, rendering it a more appropriate option for applications requiring enhanced structural integrity and productivity. The Table 2 presents the comparison characteristics of weld with 2.5 mm and 4 mm diameter electrode.

Table 2. Characteristics of weld with 2.5 mm and 4 mm diameter electrode

Parameters	**2.5 mm Electrode Diameter**	**4 mm Electrode Diameter**
Yield Stress Behavior	Peaks around 250 A, then decreases sharply	Gradual increase, peaks near 260 A
Tensile Strength Behavior	Peaks around 250 A, sharp and early peak	Decreases first, then peaks near 270 A
Response to Current	More sensitive to changes	Less sensitive, smoother trend
Optimum Current Range	Around 250 A for best mechanical properties	Around 260–270 A for best properties
General Trend	Sharp rise and fall	Gradual changes, delayed peak

4.2 THEORETICAL ANALYSIS USING ANSYS SIMULATION:

The analytical procedure in ANSYS involves selecting explicit dynamics for the specimen evaluation. The material is delineated in the material properties, which encompass the specifics of its physical characteristics. A CAD model analogous to the specimen is created using the Space- Claim workbench of ANSYS. The mesh is created with the body sizing option, resulting in a size of 5mm. The multi-zone body is chosen to implement the entire mesh.The Simulation based results has been prepared on the basis of Results obtained from Simulation and presented in Table 3 below.

Table 3. Results from Simulation (ANSYS)

Sample No.	**Electrode dia (mm)**	**Current Input (Amps)**	**C/S Area (mm^2)**	**Range of Equivalent Stress at weld(MPa)**	**Average equivalent Stress (MPa)**	**Theoretical Weld efficiency (%)**
Original	-	-	161.905	407*	-	-
1	2.5	240	194.495	132.11-190.78	161.44	39.67
2	2.5	250	179.895	158.93-198.66	178.79	43.93
3	2.5	260	177.356	129.61-162.01	145.81	35.82
4	2.5	270	186.12	129.25-193.86	161.55	39.69
5	4	240	190.271	125.14-187.70	156.42	38.43
6	4	250	173.925	141.41-185.58	163.49	40.17
7	4	260	169.138	180.69-262.08	221.38	54.39
8	4	270	181.119	151.12-223.69	187.40	46.04

***maximum stress obtained in the original work piece weld efficiency**

The Theoretical Efficiency in percentage of the weld can be found out as,

$$\eta_{weld} = \frac{\text{Average Equivalent stress}}{\text{Maximum stress of the original workpiece}(=407)} \times 100 \quad (1)$$

5. CONCLUSION AND FUTURE SCOPE:

This research successfully achieved optimum outcomes using ANSYS for mild steel in the Shielded Metal Arc Welding process, a manual arc welding technique. ANSYS has been employed for theoretical validation. The software outcomes and experimental findings exhibit analogous characteristics in their respective graphs and charts. The parameters for mild steel considered were the diameter of electrode and current applied, and the observed differences are analogous.

Consequently, the results of the comparison analysis have been corroborated, and the objectives have been fulfilled. The experimental research and ANSYS values were analogous, and their graphs demonstrated consistency across all variables. Comparing the data received from the ANSYS simulation results, which show that the experimental and simulation results are almost identical to one another, as shown by a number of graphs that compare the two sets of data, reveals that the characteristics of the two sets of data are almost identical. In conclusion, it has been established that the experimental and theoretical data that were included in this study have been validated to a significant degree within the scope of the study's stated purpose.

5.1 Future Research Scope: Future research may encompass a more extensive examination of various welding currents beyond the 240–270 A range, as well as the use of diverse electrode types and sizes. The impact of welding speed, electrode angle, and environmental factors (such as humidity and shielding gases) on weld quality warrants more investigation. Moreover, comprehensive microstructural examination utilizing techniques such as SEM and hardness profiling may provide enhanced understanding of the relationship between welding settings and mechanical properties. Evaluating the fatigue life and corrosion resistance of welded joints would be beneficial for broadening the use of mild steel in increasingly challenging situations.

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