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"Optimization of Welding Parameters for Minimizing Defects and Porosity in Electric Arc Welding of Mild Steel Grade Fe 500 Using of Taguchi Method"

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Abstract: Electric arc welding is a widely used technique in industrial applications for joining metals, including mild steel grade Fe 500. However, the process is susceptible to defects such as porosity, which can compromise the integrity and quality of welds. In this study, we investigate the optimization of welding parameters to minimize defects and porosity in electric arc welding of mild steel grade Fe 500, utilizing the Taguchi method.
The Taguchi method, known for its efficiency in optimization studies, is employed to systematically identify the most influential welding parameters and their optimal levels. Through a series of experiments based on the Taguchi orthogonal array design, we vary parameters such as current amperage, voltage, and electrode size to explore their effects on weld quality.
The experimental results reveal significant insights into the relationship between welding parameters and defect formation. By analyzing signal-to-noise ratios and ultimate tensile strength, we quantify the effects of parameter variations on weld quality. The Taguchi analysis enables us to identify the optimal combination of welding parameters that minimizes defects and porosity while maximizing weld strength.
Our findings demonstrate the effectiveness of the Taguchi method in optimizing welding processes for improved quality and reliability. The optimized parameters offer practical guidelines for welders and engineers to enhance the performance and durability of electric arc welds in mild steel grade Fe 500 applications.
In conclusion, this study contributes to the advancement of welding technology by providing a systematic approach to optimizing welding parameters for defect reduction in electric arc welding of mild steel grade Fe 500. The insights gained from this research can inform future studies and industrial practices aimed at achieving higher weld quality and productivity.
Keywords: Welding defects, Parameter optimization, Robust design, Taguchi orthogonal arrays, Response surface methodology, Welding process control, Welding technology

I. INTRODUCTION

Welding is the process of joining materials, typically metals or thermoplastics, together by causing fusion. This is usually done by melting the workpieces and adding a filler material to form a pool of molten material that cools to become a strong joint. Welding is widely used in manufacturing, construction, and various other industries due to its ability to create strong and permanent connections between materials. There are several different welding techniques, including arc welding, gas welding, and resistance welding, each with its own advantages and applications.

A. History of Electric Arc (EAW) Welding

The concept of joining materials through welding has been known for thousands of years, with forge welding being a notable historical method. Modern welding techniques emerged in the late 19th century with the development of welding currents capable of generating arcs. Initial welding experiments utilized electrodes, with advancements like coated electrodes patented by Oskar Kjellberg enhancing the process [2-3]. Significant developments in welding techniques occurred over time, including the introduction of gas metal arc welding (GMAW) and manual metal arc welding (MMAW). These innovations paved the way for various welding methods such as submerged arc welding (SAW) and tungsten inert gas (TIG) welding, which found applications during World War II [5].

The history of electric arc welding (EAW) dates back to the late 19th century, with significant advancements made over the following decades. Here's a brief overview:

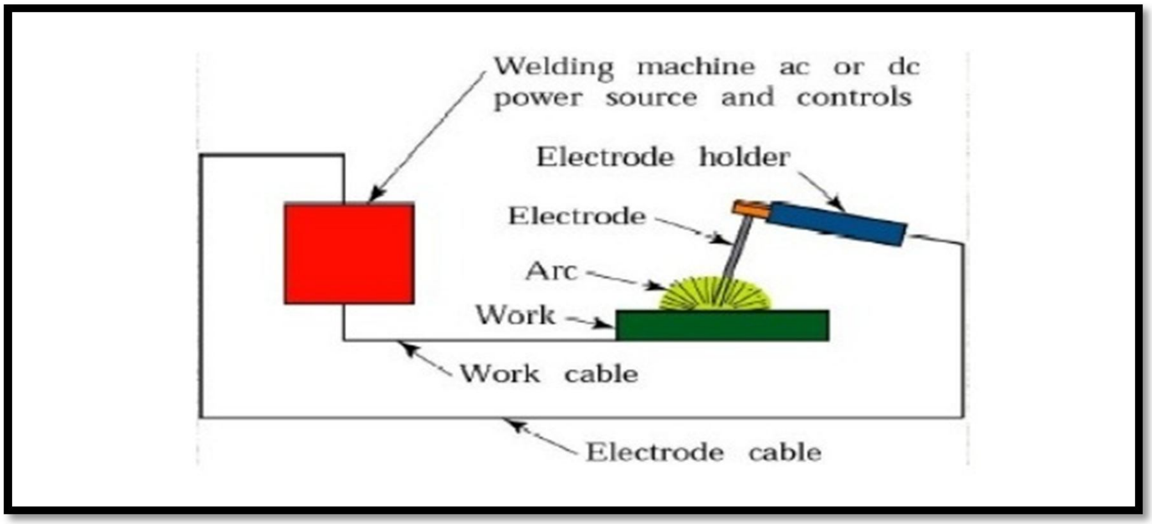

Figure 1. Principle of Arc welding

The foundation for arc welding was laid in the early 1800s with the discovery of the electric arc. Sir Humphry Davy is credited with discovering the electric arc in 1800 while experimenting with electric current passing between two carbon electrodes. However, it was not until the late 19th century that this discovery was applied to welding. In the 1880s, Nikolay Bernard's, a Russian inventor, and Stanislaw Olszewski, a Polish scientist, independently developed the first practical arc welding methods. They utilized a carbon arc to weld metals together. This process, known as carbon arc welding, was initially used for welding lead plates in storage batteries and later for welding rail tracks. American engineer Charles Coffin made significant contributions to the development of arc welding in the late 19th and early 20th centuries. In 1889, he patented the first true arc welding method using a metal electrode. Coffin's method involved feeding a metal electrode into the arc, creating a molten pool that fused the workpieces together. This laid the groundwork for modern arc welding techniques. During the early 20th century, advancements in electrical technology, particularly the widespread adoption of alternating current (AC), led to further improvements in arc welding. AC arc welding allowed for better control of the welding process and expanded its applications. SMAW, also known as manual metal arc welding or stick welding, became popular in the early 20th century. This technique, patented by Oscar Kjellberg in 1907, involved using a coated electrode to generate an arc and protect the weld pool from atmospheric contamination. Throughout the 20th century, arc welding techniques continued to evolve and find applications in various industries, including shipbuilding, automotive manufacturing, construction, and aerospace. Advancements such as gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and flux-cored arc welding (FCAW) further expanded the capabilities of arc welding.

Today, electric arc welding is one of the most widely used welding processes globally, playing a vital role in manufacturing, construction, and infrastructure development. Its history reflects a continuous process of innovation and refinement driven by the quest for stronger, more efficient, and versatile welding techniques.

B. Working of Electric Arc Welding

Electric arc welding (EAW) holds significant importance in various industries due to its ability to create strong and permanent bonds between metals. It is extensively used in construction, automotive, aerospace, shipbuilding, and manufacturing sectors for fabricating structures, assembling components, and repairing metal parts.

The working principle of EAW involves creating an electrical arc between a consumable or non-consumable electrode and the workpiece. This arc generates intense heat, melting the base metals and forming a molten weld pool. As the weld pool cools and solidifies, it creates a strong and durable joint between the materials. EAW offers several advantages, including high welding speeds, versatility in joining different metals, and the ability to perform welds in various positions. Additionally, it enables precise control over welding parameters, ensuring consistent and reliable results. Overall, EAW plays a crucial role in modern manufacturing processes, contributing to the fabrication of structures and products essential for numerous industries.

C. Welded Joint

A welded joint is a connection between two or more pieces of metal that have been joined together using welding techniques. Welded joints are essential in various industries, including manufacturing, construction, automotive, aerospace, and shipbuilding, as they provide strong and durable connections between metal components.

The quality and strength of a welded joint depend on several factors, including the welding process used, the type of welding electrodes or filler material, the welding parameters (such as heat input and travel speed), and the skill of the welder.

Common types of welded joints include:

1) Butt Joint
2) Lap Joint
3) T-Joint
4) Corner Joint
5) Fillet Joint

D. Process Parameters

Welding parameters are the settings and conditions that control the welding process and affect the quality and characteristics of the weld. These parameters vary depending on the welding process used but typically include:

1) *Voltage:* The electrical potential difference between the welding electrode and the workpiece, which determines the heat input into the weld.
2) *Current:* The flow of electrical charge through the welding circuit, which generates the arc and provides the heat necessary for melting the base metals and filler material.
3) *Welding Speed:* The rate at which the welding torch or electrode moves along the weld joint, affecting the size and penetration depth of the weld bead.
4) *Arc Length:* The distance between the welding electrode and the workpiece, which influences the stability and characteristics of the welding arc.
5) *Electrode Size:* The diameter of the welding electrode or filler wire used, which determines the amount of filler material deposited and the size of the weld bead.

II. LITERATURE REVIEW

1) Investigate the effect of process parameters on welding properties.
2) Explore the impact of vapour gases on the mechanical properties of mild steel.
3) Study different optimization techniques, such as the Taguchi Method.
4) Examine the effects on microstructures resulting from welding.
5) Analyses welding parameters across different welding positions.
6) Identify novel interpretations of prior research findings.
7) Highlight gaps in existing literature.
8) Identify areas of prior scholarship to avoid duplicative efforts.
9) Situate the research within the context of existing literature.

Sufian Raja a,b, Farazila Yuso et. Al. [1] The adaptability of Additive Manufacturing (AM) technologies in metal 3D printing has garnered substantial attention in both research and industry, enabling the fabrication of intricate Near-NetShape (NNS) geometry designs. Achieving desired characteristics in Wire-Arc Additive Manufactured (WAAM) components relies heavily on meticulously selecting and precisely controlling significant processing variables, including bead deposition strategy, wire materials, heat source type, wire feed speed, and shielding gas application. Optimizing these critical process parameters has led to enhanced WAAM-manufactured component quality, bolstering the method's popularity and applications. This article provides an overview of wire deposition strategy and the optimization of process parameters in WAAM, summarizing the optimization of various wire deposition techniques and process parameters necessary for high-quality additively manufactured metal parts. It proposes a WAAM optimization algorithm to anticipate technological advancements and discusses the potential for WAAM optimization in the rapidly expanding field of WAAM. Finally, conclusions are drawn from the reviewed research.

Fasil Kebede Tesfaye et.al. [2] Metal Industry and Machine Technology Development Enterprise, Ethiopia's foremost manufacturing industry, produces a diverse range of industrial machinery and products. While MIG welding is the primary welding process used, it exhibits flaws such as low weld-metal toughness, spatter formation, undercutting, and inadequate tensile strength and toughness. TIG welding, employed for its precision and reduced smoke and fumes, suffers from slower production rates. Hence, a hybrid TIG-MIG welding approach is proposed to combine the benefits of both processes. This paper presents the optimization of process parameters for TIG-MIG hybrid welding of EN24 mild steel. Tests conducted on a 6mm EN24 mild steel plate with a butt joint configuration utilized parameters such as MIG welding current, MIG welding voltage, TIG welding current, TIG welding voltage, and welding gun travel speed. Optimization was achieved using a single-level L27 orthogonal array. Mechanical properties evaluation involved tensile and hardness tests, with optimal parameter settings determined through mean effect plot analysis. ANOVA identified significant factors, with MIG welding current and voltage contributing significantly. Confirmation tests verified experiment reliability, with the TIG-MIG hybrid welding process demonstrating superior hardness and tensile strength compared to MIG and TIG welding alone. These findings suggest the adoption of the hybrid welding method to enhance weld joint properties.

Muhammad Saad Afzal et.al. [3] The quality of a weld is heavily influenced by the mechanical characteristics of the joint, the welding process, and its input parameters. Inadequate parameter values can result in welding defects and distortion, negatively impacting mechanical properties. Hence, selecting appropriate parameters at optimal levels is crucial to minimize defects, boost productivity, and achieve desired mechanical attributes in shielded metal arc welding (SMAW). This study focuses on optimizing SMAW parameters for ASTM A572 Grade 50 steel joints, crucial in heavy machinery applications. Using Taguchi L16 array, parameters were varied across four levels. Grey relational and principal component analysis facilitated optimization. Results indicate the significant impact of groove angle on tensile strength, electrode diameter on impact toughness, and welding current on hardness and angular distortion. Optimal parameters include a welding current of 160 A, a groove angle of 60°, an electrode diameter of 3.25 mm, a 3 mm root gap, and a 3 mm root face. Implementing these parameters led to notable improvements: a 10.53% increase in tensile strength, a 14.28% enhancement in impact toughness, an 8.55% reduction in hardness, and a significant 33.33% decrease in angular distortion.

Pushp Kumar Baghel et.al. [4] Shielded metal arc welding (SMAW) is an economical, portable, and robust welding process that utilizes a power source, electrode holder, and electrode to join metals. Traditionally used for ferrous metals, its application has expanded to include non-ferrous metals due to advancements in material science. SMAW has been successfully applied to weld ferrous and non-ferrous metals, such as oxygen-rich copper with chromium and nickel-rich stainless steel 304. Stainless steel's corrosion resistance, resilience, and toughness make it suitable for automotive, household, and aerospace applications, while copper finds use in engineering structures, electrical components, and power plants due to its unique properties. This review aims to assess research conducted by various scholars on arc welding of similar and dissimilar metals, explore the feasibility of SMAW for welding copper to stainless steel 304, evaluate the economic and sustainability aspects of SMAW as a green technology, and identify suitable electrodes for welding.

P.G. ahire, US patil et.al. [5] Optimizing process parameters is crucial for achieving better quality welds in dissimilar metal welding, as they significantly impact weld strength. Dissimilar metal joints are widely used in industries such as boilers, economizers, and pressure vessels. This research paper investigates the influence of process parameters on manual metal arc welded joints regarding weld strength and weld deposition rate. The independently controllable parameters include welding current (I), welding speed, root gap, and electrode angle (A). Experimental runs are determined using the Response Surface Method. A Genetic Algorithm (GA)-based technique is developed successfully to model, simulate, and optimize welding process parameters to maximize weld strength and minimize weld deposition rate. This approach aims to enhance the quality and efficiency of dissimilar metal welding processes, benefiting various industrial applications.

Davi Sampaio Correia et.al. [6] This paper introduces a methodology for comparing two welding processes, Submerged Arc Welding (SAW) and Gas Metal Arc Welding (GMAW), to determine the optimal choice for a specific application. The selection process considers two criteria: operational costs and non-quality costs. Operational costs encompass typical expenses such as consumable and labour costs. Non-quality costs represent the financial losses incurred when response variables deviate from target values or exhibit variability. Minimizing non-quality costs entails adjusting process variables to minimize deviations from targets and enhance robustness to noise and process fluctuations. Given the multi-response, multi-objective nature of the problem, the optimal solution requires compromise. Both welding processes were optimized before comparison. Results indicated that while non-quality costs were slightly higher for the SAW process, they were offset by its lower operational costs. Consequently, SAW was determined to have the lowest total cost and was deemed the most suitable process for the given application.

A. Taguchi Method

The Taguchi method is a statistically developed method for improving input parameters in research and manufacturing quality. It involves system design, parameter design, and tolerance design to achieve better product quality at minimum cost. Developed by Dr. Taguchi, this method focuses on optimizing control variables to obtain optimal output results, typically measured using Signal-to-Noise Ratio or loss function value. The Taguchi philosophy emphasizes designing quality into products and processes, reducing variations, and optimizing product value.

B. Taguchi Techniques

Taguchi techniques involve using Signal-to-Noise Ratio and orthogonal array experiments to reduce variance and determine optimal control parameter settings. These techniques include identifying important process variables, developing a process analysis plan, conducting experiments, recording responses, testing materials, optimizing parameter values, and presenting the significant effects of process parameters.

C. Orthogonal Arrays

It seems like you're describing an experimental setup involving a three-level process parameter with nine experimental runs (L9) to optimize welding parameters. The parameters include welding current, arc voltage, diameter rod, and the cut of joint angle, with a single cutting joint in 15 degrees.

Additionally, you're mentioning the use of fixed process parameters based on prior research, experiments, or handbook recommendations. The effects of these parameters are then analysed using ANOVA (Analysis of Variance), likely to determine their significance on the outcome, which is measured by the ultimate tensile strength test.

Table No. 1: Orthogonal Arrays

NUMBER	FACTORS		
	Arc Voltage	Welding current	Electrode size
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Orthogonal arrays are likely used to minimize the number of experimental runs required while still capturing the main effects and interactions between parameters efficiently. The total degree of freedom and calculated orthogonal arrays help ensure a balanced and systematic approach to the experiment, aiding in the accurate analysis of results.

If you have specific questions or need further assistance with analysing the experimental data or interpreting the results, feel free to ask!

D. Signal-to-Noise Ratio

The Signal-to-Noise Ratio (S/N Ratio) is proposed by Taguchi to evaluate the quality of experimental outcomes. It involves different formulas for "larger the better," "smaller the better," and "nominal is best" characteristics, aiming to minimize deviations from target values.

Certainly! Here's an explanation of the three types of S/N ratios and their respective formulas:

1) *Larger the Better (LTB):* This type of S/N ratio is used when a larger value of the response variable indicates a better outcome. For example, in a battery life experiment, where longer battery life is desirable, the LTB S/N ratio formula is:

$$Xi = -10\log[1/X\sum_{k=0}^{X}\frac{1}{\mathrm{Yi}^2}]$$

Where:

- X = Number of trials or measurements
- Yi = Measurement value of the I th run

2) *Smaller the Better:* This type of S/N ratio is used when a smaller value of the response variable indicates a better outcome. For example, in situations like computer response time or automotive emissions, where lower values are preferable, the S/N ratio formula is:

Xm=]$-10log[1/X \sum_{k=0}^{X}$ yi²

Where:

- yi = Measurement value of the ith run

3) *Nominal is Best:* This type of S/N ratio is used when the ideal value of the response variable is known, and the goal is to minimize deviations from this ideal value. The formula for Nominal is Best S/N ratio is:

==10log (S^2/Y^{-2})

Where:

- Y^{-} = Mean of measured values
- S = Standard deviation

E. Experimental Procedure

The welding method used in the experiment was conventional Electric Arc Welding (EAW). The joint type employed was a double V-groove butt joint, with one pass on each side. Arc voltage ranged from 24,26,28 volts, welding current varied from 90,110 to 130 amps, electrode size ranged from 2 to 4 mm, and groove angles varied from 20 ^{o} to 60^o. The welding materials utilized were MS-Fe-500 low carbon steel, and the welding direction was along the width of the workpiece

F. Filler Material

The filler material employed in the experiment is a 4 mm (4.5 mm) double deoxidized electrode, featuring a coating of Copper-Coated Mn-Si. This filler material plays a crucial role in facilitating effective welding while preserving the integrity of the welded joints.

Table no.2: Filler material.

MATERIAL	C%	Si%	Mn%	P%	S%	Cu%
LOW CARBON STEEL	0.090	0.070	1.65	0.025	0.025	0.050

III. CHEMICAL COMPOSITION

Table No.3: Chemical Composition grade-Fe-415.

Element grade-Fe-415	C%	Si%	Mn%	P%	S%
Weight (%)	0.16	0.12	0.56	0.035	0.050

A. Joint Welded for Double Buttering

In some applications, mild steel weld metal is connected to filler material, often referred to as "buttering" or Double V-groove shaped butt joint. The utilization of two narrower V-joints in comparison to a wider single V-joint necessitates less filler metal. Welding is accomplished through a single-pass bead-on technique.

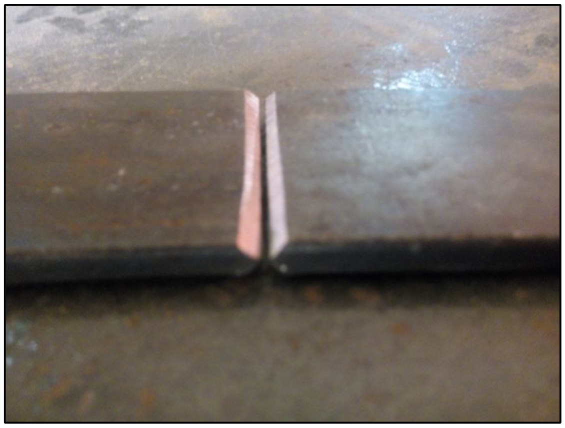

Figure 2: Prepared double V- groove shape joint for butt welding

B. Sample Preparation

The experimental samples consist of low carbon steel rods with dimensions of 300mmx200mmx50mm. These specimens are fabricated with butt joints having double V-groove shapes, with groove angles varying from 20˚ to 60 and a root face gap of 2 mm. Welding two bars along the width forms the butt joint, and some welded rods are machined to obtain the required shape for conducting tensile tests.

Figure 3: Tensile Test specimen

C. Selected Parameter and Their Levels

The parameters selected for the experiment are based on previous research and availability. Four machine input parameters with three levels each are considered, as tabulated in Table 4.4.

1) Input Parameters

Table 4 Considered Parameters	
1	Current (A)
2	Voltage (Volt.)
3	Electrode size (mm)

2) Response Parameters

1	Ultimate Tensile Strength (mpa) N/mm²
2	Bending strength (KN)

D. Level of Parameters

The level of the parameter was chosen based on a thorough review of past research studies, and the available range for each parameter was set to TP-400. In the current study, four machine input parameters are considered, each with three levels. These parameters are tabulated in Table 5.

Table 5: Input parameter level and values

Parameter	Unit	Notation	Level 1	Level 2	Level 3
Current	Ampere	A	90	110	130
Voltage	Volt.	V	24	26	28
Electrode size	mm	mm	2.5	3.15	4

E. Research Objective

The objectives of this research are as follows:

1) Evaluate process parameters of electric arc welding for welding similar metals, focusing on mild steel grade Fe-500 of low carbon steel.
2) Analyses the impact of process parameters, such as arc voltage and welding current, on universal tensile strength (UTS) and Bending Strength.
3) Determine the optimum arc voltage, welding current, and electrode size using the Taguchi Method.

IV. EXPERIMENTAL SETUP FOR MEASURING TENSILE STRENGTH

A. Experimental Setup for Measuring Universal Tensile Strength

A comprehensive experimental investigation of Universal Tensile Strength was carried out using the 'FIE' electronic universal testing Machine (UTM), model UTS-100, designed by Fuel Instrument & Engineers Pvt. Ltd. This UTM is specifically designed to test materials under various loads such as tension, compression, bending, transverse, and shear. It has a wide measuring range of 0 to 1000 KN with an accuracy of ±1.0% kN. The machine comprises three major parts: the machine frame or loading unit, hydraulic system unit, and electronic control panel.

B. Machine Frame or Loading Unit

The machine frame includes two crossheads and a lower table, with adjustable canter cross head gears. Compression tests are conducted between the test canter and the lower table, while tension tests are conducted between the centre table and the upper crosshead. Load measurement is done precisely through a tension gauge type transducer.

Figure 4: Machine

C. Hydraulic System Unit

The hydraulic system unit consists of a motor pump unit with a cylinder and piston. Safety valves are provided for additional safety measures.

Figure 5: Hydraulic system control

D. Response Parameters

On the basis of previous research works, author found that important quality characteristics of weldment are bead height, bead penetration, bead width, tensile strength, bending strength etc. So out of this we have considered the three response (tensile strength, bending strength) parameters. Tensile strength determine the tensile nature of welded joint. Bending strength indicate the ductility and soundness of the weld joint. This test of weld are performed to find the resistance of the weld joint while compare to the base metal. If hardness value be too high it could shows that unwanted alteration of the microstructure which makes the weld too brittle and hence unsuitable for application. After experiment result of output parameters are tabulated in table 6

Table 6: Result of Response parameters after experiment

S.No.	Ultimate Tensile Strength (MPa)	Bending Strength (KN)
1	452	5.632
2	375	4.161
3	379	5.744
4	334	5.355
5	323	5.731
6	356	5.693
7	388	4.592
8	413	4.242
9	428	5.231

Figure 7: work specimens after testing (a) Tensile test, (b) Bending test

V. RESULT DISCUSSION AND DATA ANALYSIS

A. Data Analysis and Optimization

The values of the respective responses obtained from the experimental runs are presented in Table 6.1. The estimation of quality loss for these responses is calculated using equation (8) and displayed in Table 6.2. Since all the responses indicate higher quality, the "higher the better" criterion is applied.

Table: 7: Tensile Test results

	L_9 OA			Response parameters	
S.No.				Ultimate Tensile Strength (MPa)	Bending Strength (KN)
1	1	1	1	452	5.632
2	1	2	2	375	4.161
3	1	3	3	379	5.744
4	2	1	2	334	5.355
5	2	2	3	323	5.731
6	2	3	1	356	5.693
7	3	1	3	388	4.592
8	3	2	1	413	4.242
9	3	3	2	428	5.231

B. S-N Ratio- Tensile Strength

The discussion canters on SN Ratio-Tensile Strength and Bending Strength. S/N ratios and Mean 1-Tensile Strength are provided in Table 8.

Experiment no.	Current Ampere	Voltage Volt.	Electrode size mm	S/N RATIO	UTS
1	90	24	2.5	53.102	452
2	110	26	3.15	54.480	375
3	130	28	4	51.572	379
4	90	24	2.5	50.474	334
5	110	26	3.15	50.184	323
6	130	28	4	51.029	356
7	90	24	2.5	51.776	388
8	110	26	3.15	52.319	413
9	130	28	4	52.628	428

Table No.8 Signal to Noise Ratio - Bending Strength

Experiment no.	Current Ampere	Voltage Volt.	Electrode size mm	S/N RATIO	Bending Strength (KN)
1	90	24	2.5	15.0132	5.632
2	110	26	3.15	12.3839	4.161
3	130	28	4	15.1842	5.744
4	90	24	2.5	14.5751	5.355
5	110	26	3.15	15.1646	5.731
6	130	28	4	15.1068	5.693
7	90	24	2.5	13.2400	4.592
8	110	26	3.15	12.5514	4.242
9	130	28	4	13.1238	5.231

C. Main Effects Plot for S/N Ratio-Tensile Strength and Bending Strength

The analysis ultimate tensile value or Bending Strength. Voltage, and special test electrode siz of best signal to Noise Ratio (larger the better) value of means SN ratio in this table no. 6.3.

Table no. 9: Response for main effect (larger is better value)

Level	Welding current	Arc voltage	Electrode size
1	53.20	54.84	50.47
2	54.32	51.78	51.76
3	52.63	52.32	54.13
DELTA	1.13	0.75	0.73
RANK	1	2	3

This table no.9 shows that response table for SN ratio, to larger a better value. In this case, seen that ultimate tensile strength largely strength force by testing in rod diameter than by the max voltage value to perform the electrode and heat-affected zone size (11-13). The same result can be the main effect for SN ratio, analysis recommended special test bar size by electrode this graph are present the SN ratio, rod diameter, voltage and size of an electrode in testing material.

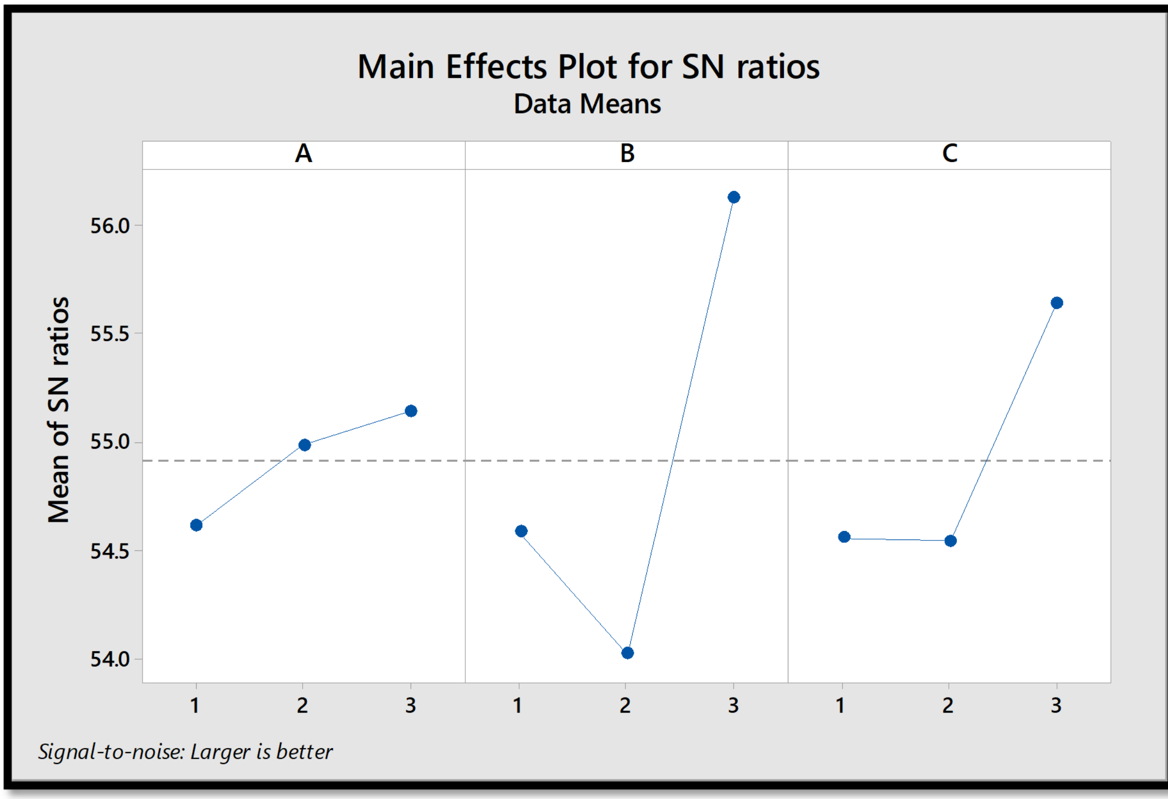

Fig. no .8: Signal to noise (larger the better).

D. Analysis of Variance (ANOVA)

Analysis of variance was present and developed by MR. RONALD FISHER. The purpose of analysis ANOVA techniques investigates design error finding parameter significantly affect welding quality characteristic total analysis error value find out MINITAB -19 SOFTWARE used.

The investigation ARC welding process parameter as a significant affect value the ultimate tensile strength in the analysis of variance out for the 95% confidence level, show that the F value is corresponding parameter value greater than (f >.05) the P-value(14-15). The main purpose ANOVA investigated in designing parameter on optimizing finishing welding quality characteristics and welded joint strength of the maximum value of test result.

Table no.10: Analysis of variance.

Source	DOF	ADJ SS	ADJ MS	P – Value	F- Value
Current	2	0.26172	1.3086	0.132	1.308
Voltage	2	0.03667	1.05925	0.224	1.059
Electrode size	2	0.16204	0.08102	0.261	1.24
Error	2	0.4237	2.449		
Total	8	0.88412			

In this table are verify, the sums of the square for the transformed data are SSA = 0.32715, SSB= 0.17829 and SSC =0.42170. These sum of square appear to differ considerably from those obtained is divided by the result are identical. For treatment sum of squares 110887/4 = 0.27721. Also for the coded data, the F ratio is F = (2.40, 2.55, 1.33/3) = 2.0933 in minimum F ratio value (F<0.006) or (F<2.09) is final value to compression which is identical to F ratio for the original data. Thus the ANOVA result.

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E. Response Table for Means

Level	A	B	C
1	13.06	12.43	12.80
2	14.26	12.50	15.13
3	12.53	13.24	14.10
Delta	1.53	0.40	2.03
Rank	2	3	1

Table no.11: Analysis of variance.

Source	DOF	ADJ SS	ADJ MS	P – Value	F- Value
Current	2	2.1686	1.0843	0.421	1.084
Voltage	2	1.8422	0.9211	0.567	2.720
Electrode size	2	6.8721	3.436	0.723	0.3986
Error	2	10.8801	5.44		
Total	8	21.763			

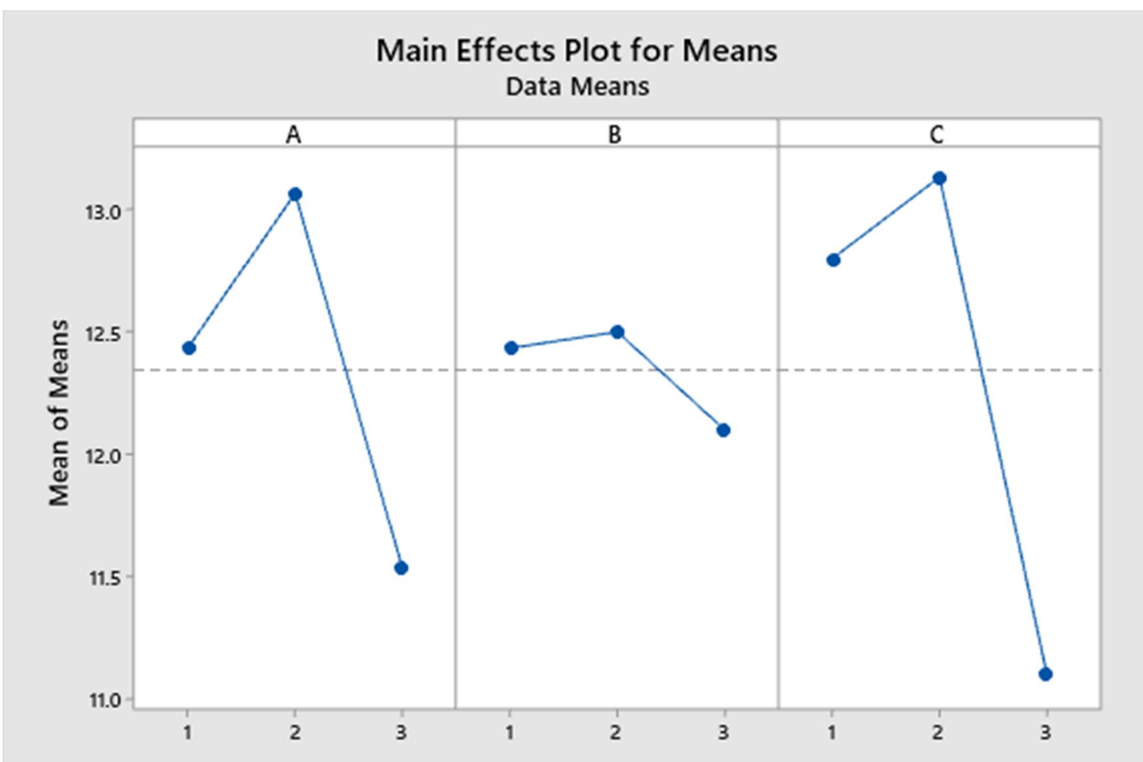

Figure 9: Discussion and Compression of Response Data as for Taguchi Mathod Analysis

The optimal parametric setting indicates the arrangement of input control factor levels that yield the best performance. The average Signal-to-Noise (S/N) ratio for each level reflects the effects of different factors' ranges on responses during the welding of Fe-500 low carbon steel. Through Taguchi analysis, it is observed that higher S/N ratio mean values correspond to enhanced quality characteristics.

Based on the examination, it is found that the most favourable welding performance for tensile strength, bending strength, and hardness is achieved at level 1 for current (90A), level 1 for voltage (24V), and level 1 for electrode diameter (2 mm). Table 11 displays the S/N ratio output, indicating that voltage and electrode capacity are the most important factors for combined multi-quality performance, ranking 1 and 4, respectively.

Further analysis of the percentage contribution (P%) of various factors reveals that voltage contributes the most, with a contribution of 58.78%. Thus, it is concluded from the analysis that voltage is the most influential factor affecting multi-performance outcomes.

In this research, the optimization process parameters for electric arc welding of low carbon mild steel material rods, with a thickness of 12mm, are investigated. The aim is to achieve greater weld strength, particularly in different diameter configurations of the universal testing machine. Various designs such as I-section rods (bars) and double V-butt joints (cylindrical V-joints) are analyzed for their weld strength using the Taguchi method.

The experiment involves analyzing the weld thickness using the universal testing machine and selecting optimum parameters, including rod diameter and maximum arrays, through regression analysis, main effect analysis, and ANOVA development models.

The results indicate that the maximum weld strength is achieved at 180 Amp current, 41 V voltage, and a 4 mm electrode diameter (with a testing specimen of 7 mm). At these parameters, the tensile strength reaches 677 N/mm². Additionally, secondary and tertiary maximum values of 643 N/mm² and 604 N/mm² are observed, respectively, confirming the robustness of the experimental setup.

Key findings include:

1) The main effect plot for the Signal-to-Noise (SN) ratio reveals that larger values are associated with better tensile strength, with significant effects observed in voltage, electrode size, and rod diameter groups.
2) Optimization of the experiment degree and welding conditions using the Taguchi method ensures maximum strength with minimum current performance and a 7 mm diameter rod for ultimate tensile strength testing, considering the heat effect on welding strength.

VII. FUTURE SCOPE

Further scope for research in the optimization of welding parameters for minimizing defects and porosity in electric arc welding of mild steel grade Fe 500 using the Taguchi method lies in several avenues. Firstly, exploring additional welding parameters beyond those considered in this study, such as shielding gas composition and flow rate, could provide a more comprehensive understanding of their impact on weld quality. Secondly, investigating the interaction effects between different parameters and their nonlinear relationships could unveil hidden optimization opportunities. Additionally, extending the study to different grades of mild steel or other materials would broaden the applicability of the findings. Furthermore, conducting long-term durability tests on the optimized welds to assess their performance under various environmental conditions would ensure practical viability. Overall, these future research directions aim to enhance the effectiveness and robustness of the Taguchi method for welding parameter optimization in industrial applications.

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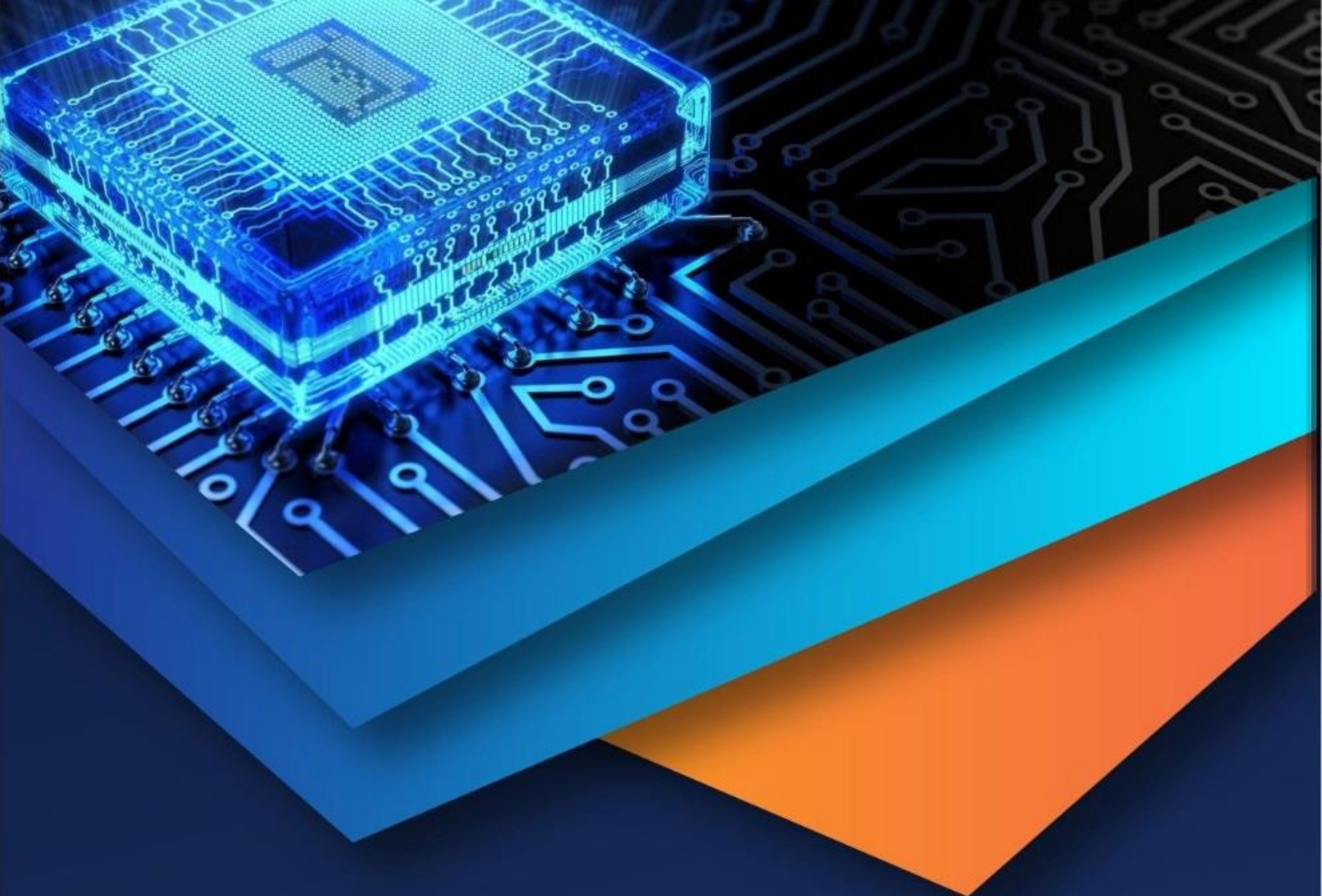

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