Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Optimizing GTAW Process Parameters for SS202 Welding using the Taguchi Method

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Abstract

Stainless steel 202 is a widely used material in the current industrial area, including for higher and lower temperature applications such as storage tanks, pressure cups, furnace equipment, etc. The use ratio of those materials is increasing constantly due to their superior corrosion resistance and mechanical properties. The GTAW process is widely used for stainless steel welding, especially for full penetration welds in thin gage materials. The weldment properties are mostly dependent on the shielding gas, since it dominates the mode of metal transfer. Parameters such as main current, start current (A), end current, and pulse (Hz) have been determined and selected as factors that can influence the weld strength. Taguchi orthogonal array L9 (Minitab 21) was used to determine the amount of runoff and the analysis of samples. In this project, the stainless steel (202) is welded using the SS310 filler rod by the GTAW process, and its mechanical properties were studied along with the process welding parameters like the main current, start current, end current, and pulse of the TIG for maximum weldments, the best mechanical properties, and the minimum heat-affected zone (HAZ). The analysis of the test results is conducted, and the combination of welding parameter ranges that gives the best result is found.

Keywords: GTAW, Taguchi method, SS202, process parameter

1. Introduction

Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, stands as a cornerstone in modern welding technology. This sophisticated process boasts a remarkable versatility, enabling the joining of various metals with precision and finesse. At its core, GTAW relies on the creation of an electric arc between a non-consumable tungsten electrode and the workpiece. This arc generates intense heat, facilitating the fusion of metals while being shielded from atmospheric contamination by an inert gas envelope. One of GTAW's distinguishing features is its ability to produce high-quality welds in a wide range of materials, including stainless steel, aluminum, titanium, and nickel alloys. Its precision and control make it particularly suitable for applications where weld quality and aesthetics are paramount, such as aerospace, automotive, and high-end fabrication. In this paper, we delve into the intricacies of GTAW, exploring its fundamental principles, process parameters, and applications. Through experimental investigation and analysis, we aim to contribute to the ongoing advancement of this vital welding technique, shedding light on its capabilities and potential for innovation in the field of materials joining.

2. Literature review

Many research work carried out around the word for predicting the mechanical and microstructural properties of different kind of metal welded by the TIG welding. A brief review of literature is presented here.

Neeraj Sharma et al. [1] this study explore TIG welding is a versatile welding process used in the diverse field of industry. This study explores the input variables that affect hardness and tensile strength (TS) at the weld center using Taguchi-based experimental planning to gauge the effect of input parameters on the response variables, followed by ANOVA analysis to identify the factors critical for TS. This allowed the researchers to conclude the welding current and electrode diameter is significant for TS. Helium as a shielding gas, low gas flow rates and groove angles resulted in high TS.

Gurudatt Ghadi et al. [2] Gas Tungsten Arc Welding (GTAW) is crucial in manufacturing, especially for Stainless Steel (SS) materials like SS 202 used in Heat Exchangers and Pressure Vessels. These studies underscore the critical role of parameter optimization in achieving desired weld characteristics and mechanical properties. By employing techniques like Full factorial Design, researchers aim to identify the optimal parameter combinations to enhance welded component performance and reliability in critical applications.

Anmoljeet Singh et al. [3] study explores TIG welding's impact on dissimilar metal joints, SS304-SS202, emphasizing parameter optimization for mechanical property enhancement. This aligns with ongoing research in welding technology aimed at improving weld quality and efficiency. By employing Taguchi Method and ANOVA, Singh and Mittal contribute to this field by identifying optimal welding conditions for impact toughness and bending strength. Their study underscores the significance of controlled welding parameters in ensuring desired mechanical properties. Additionally, their use of SEM/EDS and XRD analysis provides valuable insights into the microstructural aspects of welded joints, enhancing the understanding of welding process effects on material properties.

Sanjeev Sharma et al. [4] This study investigate the weld pool geometry of austenitic stainless steel 202 using Tungsten Inert Gas (TIG) welding. Employing Taguchi methodology, they analyze the influence of welding parameters (current, welding speed, and gas flow rate) on weld bead width and height. By conducting experiments using an L9 orthogonal array, they determine optimal parameter settings.

Prveen kumar singh et al. [5] The paper examines the optimization of TIG welding parameters for AISI 304 Stainless Steel using Taguchi's Analysis and Response Surface Methodology. It highlights the importance of welding in various applications and focuses on achieving optimal weld quality. The study employs Taguchi's method to reduce experimental trials and ANOVA to analyze the influence of parameters on weld properties. Through micro-hardness and bend strength testing, the authors identify voltage as the most influential parameter affecting weld quality. Overall, the study contributes to understanding the relationship between welding parameters and weld quality, facilitating the enhancement of TIG welding processes for AISI 304 Stainless Steel.

Kumar Rahul Anand et al. [6] The paper explores TIG welding's impact on the mechanical properties of joints between austenitic stainless steel (AISI 316) and mild steel, crucial in various industries. Taguchi optimization is used to enhance tensile strength and hardness by optimizing welding parameters: current, voltage, and gas flow ratio (GFR). The methodology includes material selection, parameter determination, and sample preparation. Taguchi's orthogonal array and ANOVA are employed for analysis, aiming to understand parameter influence. The research aims to improve welding efficiency and durability in industries reliant on stainless steel and mild steel joints, such as oil and gas, aerospace, and manufacturing.

Singh et al. [7] The impact of TIG welding parameters, such as welding speed, current, and flux, on the depth of penetration and width during the welding process of 304L stainless steel was explored. The investigation revealed that the type of flux employed exerted the most considerable influence on the depth of penetration, with welding current following closely behind. Notably, SiO_2 flux demonstrated a more pronounced effect on penetration depth. Optimization efforts were undertaken to enhance penetration depth while minimizing bead width.

Gadewar et al. [8] this study Investigated the effect of TIG welding process parameters such as weld current, gas flow rate, and work piece thickness on SS304 bead geometry. The process factors studied had a significant impact on the mechanical characteristics.

Michael Anto et al. [9] This study investigates the impact of welding current on the mechanical properties of 5mm A36LCS using TIG welding, focusing on lap and butt joints. Results indicate that the ultimate tensile strength (UTS) of welded joints initially increases with current from 80A to 110A but declines thereafter due to element burnout. Lap joints at 110A showed a UTS of 67.74MPa and butt joints 81.13MPa. Hardness peaks at 110A, with butt joints exhibiting higher values attributed to faster cooling.

Subramaniam Thangavel1 Chenniappan Maheswari et al. [10] the paper investigates the optimization of automated TIG welding parameters for SS304 using Taguchi optimization. Taguchi design of optimization is employed to determine optimal welding parameters, considering welding current, speed, gas flow rate, and arc length. Regression analysis reveals that welding current significantly influences tensile strength and hardness. Welding at higher currents and speeds increases hardness, while lower gas flow rates decrease tensile strength. The study emphasizes the importance of proper parameter selection to avoid defects like cracks and overlaps. Taguchi analysis and ANOVA validate the model's significance, with welding current emerging as the most influential factor. The results demonstrate precise prediction and control of weld quality, essential for ensuring the mechanical integrity of SS304 welds.

Mohammad Arif Khan et al. [11] the literature review highlights the significance of optimizing welding parameters for enhancing weld quality. These studies emphasize the importance of factors like welding speed, current, and gas flow rate in influencing weld strength, distortion, and bead geometry. Through experimental analysis and statistical techniques, these studies have identified optimal parameter combinations for various welding processes, contributing to advancements in manufacturing and engineering industries.

Sandip T. et al. [12] the study investigates the process parameter optimization in TIG welding using the Taguchi method. Various parameters, including main welding current, voltage, speed, and pulse, are examined to understand their influence on weld strength. Through Taguchi's optimization technique, the study aims to determine the relationship between process parameters and weld quality, with a focus on weld strength (UTS). The research emphasizes the importance of optimizing welding parameters for achieving desired weld quality, productivity, and cost-effectiveness. By utilizing Taguchi's method and experimental analysis, the study aims to identify the optimal combination of welding parameters for stainless steel Grade 302HQ, contributing to advancements in welding technology and industrial applications.

Ummal Salmaan et al. [13] The literature review provides a comprehensive overview of previous research on welding processes, optimization techniques, and their effects on mechanical and microstructural properties. These study focuses on TIG welding of 310 SS alloy, employing design of experiments (DOE) and grey relation analysis to optimize welding parameters. Results indicate that welding current and voltage significantly impact hardness and tensile strength, with gas flow rate also playing a role. Microstructural analysis reveals dendritic structures in welded zones, influencing mechanical properties. The study underscores the importance of optimization for achieving desired welding outcomes and suggests avenues for future research, including the exploration of advanced alloys and optimization methodologies.

Arvind Kumar Yadava et al. [14] the literature review explores the optimization of TIG welding parameters for enhancing the strength of weld joints. Many studies is on the effects of welding settings such as main current, speed, and electric pulse on mechanical properties and microstructure. Taguchi's experimental approach is commonly utilized for optimization, yielding significant improvements in tensile strength, impact strength, and bending strength of weld joints. Dissimilar metal welding, particularly involving stainless steel and mild steel, is a focus area, with TIG welding proving advantageous for improving joint properties. Microstructural analysis and mechanical testing, including tensile and hardness tests, provide insights into the performance of welded joints. Optimization methodologies such as Taguchi, ANOVA, and response surface method are employed to determine the optimal parameter combinations for achieving desired welding outcomes. The review underscores the importance of selecting appropriate parameters to ensure high-quality welds, especially in industrial applications requiring superior mechanical properties.

3. Objective

The purpose of this research is to investigate the effect of welding current, shielding gas nature, gas flow rate, and groove angle on various aspects of weld quality. SS202 grade stainless steel as a specimen. For welding, gas tungsten arc welding (GTAW) or tungsten inert gas welding (TIG) process were used. Taguchi Design of

Experiments and analysis of variance (ANOVA) were used to optimize process parameters. A number of tests and analysis were performed (Dye penetrant test, Load and tensile tests, SEM analysis for microstructure)

4. Methodology

4. 1 Material: SS202 grade stainless steel

Figure 4.1 Work piece

Chemical Composition of SS202

Table 4.1 Chemical composition of SS202

Fe %	C %	Mn %	P %	S %	Si %	Ni %	Cr %	V %
68	≤ 0.15	7.50-10	≤ 0.060	≤ 0.030	≤ 1	4-6	17- 19	0.0461

4.2 Specimen dimension: 700×120×3mm.

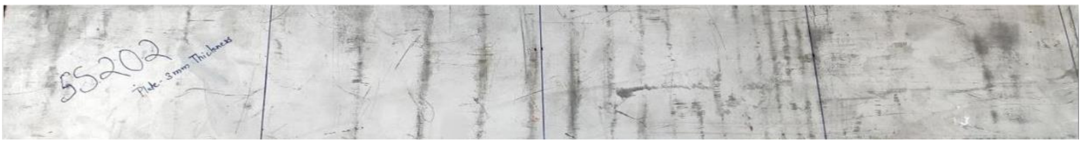

Figure 4.2 SS 202 metal sheet

4.3 Shielding gas: pure argon gas as shielding gas and gas flow rate is 10-12kg/cm^2.

4.4 Filler metal: SS 310 material is used as filler metal as per the AWS norms.

Chemical composition of SS 310

Table 4.2 Chemical composition of SS 310

(Cr)	(Ni)	C	(Si)	(Mn)	(P)	(S):	(Mo):	(Cu):	Iron (Fe):
24-26%	19.2to 22%	0.25%	1.50%	2%	0.045%	0.03%	0.75%	0.50%	Remaining

4.5 Sample Preparation: The sample is prepared from the sheet using a hand grinder with a cutter blade, followed by surface polishing with a grinder. Subsequently, a Fronius TIG welding machine is employed for metal joining.

Figure 4.3 Sample after the welding

4.6 Test: 1: Dye Penetration Test

2. Tensile Test

5. Result & Discussion

5.1 Dye penetrant test (DPT) result

A DPT test was performed on all SS 202 specimens' welded area. Figure 5.1 shows a picture of welded joints with no surface imperfections, which shows that all welding was done properly. From that, we conclude that the welded region has no surface defect or porosity in between the welding joint.

Figure 5.1 Dye penetrant test carried on SS202 specimen

5.2. Experimental Observation & Analysis

Experimental observations and analysis were based on Taguchi's orthogonal array theory, where an L9 orthogonal array was employed for the entire SS202 steel welding experimentation. This array involved 9 experimental runs, with corresponding outputs evaluated using Taguchi optimization techniques. The load on the welding joint and tensile load were measured using the aforementioned instruments (UTM), giving as output result in the Taguchi optimization method. Table 5.1 illustrates the standard structure of the L9 orthogonal array, where in the levels of each parameter are denoted as 1, 2, and 3, respectively:

Table 5.1 Taguchi orthogonal array

Serial no.	Main Current	Start Current	End Current	Pulse
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1

6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Here, the process variables are Main current, Start current, End current and Pulse.

Table 5.2 Selected process parameters

Main current	75A	90A	105A
Start current	90%	110%	130%
End current	50%	60%	70%
Pulse	0Hz	25Hz	50Hz

These are the input parameters for the Taguchi optimization. So, nine experiments are carried out as per this orthogonal array and corresponding output data are recorded serially. The Tensile strength was measured of work piece and then calculate the mean of those value. The full structure of experimentation is tabulated in Table 5.3 as per L_9 orthogonal array.

Table 5.3 Observation Table

Serial no.	Main Current(A)	Start Current	End Current	Pulse	Tensile Load	Elongation
1	75	90%	50%	0Hz	88.4KN	10mm
2	75	110%	60%	25Hz	88KN	25mm
3	75	130%	70%	50Hz	116KN	35mm
4	90	90%	60%	50Hz	92KN	28mm
5	90	110%	70%	0Hz	84KN	16mm
6	90	130%	50%	25Hz	96KN	32mm
7	105	90%	70%	25Hz	110KN	36mm
8	105	110%	50%	50Hz	110KN	24mm
9	105	130%	60%	0Hz	108KN	37mm

The observation Table 5.3 indicates that the main current and start current percentage primarily affect the load-carrying capacity of the welding joint, consequently impacting its tensile strength. Reading number 3 in the table exhibits the best performance, representing the optimized parameter for this experiment.

5.3 Analysis of result

The data mentioned above underwent analysis using the powerful statistical tool Minitab software, version 21. Initially, the input parameters were defined in the software with their corresponding values, followed by providing response data for optimization. The primary objective of this analysis was to maximize welding strength and tensile load while minimizing elongation. Hence, the optimization criterion "larger-The-Better" was applied. The software conducted analysis of signal-to-noise ratio (S/N ratio) and means. Subsequently, ANOVA analysis was performed for each parameter post-simulation of optimization. Finally, graphs were plotted to assess the influence of residuals on the parameters.

Taguchi Analysis: Load versus Main Current, Start Current, End Current, Pulse

Table 5.4 Response Table for Signal to Noise Ratios

(Larger-The-better)

Level	Main Current	Start Current	End Current	Pulse
1	39.58	39.56	39.40	39.24
2	39.14	39.13	39.61	39.79
3	40.50	40.53	40.20	40.19
Delta	1.36	1.41	0.80	0.95
Rank	2	1	4	3

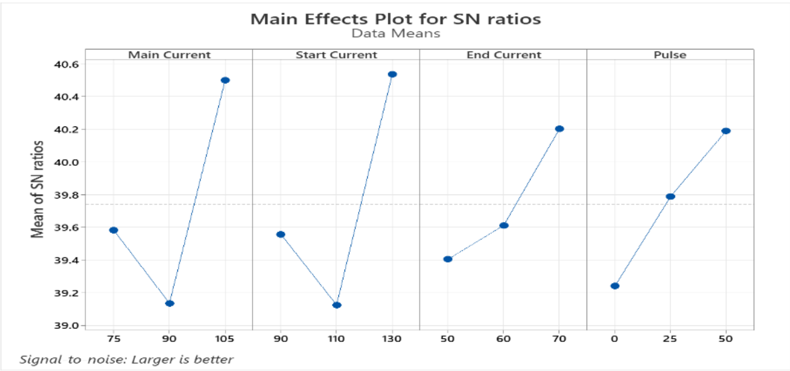

Figure 5.2 Signal to noise ratio graph

Table 5.5 Response Table for Means

Level	Main Current	Start Current	End Current	Pulse
1	96.27	95.60	93.60	92.27
2	90.67	90.67	96.00	98.00
3	106.00	106.67	103.33	102.67
Delta	15.33	16.00	9.73	10.40
Rank	2	1	4	3

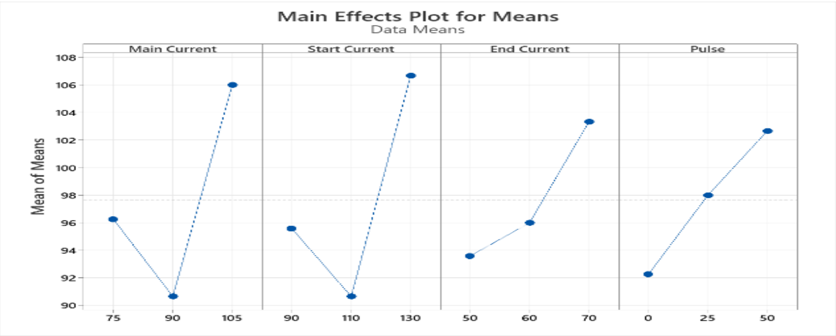

Figure 5.3 Main effect plot

Analysis of Table 5.4 and Figure 5.2 signal-to-noise ratio graph reveals that the delta rank highlights the significant influence of start current and main current on achieving high tensile strength. The most important effecting factor is start current.

Residual plot of Load

Load =3.6+0.324 Main current+0.277 Start Current +0.487 End current +0.208Pulse

Table 5.6 Process parameter Coefficients

Term	**Coef**	**SE Coef**	**T-Value**	**P-Value**	**VIF**
Constant	3.6	44.2	0.08	0.939	
Main Current	0.324	0.289	1.12	0.324	1.00
Start Current	0.277	0.217	1.28	0.271	1.00
End Current	0.487	0.433	1.12	0.324	1.00
Pulse	0.208	0.173	1.20	0.296	1.00

Table 5.7 Analysis of Variance

Source	**DF**	**Adj SS**	**Adj MS**	**F-Value**	**P-Value**
Regression	4	630.2	157.5	1.40	0.377
Main Current	1	142.1	142.1	1.26	0.324
Start Current	1	183.7	183.7	1.63	0.271
End Current	1	142.1	142.1	1.26	0.324
Pulse	1	162.2	162.2	1.44	0.296
Error	4	450.9	112.7		
Total	8	1081.1			

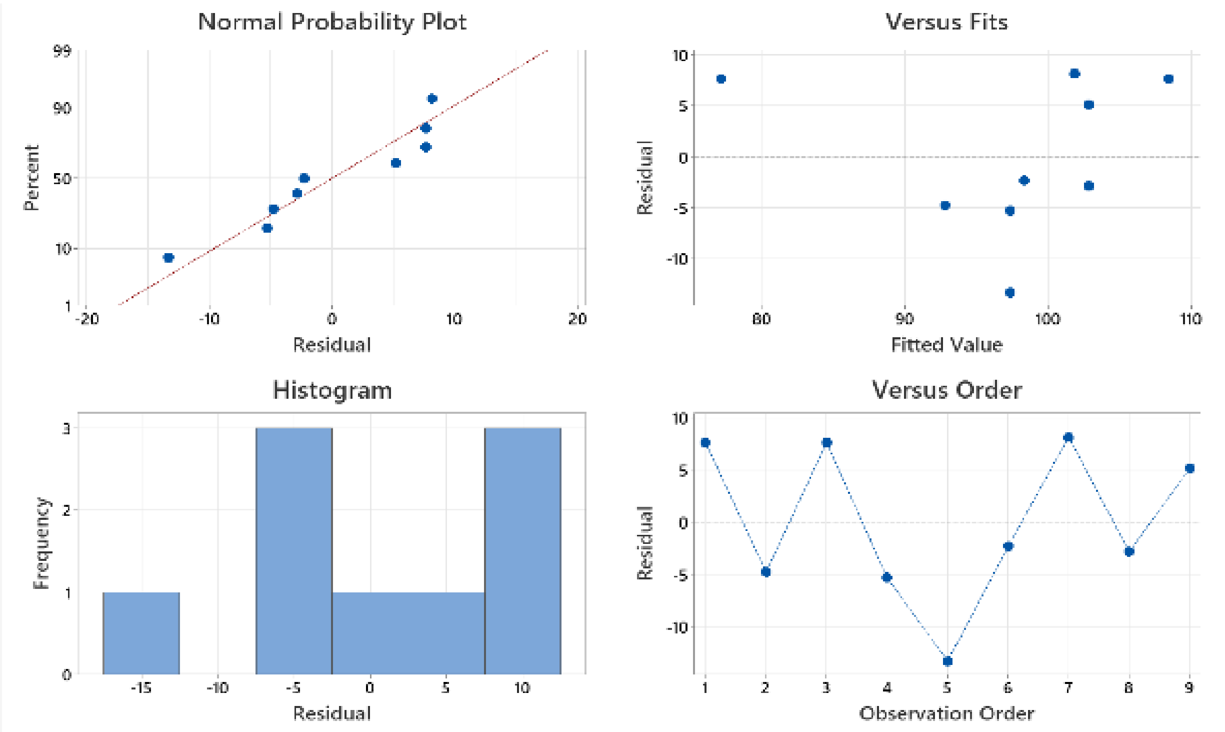

Figure 5.4 residual plot for load

In Figure 5.4, standard residues fall between 20 and -20. The parallel line to the x-axis in the fit suggests fixed variance. The histogram indicates no outliers.

Probability Plot of Main Current, Start Current, End Current, Pulse

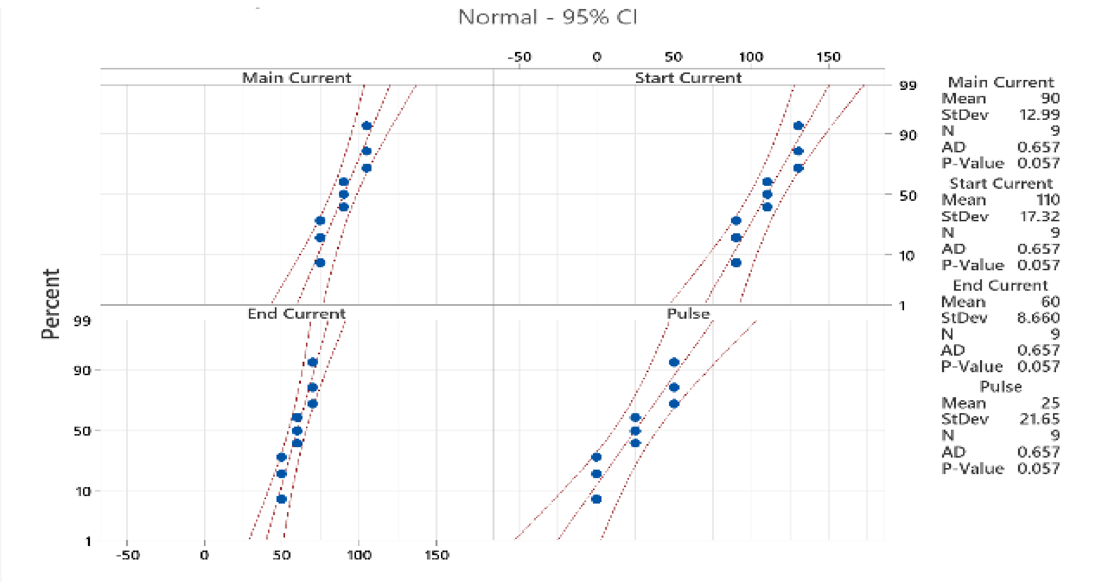

Figure 5.5

probability plot

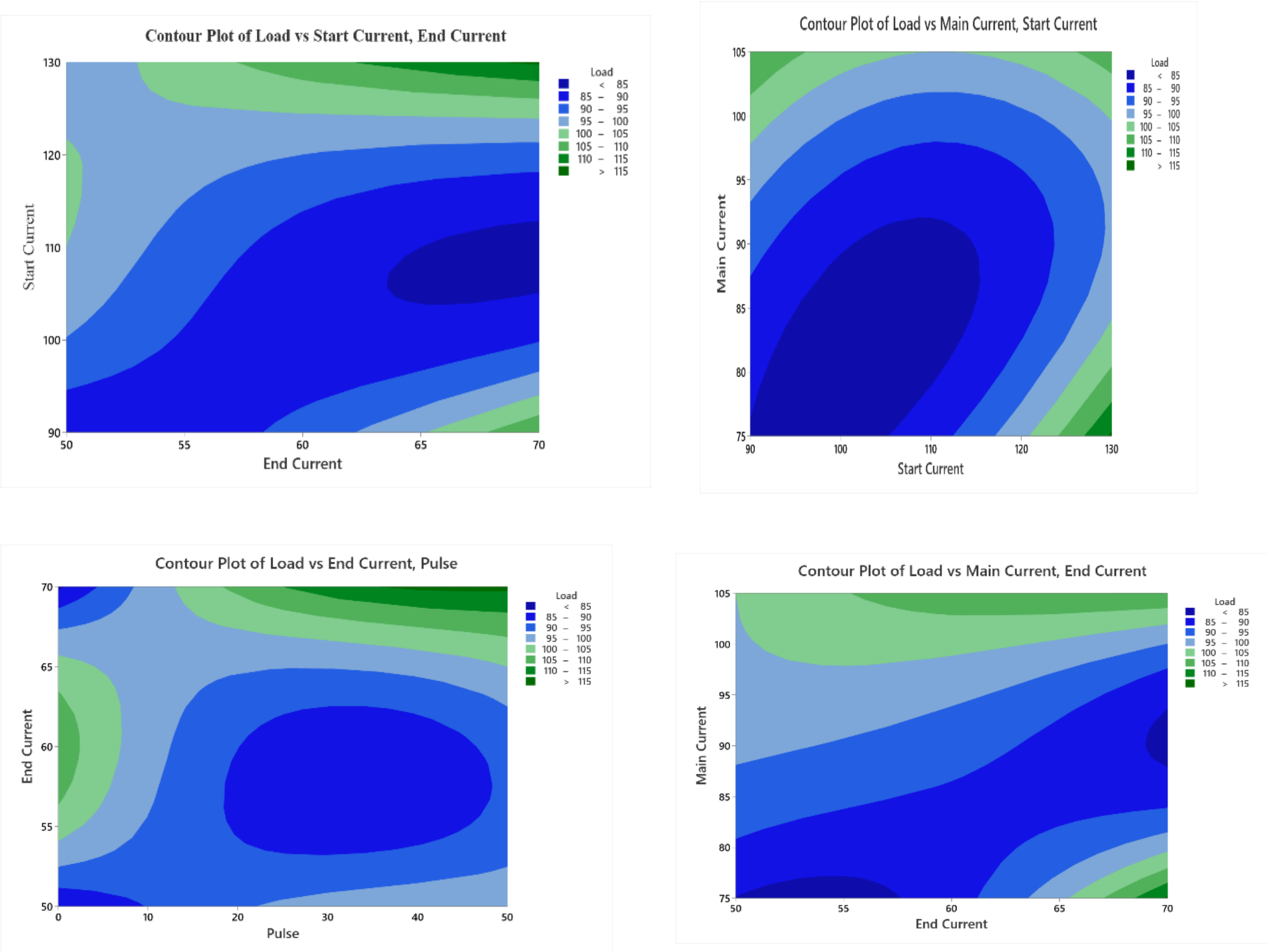

Figure 5.6 Contour plot

The analysis conducted using Minitab 21 software revealed that the main current, start current percentage, Pulse (Hz) and end current have a significant impact on welding strength. Specifically, it was observed that the start current percentage plays a crucial role in welding quality.

5.4 Microstructural image from SEM

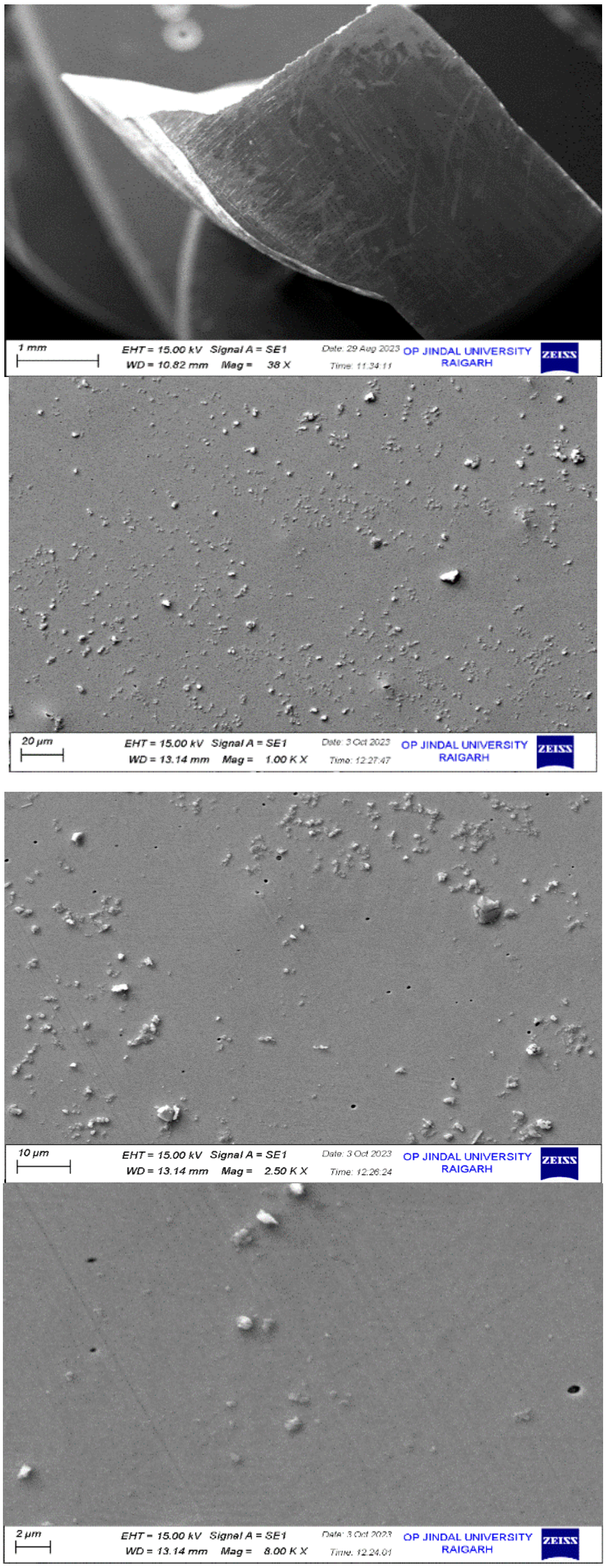

Figure 5.7 Image from SEM microscope

6. Conclusion

Based on the actual experiment and the findings obtained, one can deduce that the voltage used for welding, main welding current, start welding current, end welding current pulse, rate of shielding gas flow, so on are critical control parameters for the TIG welding process. The welding current is the most conspicuous and crucial process parameter, influencing not only weld quality but also other performance factors. Parameter optimization has been performed to determine the best parameters for improved response and the lowest residual stresses. The Taguchi method is extremely effective at optimizing process and performance parameters with minimal experimentation. It also demonstrates that the ultimate tensile strength (UTS) of the weld, as measured in specimen no. 3, will provide the best level for each process parameter. The study discovered that the control elements had different effects on tensile strength, with welding current having the greatest influence.

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