OPTIMISATION OF PROCESS PARAMETERS FOR JOINING AISI 409 STAINLESS STEEL AND MILD STEEL BY USING MIG WELDING

Abstract.

Considering various aspects like performance parameters, cost effectiveness, saving energy, environmental concern it has been observed that joining of metals, which are dissimilar in nature, has a versatile use in the field of Electronics, Chemical, Petrochemical Industry, in power generation and in nuclear reactors too. It is quite challenging to join dissimilar metal in a very efficient way because of chemical, mechanical and thermal properties under the common condition of welding. In the welding section, a steep gradient has been observed in the mechanical properties. Various problems have noticed during joining of dissimilar metals. The problems include stresses that occur due to the migration of atoms, various cracks, residual stresses in the welding section, tensile stresses, compressive stresses, stresses in cracking etc. Thus, the effect of all individual parameters must be determined that effect the mechanical property. The aim of this investigation is to fabricate and optimize the process parameters of welding for dissimilar metal by implementing MIG Welding Process. Taguchi Method has been implemented to optimize the input responses. Welding Current, Gas Pressure and Welding Voltage are the main input parameters to get the desire output Ultimate Tensile Strength. AISI 409 Stainless Steel and Mild Steel are the dissimilar metals that have been used to carry out the experiment. The range of Welding Current includes 150, 170, 190 Amp. Gas pressure includes 12, 15, 18 Psi. Welding Voltage includes 15, 20, 25 Volts. The investigation states that the ultimate tensile strength gets increased due to increase in voltage. Voltage is considering being the most significant parameters in MIG Welding of dissimilar metals followed by Gas Pressure and Current. The percentage of contribution include 74.86 % of Voltage, 1.45% of Gas Pressure, and

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19.05% of current to get the Ultimate Tensile Strength for joining dissimilar Welding.

Keywords: Dissimilar Joint, MIG Welding, Ultimate Tensile Strength, and ANOVA.

I. INTRODUCTION

One of the permanent joining processes is welding. Welding is performed by the fusion of two base metals. Filler material is applied in some of the cases and in some cases, pressure has been used. Dissimilar materials as well as similar materials could be joining by using welding process. Using electric arc or by burning gas heat is generated for the fusion of the material. Electric arc welding is preferred in most of the cases just because of welding speed [1]. Alternative method for forging or casting, welding is considered as fabrication process, which is extensively used. Application of welding is considered in many cases like joining broken parts, breakage of tooth of gears, joining metal cracks, surface repairment of bearing surface etc.

Welding processes are classified in two categories:

a. Welding Process by implementation of Heat i.e. Fusion Welding
b. Welding Process by the combination of heat and pressure i.e. Forge Welding [2]

Figure 1. explains the Fusion welding process, which shows that the two metals are joined by filling the gap with the filler material. The gap is filled with molten materials which either come from filler material or the melting of the parent or base materials. Filler materials can same as base metal or it may differ. The joining occurs either by fusion or by solidification of the molten material.

Based on heat generation, fusion welding is classified as:

a. Gas Welding
b. Thermit Welding
c. Arc Welding.

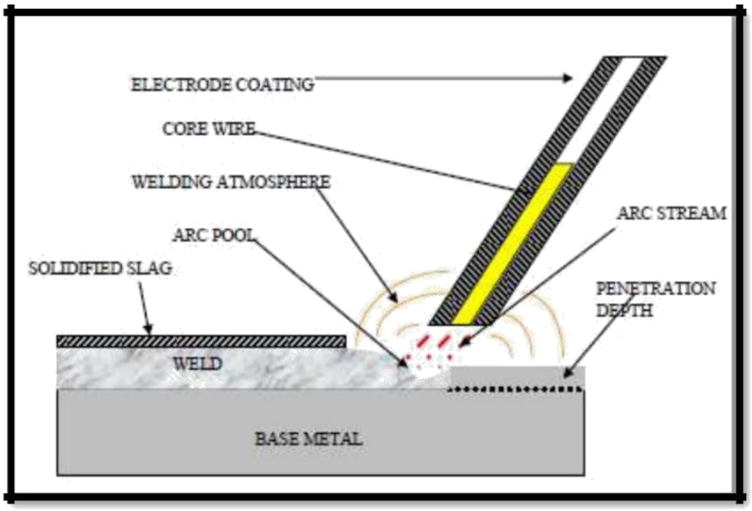

Figure 1: Fusion Welding

In a furnace at a proper temperature, heating and then by hammering join the parts and in this manner; forged welding processes are performed. Electric Resistance Welding is one of the examples of forge welding. Principle application of pressure and heat, either simultaneously or consecutively is widely preferred in many processes, which are consider as Projection Welding, Spot Welding, Flash Welding, Upset Welding and Seam Welding.

To generate electric arc a struck is made either between two electrodes or between workpiece. In case of Arc welding process, the struck is made in electrode. Luminous electrical discharge is an electric arc, which is obtained between the two electrodes in the presence of ionized gas [3]. The electric arc is obtained between the electrode and the parent materials. The temperature obtained in the fusion region is almost 2000°C. The temperature is quite enough to melt the base metal and the electrode to fill the gap and complete the welding process. In most of the Welding process, shielding gas has been used to protect the molten pool during Welding process. In some of the cases coated electrode is preferred to protect the Weld pool too [5,10]. Figure 2. has explained arc welding.

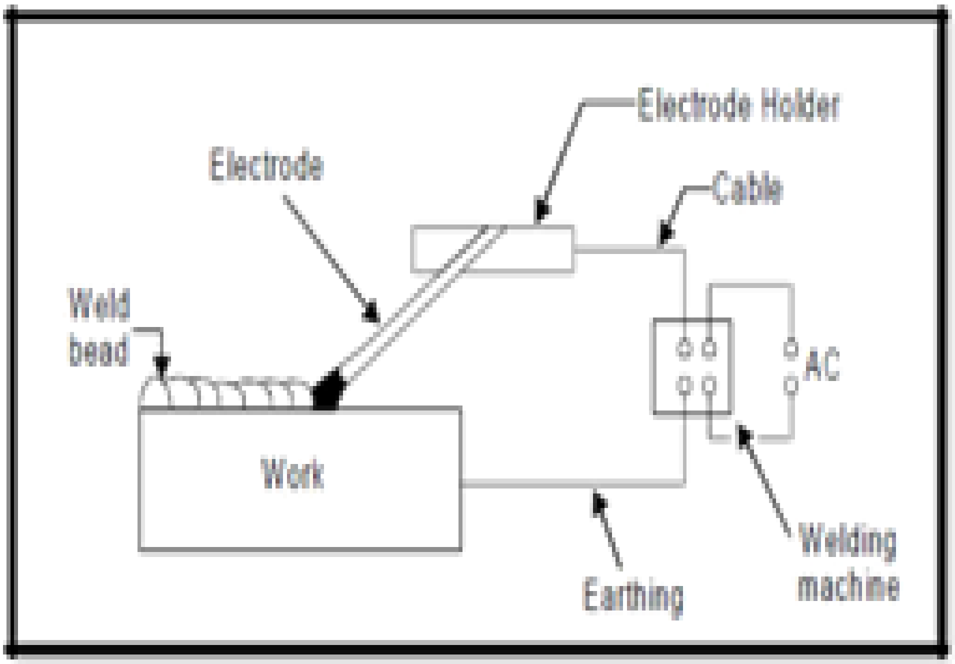

Figure 2: The basic principle of Arc welding

Gas Metal Arc Welding is also known as Metal Inert Gas Welding. In MIG Welding, consumable electrode is used. Shield Gas Arc Welding is also known as Flux core Arc Welding. In Shield Gas Arc Welding, consumable electrode is used. Thin sheets are joined by implementing Tungsten Inert Gas Welding process. It is difficult to weld thick plate due to the deposition of the filler materials. For thick metal sheet, Gas Metal Arc Welding is preferred.

Joining of dissimilar metals has been very demanding in today’s era. The areas where it has implemented are electronics industry, power generation, nuclear reactor, chemical industry, petrochemical industry etc. Major challenges have been arisen due to different thermal as well as chemical properties of material during joining process. Steep gradient occurs in the properties of thermo- mechanical during the welding.

Problems that are associated with dissimilar welding includes residual stress, atom migration, cracking, stress concentration, tensile stress, compressive stress, thermal stress, corrosion due to stress etc. Now while performing dissimilar welding the causes related to the problem are getting known.

Solubility of parent materials in case of dissimilar welding depends upon the crystal structure. Crystal structure also helps to get the atomic diameter. Intermetallic phase is obtained in the weld pool. The ductility property and the mechanical strength are affected because of the formation of brittle and hard Intermetallic phase.

Cracking occurs during solidification because of residual stress as well as misfit strains. Due to the difference of thermal conductivity and coefficient of thermal expansion misfits strains and residual stress occurs.

In [7], the researcher's main objective was to investigate the effect of welding parameters in mild steel plate. The input parameters include heat input, welding speed, welding current, and arc voltage. The output responses include weld width and depth of penetration. The main investigation deals with the effect of rate of heat input and welding speed on the output response.

In [6], the researcher's main objective was to investigate the effect of root gap, welding current and arc voltage on mechanical properties of 1018 grade Mild Steel while performing MIG Welding. Hardness, Tensile strength and microstructure have considered as output responses. Methodology that has used is Taguchi Method. Validation has carried out by Analysis of Variance. The significant parameters have observed by implementing ANOVA process.

In [6], the researcher's main objective was to investigate the effect of Gas Flow Rate, Voltage, Speed and Current on st-37 low alloy steel while performing Gas Metal Arc Welding (GMAW). The output response is to get Ultimate Tensile Strength. L9 Orthogonal Array was considered. The optimal value to get the required output has considered.

During the study, it was observed that voltage and current are the significant factors while performing MIG Welding.

In [2], the researchers used Taguchi Method to optimise the process parameters to get required Hardness while performing MIG Welding. Current, Voltage and welding speed has been considered as process parameters. 6061Grade and 5083 Grade Aluminium Alloy was used as parent materials of dimensions (75x60x6) mm. Argon act as a shielding gas. 4043 Grade Filler wire was used of diameter 1.2mm. L9 Orthogonal Array was considered. The optimal value to get the required output has considered. Rockwell Hardness Tester has been used to test the hardness of the welded bead. It was observed that Current is the effective parameters that affect the hardness values.

In [8,9], it was found to achieve good combination of certain mechanical properties such as corrosion resistance, strength at low cost, dissimilar metal joints are preferred. Joining of Mild Steel and Stainless steel is critical because of the presence of Carbon and at the same time the there is a loss of Chromium thus affect the joint quality, deteriorate weld strength. There is an increase in porosity too. Research and development in the field of dissimilar metal welding is still needed, especially in light of the growing need for customized materials in contemporary engineering and industrial applications [11-15].

II. DETAILS OF EXPERIMENTATION

1. Selection of Process Parameters

In this present experiment Current, Voltage, and Gas pressure has been consider, as it is controllable by operator. Electrode size and Shield Gas are the constant parameters. To measure the tensile strength is the sole objective of this investigation.

Table 1: Parameter considered for experiment

Input Parameters	
1	Current (Amp)
2	Gas Pressure(Psi)
3	Voltage(V)
Constant Parameters	
1	Shielded Gas
2	Electrode Size
Output Parameter	
1	Tensile Strength(KN)

2. Controllable parameters and their Limits

Based on the literature survey the effective parameters as well as their working range have been considered. The values are enlisted in Table 2. Based on the below mentioned data Design of Experiment has been developed.

Table 2: Input parameter level and value

Parameter level	Gas Pressure (Psi)	Current (Amp)	Voltage (Volt)
	(A)	(B)	(C)
1	12	150	15
2	15	170	20
3	18	190	25

3. Design of the Sample

Mild Steel and AISI 409 Grade Steel has been considered as parent materials of dimension 150mmx40mmx6mm. Bevel Angle and height are considered as 45° and 6 mm. 1mm of root gap has maintained to carry out the experiment.

Figure 3. shows the sample preparations for carrying out experiment.

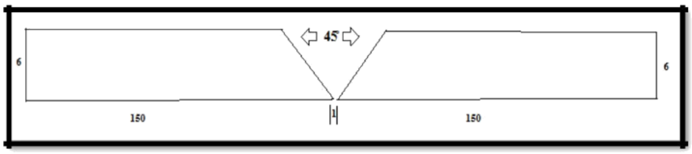

Figure 3: Sample specimen with bevel angle

4. Machine Setup

Figure 4: Experimental Set Up (MIG Machine)

III. RESULTS AND DISCUSSIONS

1. Design of Experiments

By putting variation levels parameter as per Table 2.2 in Minitab-17 statistical software, the Minitab suggests 9 (3×3) full factorial experiment. The design of experiments table suggested for full factorial designs as shown in Table 3.

Table 3: Design of Experiment

Sl. No	Gas Pressure	Current	Voltage
1	12	150	15
2	12	170	20
3	12	190	25
4	15	150	20
5	15	170	25
6	15	190	15
7	18	150	25
8	18	170	15
9	18	190	20

2. Experimental Results

Model UTS 100 (Universal Testing Machines) was used to carry out the Tensile Test. Maximum capacity of the Machine is 1000kN. 0 to 1000kN was the range of the machine. ±5.0k N/mm^2 is the machine accuracy range.

Table 4: Results of Tensile Strength obtained from experiment

Sl.No	Gas Pressure(Psi)	Current (Amp)	Voltage (V)	Tensile Strength (kN/m^2)
1	12	150	15	11.525
2	12	170	20	22.5
3	12	190	25	17.5
4	15	150	20	28.75
5	15	170	25	61.25
6	15	190	15	3.75
7	18	150	25	37.5
8	18	170	15	6.25
9	18	190	20	12.5

3. Analysis *of Variance (ANOVA)*

ANOVA has been used to get the data regarding the effect of parameters on output response. Individual parameters are having individual significant values and it is calculated from F-Values for every individual response. For individual model significant values for Co-efficient as well as model adequacy has been checked by using F Ratio Test and Analysis of Variance (ANOVA). The value for P must be less than 0.05 as seen in Table 5., which indicates the parameter is effective and lies within confidence level (i.e. 95%).

Table 5: ANOVA of Ultimate Tensile Strength

Source	DF	Seq SS	Adj SS	AdjMS	F	P
GP	2	8.306	8.306	4.153	0.49	0.078
CUR.	2	108.154	108.154	54.077	6.39	0.000
VOLT.	2	331.608	331.608	165.804	19.60	0.000
ERROR	20	16.919	16.919	8.459		
TOTAL	26					
TOTAL	26					
R-Sq =96.4%			R-Sq(adj) =94.29%			

4. Sample of the experimental Workpiece

Figure 5: Tensile Testing Specimen

5. Experimental Results and Analysis

Table 4. shows the results of the experiments that were carried out. It has been observed that maximum Tensile Strength value obtained is 61.25kN/m^2 when the Gas Pressure was considered as 15 Psi, Current as 170 Amp, and Voltage as 25V. In fact, it has also been observed that minimum Tensile Strength value obtained is 3.75kN/m^2 when the Gas Pressure was considered as 15 Psi, Current as 190 Amp, and Voltage as 15V.

The effect of Gas Pressure on Tensile Strength has been shown in Fig. 6. On average the Ultimate Tensile Strength remains constant till 15Psi Gas Pressure and further the tensile strength increases with increase in Gas Pressure.

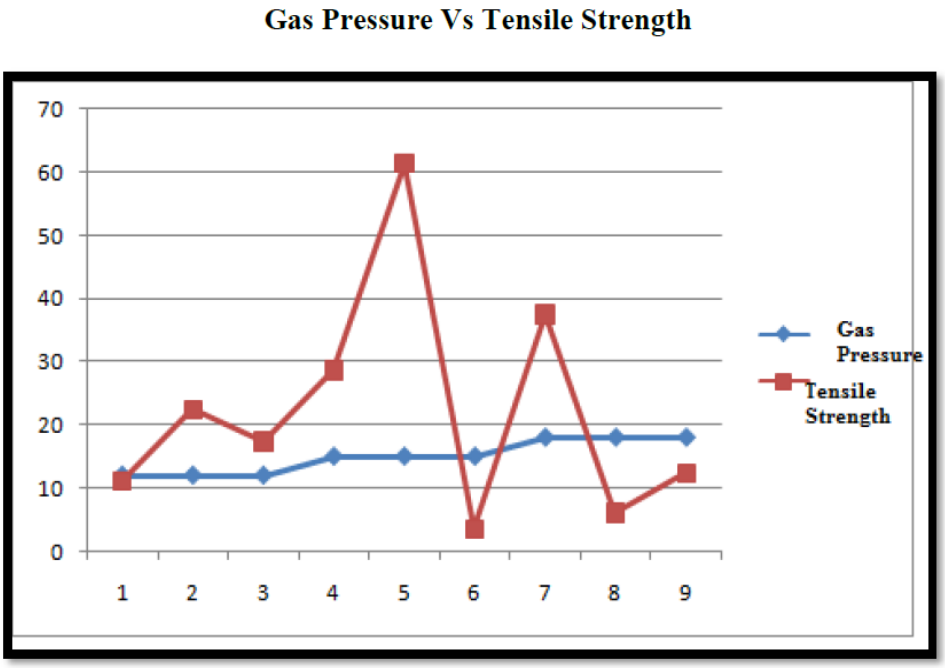

Figure 6: Main effect plot of Gas Pressure Vs Average Tensile Strength

The effect of Welding Current on Tensile Strength has been shown in Fig. 7. From the below mentioned figure it has seen that the Tensile Strength of the Weld Beads increases with increase in current from 150A to 190A.

Current Vs Tensile Strength

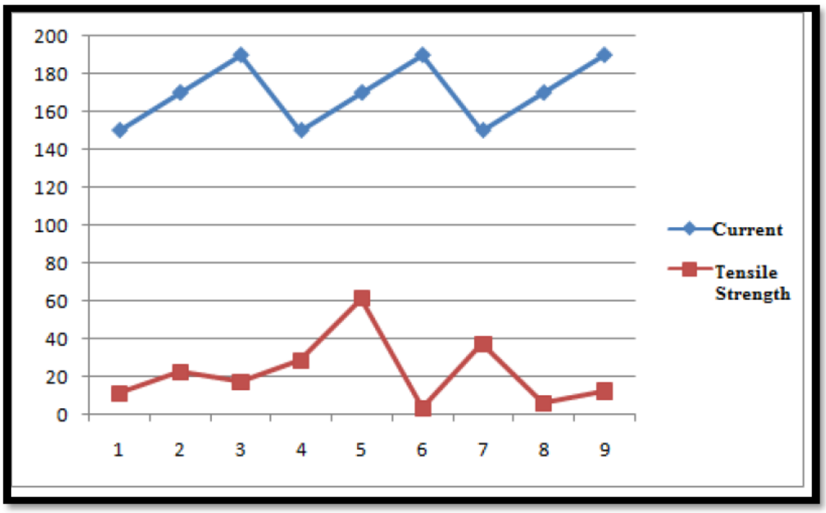

Figure 7: Main effect plot of Current Vs Average Tensile Strength

The effect of Welding Voltage on Tensile Strength has been shown in Fig. 8. From the below mentioned figure it has seen that the Tensile Strength of the Weld Beads increases when the voltage varies between 15V to 20V but on further increase of voltage to 25V the tensile strength decreases.

Voltage Vs Tensile Strength

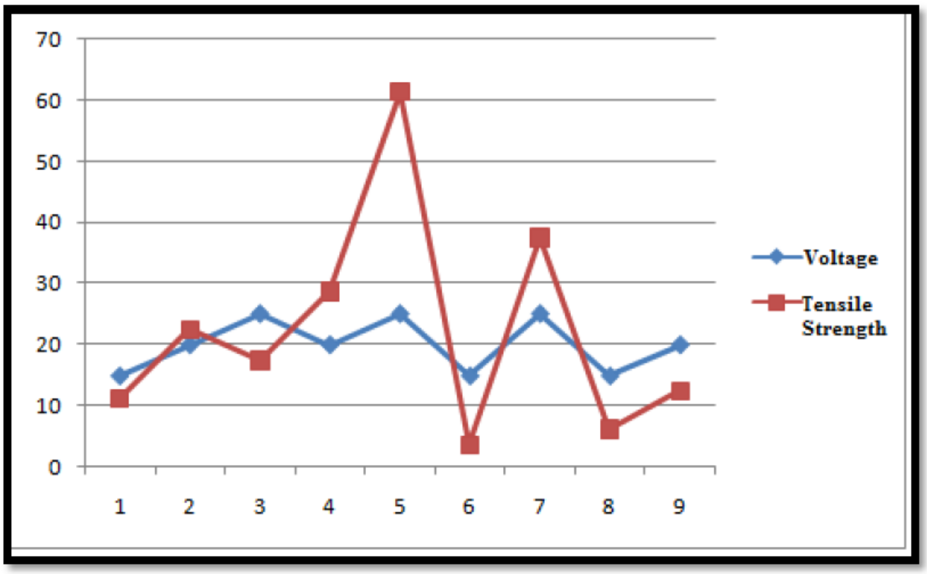

Figure 8: Main effect plot of Voltage Vs Average Tensile Strength

Below mentioned Fig. 9 shows the main effect of Gas Pressure, Voltage Vs Tensile Strength. It has been observed that maximum Tensile Strength was achieved when the Gas Pressure is 15 Psi and the voltage is 25V, which is the maximum voltage to carry out the experiment.

Gas Pressure, Voltage Vs Tensile Strength

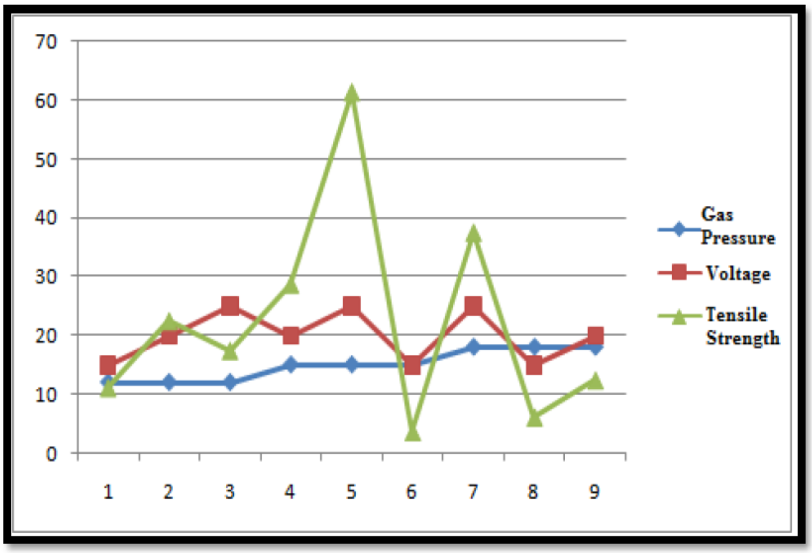

Figure 9: Main effect plot of Gas Pressure, Voltage Vs Average Tensile Strength

The ANOVA analysis presents the input parameters percentage contribution to get the desired output with Minitab 17 Software.

Table 6: Shows the percentage contribution of each input factors for Tensile Strength

Input parameter	**Percentage contribution (%)**
Gas pressure	1.45
Current	19.05
Voltage	74.86
Error	4.64

6. SEM Analysis

The image shows elongated grooves and ridges, which likely indicate thermal stress patterns during solidification. The striations and deformation patterns are typical in the HAZ due to rapid heating and cooling cycles. The rough texture and irregular microstructure suggest grain coarsening in the HAZ due to thermal exposure. Plastic deformation and crack-like features are also visible, likely formed due to residual stress from uneven thermal expansion. The bright white regions (especially in the bottom-left and centre-right of the image) are likely oxide inclusions or impurities, which may have formed due to high temperatures or shielding gas inefficiencies. A rounded void or inclusion is visible at the bottom left, possibly indicating gas entrapment during welding. Presence of spherical particles in the bottom-right region may indicate segregated alloying elements or solidification-related particles, sometimes seen in fusion zones but can also diffuse into HAZ. There are several faint intergranular cracks or thermal stress fractures, which can propagate due to brittleness induced by the welding heat.

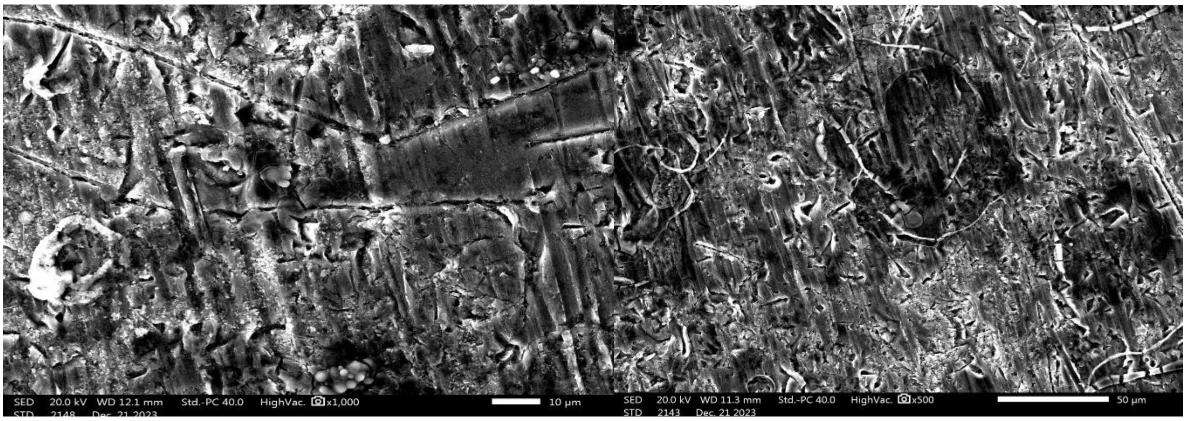

Figure 10: SEM images of the weld bead

IV. CONCLUSION

It has been concluded by performing the experiment that maximum Tensile Strength value obtained was 61.25kN/m^2, which was obtained when the Gas Pressure was considered as 15 Psi, Current as 170 Amp, and Voltage as 25V. In fact, it has also been observed that minimum Tensile Strength value obtained was 3.75 kN/m^2 when the Gas Pressure was considered as 15 Psi, Current as 190 Amp, and Voltage as 15V. On average, the Ultimate Tensile Strength remains constant till 15Psi Gas Pressure and further the tensile strength increases with increase in Gas Pressure.

The Tensile Strength of the Weld Beads also increases with increase in current from 150A to 190A. Tensile Strength of the Weld Beads increases when the voltage varies between 15V to 20V but on further increase of voltage to 25V, the tensile strength decreases. It has also been observed that maximum Tensile Strength was achieved when the Gas Pressure is 15 Psi and the voltage is 25V, which is the maximum voltage to carry out the experiment.

From ANOVA Table the percentage contribution was detected and it has been observed that contribution of Gas Pressure was 1.45%, Welding Current was 19.05%, and Welding Voltage was 74.86% to achieve the Ultimate Tensile Strength for joining Dissimilar Welding Joint. The most effective input parameters have been considered as Welding Voltage which is followed by Current and Gas Pressure in case of MIG Welding.

REFERENCES

[1] R. Duhan, R. Nandal, "A Study of Microstructure and Hardness in AISI 50110 (EN 31) Welded Joints Using Gas Metal Arc (GMAW) Welding", International Journal of Engineering Sciences Paradigms and Researches, Vol.08, No. 01, pp. 29-40, 2013.
[2] V. Kanwal, R. S. Jadoun, "Optimization of MIG Welding Parameters for Hardness of Aluminium Alloys Using Taguchi Method", SSRG International Journal of Mechanical Engineering. Vol.02, No.06, pp.53-56, 2015.

[3] B. Mishra, R.R. Panda and D. K. Mohanta, "Metal Inert Gas (Mig) Welding Parameters Optimization", International Journal of Multidisciplinary and Current Research, Vol.2, No.5, pp.637-639, 2014.
[4] S. Utkarsh, P. Neel, M.T Mahajan, P. Jignesh, R.B. Prajapati, "Experimental Investigation of MIG Welding for ST-37 Using Design of Experiment", International Journal of Scientific and Research Publications, Vol.4, No.5, 2014.
[5] M. M. Ghogale, Prof. S. A. Patil, "Optimisation of process parameters of MIG Welding to Improve Quality of weld by using Taguchi Methodology", International Journal of Engineering Research & Technology, Vol.2, No.12, 2013.
[6] R. Kumar, S. Kumar, "Study of Mechanical Properties in Mild Steel Using Metal Inert Gas Welding", International Journal of Research in Engineering and Technology, Vol.03, No. 04, pp.751-756, 2014.
[7] K. Abbasi, S. Alam and Dr. M.I. Khan, "An Experimental Study on the Effect of MIG Welding parameters on the Weld-Bead Shape Characteristics", IRACST – Engineering Science and Technology: An International Journal (ESTIJ), ISSN: 2250-3498, Vol.2, No. 4, August 2012.
[8] R. R. Mishra, and V. K. Tiwari, "A Study of Tensile Strength of Mig and Tig Welded Dissimilar Joints of Mild Steel and Stainless Steel", International Journal of Advances in Materials Science and Engineering (IJAMSE) Vol.3, No.2, April 2014.
[9] A.Wahab, H.Khuder and Esam J. Ebraheam, "Study the factors effecting on welding joint of dissimilar metals", Al-Khwarizmi engineering journal, April (2011), Vol 7, No. 1, pp.-76-81.
[10] A.Kumar, Dr.R.S.Jadoun and A.S.Bist, "Optimization ofMIG welding parameters using Artificial Neural Network (ANN) and Genetic Algorithm (GA)", International journal of engineering sciences &research technology.
[11] Y.Q. Liu, D. Yu, Y. Zhang, J.P. Zhou, D.Q. Sun, and H.M. Li, "Research advances on weldability of Mg alloy and other metals worldwide in recent 20 years", J. Mater. Res. Technol., 2023, vol. 25, pp. 3458-3481.
[12] M. Abdul Karim, and Y.D. Park, "A review on welding of dissimilar metals in car body manufacturing", Journal of Welding and Joining, 2020, vol. 38, no. 1, pp. 8-23.
[13] C. Chen, L. Kong, M. Wang, A.S. Haselhuhn, D.R. Sigler, H-P. Wang, and B.E. Carlson, "The robustness of Al-steel resistance spot welding process", J. Manuf. Process., 2019, vol. 43, pp. 300-310.
[14] J. Wang, X. Li, H. Yan, X. Wang, and Y. Wang, "Research on titanium-copper explosive welding interface with different welding parameters", Int. J. Adv. Manuf. Technol., 2022, vol. 122, no. 9-10, pp. 3595-3606.
[15] Y. Xie, J. Huang, J. Su, Y. Luo, H. Du, and D. Fan, "Effect of nickel interlayer on laser welding of copper/titanium dissimilar metal joint", J. Mater. Res. Technol., 2023, vol. 27, pp. 4416-4429.