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Effect of GMAW process parameters on the influence of bead geometry and HAZ area on ASTM A516 grade 70 Low alloy Pressure vessel steel

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Abstract: ASTM A516 grade 70 low alloy steels is a pressure vessel grade steels .The present research investigates the effect of GMAW (Gas Metal Arc Welding) process parameters on the bead geometry and HAZ area on 6mm thick plate through bead on plate experiments. The GMAW process parameters such as voltage, welding speed, wire feed rate and their effect are studied. The Taguchi L_9 orthogonal array design is applied for this approach. In this design the three factors with three levels voltage (17, 18,19V), welding speed (600,800,1000mm/min), wire feed rate (50, 60,70mm/s) are used for investigation. ANOVA (Analysis of variance) was used in this study to find the most significant parameters. The results from Taguchi analysis indicated that the parameters under consideration have an influence in the bead geometry and HAZ area. ANOVA result showed that the parameter wire feed rate was the most significant parameter which influence bead height and depth of penetration .The Bead Width is dominated by the voltage influence and wire feed rate being the most influential parameter on HAZ area.

Key words: GMAW (Gas Metal Arc Welding); ASTM A516; Taguchi; Bead geometry; HAZ area.

1 Introduction

ASTM A516 grade 70 is a custom made steel grade for pipeline and pressure vessel fabrication. The steel belongs to a family of alloys known as low alloy steels and these steels have a variety of alloying elements and contain carbon level between 0.05% to 0.25%. According to ASTM A20/A20M-14 the recommended method for fabrication of the pressure vessel is welding. The A516 is tailor made to work in extremely low temperatures (-29˚C) and has a good notch sensitivity at low temperature. The A516 has good weld ability since its carbon equivalent value is 0.42%. The SAW (Submerged Arc Welding) is a commonly used welding process for the SA 516.From the literature survey the effects of SAW on A516 are studied. Datta et al. [1] indicated about the problem of powdered flux disposal in SAW process which can cause pile up waste flux. J.Amaine et al.[2] proposed that unwanted phase transformations and variation in the local chemical composition occur in SAW due to the high heat input this affects the microstructure of the welding. R.S.Chandel et al.[3] investigations conclude the formation of coarse grain ferrite was caused by presence of high amount of oxygen and molybdenum and they affected the low temperature notch sensitivity A516.

To overcome these limitations of SAW the current research focuses on GMAW (Gas Metal Arc Welding) of A516.The GMAW process uses an inert gas to prevent oxidation of the weld metal instead of a powdered flux this has many advantages in the industry, it has a consumable electrode which provides a good gap bridging ability and welding can be performed in all positions. Improvements in robotic technology and increased requirement of high quality products have increased the versatility of the GMAW process [4]. The automatic GMAW process is more productive than other welding process [5].The GMAW process has various parameters and the current research focuses on the effect of these process parameters on A516 through bead on plate [6,7] welding. Since a weldbead is a non-homogeneous part of a component its quality should be very high and pressure vessels need a great care for quality as they have to encounter high stress concentrations during their operational life cycle. Erdal Karandenziz et al.[8] categorized the parameters into first order adjustable and second order adjustable parameters. Parameters such as welding current, arc voltage, and welding speed belong to the first order. Torch, angle wire stick out, nozzle distance, welding direction position and flow rate belong to second order parameters. P.K.Ghosh and B.K.Rai [9] investigated the effect of various parameters such as voltage, pulsed current, welding speed by bead on plate experiments of pulsed GMAW process.Mario Teske et al.[10]experimented with various compositions of the shielding gases for GMAW process and concluded that Ar+CO_2 mixture has a good penetration the A516.The shielding gas composition and flow rate directly influence the penetration and quality of the welds[10,11].

The microstructure of the weldments is an important area in GMAW process and they are also influenced by the process parameters [12,13].The mechanical properties such as hardness[14],toughness[15]of the welding are directly connected to the microstructure of the weldment . Aloraier A et al. [16] suggested that heat input is influenced by parametric value changes. Y. Shi and Z. Han[17] study show that the toughness and size of the HAZ is affected by the cooling rate and the amount of heat input causes microstructural changes[18,19].M.Shome[20] from his investigation concluded that heat input major impact on the grain size of both SAW and GMAW .Welding parameters affected the low temperature operations of weld metal[17].Establishing a relationship between process parameters and bead geometry is important N.Murugan and R.S.Parmar [21]used a factorial technique in predicting the bead geometry of a GMAW process. H. Huang [22] established a relation between the effects of activated flux on the bead geometry in GMAW process by Taguchi method and W.H.Xu et al.[23] used an numerical model for predicting the bead under cuts in a GMAW process. . The investigation of the parameters will be useful in the application of GMAW process in operations such as Hybrid laser arc welding [24]. To find the effect of process parameters on the bead geometry of A516 low alloy steel through bead on plate experiment Taguchi analysis is used. This would help to perform high quality welds in pressure vessel fabrication.

2 Experimental details

2.1 Taguchi Method

Genichi Taguchi developed a mathematical technique known as Taguchi technique which is widely used in the field of engineering for optimizing the performance characteristics of the design parameter. The Taguchi approach provides a robust design which greatly reduces the manufacturing and developmental cost [1].Taguchi orthogonal array designs is able to determine the main effects with a few experimental runs. The significance of the parameters can be established through ANOVA and optimal combination of process parameters can be predicted by main effects and ANOVA analysis. Taguchi method is a blend of DOE with optimization of control parameters to obtain the best results. For the bead on plate experiments three factor three levels L_9 orthogonal array. The three parameters which were in consideration are the voltage, welding speed, wire feed and the three levels (low, medium, high) are set based on the literature study and **Table1** shows values. L9 notations indicate that three factors and three levels are investigated with nine degrees of freedom **Table 2** displays the Taguchi design. The bead geometry and size of the HAZ are the output parameters for the design. The schematic diagram of the bead geometry is shown in **Fig.1** indicating depth of penetration, bead width, bead height and HAZ area**.**

Table 1.Welding parameters and levels for the experiment

Parameters	Level 1	Level 2	Level 3
Welding speed(mm/min)	600	800	1000
Wire feed rate(mm/sec)	50	60	70
Voltage(V)	17	18	19

Table 2.Experimental Design for Taguchi L_9 orthogonal array

Experiment number	Welding speed (mm/min)	Wire feed rate (mm/sec)	Voltage (V)
1	600	50	17
2	600	60	18
3	600	70	19
4	800	50	18
5	800	60	19
6	800	70	17
7	1000	50	19
8	1000	60	17
9	1000	70	18

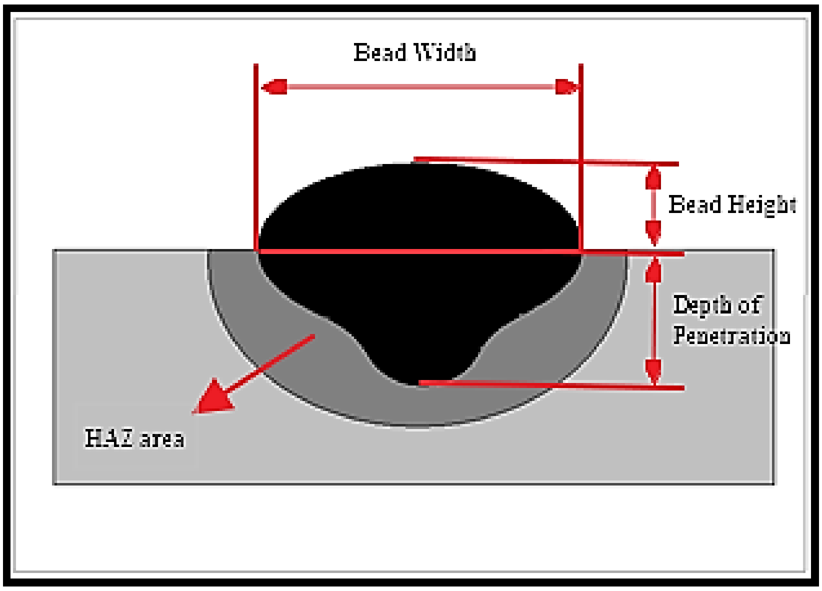

Fig. 1 Schematic Representation of Bead Geometry and HAZ area.

2.2 Materials

The A516 plates used in the bead on plate experiment have a dimension of 270×110×6 mm as shown in **Fig. 2** .The beads are placed at an interval of 20mm between them for analysis and the sample is cleaned with hydrochloric acid to remove rust or stains before the experiment. The chemical composition of the base metal filler wire are shown in **Table 3** and the chemical composition are verified using ASTM 415. ER70-6 copper coated solid wire is used as the filler wire which act as a consumable electrode for the GMAW process. The shielding gas used in the welding process is a mixture of argon and carbon-di-oxide (80%-20%).

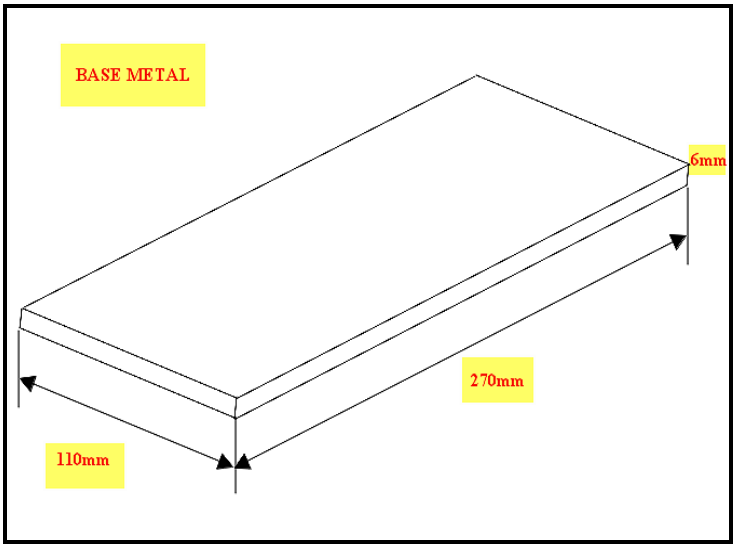

Fig. 2 Schematic Representation of Base Metal

Table 3.Chemical composition for base metal and Solid filler wire

Element%	C	Si	Mn	P	S	Cr	Mo	Ni	Cu	Nb	Ti	V	B	N	Fe
A516	0.222	0.32	1.12	0.13	0.007	0.048	0.006	0.012	0.018	0.014	0.002	0.005	0.001	0.006	98.089
ER70S-6	0.07	0.7	1.05	0.025	0.035	0.10	-	0.05	0.15	-		0.02	-	-	97.80

2.3 GMAW Equipment and Parameters

The GMAW parameters torch angle, wire stick out, standoff distance, gas flow rate and composition whose values remains constant throughout the experiment are shown in **Table 4** and a schematic representation is shown in **Fig. 3**. Kemppi Arc SYN 500 with automatic wire feeder is used to perform GMAW welding. A six axis ABB IRB2600 robot is used for the GMA welding with high precision. The use of a robotic arm provides a good quality and consistent weld bead. The welding was performed based on the parameters set in the Taguchi orthogonal array.

Table 4.Fixed Welding Parameters for GMAW

Parameters	Values
Welding position/direction	1G/Back Hand
Current	200A
Wire stick out	15mm
Standoff distance	2mm
Shielding gas	Argon 80%+CO_2 20%
Shielding gas flow rate	30lit/min
Torch Angle	60

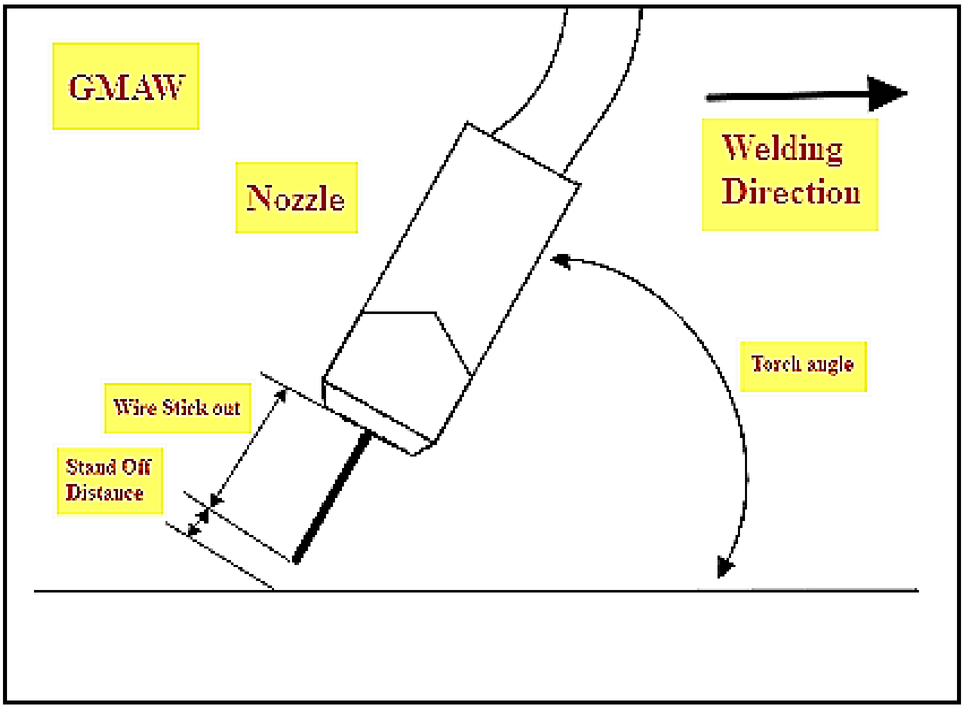

Fig. 3. Schematic Representation of Welding Torch

2.4 Metallography

After the L_9 orthogonal array bead on plate experiments were completed as shown in **Fig. 4**. Nine samples are cut to 15×6×6mm size from each bead using an EzzecutNxg wire cut electrical discharge machine. The samples are used for studying the bead geometry, macrostructure, micro structure and hardness. The ASTM E3-11[25] is used for sample preparation of the metallographic specimens. The specimens are polished using an automatic polishing machine the specimens are etched to reveal the microstructure and macrostructure of the weld bead and the etchant used was nital (2ml con.HNO_3+100ml C_2H_5OH). Immediately after etching the macrostructure of the samples are recorded using Tesa Visio 300 DCC and the geometries are measured.

Fig. 4.Weld Beads on base metal base on L_9 Design

3 Results and Discussion

3.1 Macroscopic analysis

The geometries of the weld beads and area of the HAZ are measured using the Tesa Visio 300 DCC optical coordinate measuring machine interfaced with PC-DMIS Vision software. The macrostructure of the weld beads shows an inverted bell shaped weld penetration with the maximum penetration in the middle of the weld bead this type of bead was witnessed by M. Teske, and F. Martins [6]. These output values are arrived from the macrostructure of the weld bead as shown in **Fig. 5** the images of the transverse cross section of the bead are at 20× magnification**.**

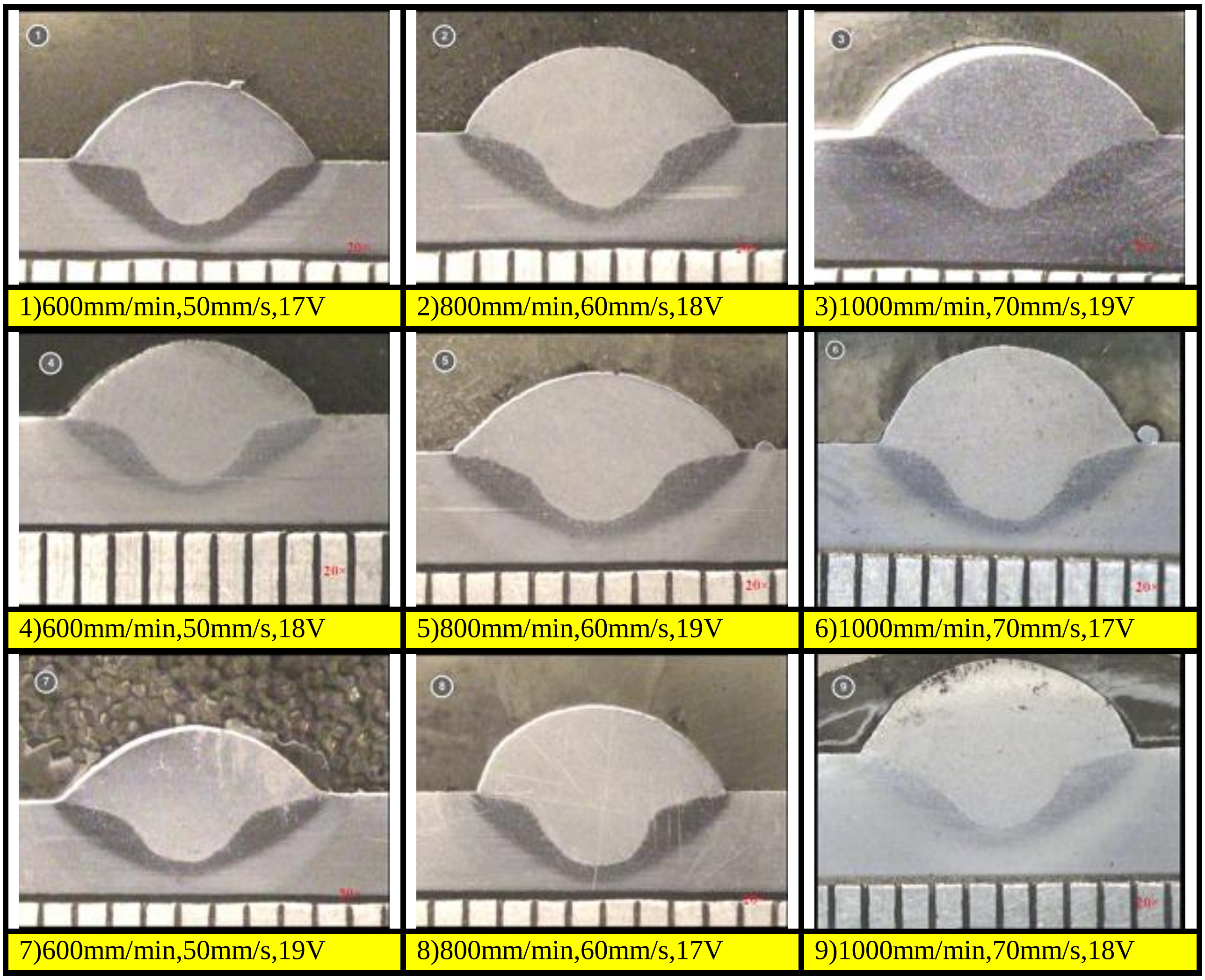

Fig. 5 Macroscopic images of the weld bead cross section

4.2 Taguchi and ANOVA Results

Based on the orthogonal array the experiments are conducted and the values of the output parameters are shown in the **Table 5.** From the output variables the effect of the process parameters on these variables can be identified. The main effects plot for means of depth of penetration, bead width, bead height, HAZ area responses which were measured during macroscopic analysis are plotted for the weld beads. By analyzing these results for the variable input parameters good quality welding can be achieved.

Table 5.Results for Bead Geometry and HAZ area

Experiment number	Welding speed (mm/min)	Wire feed rate (mm/sec)	Voltage (V)	Bead height (mm)	Depth of penetration (mm)	HAZ area (mm)	Bead width (mm)
1	600	50	17	2.235	1.895	5.08	6.5
2	600	60	18	2.285	2.225	5.4	7.265
3	600	70	19	2.49	2.025	6.24	8.31
4	800	50	18	2.105	1.89	4.84	6.775
5	800	60	19	2.33	1.865	6.4	7.74
6	800	70	17	2.71	2.17	5.44	7.08
7	1000	50	19	1.955	1.89	5.36	7.28
8	1000	60	17	2.29	2.13	4.96	6.655
9	1000	70	18	2.635	2.1	6.44	7.5

4.3 Effect of parameters on Depth of penetration

From the main effect plot for means for the penetration **Fig.6a** it has to be established that there was no significant increase in the penetration of the bead with the increase of the weld speed .This was due to the fact that as the welding speed increases the amount of molten filler wire deposited on the base metal was reduced this reduces the heat input to the base metal and therefore the penetration decreases[15]. But when the voltage and wire feed rate gets increased the depth of penetration increases. Increase in penetration due to increase in voltage is attributed to the fact that it increases the heat input and therefore the molten filler wire easily penetrates the base metal and fusion takes place. A high depth of penetration is caused by the high voltage (19V) ANOVA results from the **Table 6a** give the significance of the process parameters on the depth of penetration and wire feed rate has the most significant contribution to the penetration of the weld bead.

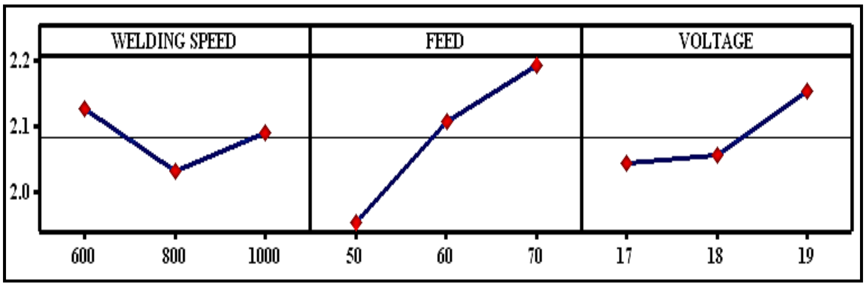

Fig. 6a Main effects plot of means for Depth of penetration

4.4 Effect of parameters on Bead width

Bead Width was greatly influenced by the welding parameters which can be found by using the main effect plot for means as shown in **Fig. 6b** and the welding speed has a profound effect on the bead width, the width of the bead decreases as the speed increases. Weld beads having 1000mm/min have a low bead width compared to the slower speeds. The voltage also influences the bead width and higher voltages causes the bead to widen since higher voltages have high heat input therefore reducing the viscosity of the weld pool and this increases the tendency of the molten filler wire to flow and produce a wider weld bead and this phenomenon was also encountered by N.Murugan and R.S.Parmar [21] .And the high wire feed rate also increases the bead width and the increase was linear in nature from the results. The ANOVA results show that the voltage has the highest contribution with 62% in affecting the bead width which was followed by wire feed rate and welding speed **Table 6b**.

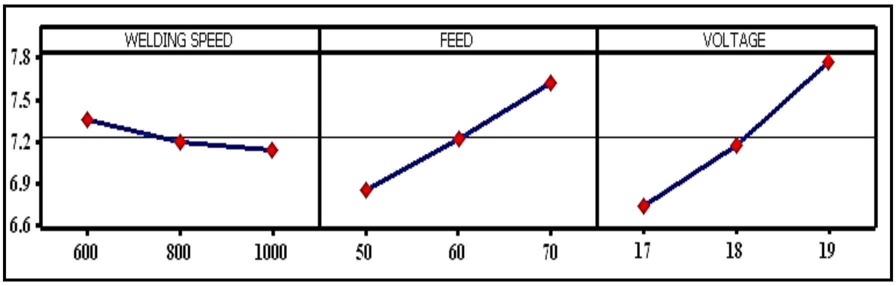

Fig. 6b Main effects plot of means for Bead Width

4.5 Effect of parameters on Bead Height

The results **Fig. 6c** indicate that the lower voltage provides a larger bead and at high voltages the height was small this is due to the fact that from the results of bead width we can say that they both are interrelated [21,23] .Smaller bead height can be achieved by choosing a lower wire feed rate as the high wire feed rate cause a flow of large amounts of molten filler wire it causes an larger bead. While a high welding speed has significantly reduced the bead height from the results obtained. ANOVA results from **Table 6c** shows that the wire feed rate has a significant effect with a contribution of 85.9% on the bead height compared to wire feed rate or welding speed.

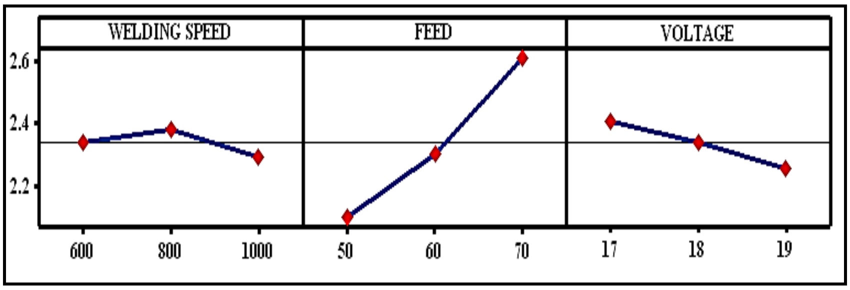

Fig. 6c Main effects plot of means for Bead Height

4.6 Effect of parameters on HAZ area

The HAZ area **Fig. 6d** was influenced by the increase in voltage and the area is larger for higher voltages. The voltage causes high input and this causes the formation of a larger HAZ region the literature survey supports this result [7,21]. The results the welding speed has less significant effect on the HAZ area and for all welding speed the size of HAZ remains similar. The Wire feed rate has significantly influenced the HAZ area and the HAZ area increased with the increase in the wire feed rate, this was due to amount of molten filler on the base metal influences the HAZ area. From the ANOVA results **Table. 6d** the wire feed rate has a greater contribution from than the voltage (56.8%) with a small margin, and we can say that an increase in wire feed rate increases the HAZ area compared to voltage or welding speed and by controlling it the size of the HAZ can be controlled

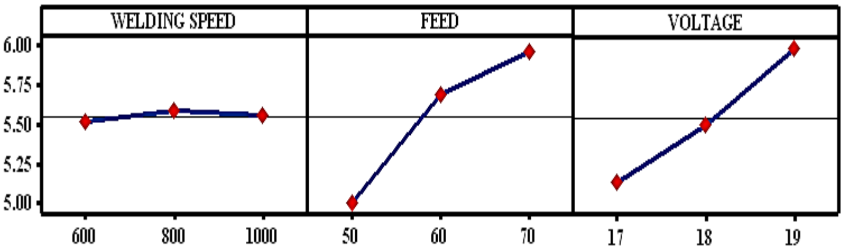

Fig. 6d Main effects plot of means for HAZ area

Table 6a. ANOVA result for Depth of Penetration

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Welding speed	2	0.014155	0.014155	0.007077	6.51	0.133	11.11
Feed	2	0.088758	0.088758	0.044379	40.81	0.024	69.72
Voltage	2	0.022208	0.022208	0.011104	10.21	0.089	17.44
Error	2	0.002175	0.002175	0.001087			1.73
Total	8	0.127296					100

Table 6b. ANOVA result for Bead Width

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Welding speed	2	0.07396	0.07396	0.03698	25.16	0.038	2.8
Feed	2	0.90957	0.90957	0.45479	309.50	0.003	35
Voltage	2	1.60957	1.60957	0.80479	547.68	0.002	62
Error	2	0.00294	0.00294	0.00147			2
Total	8	2.59604					100

Table 6c. ANOVA result for Bead Height

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Welding speed	2	0.011706	0.011706	0.005853	0.63	0.612	2.5
Feed	2	0.400956	0.400956	0.200478	21.75	0.044	85.9
Voltage	2	0.035356	0.035356	0.017678	1.92	0.343	7.5
Error	2	0.018439	0.018439	0.009219			4.1
Total	8	0.466456					100

Table 6d. ANOVA result for HAZ area

Source	DF	Seq SS	Adj SS	Adj MS	F	P	%Contribution
Welding speed	2	0.00740	0.00740	0.00370	0.50	0.668	0.4
Feed	2	1.48987	1.48987	0.74493	100.22	0.010	56.8
Voltage	2	1.10927	1.10927	0.55463	74.61	0.013	42.3
Error	2	0.01487	0.01487	0.00743			0.5
Total	8	2.62140					

5 Conclusion

The present study is on the influence of GMA welding parameters on bead geometry and HAZ area of ASTM A516 grade 70 low alloy steel and the results were analyzed with the help Taguchi orthogonal array design and ANOVA .The following conclusions are arrived through the above results and discussions.

1. The Depth of penetration, bead width and head height are strongly influenced by the welding parameters such as voltage, welding speed and wire feed. While the depth of penetration of the weld bead and bead height are greatly influenced by the wire feed rate than other welding parameters.
2. The voltage was the most influential parameter affecting the bead width and wider beads formed with increase in voltage.
3. HAZ area was affected by the welding parameters with the wire feed rate being the most influential parameter on the size of HAZ.

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