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Investigation of Process Parameters during MIG Welding of AISI1010 Mild Steel Plates

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Abstract - *An attempt is made in the present paper to investigate process parameters like welding current, voltage, welding speed and electrode extension in MIG welding of AISI 1010 Mild Steel plates of thickness 2 mm through the experiments based on design matrix of L16 orthogonal array to obtain high quality weld bead for var752ious engineering applications are having minimum bead width and height, maximum bead penetration and dilution percentage, high weld area hardness and high heat affected zone hardness. Hardness at different zones like parent metal, weld area and heat affected zone has been compared to show weld area hardness is more than parent metal hardness and less than heat affected zone hardness. Effect of process parameters like welding current, voltage, welding speed and electrode extension on various responses like weld area hardness, heat affected zone hardness from hardness test and weld bead width, bead height, bead penetration, dilution percentage from microscopic analysis are investigated and analyzed. Finally significance of process parameters on individual responses has been estimated using ANOVA.*

Key Words: *MIG Welding, AISI 1010 mild steel, Taguchi, ANOVA, MINITAB 16.*

1. INTRODUCTION

Metal Inert Gas (MIG) welding is an arc welding process which produces the coalescences of metals by heating them with an arc between a continuously fed filler metal electrode and the work.

The basic principle of MIG Welding is, an arc is maintained between the end of the consumable electrode wire and the workpiece. A consumable electrode is fed in the form of wire from a spool through the welding gun or torch at a preset controlled speed. As the wire passes through the contact tube of the gun, it picks up the welding current. The consumable wire electrode serves two functions like maintains the arc and provides filler metal to the joint. The arc and the weld pool are shielded from the atmospheric contamination by an externally supplied shield gas. The following Figure-1 shows the MIG welding working principle.

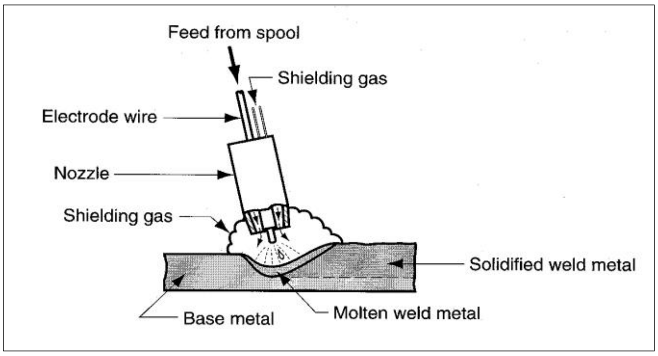

Fig-1: MIG Welding Principle

MIG welding process lends itself to semiautomatic, robotic automation and hard automation of welding applications. The alloying material includes: carbon steel, stainless steel, aluminum, magnesium, copper, Nickel, silicon bronze and tubular metal-cored surfacing alloys. The molten metal at the electrode tip can be transferred to the weld pool by one of four methods: Short circuiting transfer, Globular transfer, Axial Spray transfer, Pulsed Spray transfer.

2. LITERATURE SURVEY

K. Abbasi *et al.*, [1] has investigated the effect of welding speed and heat input rate parameters on depth of penetration and weld width during MIG welding of bright drawn mild steel specimen having 10mm thickness by taking welding current, arc voltage, welding speed, heat input rate as welding parameters. Rakesh kumar *et al.*, [2], Satish kumar *et al.*, has invstigated on mechanical properties of mild steel 1018 during MIG welding and concluded that welding current was the most significant parameter affecting the mechanical properties and hardness of weld joint. Ajay N. Boob *et al* [3], have investigated on MMAW welding process parameter of heat affected zone (HAZ) for mild steel 1005 and found that heat input rate was most significant parameter for controlling width of HAZ. Erdal Karadeniz et al.[5] has investigated the effects of robotic gas metal arc welding parameters for Erdemir 6842 steel having 2.5 mm thickness . The study revealed that increasing welding current increased the depth of penetration. In addition, arc voltage is another parameter in incrimination of penetration.

Shreyash Patel *et al.*, [7], has studied the effect of MIG welding parameters like weld current, weld voltage and weld wire rate on strength and hardness for IS2062 E 250A mild steel and concluded that the wire feed rate has maximum effect on tensile strength and arc voltage has maximum effect on hardness. Merchant Samir Y *et al.*, [8], has studied the effect of MMAW (Manual Metal Arc Welding) process parameters on hardness of heat effected zone for mild steel material. It was observed that hardness of HAZ and weld metal are decreased with increase in welding current due to increase in heat input, but hardness of the joint was increased With increase in welding speed due to decrease in heat input. P.Hema et al.[9],has studied the effect of process parameters on friction stir welded joints of dissimilar Al alloy AA2014 and AA6061 using taper pin profile.

In the present work [12], MIG welding is performed on AISI1010 mild steel plates having 2mm thickness using Industrial robot. Experiments are conducted based on the L16 orthogonal array by varying the different process parameters like current, voltage, welding speed and electrode extension in order to study their effect on output bead quality characteristics like bead width, bead height, bead penetration, dilution percentage, weld area hardness and heat affected zone hardness by using ANOVA [11].

3. EXPERIMENTAL DESIGN FOR PRESENT WORK

The input process parameters which affect the output responses like Bead Width, Bead Height, Bead penetration, Dilution percentage, weld area hardness, heat affected zone hardness are selected. The following Table-1 represents the range and level values of Current(C), Voltage (V), Welding Speed (WS) and Electrode Extension (EE).

Table -1: Process Parameters with Designed Levels

Process Parameters	Range	Level			
		1	2	3	4
Current (A)	80-140	80	100	120	140
Voltage (V)	14-26	14	18	22	26
Welding Speed (cm/sec)	20-35	20	25	30	35
Electrode Extension (mm)	10-16	10	12	14	16

Then the suitable orthogonal array was selected in case of considering four process parameters in four levels and is taguchi L16 orthogonal array. The following Table-2 represents the Experimental design for present work using L16 orthogonal array.

Table -2: Experimental design using L16 orthogonal array

Sample Number	Current (A)	Voltage (V)	Welding Speed (cm/sec)	Electrode Extension (mm)
1	80	14	20	10
2	80	18	25	12
3	80	22	30	14
4	80	26	35	16
5	100	14	25	14
6	100	18	20	16
7	100	22	35	10
8	100	26	30	12
9	120	14	30	16
10	120	18	35	14
11	120	22	20	12
12	120	26	25	10
13	140	14	35	12
14	140	18	30	10
15	140	22	25	16
16	140	26	20	14

4. EXPERIMENTATION

Due to having various engineering applications, AISI 1010 mild steel plates having dimension 120×62.5×2 mm are used as a base material for performing MIG welding and its chemical composition obtained during material conformation test is given in Table.3. Here, ER70S–6 is employed as MIG welding wire.C25 (75% Argon and 25% Carbon dioxide) is selected here as a shielding gas for complete process.

Table -3: AISI1010 Mild Steel chemical composition

Element	Carbon(C)	Manganese(Mn)	Silicon(Si)	Sulphur(S)
(% by weight)	0.11	0.21	0.011	0.008

Type of joint considered is square butt joint with single passing weld by maintaining 0.5 mm root gap throughout the welding. The equipment used consist of mainly OTC DIAHEN, DP 400 AC/DC MIG welding machine and also industrial robot is employed for performing semi-automated robotic based MIG welding. After obtaining the weld joint, the testing of weld bead is performed for estimating the quality of weld bead.

Hardness Test

The VM-50 Vickers hardness testing machine is used for measuring parent metal hardness(H_PM), weld area hardness (H_WA), heat affected zone hardness (H_HAZ) by applying 1 kgf load in 10 seconds. Then observed values of weld area hardness and heat affected zone hardness are listed in Table-4.The parent metal hardness is obtained as same for all sixteen test samples and equal to 153 HV.

Bead Geometry measurement

Specimens are having 1cm × 0.5cm dimension approximately are cut transverse to the welding direction from each welded plates using bench cutting machine. These specimens are cleaned, surface grinded with emery papers, etched with 10% Nital (90% Alcohol and 10% of Nitric acid) and molded using cold mounting acrylic powder and liquid. Then finally fine polished with Alumina paste. Weld bead profiles are traced by using an optical microscope at 20X magnification. Measurements are taken for Bead Width (BW), Bead Height (BH) and Bead Penetration (BP), Area of Penetration (A_P) and Area of Reinforcement (A_R) using AUTO CAD software. Then Dilution Percentage (D_P) is calculated and shown in Table.4, by applying the below equation for measured Area of Penetration (A_P) and Area of Reinforcement (A_R) values.

$$D_P\ (\%) = \frac{A_P}{(A_P + A_R)} \times 100$$

The experimental values representing Bead Width(BW) in mm, Bead height(BH) in mm, Bead Penetration (BP) in mm, Dilution Percentage(DP) in %, Weld Area Hardness(H_WA) in HV and Heat Affected Zone hardness(H_HAZ) in HV are shown in Table.4.

Table -4: Experimental Results

S.NO	BW (mm)	BH (mm)	BP (mm)	D_P (%)	H_WA (HV)	H_HAZ (HV)
1	5.741	2.606	2.696	36.176	268	305
2	4.890	2.750	1.009	20.992	301	378
3	5.893	2.187	0.726	17.553	401	482
4	6.488	1.654	1.651	41.389	291	354
5	6.373	2.755	2.731	40.065	265	317
6	5.706	2.661	2.461	35.382	370	401
7	7.140	1.882	2.058	38.994	257	294
8	4.689	1.987	3.791	75.020	261	297
9	5.967	3.197	2.668	31.081	277	321
10	6.078	2.134	2.965	46.033	307	374
11	7.014	3.281	2.000	36.564	374	417
12	6.660	3.712	2.896	44.545	234	278
13	6.561	2.828	2.596	34.230	276	321
14	5.712	2.639	3.859	65.825	246	308
15	7.001	3.702	2.786	53.066	284	343
16	8.173	3.912	2.079	46.736	261	302

5. RESULTS AND DISCUSSIONS

Analysis of collected experimental data is performed for investigating the effect of process parameters by comparing the hardness test results to show Weld Area Hardness (H_WA) is less than Heat Affected Zone Hardness (H_HAZ) and more than Parent Metal Hardness (H_PM),predicting the optimal process parameters using Taguchi Signal-to-Noise ratio and finally checking the significance of process parameters on individual responses using ANOVA to know the most significant process parameter for every individual response.

5.1 Comparison between Hardness at Various Zones of Weld Joint

Comparison between hardness at different micro-structural zones is performed with Chart-1 to show experimentally that Weld Area Hardness (H_WA) is less than Heat Affected Zone Hardness (H_HAZ) and more than Parent Metal Hardness (H_PM). Hardness during weld joint is not uniform.

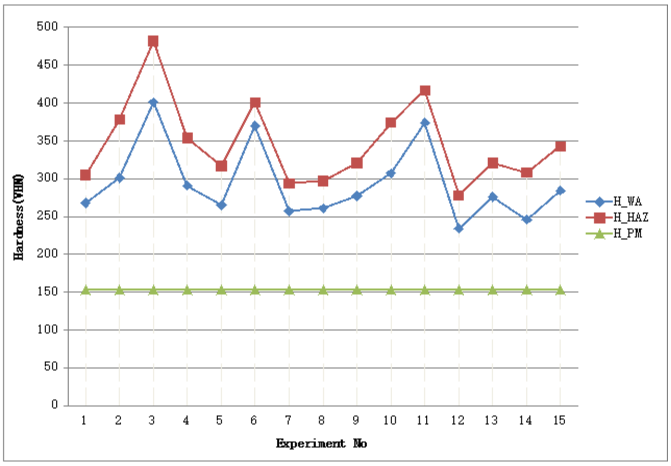

Chart -1: Graph between hardness at various zones of weld joint

The metal of weld joint was having highest temperature that is above melting point and the parent metal was having temperature very less below the lower critical line. The high temperature difference between these two regions leads to very fast cooling rate and the solidification of weld metal was under non equilibrium conditions. Due to high cooling rate in HAZ, from austenite to martensite or binatic lathe micro constituents transformation was occurred and martensite formation gives high hardness. Parent metal is not affected by heat. Therefore hardness in HAZ is more than parent metal and weld area, so HAZ is was become more susceptible to cracking [8,10,12].

5.2 Effect of Process Parameters

The collected experimental data has been analyzed to investigate the effect of process parameters like current, voltage, welding speed, electrode extension for selecting the optimal process parameters and most significant factor for bead quality characteristics like bead width, bead height, bead penetration, percentage dilution, weld area hardness and heat affected zone hardness.The main effects plots are investigated by applying taguchi's smaller-the-better criterion for bead width and bead height to reduce excess weld metal consumption where as higher-the-better criterion for remaining like bead penetration, percentage dilution,

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weld area hardness and heat affected zone hardness in order to increase joint strength. Analysis of Variance (ANOVA) is applied for identifying the most effective or significant process parameter.

The main effect plots show the variation of response on Y-axis with respect to the welding parameters at four levels on X-axis. Analysis of Variance (ANOVA) is carried out at 95% confidence level.

5.2.1 Effect of Process Parameters on Bead Width

The following Table-5 and its corresponding graph in Figure-2 shows the mean values of bead width at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-5: Response Table for Mean Values of Bead Width

Level	Current	Voltage	Welding Speed	Electrode Extension
1	5.753	6.160	6.659	6.313
2	5.977	5.596	6.231	5.789
3	6.430	6.762	5.565	6.629
4	6.862	6.502	6.567	6.291
Delta	1.109	1.166	1.093	0.841
Rank	2	1	3	4

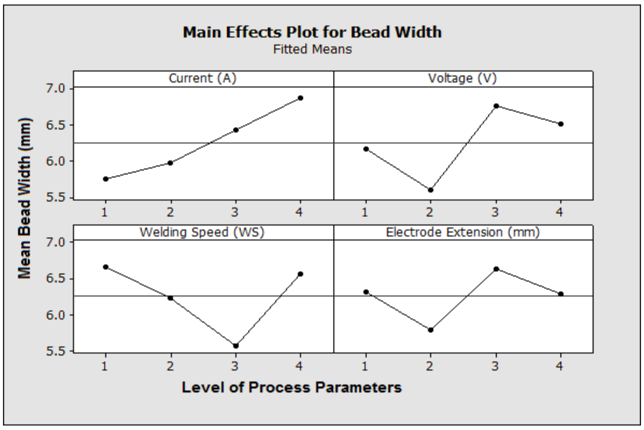

Fig-2: Main Effects Plot for Bead Width by Factor Level

The following Table-6 and its corresponding graph in Figure-3 shows the mean values of signal to noise ratio of bead width at each level of process parameters like current, voltage, welding speed and electrode extension.

Table -6: Response Table for Mean S/N Values of Bead Width

Level	Current	Voltage	Welding Speed	Electrode Extension
1	-15.15	-15.78	-16.37	-15.96
2	-15.43	-14.93	-15.81	-15.12
3	-16.14	-16.58	-14.87	-16.35
4	-16.66	-16.10	-16.33	-15.95
Delta	1.50	1.64	1.50	1.24
Rank	2	1	3	4

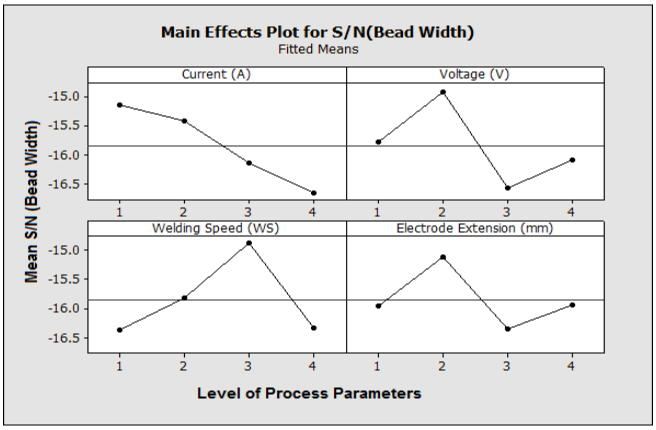

Fig-3: Main Effects Plot for S/N Values of Bead Width by Factor Level

From the above main effects plot analysis on Bead Width, it is observed that minimum Bead Width is obtained at 80A current (C1), 18V voltage (V2), 30 cm/sec welding speed (WS3), 12mm electrode extension (EE2). Decreasing of Bead Width with respect to process parameters is mainly due to low Arc wideness.

The following Table-7 represents the ANOVA results for Bead Width. From the results, it is observed that the Voltage is the most significant parameter of having high percentage contribution and F-value. It means that Voltage should be the first choice for changing Bead width. Since variation of arc width which affects the Bead Width are mainly due to variation of Voltage.

Table -7: ANOVA Table for Bead Width

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F-value	Percentage Contribution (%)
C	3	2.9119	0.9706	2.94	25.67
V	3	3.0434	1.0145	3.07	26.83
WS	3	2.9453	0.9818	2.97	25.97
EE	3	1.4494	0.4831	1.46	12.78
Error	3	0.9918	0.3306	-	8.74
Total	15	11.3418	-	-	100

5.2.2 Effect of Process Parameters on Bead Height

The following Table-8 and its corresponding graph in Figure-4 shows the mean values of Bead Height at each level of process parameters like current, voltage, welding speed and electrode extension.

Table -8: Response Table for Mean Values of Bead Height

Level	Current	Voltage	Welding Speed	Electrode Extension
1	2.299	2.846	3.115	2.710
2	2.321	2.546	3.230	2.712
3	3.081	2.763	2.502	2.747
4	3.270	2.816	2.124	2.803
Delta	0.971	0.300	1.105	0.094
Rank	2	3	1	4

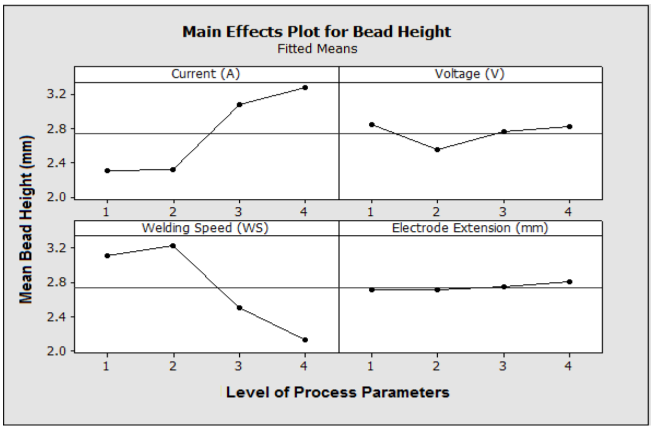

Fig-4: Main Effects Plot for Bead Height by Factor Level

The following Table-9 and its corresponding graph in Figure-5 shows the mean values of signal to noise ratio of bead height at each level of process parameters like current, voltage, welding speed and electrode extension .

Table -9: Response Table for Mean S/N Values of Bead Height

Level	Current	Voltage	Welding Speed	Electrode Extension
1	-7.068	-9.062	-9.747	-8.408
2	-7.190	-8.075	-10.087	-8.525
3	-9.598	-8.495	-7.821	-8.508
4	-10.169	-8.394	-6.369	-8.584
Delta	3.100	0.987	3.718	0.176
Rank	2	3	1	4

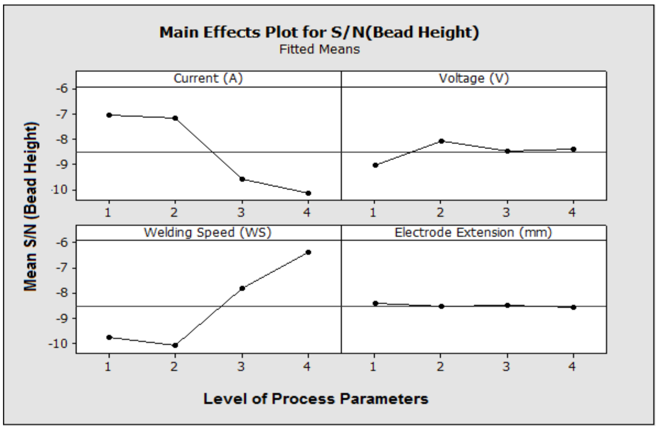

Fig-5: Main Effects Plot for S/N Values of Bead Height by Factor Level

From the main effect plots analysis on Bead Height, it is observed that minimum Bead Height is obtained at 80A current (C1), 18V voltage (V2), 35cm/sec welding speed (WS4),10mm electrode extension (EE1). Decreasing of Bead height with respect to process parameters is mainly due to low Metal Deposition rate.

The following Table-10 represents the ANOVA results for Bead Height. From the results, it is observed that the Welding Speed is the most significant parameter of having high percentage contribution and F-value. It means that Welding Speed has major influence on Bead Height. Since variation of metal Deposition rate which affect the Bead Height are mainly due to variation of Welding Speed.

Table -10: ANOVA Table for Bead Height

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F value	Percentage Contribution (%)
C	3	3.0681	1.0227	8.33	44.19
V	3	0.2211	0.0737	0.6	3.18
WS	3	3.2628	1.0876	8.86	46.99
EE	3	0.0231	0.0077	0.06	0.33
Error	3	0.3682	0.1227	-	5.30
Total	15	6.9433	-	-	100

5.2.3 Effect of Process Parameters on Bead Penetration

The following Table-11 and its corresponding graph in Figure-6 shows the mean values of Bead Penetration at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-11: Response Table for Mean Values of Bead Penetration

Level	Current	Voltage	Welding Speed	Electrode Extension
1	1.521	2.673	2.309	2.877
2	2.760	2.574	2.355	2.349
3	2.632	1.893	2.761	2.125
4	2.830	2.604	2.317	2.392
Delta	1.310	0.780	0.452	0.752
Rank	1	2	4	3

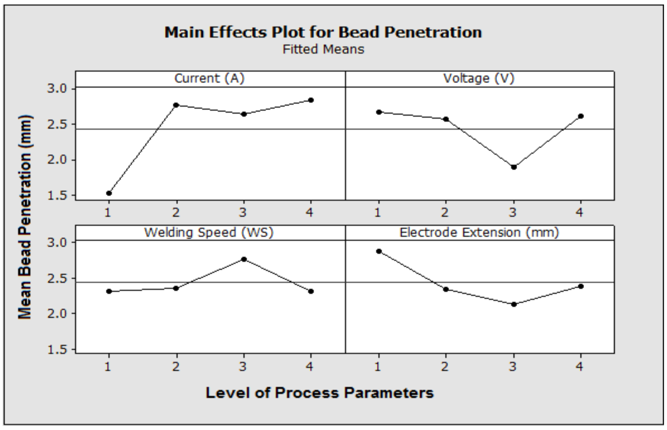

Fig-6: Main Effects Plot for Bead Penetration by Factor Level

The following Table-12 and its corresponding graph in Figure-7 shows the mean values of signal to noise ratio of bead penetration at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-12: Response Table for Mean S/N Values of Bead Penetration

Level	Current	Voltage	Welding Speed	Electrode Extension
1	2.566	8.538	7.204	8.962
2	8.598	7.268	6.735	6.490
3	8.305	4.602	7.262	5.436
4	8.818	7.881	7.088	7.400
Delta	6.252	3.936	0.527	3.527
Rank	1	2	4	3

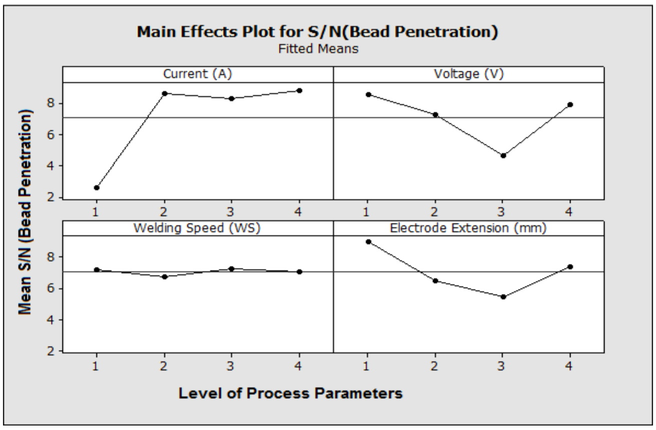

Fig-7: Main Effects Plot for S/N Values of Bead Penetration by Factor Level

From the above main effect plots analysis on Bead penetration it is observed that maximum Bead penetration is obtained at 140A current (C4), 14V voltage (V1), 30 cm/sec welding speed (WS3), 10mm electrode extension (EE1). Increasing of Bead Penetration with respect to process parameters is mainly due to high Arc Deepness.

The following Table-13 represents the ANOVA results for Bead Penetration. From the results, it is observed that the Current is the most significant parameter of having high percentage contribution and F-value. It means that Current is most effective in controlling Bead Penetration. Since variation of Arc deepness which affect the Bead Penetration are mainly due to variation of current.

Table-13: ANOVA Table for Bead Penetration

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F value	Percentage Contribution (%)
C	3	4.5481	1.5160	1.61	42.32
V	3	1.5946	0.5315	0.56	14.84
WS	3	0.5691	0.1897	0.2	5.30
EE	3	1.2033	0.4011	0.42	11.20
Error	3	2.8315	0.9438	-	26.35
Total	15	10.7467	-	-	100

5.2.4 Effect of Process Parameters on Dilution Percentage

The following Table-14 and its corresponding graph in Figure-8 shows the mean values of Dilution Percentage at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-14: Response Table for Mean Values of Dilution Percentage

Level	Current	Voltage	Welding Speed	Electrode Extension
1	29.03	35.39	38.71	46.39
2	47.37	42.06	39.67	41.70
3	39.56	36.54	47.37	37.60
4	49.96	51.92	40.16	40.23
Delta	20.94	16.53	8.66	8.79
Rank	1	2	4	3

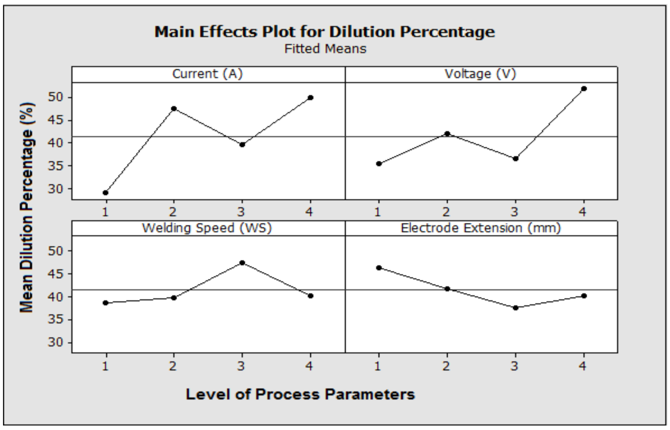

Fig-8: Main Effects Plot for Dilution Percentage by Factor Level

The following Table-15 and its corresponding graph in Figure-9 shows the mean values of signal to noise ratio of Dilution Percentage at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-15: Response Table for Mean S/N Values of Dilution Percentage

Level	Current	Voltage	Welding Speed	Electrode Extension
1	28.71	30.94	31.70	33.08
2	33.09	31.76	31.49	31.47
3	31.84	30.62	32.15	30.90
4	33.74	34.05	32.03	31.91
Delta	5.03	3.44	0.66	2.18
Rank	1	2	4	3

From the main effects plot analysis on Dilution Percentage, it is observed that maximum Dilution Percentage is obtained at 140A current (C4), 26V voltage (V4), 30 cm/sec welding speed (WS3), 10mm electrode extension (EE1). Increasing of Dilution Percentage with respect to process parameters is mainly due to high Arc Deepness & high Metal Deposition rate.

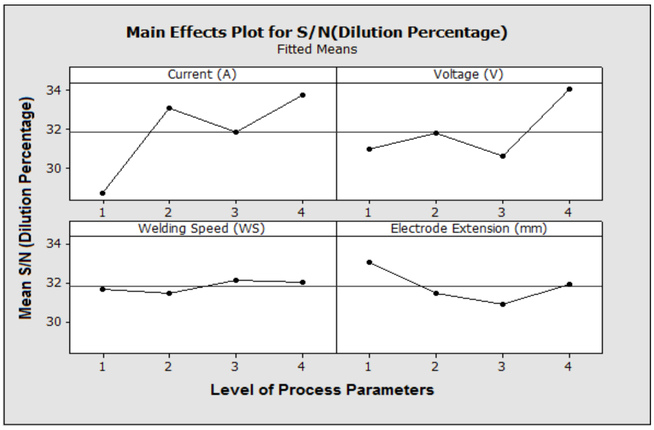

Fig-9: Main Effects Plot for S/N Values of Dilution Percentage by Factor Level

The following Table-16 represents the ANOVA results for Dilution Percentage. From the results, it is observed that the Current is the most significant parameter of having high percentage contribution and F-value. It means that Current has major influence on Dilution Percentage. Since variation of both Arc deepness and metal deposition rate which affect the Dilution Percentage are mainly due to variation of current.

Table-16: ANOVA Table for Dilution Percentage

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F value	Percentage Contribution (%)
C	3	1061.5	353.8	1.00	33.59
V	3	683.4	227.8	0.64	21.63
WS	3	189.5	63.2	0.18	6.00
EE	3	163.0	54.3	0.15	5.16
Error	3	1062.8	354.3	-	33.63
Total	15	3160.2	-	-	100

5.2.5 Effect of Process Parameters on Weld Area Hardness

The following Table-17 and its corresponding graph in Figure-10 shows the mean values of Weld Area Hardness at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-17: Response Table for Mean Values of Weld Area Hardness

Level	Current	Voltage	Welding Speed	Electrode Extension
1	315.3	271.5	318.3	251.3
2	288.3	306.0	271.0	303.0
3	298.0	329.0	296.3	308.5
4	266.8	261.8	282.8	305.5
Delta	48.5	67.3	47.3	57.3
Rank	3	1	4	2

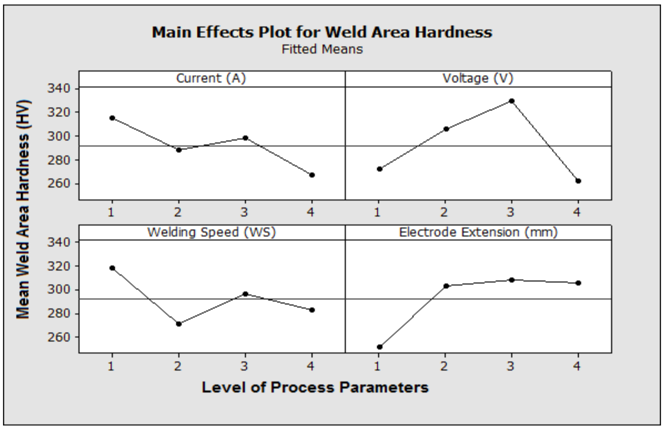

Fig-10: Main Effects Plot for Weld Area Hardness by Factor Level

The following Table-18 and its corresponding graph in Figure-11 shows the mean values of signal to noise ratio of Weld Area Hardness at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-18: Response Table for Mean S/N Values of Weld Area Hardness

Level	Current	Voltage	Welding Speed	Electrode Extension
1	49.87	48.67	49.93	47.99
2	49.09	49.62	48.62	49.54
3	49.36	50.20	49.27	49.65
4	48.51	48.33	49.01	49.64
Delta	1.36	1.86	1.31	1.66
Rank	3	1	4	2

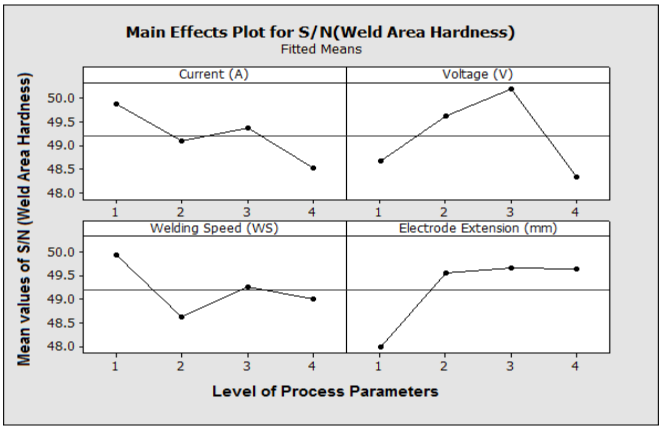

Fig -11: Main Effects Plot for S/N Values of Weld Area Hardness by Factor Level

From the above main effects plot analysis on weld area hardness, it is observed that weld area hardness is maximum at 80A current (C1), 22V voltage (V3), 20 cm/sec welding speed (WS1), 14 mm electrode extension (EE3). Increasing of Weld Area Hardness with respect to process parameters is mainly due to low Heat input.

The following Table-19 represents the ANOVA results for Weld area Hardness. From the results, it is observed that the Voltage is the most significant parameter of having high percentage contribution and F-value. It means that Voltage is most effective in controlling Weld Area Hardness. Since variation of Heat input which affect the Weld area Hardness are mainly due to variation of voltage.

Table-19: ANOVA Table for Weld Area Hardness

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F-value	Percentage Contribution (%)
C	3	4913	1638	0.97	13.85
V	3	11601	3867	2.28	32.70
WS	3	4935	1645	0.97	13.91
EE	3	8944	2981	1.76	25.21
Error	3	5080	1693	-	14.32
Total	15	35473	-	-	100

5.2.6 Effect of Process Parameters on Heat Affected Zone Hardness

Table following Table-20 and its corresponding graph in Figure-12 shows the mean values of Heat Affected Zone Hardness at each level of process parameters like current, voltage, welding speed and electrode extension

Table-20: Response Table for Mean Values of Heat Affected Zone Hardness

Level	Current	Voltage	Welding Speed	Electrode Extension
1	379.8	316.0	356.3	296.3
2	327.3	365.3	329.0	353.3
3	347.5	384.0	352.0	368.8
4	318.5	307.8	335.8	354.8
Delta	61.3	76.3	27.3	72.5
Rank	3	1	4	2

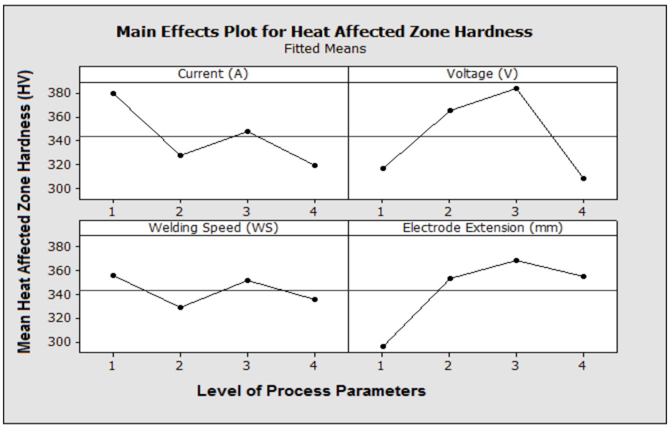

Fig-12: Main Effects Plot for Heat Affected Zone Hardness by Factor Level

The following Table-21 and its corresponding graph in Figure-13 shows the mean values of signal to noise ratio of Heat Affected Zone Hardness at each level of process parameters like current, voltage, welding speed and electrode extension.

Table-21: Response Table for Mean S/N Values of Heat Affected Zone Hardness

Level	Current	Voltage	Welding Speed	Electrode Extension
1	51.47	49.99	50.94	49.43
2	50.23	51.21	50.29	50.88
3	50.72	51.53	50.75	51.18
4	50.05	49.73	50.48	50.97
Delta	1.42	1.81	0.65	1.76
Rank	3	1	4	2

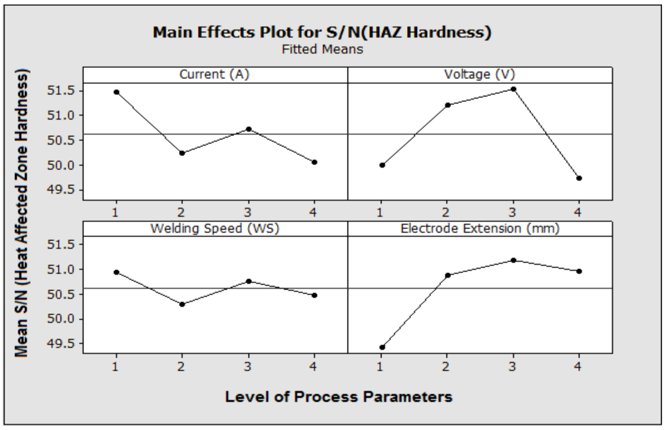

Fig-13: Main Effects Plot for S/N Values of Heat Affected Zone Hardness by Factor Level

From the main effects plots analysis on Heat Affected Zone Hardness, it is observed that Heat Affected Zone Hardness is maximum at 80A current (C1), 22V voltage (V3), 20 cm/sec welding speed (WS1), 14 mm electrode extension (EE3). Increasing of Heat Affected Zone Hardness with respect to process parameters is mainly due to low Heat input.

The following Table-22 represents the ANOVA results for Heat Affected Zone Hardness. From the results, it is observed that the Voltage is the most significant parameter of having high percentage contribution and F-value. It means that Voltage is most effective in controlling Heat Affected Zone hardness. Since variation of Heat input which affect the Heat Affected Zone Hardness are mainly due to variation of voltage.

Table-22: ANOVA Table for Heat Affected Zone Hardness

Source	Degrees of Freedom	Sum of squares	Mean of Squares	F-value	Percentage Contribution (%)
C	3	8876	2959	1.66	19.64
V	3	16589	5530	3.10	36.70
WS	3	2019	673	0.38	4.47
EE	3	12366	4122	2.31	27.36
Error	3	5353	1784	-	11.84
Total	15	45203	-	-	100

3. CONCLUSIONS

- MIG welding is performed on AISI1010 Mild steel plates of 2 mm thickness.
- Microscopic study is performed for measuring Bead Width, Bead Height, Bead Penetration and Percentage Dilution.
- Vickers hardness test is performed for measuring Hardness at Weld Area, Parent metal, Heat affected Zones. The test results reveals that Weld Area Hardness is much higher than parent metal hardness and less than Heat affected zone Hardness.
- Selected parameters and most effective process parameter for every individual response like Bead Width(BW), Bead Height(BH), Bead Penetration(BP), Percentage Dilution(DP), Weld Area Hardness(H_WA), Heat Affected Zone Hardness (H_HAZ) are identified as listed in Table.25.

Table-25: Optimal Levels and Most Effective Process Parameters

Response	Optimal Process Parameters with their Level				Most Effective Factor
	Current (A)	Voltage (V)	Welding Speed (cm/sec)	Electrode Extension (mm)	
BW	80 (C1)	18 (V2)	30(WS3)	12 (EE2)	Voltage
BH	80 (C1)	18 (V2)	35(WS4)	10(EE1)	Welding Speed
BP	140(C4)	14(V1)	30(WS3)	10 (EE1)	Current
D_P	140(C4)	26 (V4)	30(WS3)	10(EE1)	Current
H_WA	80(C1)	22(V3)	20(WS1)	14(EE3)	Voltage
H_HAZ	80 (C1)	22 (V3)	20(WS1)	14 (EE3)	Voltage

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