Effect of Parameters on Weld Pool Geometry in 202 Stainless Steel Welded Joint Using Tungsten Inert Gas (TIG) Process

Mukesh, Sanjeev Sharma

Abstract*: *Tungsten inert gas welding is found important in those applications where it is required to control the weld bead shape and metallurgical characteristics. To consider the quality characteristics, Taguchi method is applied in order to analyze the effect of each welding process parameters on the weld geometry. Orthogonal array L9 is applied for conduct the experimentation. Three input machine parameters namely current, welding speed and gas flow rate were varied at three different levels to find out the influence of parameters on weld bead geometry i.e. weld bead width and weld bead height. The quality and accuracy of the weld joint was studied along with microstructure.

This paper deals with the study of weld bead geometry of austenitic stainless steel 202 using tungsten inert gas (TIG) welding. Experimental results are provided to illustrate the proposed approach and an optimal value of 0.35 mm is obtained in case of weld bead height and 8.63 mm in weld bead width. Microstructure of weld metal structure shows delta ferrite in matrix of austenite.

Keywords: GTAW welding, Stainless steel 202, TIG welding, Weld bead geometry, Taguchi method.

I. INTRODUCTION

Austenitic stainless steel is mostly used in petrochemical, chemical and power engineering, also in vehicle and aviation industries. [1] Stainless steel is used when both the properties of steel and resistant to corrosion are required. The welding of automotive exhaust gas systems, stainless steel pipes, repairing of chemical industries equipments, etc. are done with the help of Tungsten Inert Gas Welding (TIG) [2]. Tungsten inert gas welding is one of the most commonly used welding methods. It is also used to weld stainless steel, steel, nickel alloys, as titanium, aluminum, copper, bronze and even gold. It can also weld dissimilar metals to one another such as stainless steel to mild steel and copper to brass [3]. TIG welding is also known as Gas tungsten arc welding (GTAW). It uses a non-consumable tungsten electrode and an inert gas for arc shielding. [4, 5] Argon is used as a shielding gas in this process and an electric arc is formed between the base metal and tungsten electrode. The welding parameters affect the weld bead formed during welding and quality is characterized by weld pool geometry Therefore, for obtaining optimal weld pool geometry, it is important to select the welding process parameters [6-8].

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Three weld parameters such as welding current, gas flow rate and welding speed must be maintained in a narrow range in order to achieve acceptable weld bead.

Jaung & Tarng (2000) observed optimal weld pool geometry by using TIG welding on stainless steel plate by varying flow rate, arc gap, welding current and welding speed to conclude the results for front width, front height, back width and back height. The results showed that the smaller the better quality characteristics are better used in the analysis of S/N ratio and analysis of variance (ANOVA) [9]. The effect of specific fluxes was investigated by Chern and Tseng (2010) in which oxide powders were applied on the specimen. The results showed that using SiO_2, MoO_3 and Cr_2O_3 fluxes lead to a significant increase in the penetration capability of TIG weld along with the weld depth to width ratio, joint penetration and mechanical strength. [10]. Yan (2009) investigated the mechanical properties and microstructure of stainless steel and results showed that the microstructure consists of delta ferrite and gamma ferrite phase. [11]. Morisada (2012) showed the effect and use of high frequency tungsten inert gas welding method in order to decrease the blow holes in a weld [12]. The hardness of the weld metal was lower than that of the heat affected zone (HAZ) metal area and heat affected zone was lower than that of base metal concluded by Durgutlu (2003) in the research where he observed that increasing hydrogen content in the shielding gas reduced the mechanical properties [13]. Kang (2008) analyzed the effect of alternate supply of method of shielding gases in austenitic stainless steel using Gas tungsten arc welding and concluded that welding speed of Ar+67 % He was more than that of supplying alone argon (Ar) but less than Ar ::He ratio [14].

II. EXPERIMENTAL PROCEDURE

In the present work, weld pool width and height of the specimen 202 stainless steel welded by TIG welding method are evaluated. Taguchi methodology is used to determine the welding parameters with the best optimal weld pool geometry. As Taguchi method [15-16] is a systematic application of design and analysis of experiments for designing purposes and product quality improvement. Taguchi method [17] becomes a powerful tool for improving productivity in recent years during research and development in order to produce high quality products quickly along with a low cost. Various types of tungsten electrodes are used in TIG welding process. Ceriated type of tungsten electrode of gray color is similar in performance as that of thoriated tungsten electrode due to good arc stability, long life and easy arc starting.

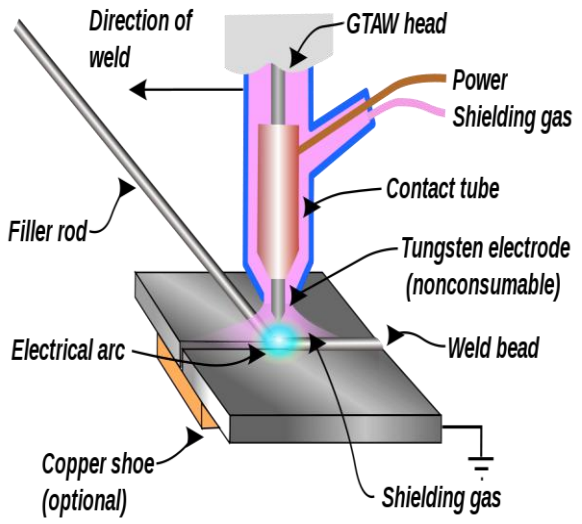

Fig. 1 Schematic diagram for TIG welding

A non-consumable tungsten electrode shielded by inert gas is used to strike an electric arc with the base metal as shown in Figure 1. The heat generated by the electric arc is used to melt and joint the base metal. As discussed earlier, Taguchi Approach is applied in this process for the analysis. It is one of the most important quality engineering method and a statistical tool used for designing high quality system at reduced costs. It helps to determine best level of the parameter used to analyze the best performance of the process.

(a) Taguchi approach

The most important statistical tool of total quality management for designing high quality systems at reduced costs is Dr. Taguchi quality engineering method. Optimization of process parameters improve the quality characteristics and optimal process parameters obtained from Taguchi method inconsiderate to variations of noise factors and other environmental conditions. When number of process parameters increase, then a large number of experiments have to be carried out. In order to solve this task, Taguchi method uses a method based on orthogonal array experiments which gives much reduced variance for the experiment with optimum settings of control parameters. Orthogonal Arrays provide a set of well balanced minimum experiments and Dr. Taguchi's Signal-to-Noise ratios (S/N) helps in data analysis and prediction of optimum results. Taguchi method divides all problems into two categories – static o dynamic. While the dynamic problems have a signal factor, the Static problems do not have any signal factor. In Static problems, the optimization is achieved by using three Signal-to-Noise ratios i.e. smaller-the-better characteristics, larger-the-better characteristics and nominal-the-best characteristics [16]. Figure 2 shows the steps involved in Taguchi procedure.

(b) Experimentation

Grade 202 stainless steel plate was selected for the study cut in the dimension of 100 × 50 × 6 mm for conduct the experiments. The chemical composition by weight percentage of Stainless Steel 202 sheet of 6 mm thickness is shown in Table 1

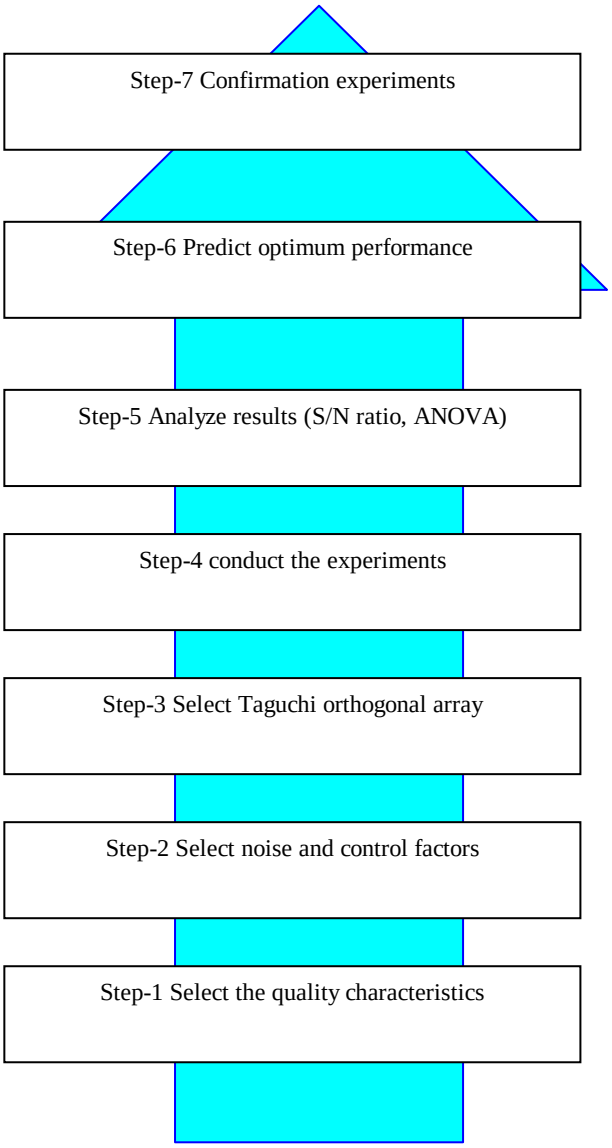

Fig 2: Steps for Taguchi analysis

Table 1 Chemical Composition of SS202

Material SS 202	Cr %	Ni %	C %	Mn %	Si %	P %	S %	N %
	17.1	4.1	0.15	9.25	0.51	0.06	0.03	0.25

Three parameters were selected such as gas flow rate, current and welding speed for weld the samples according the L9 matrix. Argon gas is used as a shielding gas in order to protect the welded area from the atmospheric gases such as nitrogen, oxygen, carbon dioxide and water vapors. The identified factors with their levels are shown in Table 2 and Table 3 shows the standard L9 array.

Table 2 Identified factors with levels

Input Parameter	Unit	Levels		
		1	2	3
Current	Amp	130	170	210

Gas flow rate	Litres/min	10	12	14
Welding Speed	mm/min	180	190	200

Table 3 L9 Orthogonal Array

Experiment No.	Welding Current	Gas Flow Rate	Welding Speed
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1

TIG welding has been performed on SS 202 grade steel for complete the experiment. In welding process, the cut and v-grooved samples were welded at different values of current, gas flow rate and welding speed as per array to finish the nine experiments. The matrix of L9 with actual value of parameters is shown in Table 4.

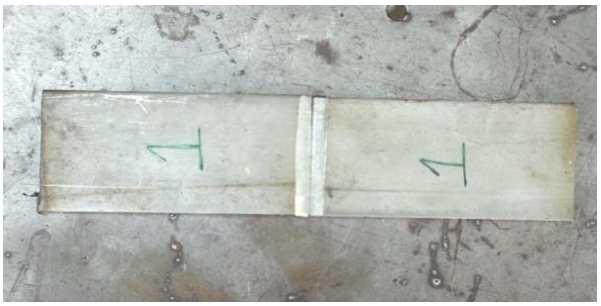

Fig 3 (a): Sample of SS202 showing V-notch before welding

Fig 3 (b): Welded sample after TIG welding

The Figure 3 (a) shows the specimen with V- notch before welding and Figure 3 (b) shows the welded sample of stainless steel 202 after TIG welding .In the same way all the nine samples are weld using different parameters and levels as shown in Table 4.

The ranges of welding parameters were fixed by conducting trial runs. The trial run was carried out by varying one of the factors and keeping all others as constant. Each process parameter was determined by inspecting the weld bead for a smooth fine appearance without any visible defects such as undercuts, porosity, etc. The welding set up used in the study to perform the experiments was shown in Figure 4 (a, b)

Table 4 L9 control log table with parameters and levels value

Experiment No.	Welding Current (amp)	Gas Flow Rate (l/min)	Welding Speed (mm/sec)
1	130	10	180
2	130	12	190
3	130	14	200
4	170	10	190
5	170	12	200
6	170	14	180
7	210	10	200
8	210	12	180
9	210	14	190

Table 4 shows Orthogonal array having different value of all input parameters i.e. welding current as 130, 170 & 210 amp, gas flow rate as 10,12 & 14 l/min and welding speed as 180,190 & 200 mm/sec

Fig 4(a) **Fig 4(b)**

Fig 4 (a): TIG welding machine, (b) Argon gas cylinder.

Figure 4 shows the TIG welding machine setup along with the argon gas cylinder. A pressure regulator valve is attached with the gas cylinder in order to regulate the pressure according to the requirement. Figure 4 (a) shows the knob at 130 amp indicating the value of the current.

The thickness of sheet 6 mm is welded and weld profile obtained is shown in Figure 5. The depth of penetration (D) is 4.70 mm

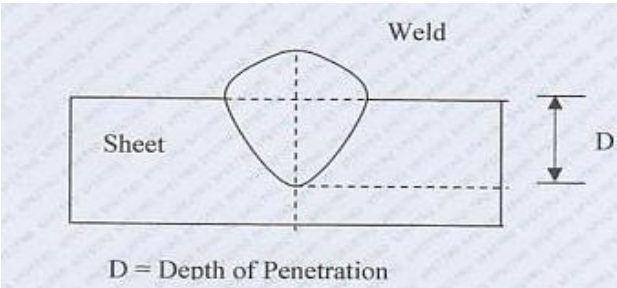

Fig 5: Weld profile showing depth of penetration

Analysis of variance technique (ANOVA) was used in order to check the adequacy of the model. As per this technique the calculated value of the F-ratio should not exceed the standard value of the F-ratio for a desired level of confidence i.e. 95 % and calculated value of the R-ratio should exceed the standard tabulated value for same level of confidence.

Table 5 Results of weld bead width

Trial N0.	Observations			S/N ratio (dB)	Average
	R_1	R_2	R_3		
1	7.28	8.91	9.70	-18.7790	8.6300
2	7.89	8.81	10.76	-19.3052	9.1533
3	9.25	9.90	10.71	-19.9750	9.9533
4	9.29	9.91	10.10	-19.8004	9.7667
5	8.11	9.83	11.58	-19.9490	9.8400
6	9.54	9.87	10.13	-19.8684	9.8467
7	9.46	10.05	10.50	-20.0026	9.9933
8	10.51	10.80	11.51	-20.7867	10.9400
9	12.10	12.59	12.85	-21.5133	12.5133

Table 6 Results of weld bead height

Trial N0.	Observations			S/N ratio (dB)	Average
	R_1	R_2	R_3		
1	0.37	0.54	0.63	5.60457	0.51333
2	0.90	1.07	1.20	-0.53706	1.05667
3	0.47	0.91	1.07	1.35904	0.81667
4	0.31	0.37	0.51	7.84186	0.39667
5	0.81	1.23	1.37	-1.29894	1.13667
6	0.37	0.43	0.50	7.19877	0.43333
7	0.50	0.57	0.76	4.15480	0.61000
8	0.37	0.45	0.73	5.36455	0.51667
9	0.36	0.69	1.24	1.46038	0.76333

The effects of various current, gas flow rate and different welding speed on austenitic SS202 is analyzed. The experimental results of weld bead width and weld bead height with S/N ratio are tabulated in Table 5 and 6 respectively. The calculated value of Signal-to Noise ratio (S/N) and mean is also displayed for all nine samples. The R1, R2 and R3 represent the repetition of the experiments.

III. RESULTS

Figure 2 shows the steps involved in the Taguchi analysis. Analysis of variance (ANOVA) is a statistical tool used to analyze the S/N ratios. In ANOVA setting, the observed variance in a particular variable is partitioned into components attributable to different sources of variation. Analysis of variance technique is used in order to check the adequacy of the model. The term "signal" represents the desirable mean value, and the "noise" represents the undesirable value. Hence, the S/N ratio represents the amount of variation, which presents in the performance characteristics. The optimal combination levels of the control parameters to optimize the material removal rate were determined from the S/N ratios response graphs.

In the present study weld bead width and weld bead height of the weld specimens were identified as the responses, therefore, "smaller the better" (SB) characteristic chosen for analysis purpose.

$$SB: S/N\ ratio(\eta) = -10\log_{10}\left[\frac{1}{n}\sum_{i=1}^{n} yi^2\right]$$

Where yi represents the experimentally observed value of the ith experiment, n is the repeated number of each experiment. The unit of calculated S/N ratio from the observed values is decibel (dB).

A. Weld bead width

Weld bead width of the weld pool belong to the smaller the better characteristics. Taguchi method is applied and analysis is done with the help of ANOVA. On the basis of data analyzed, graph of mean and signal-to-noise (S/N) ratio is formed as shown in Figure 6 and Figure 7 and calculated value of analysis of variance and response table for mean and signal-to noise ratio is written.

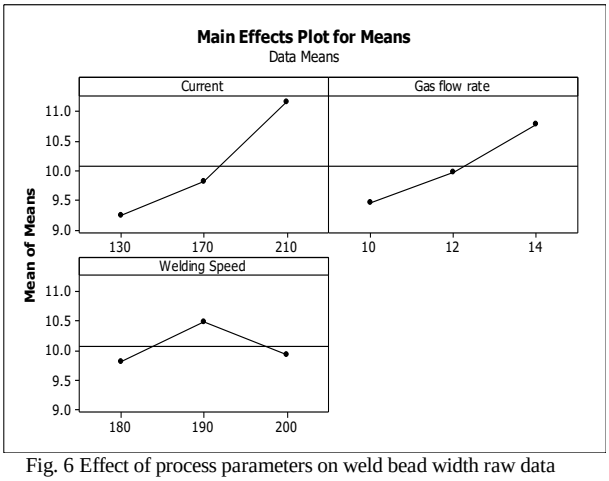

Fig. 6 Effect of process parameters on weld bead width raw data

The plot for means for weld bead width shows that mean value increased with the increase in current from 130 amp to 210 amp as shown and increased in gas flow rate from 10 to 14 l/min but it first increased from 180 mm/sec to 190 mm/sec and then decreased from 190 mm/sec to 200 mm/sec in case of welding speed. In case of S/N ratio, the S/N ratio decreased with the increase of current and gas flow rate as shown but in case of welding speed it decreased from 180 mm/sec to 190 mm/sec and then increased from a welding speed of 190 mm/sec to 200 mm/sec. The optimal results for means and S/N ratio of weld bead width is $A_1B_1C_1$ i.e. welding current at 130 amp, gas flow rate at 10 l/min and welding speed at 180 mm/sec and also shown in Table 7 and 8.

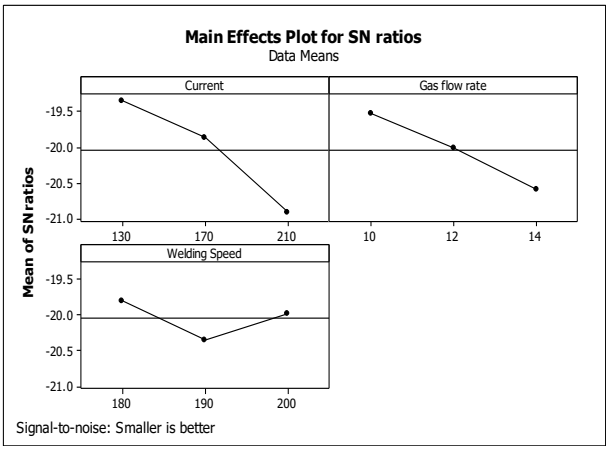

Fig. 7 Effect of process parameters on weld bead width S/N ratio

Table 7 Analysis of Variance for SN ratios of weld bead width

Source	DF	Seq SS	Adj SS	Adj MS	F	Pc
Current	2	3.7866	3.7866	1.8933	8.13	58.82
Gas flow rate	2	1.7238	1.7238	0.8619	3.70	26.78
Welding speed	2	0.4608	0.4608	0.2304	0.99	7.15
Residual Error	2	0.4656	0.4656	0.2328	-	-
Total	8	6.4367	-	-	-	-

Table 8 Analysis of Variance for Means of weld bead width

Source	DF	Seq SS	Adj SS	Adj MS	F	Pc
Current	2	5.722	5.722	2.86	7.53	58.06
Gas flow rate	2	2.604	2.604	1.30	3.43	26.42
Welding speed	2	0.768	0.768	0.38	1.01	7.79
Residual Error	2	0.760	0.760	0.38	-	-
Total	8	9.854	-	-	-	-

The response values for S/N ratio and raw data for each level of identified factors have been listed in Table 9 and 10 respectively which shows the factor level values of each factor and their ranking.

Table 9 Response table for Signal to Noise Ratios of weld bead width
For Smaller the better characteristic

Level	Current	Gas flow rate	Welding speed
1	-19.35	-19.53	-19.87
2	-19.87	-20.01	-20.35
3	-20.91	-20.60	-19.98
Delta	1.56	1.07	0.54
Rank	1	2	3

Table 10 Response Table for Means of weld bead width

Level	Current	Gas flow rate	Welding speed
1	9.246	9.463	9.806
2	9.818	9.978	10.478
3	11.149	10.771	9.929
Delta	1.903	1.308	0.672
Rank	1	2	3

The results showed that an optimal value of 8.63 mm is obtained and considered to be the best. Similarly the mean and S/N ratio plots of weld bead height is shown in Figure 6 & 7 and calculated value of analysis of variance and response for mean and signal-to- noise ratio is shown in Table 7, 8, 9, 10 respectively. Analysis of variance for S/N ratio and means shows that welding current plays a major role as it has highest percentage contribution compared to others i.e. 58.82 %. Optimal value for weld bead width is $A_1B_1C_1$ i.e. welding current at 130 amp, gas flow rate at 10 l/min and welding speed at 190 mm/sec.

B. Weld bead height

The graph of means for weld bead height shows that weld bead height decreased rapidly with the increased current up to 170 amp and decreased slowly up to 210 amps. The effect of gas flow rate shows that welds bead height first increased up to 12 l/min and then decreased to 14 l/min. The welding current effect indicates that it increased from 180 mm/min to 200 mm/min as shown

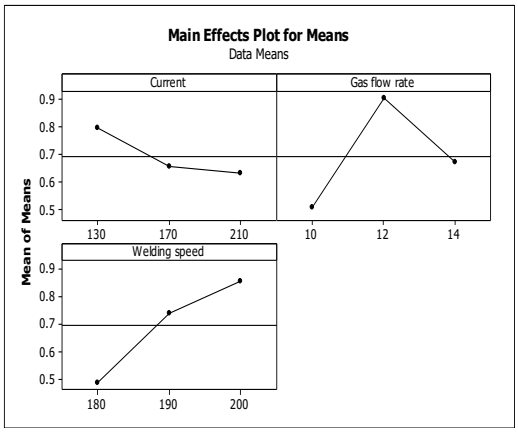

Fig.8 Effect of process parameters on weld bead height

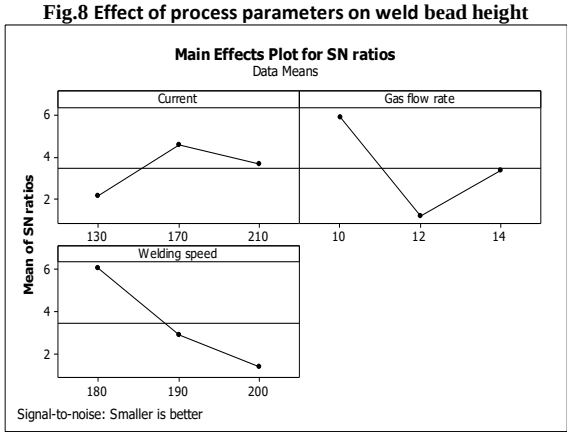

Fig. 9 Effect of process parameters on weld bead height S/N ratio

The S/N ratio graph shows that welding current increase the bead height up to 170 amp and then decreased whereas the gas flow rate decreased bead height first from 10 l/min to 12 l/min and then increased from 12 l/min to 14 l/min. The welding speed effect shows that bead height decreased.

Table 11 Analysis of Variance for SN ratios of weld bead height

Source	DF	Seq SS	Adj MS	F	PC (%)
Current	2	9.097	4.548	0.70	10.22
Gas flow rate	2	33.073	16.537	2.54	37.19
Welding speed	2	33.756	16.878	2.60	37.96
Residual Error	2	12.999	6.500	-	-
Total	8	88.925	-	-	-

Table 12 Analysis of Variance for Means of weld bead height

Source	DF	Seq SS	Adj MS	F	PC (%)
Current	2	0.048	0.024	0.61	8.29
Gas flow rate	2	0.238	0.120	3.06	41.45
Welding speed	2	0.211	0.105	2.70	36.68
Residual Error	2	0.078	0.039	-	-
Total	8	0.575	-	-	-

Table 13 Response Table for Signal to Noise Ratios of weld bead height For smaller the better characteristic

Level	Curent	Gas flow rate	Welding speed
1	20142	5.867	6.056
2	4.581	1.176	2.922
3	3.660	3.339	1.405
Delta	2.438	4.691	4.651
Rank	3	1	2

Analysis of variance for S/N ratio shows that percentage contribution of welding speed and gas flow rate is approx same but still welding speeds shows maximum contribution i.e. 37.96 % and gas flow rate has 37.19 % and welding current has a minimum contribution of 10.22 % is shown in Table 11. The results showed that an optimal value of 0.35 mm is obtained and is considered to be the best.

The response values for S/N ratio and raw data for each level of identified factors have been listed in Table 13 and 14 respectively which shows the factor level values of each factor and their ranking.

Table 14 Response Table for Means of weld bead height

Level	Curent	Gas flow rate	Welding speed
1	0.7956	0.5067	0.4878
2	0.6556	0.9033	0.7389
3	0.6300	0.6711	0.8544
Delta	0.1656	0.3967	0.3667
Rank	3	1	2

IV MICROSTRUCTURE ANALYSIS

Austenitic stainless steel is widely in a variety of industries and environment. In order to check out the structure of the material microstructure is considered to be one of the most important mechanical properties. Microstructure of parent material before welding is shown in Figure 10 and microstructure of weld metal for sample-3 and sample-7 is shown in Figure 11 and 12 respectively. Parent metal is denoted as pm3 for the third sample, wm3 and wm7 designate the weld metal structure of third sample and seventh sample respectively after welding.

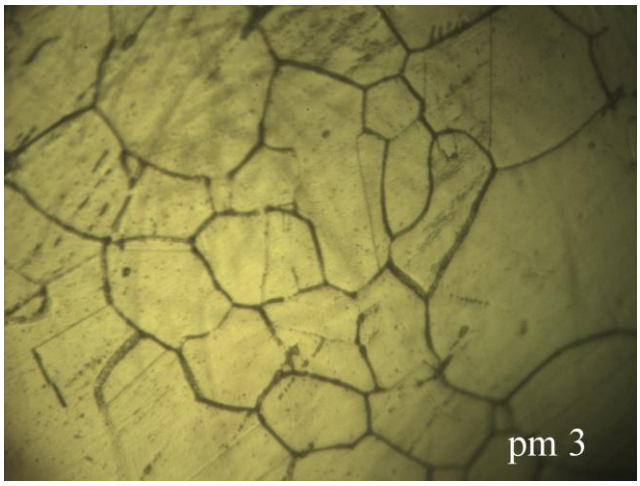

Fig 10 Microstructure of parent metal (pm3) for sample-3 before welding.

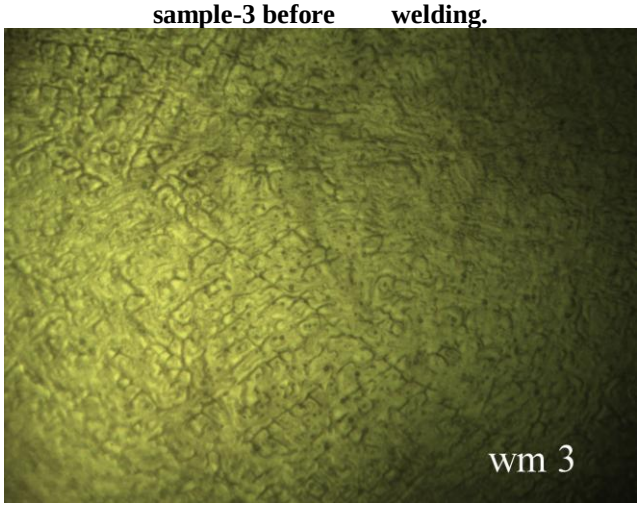

Fig 11 Microstructure of weld metal (wm3) of sample-3 at current 130 amp, gas flow rate 14 l/min and welding speed 200 mm/sec.

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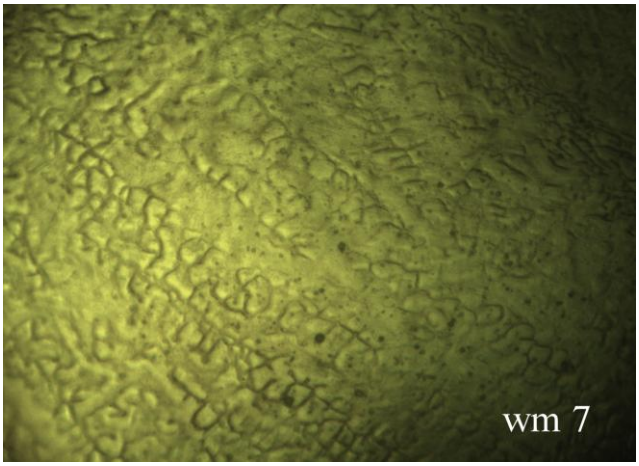

Fig 12 Microstructure of weld metal (wm7) at current 210 amp, gas flow rate 10 l/min and welding speed 200 mm/sec.

The results for the microstructure of weld metal stainless steel 202 represents a delta ferrite structure in matrix of austenite in weld metal. The experiment is performed at a magnification of 400X and third sample is made at a current of 130 amp, gas low rate of 14 l/min and welding speed of 200 mm/sec while sample seventh is made at a welding current of 210 amp, gas flow rate of 10 l/min and welding speed of 200 mm/sec.

V CONCLUSION

The appropriate TIG welding parameters for stainless steel grade 202 in argon shielding gas are established. From all the above results and graphs, it is concluded that the best optimal value of weld bead width is 8.63 mm at a welding current of 130 amp, gas flow rate of 10 l/min and welding speed of 180 mm/min. Similarly the best optimal value for weld height is at welding current at 170 amps, gas flow rate at 10 l/min and welding speed at 180 mm/sec. The results obtained from the microstructure shows that structure consists of austenite grains in heat affected zone as well as in parent metal and it has a delta ferrite structure in matrix of austenite in weld metal. This result confirms previous research of several authors and demonstrates that the interpretation applies to products obtained from very different techniques.

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