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Study of Mechanical Properties in Austenitic Stainless Steel Using Gas Tungsten Arc Welding (GTAW)

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ABSTRACT
The aim of the present study is to show the influence of different input parameters such as welding current, gas flow rate and welding speed on the mechanical properties during the gas tungsten arc welding of austenitic stainless steel 202 grade. The microstructure, hardness and tensile strength of weld specimen are investigated in this study. The selected three input parameters were varied at three levels. On the analogy, nine experiments were performed based on L9 orthogonal array of Taguchi's methodology, which consist three input parameters. Analysis of variance (ANOVA) was employed to designate the levels of significance of input parameters. Current has the maximum influence on the output characteristics. Microstructure of weld metal structure shows the delta ferrite in matrix of austenite.
Keywords - GTAW, Microstructure, Welding, Austenitic Stainless Steel, Taguchi, ANOVA

I. INTRODUCTION

Tungsten inert gas welding which is also known as Gas tungsten arc welding (GTAW) uses a non-consumable tungsten electrode and an inert gas [1-2]. In this process argon is used as a shielding gas and plate of 6 mm is welded using TIG welding. Micro-hardness testing of metals, ceramics, and composites is useful for a variety of applications for which 'macro' hardness measurements are unsuitable. Micro-hardness testing gives an allowable range of loads for testing with a diamond indenter. The resulting indentation is measured and converted to a hardness value. As Taguchi method [3-4] is a systematic application of design and analysis of experiments for designing purposes and product quality improvement. In this research work, micro-hardness, tensile strength and microstructure of the specimen 202 stainless steel welded by TIG welding method are evaluated. TIG welding can weld dissimilar metals to one another such as stainless steel to mild steel and copper to brass [5]. In this paper the use of Taguchi method is used to determine the welding parameters with the best optimal results. Taguchi method [6] 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.

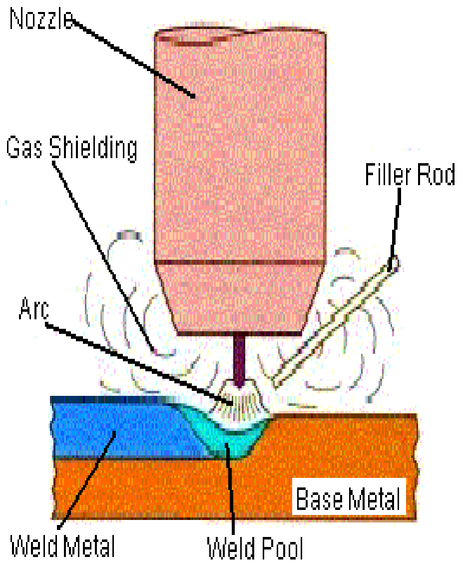

Fig 1: TIG welding of Stainless Steel

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. [7]. Shivashanmugan (2011) investigated the microstructure and mechanical properties an found that hardness is lower in the weld metal as compared to parent metal and heat affected zone.[8]. Gharibshahiyan investigated that with the increase in voltage, the grain size number decreased in case of low carbon welded steel using inert gas welding [9]. 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

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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 results. Shielding gas used in this process is argon gas.

II. METHODOLOGY

In this experimental work, the specimen is welded at three different levels of welding parameters i.e. current, gas flow rate and welding speed as shown in Table I.

Table I Welding parameters and their levels

Parameters	Current (A)	Gas flow rate (B)	Welding speed (C)
Unit	Amp	Liters/min	mm/min
Level 1	130	10	180
Level 2	170	12	190
Level 3	210	14	200

Table 2 Chemical Composition of SS202

SAE Designation	202
UNS Designation	S20200
% Cr	17.1
% Ni	4.1
% C	0.15
% Mn	9.25
% Si	0.51
% P	0.06
% S	0.03
% N	0.25

Analysis was done by the application of Taguchi's design using Minitab 16. Samples of size 100 × 50 × 6 mm with square edge butt joints were prepared in this experiment. The chemical composition of Stainless Steel 202 sheet using for present study is shown in Table 2.

Fig 2: Cutting of sample from strip

Fig 3: Final Cutting samples for welding

Figure 2 shows the cutting of the sample from the big strip with the help of the cutting machine. All nine samples are cut in same size and their pictorial view is shown in Fig3. 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 working ranges of welding parameters were fixed by conducting trial runs and satisfactory values obtained are used to conduct the experiment research work. L9 orthogonal array is used for analysis purposes and standard table of three variables with three different levels of input parameters is shown in Table 3 and actual value of selected input parameters are listed in Table 4.

Table 3 L9 Orthogonal Array design matrix

Experiment Number	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
9	3	3	2

Table 4 L9 matrix with actual value of parameters

Experiment Number	Welding Current	Gas Flow Rate	Welding Speed
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

The nine experiments were performed based on the L9 array. The effects of different input parameters such as current, gas flow rate and d welding speed on austenitic SS 202 is analyzed. The tensile strength and micro-hardness of all the nine weld samples were checked carefully and the observed values for tensile strength and micro-hardness with their S/N ratios summarized in Table 5. Figure 4 shows the photograph of weld sample.

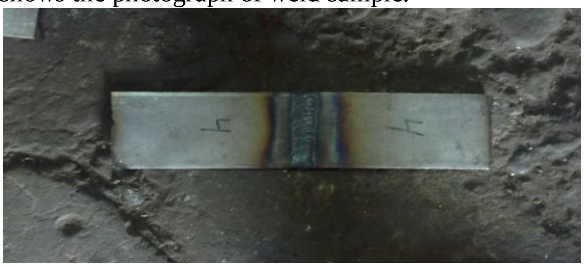

Fig 4: Welded sample of Stainless steel 202

The samples used for measuring micro-hardness are rubbed first using emery paper of size no. 400, 600, 1000 & 2000 and then clean with acetone solution. The diagonals of the indents formed by pyramid- shaped diamond indenter on the samples gives the value of micro-hardness in Vickers. A load of 500 gm is applied for 20 seconds. An average maximum force of 128 kN is applied to check the tensile strength of the weld specimens.

Table 5 Results for tensile strength and micro-hardness

Experiment Number	Tensile Strength (kN/mm^2)	S/N Ratio (dB)	Micro-Hardness (HVN)	S/N Ratio (dB)
1.	0.530	-5.515	77.327	37.766
2.	0.527	-5.564	78.157	37.859
3.	0.510	-5.848	75.610	37.572
4.	0.563	-4.989	75.917	37.607
5.	0.544	-5.288	78.363	37.882
6.	0.581	-4.716	77.317	37.765
7.	0.578	-4.761	78.270	37.872
8.	0.556	-5.098	80.473	38.113
9.	0.595	-4.509	78.827	37.934

III. RESULTS AND DISCUSSIONS

Figure 5 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.

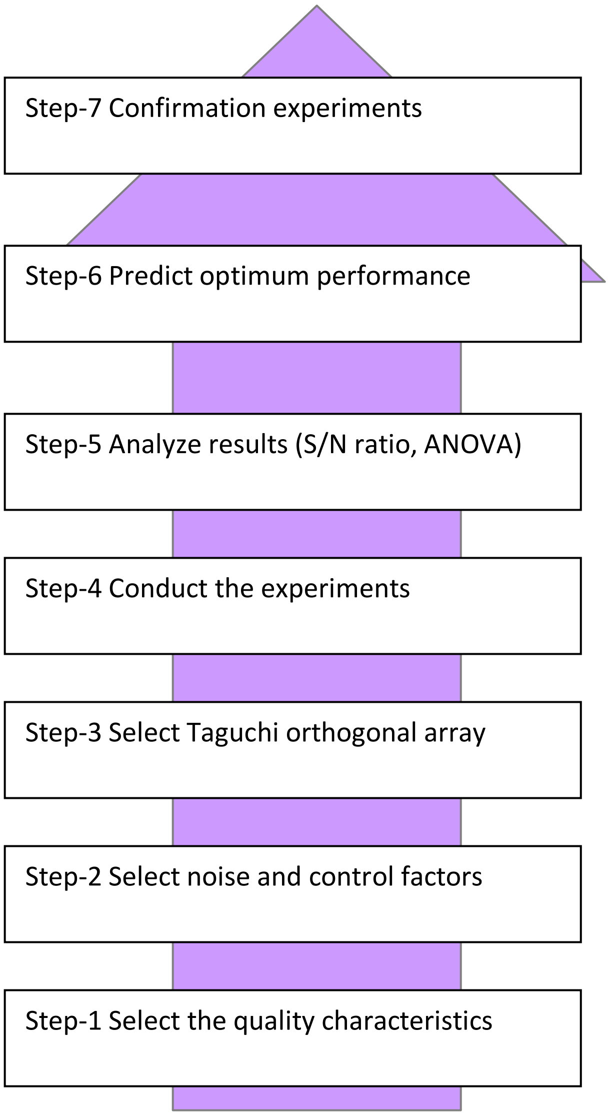

Fig 5: Steps for Taguchi analysis

In the present study tensile strength and micro-hardness of the weld specimens were identified as the responses, therefore, "higher the better" (HB) characteristic chosen for analysis purpose.

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

Where yi represents the experimentally observed value of the ith experiment, n is the repeated number of each experiment, $\overline{y}$ is the mean of samples and s is the sample standard deviation of n observations in each run. The unit of calculated S/N ratio from the observed values is decibel (dB).

3.1 Tensile Strength

Tensile strength is calculated experimentally and Taguchi method is applied for analysis with the help of ANOVA. On basis of data analyzed, plots for mean (raw data) and signal-to-noise (S/N) ratio are shown in Figure 6 and 7 respectively. The calculated S/N ratio has been tabulated in Table 5.

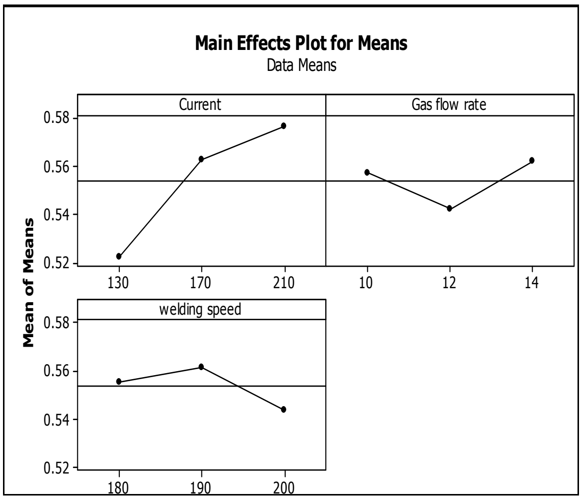

Fig. 6 Effects of process parameters on tensile strength raw data

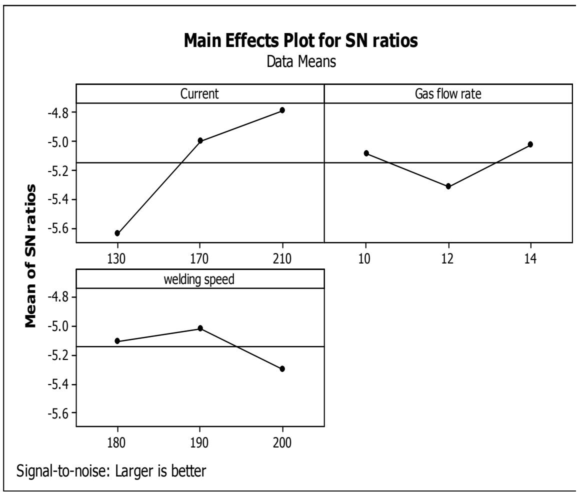

Fig. 7 Effects of process parameters on tensile strength S/N ratio

The optimal process parameters have been established by analyzing response curves of S/N ratio associated with raw data. From Figure 6 and 7 it is concluded that third level of current (210 amp), third level of gas flow rate (14 liters/min) and second level of welding speed (190 mm/min) gives the higher tensile strength. Hence the optimum condition of input parameters is $A_3B_3C_2$. Analysis of variance for S/N ratio and raw data are summarized in Table 6 and 7 respectively and it is observed that current is the most prominent factor which effects tensile strength maximum with percent contribution of 74 61% followed by gas flow rate with percent contribution 8.89% then welding speed with percent contribution 7.63%.

Table 6 ANOVA for SN ratios of tensile strength

Source	DoF	Seq SS	Adj MS	F	PC (%)
Current	2	1.185	0.593	8.43	74.61
Gas flow rate	2	0.141	0.0706	1.01	8.89
Welding speed	2	0.121	0.0606	0.86	7.63
Residual Error	2	0.141	0.0703	-	-
Total	8	1.580	-	-	-

Table 7 ANOVA for Means of tensile strength

Source	DoF	Seq SS	Adj MS	F	PC (%)
Current	2	0.0047	0.0024	8.28	73.76
Gas flow rate	2	0.0006	0.0003	1.10	9.77
Welding speed	2	0.0005	0.0002	0.85	7.54
Residual Error	2	0.0005	0.0003	-	-
Total	8	0.0061	-	-	-

The response values for S/N ratio and raw data for each level of identified factors have been listed in Table 8 and 9 respectively which, shows the factor level values of each factor and their ranking.

Table 8 Response table for S/N ratios of tensile strength

Level	Current	Gas flow rate	Welding speed
1	-5.642	-5.089	-5.110
2	-4.998	-5.317	-5.021
3	-4.790	-5.025	-5.299
Delta	0.852	0.292	0.278
Rank	1	2	3

Table 9 Response table for means of tensile strength

Level	Current	Gas flow rate	Welding speed
1	0.5223	0.5570	0.5557
2	0.5627	0.5423	0.5617
3	0.5763	0.5620	0.5440
Delta	0.0540	0.0197	0.0177
Rank	1	2	3

3.2 Micro-hardness

The samples used for measuring micro-hardness are first rubbed with emery paper of size no. 400, 600, 1000 & 2000 and then cleaned with acetone solution. The diagonals of the indents formed by pyramid- shaped diamond indenter on the samples

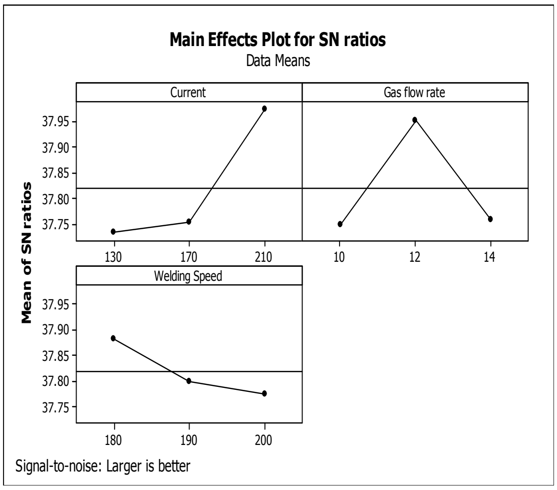

Fig. 8 Effects of process parameters on micro-hardness S/N ratio

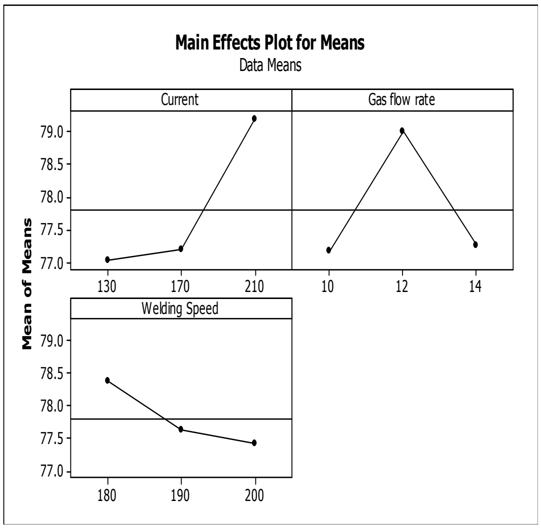

Fig. 9 Effects of process parameters on micro-hardness raw data

The optimal process parameters have been established by analyzing response curves of S/N ratio associated with raw data. From Figure 8 and 9 it is concluded that third level of current (210 amp), second level of gas flow rate (12 liters/min) and first level of welding speed (180 mm/min) gives the optimal micro-hardness. Hence the optimum condition of input parameters is $A_3B_2C_1$. Analysis of variance for S/N ratio and raw data are summarized in Table 10 and 11 respectively and it is observed that current is the most prominent factor which effects micro-hardness maximum with percent contribution of 48.70 % followed by gas flow rate with percent contribution 36.03 % then welding speed with percent contribution 8.47 %.

Table 10 ANOVA for SN ratios of Micro-hardness

Source	DoF	Seq SS	Adj MS	F	PC (%)
Current	2	0.1071	0.0535	7.18	48.70
Gasflow rate	2	0.0793	0.0397	5.31	36.03
Welding speed	2	0.0187	0.009	1.25	8.47
Residual Error	2	0.0149	0.0074	-	-
Total	8	0.2198	-	-	-

Table 11 ANOVA for Means of Micro-hardness

Source	DoF	Seq SS	Adj MS	F	PC (%)
Current	2	8.652	4.326	7.81	48.98
Gas flow rate	2	6.392	3.196	5.77	36.18
Welding speed	2	1.511	0.756	1.36	6.51
Residual Error	2	1.108	0.554	-	-
Total	8	17.663	-	-	-

The response values for S/N ratio and raw data for each level of identified factors have been listed in Table 12 and13 respectively which shows the factor level values of each factor and their ranking.

Table 12 Response table for S/N ratios of Micro-hardness for Larger the better characteristics

Level	Current	Gas flow rate	Welding speed
1	37.73	37.75	37.88
2	37.75	37.95	37.80
3	37.97	37.76	37.78
Delta	0.24	0.20	0.11
Rank	1	2	3

Table 13 Response table for means of Micro-hardness for Larger the better characteristics

Level	Current	Gas flow rate	Welding speed
1	77.03	77.17	78.37
2	77.20	79.00	77.63
3	79.19	77.25	77.41
Delta	2.16	1.83	0.96
Rank	1	2	3

3.3. Microstructure analysis

Austenitic stainless steel is considered to be one of the most important stainless steel and is used widely in a variety of industries and environment. Microstructure is one of the mechanical properties which are helpful for checking out the structure of the material. Microstructure of parent material before welding is shown in Figure 10 and microstructure of weld metal for sample-1 and sample-2 is shown in Figure 11 and 12 respectively. Parent metal is denoted as pm1 for the first sample, wm1 and wm2 designate the weld metal structure of first sample and second sample respectively after welding.

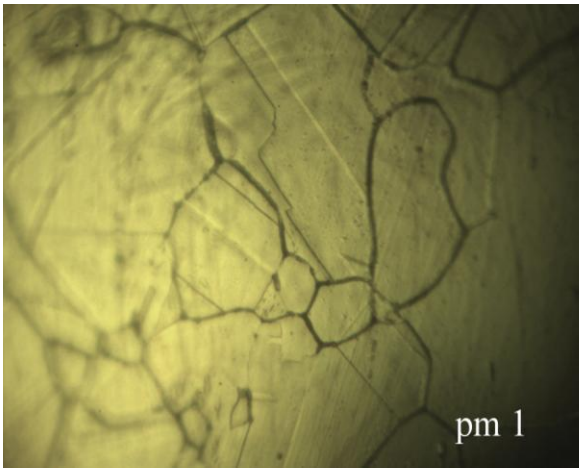

Fig 10 Microstructure of parent metal (pm1) for sample-1 before welding.

The results of the structures of 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 first sample is made at a welding current of 130 amp, gas low rate of 10 l/min and welding speed of 180 mm/sec while sample two is made at a welding current of 130 amp, gas flow rate of 12 l/min and welding speed of 190 mm/sec.

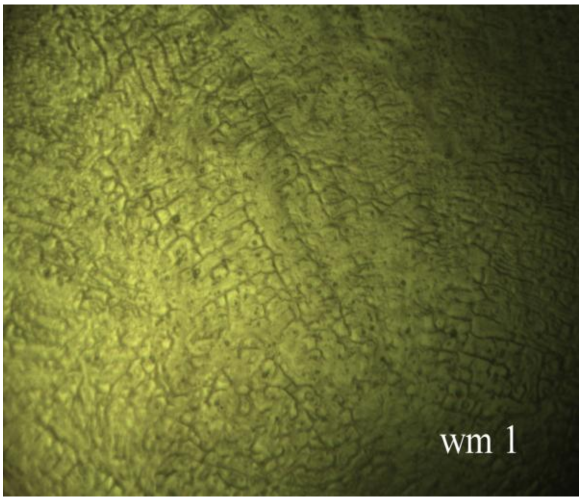

Fig 11 Microstructure of weld metal (wm1) of sample-1 at current 130 amp, gas flow rate 10 l/min and welding speed 180 mm/sec.

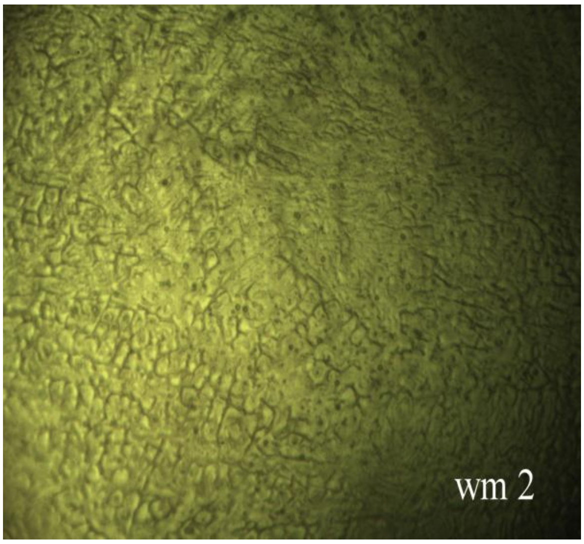

Fig 12 Microstructure of weld metal (wm2) at current 130 amp, gas flow rate 12 l/min and welding speed 190 mm/sec.

IV. CONCLUSION

The stainless steel grade 202 was used for the present study to explore the different input process parameters on the tensile strength and micro-hardness of the weld samples. The L9 orthogonal has been used to assign the identified parameters. ANOVA analysis was performed for the analysis purpose which shows that current is the most significant parameters that influenced the tensile strength and micro-hardness of the weld. The highest tensile strength obtained in the research is 0.595 KN/mm^2 at a welding current of 210 amp, gas flow rate of 14 l/min and welding speed of 190 mm/sec. The maximum micro hardness is 80.473 HV obtained at a welding current of 210 amp, gas low rate of 12 l/min and welding speed of 180 mm/sec.

The results obtained from the microstructure shows that it has a delta ferrite structure in matrix of austenite in weld metal and structure consists of austenite grains in heat affected zone as well as in parent metal.

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