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Optimization of Welding Parameters by Using Taguchi Method and Study of Fracture Mode Characterization of SS304H Welded by GMA Welding

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Abstract

This study focuses on optimizing different welding parameters which affect the mechanical properties such as YS, UTS, Toughness, and Vicker hardness (VHN) of SS304H, Taguchi technique was employed to optimize the welding parameters, and fracture mode characterization was studied. A series of experiments have been carried out. L9 orthogonal array (3xx3) applied for it. Statistical methods of signal to a noise ratio (SNR) and the analysis of variance (ANOVA) was applied to determine the effects of different welding parameters such as wire feed speed, welding current and gas flow rate on Mechanical properties. Tensile strength, toughness, Vicker hardness (VHN), and mode of fracture were examined to investigate the weld quality of SS304H, and it was observed from the results that the welding voltage has significant effect whereas gas flow rate has insignificant effect on tensile strength of the weldment, and optimum process parameters were found to be 23 V, 350 IPM travel speed of wire and 20 l/min gas flow rate for tensile strength and mode of fracture was ductile fracture for tensile test specimen.

Keywords: *GMAW/MIG, Mechanical properties, ANOVA, stainless steel, mode of fracture, SEM, S/N ratio*.

1. Introduction

Gas metal arc welding (GMAW) is an advanced version of electric arc welding in which no pressure is applied during the welding process and arc is created between a continuous copper coated wire and work piece [1]. This GMAW commonly used method for joining of steels structural, components for the automotive industry [2-3]. Type 304/304L is the modern evolution of the original “18-8” austenitic stainless steel. It is very economical and versatile corrosion resistant stainless steel suitable for a wide range of general purpose applications.SS304H with a higher chromium and lower carbon content. Lower carbon contents minimize chromium carbide precipitation during welding and its susceptibility to intergranular corrosion.SS304H frequently was used in various industries such as Chemical and Petrochemical, Processing industries, pressure vessels, tanks, valves and pumps, heat exchangers, piping systems, flanges, fittings, Medical, Pharmaceutical Processing, Food, Beverage Processing and nuclear industries due to its excellent tensile strength, good weldability, and better corrosion resistance properties [4]. Dinesh Mohan arya et al [5] investigated process parameters for Metal Inert Gas welding and they reported that welding current is having maximum percentage contribution in experimental work. Nabendu Ghosh et al [6] optimized the metal inert gas welding parameters, by Grey-Based Taguchi method and they reported in their result that current having the more significant effect than gas flow rate in influencing the strength of the welded joints.

Vikas Chauhan and R. S. Jadoun [7] studied the joining of two dissimilar metals SS304 and Low Carbon Steel by metal inert gas Welding (MIG) and they optimized the process parameter by using Taguchi Design Method and finally they informed that the effect of welding parameters on the ultimate tensile strength can be ranked in decreasing order as follows: voltage >speed > current. Abhishek Prakash et al [8] determined the (welding) process parameters which influence the mechanical properties by using the Taguchi method and they produced a result that Welding Current has the greatest influence on Tensile and Hardness in the Weldability of welded joint followed by wire feed speed and arc voltage. S. M. Bayazid et al [9] predicted welding parameters such as travel speed, rotational speed and plates position on microstructure and mechanical properties of Friction Stir Welded joint of two dissimilar Aluminum 6063 and 7075 alloys via Taguchi method and they reported that rotational speed, travel speed and plates position have 59, 30 and 7 % influence on

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tensile strength of welded joint respectively. Saurav Datta et al [10] developed a multi-response problem to optimize parameters by combining to yield favorable bead geometry of submerged arc bead on-plate weldment and they coupled the Taguchi optimization method with Grey relation technique to evaluate the optimal parametric combination for deeper penetration, minimum bead height and depth HAZ of welded part. D Kalita and P. B Barua[11] investigated the effect of the process parameters of Metal Inert Gas Welding such as welding current, arc voltage and shielding gas flow rate on tensile strength of welded joints by the Taguchi Optimization method and they concluded that welding voltage has significant effect, both on mean and variation of the Tensile strength of the weld having 87.019% and 85.398% contribution respectively, whereas welding current has significant effect on mean only (10.807% contribution) whereas Shielding gas flow rate has insignificant effect on the tensile strength of the welded joint.

Therefore, in this research article, an attempt has to be made to optimize the process parameters of metal inert gas (MIG) welding. S R.Chikhale et al [13] predicted the mechanical properties of Al Alloy 6061-T6 by metal inert gas welding and they consider the welding current, arc voltage and wire feed speed as welding parameters and finally they optimized the parameters by reporting that welding current has the most significant effect on the Tensile strength, depth of penetration and toughness of weld joint. Saadat Ali Rizvi et al [14] optimized various welding process parameters by application of Taguchi method on MIG welding during welding of IS2062, and they mentioned in their research results that welding current and welding voltage have significant effect whereas gas flow rate has an insignificant effect on tensile strength of the weldment. Emmanuel O. Ogundimu et al [15] studied the mechanical properties and microstructure of AISI 304 weldment, welded by MIG and TIG welded and they concluded that welding current has the most significant effect on weldment hardness and they also added that UTS is depended on welding parameters. Woei-Shyan Lee et al [16] studied the fracture behaviour of SS 304 welded and they analysed the fractography of failed samples and observed that weldments, all fail in a ductile manner as a result of an extensive localized shearing in the fusion zone and they also added that failure of the weldments initiates at the site of second-phase particles within the fusion zone. Uğur ÇALIGÜLÜ et al [17] observed the tensile fracture of weldment and they concluded that after welding, it is seen that tensile strength values can be decreased depending on increasing the welding speed and this values can be increased depending on increasing the heat inputs, mainly in ductile fracture manner due to the fact that the ferritic stainless steel is a ductile steel. Anmol jeet Singh and Rutash Mittal[18] applied the Taguchi technique to optimize the process parameters and the observed that a dimple pattern in the whole width of impact fracture specimen which confirms the ductile mode failure of the joints. Ýhsan Kirik and Niyazi Özdemýr [19] examined the fracture mode of SS 304 weldment and mentioned that the tensile test mostly occurred on the AISI 1040 side, and especially ductile fractures in the form of quasi-cleavages were observed in the dimples. Ravindra V. Taiwade et al [20] examined the fractured surface of tensile test of AISI 304 weldment and they observed that the AISI 304 SS failed due to ductile fracture. The fractured surfaces of AISI 304 SS showed a wide range of dimple sizes of equiaxed type.

2. Design and Experimental work

2.1. Workpiece material

In this research article i,e Stainless steel 304H was used as a raw material.SS 304H plate of dimension 150mm × 60 mm× 5 mm were welded using Gas Metal Arc Welding (GMAW) machine, with Polarity Direct Current Electrode Negative [DCEN]. Actual GMA welding set up is shown in fig 1.

Figure 1: Actual welding setup of GMA

After completed weld, welded plates were machined on a horizontal milling machine for making V-groove. The chemical composition of the base metal plate and filler wire used in the process for welding purpose is given in Table .1 respectively.

Taguchi design of the experiment is a simple and foolproof approach which is used to reduce the analysis up to an optimal level. In this research article, three factors were selected with their levels as shown in Table 2. Selection of the orthogonal array was based on DOF. The degree of freedom for all three factors is 6 in this design and welded by GMAW process with different welding parameters, nine tensile test specimens were cut from welded piece longitudinally; vertical milling machine is used to produce an arc of R12.5mm and to produce “V” notch in Charpy impact test specimens. Tensile test specimens are fabricated as per ASTM standard and a tensile test specimen is shown in fig 2.

Table 1: Composition of base metal and filler wire

Material	% C	% Cr	% Ni	% Mn	% Si	% P	% S	Cu	Fe
Base plate	0.06	18.68	8.54	1.9	0.41	0.031	0.005	----	rest
Filler wire	0.08	19.5-22.0	9.0-11.0	1.0-2.5	0.3-0.65	0.030	0.03	0.75	rest

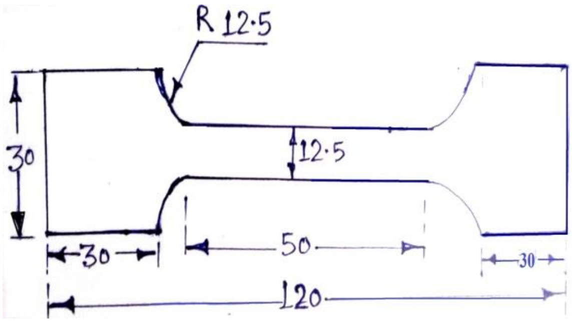

Figure 2: Tensile test specimen as per ASTM [12]

All tensile test specimens are tested on UTM-40T at room temperature. Tensile test specimens after fracture are shown in fig 3. Three different welding parameters are used to perform the welding. In entire, this research work pure Argon (Ar) was used as shielding gas to avoid any contamination of weld pool , as pure argon having special characteristics.

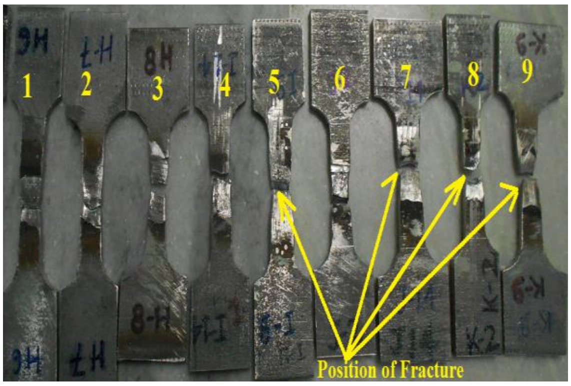

Figure 3: Tensile test specimens after fracture

2.2. Welding parameters

In this research article, parameters which are used for welding purpose are given in Table 2.

Table 2. Input (welding) parameters with their level

Variable	Level I	Level II	Level III
Voltage(V)	22	23	24
Gas flow rate (l/min)	10	15	20
Wire feed rate(IPM)	250	300	350

In the present experimental work, an L_9 OA with 3 columns and 3 rows was used. This array can handle three level process parameters. Nine experiments conducted to study the welding parameters using the L_9 OA.OA and the corresponding values of welding parameters are listed in Table 3.

3. Results

3.1. Evaluating the signal-to-noise (S/N) ratios

Noise factors are those uncontrollable factors which affect the process result (Output), whereas derived response is known as the signal. The variation of the index is known as S/N ratio. Variations are usually three types i, e "lower is better", "higher is better'' and "Normal is better". In the Present study Ultimate tensile strength (UTS), Vicker hardness (VHN), Toughness was output (weld quality). For good quality of weld hardness (VHN), Toughness and Ultimate tensile strength (UTS) consider as "higher is better''. In order to evaluate the influence of each selected factor on the response, S/N ratios for each control factor was calculated.

In the present research work tensile strength, Vicker hardness (VHN) and Toughness of welded pieces were identified as the responses, therefore, "higher the better" consider for tensile strength and "nominal the best" for Vicker hardness (VHN) characteristic chosen for analysis purpose

$$\frac{S}{N} = -10\log_{10}\left(\sum_{i=0}^{n}\frac{1}{y_i^2}\right), \text{ Higher is better} \quad (1)$$

$$\frac{S}{N} = -10\,log_{10}\left(\frac{1}{n}\sum_{i=0}^{n}(y_i^2)\right), \text{ Lower is better} \quad (2)$$

$$S/N = \ -10\,log_{10}\left(\frac{1}{n}\sum_{i=0}^{n}(y_i - m)^2\right), \quad (3)$$

Normal is better

For tensile strength. Response table or signal to noise is shown in table 4.

Table 4: Response Table for Signal to Noise Ratios

Level	Voltage (V)	Gas flow rate (l/m)	Wire feed speed (ipm)
1	53.83	54.31	54.44
2	55.79	54.74	56.64
3	54.24	54.81	54.78
Delta	1.96	0.50	0.24
Rank	1	2	3

Table 3: Result for Ultimate Tensile Strength, Vicker Hardness (VHN), and Toughness

Experiment No	**Voltage (V)**	**Gas flow rate (l/m)**	**Wire feed speed (IPM)**	**UTS (MPa)**	**SNRA1**	**VHN**	**SNRA2**	**Toughness (Joule)**	**SNRA3**
1	22	10	250	480	53.6248	190	45.5751	250	47.9588
2	22	15	300	453	53.1220	199	45.9771	262	48.3660
3	22	20	350	546	54.7439	177	44.9595	240	47.6042
4	23	10	300	636	56.0691	180	45.1055	180	45.1055
5	23	15	350	657	56.3513	187	45.4368	232	47.3098
6	23	20	250	559	54.9482	180	45.1055	176	44.9103
7	24	10	350	459	53.2363	179	45.0571	234	47.3843

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8	24	15	250	546	54.7439	202	46.1070	230	47.2346
9	24	20	300	545	54.7279	187	45.4368	264	48.4321

3.1.1. Tensile strength

Ultimate tensile strength (UTS) was calculated experimentally, Taguchi technique was applied for analysis with support of ANOVA and mode of fracture was studied. On the basis of data analyzed, plots for S/N ratio are shown in fig 4.it is much cleared from fig 4 that third level of voltage (23V), the second level of gas flow rate (20 l/min) and third level of wire feed speed (350IPM) gives higher tensile strength.

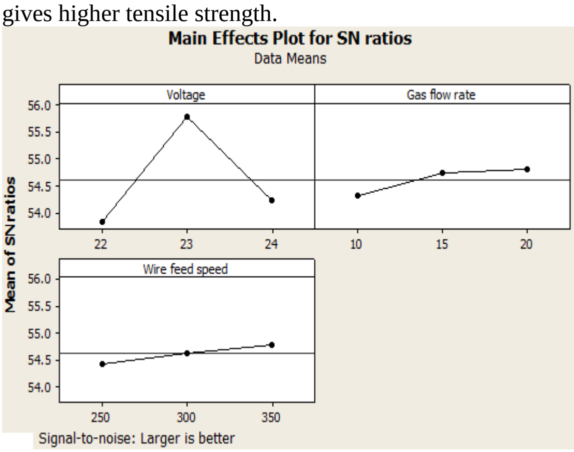

Figure 4: Main Effects Plot for SN ratios (UTS)

3.1.2. Hardness

Vicker hardness (VHN) of test samples also experimentally calculated, Taguchi technique was applied to determine the optimal process parameters with help of ANONA .on the basis of data analyzed, plots for S/N ratio are shown in fig 5. From fig 5 it is observed that and voltage (24V), second level of gas flow rate (15 l/min) and third level of wire feed speed (250IPM) gives normal values of hardness.

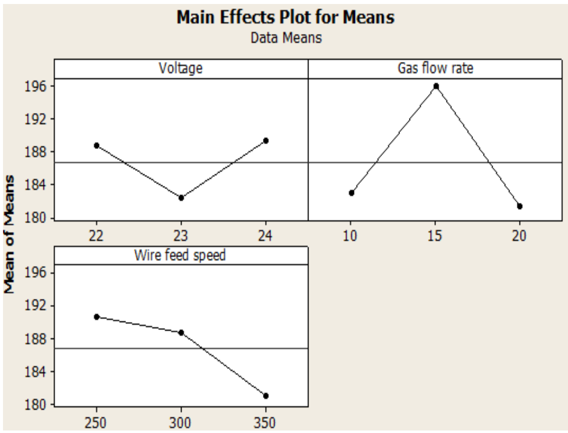

Figure 5: Main Effects Plot for SN ratios (VHN)

3.2. ANOVA-

Analysis of variance is a statistic technique, which is used to evaluate the differences between the mean and their associated procedure. ANOVA result for Ultimate tensile strength (UTS) is given in table 5, shows that Arc voltage has the most significant effect with 63.72%, while gas flow rate and wire feed speed having least effect.

Table 5: Analysis of Variance for SNRA1 (UTS), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Arc voltage	2	26153	26153	13076	2.09	0.324	63.72
Gas Flow rate	2	1358	1358	679	0.11	0.902	3.31
Wire feed speed	2	1013	1013	506	0.08	0.925	2.47
Error	2	12521	12521	6260			30.50
Total	8	41044					

ANOVA for S/N ration for hardness is summarized in Table 6 and it is observed that gas flow rate has the most significant effect with 60.49% contribution followed by arc voltage 25% contribution, while wire feed speed having least effect.

Table 6: Analysis of Variance for SNRA2 (Hardness), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
Arc voltage	2	89.56	89.26	44.78	13.0	0.071	14
Gas Flow rate	2	386.89	386.89	193.44	56.16	0.017	60.49
Wire feed speed	2	156.22	156.22	78.11	22.68	0. 042	24.43
Error	2	6.89	6.89	3.44			1.1
Total	8	639.56					

4. Mode of fracture

4.1. Fracture mode of the tensile test specimen

Fracture mode of the tensile test specimens was studied by SEM apparatus at room temperature. The fracture surface of SS304H welded joint obtained with MIG welding is shown in Fig 6. Mode of fracture of tensile test specimens is tried to understand by given Figure. Fig 6(b) shows the fractography of tensile fractured surface. It is very clear from the figure that mode of fracture was ductile with numerous dimples. It is also observed from the result that fracture pattern is not uniform; cleavage fracture is a tear type fracture. Cleavage and secondary cleavage are clearly visible in SEM image of the fracture surface.

4.2. Fracture mode of toughness test specimen

To determine the toughness "V" notch Charpy samples were prepared as per ASTM. Specimens after fracture are shown in fig 7. Toughness fractured specimens examined to determine the surface morphology.

Figure 8 (a) and (b) shows the images of fractography of impact charpy "V" notch test piece. Sample 1 in Figure 8 shows the ductile fracture with coarse dimples. Enough finer dimples are observed in sample 3 in figure 8.combined ductile and brittle fracture mode formation is responsible for poorly absorbed energy. Sample 2 shows shallow dimples.

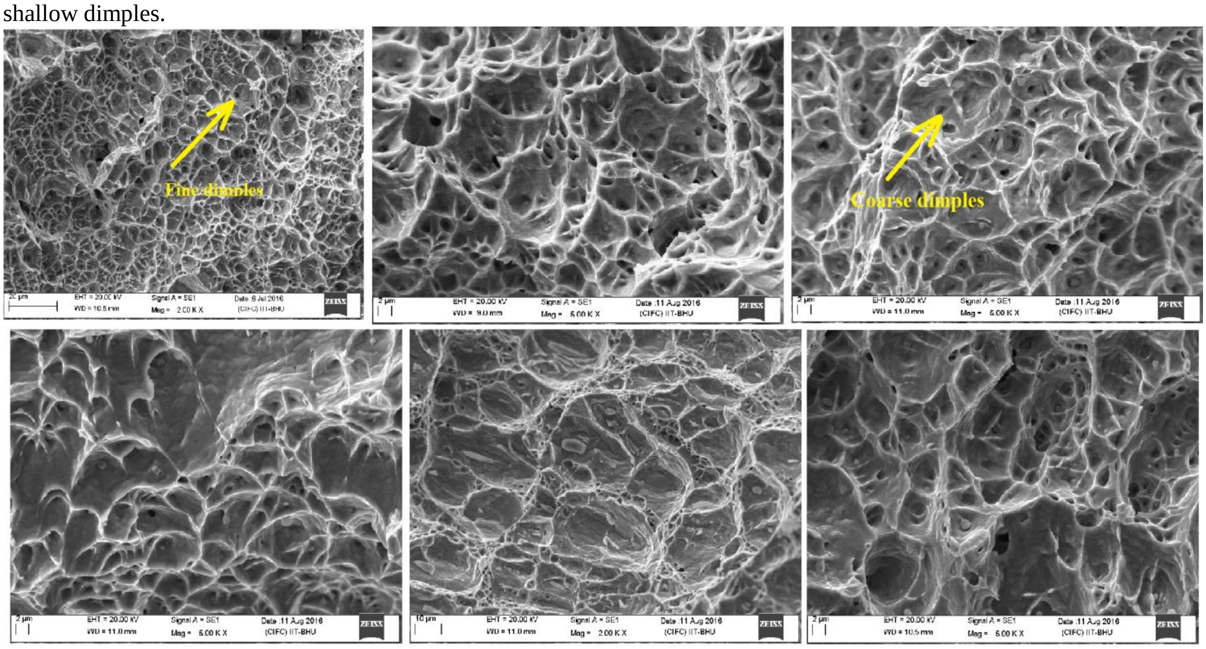

Figure 6: Fractograph morphology (SEM) of tensile test specimens

(a) Toughness test before fracture

(b) Toughness test after fracture(Centre)

Figure 7: Toughness test samples

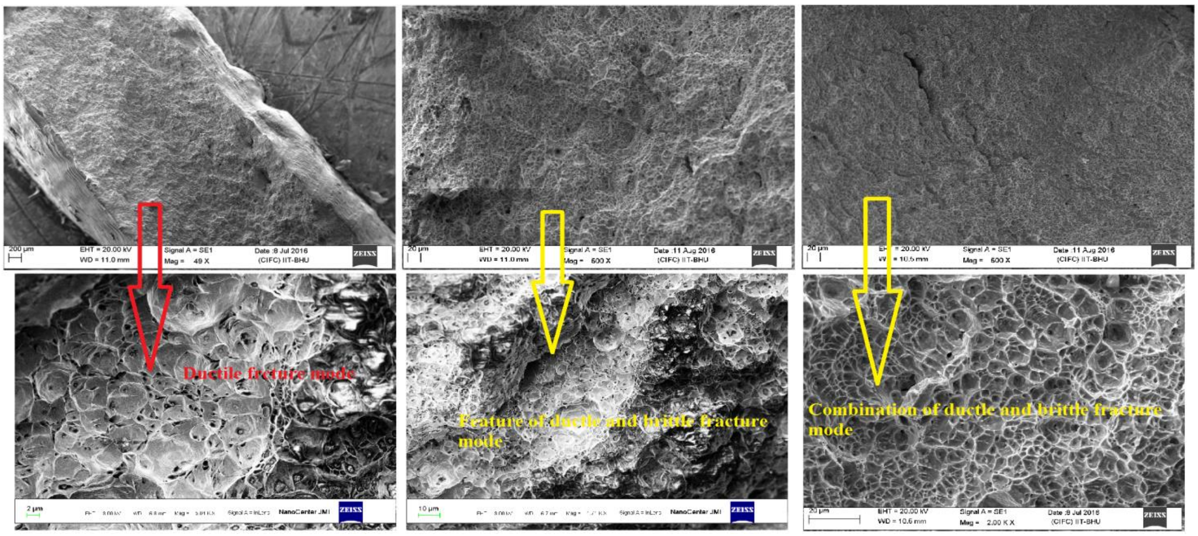

Figure 8: Macro images and SEM images of Impact fracture samples for morphology

5. Conclusions

In this study to investigate the effect of GMAW processes on different welding parameters and fracture mode characterization was studied. The variables parameters in this experiment were arc voltage, wire feed speed, and gas flow rate. In this conclusion it found that:

- In this experimental work, the selection of the process parameters for MIG welding of SS 304 weldment with the optimal mechanical quality has been presented.
- Weld bead surface finish is better by this process.
- It is also observed from experimental work that mechanical properties and microstructure of weldments depend on the heat input.
- It is also observed from fractograph morphology (SEM) of tensile test specimens that small dimple size or high dimple size are responsible for fracture.
- SEM analysis of fractured samples fracture morphology shows coarse dimples with the combination of ductile and brittle fracture in impact toughness weldment samples
- Deeper penetration is achieved in this process.
- Taguchi technique is method power pull tool to discover the effect of welding process parameters on mechanical quality.
- It is also observed that from the SEM result that if the dimple size is smaller, the strength and ductility of weldments is higher.
- ANOVA (Analysis of variance) depicts that Arc voltage having a significant parameter that affects the UTS and VHN followed by gas flow rate and wire feed speed
- Ductile fracture mode observed with fine dimples for tensile test samples.

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