Optimization of Welding Parameters and Microstructure and Fracture Mode Characterization of GMA Welding by Using Taguchi Method on SS304H Austenitic Steel

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Received (28 September 2017)
Revised (12 March 2018)
Accepted (20 November 2018)

This study is centre on optimizing different welding parameters which affect the weldability of SS304H. Taguchi technique was employed to optimize the welding parameters and fracture mode characterization was studied. A number of experiments have been conducted. L9 orthogonal array (3x3) applied for it. Analysis of variance (ANOVA) and signal to noise ratio (SNR), a statistical technique was applied to determine the effect of different welding parameters such as welding current, wire feed speed and gas flow rate on weldability of SS304H. Tensile strength, toughness, micro hardness and mode of fracture was examined to determine weldability of SS304H and it was observed from result that welding voltage have major impact whereas gas flow rate has minor impact on ultimate tensile strength of the welded joints and optimum process parameters were found to be 23 V, 350IPM travel speed of wire and 151/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 weldability.

1. Introduction

Metal inert gas welding or gas metal arc welding (MIG/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]. SS304 or 304L is the modern evolution of the noval “18-8” austenitic stainless steel. This steel is very inexpensive and versatile anti corrosion stainless steel, suitable for a broad range of general purpose use. SS304H with a higher chromium and lower carbon content. Lower carbon con-
tents reduces chromium carbide precipitation during process and its susceptibility to intergranular corrosion. SS304H frequently 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 technique and they reported in their result that Current having major impact in influencing the tensile strength of welded joint as compared to gas flow rate.

Chauhan and 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 tensile strength can be arranged in reducing manner as given: voltage > speed > current. 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. Bayazid et al. [9] predicted welding variables like travel speed, rotational speed and position of plates on mechanical and microstructural properties of Friction Stir Welded joint of two dissimilar Aluminum alloys, i.e., AA6063 and AA7075 with Taguchi technique and they reported that rotational speed, travel speed and plates position have 59, 30 and 7% influence on tensile strength of welded joint respectively.

Saurav Datta et al. [10] developed a multi-response problem to optimize parameters by combining to yield favourable bead geometry of submerged arc welding 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.

Kalita and 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) where as 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. Chikhale et al. [13] predicted the mechanical performance of AA 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 having principal impact on the tensile strength, depth of penetration and toughness of weld joint. Rizvi et al. [4] optimized different welding process parameters by application of Taguchi technique on MIG welding during bonding of IS2062 steel and they
mentioned in their outcome that welding voltage and welding current have major impact on tensile strength of welded joint whereas gas flow rate have least significant effect on tensile strength of the weldment.

Liu et al. [16] investigate the tensile behavior and fracture characteristics of SS clad plate by vacuum rolling and they observed that tensile ductility increases with increasing rolling temperature. Buddu et al. [17] investigate mechanical properties, microstructure and fracture morphology of SS304L plate welded by laser welding and they reported in their result that tensile fracture has revealed ductile fracture mode with fine dimples and impact fracture test having lower value for weld zone, HAZ as compared to base metal. Doddamani and Kaleemulla [18] investigate the fracture toughness of Al 6061-graphite particle composite and authors told that maximum fracture toughness was found for Al6061- 9%Gr for $a/w = 0.45$ and the value is 16.74 MPa $\sqrt{m}$. Gryguc et al. [19] studied tensile and fatigue behaviour of as-forged AZ31B extrusion and it was observed that fracture was ductile fracture in forged and as extruded samples. More dimples and plastic deformation was identified in fractures surface in forged samples.

Patil et al. [20] conduct experiment to identify the hardness of Friction Stir welding and Tungsten Inert Gas welded joints of two different Aluminium alloys, i.e., AA7075 and AA6061 and they recorded that for two different Aluminium alloys welded by FSW, on increasing the rotation speed and transverse speed hardness value reduces and hardness is too much affected by precipitate distribution. The voids presence in the TIG welds contributes to reduced hardness. Authors concluded welded joint prepared by FSW having more hardness value as compared to welded joint prepared via TIG welding. Singh et al. [21] applied Taguchi technique to determine the effect of FSW on tensile properties of AA6063 under different welding condition and authors observed from their result that tensile strength of AA6063 welded joint increases with increasing the rotational speed and reduces with increasing transverse feed. Rizvi and Tewari [22] coupled Taguchi technique with grey relational analysis to optimize the process parameter during the welding of SS304 by MIG welding. It was observed that wire feed speed had most significant effect followed by voltage and gas flow rate.

2. Design and Experimental Work

2.1. Work Piece Material

In this research article, i.e., stainless steel 304H was used as raw material. SS 304H plate of dimension $150 \times 60 \times 5$ mm were bonded by using gas metal arc welding (GMAW) machine, with polarity direct current electrode negative [DCEN]. A schematic diagram of GMAW is shown in Fig. 1.

After completed weld, welded plates were machined on horizontal milling machine for generating V-groove. Chemical composition of parent metal plate and filler rod used in process for welding purpose is given in Tab. 1 respectively.

<table>
<thead>
<tr>
<th>Material</th>
<th>% C</th>
<th>% Cr</th>
<th>% Ni</th>
<th>% Mn</th>
<th>% Si</th>
<th>% P</th>
<th>% S</th>
<th>Cu</th>
<th>Fe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base plate</td>
<td>0.06</td>
<td>18.68</td>
<td>8.54</td>
<td>1.9</td>
<td>0.41</td>
<td>0.031</td>
<td>0.005</td>
<td>rest</td>
<td></td>
</tr>
<tr>
<td>Filler wire</td>
<td>0.08</td>
<td>19.5-22.0</td>
<td>9.0-11.0</td>
<td>1.0-2.5</td>
<td>0.3-0.65</td>
<td>0.030</td>
<td>0.03</td>
<td>0.75</td>
<td>rest</td>
</tr>
</tbody>
</table>
Taguchi design of 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 Tab. 2. Selection of orthogonal array was based on DOF. 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 R 12.5mm and to produced “V” notch in charpy impact test specimens. Tensile test specimens are prepared as per ASTM standard and a standard tensile test sample is shown in Fig. 2.

![Figure 1: Schematic diagram of GMA welding setup [15]](image1)

![Figure 2: Tensile test specimen as per ASTM [12]](image2)

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

### 2.2. **Welding Parameters**

In this research article, parameters which are used for welding purpose are given in Tab. 2.
In present research, 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 Tab. 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), where as derived response is known as signal. The variation of 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 experimental work the UTS, micro hardness, toughness (impact strength) were output (weld quality). For good quality of weld hardness, impact strength and UTS were considered as “higher is better”. In order to evaluate the influence of each selected factor on the responses, S/N
ratios for each control factor was calculated.

In this present research work tensile strength, micro hardness and impact strength of welded pieces were acknowledged as the responses, hence, “higher the better” consider for ultimate tensile strength and “nominal the best” for hardness properties for the analysis purpose.

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

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

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

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

<table>
<thead>
<tr>
<th>Level</th>
<th>Voltage</th>
<th>Gas flow rate</th>
<th>Wire feed speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>54.45</td>
<td>53.11</td>
<td>54.77</td>
</tr>
<tr>
<td>2</td>
<td>54.71</td>
<td>55.96</td>
<td>55.34</td>
</tr>
<tr>
<td>3</td>
<td>55.49</td>
<td>53.97</td>
<td>54.54</td>
</tr>
<tr>
<td>Delta</td>
<td>1.04</td>
<td>1.59</td>
<td>0.79</td>
</tr>
<tr>
<td>Rank</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

![Figure 4 Main effects plot for SN ratios (UTS)](image)

### 3.1.1. Tensile Strength

UTS were 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 (23 V), second level of gas flow rate (15 l/min) and third level of wire feed speed (350 IPM) gives higher tensile strength.

3.1.2. Hardness

VHN of test samples also experimentally calculated, Taguchi method was applied to find out the optimal welding process parameters with support of ANOVA. On the basis of data summarized, plots for the S/N ratio are expressed in Fig. 5. From Fig. 5 it is observed that and voltage (22 V), second level of gas flow rate (10 l/min) and third level of wire feed speed (350 IPM) gives normal values of hardness.

\[\text{Figure 5 Main effects plot for SN ratios (VHN)}\]

3.2. ANOVA

Analysis of variance is a statistic tool or technique, which is applied to evaluate the differences between the mean and their associated procedure. ANOVA result for UTS is given in Tab. 5, shows that gas flow rate has the major principal effect with 59% contribution followed by arc voltage 25% contribution, while wire feed speed having least effect.

\[\text{Table 5 Analysis of variance for SNRA1 (UTS), using adjusted SS for tests}\]

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj. SS</th>
<th>Adj. MS</th>
<th>F</th>
<th>P</th>
<th>% contrib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc voltage</td>
<td>2</td>
<td>6613.6</td>
<td>3306.8</td>
<td>11.58</td>
<td>0.079</td>
<td>25.5</td>
</tr>
<tr>
<td>Gas flow rate</td>
<td>2</td>
<td>15213.6</td>
<td>7606.8</td>
<td>26.65</td>
<td>0.036</td>
<td>58.7</td>
</tr>
<tr>
<td>Wire feed speed</td>
<td>2</td>
<td>3494.2</td>
<td>1747.1</td>
<td>6.12</td>
<td>0.049</td>
<td>13.5</td>
</tr>
<tr>
<td>Error</td>
<td>1</td>
<td>570.9</td>
<td>285.4</td>
<td></td>
<td>0.140</td>
<td>2.2</td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>25892.2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

ANOVA for S/N ration for hardness is summarized in Tab. 6 and it is very cleared from it that gas flow rate has the major significant impact with 58% 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

<table>
<thead>
<tr>
<th>Source/parameters</th>
<th>DF</th>
<th>Adj. SS</th>
<th>Adj. MS</th>
<th>F</th>
<th>P</th>
<th>% contrib.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc voltage</td>
<td>2</td>
<td>968.2</td>
<td>484.11</td>
<td>4.88</td>
<td>0.170</td>
<td>25</td>
</tr>
<tr>
<td>Gas flow rate</td>
<td>3</td>
<td>310.2</td>
<td>155.11</td>
<td>1.57</td>
<td>0.390</td>
<td>58</td>
</tr>
<tr>
<td>Wire feed speed</td>
<td>2</td>
<td>1828.2</td>
<td>914.11</td>
<td>9.22</td>
<td>0.0985</td>
<td>14</td>
</tr>
<tr>
<td>Error</td>
<td>1</td>
<td>198.2</td>
<td>99.11</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>8</td>
<td>3304.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Mode of fracture

4.1. Fracture mode of tensile test specimen

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

5. 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. Impact fractured specimens examined to determine the surface morphology.

Figure 6 Fractograph morphology (SEM) of tensile test specimens
Figure 7 Impact test samples after fracture

Figure 8(a) and (b) shows the images of fractograph of impact chirpy “V” notch test piece. Sample 1 in Fig. 8 shows the ductile fracture with coarse dimples. Enough finer dimples are observed in sample 3 in Fig. 8. Combined ductile and brittle fracture mode formation is responsible for poor absorbed energy. Sample 2 shows shallow dimples.

Figure 8 Macro images and SEM images of impact fracture samples for morphology
6. Conclusions

In the present research work it is tried to investigate the effect of gas metal arc welding (GMAW) processes on various welding variables and fracture mode characterization was studied. The welding process parameters in this experiment were arc voltage, wire feed speed and gas flow rate. In this conclusion it found that:

- in this research article, the choice of the process parameters for MIG welding of stainless steel (SS) with the optimal weldability has been marked;
- the modified Taguchi technique is applied to determine the optimal weldability with three higher-the better quality characteristics;
- analysis shows that gas flow rate having significant parameter that effect the UTS and VHN followed by arc voltage and wire feed speed;
- ductile fracture mode observed with fine dimples for tensile test samples;
- SEM analysis of fractured test pieces, fracture morphology shows rough dimples with combination of ductile and brittle fracture in impact toughness weldment samples;
- all chirpy “V” notch test samples break from the centre line.

References


