INVESTIGATION ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF SIMILAR, DISSIMILAR METAL WELD JOINTS BY GAS TUNGSTEN ARC WELDING

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Abstract- This study aims to evaluate and compare the mechanical and metallurgical properties of similar and dissimilar metal weld joints between duplex stainless steel/duplex stainless steel and duplex stainless steel/corten-A steel by gas tungsten arc welding (GTAW) process. Plates of 2 mm thickness of duplex stainless steel, conforming to grade AISI 2205 and high strength low alloy steel conforming to grade ASTM A242 Corten-A were butt welded using gas tungsten arc welding with argon as shielding gas. Electrode conforming to specification E 309L was used as filler metal. The joints were evaluated for microstructure and mechanical properties. Tensile, Bend, and Hardness tests were carried out to evaluate the mechanical properties. Micro structure was examined with optical microscopy. Micro examination of the weld region revealed dendritic grains of austenite with ferrite. The structure was free from sigma, intermetallic phases and other precipitates in similar metal. Micro examination of the weld region revealed dendritic structure in dissimilar metal.

Keywords- Corten-A steel, Duplex Stainless Steel, Dissimilar welding, Gas Tungsten Arc Welding, Microstructure, Mechanical properties.

I. INTRODUCTION

Gas Tungsten Arc Welding (GTAW), formerly known as tungsten inert gas welding, is the widely used arc welding process that uses a non-consumable electrode to produce the weld [1]. An electric arc is formed between a tungsten electrode and the base metal [2]. In GTAW shielding gas and filler material is important to achieve weld quality, the microstructural and mechanical properties of weldments. Argon is the ideal gas for GTAW of stainless steels and nickel alloys. Argon produces a clean welding arc and is suitable for all grades of stainless steel. The weldment properties strongly depend on the shielding gas, since it influences the mode of metal transfer. The shielding gas also plays a major influencing role in the weldability, appearance, bead shape, and penetration. In GTAW 99.9 percent pure argon is used as shielding gas since arc shielding is extremely important in welding process [3]. Duplex stainless steel combines the high strength of ferritic steels and the corrosion-resistance of austenitic steels. They are used in corrosive environment applications as integrity of the weldment is critical, especially in offshore and petrochemical plants. The duplex stainless steel has the great advantage of offering a combination of high strength and excellent corrosion resistance which allows plate thickness to be reduced by as much as 30%.

Corten-A steel is widely used in architectural applications, due to its aesthetical and hi tech features especially, the auto-protection from atmospheric corrosion [4]. Corten-A steel belongs to the family of high strength low alloy steel and is also known as weathering steel. These steels can provide corrosion protection without any additional protective coating. The increase in the percentage of copper content as the alloying elements, acts as an arresting mechanism to atmospheric corrosion in the material itself with the help of a rust (oxide) layer. Corten-A steel is superior to low carbon steel especially in strength and corrosion resistance aspects.

Several situations arise in industrial practice, wherein a dissimilar metal joint is required to be made. This is basically to ensure effective and economic utilization of special properties of each of the material. Joining dissimilar material is generally more challenging than that of similar metals because of difference in physical, mechanical and metallurgical properties of the parent metals to be joined. The joining of dissimilar metals by GTAW requires careful consideration of aspects like selection of filler wire to optimize dilution, alloying, melting temperature ranges of both base metals, thermal properties, viz, thermal conductivity, co-efficient of thermal expansion, weld metal-base metal interaction and joint design [5]-[6].

Gas Tungsten Arc weld joints of ferritic stainless steel have superior tensile and impact properties compared with shielded metal arc and gas metal arc weld joints and this is mainly due to the presence of finer grains in fusion zone and heat affected zone[7]. Many studies have been reported on microstructure and mechanical properties of various types of stainless steel. Similarly many of the reported literature focussed more on the corrosion behaviour of corten-A steel in different environments. But
published information on the study and comparison of microstructure and mechanical properties of similar/dissimilar weld joint between DSS/DSS and DSS/Corten-A steel is not much. Such weld joints have practical applications in industries such as rail coach fabrication. The main aim of this study is to determine microstructure and mechanical properties of DSS/DSS and DSS/Corten-A material weld by GTAW. For this, hardness measurement, microstructures of BM, HAZ and WM and tensile test of 2205 DSS material and Corten-A butt welded by GTAW were carried out between the electrode tip and work piece. The arc length in GTAW is usually from 2 to 5mm [10].

In this experiment, TRIDENT 4009 make GTAW machine was used. During welding, welding gun was controlled manually and the filler rod was fed manually into the welding area.

2mmx150mmx250mm sizes of both DSS/DSS cut plates were kept together with 1.2 mm root gap and the plates were tack welded followed by run weld. Similarly DSS/Corten-A cut plates were welded with the same arrangement. Clamps were used to align and hold the plates together in order to avoid misalignment and distortion. Welding was carried out by means of GTAW with argon as shielding gas. After welding, specimens were cooled in the air. 10 samples were made on each method and finally 2 samples on each method selected based on the visual inspection parameters like uniform bead width, and weld appearance. The welding conditions and process parameters used are given in Table 2.

Welded joints were then cut in to sections of required size, using band saw for making tensile test specimens. Vickers hardness test was carried out to record hardness of the joint at various locations ranging from 2205 base metal side to corten-A steel base metal side through HAZs and weld zone. Microscopy of the structure was done by microscope with a magnification of 220 x and 500x to assess the micro structure of the weld zone as well as HAZ of both the sides. Macro etching test was also conducted to evaluate the level of fusion and penetration of the weld using 10% NaOH as etchant.

To observe microstructures, cross sections of the specimens were vertically taken and those cross sections were covered by bakelite. After covering, the specimens were sanded with several grades of emery papers like 80-150-400-600- 800-1200. Standard metallurgical polishing procedure was followed for carrying out the micro structural investigations [11]. The uniaxial tensile tests were carried out to determine the tensile properties like yield strength, ultimate tensile strength, percentage of elongation and reduction of cross sectional area at room temperature. The tests were carried out in x-direction

II. EXPERIMENTAL PROCEDURE

2.1 Material
The work piece sheets were made from 2205 duplex stainless steel and corten-A of thickness 2mm. Test specimens of both DSS and corten-A sheets were cut in to the size of 2mmx150mmx250mm and welded with GTAW process. 309L filler rod was used as the welding materials. The Chemical Compositions of duplex stainless steel, corten-A steel and filler rod 309 were shown in the Table1

Table 1 Chemical Composition of base metals and electrode by % weight

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Cr</th>
<th>Mn</th>
<th>Mo</th>
<th>Ni</th>
<th>Al</th>
<th>Si</th>
<th>Fe</th>
<th>Cu</th>
<th>P</th>
<th>S</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSS</td>
<td>0.022</td>
<td>22.54</td>
<td>4.999</td>
<td>1.113</td>
<td>0.701</td>
<td>0.123</td>
<td>0.131</td>
<td>1.622</td>
<td>1.689</td>
<td>-</td>
<td>0.038</td>
<td>0.035</td>
</tr>
<tr>
<td>Corten-A</td>
<td>0.078</td>
<td>0.328</td>
<td>2.376</td>
<td>0.616</td>
<td>0.114</td>
<td>0.392</td>
<td>0.318</td>
<td>0.839</td>
<td>0.108</td>
<td>0.032</td>
<td>-</td>
<td>Niobe</td>
</tr>
<tr>
<td>Filler</td>
<td>0.032</td>
<td>22.63</td>
<td>12.6</td>
<td>0.61</td>
<td>0.124</td>
<td>0.321</td>
<td>0.110</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2.2 Welding process
The Gas Tungsten Arc Welding Equipment Arrangement is shown in Fig. 1. The welding torch holds the non consumable electrode assures the transfer of current to the electrode and the flow of shielding gas to the weld pool. Torches with the welding regimes up to 200A are generally gas cooled and those with continuous operation between 200 and 500A are water cooled. Gas cooled torch was used in the above arrangement. The shielding gas is directed on the puddle via a nozzle or cup which is concentric with the torch collet that holds the electrode [8].

Fig. 1. [9] Gas Tungsten Arc Welding Equipment Arrangement

The regulator is a device that reduces source gas pressure to a constant working pressure, independently of source pressure variations. The effect of increasing the welding feed resulting reduced heat input. The arc length is the distance
and with INSTRON 1195 tensile testing machine with loading rate of 0.5 mm/min. The specimens were prepared according to ASTM E8-04, as shown in Fig. 2. [12].

III. RESULTS AND DISCUSSION

Welding of similar metal and dissimilar metal joints revealed satisfactory results in terms of weldability. Tensile, macro, micro and hardness results of both similar/dissimilar metal joints have been mentioned and compared.

3.1 Tensile properties of DSS/DSS

Tensile test was carried out in a UTM (40 ton) on test pieces of DSS/DSS as shown in Fig. 2 to assess the tensile strength of the weld. We observed that, fracture occurred at the base metal area side Fig. 3. It gives the indication that the strength of the weld metal is stronger than the base metal among the two. Also, the load value at the time of fracture during tensile test seems to be high in similar metal weld joint. Tensile test values for the similar metal weld joint given in Table 3.

DSS/DSS Tensile Test:

Table 3 Tensile test values-similar metal joint

<table>
<thead>
<tr>
<th>Observation</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Thickness (mm)</td>
<td>1.90</td>
</tr>
<tr>
<td>Original Width (mm)</td>
<td>18.97</td>
</tr>
<tr>
<td>Original Cross Sectional Area (mm²)</td>
<td>36.04</td>
</tr>
<tr>
<td>Ultimate Tensile Load (KN)</td>
<td>23.74</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (Mpa)</td>
<td>659.00</td>
</tr>
<tr>
<td>Fracture Location</td>
<td>Base metal</td>
</tr>
</tbody>
</table>

3.2 Tensile properties of DSS/HSLA

Tensile test was carried out in a UTM on test specimen of DSS/HSLA as shown in Fig. 4 to assess the tensile strength of the weld. We observed that, fracture occurred at the corten-A steel side as shown in Fig. 5. It gives the indication that the strength of the weld metal is stronger than that of base metal. Tensile test values for the dissimilar metal joint given in Table 4.

DSS/Corten-A Tensile Test:

Table 4 Tensile test values-dissimilar metal joint

<table>
<thead>
<tr>
<th>Observation</th>
<th>Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gauge Thickness (mm)</td>
<td>1.80</td>
</tr>
<tr>
<td>Original Width (mm)</td>
<td>18.75</td>
</tr>
<tr>
<td>Original Cross Sectional Area (mm²)</td>
<td>33.75</td>
</tr>
<tr>
<td>Ultimate Tensile Load (KN)</td>
<td>16.26</td>
</tr>
<tr>
<td>Ultimate Tensile Strength (Mpa)</td>
<td>482</td>
</tr>
<tr>
<td>Fracture Location</td>
<td>Corten-A steel</td>
</tr>
</tbody>
</table>

3.3 Ductile properties

Bend tests for ductility provide a simple way to evaluate the quality of materials by their ability to resist cracking or other surface irregularities during one continuous bend condition. The specimens after welding were thoroughly ground in a pedestal grinding machine to flatten the welding projections above the base metal. The sides were also perfectly rounded off and smoothened to remove any sharp edges present which may develop crack during the bending. The specimen were uniformly ground using fine grade belt emery. The specimens after polishing were tested in a UTM suitably by changing the rollers and ram, and then applying the load gradually on
them. During the bend test the roller size is kept three times of the thickness of the mandrel size. The bend test was performed according to IS: 1599 – 1985 standards and the test specification given in Table 5.

The following Fig. 6 & 7 shows the condition of specimens after the bend tests for both similar and dissimilar joints. No development of crack was noticed during the bend test. The ductility of the weld was found satisfactory in the bend tests.

<table>
<thead>
<tr>
<th>Table 5 Bend test specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (mm)</td>
</tr>
<tr>
<td>380</td>
</tr>
</tbody>
</table>

3.4 Mechanical properties comparison between DSS/DSS and DSS/Corten-A

Ultimate tensile strength (659 MPa), yield strength (596 MPa) and breaking load (23.74 KN) is high in DSS/DSS joint compared to DSS/Corten-A which is 482 MPa, 372 MPa and 16.26 KN respectively.

Both the results were compared and mentioned in the Fig. 8. This indicates that the mechanical properties of DSS/DSS weld metal joint are superior to DSS/Corten-A weld metal joint. Feasibility of welding dissimilar metal joint DSS/Corten-A found satisfactory through this experiment and this can be used as an optional process for future requirements considering the cost impact.

3.5 Hardness Comparison between DSS/DSS and DSS/Corten-A

Vickers hardness measurement was carried out using a DUKON WILSONTESTER device and the specimens were prepared according to ASTM E92-82 [13]. Hardness was measured using Vickers hardness using 1 kg load as per ISO 6507: 1997 standards. The comparative graphs Fig. 9 clearly shows decreasing pattern of hardness values from weld metal to base metal through HAZ in both the cases. This indicates that the hardness value in weld metal (283HV) is high as compared to HAZ (265HV) and base metal (252HV) in DSS/DSS metal weld joint. Similarly hardness value shows decreasing trend from weld metal to base metal in dissimilar metal weld joint. This indicates that hardness value in weld metal (290HV) is high compared to HAZ (228HV) and base metal (190HV). Both the similar and dissimilar metal joint hardness results revealed that strength of the weld metal is high compared to HAZ and base metal area.

3.6 Macro etching-Similar & dissimilar metal weld joint

The weld joint was etched with 10% NaOH electrolytic etchant. We observed that the macro analysis of the specimen revealed complete weld fusion.

3.7 Similar metal Micro structure analysis (DSS/DSS)

Micro examination of the parent metal region revealed grains of austenite (white in colour) with ferrite (brown in colour) Fig. 10 & 11. The coarsening of grain was also observed in the HAZ region near to the weld zone (Fig. 12 & 13). Refined grains were observed in the HAZ region. This finding
is in line with the hardness value observed in between base metal and weld metal during Vickers hardness test (Fig. 9). The examination of microstructure in similar metal weld revealed that the grain structure in weld zone is a mixture of ferrite and austenite (Fig. 14). Micro examination of the weld region revealed dendritic grains of austenite (white) with ferrite (brown). The structure is free from sigma, intermetallic phases & other precipitates.

3.8 Dissimilar metal macro analysis (DSS/HSLA)

The weld joint was etched with 10 % NaOH electro etchant. We observed that the Macro analysis of the dissimilar specimen revealed complete weld fusion.

3.9 Dissimilar metal Micro structure analysis (DSS/HSLA)

The micro examination of the DSS parent region revealed that the grains of austenite with ferrite Fig. 15. The micro examination of the HSLA parent metal region revealed ferrite with pearlite as shown in Figure 16. The structure is free from sigma, intermetallic phases & other precipitates. The microstructure analysis revealed that the grain structure of the HAZ as shown in Fig. 17 and 18 found to be very fine compared to all other zones. Also, micro examination of the HAZ reveals martensite with areas of ferrite Fig. 18. This finding is in line with the hardness value observed in between base metal and weld metal at the above region during vickers hardness test Fig. 9. The micro examination of the weld region shows dendritic structure as shown Fig. 19.
CONCLUSION

The following results were obtained from this investigation with respect to properties of similar and dissimilar metal weld between DSS/DSS to grade 2205 and DSS/weathering steel to grade Corten-A steel:

1. Satisfactory results can be obtained by joining DSS/DSS and DSS/Corten-A steel in terms of weld quality.
2. Ultimate breaking load is 23.74KN in similar metal joint and in dissimilar metal joint breaking load is 16.26KN which reveals a 31.5 percentage reduction in the breaking strength of the dissimilar metal joints when compared with similar metal joints.
3. Fracture in tensile test occurred at the Corten-A steel side of the welded joint, giving indication that the tensile strength of weld area is higher than that of Corten-A steel (base metal).
4. The bend test revealed satisfactory ductile behavior of the joint in both the cases.
5. Coarsening of grains was observed on the fusion area of both DSS and Corten-A Steel side.
6. Lower hardness values were observed at the base metal area than HAZ and WM on both similar and dissimilar metal joints.
7. The area of HAZ in Corten-A steel side was found to be high than that of DSS side, probably due to higher heat conductivity value of Corten-A steel.
8. Dissimilar metal joint result indicates that, it can give better welding strength and can be a better option considering the cost impact of similar metal joint since the fracture occurred at base metal area only not at the weld area.
9. Currently rail coaches are being manufactured by using DSS/DSS similar metal joint with GTAW process. This experiment will explore the possibility of using dissimilar metal joint for fabrication of rail coach side wall to the roof, side wall to the end wall and the side wall to the under frame.

REFERENCES

[8]. “Welding Health and Safety by American Industrial Hygiene Association”.