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Analysis of Dissimilar Metal Welding of EN19 and SS304L

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ABSTRACT:

Dissimilar welding between low carbon steel and austenitic stainless steel using both Tungsten inert gas and metal inert gas welding has been reported. However, the combination of SS304 and mild steel has less tensile strength in both TIG and MIG welding. Therefore, this study is undertaken with the objective of finding the weld strength of EN19 and SS304L using TIG and MIG welding with different parameters. Tensile strength and hardness of the welded region is found to be higher than that of the base material. The comparison of microstructure near the weld pool and the base material revealed the changes in composition of materials besides the formation of martensite in the welded region. The main application of this material thus prepared by welding processes could be in automobile industries, food industries and nuclear pressure vessels.

KEYWORDS:

Austenitic Chromium-Nickel stainless steel; Inert gas welding; TIG welding; Mechanical properties; Microstructure

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1. Introduction

It is well known that welding of materials, in particular of metals and alloys, is one of the simplest easiest, very important and versatile fabrication process used by the industries [1-2]. Welding of single metal or alloy is well known, which involves localized coal essence of these by the application of suitable combination of temperature and pressure. Of course, metallurgical aspect of the materials being welded is also important. Thus, manufacturing of products in different geometrical shapes using welding process has become one of the most important production technologies used in industrial applications. Accordingly, there are various welding processes available. Commonly used welding processes are TIG and MIG welding [3]. There are many parameters for optimum welding joints to takes place [1-4]. These include: current, voltage, welding speed, diameter of the filler material, shielding gases, gas flow rate, etc. [5]. During welding process, shielding gas is very important to get defect free welding besides the need to keep away hydrogen and oxygen from welding zone to avoid hydrogen embrittlement resulting in cracks and porous area at the weld joint [2, 6].

Many factors have to be considered before selection of filler wire for TIG and MIG welding process [6-8]. These include: type of base material, weld-ability, surface finish, corrosion resistance etc. While the single metal or alloy welding may be suitable for conventional applications such as construction, off shore and on shore applications, advanced applications such as in chemical and petrochemical industries, nuclear installations, aerospace, marine sectors, energy conversion systems, etc., look for aspects such as high resistance to different environments, corrosion, heat, tolerance to thermal cycles, etc., [9-12]. These can be met by the joining of dissimilar metals such as ferrous to ferrous or ferrous to non-ferrous materials to get robust joints, which may meet the required characteristics. However, joining of dissimilar metals or alloys poses a number of challenges due to differences in physical, chemical including corrosion resistance and metallurgical properties of the materials involved in such welding [9-16]. These include migration of elements, which affect various properties (mechanical, metallurgical and corrosion resistance) of weld-ment, etc., [10, 17]. On the other hand, there are some advantages in this type of welding such as saving of materials and thus becoming economical and possible reduction in weight [9-10, 12, 16-17]. While a large number of published reports are available for single metal/alloy welding using different welding processes, very few reports are available in the case of welding of dissimilar metals/alloys.

Keeping the length of the paper in mind only few references are cited for both single metal welding [1-4, 6, 18-27] and dissimilar metals welding [5-7, 9-17, 28-35]. A study of these revealed the following: (i) Most of these deal with ferrous materials (carbon steel and stainless steel) and only very few are related to non-ferrous metals/alloys (Aluminium, Inconel, Monel, etc.) [7, 9, 10, 16, 20]; (ii) All these have used either a single welding process or combination of different welding processes using different welding parameters [12, 15, 17, 26, 35]; (iii) In general, in all the reported literature cited above both MIG and TIG welding processes are reported to show improvement in dissimilar welding through improvement in properties particularly mechanical properties and some in corrosion resistance [6, 13, 14, 17, 30]. (iv) Obtained properties have been explained in some studies based on the resulting microstructures of weldment and the base metals/alloys used, while some have used non-destructive tests to assess the quality of the welds (defects such as porosity, agglomerations, etc.) [2, 22, 24]; (v) Furthermore, some of the studies regarding both single metal welding and dissimilar metal welding mentioned above have used mathematical models such as Taguchi method as part of the design of experiments to predict various process parameters used as well as to predict the geometry and shape of the bead obtained after welding and mechanical properties of welded materials [2, 4, 6, 19, 23, 27, 31]; (vi) Some of the studies have used ANOVA to analyse the obtained results particularly regarding the mechanical properties [2, 6, 19, 23, 27]; (vii) Studies are also (a) on effect of pulsed and non-pulsed current on obtained properties [22-24] and filler material used [8, 28], (b) chemical composition of weldment [10, 17, 30] (c) only studies on microstructures [16, 28, 29] and (d) single studies on flexural properties [8] and EN19 steels [31].

From the foregoing it becomes clear that (i) none of the studies mentioned above has reported the combined use of two processes on a single combination of two dissimilar steels and its effect on the performance of the resulting weld material and (ii) there is only one study using EN19 steels. Considering welding of two different ferrous metals is more important for various advanced applications, this study was undertaken with the following objectives: (i) welding of dissimilar ferrous metals, viz., low alloy carbon steel (EN-19) and austenitic stainless steel (SS304L) using both TIG & MIG welding process in double V-groove, and (ii) study the weld strength and quality of weld by suitable techniques (destructive and NDT techniques). Selected austenitic stainless steel has different carbon composition, which has helped to determine the dilution of weld region. Reasons for the selection of materials and the welding processes are given in the next Section. It is expected that this study would not only reveal about the morphology of the structure formed near the weld region, but also presents the influence of welding on the strength around the heat affected zone (HAZ). This is because, it is known that region near the HAZ is a high temperature zone, which affects the material properties including its strength properties. Besides, dilution of weld region helps in determining the usage of filler rod and the strength of the weld. It is hoped the alloys used in the present study may have the potential for suitability for their use in automotive, nuclear, marine and petrochemical applications.

2. Experimental methods

Two base materials SS304L and EN19 were machined according to ASME standard. The dimensions of base material were 300x150x16mm with a bevel height of 1mm and bevel angle of 30° on both sides. Both the materials were placed in the fixture for TIG welding process with a gap of 1mm. Using filler material ER309L three passes of TIG welding is performed on both sides of the base material by maintaining inter-pass temperature of 120°. Upon TIG welding MIG welding was used on both sides of the base material. Welded plates were cut using water jet machining to prepare suitable samples for tensile and bend testing as per ASME section IX standard. Hardness test of welded samples was carried out on samples of size100×25×16 mm using Brinell Hardness Tester (make - Krystal and model No.KAB-1). Cone indenter of 2.5mm with applied load of 187.5 kgf for a dwell time of 15 seconds was used in all the experiments. Nine readings on each sample were taken from the welded specimen for every 5mm interval on either side of the welded region and the average of these were taken as the hardness value of each tested sample. Three samples of thus prepared samples were tested. Tensile test was carried out using FIE make Universal testing machine, (Model No. UTE-100, Sr.no:11/2002-2892) with 164.85kN load and cross head speed or strain rate of 75 mm/min. From the obtained stress-strain curves, values of Young’s modulus (YM), yield strength (YS), ultimate strength (UTS) and, % elongation were determined.

Face bend test was carried out on prepared welded samples using Micro Control System make universal testing machine (Model: UTE-600kN-MCS). The main principle of bend test is cantilever beam with a point load at the centre of the specimen. For microstructural analysis, first all greases, oils, coolants and residues from cut-off blades present on the specimens were removed using an organic solvent. This was then followed by ultrasonic cleaning of samples with a view to remove effectively the last traces of residues on the welded zone. These samples were then polished using emery papers of different grit size to get proper surface for the microscopic observation. These samples were observed under Nikon microscope LV15.

3. Results and discussions

3.1. Hardness test

The hardness test values have been tabulated in Table 1 and graph of hardness vs. distance from weld region has been plotted. Fig. 1 shows average hardness values obtained for both the base materials and their welded samples at various locations. The value at welded portion is 193 BHN. The hardness value decreased at SS304L portion of the welded sample (141-151 BHN), then slowly increased in welded portion (193 BHN) as well as at HAZ portions on either side of the weld-ment (171 and 196 BHN). This hardness value further showed increase at EN19 portion (203-208 BHN). This is understandable due to the nature of the base materials and also absence of any welding defects in the weld-ment as corroborated by the microscopy studies.

Table 1: Hardness values

Indent. area	SS304L			HAZ	Weld portion	HAZ	EN19		
BHN	151	147	141	171	193	196	203	208	208

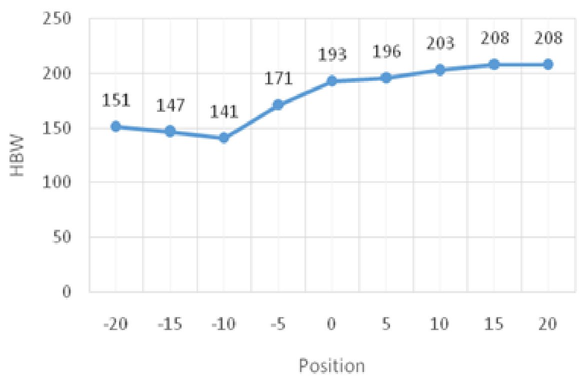

Fig. 1: HBW vs. Distance from weld region

3.2. Tensile test

The tensile test result is shown in Fig. 2. From the obtained stress-strain curves, values of Young's modulus (E), yield strength (YS), ultimate strength (UTS) and, % elongation were determined. The values of E, YS and UTS of weld EN19 and SS304 L were found to be about 1.15, 1.13 and 1.5 times respectively lower than that those of base material EN19 (850MPa). Whilst the values of E of weld EN19 and SS304L was about 1.11 times lower, the values of YS and UTS were about 2.9 and 1.2 times higher than those of SS304L (450-500MPa). During the tensile test the specimen broke from the weld region towards SS304L indicating a good weld strength.

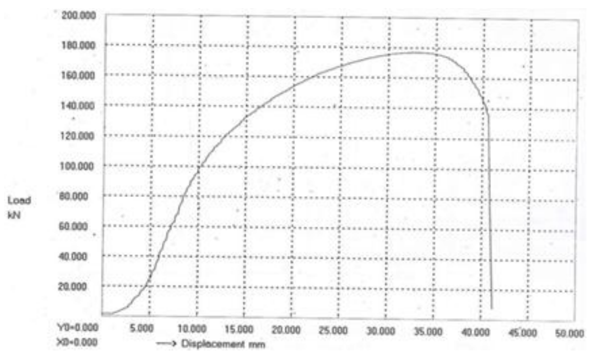

Fig. 2: Load vs. Displacement from tensile test of welded EN19 and SS 304L sample

3.3. Bend test

The main principle of bend test is cantilever beam with a point load at the centre of the specimen. The bend test result is shown in Fig. 3. Weld material of EN19 and SS304L showed increase in flexural modulus and flexural strength values of about 7.7 times and 12 times over the respective values for EN19 and about 4.56 times and 7.4 times that of SS304L respectively. The results of tensile and bending tests are summarised in Table 2.

Table 2: Summary of tensile and bending tests' results

Result	Values
Ultimate load	13.32 kN
Percentage elongation	0.13
Flexural modulus	12.5888 GPa
Ultimate stress	567 MPa
Max. displacement	41.2 mm

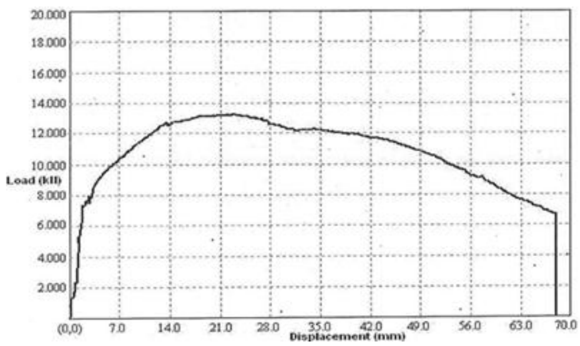

Fig. 3: Load vs. Displacement from flexural test of EN19 and SS 304L welded sample

3.4. Microstructure analysis

Microstructure of SS304L and EN19 weldment using TIG and MIG process are shown in Figs. 4 (a-e). It can be seen from these micrographs that base material SS304L consists of equi-axed fine grains of austenite (Fig.4(a)), while that of EN19 contains mixture of pearlite and ferrite (Fig.4(e)). These consist of carbon and small percentage of chromium and molybdenum. Dendritic structure observed at the welded portion and mixture of fine pearlite and martensite observed at HAZ weld (Fig.4(b)). While Fig. 4(c) presents the microstructure of the welded joint, Fig. 4(d) shows the morphology of welded sample with HAZ on the side of EN19. Further, compared to EN19 microstructure, fine grain is seen in the welded portion. It may also be noted that EN19 base material during welding absorbs some small percentage of nickel from filler material and due to this toughness increased. On the other hand, austenitic SS304L, with major components of chromium and nickel, picks up carbon from EN19 and forms martensite at the welded region along with austenite. These could be the reason for the observed higher strength/hardness at weld region compared to that of base materials.

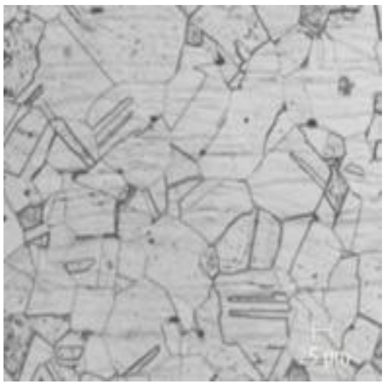

Fig. 4(a): Morphology of welded sample - Portion of SS304L

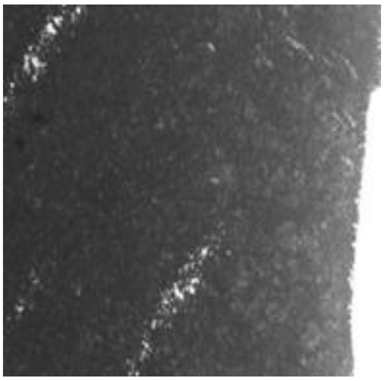

Fig. 4(b): Morphology of welded sample - HAZ on the SS304L side

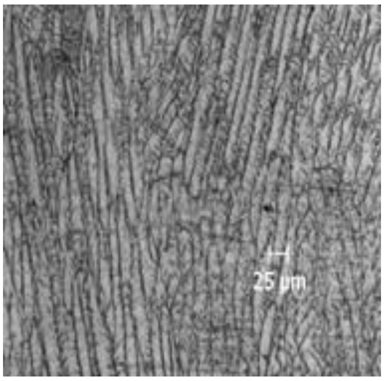

Fig. 4(c): Morphology of welded sample - Weld joint

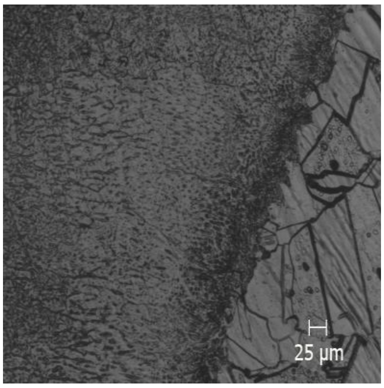

Fig. 4(d): Morphology of welded sample - HAZ on the EN19 side

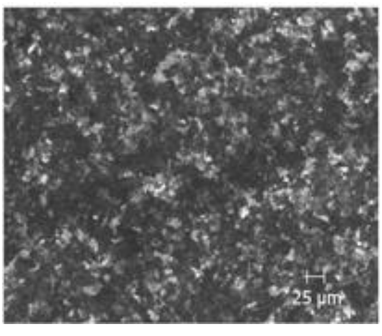

Fig. 4(e): Morphology of welded sample - EN19

4. Conclusions

After conducting series of experiments on the welding of EN19 and SS304L, the following can be concluded:

- Dye penetrant test revealed that, the weld was free from cracks, blowholes and other defects.
- Hardness at the weld region (193-196 BHN) was found to be higher than that of SS304L (147-151 BHN) while it was comparatively almost the value as that EN19 (208 BHN) suggesting that the weld has good hardness property. The hardness value of HAZ (171 BHN) was higher than that of SS304L.
- The yield strength of weld material was about 1.13 and 2.9 times higher than those EN19 and SS304L respectively. The ultimate tensile strength of weld material was about 1.5 and 1.2 times higher than those EN19 and SS304L respectively.
- The value of % elongation of weld remained almost the same as that of EN 19, while it decreased by about 3 times compared to that of SS304L.
- The microstructure of the weld was found to consist of random mixture of austenite and pearlite.

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