ENGINEERING RESEARCH JOURNAL (ERJ)
Vol. 1, No. 44 April 2020, pp.1-4.
Journal Homepage: erj.bu.edu.eg

Effect of Electrode Material on Microstructural and Mechanical Characteristics of AISI 304 Stainless Steels Plates Joined Using Shielded Metal Arc Welding

A. S. Abdel-Wanees[1], T. S. Mahmoud[2] and I. M. Ibrahim[3]

[1] Manufacturing Engineering and Production Technology Department – Modern Academy in Maadi – Egypt.
[2, 3] Mechanical Engineering Department – Faculty of Engineering at Shoubra – Benha University – Egypt.

Abstract. In the present investigation, the microstructural and mechanical characteristics of AISI 304 austenitic stainless steels (SS) plates welded using shielded metal arc welding (SMAW)were studied. The AISI 304 SS plates were joined using two different electrodes, typically, E308L-16 and E312-17 (according to AWS). Tensile and hardness tests were employed at room temperature to highlight the changes in mechanical behavior of welded joints. Both macro- and microstructure examinations have been used to evaluate the effect of electrode material on phases and grains structure of the welded joints. Microstructural investigations showed that the welded regions exhibited a vermicular ferrite structure distributed in austenitic structure with a varied grain size due to temperature distribution along specimens. The AISI 304 SS specimens, welded using E308L-16 electrodes, lower joint efficiency and higher elongation than those welded using E312-17 electrodes, also the hardness is higher when applying E312-17 electrode.

KEYWORDS: Stainless Steel, Microstructure, SMAW, Mechanical Properties, Electrode Material.

1. INTRODUCTION

Austenitic stainless steels (SS) are an extraordinary family of alloys that have exceptional corrosion resistance and equally impressive mechanical properties. They have unsurpassed strength, toughness, and formability among the commercially viable alloys from cryogenic to elevated temperatures. They are also valued aesthetically and are environmentally benign [1,2]. Austenitic SS induces brilliant combination of mechanical properties which makes them very useful at industrial application. It also has good formability and cold working can increase the strength of some grades as well as toughness and weldability. Typical applications for austenitic SS include cooking utensils, containers and pipework in the food industry, storage vessels, pipes and tanks for corrosive liquids, architecture, mining, chemical and pharmaceutical equipment.

Shielded metal arc welding (SMAW) is the simplest, least expensive, and mostly widely used arc welding process. It is often referred to as ‘stick welding’ or manual metal arc welding. This process produces coalescence of metals by heating them with an arc between a covered metal electrode and the base metal workpiece. Shielding is provided by decomposition of the electrode covering. The main function of the shielding is to protect the arc and the hot metal from chemical reaction with constituents of the atmosphere. The electrode covering contains fluxing agents, scavengers, and slag formers. Pressure is not used in the process and the filler metal is obtained from the electrode. All ferrous metals can be welded in all positions using SMAW [3,4].

In SWAW, electrode selection plays an important role in achieving the desired mechanical properties of the welded joints [5-8]. There are two major factors that essentially regulate the selection of electrodes, typically, types of base material and service condition. There are other factors, which can influence the choice on welding electrodes; however, the aforementioned two factors mainly decide the welding electrodes. Accordingly, the effect of the electrode material on the mechanical characteristics of AISI 304 and AISI 316 austenitic SS plates joined using SMAW was investigated. In this study, the variable parameters were the welding electrodes while the other SMAW welding parameters were kept constant.

2. EXPERIMENTAL PROCEDURES

The chemical compositions of the AISI 304 austenitic SS base materials are shown in Table 1. The material was received in form of rolled plates and then machined into smaller pieces having dimensions of (50 mm width × 600 mm length and 10 mm thickness). Before welding, the plates have been prepared and machined to get single V-groove with an angle of 60^o when welding as shown in Fig. 1. Similar joints from AISI 304 austenitic SS plates (i.e. 304-304) were joined by employing SMAW technique using constant DC welding current with reverse polarity and welding voltage about 30 Volts and current of 100 Ampere. The complete welding process was performed manually in four passes with an average welding speed of 8 mm/sec. The AISI 304 SS plates were welded using E312-17 and E308L-16 AWS electrodes. The E312-17 and E308L-16 AWS electrodes have 3.2 mm diameter. Table 2 shows the chemical compositions of the E312-17 and E308L-16 AWS electrodes used in the present investigation.

Table 1. Chemical composition of AISI 304 stainless steel (wt.-%).

Base Alloy	Elements (wt.-%)							
	C	Si	Mn	P	S	Cr	Ni	Fe
AISI 304	0.06	0.42	1.89	0.032	0.014	18.67	8.53	Bal .

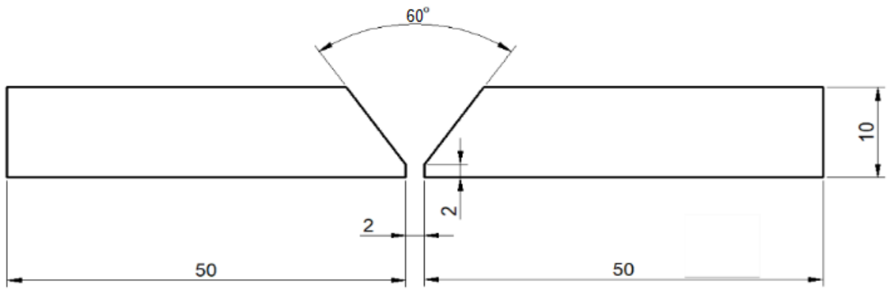

Figure 1. The welded joint configurations (dimensions in mm).

Table 2. Chemical composition of electrodes (wt.-%).

Electrode	Elements (wt.-%)									
	C	Si	P	S	Mn	Ni	Cr	Mo	Cu	N	Fe
E308L-16	0.03	0.78	0.02	0.01	0.7	9.7	19.4	0.02	0.03	-	Bal
E312-17	0.14	0.64	0.02	0.007	0.9	10.1	29.1	0.07	0.05	0.07	Bal.

The tensile properties of the AISI 304 SS welded joints were evaluated at room temperature. The tensile tests were performed using *Shimadzu* universal testing machine having maximum load of 200 kN. The tensile specimens were machined from the transverse sections. The crosshead speed during tensile tests is kept constant at 5 mm/min. Tensile specimens have gauge length of 50 mm and 6×8 mm^2 cross-section. The test was carried out according to ASTM-E8, "Standard for Tensile Test of Metallic Specimens". The hardness of the welded regions was measured by *Wolpert DiaTestor* Rockwell hardness tester (HRA) using a load of 60 kg for 10 s, according to ASTM E18-07, "Standard Test Methods for Rockwell Hardness of Metallic Materials".

Both macro- and microstructural examinations have been performed using a *Kern* Optical Metallurgical Microscope. Specimens were ground under water on a Metasery Grinder 2000 polishing/grinding machine using SiC abrasive discs of increasing fineness up to 2000 grit, then polished using 0.1 μm alumina suspension. Both of the micro- and macro-etching in solution of 33% HCL, 33% HNO_3 and 34% H_2O for one minute according to ASTM E407, "Standard for Metal Microscopic Examination".

3. RESULTS AND DISCUSSION

3.1. Macro- and Microstructural Examinations.

Figure 2 shows typical macrograph of AISI 304 SS specimen welded using E312-17 electrode. The fusion zones are clearly seen in the macrograph. Complete penetration was observed in the welded region. The welded joints are free from macroscopic defects such as lack of fusion, voids formation …etc. Figures 3 show micrographs of the microstructure of the AISI 304 SS welded regions. The fusion zones (FZ) exhibited microstructure consists of discontinuous network of vermicular ferrite structure (dark) in austenitic matrix (light). However, acicular morphology (Fig. 3a) was also observed at a few locations where the ferrite content was higher. Some coarse dendrites in the seam center was also observed. Coarse columnar dendritic crystals were observed along the heat dissipation direction, in the near FZ of the seam. From the melting boundary to the seam center, the temperature changes, which effect the speed of crystallization, so the crystal morphology changes from cellular crystal to columnar crystal, and then to free dendritic crystal. Heat affected zones (HAZs) are observed in the welded regions and it is located next to the fusion line (FL).

3.2.1. Tensile Characteristics of the Weldments.

The welded joints exhibited higher tensile strength and elongation percentage than the AISI 304 SS base alloy. The AISI 304 SS joints welded using E308L-16 electrodes exhibited lower strength and higher elongation % than those welded using E312-17 electrodes. The AISI 304 SS base alloy exhibited ultimate tensile strength and elongation percentages of 520 MPa and 70%, respectively. The AISI 304 SS joints welded using E308L-16 electrode showed ultimate tensile strength and elongation percentages of 845.8 MPa and 64%, respectively. While the joints welded using E312-17 electrode showed ultimate tensile strength and elongation percentages of 927.08 MPa and 50.5%, respectively.

3.2.2. Hardness of the Welded Regions.

Figures 4 shows the hardness profiles at the middle-height of the cross-section of the welded regions for AISI 304 SS. Generally, the FZ exhibited higher hardness in center of FZ and start to slightly decrease with a little variation along the specimens. This may attribute to alloying elements of electrodes like chromium and molybdenum and their mechanical properties and variation of grains size and the presence of ferrite structure (BCC) in the internal structure of the welds. The regions welded using E308L-16 electrodes exhibited lower hardness than those welded using the E312-17 electrodes. After reaching peak value, the hardness decreases in the HAZ. In all welded regions, the HAZ, adjacent to the fusion boundary, showed fine grained structure which possessed high hardness, whereas the HAZ adjacent to the base metal showed coarse grained HAZ which possessed lower hardness. The areas of HAZ, that are adjacent to the weld/FZ, experiences appropriate cooling rate due to steeper thermal gradients and consequently has finer grained microstructure whereas the area adjoining the base metal undergoes relatively slower cooling rate and hence has coarse grained microstructure, In general, it is observed from the hardness measurements that the hardness follows a decreasing trend in the order of weld metal, HAZ and base metal.

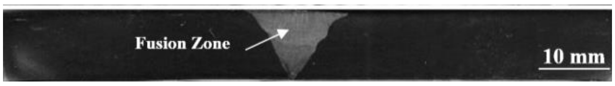

Figure 2. Typical photographs of the macrostructure of AISI 304 SS welded using E312-17 electrode.

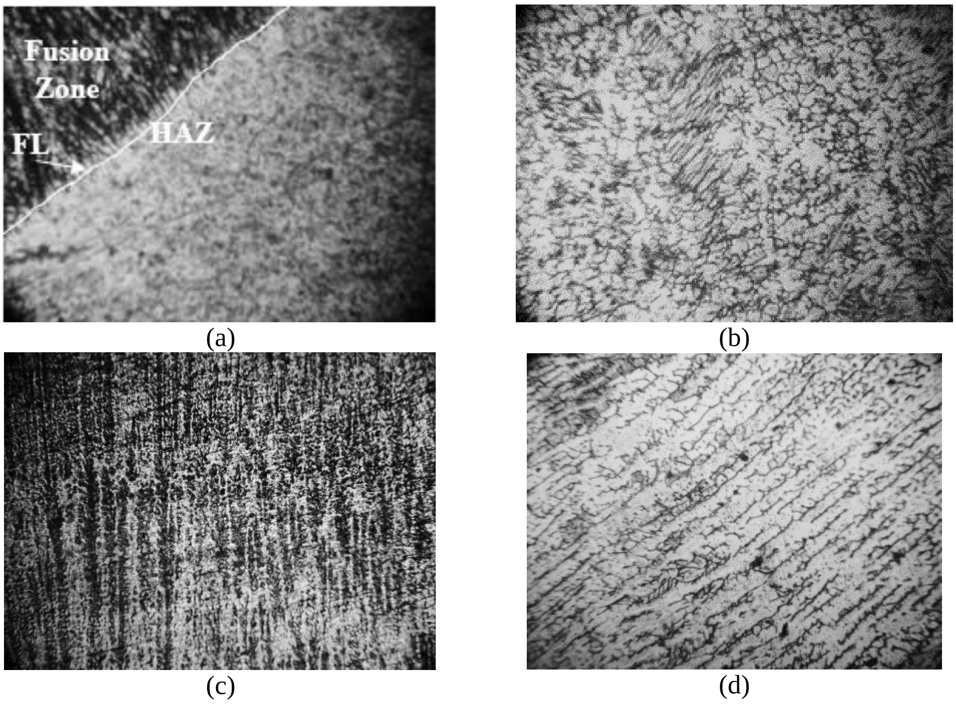

Figure 3. Micrographs of the microstructure of AISI 304 SS welded using (a,b) E312-17 and (c,d) E308L-16 electrodes (×50).

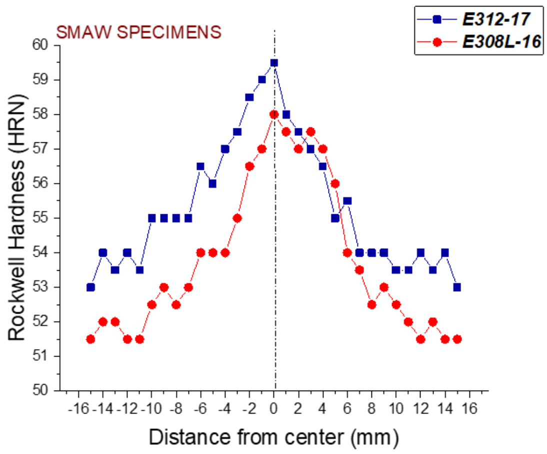

Figure 4. Hardness distribution in the welded regions for AISI 304 SS specimens welded using E312-17 and E308L-16 electrodes.

4. CONCLUSIONS

The following conclusions can be drawn from the present work:

1. Generally, the welded joints exhibited higher tensile strength and lower elongation percentage when compared with the stainless-steel base alloys. AISI 304 stainless steel, joints welded using E312-17 electrodes exhibited higher strength and lower elongation % when compared with those welded using E308L-16 electrodes.
2. For AISI 304 SS, the regions welded using E308L-16 electrodes exhibited lower hardness than those welded using the E312-17 electrodes. The hardness follows a decreasing trend in the order of weld metal, HAZ and base metal.

REFERENCES

[1] Y. Cui, C.D. Lundin and H. Vasudevan, "Mechanical Behavior of Austenitic Stainless-Steel Weld Metals with Microfissures", Journal of Materials Processing Technology, 2006,**171**, pp.150-155.

[2] O.H. Ibrahim, I.S. Ibrahim and T.A.F. Khalifa, "Impact behavior of different stainless-steel weldments at low temperatures", Engineering Failure Analysis, 2010, 17, pp. 1069–1076.

[3] W.D. Callister and D.G. Rethwisch, "Materials Science and Engineering: An Introduction", John Wiley and Sons, 8th ed., 2010.

[4] J.F. Lancaster, "Metallugy of Welding", Chapman and Hall, London, 1993.

[5] Bolarinwa Johnson Kutelu, Emmanuel Gbolade Adubi, Saliu Ojo Seidu, "Effects of Electrode Types on the Microstructure, Tensile and Hardness Properties of 304 L Austenitic Stainless-Steel Heat-Affected Zone (HAZ)", Journal of Minerals and Materials Characterization and Engineering, 2018, 6, pp. 531-540.

[6] Oyetunji and N. Nwigboji, "Effects of Welding Process, Type of Electrode and Electrode Core Diameter on The Tensile Property of 304L Austenitic Stainless Steel", Leonardo electronic Journal of Practices and Technologies, 2014, pp. 210-222.

[7] A.U. Iwuoha, "Influence of Electrode Coating on Mechanical Properties of Structural Steels" Journal of Sustainable Technology, 2013, 4(1), pp. 51-80.

[8] F.A. Ovat, L.O. Asuquo and A.J. Anyandi, "Microstructural Effects of Electrodes Types on The Mechanical Behaviour of Welded Steel Joints.' Research journal in engineering and applied sciences, 2012, 1(3), pp. 171-176.

[9] J. U. Anaele, O. O. Onyemaobi, C. S. Nwobodo, and C. C. Ugwuegbu, "Effect of Electrode Types on the Solidification Cracking Susceptibility of Austenitic Stainless-Steel Weld Metal", International Journal of Metals, 2015, pp. 1-7.

[10] American Welding Society," Welding Inspection and Technology" fifth edition – 2008.