Weldability of Dissimilar Joint of AISI 304 to CK45 by GTAW Method

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Received: 15 November 2018 - Accepted: 28 January 2019

Abstract

Joint of dissimilar steels is widely used in the chemical, food, oil, water and sewage industries. In the meantime, the joint of carbon steels to austenitic stainless steels is important with the GTAW welding process. In this paper, weldability of 304 stainless steel to CK45 carbon steel by GTAW method according to the filler metal parameter has been investigated. Welding of the samples was performed via gas tungsten arc welding (GTAW) method using 3 types of ER308L, ER310, and ER316L metal filler. Tensile test was done to evaluate the joint weldability. The microstructure of the samples was also studied using OM and FE-SEM microscopes. In the tensile test, the welded sample with ER308L electrode was fractured from HAZ area close to Ck45 base metal. Microstructure investigations showed that the best structural quality in this joint is the achievement of the stable austenite with a low amount of ferrite when using ER308L metal filler, and the worst structure was related to the use of ER310L metal filler that completely austenite structure with crack in the weld metal area was created. The results of tensile test showed that the maximum yield strength and tensile strength is achieved 382 MPa and 675 MPa using ER308L metal filler, respectively.

Keywords: Welding of Dissimilar Steels, 304 Stainless Steel, Ck45 Carbon Steel, GTAW.

1. Introduction

The construction of structural parts of dissimilar steels has always been considered for lighter and more cost-effective components; so for structural applications, the use of stainless steel for dissimilar joint of steels is effective, because by low cost, properties of both steels are provided in the joint [3-1], for example, in the power generation industry, pieces are used that require the joint between dissimilar steels [4].

Mamant et al [5], Investigated the effect of different filler materials on the microstructure and mechanical properties of dissimilar joint of low-carbon steel and 316 L stainless steel by GTAW and GMAW methods. They used ER309L filler metal for the welding of GMAW and ER316L filler for the GTAW welding. The results of mechanical tests indicated that the yield strength and tensile strength of the samples welded with ER316L filler metal is slightly higher than the samples welded with ER309L. Mishra et al [6], investigated the joint of 202, 304, 310, and 316 stainless steels to soft steel using GTAW and GMAW with ER309L. The parameters used for analysis in this study were the percentage of tensile strength of welding joints. The results of the project showed that for stainless steel welded to the low-alloy steel, the GTAW method is more suitable for GMAW and creates more strength. Also, the best possible ductility in the joint of stainless steel to low-alloy steel, the highest yield strength in welding of steel 202 to low alloy steel and the lowest tensile strength in the joint of steel 304 to low alloy steel was obtained.

Brackarnes et al [7], have studied weldability of AISI316 stainless steel and A508 low alloy steel using SMAW and GTAW and the use of 82 and 182 nickel alloys as filler metal. In this project, the tests of microhardness, scanning electron microscopy, optical microscopy and EDS were used, and to investigate the corrosion behavior of weld metal and base metal, Anodic Potentiodynamic Polarization was used. In recent years, many studies have been done on the joint of carbon steels to stainless steels. The result showed that the choice of suitable filler materials and suitable welding process leads to the maximum mechanical properties of the joint and fracture is postponed. Application of this kind of joint in power plants for fluid transfer leads to increase the life of the transfer pipes to prevent the release of pollutants in the development of environmental friendly materials and processes. In the present study, AISI 304 stainless steels were welded to CK45 carbon steel by the GTAW process with ER308L, ER310, and ER316L.

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2. Materials and Methods

Both AISI 304 austenitic stainless steel and CK45 plain carbon steel were welded in size of 100×120×3 mm. For convenience in referring to welded joints, the filler materials of ER308L, ER310, ER316L were used. Table. 1. given the chemical composition of filler and base metals. In Table. 2., the welding parameters are presented by considering the protective gas of argon blown in double-sided.
To evaluate microstructure according to the binary nature of welding metal, austenitic part was etched with glyceride solution and low carbon content with 2% Nital. Microstructural investigation was carried out by Field Emission Scanning Electron Microscope (FE-SEM: VEGA/TESCAN, Czech Republic) in secondary electron mode with working voltage of 15 kV and Optical Microscopes (OM: Euromex-IScope-Netherland).
The mechanical properties of joint by the tensile test were examined. The tensile test was also done according to the ASME SEC IX (2015) standard with Go-Tech 7052-D30 machine [8]. Two samples were prepared from each joint perpendicularly to the weld metal.

Table. 1. Chemical composition (wt. %.) of base metals and filler metals[1-3].

Material	C	Si	Mn	Cr	Mo	Ni
Ck45	0.43	0.40	0.75	0.04	0.01	0.04
AISI304	0.05	0.60	0.02	18.90	0.33	9.11
ER308L	0.03	0.06	1.75	20.75	-	10.00
ER309L	0.03	0.65	1.75	24.00	-	13.00
ER310	0.15	0.65	1.75	26.50	-	21.25
ER316L	0.03	0.65	1.75	19.00	-	12.50

Table. 2. Welding Parameters in the GTAW Process.

Welding speed (mm/s)	Gas Flow m^2/s	Gas Composition	Diameter of Filler (mm)	E (V)	I (A)
2.5	7	Ar (Pure)	2.4	90-120	12-20

3. Results and Discussion

3.1. Microstructural study

Fig. 1. shows the optical microscope (OM) image of Ck45 steel microstructure in the initial heat affected area in one of the samples. As it is shown in this figure, the microstructure of Ck45 steel in the initial heat affected area is the widmanstatten structure formed by the high cooling rate. In all of the samples after welding, the structure of the initial area affected by heat is formed as widmanstatten. The formation of ferrite in the grain boundary and morphology of delta ferrite can be a solidifying factor.

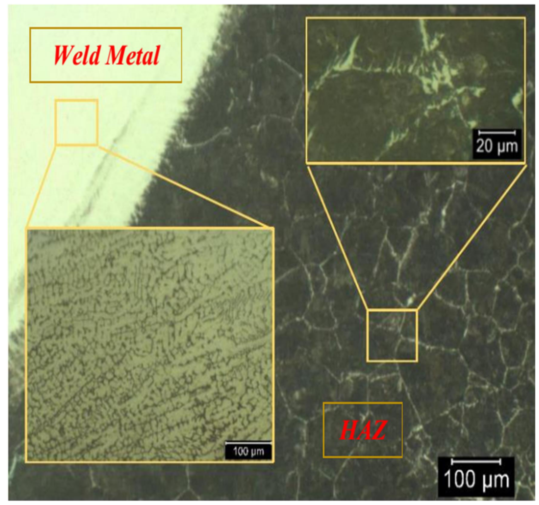

Fig. 1. OM image from transitional area of CK45 base metal.

Fig. 2. shows the optical microscope image of the AISI 304 steel microstructure in the initial heat affected area.
As seen in Fig. 2, AISI 304 has an austenitic microstructure and decrease in the size of the grains near the welding metal is observed.
The structure of the weld metal due to freezing is related to the chemical composition of the welding area and freezing conditions [9]. Fig. 3. shows OM image of the microstructure of the welding metal with ER308L filler metal.
In Fig. 3., the solidification microstructure (cells and dendrites) is clearly recognizable which the presence of chromium and nickel in the chemical composition shows the separation of the cellular and dendritic austenite boundaries.

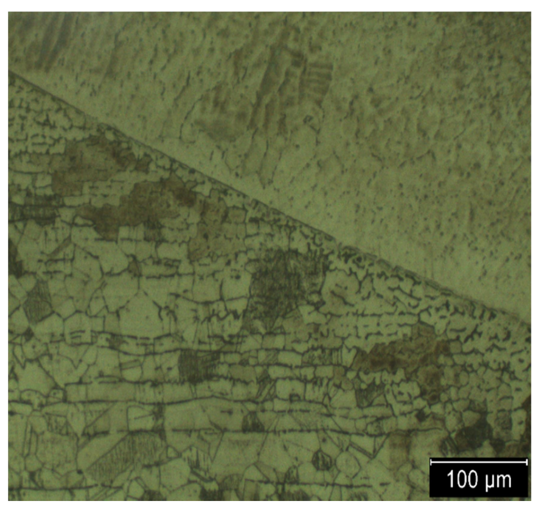

Fig. 2. OM image from transitional area of AISI 304 base metal.

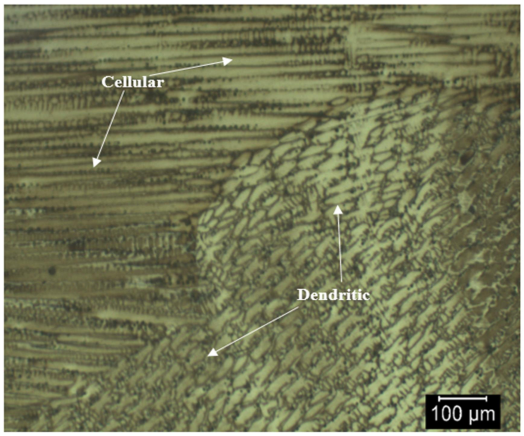

Fig. 3. OM image from the weld metal of the first sample.

Fig. 4. shows the microstructure of weld metal with ER310 filler metal. The weld metal structure is quite austenitic.

Researches have been shown due to the increase in the percentage of alloying elements (chromium and nickel), the accumulation of alloying elements occurs [10].

At the end of solidification of the initial austenite, some delta ferrite is formed on the grain boundary [9-11].

The ferrite seen in the welded transitional area is almost stable and, due to the presence of ferrite elements in that area, it is resistant to becoming austenite during the cooling process.

As it is shown in the SEM image in Fig. 5., in the weld metal with ER310 filler metal, the second sample has crack.

The absence of the ferrite phase and the fully austenitic structure of this area can be the main reason for the occurrence of this crack.

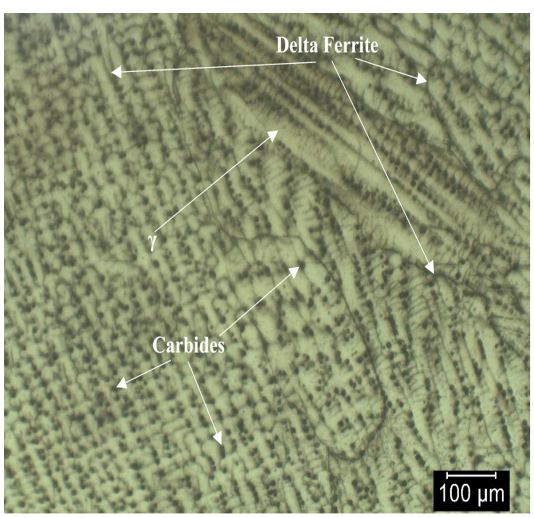

Fig. 4. OM image from the weld metal of second sample.

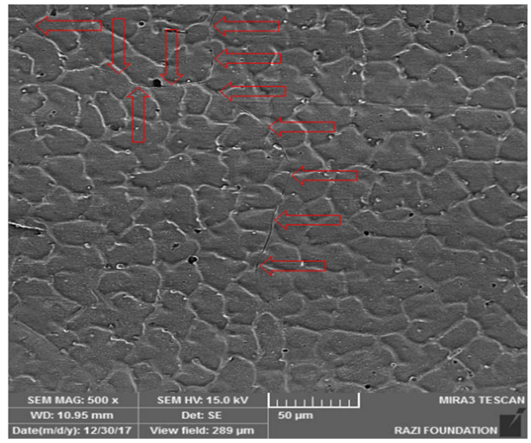

Fig. 5. FESEM image from the weld metal of second sample.

Fig. 6. shows the microstructure of the weld metal with ER316L filler metal. The structure of the weld metal in this area is Austenite and ferrite type, in which the ferrite phase is formed at the boundary of the grains. Ferrite level in this area was also predictable from the Shaefler diagram [12]. Increasing ferrite elements in the presence of ferrite phase reduces the yield strength and corrosion resistance [13].

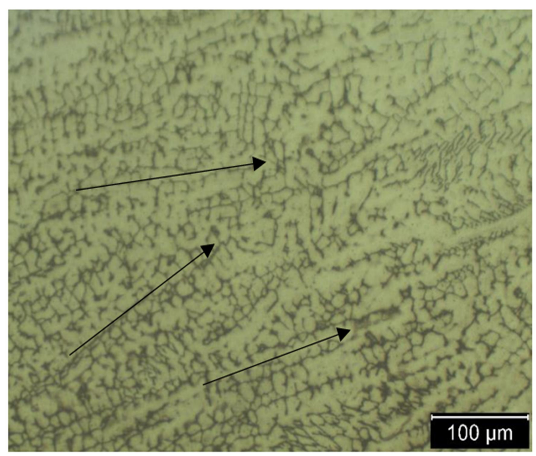

Fig. 6. OM image from the weld metal of third sample.

3.2. Mechanical properties

The results of transverse tensile test in all samples are given in Table. 3. As it is shown in Fig. 7.

All fractures have been occurred in the weld metal, but the sample welded with first sample fractured from near the weld metal of the plain carbon steel, that could be due to the formation of a fragile structure of Widmanstatten in the HAZ areas of plain carbon steel after welding, which is more visible than other samples.

Fracture of the sample from the weld metal in the other samples indicates that this area is considered as the weakest area of joint. This can be due to the formation of carbides that cause the weakness of this area [13, 14]. In the first sample, the highest tensile strength was obtained. Also, the second sample has the least tensile strength. Since in the first and second samples there are the most and the least similarity between the filler metal and the base metal, respectively, the most and the least amount of tensile strength for these two samples was obtained.

Fig. 7. Place of fracture of samples.

Table. 3. Results of tensile test.

Samples Code	Elongation (%)	Offset (Mpa)	UTS (Mpa)	Fracture region
1	8.410	382	675	Base Metal (CK45)
2	4.980	345	476	Weld Metal
3	6.740	348	593	Weld Metal

In the Fig. 8 and Fig. 9. the stress-strain graph of the first and second samples has been presented. According to the graphs, the highest percentage of elongation is related to the first sample and the least percentage of elongation is related to the second specimen, which results from the fracture behavior of the samples. The high percentage of elongation of the first sample in the tensile test indicates the softness of the fracture, as well as the low percentage of elongation in Fig. 9. Indicates a brittle fracture in the second sample.

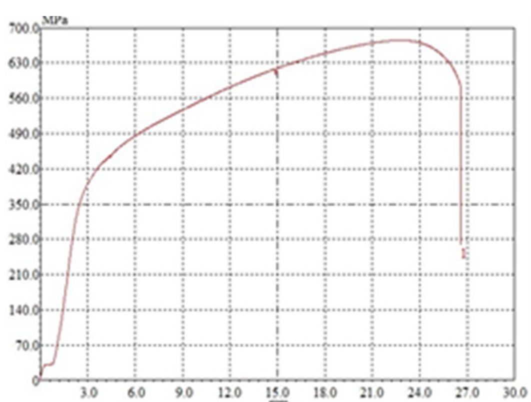

Fig. 8. Tensile test Curve of the first sample.

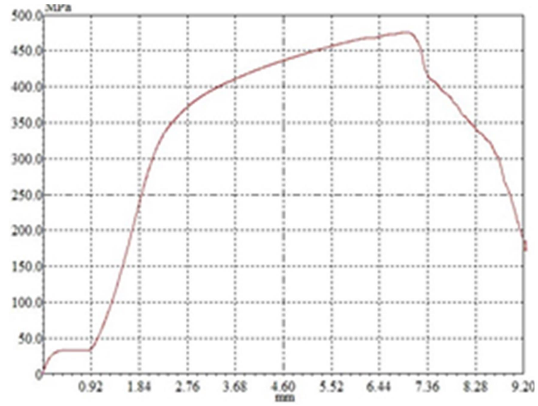

Fig. 9. Tensile test Curve of the second sample.

4. Conclusions

1. With all the fillers mentioned in this study, the proper quality of the joint can be obtained for dissimilar welding AISI 304 to 45 CK.
2. The structure of heat affected zone in the plain carbon steel CK45 includes Widmanstatten ferrite, and the heat affected zone of stainless steel are composed of austenite and ferrites formed on the grain boundary. The structure of the weld metal showed the presence of ferrite phase in the third mode sample, which indicates the resistance to solidification crack. Also, the welding metal of first and second samples is completely austenitic.
3. The results of the tensile test indicated that the strength of the weld metal except for the first sample that fractured in the base metal, other samples were fractured from the weld metal. The first sample was fractured due to the formation of Widmanstatten structure and the accumulation of carbides and interphase compounds from the welded area near Ck45 carbon steel.
4. The microstructure investigations and tensile test showed that ER316L filler can provide a proper joint for two dissimilar metals compared to other consumable fillers.

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