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Research Article

Microstructure and tensile properties of AISI 410 stainless steel welded TIG method

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Abstract:

In this study, the weldabilities, microstructures and tensile properties of AISI 410 stainless steel joints fabrication by tungsten inert gas (TIG) welding method were investigated. TIG welding was carried out on steels by using welding wire ER 410 (AWS A5.9) 2.8 mm in diameter. Tensile test results showed that while tensile and yield strength increased, the elongation value decreased significantly. The yield strength and tensile strength were measured as 619 and 801 MPa after welding process, respectively. In addition, the failure location occurred without any significant cross-sectional narrowing. Microstructure investigations have been carried out using optical microscopy and Scanning Electron Microscopy (SEM). The obtained results indicated that the microstructure of weld metal region had a dual phase such as martensite and ferrite.

1. Introduction

Martensitic stainless steels are obtained by adding 12% chromium and 0.12% carbon elements on a mass basis [1,2]. This group of steels can be easily heated and hardened due to their low carbon content [3]. They are generally hard and therefore brittle. Martensitic stainless steels are a class of stainless steels generally used in applications where better mechanical strength is required [4,5]. AISI 410 stainless steel is one of the most commonly used martensitic stainless steels that provide high strength and hardness with moderate corrosion resistance [6,7]. These steels can also be welded easily. In a study [8], the mechanical properties and microstructures of steels joined by laser welding were characterized. Due to the heat treatment applied after welding, it was determined that the grain structure became coarser and there was a decrease in hardness and tensile strength. As a result, it was concluded that the mechanical properties were negatively affected due to the heat treatment applied after welding. Muthusamy et.al.[9] showed that the tensile strength of gas tungsten arc welded (GTAW) AISI 410 stainless steel decreased with increasing heat input and testing temperatures. In addition, it was also found that the toughness of the welded joints corresponded to approximately 80% of the toughness of the base metal. In another study by Kim et.al.[10] on steels joined by methods of metal inert gas (MIG) welding and friction stir welding (FSW), the hardness of the MIG welded steels was the highest in the weld metal, decreased in HAZ, and rose slightly in the base metal. The weld metal had a Widmstatten structure that consisted of fine or coarse laths. On the other hand, the microstructure of welded FSW consisted of the stir zone. The stir zone had a relatively high hardness, owing to intense plastic deformation and dynamic recrystallization. These studies show that microstructure and mechanical properties are closely dependent on welding methods [11,12]. AISI 410 martensitic stainless steel is widely used in marine applications, especially for turbine blades [13,14]. In these work areas, two or more parts often need to be joined as one piece. Then, it is important to know the properties of the new material. In the literature, there have been limited studies related to welded joints of AISI 410 stainless steels. This research investigates the microstructure and some mechanical properties of welded joints of AISI 410 stainless steel by Tungsten inert gas welding (TIG welding).

2. Material and Methods

In this study, AISI 410 martensitic stainless steels used in this study were initially cut to dimensions of 200x50x4 mm. The chemical composition of AISI 410 martensitic stainless steel and welding wire is given in Table 1.

Table 1 *Chemical composition of AISI 410 stainless steel and welding wire (in wt.%)*

	AISI 410	AWS 5.9
C	0.20	0.10
Cr	13.4	13.0
Mn	1.0	0.5
Si	1.1	-
S	0.03	0.35
P	0.04	-
Fe	Bal.	Bal.

Table 2 *Tensile test results of AISI 410 stainless steel*

	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)
Before welding	286	504	30
After welding	619	801	7.8

TIG welding is a welding method in which the arc is formed between a non-consumable electrode and the workpiece and is protected by an inert gas atmosphere. The filler metal is delivered to the welding area manually or with an automatic system. The main application area is stainless steel, aluminum and nickel alloys. In the present study, the TIG process was performed using an INV DC TIG 200 A welding machine. In addition, AWS/ASME SFA - 5.9 (ER 410) welding wire was used, which is a martensitic stainless steel welding wire that is also used in TIG welding of stainless steels containing up to 13% chromium. Argon gas is used as the shield gas in TIG welding. Tensile processes were carried out at room temperature on welded samples prepared according to the ASTM E8: 2016 standard. The yield, tensile strength and elongation values were determined from these stress–strain curves as displayed in Table 2. On the other hand, the microstructures of the AISI 410 stainless steels joined by TIG welding were determined by optical microcope and SEM.

3. Results and Discussions

The tensile test results of welded AISI 410 stainless steel are given in Table 2. From this table, we see that the yield and tensile strength values of the welded AISI 410 stainless steel have increased significantly compared to their values before welding. However, a strong decrease in elongation value was observed. As a result, it is possible to say that the welded sample turns into a very hard but brittle structure. A similar result is also found in Kumar and Shahi' s study [15]. They obtained that the tensile strength and elongation of AISI 304 stainless steel welded by the TIG method are 657.32 MPa and 24.28 %, respectively. In another study [16], the tensile strength value for TIG welded Cr13Ni5Mo martensitic stainless steel was recorded as 910 MPa. This value is quite high. However, it should not be forgotten that the tensile properties of welded samples will change with the welding parameters. In our study, the obtained results showed that the welding process increases yield and tensile strength. But, while CrC compound formation has a negative effect on the tensile properties of AISI 304 series martensitic stainless steel welded with TIG [17], no difference was observed between the mechanical properties of AISI 316L stainless steel steels before welding and after TIG welding [18].

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Figure 1 *Photograph showing the failure location in AISI 410 stainless steel welded with TIG*

Looking at the tensile test results (Fig. 1), it appears that the failure location occurred without any significant cross-sectional narrowing. This result shows us once again that the AISI 410 stainless steel welded with TIG is brittle in this study. From Table 3, we say that carbon (C) content in the weld metal region increases after the welding process. This increase can be explained by the transfer of C from the base material to the weld metal region through heat flow during the welding process. The similar results were observed in the studies of Akhatova et al. [19] and Ata et al. [20]. In addition, since the welding was done in an environment open to the atmosphere, an increase in oxygen (O) was observed in the weld metal region after welding. Besides, it is seen that chromium carbide precipitations cause a decrease in the amount of Cr in the weld metal region (Table 3). Similar thoughts are also mentioned in literature [21].

Table 3 Chemical compositions of weld metal region of AISI 410 stainless steel

Element (weight %)	Before welding	After welding
C	0.6	11.7
Si	1.7	1.06
Mn	1.14	-
P	2.3	-
S	0.3	-
Cr	11.27	7.64
Ni	4.6	-
N	1.3	-
Ti	1.0	-
O	-	13.71
Na	-	0.56
Mg	-	0.39
Al	-	0.43
Cl	-	0.4
K	-	0.68
Ca	-	1.45
Fe	52.48	55.85
Cu	-	0.87
Zn	-	5.27

The dual-phase microstructure of welded AISI 410 martensitic stainless steel consisted of the ferritic extensions in the martensitic matrix (Fig. 2). The phase transformation that occurs heterogeneously in the weld metal region is also partially visible in region heat affected zone (HAZ) (Fig. 3). Meanwhile, it is possible to say that the porosity seen in this structure originates from increasing O content during welding. It is well known that O causes porosity in the weld metal region [22].

Figure 2 *Optical micrograph of weld metal region of AISI 410 martensitic stainless steel*

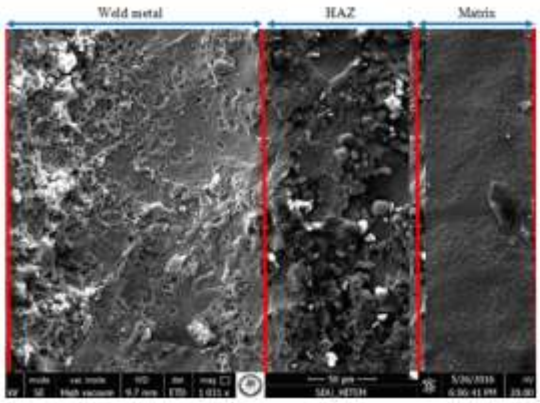

Figure 3 *SEM micrograph of AISI 410 martensitic stainless steel after welded by TIG.*

4. Conclusions

In this study, the microstructure and tensile properties of AISI 410 martensitic stainless steel welded with the TIG method were determined. The following conclusions have been drawn from this study.

- While the yield and tensile strength values of the welded AISI 410 martensitic stainless steel have increased significantly compared to their values before welding, a strong decrease in elongation value was observed.
- Tensile failure location occurred in the weld metal region without any significant cross-sectional narrowing**.**
- The dual-phase microstructure of welded AISI 410 martensitic stainless steel consisted of the ferritic extensions in the martensitic matrix.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper
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