TIG WELDED AA6061 ALLOY UTILIZING COMPOSITE FILLER METAL CONTAINING TiO_2: MICROSTRUCTURE AND MECHANICAL PROPERTIES

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Abstract

In the present research the microstructure and mechanical properties of TIG welded AA6061 Al alloy utilizing TiO_2 containing filler metal were investigated via microscopic observation, microhardness measurement and tensile test evaluation. For this purpose, spray method was used to make various TiO_2 containing filler metal with 0.5 and 1.5 wt% TiO_2 nano particles. The size of the TiO_2 nanoparticles were 50 nm in average. The optical microscopic results showed that increase of TiO_2 nanoparticles in filler metal have significant effect on refinement of FZ microstructure. The mean grain size of TiO_2 free and containing 1.5 wt% TiO_2 samples were 65 μm and 38 μm respectively. The microhardness test was conducted to demonstrate the effect of TiO_2 on the hardness of different zones of welded specimens. The results showed that increase in TiO_2 nanoparticle in FZ results to higher FZ hardness due to grain refinement and composite effect of TiO_2 nanoparticles. The HAZ softening also were observed in all samples. The ultimate tensile strength of FZ was measured utilizing tensile test examination. The results showed that with increasing TiO_2 in the FZ, the tensile strength of this region increased. The tensile strength of TiO_2 free and containing 0.5 and 1.5 wt% of TiO_2 were 185, 200 and 215 MPa respectively.

Keywords: AA6061 aluminium alloy, TIG, TiO_2, microstructure, mechanical properties

1. INTRODUCTION

Al and its alloy due to their unique features such as low density, good corrosion resistance and high strength to weight ratio have found many applications in various industries such as aeronautical and automotive industries [1,2]. It worth noting that by increasing consumption of aluminium in various industries, the terms and conditions of Al alloy welding also must be discussed. There is several fusion and non-fusion welding method for joining of Al alloy. Among them TIG welding process is one the most popular welding method for Al alloy due to its capability to produce high quality welds [3,4]. In general, the microstructure and mechanical properties of the TIG welded joints are strongly related to the chemical composition of the filler metal used in this process [4]. Several methods have been proposed to increase the mechanical properties of the joints using the TIG welding process, including of utilizing grain refiner materials [5,6] or ceramic particles [7,8] in the weld zone. The results showed that utilizing titanium carbide nanoparticles [9] or simultaneously using of titanium carbide and zirconium carbide nanoparticles [10] in filler metal for TIG welded 6061 Al alloy results to increase in mechanical properties of weld zone in terms of tensile strength and hardness due to strengthening and grain refining effects of used nanoparticles. To describe the effect of ceramic particles on increasing weld mechanical properties, several mechanisms have been proposed. These include differences in thermal expansion coefficients between the matrix and the strengthening phase [11], as well as the grain refining effects of ceramic particles [12]. It should be noted that grain size plays a very important role in improving mechanical properties such as ductility and hardness. In the present research, the effect of TiO_2 nanoparticles on the microstructure and mechanical properties of TIG welded 6061 aluminium alloy joints was evaluated using filler metals containing TiO_2 nanoparticles.

2. MATERIALS AND METHOD

In current study 6061 aluminium alloy sheet and 5083 aluminium alloy rod were used as base metal and filler metal respectively. The base metal sheet thickness was 8 mm. **Table 1** shows the chemical composition of used 6061 and 5083 Al alloy.

Table 1 Chemical composition of used base and filler metal in present study (wt%)

Composition	Al	Fe	Cu	Mn	Mg	Cr	Zn	Si
6061	bal.	0.2	0.3	0.08	0.9	0.12	0.2	0.6
5083	bal.	0.28	0.06	0.7	4.2	0.12	0.03	0.26

Titanium oxide (TiO_2) nanoparticle with the purity of 99 %wt. used as reinforcing phase. The diameter of utilized TiO_2 nanoparticles was 50 nm in average. Titanium oxide nanoparticles were applied to the welding basin using the spray method. For this purpose, the filler metals were degreased in a bath of acetone for 10 minutes. Then the acetone suspended titanium oxide sprayed to the filler surface. The TiO_2 weight percent of the filler metal were determined by weighing filer metal before and after spraying. The prepared filler metals were used in TIG process under high purity Argon gas flow. The flow rate of Argon gas was 9 lit/min. **Figure 1** shows the utilized but joint design in current research.

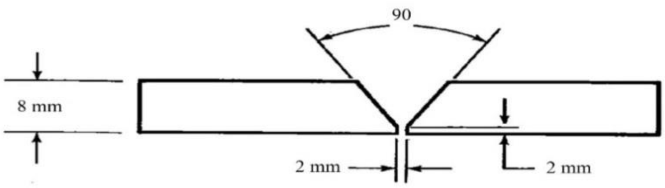

Figure 1 Joint design in the present study

To assess the impact of titanium oxide nanoparticles on the mechanical and microstructural characteristics of 6061 welded joints, two samples were prepared. One sample was welded using TiO_2-free filler metal under identical welding parameters as the second sample, which utilized TiO_2-containing filler metal.

Microstructural evaluation was performed using optical microscopy (BK3000, Infinity, Japan) and scanning electron microscopy (Vega2, Tescan, Czech Republic). For this purpose, the samples were sectioned and prepared according to standard metallography methods and etched after grinding and polishing. Etching solution contained 5 ml of HNO_3 acid, 3 ml of HCl acid and 2 ml of HF acid in 190 ml distilled water.

Microhardness test (MH4, Koopa, Iran) were conducted to measure the hardness of different zone of welded 6061 alloy including base metal (BM), heat affected zone (HAZ) and weld metal (WM) in the transverse cross section of the joint (**Figure 2**). The applied load and dwell time were 25 g and 10 second respectively. The microhardness value recorded at each zone with 1 mm interval.

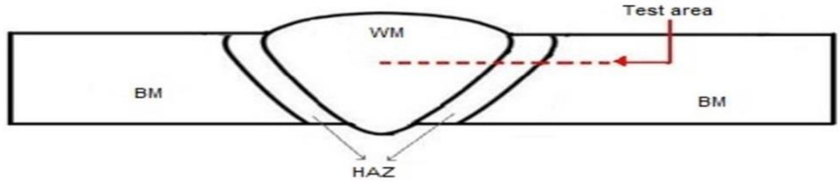

Figure 2 The location of the Microhardness test (schematically)

In order to determine the tensile strength of the welded joints longitudinal tensile test were carried out utilizing tensile test machine (H50KS, Hounsfield, England). The tensile test performed according to ASTM E8 standard. The cross head speed of tensile test machine was 10 mm/min. **Figure 3** shows the configuration of tensile test specimens schematically.

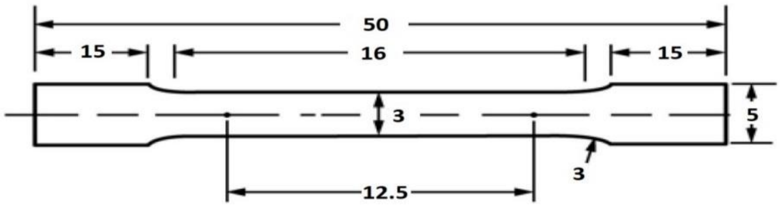

Figure 3 Tensile test specimens' illustration (all dimensions are in mm)

3. RESULTS AND DISCUSSION

3.1. Microstructural study

Figure 4 shows the microstructures of weld metal in 6061 TIG welded joints with TiO_2 free (**Figure 4a**) and TiO_2 containing filler (**Figure 4b** to **4c**).

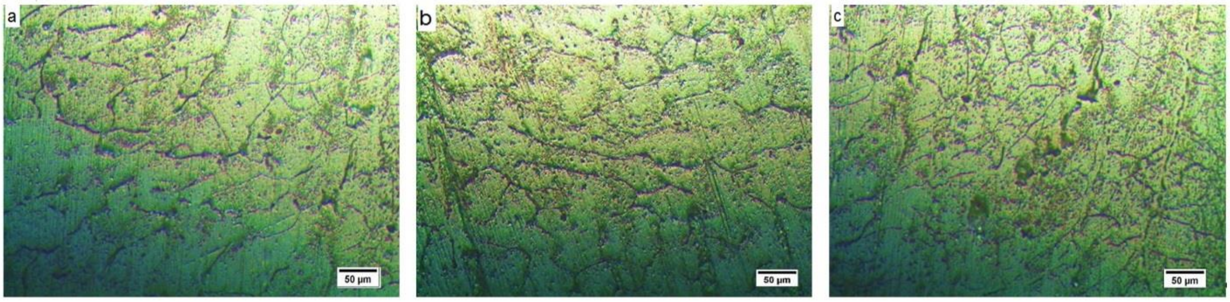

Figure 4 Weld metal microstructures of welded specimens utilizing TiO_2 free filler (a), (b) 0.5 wt% TiO_2, (c) 1.5 wt% TiO_2

As shown in **Figure 4**, utilizing TiO_2 in filler metal cause to decrease in weld metal grain size. The results showed that the average grain size in a powder less, 0.5 wt% TiO_2 and 1.5 wt% TiO_2 specimens are about 65 μm, 56 and 38 μm respectively. It worth noting that the excessive use of the powder (more than 1.5 wt% TiO_2) results to powder agglomeration.

Reduction in grain size of weld zone is attributed to two different mechanisms of non-homogeneous nucleation and particle locking effect of the reinforced phase. As reported elsewhere the presence of the TiO_2 nanoparticle increases the heterogeneous nucleation site and then finer microstructure will result [13]. On the other hand, these nanoparticles could prevent the grain growth effectively. According to the Zener pining mechanism [14] the locking force of the nanoparticles can be described by following **equation (1)**:

$$F_z = f/kr \quad (1)$$

where:

F_Z – pining force (N),

f – volume fraction of nanoparticles,

r – radius of nanoparticles (m),

k – Zener constant.

By increasing the nanoparticles volume fraction, the pining force increases that results in more barrier against the grain growth which ultimately causes the finer weld zone microstructure.

3.2. Mechanical properties examination

3.2.1. Longitudinal tensile strength

Figure 5 shows the results of the longitudinal tensile test of the welded specimens using fillers containing nanoparticles (0.5 and 1.5 wt% TiO_2) and without nanoparticles. As can be seen, the longitudinal tensile strength of the welded specimens increases with increasing volume fraction of the titanium oxide nanoparticles.

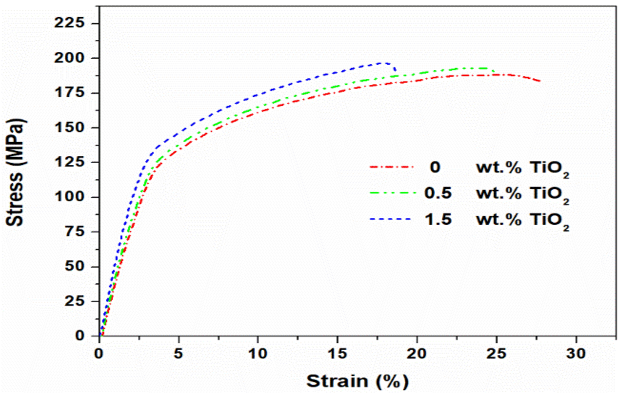

Figure 5 Longitudinal tensile characteristics of welded specimens using fillers containing TiO_2 nanoparticles and TiO_2 free specimen

The enhancement of tensile strength with increasing volume percent of nanoparticles can be attributed to various reinforcing mechanisms. The presence of nanoparticles due to the difference in their thermal coefficients with the weld metal causes generation of new dislocation around the nanoparticles during the solidification process that will increase the strength of the weld metal [15]. On the other hand, as shown (**Figure 4**), with the increase of nanoparticles in the weld metal, the size of the grain decreases. According to the Hall-Patch relationship [16], decreases the grain size increases the tensile strength of the weld metal. The scanning electron microscope was used to study the fractured surfaces of the tensile samples (**Figure 6**).

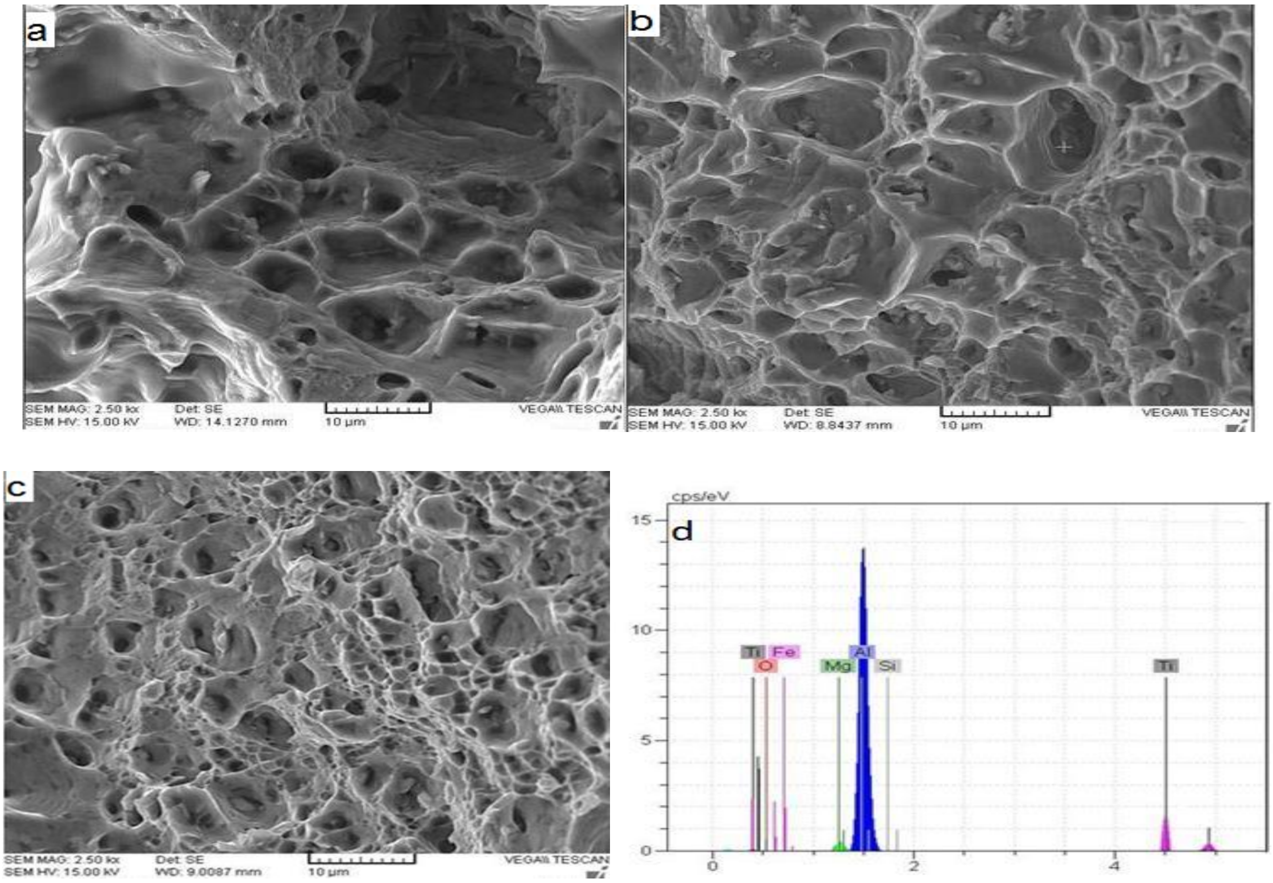

Figure 6 SEM images of the fractured tensile samples, (a) without particles, (b) 0.5 wt% TiO_2, (c) 1.5 wt% TiO_2, (d) corresponding EDS result of particles showed by arrow in (b)

The results indicated that all fractured samples had ductile fractures. In TiO_2 free specimens there is a combination of large and small dimples while presence of the nanoparticle results in finer and more homogeneous distribution of dimples that means more ductile fracture.

3.2.2. Microhardness

Microhardness measurements were conducted on welded samples to determine the hardness of different zones of joints. **Figure 7** shows the hardness test results. As shown, increasing the amount of titanium oxide increases the hardness of the weld area. In this area, combination of the composite effects of TiO_2 nanoparticles and the grain refining effect of the TiO_2 nanoparticles results in increase of the weld zone hardness. With the increasing content of nanoparticles, the number of dislocations also increases. This phenomenon arises from the mismatch in the thermal expansion coefficients between the reinforcing particles and the matrix phase, resulting in strains around the nanoparticles. Consequently, this leads to an enhanced hardness in the weld zone [17]. On the other hand, the reduction in hardness in the heat-affected area primarily stems from grain growth within this region [11].

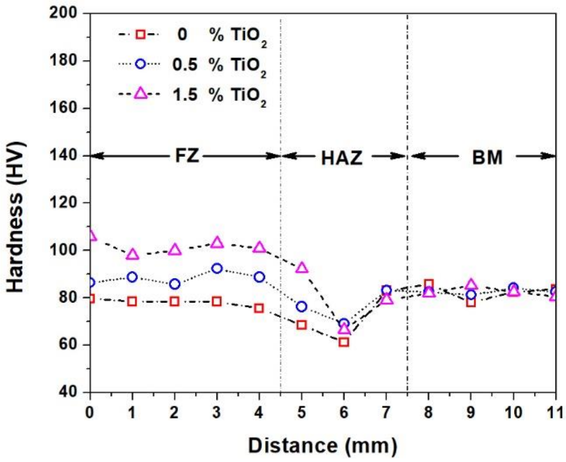

Figure 7 Variation in hardness across different zones (base Metal (BM), heat affected zone (HAZ), and fusion zone (FZ)) in welded samples with titanium oxide nanoparticles (0.5 and 1.5 wt% TiO_2) and without nanopowder

4. CONCLUSION

In the present research the effect of the TiO_2 nanoparticles on the microstructural and mechanical properties of the TIG welded 6061 Al alloy were investigated. The following results can be concluded:

- The presence of nanoparticles in the fusion zone will increase the number of heterogeneous nucleation sites. The microstructural results showed that the grain size in the weld area decreased by increasing the weight percentage of titanium oxide.
- The grain size in the powder less sample was 65 μm while in samples containing 0.5 and 1.5 wt% of titanium oxide the fusion zone grain size was 56 and 38 μm, respectively.
- Longitudinal tensile test results showed that with increasing titanium oxide in fusion region, tensile strength increases compared to non-powdered sample (185 MPa). Tensile strength of samples containing 0.5 and 1.5 wt% of titanium oxide was 200 and 215 MPa, respectively.
- Micro hardness test results showed that the hardness of the fusion zone increases with the increase in the weight percent of nanoparticles.

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