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Effect of NANO-Aluminum Oxide Percentage of A-TIG on Mechanical Properties of Welded Joints of 7075 Aluminum Alloy

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Abstract

This work aims to weld 7075 aluminum alloy by ATIG welding using ER4043 filler metal and to investigate the effect of adding Al_2O_3 nanoparticles to the coating on the microstructural and mechanical properties of welds. For this purpose, the nanoparticles were first coated on the samples using a brush, and then the gas tungsten arc welding process was performed using the appropriate welding parameters on the samples. Microstructural and mechanical evaluations were performed on the samples. Microstructural studies revealed that the presence of nanoparticles in the heat-affected zone reduced grain size and modified the microstructure. Hardness test on gas tungsten arc welding joints specimens found that in the melting zone, the hardness in this area was reduced by approximately 20% compared to the base metal due to the coarse grain size and the Casting structure. Based on the results of the tensile test, it was observed that microstructural changes reduced tensile strength and yield strength for the welded sample compared to the base metal. Using nanoparticles increased the hardness in this area to approximately 120 HV. Also, the presence of nanoparticles conforming to the strengthening mechanisms of nanoparticles increased the tensile strength to 300MPa. According to the results of this study, the presence of nanoparticles in the coating improves the welding properties of 7075 aluminum alloy.

Keywords: Alloy AA7075, Activated Flux Tungsten Inert Gas(A-TIG), fusion zone, heat affected zone, microstructure, hardness, tensile strength.

1. Introduction

The problems of the fusion welding process are solved by using nanomaterials in the manufacturing of welding electrodes, filler metals as well as base metals. The presence of nanomaterials increases the strength of the joint. In the coating process, the presence of nanomaterials also improves surface quality and strength; therefore, by adding nanomaterials, the integrity of the joint is improved. Adding nanomaterials to the joint requires understanding the effect of nanomaterials on weldability [5]. Karbalaei Akbari et al. [6] showed that for Al/Al_2O_3 casting composites, a significant improvement in hardness and strength was obtained in amplified nanocomposites with 1.5 and 2.5% by volume of Al_2O_3 nanoparticles (with an average size of 20 nm particles), respectively. Mazaheri and Ostad Shabani [7] proved that, in the Al-Si alloy (A356), the addition of Al_2O_3 nanoparticles improves tensile strength and yield strength. Research has shown that using nanomaterials to improve welding properties is the most cost-effective and efficient method. Before the welding process, the nanomaterial is mixed with a volatile liquid such as methanol or acetone to form a paste-like state. Then the dough is covered only in the heat-affected area of the base metal. The thickness of the coating varies according to the welding process and its parameters. Previous research has shown that coating containing microstructural particles in welding joints improves the structure and properties of the joint. The research also found that particle size was a major factor in improving the strength of the joint.

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Also, the thermal stability of the articles used during welding determines the type of weld formation. These factors affect heat transfer between materials and fluid flow and also play a vital role in improving bonding properties, particle scattering, and grain refinement. Welding joints formed by adding Nanoparticles have better strength and properties than other joints. Research has shown that using Nanoparticles has a good effect on the appearance of welding, microstructure, and properties in the process of gas tungsten arc welding [8-10]. In this regard, this study aimed to investigate the effect of the presence of nano aluminum oxide in the flux on gas tungsten arc welding 7075 aluminum alloy. A-TIG welding was used for the first time in the Pantone Electric Welding Institute in Ukraine in the mid-sixties, where a coating of flux is used on the surface of the joint to be welded before welding. This flux consists of oxides and halides in the form of fine powder that turns from a powder into a paste (Slurry) by adding a suitable organic solvent. This method reduces the time required for groove preparation and increases the penetration of the weld, thus enabling the use of high welding speeds [17]. Figure 1 shows a cross-section of a welding joint by the traditional TIG method and the ATIG method, using the same welding variables.

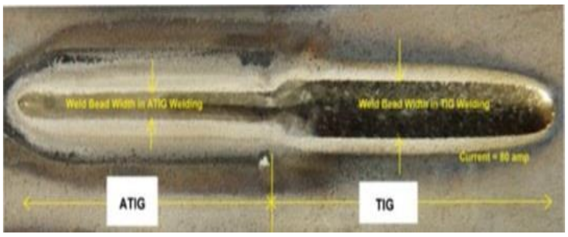

Fig. 1 A weld bead shape of a welding joint by the conventional TIG and ATIG methods [17]

2. Experimental work

Aluminium sheets 7075 with a thickness of 5 mm, the chemical composition of which was confirmed in the spectroscopic analysis (OES), Aluminium oxide Nano powder with a grain size of 18 nm, and acetone solvent. Table 1 shows the chemical composition of the plate, and Table 2 shows the mechanical properties of these plates after Vickers hardness test and tensile test

2.1 Paint preparation steps:

The paint was mixed using an electric mixer, the number of revolutions of which was 200 rpm, by mixing the required percentage of nano aluminum oxide (10, 20, 30) % with the addition of acetone gradually to reach the required percentage. The Flux is converted into a paste layer applied by brushing, depending on the shape of the workpiece. Figure 2 shows a method for preparing a coating. Figure 3 shows the dimensions of the obtained samples.

Table 1 Results of spectral analysis of the base metal.

	Ti%	Fe%	Si%	Cr%	Mn %	Zn%	Cu%	Mg%	Al %
ASTM AA7075 T6	<0.2	<0.5	<0.4	0.18-0.28	<0.3	5.1-6.1	1.2-2	2.1-2.9	Bal.
Analysis results	0.04	0.2	0.1	0.12	0.03	6.4	2.3	2.6	-

Table 2 Mechanical properties of AA7075-T6.

Vickers hardness	150 HV
Tensile strength	450 MPa
Melting point	477-635 °C

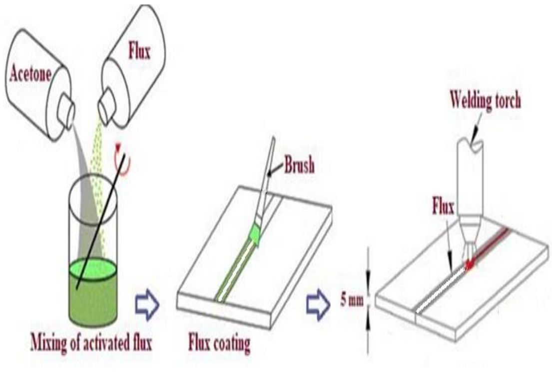

Fig. 2 Paint preparation steps.

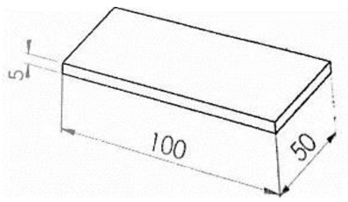

Fig. 3 Dimensions of samples after the operation.

2.2 Preparing the plates for welding

Raw materials (500 x 500 x 5 mm) were obtained from aluminium alloy AA7075, and the sheets were cut on the manual shearing machine located at the Higher Institute of Applied Sciences and Technology to obtain the required dimensions for the samples (100×50×5) mm.

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2.3 Sample cleaning and coating process

The plates were cleaned using a sharpening disc and cleaned with acetone to remove all oxides from the surface. Then the plates were coated on both sides of the welding line, this method is called Face bound (FB), which is recommended when welding aluminum sheets using the ATIG [17]. Figure 4 shows the sample coated with aluminum oxide Nanoparticles.

Fig. 4 One of the samples coated with Aluminium oxide Nanoparticles

2.2 Welding machine ESAB Origo TIG 3000i

This machine is used in many industrial sectors and gives excellent results in welding many alloys. In its work, it uses either direct or alternating current, and in both cases, it achieves a stable electric arc. The following variables were installed for the welding machine and several low current values were tested compared to the required current for 5mm thickness welding, which is 250A, and it was found that the appropriate current intensity with coating is 200A [18].

Table 3 Welding parameters

Current	200A
Frequency	6 HZ
(Pulse on Time)	60
Gas flow	17 l/min

3. Results and Discussion

3.1 Comparing the obtained weld beam shape

After welding 9 samples with the previous variables using the TIG method, with ER4043 filling metal, and with three coating percentages of nano-aluminum oxide (10%, 20%, 30%), it was found that the joint was free from cracks and the root depth after measuring was 3 mm, while without the use of coatings, the plates cracked and penetration did not take place sufficiently, Figure 5 shows that, and the Figure 6 shows the cross-section of uncoated weld beam and Figure 7 shows the cross-section of 30% nano aluminum oxide coating at the same parameters current 200A and 17 l/min gas flow.

Weld bead shape Weld root shape

Fig. 5 The shape of the weld joint with 30% nano aluminium oxide coating

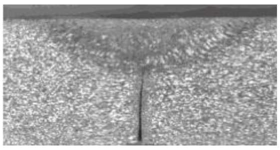

Fig. 6 Cross-section of an uncoated joint with no penetration with 200A current

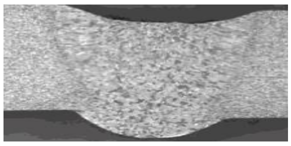

Fig. 7 Cross section of joint with 10% nano aluminium oxide coating and 200A current

The microstructure of the different regions of the ATIG process using the 4043 filler metal and nano aluminum oxide coating is shown in Figure 9. The base metal microstructure (7075-T6 Al) is shown in Figure 8. In 7xxx Al alloys, two different types of reinforcing precipitates are formed, which are: (i) $MgZn_2$ and (ii) Al_2Cu, which are visible as black particles in the base metal. Given that the maximum amount of copper available for precipitation reaction is 1.6%, but the amount of magnesium and zinc is high, the fine black precipitates belong to Al_2Cu and the large precipitates belong to $MgZn_2$ [11]. The weldability of 7xxx series Aluminum alloys is low, there are different reasons for the low weldability of these alloys. First, due to the presence of some Mg and Zn with low boiling temperatures, high vapor pressure occurs during welding. Second, there is the possibility of solidification cracks in the structure of these alloys [1-2]. In the use of welded aluminum alloy 7075, there are two important cases: (a) microstructural changes, with significant changes in grain size and precipitates distribution, and (b) the formation of new crack distributions that are not present in the non-welded alloy [12].

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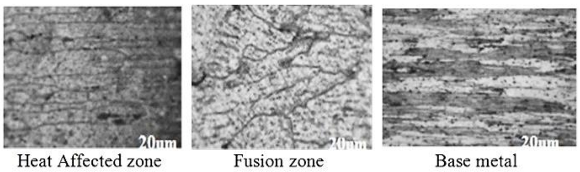

Fig. 8 Base metal and Fusion zone and heat affected zone Microstructure welding joints with ER4043 and without nano aluminum oxide

The choice of filler metal is mainly based on the composition of the base metals. The chemical composition of the filler metal is one of the determining factors in the formation of microstructure and welding properties. Adding nano oxide alters the chemical composition of the weld [13]. In the melting zone, the formation of the weld metal depends mainly on the solidification conditions, which include growth rate, temperature, and penetration [12]. As seen in Figure 8, the GTAW process has created a significant structural change in the structure that leads to grain deformation. Grain boundaries are not formed in the structure because of the rate of rapid cooling and solidification. [14]. The grains in the HAZ and melting regions have a larger diameter than the base metal due to the high heat input and dendritic structure in the weld, and there is also a non-coherent grain distribution in the weld zone [16].

Figure 9 shows the images of an optical microscope microstructure of the melting area of the welded joints with nano aluminum oxide particles. According to Figure 9, it is observed that the presence of nanoparticles improves the formation of microstructures and reduces defects. Adding nanoparticles in the coating reduces defects such as imperfect penetration and coarse microporosity. Some of the factors that affect the microstructure of aluminum are related to the addition of nanoparticles [16]:

• Distribution of nanoparticles in aluminum
• The reaction between aluminum and nanoparticles.

Comparing the images, it can be seen that the presence of nano aluminum oxide has reduced the grain size and increased the uniformity of the grains. Improvement of grain refinement using nano aluminium oxides can be the result of the following two mechanisms [4]:

•The locking force of Al_2O_3 nanoparticles on grain boundaries migration
•Non-homogeneous nucleation.

a)
b)
c)

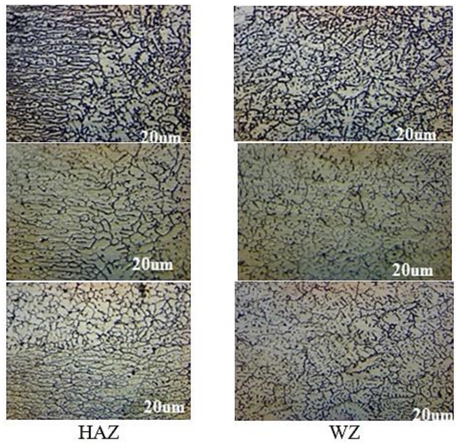

Fig. 9 Microstructure of welded joints at 100× for each of the joints with 10% coating (a), the joint with 20% coating (b), and the joint with 30% coating (c)

3.2 Hardness

The hardness of the welding AA 7075 welding joints with nano aluminum oxide base depends on the grain size, dislocation density, Flux properties, and heat input in this region [16]. The hardness of the coating weld has significantly increased due to the presence of nano aluminum oxide particles in the weld and grain refinement compared to the non-coated weld. The presence of hard particles has increased hardness. In general, the hardness of metals increases with decreasing grain size due to an increase in the volume fraction of grain boundaries. By reducing the grain size and adding Al_2O_3nanoparticles to the coating, the grain size of the primary phase Al-α is reduced, thus increasing the weld hardness [4].

The hardness in the joint area, which is the aluminum base composite, depends on the size of the grain, the density of the dislocation, the Nano-reinforcing Nanoparticles, and the heat input to the area. Due to the hall-patch relationship, the hardness increases with decreasing grain size. Reinforcing particles have a double effect on the amount of hardness because both the particles themselves have a high hardness and the effect they have on the pinning phenomenon causes the hardness of the samples to increase [17]. On the other hand, the hardness in the welding area did not reach the hardness of the metal because the amount of nano-aluminum oxide flowing to it was less than the amount of oxide in the thermal area where the coating was located before welding.

Figure 10 shows the hardness curve within the joint coated with 10% nano aluminium oxide which is the best result in this research.

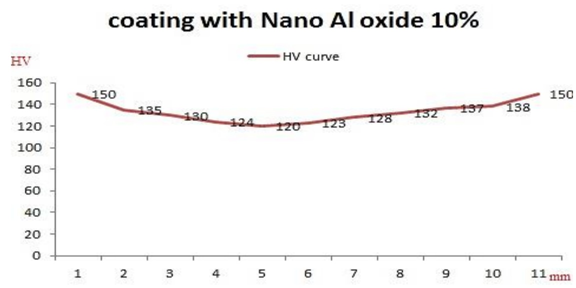

Fig. 10 Hardness curve within the joint coated with 10% nano aluminium oxide

3.3 Tensile property:

The results showed an increase in tensile strength and yield strength for samples coated with 10% nano aluminium oxide, due to**:**

- The uniform dispersion of Nanoparticles
- Grain refinement and properties of Nanoparticles.

As can be seen, mechanical properties are improved by the addition of Nanoparticles. Two factors affect the strength of the composite [16]:

- Reinforcing particles by simple load transfer increase the strength of the material, which depends on the integrity between the particles and the matrix as well as the movement of the Dislocation.
- Inhibition of plastic release in the interface between particles and matrix.

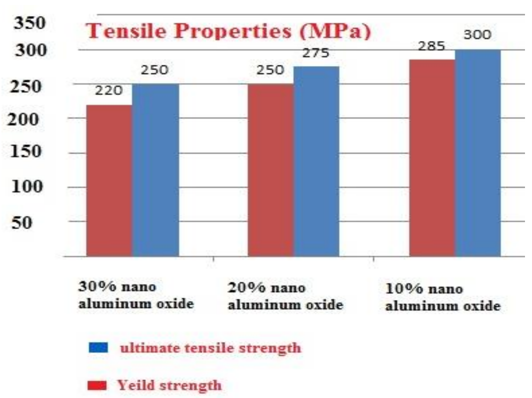

Fig. 11 Tensile properties formed in the AA7075 weld metals by varying Nano Aluminium oxide in the coating

Adding the right size and even distribution of nanoparticles increases the pinning effect of nanoparticles on the grain boundary and nucleation during welding. Improving tensile strength by modifying the grains created by good grains also disrupts the mobility of movement dislocations. This disorder led to an increase in dislocation density with uniform grain boundaries, which improved the strain hardening rate [15].

And according to previous research, the tensile strength did not exceed 200 MPa in TIG welding without coating and with the same filling metal used ER4043 [3]

4. Conclusions

Using ATIG welding:

- It is possible to obtain crack-free solder joints due to the Nanoparticles of oxide that restrict the growth of the phase
- Reduce weld beam width and increases the penetration depth.
- The hardness of the welded area is higher compared to the conventional TIG method, due to the lower grain size, which affects the cooling speed.
- The added particles act as an obstacle to the growth of the granules and settle on the surface of the formed phase and limit its growth, which enables continuous nucleation in the entire cooling period, thus achieving a very fine microstructure.
- It is possible to reduce the required current intensity for welding the required thickness by 25% of the required current intensity

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