POST WELD HEAT TREATMENT ON TIG WELDED ALUMINIUM 6063 PLATES

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Abstract

Aluminium and its alloys play a critical role in engineering material field, due to its light weight and resistance to corrosion. Mg will strengthen the alloy through the precipitation of Mg_2Si in the aluminium matrix. The excess silicon exists in the alloy in the form of silicon element and further strengthens the aluminium alloy. The silicon elemental constituent can influence the physical properties of the alloy such as thermal expansion coefficient, wear and corrosion resistance. The properties of any material are determined by its microstructure and distribution of alloying elements or phases that make up the material. These properties include strength, toughness, stiffness (Young's modulus), hardness, elasticity and electronic properties such as conductivity. Heat treatment is a very essential process in material research aimed at improving the mechanical properties of metal by altering its microstructure. Therefore, different types of heat treatment are conducted to enhance the strength and hardness of TIG (Tungsten Inert Gas) welded Aluminium 6063 plates, which is limited by its low welded strength.

Keywords: TIG Welding, Tensile Strength, Heat Treatment, Microstructure Study, Hardness

1. Introduction

Aluminum alloys have the most desirable properties like light weight, good resistance to corrosion, good weldability, high strength to weight ratio etc. Hence they are widely used in aerospace, automobile, transportation and packaging industries. Aluminium is a strongly electro-negative metal and possesses a strong affinity for oxygen. During welding of aluminium alloys, atmospheric contamination is possible and hence a shielding gas is preferred to protect the weld pool. Tungsten Inert Gas (TIG) or Gas Tungsten Arc welding (GTAW) is an arc welding process in which arc is generated between non-consumable tungsten electrode and work piece, in the presence of an inert gas. The shielding inert gases generally used are Argon, Helium or their mixtures. A constant current AC power source is used with water or air-cooled TIG torch. But, there is yet another problem of welding the Aluminium alloys. It is the improper fusion of weld metal with parent metal and segregation during solidification process which leads to lessening of the mechanical properties of the joint. Therefore, it is necessary to understand the extent of strength reduction due to TIG welding and to study the improvement possible by post weld heat treatment which can stabilize the microstructural changes at the heat affected zone.

2. Literature survey

The effect of welding current on the mechanical properties of welded Al6063 plates was studied by Susmitha et al. (2016). An increase in welding current resulted in an increase of the heat input at the weld zone. The welding current adversely affected the bead formation beyond a permissible value. By increasing the current from 300 to 400 A, the ultimate strength of the weld linearly increased by from 78 to 96 MPa while the hardness increased from 27 to 53 BHN[1]. From the experiment of TIG welding of an Aluminium plate (grade 6063 and 7075), the voltage was observed to be the most influencing parameter and gas flow rate was the least influencing parameter [2].

The mechanical properties of the welded joint prepared by TIG welding of Aluminium 6063 plates were compared to that of friction stir welded plates. First, the welded joint was obtained using Gas Tungsten Arc Welding (GTAW), which is a fusion welding method, and another one joint was obtained using Friction Stir Welding (FSW), which is s solid state welding method. The effect of welding processes on mechanical properties of Aluminium 6063 alloy was studied with the help of optical microscope, tensile test, impact test and hardness test. Results obtained from these tests reveal that the friction stir welding provides better mechanical properties of the welded joints [3]. The welding of 15 mm and 20 mm plate of 6063 Aluminum alloy, on the solar wing expansion frame of a certain type of satellite was studied and their microstructure and mechanical properties were tested. Microstructure studies show that there is a softening region in the heat affected zone and at the same time, there will be a high hardness point (70HV) in the fusion zone, which is due to the presence of the strengthening phase, Mg_2Si [4]. The effect of different heat treatment processes on mechanical properties of 6063 Aluminum alloy was investigated and found that, compared to annealed material, the solution heat treated and quenched material has shown 30% increase in strength. But when the material is allowed for ageing at 20°C after solution heat treatment, it resulted in 100% increase in strength, due to the formation of GP zones. The highest strength was obtained after the quenched aluminum-magnesium-silicide alloy was allowed for aging for 5 hours at 185°C. In spite of decreased elongation, the alloy is highly ductile with 17% elongation [5]. In order to optimize the parameters for maximum strength of welded joint, butt welding of aluminium alloy 6063-T6 was carried out by tungsten inert gas (TIG) welding, at various levels of welding current, gas flow rate and preheat of samples. Unlike the base metal, the HAZ consisted of fine equiaxed grains, due to which the strength of the joints welded at high current was higher than that of the joints welded at low welding current [6]. Investigation of Al6063 welded plates made by MIG and TIG welding with different filler materials revealed that MIG welding with 6061 filler and TIG welding using Al with 5% Mg filler recorded maximum hardness of 53BHN and 97BHN respectively at the weldment. The strength of TIG welded joint using pure Aluminium filler was least; whereas the tensile strength was 89MPa after MIG process with 6061 alloy filler, it was 71MPa after TIG process using Al with 5% Mg filler. Because of fine grain structure TIG process dominates over MIG welding in terms of mechanical properties [7].

3. Materials and Methods

The chemical composition of 6063 Aluminum alloy used in this TIG welding investigation is given in Table 1. Two plates of Aluminium 6063 (with no prior heat treatment) having dimensions 100*50*6 mm are butt welded with groove angle of 60°.

Table 1. Typical composition of AA6063.

Aluminum (UNS)	Si	Fe, ≤	Cu, ≤	Mn, ≤	Mg	Cr, ≤	Zn, ≤	Ti, ≤	Al
6063 (A96063)	0.20-0.60	0.35	0.10	0.10	0.45-0.90	0.10	0.10	0.10	Remainder

TIG welding was performed using the welding parameters shown in Table 2. Filler rod of same grade as that of parent material was used. Figure 1 shows the two Al6063 plates to be welded and Figure 2 shows the welded workpiece. After welding the workpiece was cut into 5 specimens with the help of cutting tool, as shown in Figure 3. Specimens are prepared with the dimensions according to American Society for Testing Material [ASTM E8M-04].

Table 2: Welding parameters

Parameters	Values
Voltage	60 Volt
Current	180 Ampere
Inert gas	Argon
Gas flow rate	5 Cubic feet/hour (Cup size 3)
Weld Speed	1 mm/sec

Fig. 1 Filler metal and Aluminium 6063 plate

Fig. 2 Welded workpiece

Fig. 3 Tensile test specimens

The tensile strength test was conducted on the welded Al 6063 specimen with the help of Universal Testing Machine and the weld metal was tested for its Brinell hardness. From the tensile test results, the yield strength and ultimate tensile strength of the welded joint is recorded. Apart from observing the change in the mechanical properties of the welded joint commpared to that of parent metal, the purpose of this investigation is to findout how to improve the quality of the weld. Therefore, it was decided to carry out Post Weld Heat Treatment (PWHT) on three specimen of the welded joints. The details of heat treatment process is discussed in the next section. After heat treatment, tensile strength test and hardness test were again conducted to get a basic understanding of the changes in the mechanical properties and material behaviour after the welding process.

3.1 Heat Treatment

Aluminium and its alloys play a critical role in engineering applications, due to its light weight and resistance to corrosion. It is widely used in extruded architectural profiles and decorative finishes. It has excellent extrudability, moderate strength, good weldability and resistance to stress corrosion cracking. Properties of Aluminium alloys are related to its average grain size, volume fraction of precipitate and the crystallographic orientation in the microstructure[8]. Aluminium 6063 is one of the Al-Mg-Si series of alloys, containing about 1.1% Mg_2Si which acts as a strengthening agent. It is strengthened by age hardening due to precipitation of Magnesium Silicide. It is characterized by low quench sensitivity and it can be air quenched at the extrusion press without requiring solution treatment. On the other hand, the 6061 alloy with 1.5% Mg+Si and 0.3% Cu is quench sensitive with a higher solutionizing temperature [9]. The excess Silicon exists in the alloy in the form of Silicon element, further strengthens the alloy.

The quantity of Magnesium Silicide present in the alloy exceeds the equilibrium solid solubility limit at room temperature; however, it does not exceed the maximum solubility limit of 1.85% at 595°C, as shown in Fig. 4 [10]. The quasi-binary phase diagram of Al-Mg_2Si, in Fig. 4 indicates that, as the temperature is increased from the room temperature into the α (alpha) region and held for sufficient time, equilibrium is attained and Magnesium Silicide goes completely into solid solution. If the temperature is subsequently reduced below the solvus line (separating the α region from the α+Mg_2Si region) by water quenching, there is a tendency for excess Magnesium Silicide to precipitate, according to the change in solubility at lower temperature. The driving force for precipitation increases with the degree of supersaturation. The formation of fine precipitates of Mg_2Si in the α-Al matrix gives rise to higher value of strength and hardness.

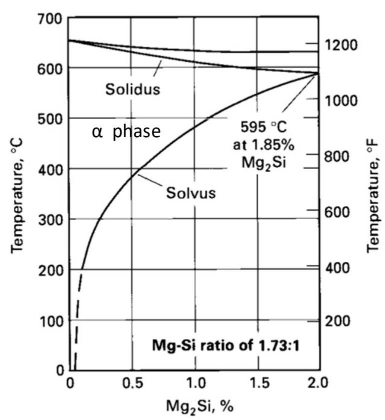

Fig. 4 Al-Mg_2Si Phase diagram (showing temperature range of heat treatment)[11]

Magnesium Silicide remains in solution when quenched in air. Moderate strengthening occurs at room temperature over an extended period of time. This is called as age hardening or natural ageing. The Magnesium Silicide being an unstable state, can be subject to artificial ageing treatment at 200°C, to get improved mechanical properties. Short ageing time at 200° C gives rise to Guinier-Preston (GP) zones in the microstructure, which are ordered arrangement of atoms, producing fine needle shaped zones of approximately 6nm diameter and 20-100 nm length. Further ageing causes three dimensional growth into rod shaped particles with a structure corresponding to ordered Mg_2Si. The formation of GP zones are known to strengthen the material. At higher temperatures this transition phase, β', undergoes diffusionless transformation to the equilibrium Mg_2Si[11].

4. Experimental Details

The following three heat treatments are given to three different welded joint specimens in order to check the possible improvement in the strength and hardness.

4.1 Precipitation Treatment by Quenching

The first specimen is subjected to precipitation heat treatment by quenching in water. For this, it is necessary to first produce a homogenous solid solution. The process consists of soaking the material at a temperature sufficiently high and for a time long enough to achieve a nearly homogeneous solid solution. As mentioned in Section 3.1, the specimen is slowly heated up to 500° C and maintained at that temperature for 1 hour. This process is termed as ‘solution heat treating’, where the maximum practical amounts of the soluble alloying elements are taken into solid solution. The specimen is then quenched in water as soon as it is taken out of the furnace.

4.2 Artificial Aging treatment

The second specimen is taken for artificial aging heat treatment (T6 temper condition). Here the specimen is solution treated at 500° C for 1 hour and removed from furnace to attain room temperature. Even though natural ageing at room temperature may produce increase in hardness over several hours, artificial ageing is expected to give better results. So the specimen is heated to 175° C for 3 hours followed by cooling in air at room temperature.

3.3 Both Quenching Treatment and Ageing

In third case, the specimen is first subject to precipitation treatment by heating slowly up to 500° C and soaked for 1 hour, followed by quenching in water. Then again, it is heated in furnace at 175° C for 3 hours and allowed to cool in air at room temperature.

5. Results and Discussion

5.1Tensile Strength Test

Tensile strength test of welded joint is conducted on the Universal Testing Machine (UTM) for all the four specimen:

Specimen I - normal TIG welded,
Specimen II - welded and precipitation hardened after quenching,
Specimen III - welded and age hardened,
Specimen IV - welded specimen subject to both the heat treatments.

Figure 5 shows the stress-strain diagram for the welded workpiece (specimen I) and it is seen that the maximum strength is 35.5 MPa and the material has undergone 5.5% strain before failure. But for the parent material, the ultimate tensile strength is 131 MPa. Thus, it is clear that TIG welding has resulted in reduction of strength as well as toughness. The tensile strength of welded joints is reduced due to improper fusion of filler material with the base metal. Further, the prescence of porosity, hard phase and other welding defects could be the cause of reduced strength and toughness.

Figure 6 shows the stress-strain diagram for the specimen II (precipitation treatment by quenching). It shows a maximum strength is 30.03 MPa and the material has undergone 7.6%

strain before failure. Figure 7 shows the stress-strain diagram for the specimen III (artificial age hardened). The maximum strength in this case is 36.78 MPa and the material has undergone 6.4% strain before failure. Figure 8 shows the stress-strain diagram for the specimen IV (after both treatments mentioned earlier). It shows that the maximum strength is 25.19 MPa and the material has undergone 5.2% strain before failure. The mechanical properties of the welded joints of Al 6063 in the as-welded condition and after the PWHT conditions are summarized in Table 3. It can be seen that, both quenching-precipitation hardening and age hardening have effectively improved the % strain before failure but a combination of the two treatments is not effective. Moreover, strength of welded joint is marginally increased after age hardening but it shows a decrease in strength after quenching-precipitation treatment and also in the third case when both treatments are combined. Observing Fig.5, 6 & 8 and the proof stress at 0.2% strain indicated in Table 3, it can be said that quench-precipitation hardening has effectively reduced the elastic region in the stress-stress diagram.

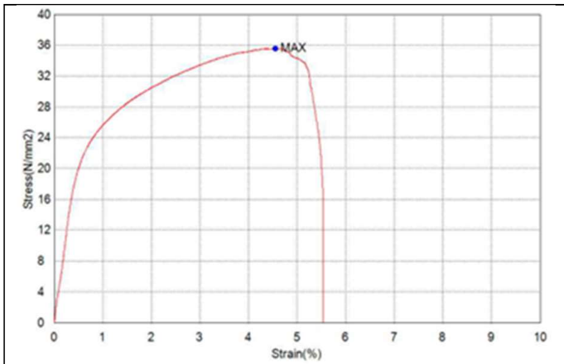

Fig.5 Stress-strain diagram for as-welded Al6063 joint

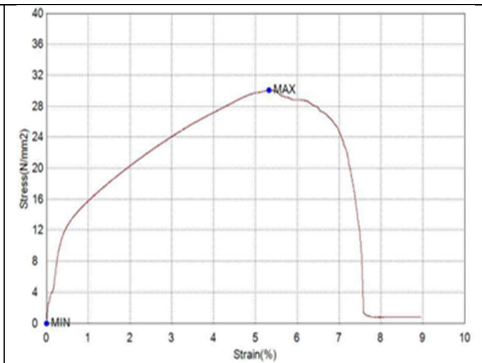

Fig.6 Stress-strain diagram for quench-precipitation hardened Al6063 welded joint

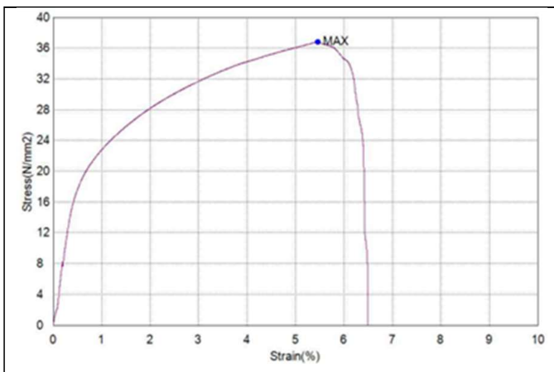

Fig.7 Stress-strain diagram for Al6063 welded joint after artificial age hardening at 200°C.

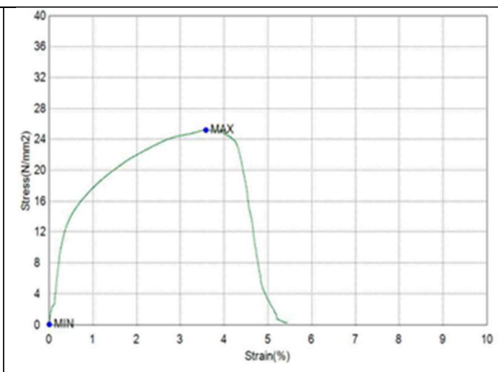

Fig.8 Stress-strain diagram for Al6063 welded joint after both quenching and artificial ageing

Table 3. Properties of as-welded Al6063 plates and after PWHT of joints obtained from stress-strain diagram.

Properties	Welded	Quench-Precipitation hardened (500°C)	Artificial Age hardened (175° C)	Precipitation hardened and Artificial Ageing (Both 500° C and 175° C)

Proof stress (0.2%) (MPa)	24.00	12.00	20.00	16.00
Ultimate Tensile Strength (Experimental) (MPa)	35.55	30.03	36.78	25.19
Strain % before failure	5.50	7.06	6.40	5.20

5.2 Brinell Hardness Test

The hardness of a material is its ability to resist localized permanent deformation, penetration, scratching or indentation. It is an important parameter in engineering applications requiring good friction and wear resistance. The Brinell Hardness Test is the most commonly used hardness measurement technique in the industry. In Brinell Hardness Testing, the hardness of a metal is determined by measuring the permanent indentation size produced by an indenter. Harder materials will generate shallow indentations while the softer materials will produce deeper indentations.

In this test, a predetermined force (P) of 110 kgf is applied to a Tungsten Carbide ball of fixed diameter (D) of 5mm and held for a predetermined time period of 20 seconds, and then removed. The spherical indenter creates an impression (permanent deformation) on the test metal piece. This indentation is measured across two or more diameters and then averaged to get the indentation diameter (d). Using this indentation size (d), Brinell Hardness Number (BHN) is found using a chart or calculated using the following Brinell hardness test formula.

$$BHN = \frac{2P}{\pi D(D - \sqrt{D^2 - d^2})}$$

Table 4 shows three readings of the indentation diameter measured in different samples tested and the BHN respectively. On the whole it is seen that, welding has resulted in increase in hardness. The maximum hardness of the unwelded specimen is 47BHN. Due to welding, the hardness increased to 53BHN in the weld zone. Quench-Precipitation hardening resulted in a maximum hardness of 70BHN and it is 53 BHN after artificial age hardening. During precipitation hardening, Mg_2Si precipitates as β phase in the microstructure, thus increasing the hardness. But due to the artificial age hardening process, the microstructure stabilizes with dissolution of Silicon atoms thereby decreasing the hardness. In the third case when both heat treatments are combined, the maximum hardness was 53BHN meaning that the effect of the previous heat treatment is lost.

Therefore, if more strength is neededfor any application then the material is subject to ageing heat treatment and if high hardness is needed in any application then the material is subject to precipitation heat treatment.

Table 4. Observation of Brinell Hardness Number of the welded joints

S No.	Specimen	Reading 1		Reading 2		Reading 3	
		Indentation dia (mm)	BHN	Indentation dia (mm)	BHN	Indentation dia (mm)	BHN
1	Unwelded Material	1.7	47.04	1.9	37.36	1.7	47.04
2	Welded joint	1.6	53.29	1.8	41.79	1.7	47.04

3	Welded joint, quench-precipitation hardened (500° C, 1hr)	1.5	60.84	1.4	70.06	1.7	47.04
4	Welded joint, artificial age hardened (175° C, 3hr)	1.6	53.29	1.8	41.79	1.6	53.29
5	Weded joint, after treatment (4) followed by (5)	1.8	41.79	1.6	53.29	1.8	41.79

6. Conclusion

Strength of the welded joint is a point of concern as it determines the efficiency of welded joint. Hardness testing of the TIG welded Al6063 specimen indicates that hardness of weldment is increased by 10% compared to that of the parent metal due to welding. The hardness further increased by 50% after precipitation hardening treatment, whereas artificial ageing or a combination of the two treatments do not give a significant improvement.
The ultimate strength obtained from the stress-strain curve upon tensile testing of welded specimen is seen to be nearly 1/4th of that of parent material and the amount of strain undergone before failure is also reduced by the same ratio. The artificial age hardened specimen shows marginal improvement in strength over the welded specimen, but the specimen from other two heat treatments show lower value of strength compared to the welded specimen. The tensile strength of welded joints was lesser because of improper fusion of filler material with the base metal. The welded joints show an equivalent percentage of strain before fracture under the different heat tretment processes. In total, it can be said that post weld heat treatment of Al6063 welded joint has not effectively increased the joint strength, but increase in hardness is significant.

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