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Influence of Post Weld Heat Treatment on Mechanical and Metallurgical Properties of TIG Welded Aluminium Alloy Joints

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Abstract**—**Aluminium and its alloys have excellent corrosion resistant properties, ease of fabrication and high specific strength to weight ratio. In this investigation an attempt has been made to study the effect of different post weld heat treatment methods on the mechanical and metallurgical properties of TIG welded joints of the commercial aluminium alloy. Three different methods of post weld heat treatments are solution heat treatment, artificial ageing and combination of solution heat treatment and artificial aging are given to TIG welded aluminium joints. Mechanical and metallurgical properties of As welded joints of the aluminium alloys and post weld heat treated joints of the aluminium alloys were examined.

Keywords**—**Aluminium Alloys, Post weld Heat Treatment, TIG welding.

I. INTRODUCTION

WELDING is used in many industrial applications and involves more sciences and variables than those involved in any other industrial process. In many cases welding is the most cost effective and structurally sound joining technique. TIG welding is an electric arc welding process in which the fusion energy is produced by an electric arc burning between the work piece and the tungsten electrode. During the welding process the electrode, the arc and the weld pool are protected against the damaging effects of the atmospheric air by an inert shielding gas [1]. In any structural application of this alloy consideration its weldability is of utmost importance as welding is largely used for joining of structural components. Generally TIG welding process is extensively used due to its good bead quality [2]. The problem of the weld strength is highly prominent for joints of the aluminium alloys. Heat treatment may be any one or combination of a series of operations involving the heating and cooling of alloys in the solid state. Its purpose is to alter the mechanical properties of the alloy, either to make the alloy soft for forming operations, or to achieve a specific mechanical strength. The heat treatment process achieves the required results by either permanent or temporary modification of the alloy grain structure. There are different heat treatment methods which are used extensively in the aircraft manufacturing and repair industries and aircraft structural integrity is highly dependent on correct process and application. In the solution heat treatment temperature is raised above a particular high temperature, a Super-Saturated Solution of the alloy elements occurs. if the alloy is heated to its super-saturated condition (approx. 500°C) and then rapidly quenched in cold water, the copper fails to come out of solid solution as fast as the temperature changes. Instead, over a period of days, the alloy begins to Age, i.e., the copper atoms begin to move within the crystal structure to form compounds containing higher concentrations of copper. In time, these copper-rich compounds migrate to the metallic grain boundaries and they interfere with movement between slip-planes as load is applied to the material. This slip-plane interference results in a hardening effect similar to the Cold Working process. The Artificial Aging process consists of taking parts previously Solution Heat Treated and forcing the material to age by holding it at a prescribed temperature for a considerable period of time. During the aging period, some of the alloy compounds precipitate out of solution and end up at the grain boundaries to increase material strength by interfering with the slip-planes. Precipitation Heat Treatment may also be used to Over-Age certain products and so improve resistance to attach by inter granular Corrosion. Process temperatures and soak times are critical if full alloy strength and corrosion resistance is to be assured. In the present study an effort has been made to find best setting of input parameters of TIG welding for better strength of commercial aluminium alloy and the effect of different post weld heat treatment methods on TIG welded joints of the aluminium alloy.

II. EXPERIMENTATIONS

The pilot experiment was conducted to finalize the values of welding current. Sample specimens of commercial aluminium of thickness 6 mm, 150 mm X 75 mm cross section were prepared with the help of power hacksaw. Each sample specimen was machined to obtain double V-groove, having an angle of 65^0 on both sides, as per BIS Standard No. 813-1961 [3]. Prior to welding, the grooves were thoroughly cleaned with wire brush, followed by cleaning with acetone, to remove the oxide layer, adhering to grooves surfaces to obtain good weld. Diameter of the filler wire was 2.4 mm and the diameter of tungsten electrode was 3 mm. The chemical composition of the base material and filler wire is presented in Table I. For

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welding of this material of 6 mm thickness, manufacturers have recommended the use of filler wire. All general precautions and procedure to be adopted for TIG welding of Aluminium were studied. As observed from the literature that for a flat sheet thickness of 6 mm, the current range may be varied from 80 Amp to 250 Amp with gas flow rate 15 lit./min. It was observed from the trial experiments that below the current range of 80 Amp the welding joint was not properly made and at the current range of 250 Amp burning of specimen starts. So, on the basis of the trial experiment that, the current range between 140 Amp to 170 Amp was decided for final experimentations. This range gave a steady arc with least spatter. Since welding was done in open and not in closed chamber. Adequate precautions were taken to prevent welding zone from atmospheric contaminations. Argon gas of high purity (fit for welding) was used for creating an inert atmosphere. Proper primary and secondary shielding was provided. Angle between electrode and workpiece was maintained at 60^0-70^0 and angle between electrode and filler wire was maintained between 80^0-90^0 as per B.I.S. Standard No. 813-1961 [3]. Four joints were prepared using optimized TIG welding parameters.

TABLE I
Chemical Composition of Base Metal and Filler Wire

S No	Elements	Composition % Base Metal	Composition % (4043) Filler Wire
1	Manganese (Mn)	0.00-0.10	0.05
2	Iron (Fe)	0.00-0.35	0.08
3	Magnesium (Mg)	0.45-0.90	0.05
4	Silicon (Si)	0.20-0.60	5.00
5	Copper (Cu)	0.00-0.10	0.3
6	Zinc (Zn)	0.00-0.10	0.1
7	Titanium (Ti)	0.00-0.10	0.2
8	Chromium (Cr)	0.00-0.10	--
9	Aluminium (Al)	Balance	Balance

To study the influence of post weld heat treatment on the mechanical and metallurgical properties of TIG welded joints, there are three heat treatment processes were used to alter or improve the mechanical and metallurgical properties of aluminium alloys joints. The welded joints are grouped into four different categories, like As welded, Solution Heat Treated, Artificial Aging and combination of post weld heat treatment and artificial aging. The Solution Heat Treatment was carried out at 500^o for soaking period of 5 hours and then rapidly quenched in cold water. The artificial aging was carried out at 175^o for soaking period of 18 hours. After completion of soaking period the joints were allowed to cool in the furnace. For combination heat treatment both the above heat treatment procedure were followed. After post weld heat treatment the transverse tensile test specimens were from the weld plates as per ASTM-E8M-08 [4] and the dimensions of tensile test specimen shown in Fig. 1. The impact test specimens were removed as per ASTM-E23 [5] guidelines before and after post weld heat treatment and dimension of impact test specimen presented in Fig. 2. The metallurgical specimens were prepared according to standard metallographic procedures. After polishing and macro etching the cross sections of the joints were captured with the help of image analysis software coupled with a microscope at a magnification of 100 X facilitate measuring of the details like cross sectional areas of the fusion zone and HAZ. Standard polishing procedures were used for general microstructure observations.

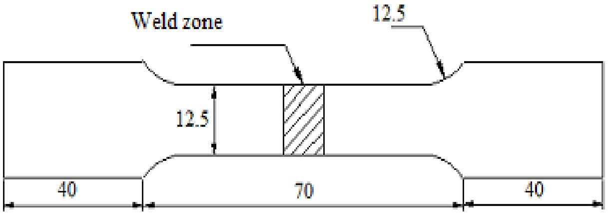

Fig. 1 Dimensions of the tensile test specimens [ASTM E8M-08]

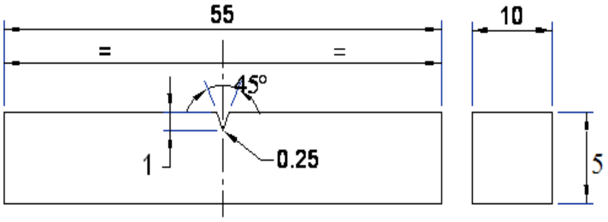

Fig. 2 Dimensions of the impact test specimens with tolerances [ASTM E 23]

III. Results and Discussion

Tensile strength of As welded and after post weld heat treatment was evaluated with corresponding variation with the current (see Table II). It was observed that most of the specimens of the tensile test were fractured within the weld region. As shown in the Table II, the tensile strength of TIG welded joints was varied with the variation in the welding current. The tensile strength of the base material was recorded 125 N/mm^2. The tensile strength of welded specimen was varied from 80 N/mm^2 to 101 N/mm^2. This indicates 30-35% reduction in the tensile strength for TIG welded joints. As observed from the Table II, after three PWHT procedures were applied to the joints, the artificial aging offered maximum improvement in the tensile strength as compared to solution heat treatment and combination of solution heat treatment and artificial aging [6], [7]. The tensile strength of all the joints improved with three post weld heat treatment methods but the maximum effect of post weld treatment on the tensile strength was observed with artificial aging.

TABLE II
Comparison of Tensile Strength results of as Welded and Post Weld Heat Treated Aluminium Alloy Joints

Current Rating (Amp)	AS Welded (MPa)	Solution Treatment (MPa)	Artificial Ageing (MPa)	Combination of Solution Treatment and Artificial Ageing Wire (MPa)
140	100.5	92	111	87
150	79	123	101	100.5
160	83	101	89	98.5
170	87	95	96	100

The impact test was conducted on the entire welded specimen and the result of the impact test is presented in Table III. Impact toughness was measured with corresponding variation with the current and after post weld heat treatment. Impact toughness represents resistance of a material, in presence of notch and high strain rate loading. The measured value of impact toughness of base material was 4 Joules. Welds made by TIG welding with different welding currents showed impact toughness values slightly lower than those of the base material. Ductile failures occurred in all the specimens and the failure location of all the joints was at the notch which was provided at the stir zone. As shown in Table III the impact toughness of all the joints was improved with post weld heat treatment methods but maximum toughness was observed with artificial aging methods.

TABLE III
COMPARISON OF IMPACT TOUGHNESS RESULTS OF AS WELDED AND POST WELD HEAT TREATED ALUMINIUM ALLOY JOINTS

Current Rating (Amp)	AS Welded (J)	Solution Treatment (J)	Artificial Ageing (J)	Combination of Solution Treatment and Artificial Ageing Wire (J)
140	03	5.5	09	04
150	3.5	04	08	08
160	04	05	09	05
170	4.5	06	08	4.5

Optical micro graphs of the TIG welded joints showing the micro structure of weld zone and heat affected zone, at different welding currents are shown in Figs. 3 to 6. From the micrographs, it was observed that there was an appreciable difference in grain size of the weld zone and HAZ regions with different welding currents. The grain size of the weld zone and HAZ are influenced by the heat input of the welding process. In the HAZ, it was found that the grains were grown larger due to the heat and high temperature during TIG welding process. The coarse grain structure was observed at the fusion boundary at all range of the currents [8]. From all the micro graphs it was observed that the weld zone contain dendrites structure and it may be due to fast heating and cooling of the base metal and filler wire during welding [9].

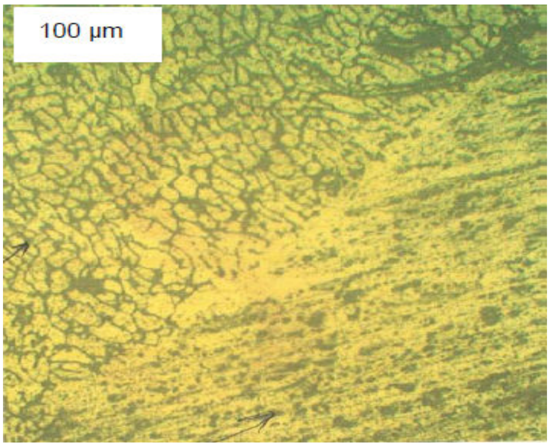

Fig. 3 Micrographs at welding current of 140 Amp (100X)

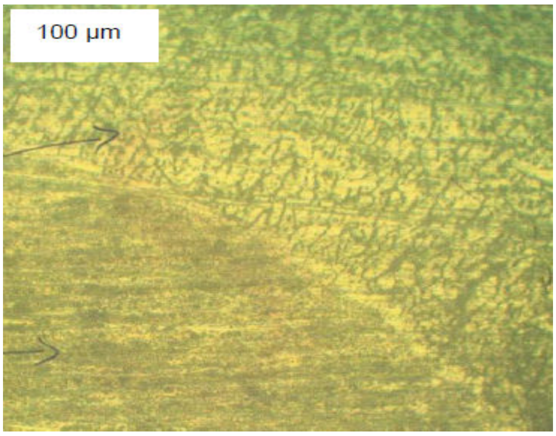

Fig. 4 Micrographs at welding current of 150 Amp (100X)

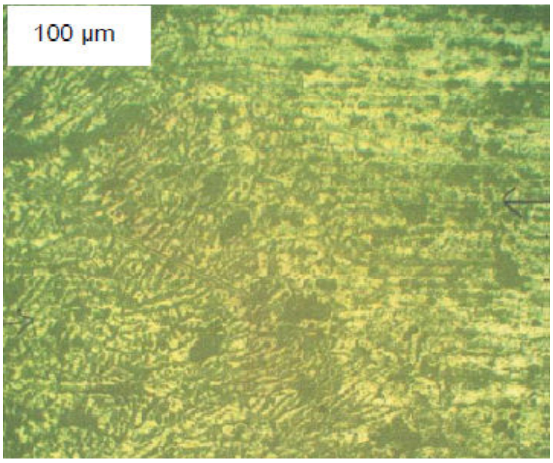

Fig. 5 Micrographs at welding current of 160 Amp (100X)

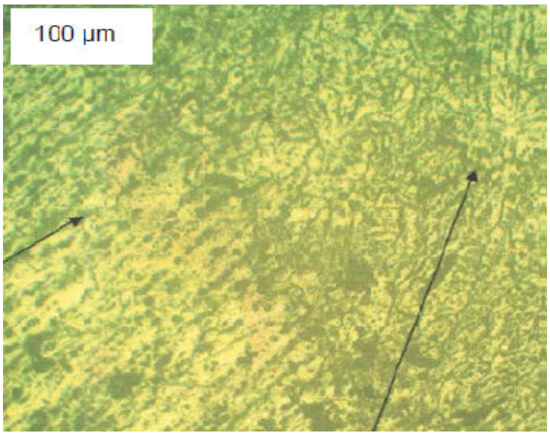

Fig. 6 Micrographs at welding current of 170 Amp (100X)

IV. CONCLUSION

In this investigation, the effect of post-weld heat treatment on the mechanical and metallurgical properties of TIG Welded joints of aluminium alloy was analyzed in detail. From this investigation, the following important conclusions were obtained.

1) From all the TIG welded joints, the joint welded with 140 Amp current has higher Tensile Strength and impact toughness.
2) The three post weld heat treatment methods were examined on the TIG welded joints of the aluminium alloys and concluded that the artificial ageing treatment method is beneficial to improve the tensile properties of the TIG welded aluminium alloy joints.
3) The impact toughness of all the joints improved with three post weld heat treatment methods but the maximum impact toughness was observed with artificial aging treatment.

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