RESEARCH ON MECHANICAL PROPERTIES OF TIG WELDED ALUMINUM ALLOY

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Abstract

Different welding parameters (welding current 165 A, 180 A, and 200 A) and weld groove angle values were changed in order to evaluate mechanical properties of Tungsten Inert Gas (TIG) welded. Different groove angles (60°, 70°, 80°, and 90°) have been chosen to identify the peculiarities of weldment structure formation and the resultant quality of the weld. Mechanical properties were assessed in the terms of Vickers HV1 hardness and tensile strength testing. The transverse tensile tests were executed on the welded samples to ascertain influence of welding current and groove geometry to the tensile strength of weld joint and its working conditions during exploitation. The obtained results proved that the tensile strength of the welded samples is closely connected with welding parameters: the highest welding current 180A ensured the highest tensile strength of welded samples, in the same way as the biggest groove angle 90° made up good conditions for proper fusion and the adequate quality of major welds, herewith good penetration and adhesion of weld and base metal directly proportional to welding current.

Keywords: Tungsten inert gas welding, aluminum alloy, mechanical properties, welding parameters, tensile test

1. INTRODUCTION

Aluminum alloys are used for many industrial applications due to its manufacturing properties, strength and weight ratio, ductility, high corrosion resistance, and abundance. Herewith aluminum alloys have a good strength and toughness ratio at low temperatures together with high weldability, these properties make up this alloy suitable for the production of pressure vessels [1,2]. Excellent weldability is the main reason to use welding for joining of for this type of material. Tungsten Inert Gass (TIG) process and Gas Metal Arc Welding (GMAW) are the most useful welding processes for manual and automatic welding. Main advantages of GMAW are high deposition rate, high welding speed as well as deep penetration, unfortunately high heat input initiates grain coarsening and essential deformation, particularly in welding of thin aluminum sheets. TIG process is preferred over GWAW, because of possibility to obtain high quality weldments [3,4].

Some physical and chemical properties of aluminum alloys should be solved when choosing various welding methods. One of the most important problems in the aluminum alloys' welding is a porosity caused by gases capturing from shielding gases and air during turbulence of liquid metal in the weld pool. When the cooling rate is too high, the gases cannot escape from the weld pool, which leads to the porosity. TIG gives lower rate of porosity than Metal Inert Gas Welding (MIG) due to hydrogen contamination of the wire [5]. Hot cracking occurs in the late stages of solidification when the volume fraction of solid is above 85-95% [6]; it can be reduced selecting suitable composition of a filler metal and heat input [7]. The relationship between strength and hardness of aluminum alloys gives an opportunity to assess mechanical properties of the welds, especially tensile strength and yield stress [8-11]. The stress-hardness ratio in different weld zones of AA 6082-T6 for a wide range of welds produced under different welding conditions were investigated [12]. It was claimed that obtained stress-hardness ratio is suitable for assessing elastic properties from hardness data for 6082 alloys in the naturally aged and overaged conditions. It was stated that hardness was found to be a reliable method of estimating the yield and tensile strength of the Heat Affected Zone (HAZ) for 6061-T651 aluminum alloy

[13]. Authors have reported that low heat input causes higher yield strength values of the welds of 6082-T651 aluminum alloys [14, 15]. The effect of heat input of a 7025 Al-alloy was investigated [16] with main focus on metallurgy of the Fusion Zone (FZ), Partially Melted Zone (PMZ) and HAZ. It was reported that on high heat input, the nucleation is lower and the grains around the weld interface are coarser. Furthermore, high heat input determines higher hardness of the weld interface as the result of solution hardening. Aluminum alloy AA6082-T6 tubular joint TIG welded joints were characterized in the terms of microhardness values, strength and microstructure analysis. It was found that slow cooling rate produces relatively wider grain spacing and results in a lower microhardness values in the HAZ [16]. As it has been reported [17, 18] that TIG welded joints are often used in the pressure vessels, fuel tanks, large vehicles, and in other industries such an aviation and aero-space. As weld metal has lower hardness and strength, this strength shortage could be compensated by weld reinforcement, which on another hand can generate stress concentration in the joint in such a way decreasing effect of reinforcement. Moreover, partially melted zone (PMZ) which composes next to the weld exhibits low plasticity. Due to heat effect, an over aged zone (OAZ) exists in the majority of welds [17], besides of these two beforehand mentioned weak areas. Hence it can be concluded that all joints consist of zones with different mechanical properties, wherefore tensile properties are hardly predictable.

Considering the studies performed by other authors on TIG welded aluminum alloys, it can be argued that for each specific set of welding current such as joint shape, base metal thickness, chemical composition of alloy, the specific set of process parameters should be selected in order to ensure the required welding seam properties and quality. The present study has been done to evaluate influence of different groove angles and welding current on the tensile behavior of TIG welded aluminum joints. Hardness of the welded joints was investigated and optimum weld current was determined as well.

2. METHODOLOGICAL BASES

The base metal used for the experiments was aluminum alloy AW6082-T6 in condition T6+solution heat treatment and artificial hardening in the form of plates with thickness of 10 mm (Si - 0.7 - 1.3 wt.%; Fe - max 0.5 wt.%; Cu max - 0.10 wt.%; Mn - 0.4 - 1.0 wt.%; Mg - 0.6 - 1.2 wt.%; Cr max - 0.25 wt.%; Zn max - 0.2 wt.%; Ti max - 0.1 wt.%; Al - balance). Alloy 6082 posses the highest strength among the aluminum alloys of 6xxx series. Magnesium silicide Mg_2Si [5,19] gives necessary hardness for 6xxx series; silicon alongside with magnesium generates the necessary conditions for a precipitation hardening. The aluminum alloy plates were cut according to the recommendations of EN ISO 9692-3:2001 for single V butt weld [20]. Four different groove angles 60°, 70°, 80°, and 90° have been milled seeking to ascertain its influence to the quality of the weld and tensile properties of resultant joint. All samples (10 test samples for each sample number) were cleaned with ethanol and polished to remove surface impurities, dusts and oxides.

Kemppi MASTERTIF AC/DC 2500W was used to accomplish weld joints. The weld samples were properly fixed in the machine; five passes along the groove were carefully accomplished. Cleaning with wire brush followed each pass of welding. The main parameters of welding were optimized according to the weld seam quality: welding currant 165 A, 180 A, 200 A; voltage 16 V, welding speed 82.9 mm/min; heat input for 180 A - 1.25 kJ/mm, 165 A - 1.14 kJ/mm, 200 A - 1.39 kJ/mm. 100 % argon was used as shielding gas, which gives a wide, shallow penetration weld bead and enables to change the arc length without disrupting the heat of the arc.

Hardness test along the joints were executed using Nano-Hardness Tester produced by CSM Instruments, Switzerland with load of 9.86 N and diamond indenter; for 10 s dwells period at 0.7 mm intervals, across and along the weld at the location of 2 mm from the surface. All the tests were conducted at the ambient temperature in the laboratory. Tensile test samples were prepared according to the ISO 4136:2012 International Standard [21] with gauge length of 50 mm. The tensile tests were conducted on 50 kN “Amsler” versatile electromechanical testing machine and Hottinger Baldwin Messtechnik GmbH (HBM) testing equipment. All tests were conducted in at room temperature with a crosshead speed of 2 mm/min.

3. RESULTS AND DISCUSSION

Mechanical properties of the welded joints were estimated on the basis of hardness test and tensile strength test. Variation of the heat input through the weldments was presented as distribution of hardness values across and along to the welding direction. The main factors effecting hardness of the weld seam are precipitated volume fraction, morphology, and grain size of structure [22], which are mainly can be explained by distribution of heat. **Figure 1** shows distribution Vickers hardness values from the centre of the weld.

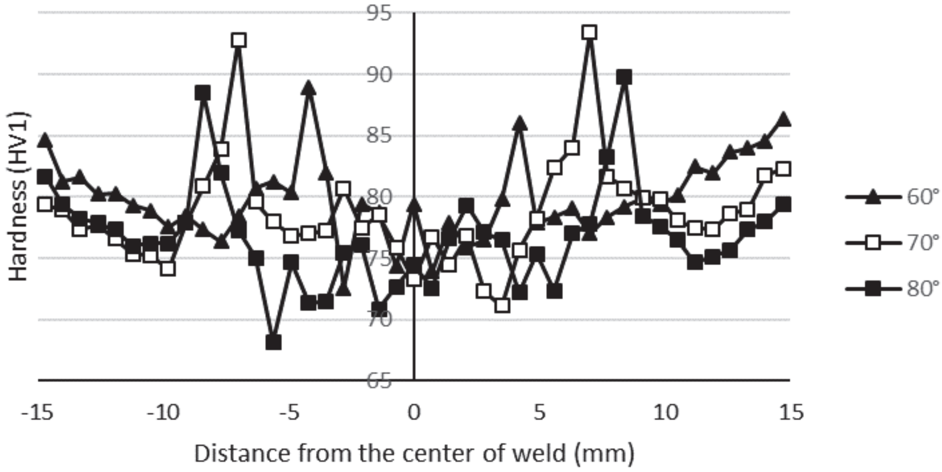

Figure 1 Hardness profiles of weld samples with different groove angles when welding current 180 A, voltage 16, welding speed 82.9 mm/min, heat input kJ/mm

Hardness curves presented in **Figure 1** show distribution of hardness values in the welded samples with different groove angles. **Figure 2** demonstrates influence of welding current on the hardness of welded samples.

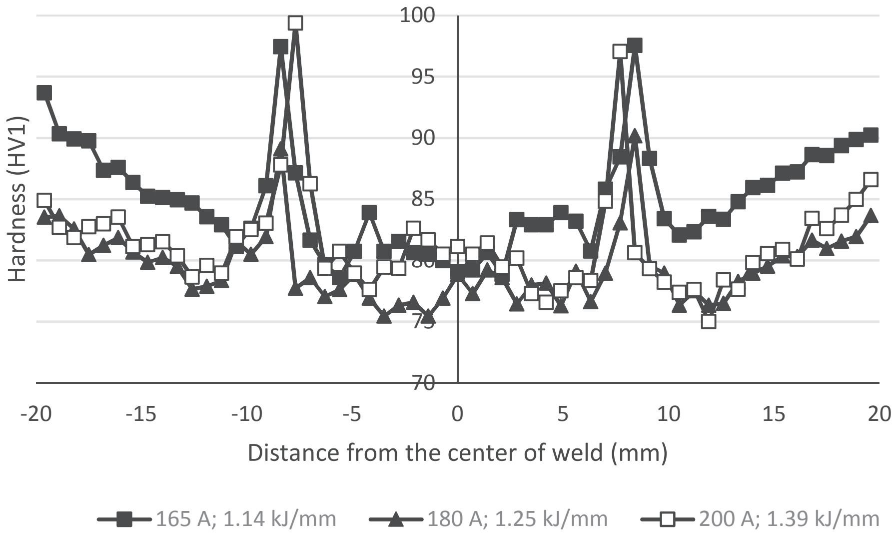

Figure 2 Hardness profiles of weld samples produced with different welding current and heat input values when groove angle 90°, voltage 16, welding speed 82.9 mm/min, heat input kJ/mm

The hardness was measured along the welding seam and the three different regions could be distinguished according to the hardness values: FZ, PMZ and HAZ. It has been noticed that the hardness of the welded samples is related to the formed microstructure. The highest hardness of PMZ corresponds to fine grain structure in the zone while FZ cannot be characterized in such a way. PMZ can be characterized by dissolution of precipitates [23]. HAZ zone was the worst region in the tensile test, therefore the majority of samples experienced fracture in this zone. However, hardness in the HAZ can be restored applying postweld heat treatment. As it can be seen in **Figure 1** and **Figure 2** descending of hardness (HV) is concentrated mainly in the FZ as melting and recrystallization causes shifting of precipitate hardening effect. The welding process softened the material noticeably reducing the hardness in the FZ in overaged zone up to the 75 HV1. Comparing hardness values of the welds with different groove angles (**Figure 1**) it is obviously that all welds had almost the same hardness values at the centre of FZ. The tensile tests have been accomplished after certain time when the natural aging was sufficient to achieve the strength. The tensile strength of welded samples manufactured using different values of welding current has been analysed. Welding current is one of the most influential parameter in TIG [5, 25, 26]. Generally low welding current results in low heat input and insufficient penetration. However, to high welding current could lead to excessive heat generation, too big weld pool dimensions and poor joint quality. It is known that the strength loss in the 6xxx series alloys is lower in the naturally aged aluminum alloys (T4 condition) than in the artificially aged alloys (T6 condition) [5]. Tensile stress test profiles in **Figure 3** clearly show that changing the welding current it is possible to ensure the required strength of the welded joint. With controlled heat input it is possible to achieve sufficient constant strength of the welded samples of AW6082-T6 alloys.

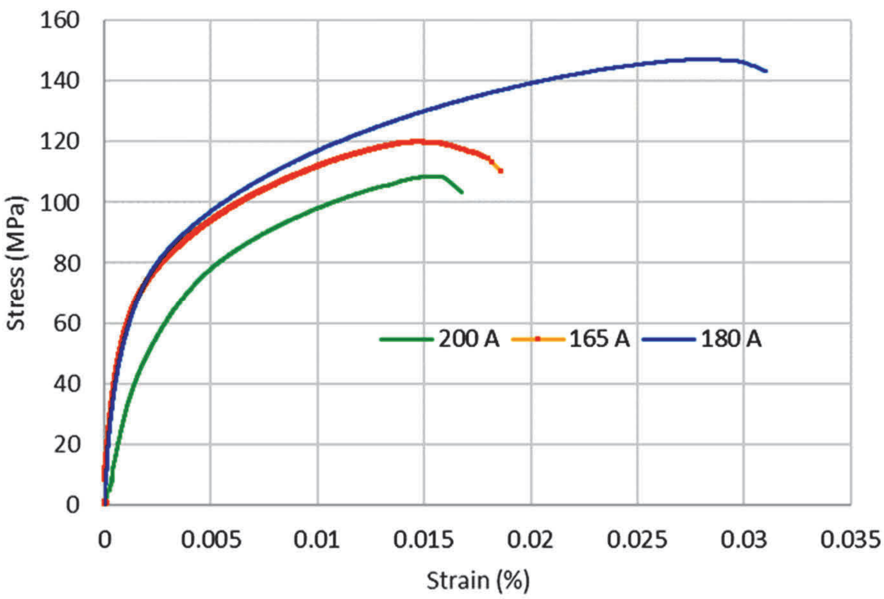

Figure 3 Stress-strain diagrams of welded samples produced using different welding current

The tensile tests showed the remarkable reduction in tensile strength of welded specimens as compared to values of the base material. The tensile strength of the welded samples composes just 45 % of the base metal strength. Obviously, test sample made of base material has the highest strength and elongation comparing with the welded samples.

Weld seam structure is the mixture of the filler rod metal and the dilution from the base metal. It is known that Mg and Si content has a positive effect on the mechanical properties of series 6xxx alloys after aging [17, 28]. Due to the usage of filler rod ER4043 (C $\leq$ 0.30 wt.%, Fe $\leq$ 0.80 wt.%, Si - 4.5-6.0 wt.%, Mn $\leq$ 0.05 wt.%, Mg $\leq$ 0.05 wt.%, Zn $\leq$ 0.10 wt.%, Al - balance) sufficient content of Si could be reached in the weld pool, however Mg is only available from the base metal; consequently just few of Mg_2Si precipitates could be formed in the weld area. Therefore, weakness of welded joints can be attributed to the fact that Mg_2Si precipitates were smaller and thinner, and its concentration was decreased in the weld area compared to the base metal.

Because of the major effect of the weld thermal cycle, HAZ overaged due to the coarsening of Mg_2Si precipitate. The composition of the weld metal is basically binary, with some proportions of third element (because of dilution from the base metal) to form Mg_2Si; in any case, it does not form during hardening under the weld thermal cycle. In consequence, the tensile properties of the weld are usually lower than of base materials. The fracture location corresponded to the reduction of hardness and strength in the weld resulting from the welding process. The huge drop in strength was caused by precipitate coarsening in the over-aged zone. Results showed that the ultimate tensile strength of welded samples obtained using welding current 168 A, 180 A and 200 A is approximately 120 MPa, 150 MPa and 110 MPa respectively. The strain varied from 0.016 % to 0.032 %. It was found that the joint with smallest groove angle had the lowest strength and lower elongation.

4. CONCLUSION

The experimental study showed that reduced strength and hardness was an evidence of structural instability emerged due to coarsening or over ageing of the precipitates in HAZ. PMZ is harder than the rest of the HAZ, but still softer than the base metal because the joints are under the influence of relatively high temperature and rapid cooling rate. Performed work indicated the loss of strength in the PMZ and HAZ of welds due to grain growth during the welding. In HAZ, larger recrystallized grains were observed close to FZ, and smaller grains away from the weld bead. Results of the experiments proved that the welding current is the one of the most essential criterion on weld pool geometry, HAZ dimensions as well as on mechanical properties of the welded joint. Reduction in tensile strength of welded joints is caused by precipitation reactions involving coarsening or over ageing of precipitates in the AW6082-T6 aluminum alloy. The fracture location on tensile samples correlated with hardness decrease in the welded joint. In spite of the fact that hot cracking was avoided during the welding due to silicide presence in the filler metal, the results of tensile testing showed that the PMZ can still be susceptible to ductility loss after welding.

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