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TUNGSTEN INERT GAS (TIG) WELDING OF ALUMINUM ALLOY EN AW-AlZn5.5MgCu

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Preliminary Note – Prethodno priopćenje

The paper presents the results of tungsten inert gas (TIG) welding of aluminium alloy 7075-T6 in the butt joint, with single-V edge preparation. The sample dimensions were 100 × 75 × 20 mm^3. The TIG welding was done with 2 mm diameter filler wire made of 5183 (AlMg4,5Mn) at four preheating temperatures. During the welding a temperature was measured at six locations with thermocouples. For successfully welded samples tensile test were done and microstructure of base metal, heat affected zone and weld was analysed. The welds brake at heat affected zone between base metal and the weld. The optimal preheating temperature was at 200 °C.

Key words: TIG welding, aluminium alloy 7075–T6, repair welding of tools, preheating temperature, microstructure, tensile test

INTRODUCTION

Aluminium and its alloys are used in industry due to their good corrosion resistance, weldability, thermal conductivity and strength to weight ratio [1-9]. Pure aluminium is soft and has good thermal conductivity. Addition of small amounts of alloying elements changes their properties. They can be subjected to various technological processes and be used for tools, structural elements, and other products [10-14]. The alloys are classified according to the principal alloying elements into eight series from 1xxx to 8xxx, according to EN 573-1 (AW-5052) or by chemical composition according to EN 573-2 (Al Mg2,5). They can be further classified as non-heat-treatable or heat-treatable alloys (Figure 1) [15]. The state of treatment is defined by EN 515, and is written after numeric classification, for example EN AW 7075-T6, where T6 means solution heat treated and artificially aged.

Aluminium alloys can be joined without cracking related problems by most fusion and solid-state welding processes as well as by brazing and soldering (Figure 1) [4-9, 15-18].

For fusion welding a combination of proper filler alloy, welding operation and welding procedure is significant for success. Filler wire composition is determined by weldability of base metal, minimal mechanical properties of the weld, corrosion resistance and anodic coating requirements [19]. Usually matching filler metals are used for welding non-heat-treatable alloys, but for alloy-lean materials and heat-treatable alloys, non-matching fillers are used to prevent solidification cracking [17]. The selection of proper filler alloys for various weldable alloys are specified in EN 1011. The filler alloys are usually materials of the series 1xxx, 3xxx, 4xxx and 5xxx [15, 19].

Non-heat treatable alloys gain their mechanical properties by work hardening and solid solution hardening. At welding of these alloys a softening of the heat affected zone (HAZ) adjacent to the weld may occur [17, 18].

Mechanical properties of heat treatable alloys depend on alloy composition and heat treatment (solution heat treatment and quenching followed by ageing produces a fine dispersion of the alloying elements). Fusion welding redistributes the hardening constituents in the HAZ, which locally reduces material strength [17, 18].

In the fusion welds porosity, cracking or poor weld bead profile can occur. The main cause for porosity is absorption of hydrogen in the weld pool, which forms discrete pores in the solidifying weld metal. The hydrogen comes from hydrocarbons and moisture from the base metal and filler wire surfaces, and water vapour

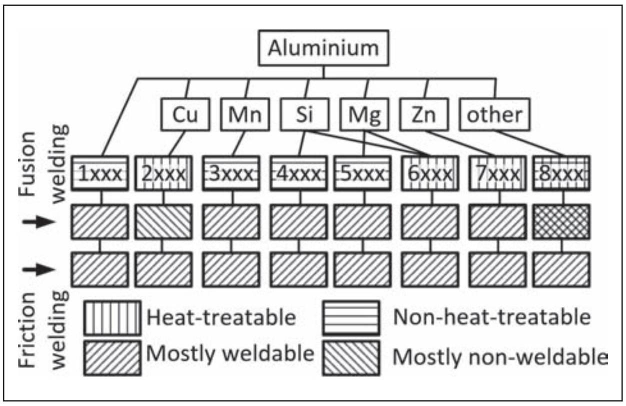

Figure 1 Weldability of aluminium and its alloys [15].

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from the shielding gas atmosphere. The porosity can be minimised, if surfaces of the base metal and filler wire are thoroughly cleaned. The cleaning can be done mechanical, by solvent degreasing or by chemical etch cleaning. In gas shielded welding, air entrainment could be avoided by efficient gas shield and by avoiding of draughts [5-9, 15-18].

Hot cracking is the usual cause of cracking in aluminium welds. It occurs due to high stresses in the weld as the consequence of the high thermal expansion and substantial contraction on solidification. Solidification cracks are formed in the weld centre along the centreline during solidification and in the weld crater at the end of the welding. They can be minimized by selection of susceptible base alloy chemistry, by using a non-matching, crack-resistant filler wires (4xxx and 5xxx series alloys) and selection of joint design and weld sequence to prevent high restraint loads. To understand cracking phenomena of aluminium welds the crack sensitivity curves are used. They reveal that with the addition of small amounts of alloying elements, the crack sensitivity becomes more severe, reaches a maximum, and then falls off to relatively low levels. This means that most of the aluminium alloys are unweldable without filler wire, since their chemistries are at or near the peaks of crack sensitivity [5-9, 15-18].

The article describes the conditions that were taken in TIG welding of EN AW 7075-T6 in order to get crack free welds.

EXPERIMENTAL WORK

A standard aluminium alloy EN AW 7075-T6, which was solution heat treated and artificially aged was used. Its yield strength was 505 MPa and tensile strength 570 MPa [20]. The test coupons dimensions were 100 × 75 × 20 mm^3, and were welded in a butt joint with single-V edge preparation with 4 welding passes. At TIG welding argon shielding gas at 10 l/min was used and the electrode with 2,4 mm in diameter. The welding was done at 240 A of welding current and 21.5 V welding voltage with 2 mm diameter filler wire made of 5183 (AlMg4,5Mn) at four preheating and interpass temperatures (A = 20 °C, B = 120 °C, C = 200 °C and D = 250 °C). The energy input at sample A and B changed from 9 to 3,5 kJ/mm, for sample C changed from 6 to 2,5 kJ/mm, and for sample D changed from 4,5 to 2 kJ/mm. At first two weld passes the energy input was higher, and was later lower as the sample heated up. During the welding a temperature was measured at six locations using K-type thermocouples. From the welds, samples for macro/microstructure analysis were prepared and hardness was measured, tensile tests were done and microstructure of base metal, HAZ and weld was analysed. The samples were examined using a light optic microscope and a scanning electron microscope (SEM).

RESULTS AND DISSCUSION

Figure 2 a shows a solidification crack in the weld centre along the centreline for the sample A, without preheating. Figure 2 b and c shows the cracked surface after tensile test for sample A and B, which were preheated to 20 °C and 120 °C. At welding at lower temperature the hot crack was deeper that at welding at higher preheating temperature. The area of material which breaks during the tensile test indicates that the tensile strength of these two samples was low due to big area of hot crack. The tensile strength of sample B was higher, than at sample B. Figure 3 shows the tensile strength of the sample welded at 250 °C preheating and interpass temperature. This weld achieved the highest tensile strength of 288,9 MPa, which is the tensile strength of the filler metal (275 – 320 MPa) and is the 50% the strength of the base metal [19, 20]. The welds made at preheating temperature of 200 °C and 250 °C were without cracks.

Figure 4 shows temperature welding cycle for samples B, C and D, welded at different preheating temperature. All welded samples were welded with four weld passes. If the samples were preheated to a higher temperature, the welding speed (w) was higher (w_D = 1,4 – 2,94 mm/s, w_A = 0,63 – 1 mm/s). Here less energy input was needed to make a weld pool (Figure 4 a). Figure 4 shows temperature welding cycle for the first weld

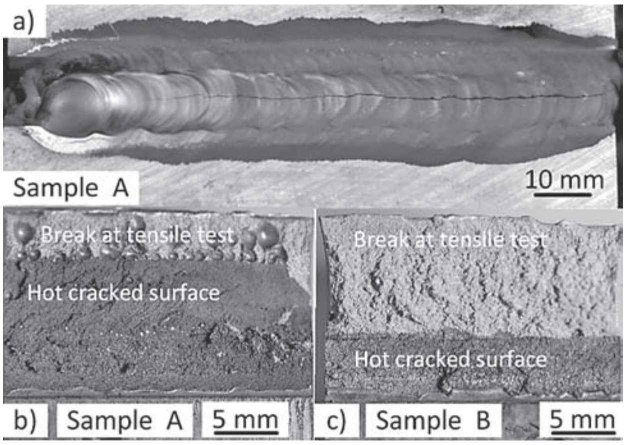

Figure 2 Hot cracks in weld: a) and b) sample A and c) sample B.

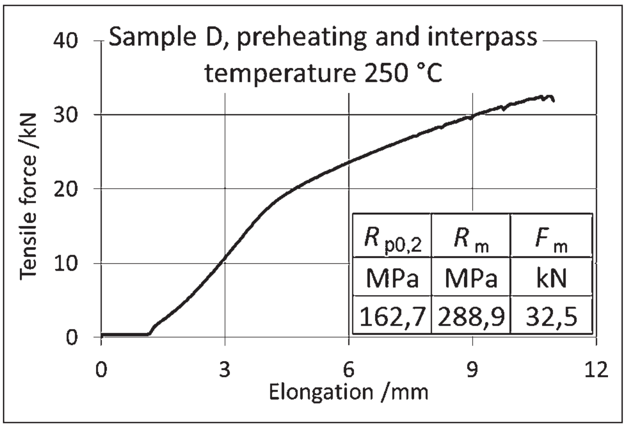

Figure 3 Tensile strength of sample D.

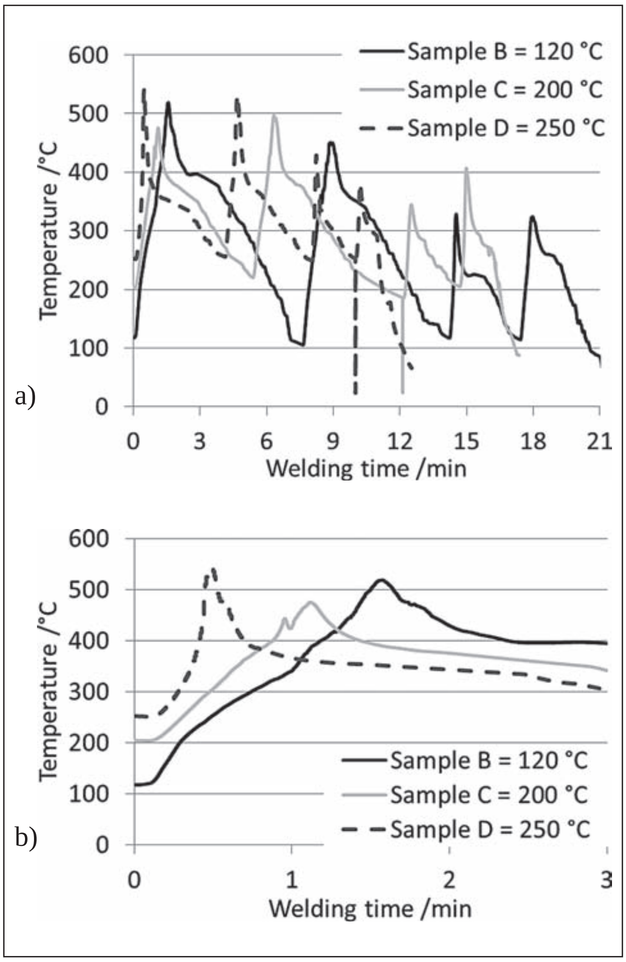

Figure 4 Temperature welding cycle for TIG welding with different preheating temperature: a) compete cycle, and b) for first weld pass.

pass for the three samples. From the cooling side of the curves we can note, that the slowest cooling rate was achieved at sample B, the cooling rates for sample C and especially D were higher. The energy input for successful welding was ~ 9 kJ/mm for sample B, ~ 6 kJ/mm for sample C, and ~ 4,5 kJ/mm for sample D. At samples C and D there was a good combination of preheating and interpass temperature with the energy input in order to achieve sufficient cooling rates to avoid solidification cracking.

Figure 5 presents the Vickers hardness measured at the apices of the welds. The average weld hardness was ~ 90 HV, the hardness of HAZ reached the values between 100 and 130 HV, while we noted a hardness drop to ~ 85 HV also in the base metal close to the weld. The reason for the hardness drop is in the recrystallization of base metal or overaging, due to high energy input during welding and/or higher preheating temperatures [21].

Figure 6 shows SEM images of a complete weld and parts of weld. In Figure 6 b fibrous structure is present, as the result of previous rolling process. In the images there are present white and black inclusions. The X-ray diffraction (XRD) analysis revealed that the white phases are rich in Cu (6,5 wt. %) and Fe (23 wt.%). If they are without Fe, they are composed of Cu (~ 25 wt. %),

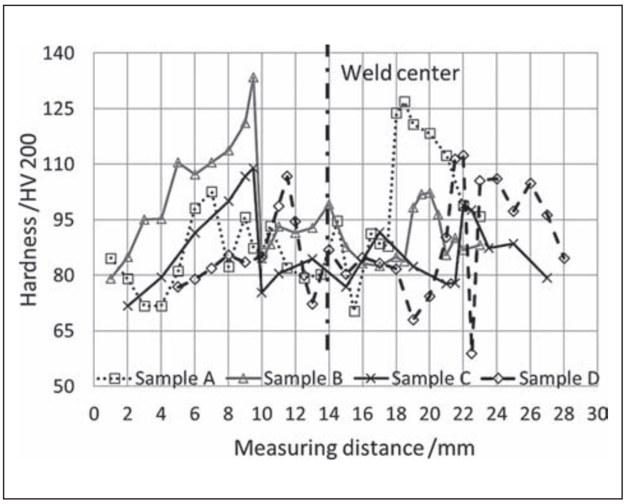

Figure 5 Vickers hardness measured across weld apices.

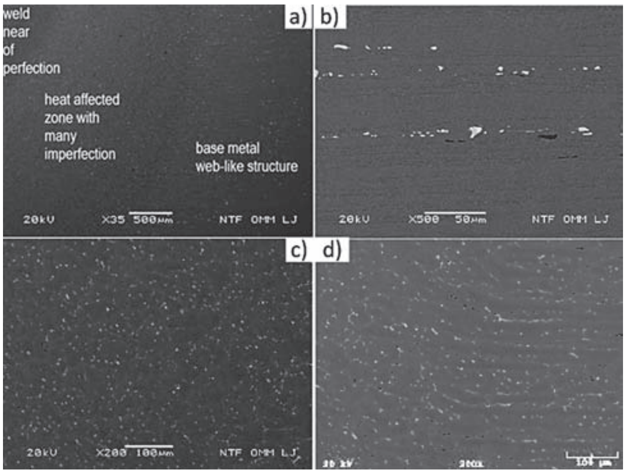

Figure 6 SEM images of a) complete weld, b) base metal, c) weld and d) HAZ.

Mg (~ 5 wt. %) and Al (~ 65 wt. % (Al_2CuMg).The black regions in the base metal have ~ 36 wt. % of Mg, ~ 40 wt. % of Si and ~ 15 wt. % of Al.

CONCLUSIONS

The following conclusions can be summarized:

– The optimal preheating and interpass temperature is 200 °C. The TIG welding should be done with the energy input from 2 – 6 kJ/mm in the way that fast cooling rates are achieved to avoid solidification cracking.
– The proper filler wire composition must be used to avoid cracking. The tensile strength of the weld will be smaller than base metal but equal to the filler metal.
– The workpiece should be cooled during welding to avoid overaging of base metal.

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Note: The responsible translator for English language is mag. Katja Hrovat, prof.