Mechanical Behaviour of MAG Pulsed Welded Joints from 6082 T6 Aluminium Alloy

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Abstract. One of the difficulties encountered by aluminium alloys fusion welding consist in reducing of the mechanical resistance characteristics of the weld seam and of the heat-affected zone (HAZ) compared to those of the base metal. The paper investigates the microstructural and mechanical properties changes of pulsed MAG welded joints made from the 6082-T6 alloy delivered in the form of 5 mm thick sheets. The dissolving phenomena of the hardenable phases in the sub-zones near the molten metal bath and the overaging of alloy in HAZ sub-zones at temperatures lower than those of precipitates redissolving, justifies the decrease of the mechanical resistance in the HAZ zone.

1. Introduction

Due to attractive usage properties obtained by heat treatments and reduced specific mass, Al-Mg-Si alloys have a growing expansion for structural applications and for the automotive industry [1],[2]. Although they have relatively low mechanical properties compared to steels, they are characterized by an excellent specific strength (Rm/ρ). Therefore, they are widely used in the aerospace and automotive industry. The most common aluminium alloys are: Al-Cu, Al-Si, Al-Mg, Al-Cu-Mg, Al-Cu-Mg-Si, Al-Mg-Si, and Al-Zn-Mg-Cu. In state of equilibrium, these alloys form a poorly alloyed solid solution and intermetallic phases CuAl2 (phase θ), Mg2Si, Al2CuMg (phase S), Al2CuMg4 (phase T), Al3Mg2, Al3Mg2Zn3 (phase T) etc. [3],[4].

A series of these alloys can be hardened by applying solution treatment followed by natural or artificial aging. The hardening ability is related to the variation in the solubility of the components (Mg, Si, etc.) in Al, depending on the temperature. Heating leads to the dissolution of excess phases and to the formation of an over saturated solid solution after solution treatment. The aging process is accompanied by the separation of the hardenable phases. The nature, shape, size, and distribution of the precipitated phases has a strong influence on growth of the ultimate tensile strength of Al-Mg-Si alloys. One of the difficulties encountered in the use of welded structures in these alloys is the overall reduction in the mechanical properties of the welded joint areas compared to the base material. This is due to the lower mechanical strength of the weld seam and the deterioration of the initial structure of the HAZ under the thermal welding cycles. Other papers [4], [5] highlight the microstructural stability of the 6082 - T6 alloy and the mechanical strength losses in welded seam and HAZ. Studies related to the effects of the heat of welding on precipitation phenomena and liquation cracking, which are responsible for the worsening of the mechanical properties of welded joints, are incompletely analysed [4],[6],[7].
2. Examined material and working procedure

Aluminium alloy, 6082 - T6 (AlSi1MgMn according to EN 573), delivered in the form of 5 mm thick sheets, was solution treated at 535 ± 5 °C/25 min./water followed by artificial aging, 175 ± 10 °C for 8 h/air.

The nominal chemical composition of the alloy sheets used to make the full penetrated butt welded joint is: Si = 1.18 %, Fe = 0.39 %, Cu = 0.065 %, Mn = 0.70 %, Mg = 0.80 %, Cr = 0.10 %, Ni = 0.015 %, Zn = 0.044 %, Ti = 0.011 %, Ga = 0.01 %, V = 0.023 %, Al = Rest.

As filler material was selected the electrode wire AlSi 5 (Alloy 4043) according to ISO 18273 and EN 573 – 3 having a diameter of 1.2 mm, which has the following chemical composition prescriptions: Si = 4.5 – 6.0 %, Fe ≤ 0.8 %, Cu ≤ 0.30 %, Mn ≤ 0.05 %, Mg ≤ 0.05 %, Zn ≤ 0.10 %, Ti ≤ 0.20 %, Be ≤ 0.0003 %, Al = Rest.

The references [1], [3], [5] recommend using this wire to obtain a molten area without cracks.

As shielding gas was used Argon 4.8 (purity ≥ 99.998%), Linde, with a flow rate of Q = 14 - 15 l/min.

The welding was made in a horizontal position, the position PA/SR EN ISO 6943, the welding direction being to the left with a 85° electrode wire inclination. The joint preparation and positioning of the components is shown in Figure 1.

![Figure 1. Geometry of the butt welded joint.](image)

The welded joints were made in one pass with the following welding technological parameters:

- Wire feed speed: 6.2 m/min.
- Welding medium current: ≈ 130 A
- Arc voltage: 23 V (ΔUa = 0)
- Pulse current: 220 A
- Pulse time: 2 ms
- Background current: 64 A
- Pulse frequency: 210 Hz
- Slope time: 9
- Self-regulating coefficients : kₐ = 36 %; kᵢ = 0 %
- Welding speed: 25 cm/min

The used welding equipment (ESAB ARISTO LUD 450 W) allows a synergic control of process parameters. Their determination was made by properly selecting the wire feed speed, \( v_w = 6.2 \) m/min., Fig.2. In Fig. 3, 4 and 5 it is presented the recording of pulse current welding parameters under the conditions described above.
Figure 2. Setting of the wire speed feed.

Figure 3. Record of the pulse parameters.

Figure 4. Record of pulse frequency.

Figure 5. Measured value of arc voltage.

The corresponding value of the arc voltage for these pulse current conditions is shown in Fig.5. The obtained welded joints were performed to tensile testing, Vickers microhardness and metallographic investigations.

3. Evaluation of experimental results

3.1 Macrography of welded joints

For the examination of the overall structure and highlight the heterogeneities occurred in welded joints, samples with transverse faces (normal to the longitudinal welding axis), in accordance with standard techniques, were taken and prepared.

The macroscopic image of a cross section through a welded joint is shown in Fig.6.
Although the welding operation provides the continuity of the material, the welding area does not have a homogeneous structure. As a result of high-speed heating, melting of the filler material and a small portion of the base material occurs, and subsequent cooling in the molten zone causes a series of structural transformations. Thereby, the liquid of the molten zone first reaches the solidification temperature in the areas in contact with the edges of the weld, where the solid grains of the two welding components are located. Consequently, the solid begins to grow from these grains in a columnar manner. The development of crystalline grains in the molten area from pre-existing grains is called epitaxial growth. The appearance of the outer surface of the weld is shown in fig.7.

It is noted that there are no surface defects such as cracks and cap undercuts and it’s looks like there is a good moistening of deposits to the base metal. The correct positioning of the electrode wire in the joint at the execution of a single pass is evidenced by the symmetry of the joint and a corresponding excess of the weld metal height. The selected filler material led to the following chemical composition for the deposited metal: Si = 4.95 %, Fe = 0.15 %, Cu = 0.010 %, Mn = 0.0016 %, Mg = 0.0008 %, Zn = 0.002 %, Ti = 0.010 %, Al = Rest.

3.2 Micrography of welded joints

Figures 8…10 show some microstructural images of the characteristic areas of the welded joints made with parameters established by the experimental tests. The chemical reagent used etching has the following chemical composition: 1 ml of 40%HF + 1.5 ml of concentrated HCl + 2.5 ml of concentrated HNO₃ + 95% of H₂O₂.

Crystallization of the molten metal bath is initiated by the precipitation of relatively large grains of solid solution with aluminium base, α, having a dendritic character, after which, upon reaching the eutectic transformation line, starts the formation of mechanical mixtures of solid solutions with aluminium base and intermetallic phases intergranularly arranged. The further decrease of the temperature to that of the room causes separation from the solid solution α of secondary phases distributed inside and on the limits of the crystalline grains (Fig. 8).
The bonding zone of the metal deposited with the base metal is achieved through a very narrow range of fine grains of solid solution with intermetallic phase particles having a punctual appearance (Fig. 9).

The base metal microstructure consists of a matrix of $\alpha$ solid solution and secondary phase particles with a hardening role (Fig.10).

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**Figure 8.** Microstructure of the welded bead (x 100).

**Figure 9.** Base metal microstructure (x100).

**Figure 10.** Microstructure of the interface welding - base metal (x100).
3.3 Static traction tests

Tensile testing was performed on samples taken from welded joints as well as samples taken from the base metal. The results are centralized in Table 1 and they highlight the following aspects:

- A decrease in ultimate tensile strength from approx. 328 N/mm², characteristic of the base metal, at ca. 202 N / mm², characteristic of the welded samples.
- A reduction in elongation at break from approx. 16% (unwelded samples), at ca. 9.8% (welded samples).
- At all tested samples the rupture occurred at the interface between weld and heat-affected area (HAZ) or in weld.

The data obtained demonstrates that the welding process eliminates the effects of the heat treatment applied to the base metal through structural changes in the weld and HAZ. The coarse microstructure resulted from primary and secondary crystallization along with the formation of light fusible eutectic mechanical mixtures and excess phase precipitation justifies the decrease of the mechanical characteristics of the welded joints.

| No. | Source            | Rm, N/mm² | A5, % | Location of rupture |
|-----|-------------------|-----------|-------|---------------------|
| 1   | Base Material, BS | 329       | 18,5  | -                   |
| 2   | BS                | 327       | 14,5  | -                   |
| 3   | BS                | 328       | 16,0  | -                   |
| 4   | Welded Joint, WJ  | 200       | 9,6   | HAZ                 |
| 5   | WJ                | 202       | 9,8   | HAZ                 |
| 6   | WJ                | 201       | 9,8   | HAZ                 |
| 7   | WJ                | 204       | 10,2  | WELD                |
| 8   | WJ                | 200       | 9,6   | HAZ                 |

3.4 Vickers microhardness tests

Since hardness is the mechanical characteristic most sensitive to the structural changes that occurred during the welding process, cross-faced samples subjected to such tests were taken from the joints. Based on the results obtained, the graph of Fig. 11 was drawn. The main observations from this graph are:

- The hardness of the base metal has values of 100-118 HV, corresponding to the applied heat treatment.
- The welded seam, without heat treatment after the welding operation, has values of 66-75 HV.
- At a distance of about 2 mm from the welded joint axis, the lowest hardness values (58-61 HV) occur due to the over-aging of the alloy in the strip of material that was heated to a temperature lower than redissolving the secondary phases in the solid solution.

![Figure 11. The hardness gradient curve on the cross section of the welded joint.](image-url)
4. Conclusions
For used experimental conditions, the ultimate tensile strength of welded joints decreases with approx. 39% and elongation at break with approx. 40% compared to the base metal nominal values. In the heat affected zone, at a distance of approx. 2 mm from the joint axis there is a pronounced softening of the material (HV hardness decreases with about 45%) as a result of the over-age phenomenon induced by the thermal welding cycle.

5. References
[1] Malin V 1995 Welding Journal 74 (9) 305
[2] Miyazaki M, Nishio K, Katoh M, Mukae S and Kerr W 1990 Welding Journal 69 (9) 362
[3] Kluken AO and Bjoerneklett B 1997 Welding Journal 76 (2) 39
[4] Huang Cand Kou S 2004 Welding Journal 83 111
[5] Singh G, Kumar S and Singh A 2013 Int. J. Res. Mech. Eng. Technol. 3(2) 143
[6] Utu ID, Mitelea I, Urlan SD, Craciunescu CM 2016 Materials 9 606
[7] Mitelea I, Utu ID, Urlan SD, Craciunescu CM 2017 Mat.-wiss. u. Werkstofftech. 2017 48 1040