Fatigue Behaviour of Aluminium Lap Joints Produced by Laser Beam and Friction Stir Welding

L. Reis\textsuperscript{a}, V. Infante\textsuperscript{a}, M. de Freitas\textsuperscript{a}, F.F. Duarte\textsuperscript{b}, P.M.G. Moreira\textsuperscript{c}, P.M.S.T. de Castro\textsuperscript{c}

\textsuperscript{a}Instituto Superior Técnico, ICEMS, Universidade de Lisboa, Av. Rovisco Pais, 1049-001 Lisbon, Portugal
\textsuperscript{b}INEGI, Campus da FEUP, Rua Dr. Roberto Frias, 400 4200-465 Porto, Portugal
\textsuperscript{c}FEUP, Rua Dr. Roberto Frias 4200-465 Porto, Portugal

Abstract

Railways passenger transportation seeks weight reductions as a means to reinforce its sustainability. The use of aluminium alloys for the vehicle car bodies is a possible alternative, but difficulties are foreseen concerning the fatigue behaviour of the connection of heavy equipment to the underside of the structural floor panels.

This study was conducted within the LighTRAIN project, involving two universities, two industrial companies and one research centre, that aims to improve the life cycle of the underframe of a passenger railway car, with a novel light-weighted solution.

The main objective of present work was to study the fatigue behaviour of 2.0 mm thick aluminium AA6082-T6 welded joints based on two different welding processes: Friction Stir Welding (FSW) manufactured at Instituto Superior Tecnico (IST) and Laser Beam Welding (LBW) manufactured at QUANTAL.

The paper presents the experimental results obtained in tensile and fatigue tests of welded lap joints. The specimen types include the loading condition applied to the specimen in a transverse or longitudinal direction to the weld bead. The fatigue tests were carried out under a constant amplitude loading with a stress ratio \(R=0.1\) for a wide range of applied stress.

The mechanical behaviour, including microstructural, microhardness, tensile and fatigue tests results of AA6082 2.0 mm thick FSW welded joints are compared with LBW welded joints in the framework of the aforementioned QREN project. Moreover, details of fracture surfaces obtained with optical microscopy are also presented.

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* Corresponding author. Tel.: 00351966415585
E-mail address: luis.g.reis@ist.utl.pt
1. Introduction

This study was conducted within the LighTRAIN project, involving two universities (IST-Portugal, FEUP-Portugal), two industrial companies (ALSTOM-Portugal, QUANTAL-Portugal) and one research centre (ISQ-Portugal), that aims to improve the life cycle costs of the aluminum underframe of a passenger railway car, with a novel light-weighted solution. Aluminum alloys market for railway industries is still expanding due to their unique characteristics, such as, light weight, high strength, high toughness, versatility of extruding in diverse shapes, excellent corrosion resistance and recycling capabilities [1,2]. It is known that mechanical fastening suffers from difficulty of automation, problems with corrosion and the requirement for sealants. Therefore the potential for the use of Friction Stir Welding (FSW) and Laser Beam Welding (LBW) is extremely large. FSW is a purely mechanical process and because it takes place in the solid phase, all the problems related to the solidification of a melted material are avoided [3,4]. Several recent comprehensive reviews such as references [5-9] present the state of the art of FSW. Laser Beam Welding (LBW) is a fusion joining process that relies on the radiant energy produced to heat and melt the base materials to be joined. In this study CO₂ laser was used which, in general, present efficiencies around 20%, very good beam quality, high precision and welding speed, and high mechanical proprieties of the weld [10]. Many other fabrication technologies are relevant, as laser and laser hybrid welding, or adhesive technologies as in the case of the use of honeycomb cores [11-13]. This paper presents microstructural analysis, microhardness, tensile and fatigue tests results of welded lap joints obtained by FSW and LBW in the framework of the aforementioned QREN project.

2. Material and Experimental Procedure

2.1. Material characterization

In this research, the material used was an aluminum alloy AA 6082-T6 through sheets of 2.0 mm thickness. Tables 1 presents the mechanical properties of this alloy and Fig. 1 presents the specimen’s geometry used in fatigue experimental tests, with a width gauge of 15.0 mm.

Table 1. Mechanical properties of AA 6082-T6, [14].

<table>
<thead>
<tr>
<th>Yield strength, σ₀ (MPa)</th>
<th>Ultimate Tensile strength, σₜₚ (MPa)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>310</td>
<td>340</td>
<td>11</td>
</tr>
</tbody>
</table>

Fig. 1. Specimen's geometry (mm).

2.2. Welded procedure and parameters

In the present study, FSW lap joints were produced at the Instituto Superior Técnico, and LBW lap joints at QUANTAL, Portugal. Fig. 2 shows the conventional tool used in this study composed by a: spiral shoulder and a conical pin.

Fig. 2. (a) Spiral shoulder; (b) Conical pin.
All the welds were done perpendicular to the rolling direction at room temperature. The FSW equipment used was an ESAB Legio FSW 3UL. Plunge and dwell periods were performed under vertical position control and weld period was carried out under vertical downward force control.

2.3. Experimental tests

To characterize the welded lap joints, several mechanical tests were selected and performed: non-destructive tests through microstructure examination and hardness measurements; tensile, bending and fatigue tests using a servo-hydraulic test machine, with 100 kN load capacity, and according to ASTM-E8-M [15] and ASME code [16]. The load in the tensile tests was perpendicular to the weld line, using a 1.0 mm/min cross-head speed, to obtain the yield stress and the ultimate tensile strength. A 3-point configuration was used in the bending tests, with a span of 120 mm. Fatigue tests were performed under constant amplitude load, (R=0.1) and a frequency range of 10-15 Hz.

3. Results and Discussion

3.1. Microstructural Analysis

Fig. 3 shows the optical microstructures obtained in FSW lap-joined component. Scratch-like lines are observed in the welded zone but identified as interfaces. Reaction layer and second phase were not identified at the interface because the temperature and time at that temperature were not sufficient for the diffusion due to the solid-state bonding of FSW.

Fig. 3. Optical microstructures obtained in FSW lap-joints.

3.2. Fatigue Test Results

The S-N experimental data are plotted in Fig. 4. The conventional fatigue limit considered for this study was taken as 5×10⁶ cycles. Comparisons were established between the FSW and LBW joints so that correct and consistent conclusions could be drawn.

It can be seen that LBW specimens present the better fatigue performance. For the FSW specimens the crack starting point was located in the existing “hook” of the retreating side of the weld line. Crack propagation occurs in few life cycles, which ends up creating identical crack appearance between all specimens.
4. Conclusions

Fatigue results of lap joints of Al alloy AA6082-T6 loaded perpendicular to the weld line show that the LBW joints have higher fatigue strength in comparison with the FSW joints. The LBW process is better especially for lower loads and allows an increase in strength in the high cycle fatigue regime. Tests performed on FSW and LBW show low fatigue strength, which, for the FS welded lap-joints, is associated with the typical ‘hook’ defect inherent to this geometry.

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