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Effect of geometrical parameters on Friction Stir Welding of AA 5083-H111 T-joints

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Abstract

The aim of this research is to study the effect of three different tool geometries and two joint geometries on quality of AA 5083-H111 T-welds done using the friction stir welding process (FSW). All the tools have concave shoulder with different pin geometries: tapered and threaded, quadrangular pyramidal and progressive pin, part threaded cylindrical and part pyramidal. T-lap and T-butt joints configurations have been studied. Tunnel and kissing-bond type defects have been found in joints produced with a pyramidal pin tool, while welds produced with the tapered pin tool only show presence of oxide lines. Sound welds were produced with the progressive tool. No significant change in hardness has been observed in all combinations of tool and joint geometry. The tensile strength efficiency in joints welded with the progressive pin tool has been found to be 100%. The fatigue results(R=0) show a higher fatigue strength of FSW T-joints than T-joints welded by conventional process as Metal Inert Gas (MIG).

Keywords: Friction stir welding; AA 5083-H111; T-joints

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1. Introduction

The T joints in aluminium alloys are widely used in the industry in the transport sector, for example in aircraft, shipbuilding and land transport vehicles. The welding of T-joints in these alloys by MIG process has many difficulties such as high porosity, hot cracking and large distortion these defects behaviour. Friction Stir Welding

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(FSW) is an interesting alternative to conventional technologies that removes the first two types of defects, because it is a solid state welding process, and allows significant reduction of distortion. The realization of these welds by FSW however presents several difficulties. Tunnel defects are current in the advancing side of the weld close the fillet radius between the skin and the stringer due to poor material flow, Hou et al (2014). These authors reported that the reduction of the welding speed relative to the tool rotation speed reduces the appearance and size of the defects. Another common defect in this type of joint is the kissing bond induced by inappropriate interaction between the flux induced by the base material and the flux induced by the tool pin. This defect extends over a line of oxides which is diagonally oriented from the fillet radius to the original interface of the plates. The extension of the defect increases with the welding speed, forming a preferential tear area in tensile test Cui et al. (2013). Besides these welding parameters other factors such as the geometry of the tool and the joint geometry also seem to have large influence on the formation of defects, Tavares et al. (2010). All studies found focus their research mostly in the 6000 series alloys, Fratini et al. (2009).No articles were found in T-joints in AA 5083, perhaps because it is a more difficult to induce hot plastic flow in this alloy, Leitão et al. (2012).

Although no articles were found in T-joints in AA 5083, is possible to found several studies in butt joints welded by FSW. Kumagai et al. (1999) compared tensile properties of 5083-H112, butt joints welded by FSW to metal inert gas (MIG) welding. They exhibit only slight differences in yield and tensile strength for the three material conditions. The friction stir and base material presented a similar elongation, yield stress and tensile strength but higher than MIG welds. Zhou et al. (2005) concluded that the fatigue life of FS welds is 9–12 times longer than that of MIG-pulse welds under the stress ratio R=0.1, for 5083 aluminum alloy. Commonly, the friction stir butt welds of AA5083 present a higher mechanical behaviour than MIG butt welds.

The main goal of this research is analyse the tool geometry and T-joint effect on FSW to produce T-joints welds by FSW with excellent quality without defects creating a weld toe fillet avoid tick reduction, comparing their mechanical behaviour with other welds made with conventional technique, namely MIG process, in AA 5083-H111.

2. Experimental details

2.1. Base material

The welds were done in plates of AA 5083-H111 of 3 mm thick. The main characteristic of AA 5083-H111 is mechanic work type and is not heat-treatable, being plastic deformation the main hardening mechanics in these alloys. The H111 condition was obtained with some work hardening by shaping processes but less than required for a H11. The Table 1 and Table 2 show chemical composition and main mechanical properties, respectively.

Table 1. Chemical composition of the 5083 aluminium alloy (wt %)

Si	Mg	Mn	Fe	Cr	Cu	Zn	Ti
<0.4	4.5	1.0	0.4	0.05	0.1	0.25	0.15

Table 2. Mechanical proprieties of the 5083-H111 aluminium alloy

Tensile strength, σ_{uts} [MPa]	320
Yield strength, σ_{ys} [MPa]	158
Elongation, ε_r [%]	23.7
Hardness, $Hv_{0.2}$	80

2.2. T-joints and welding parameters

Two different T-joints were studied in this work, T-lap and T-butt joint. The Fig. 1 shows a schematic view of each one, respectively.

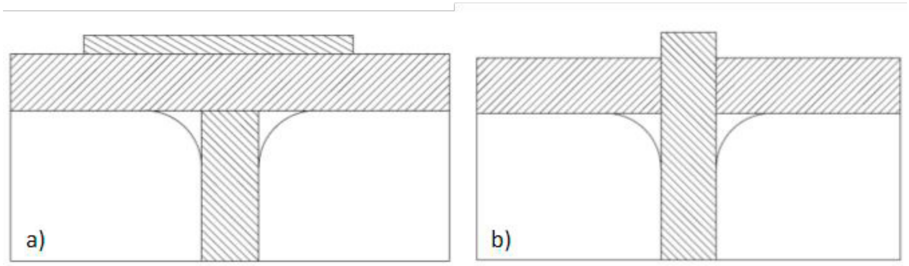

Fig. 1. (a) T-lap; (b) T-joint.

Three different tools were used, with the same shoulder but different pin, respectively pyramidal pin, tapered threaded pin and progressive pin, as shown in Fig. 2 in images a), b) and c). The tool with tapered and threaded pin was constructed in order to improve the vertical material flow while the tool with progressive pin was designed with the aim of approaching the material flow to the fillet zones. The tool rotation (660 – 1140 rpm) and traverse (60 mm/min) speeds were chosen based on previous tests. The process were done in a Cincinnati milling machine and in position control, the tool plunge depth was set tentatively. In the Fig. 2 can be observe the work piece clamped and prepare to FSW of T-butt joint.

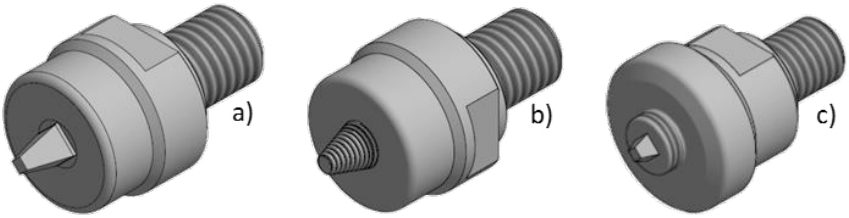

Fig. 2. Tool geometries tested: a) Pyramidal pin; b) Tapered and threaded pin; c) Progressive pin.

2.3. Experimental test procedure

After welding by FSW, the aluminium alloy plates were cut in slices of 18x160x3 mm, perpendicularly to the welding direction (transverse orientation), creating specimens to perform the fatigue and tensile test.

According to standard metallographic practice, etched with modified Poulton´s reagent and using optical microscopy the metallographic analysis was performed on 15x80x3 mm samples (cut perpendicularly to the Friction Stir weld) , in order to identify the weld microstructures.

In order to characterise the welded joint, Vickers hardness profiles were obtained using a Struers Type Duramin microhardness tester, with an indentation load of 200 gf during 15 s, according to the ASTM E 348 standard. The hardness profiles were obtained at the welded joint cross-sections, along a longitudinal line at 0.5 mm from the plate surface in samples identical to the ones used in the metallographic analysis. The measurements were performed at each 0.5 mm, along a distance from the weld bead centre until hardness stabilization.

Tensile test and pull out test were carried out at room temperature in an Instron mechanical tensile/compression testing machine, model 4206, using a testing speed of 2 mm/min and two different extensometers, a conventional and optical one (Aramis), respectively. The fatigue tests were carried out using an Instron hydraulic machine, loading the specimens perpendicularly to the to the weld direction (i.e. in the parent material rolling direction), applying a sinusoidal load wave with a frequency within the range 20-30 Hz, under constant amplitude loading for stress ratio R=0. The results of fatigue tests will be presented as S-N curves.

3. Results and discussion

3.1. Metallographic analysis

All welds showed excellent appearance, free of skin thickness reduction, however welds performed with pyramidal pin tool had cavities, as shown in Fig. 3a) for a T-lap joint. These cavities tend to decrease its size with increasing plunge depth of the tool, but never disappear. In the welding carried out with the tapered and threaded pin tool on the T-lap configuration (LC series) does not occur cavities, but there was the appearance of a line of oxides on the retreating side, as illustrated in Fig. 3b). It was found that the length and thickness of the line of oxides increase with increasing tool rotational speed. Welds made with the tool with progressive pin and T-butt joints (BPP series) using low speed of rotation and advance (660 rpm and 60 mm / min) did not exhibit any defects, even oxide lines, as shown in Fig .3c). The average grain size in the nugget area of the welds is about 8 μm and less influenced by the geometry of the tool, while the grain size of the base material is of 14.9 μm.

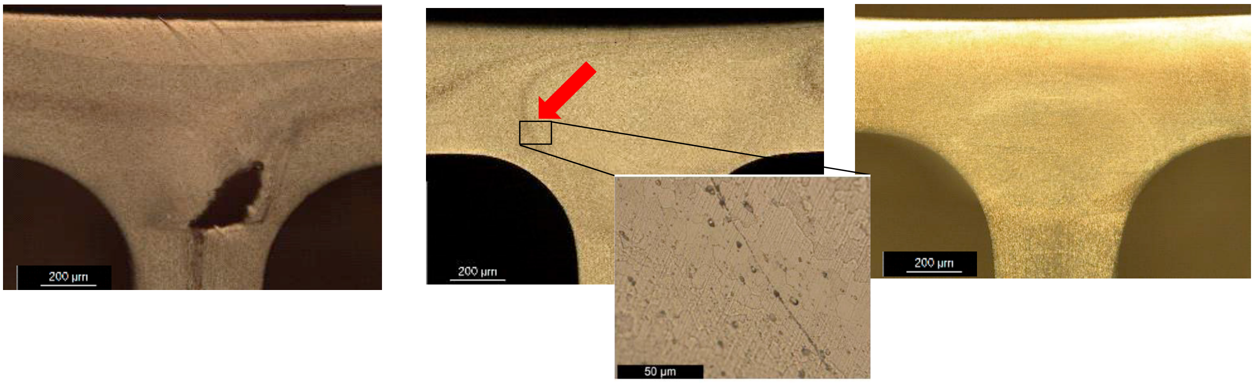

Fig. 3. Morphology of welds done with: a) Pyramidal pin on T-lap joint; b) Tapered and threaded pin on T-lap joint (LC) ; c) Progressive pin on T-butt joint (BPP).

3.2. Hardness

In the majority of welds made and regardless of the geometry of the tool or the remaining welding parameters used, it was found that there was no significant hardness variation in the weld zones, as shown in Fig. 4 for T-lap welds done with tapered and threaded pin (LC) and T-butt welds done with progressive pin (BPP). This result is understandable because the base material is in a soft state

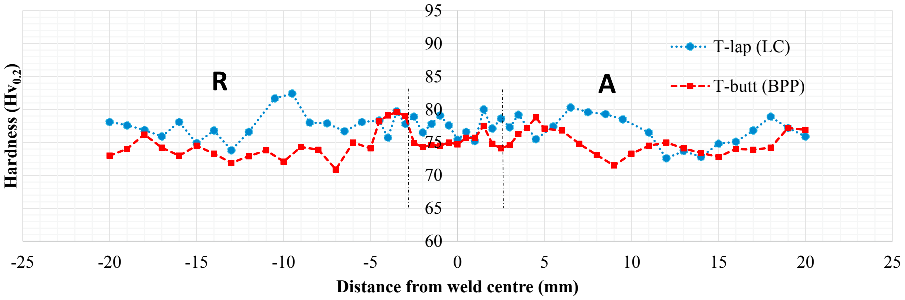

Fig. 4. Variation in hardness through the skin of welds carried out with different tools and joint geometries. LC – T-Lap joint using tool with tapered and threaded pin; BPP – T-Butt joint using tool with progressive pin.

3.3. Tensile and pull out tests

Pull-out test specimens with oxides line can show tensile efficiency as low as 63% while welds free of oxides displayed efficiency of 100%. The failure of specimens is precisely in the line of oxides in the first case and in the base material in the second, as shown respectively in figures 5a) and 5b), by the fields of strains obtained with an optical extensometer.

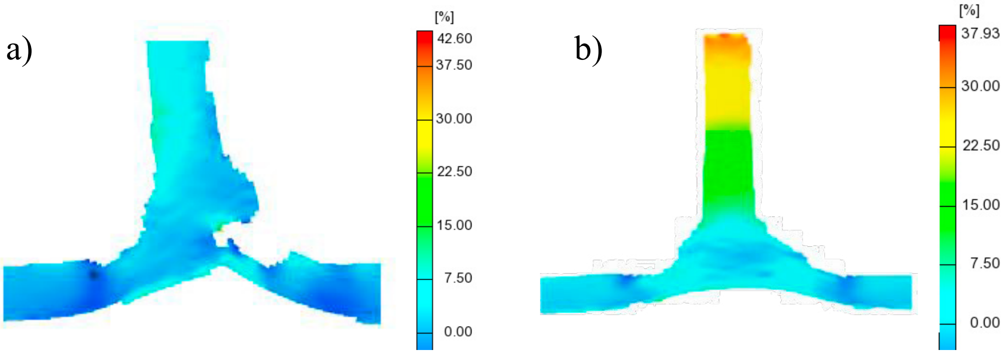

Fig. 5. Strain maps of specimens: a) LC-With oxides line; b) BPP- No Line oxides.

Fig. 6 presents the monotonic stress-strain curves for BPP and LC series. It is evident the difference between BPP and LC series concerning the maximum strain and ultimate tensile stress (UTS). The BPP series present about 58% of maximum strain and the LC series only 15 %. The UTS of the BPP series of about 299 MPa is significantly higher than the UTS value of 225 MPa for the LC series. The presence of oxides line has a decisive effect on the tensile strength of the welds, either in tests performed on the skin or in the pull-out tests.

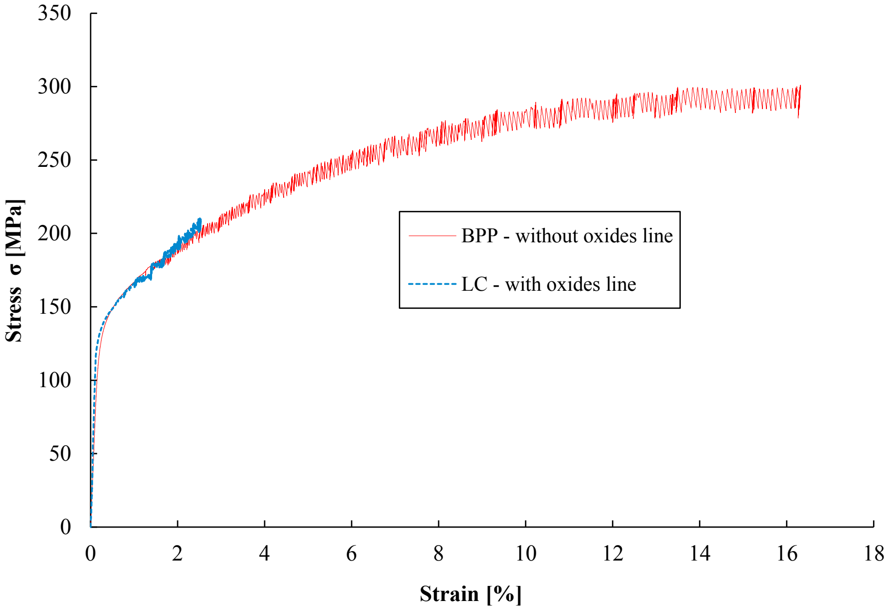

Fig. 6. Monotonic stress–strain curves.

3.4. Fatigue strength

The fatigue results are plotted in Fig. 7 with the nominal stress range $\Delta\sigma$ against the number of cycles to failure. A high data scatter is observed for LC series due to the presence of the oxides line. Both BPP and LC series present a higher fatigue strength than MIG series. BPP series is close to the base material curve and consequently is the T-welded series with the higher fatigue strength.

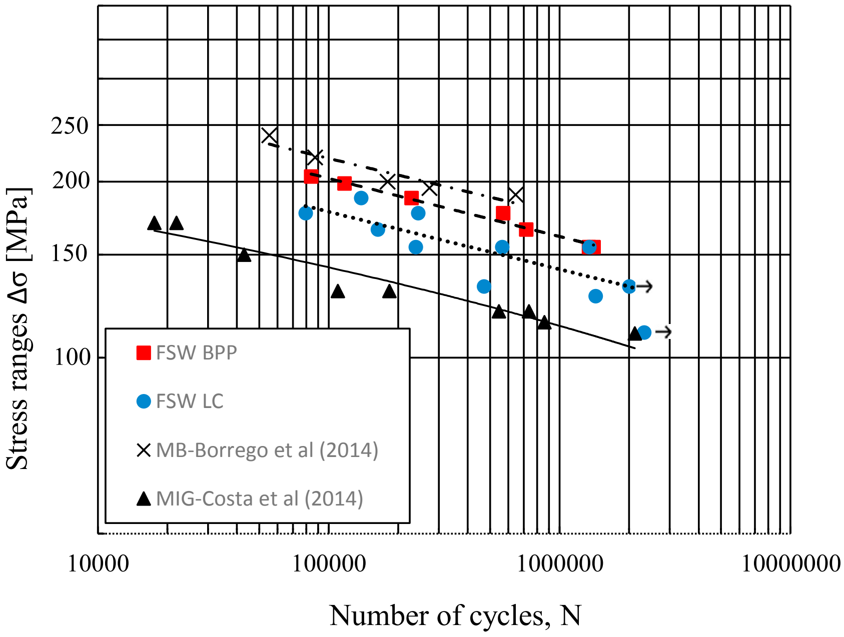

Fig. 7. S-N curves.

4. Conclusions

The following conclusions can be drawn from this research:

- Is possible to do T-joints with fillet radius by FSW without thickness reduction of the skin or other defects;
- All welds showed excellent appearance, except welds performed with pyramidal pin tool, which had cavities;
- Grain refinement in weld zones (14.9 µm to 8 µm);
- No significant hardness variation in the weld zones;
- The oxide lines disappeared using the tool with progressive pin in T-butt joint;
- The oxide lines decrease the T-joints mechanical behaviour;
- All FSW series presented higher fatigue strength than T-joints welded by MIG.

Acknowledgements

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