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EXPERIMENTAL BASED DETERMINATION AND ANALYSIS OF MECHANICAL PROPERTIES OF AA 3003 ALLOY WELDED WITH FRICTION STIR LAP WELDING PROCESS

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In recent years, friction stir welding (FSW) methods have been used to obtain good joints with mechanical and physical process properties. The development of FSW lap joint assembly will expand its use in ahigh number of industrial applications that can benefit from this technology. In this paper a study based on experimental methods were performed on FSW lap joints. The investigation includes the interface morphology and mechanical properties of the joint assembly. Experimental measurements were carried out on micro-hardness; tensile shear test, resulting material flow as well as the effect of flow variation on the obtained mechanical properties of FSW butt lap joints ofaluminium alloy AA3003. The study also presents the effects of different welding parameters on the lap joints assembly structure. It was found thatthe hardness in the welded region is significantly lower with respect to the base material.The fracture analysis shows the characteristics of ductile-brittle mixed fracture.

Keywords: friction stir welding, lap joint, aluminium AA3003, experimental measurements, parameters effects, tensile shear test, mechanical properties

1 INTRODUCTION

Friction stir welding (FSW) is a relatively new welding process that may have significant advantages compared to the fusion and other assembly processes. The FSW process allows the joining of conventionally non-fusion weldable alloys, reduced distortion and improved mechanical properties of weldable alloys joints due to the pure solid-state joining of metals [1]. In this process, the heat is originally derived from the friction between the welding tool (including the shoulder and the probe) and the welded material which causes the welded material to soften at a temperature less than its melting point [2]-[4]. FSW can also assemble various joint configurations, such as lap, butt and T-joints of which the lap joints are widely used and applied in vehicle and aircraft design and industrial assembly processes. One of the importance for friction stir lap welding (FSLW), however, is the greater diligence necessary in developing and optimizing tool designs and process parameters to break the surface oxide layer on two planar surfaces and mitigate the three main defects, i.e., kissing bonds, hooking, and top workpiece thinning [5].

Hakan Aydin et al [6], studied the effect of welding parameters (rotation speed and welding speed) on the mechanical properties of 3003-H12 aluminum alloy joints produced by friction stir welding where the weld strength increased with increasing the welding speed or decreasing the rotation speed. To produce the best weld quality these parameters have to be determined for each component and alloy.

The effectiveness of these parameters on the properties of friction stir welds as well as the realization of their influence on the properties of the weld are the subject of studies carried out by several researchers [7]-[10]and [11,12].

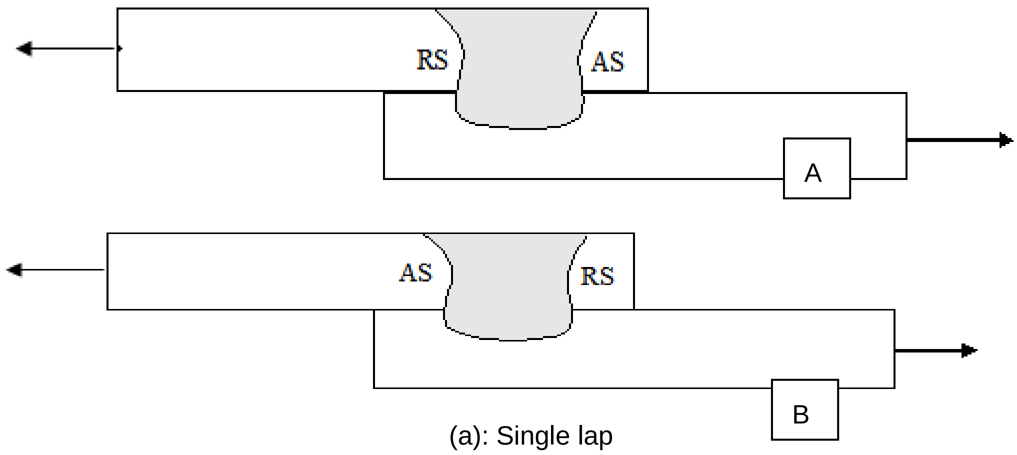
A great number of studies have been focused on the determine the microstructural and mechanical properties of the joints of heat treatable 3XXX aluminum alloys [13]– [15]. This last is the alloy which has been widely used purpose alloys for moderate-strength applications requiring good workability, such as stampings, spun and drawn parts and products, chemical equipment, storage tanks, fan blades, walk ways, flooring, and truck and trailer components [15].

The object of this paper is to develop and high mechanical properties for AA3003 during friction stirs lap welding. The effect of welding control parameters and tool design on process response was investigated.

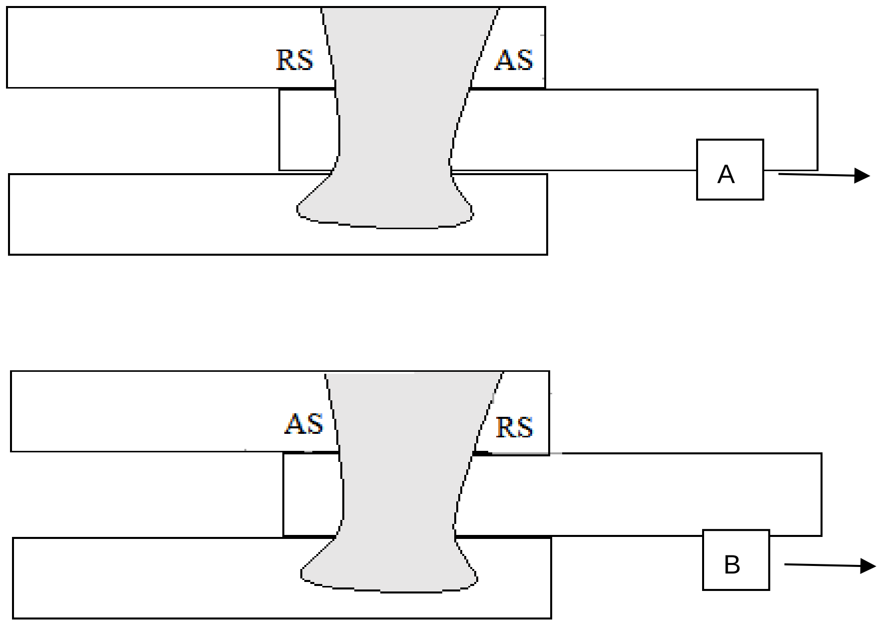
2 MATERIALS AND METHODS

The materials used were AA3003alloys of 2 mm thickness. Samples were cut according to the shape shown in the Fig. 1. The external sheets were welded parallel to the rolling direction while the central sheet was put in the long transverse direction for FSW process in order to limit potential effect of rolling texture. The chemical composition of the aluminum AA3003 sheet is presented in Table1 and the mechanical properties of the sheets are presented in Table 2. The tool used for the single overlap joint is made of steel type 42CrMo4 (Fig.2.a). The circular pin has 7 mm diameter with 3,95 mm in length and shoulder diameter of 14 mm. The mechanical properties are; Rm = 750/1300 MPa, A= 10-14 %, Re = 500/900 MPa and E = 210000 MPa.

The welds of double lap joint were made using a high-alloy steel (X210Cr12) mixing tool, with a tensile strength Rm=870 MPa (Fig.2.b), a threaded cylindrical pin (of 5 mm diameter and 5.60 mm in length) and 25 mm of shoulder diameter.



(a): Single lap



(b): Double lap

Fig. 1. Setups for Tensile strength testing.

Table 1. Chemical composition ofAA3003 aluminum alloy

Element	%
Al	96.7
Mn	1.3
Si	0.9
Fe	0.9
Cu	0.13
Ti	0.1
Zn	0.3

Table 2. Mechanical properties ofAA3003 aluminum alloy

Properties	Value	Unit
Rupture Strength	127	MPa
Ultimate Tensile Strength	160	MPa
Elongation	5.6	%
Microhardness	51	Hv
Yield Strength	110	MPa
Modulus of elasticity E	60	GPa

(a): Single lap (b) : Double lap joint

Fig. 2. Types of tools used for FSLW.

In this study, FSLW was conducted at selected rotation speeds of 1000, 1400 and 2000 rpm and selected travel speeds of 160, 200 and 250 mm/min.After the FSW welding process, the tensile test were carried out on an INSTRON tensile machine, controlled by the MTS software as shown in Fig.3 at a transverse speed of 2 mm / min.The hardness on the weld cross-section was measured point wise at speeds of 1400 rpm and 200 mm/min respectively in both forms of single and double lap joints with a load of 1000g and a dwell time of 10 s.

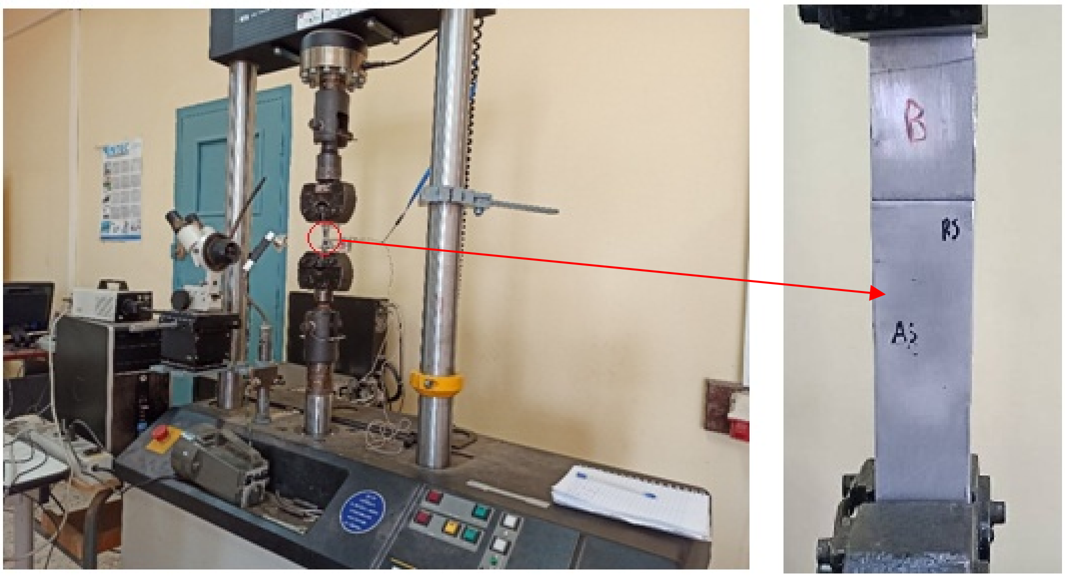


Fig. 3. INSTRON Testing machine and specimen configuration for tensile test

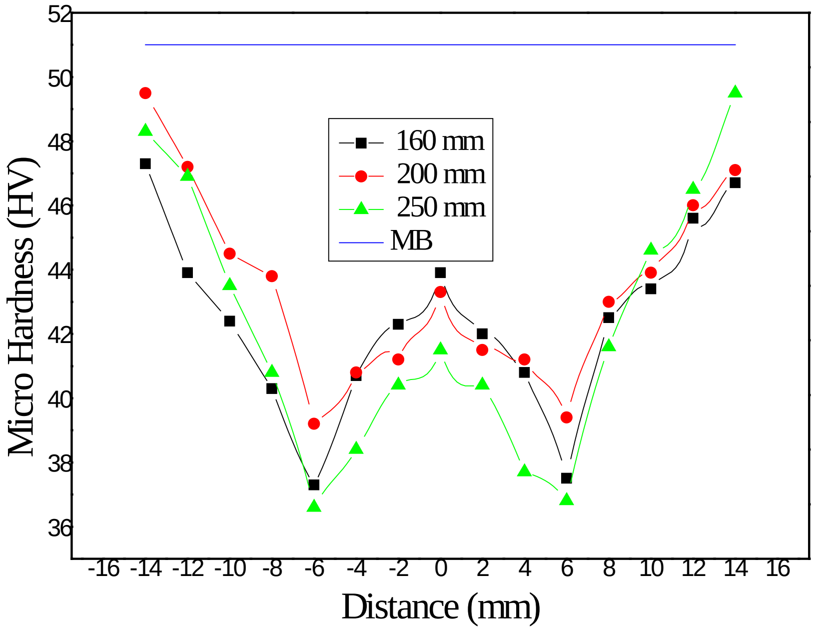
3 RESULTS AND DISCUSSION

3.1 Microhardness Measurements

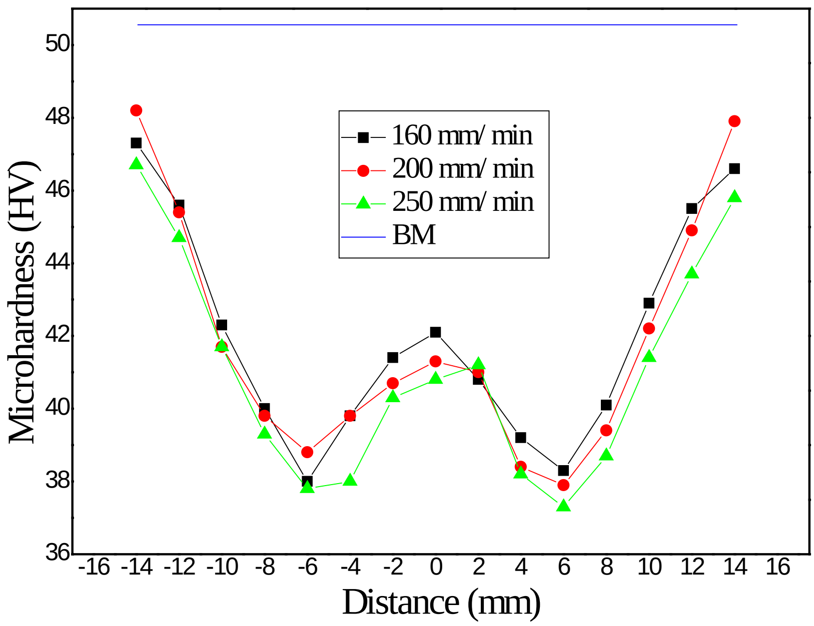
The Figure 4 shows the evolution of the hardness while varying the feed rate (160,200,250) mm/min and even the speed of rotation (1400 rpm), in both forms (single lap and double lap) on a SHIMADZU HMV-2000. In the hardness measurement, aload of 1000g is used for 10 seconds per point and distance between the two points was 2mm along 28mm in Vickers hardness (HV).

The value of the stiffness in areas HAZ, TMAZ and SZ decreases from the value in BM due to the decrease in the displacement density resulting from FSW. We notice from the Figure 4 that the value of the hardness decreases from the HAZ region in a direction TMAZ region in various measurements until it reaches a minimum value. Afterwards itrises in a direction SZ which is due to the recrystallization of the grains because of the welding process [16]. We also note a slight decrease in hardness value in the area SZ with an increase in welding speed [17].

The hardness in the welded region is significantly lower with respect to the base material (50 μHV for single lap, 48 μHV for double lap). The high temperature achieved during the FSW process can be considered as the major cause of this softening effect. Even though just a few microhardness values are reported for reasons of synthesis, It is possible to assert that the width of the softened region and the microhardness values recorded in the same region are influenced by the welding process parameters [18].



(a): Single lap

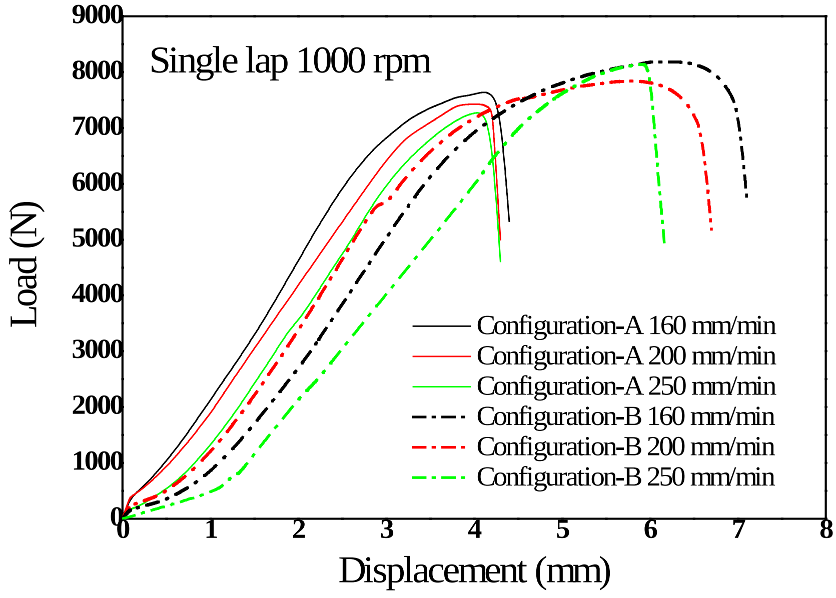


(b): Double lap

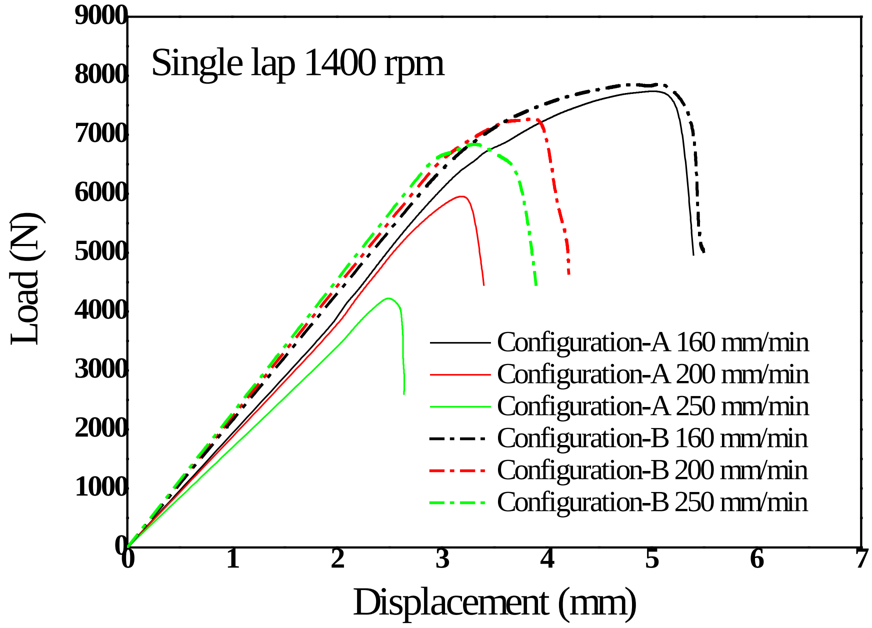
Fig.4. Hardness distribution profiles

3.2 Tensile strength test

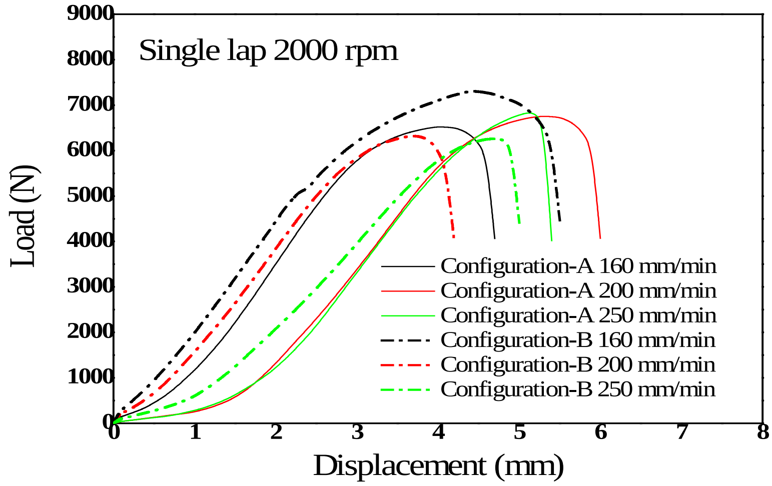
The measured tensile properties of the single and double lap in both configuration (A and B) are presented in Figure 5 and Figure6 respectively by using constant tool rotation speeds of 1000 rpm (Figurea), 1400 rpm (Figure b), 2000 rpm (Figure c). The tool displacement speeds are 160, 200 and 250 mm/min. In order to analyze the evolution of the mechanical properties with the welding parameters, an average value over several trials is calculated and used for the analysis.


Single lap 1000 rpm
Load (N)
Displacement (mm)
Configuration-A 160 mm/min
Configuration-A 200 mm/min
Configuration-A 250 mm/min
Configuration-B 160 mm/min
Configuration-B 200 mm/min
Configuration-B 250 mm/min

(a)

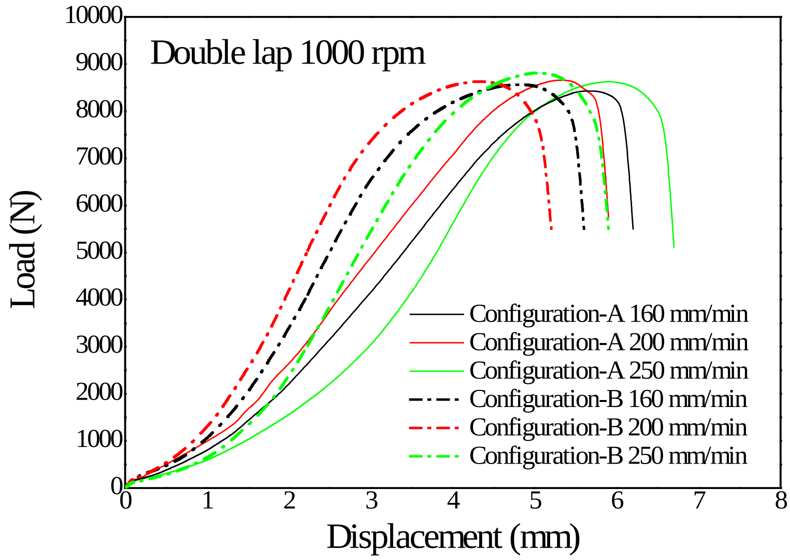

Single lap 1400 rpm
Load (N)
Displacement (mm)
Configuration-A 160 mm/min
Configuration-A 200 mm/min
Configuration-A 250 mm/min
Configuration-B 160 mm/min
Configuration-B 200 mm/min
Configuration-B 250 mm/min

(b)

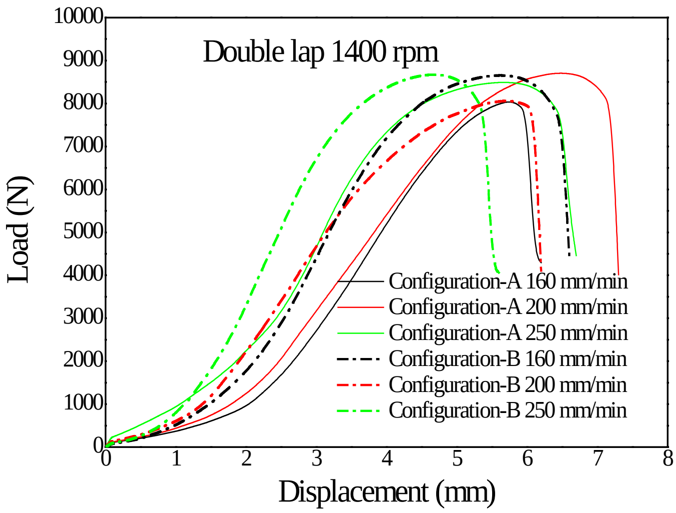


(c)

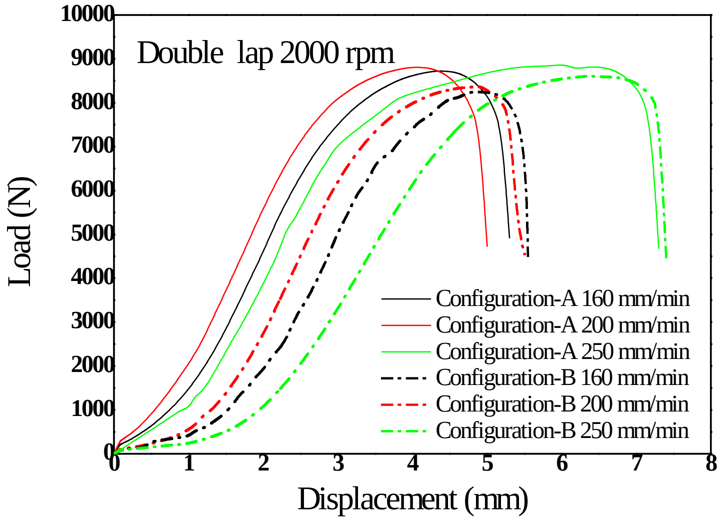
Fig.5. Effect of tool rotational speed on the mechanical behavior of the joint (single lap)



(a)



(b)



(c)

Fig.6. Effect of tool rotational speed on the mechanical behavior of the joint (double lap)

The results are presented with the same parameters in order to put into evidence the differences in mechanical resistance of both configurations (A and B). Figure 5 shows some representative curves, it is observed that the maximum load is obtained with the welding speed of 160 mm/min (configuration B) i.e where the joint advancing side (AS) supports the main principal load. It reaches a lower value for a welding speed of 250 mm/min and a rotational speed of 1400 rpm (Figure 5-b).

Moreover, the load-displacement plot shows that the joint obtained with a rotational speed of 1000 rpm has a higher displacement. Overall, for the configuration (B), the performance of the joint tensile -shear are excellent.

The same combination of parameters is illustrated in Figure 6 for the double lap joint. This clearly indicates that with the increase of the displacement speed for a constant regime the rupture strength decreases for the three cases as shown in (figures 6 a, 6.b et 6.c).

The maximum rupture strength of this type of joint has reached 9000N. From the plots of the figures, it can be observed that the double lap joint welds present better tensile mechanical properties than the single lap joint welds.

3.2.1 Failure modes

In the tensile shear tests, the friction stir welding present two failure modes [19].The first is shear fracture or interfacial fracture, which starts at the transition point and spreads toward the free edge of the tool pin hole, and the second is mixed-mode fracture. Thinning of the top sheet metal at the tool shoulder edge due to the shoulder cut also favors this failure mode. Mode III failures are associated with moderately higher shear strengths and larger fracture energies compared to Mode II [20]. For the tensile shear samples, the crack initiates in the tip of the hook and then propagates along it. In addition, as mentioned above, when the joint is subject to the external loading, the upper sheet bends upward and the lower sheet bends downward, which leads to the nugget rotation seen in Fig.7.

Fig.7. Shear specimen during the tensile test

The fracture was observed to occur predominantly in or near the interface of the SZ/TMAZ on theadvancing side (AS) of the top workpiece (Figure 8.a), where the severe stress concentration arises from the presence of the hooking defect caused the crack to propagate directly into the top workpiece.

A total separation of the two sheets is observed in the case of the double overlap joint (Figure 8.b).

(a) ：Single lap (b) : Double lap

Fig.8. Different modes of fracture

3.2.2 *Microstructure*

Fig. 9 shows the optical microstructures of the weld zone at tool rotational speed of 1000 rpm and welding speed of 160 mm/min. The HAZ had the highest grain size in contrast with the stir zone in which the finest grain size could be seen. Extended grains of the TMAZ can be seen at both advancing and retreating sides of the weld area [21].

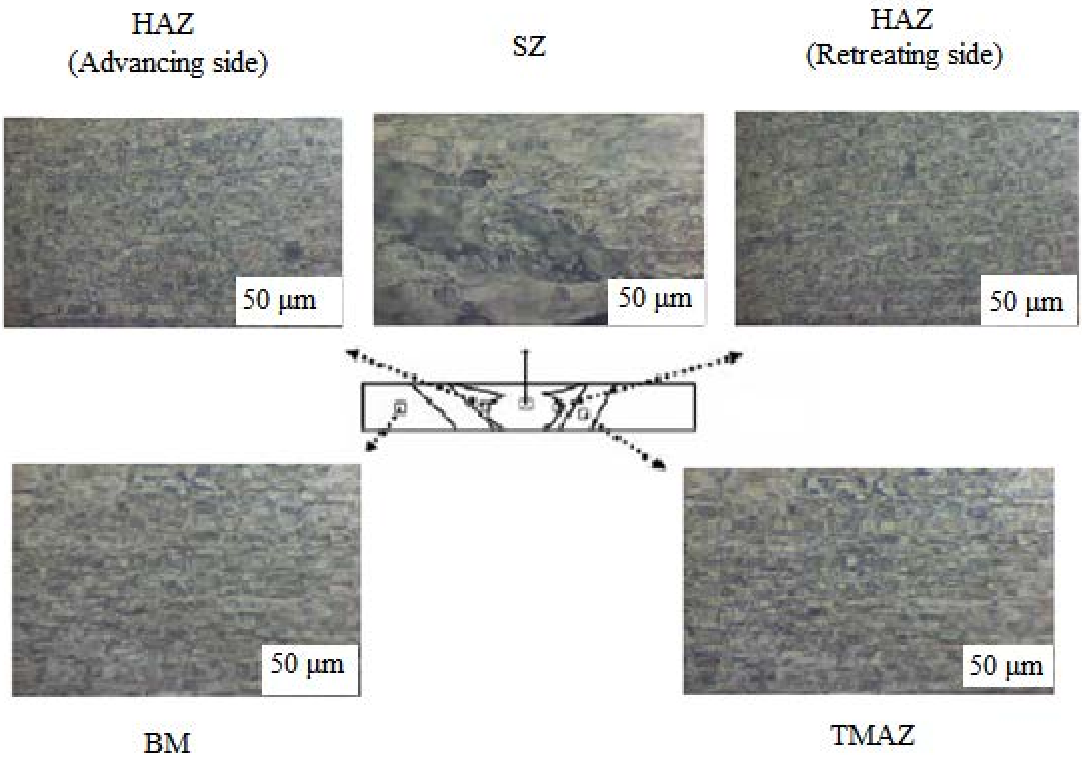


Fig.9. Microstructure of the weld zone at the condition's of 1000 rpm, 160 mm/min

The analysis of each zone reveals that the material in SZ region undergoes dynamic recrystallization process and redistribution of the strengthening phase [22]-[23]. For the TMAZ on both sides of the friction stir welded joint material, TMAZ (advancing side) has obvious contour boundary, and the TMAZ (retreating side) contour boundary is relatively blurred. It is generally believed that this phenomenon is related to the material flow direction [23].

The microstructure of the double lap joint was characterized by Light Microscopy and SEM in the base materials and in the weld nugget zone. The microstructure of the Base Materials (BM) and characteristic zones of the FSW double lap joint are shown in Figure.10. This figure is a Polarized Optical Micrograph (POM) of the BMs showing the equiaxed grains of the 3003 top and bottom sheets with a mean size of 10 μm, while the middle sheet has elongated grains in the longitudinal direction. The equivalent grain diameter measured are between 0.17 and 67.14 μm calculated by the intercept method.

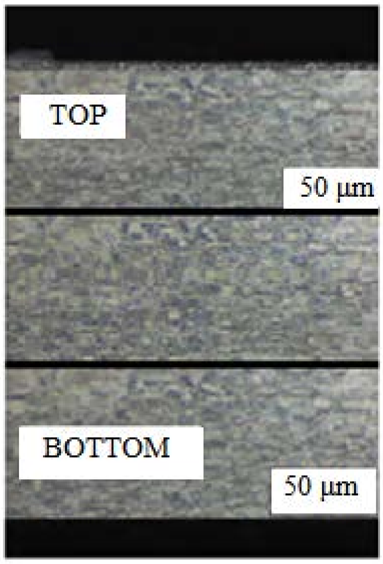


Fig. 10. Microscopy of double lap FSW joint

3.3 Temperature profiles

Figures11 and 12 shows temperature profiles with varying tool speeds. Figure 11 represents the evolution of the temperature during the linear welding of the plates as a function of time and with two positions of the tool (at 0° and 2°). It is observed that the curves have the same appearance for all the parameters chosen. The measurements on the surface of the pin show that the temperatures increase up to a certain value and then stabilize for the rest of the welding cycle. The temperature value is maximum (550°C) for a rotation of (2000 rpm) for an angle of inclination of 2°, the lowest (350°C) is estimated for a rotation of (1000rpm) with tool not inclined (0°). By comparing the values obtained, it can be seen that at the end of the cycle, the temperatures become practically equivalent. This means that at the beginning of the cycle, the high temperatures are localized at the surface of the pion. Then, at the end of the cycle, the strong heat spreads to a zone on the periphery of the pion [17].

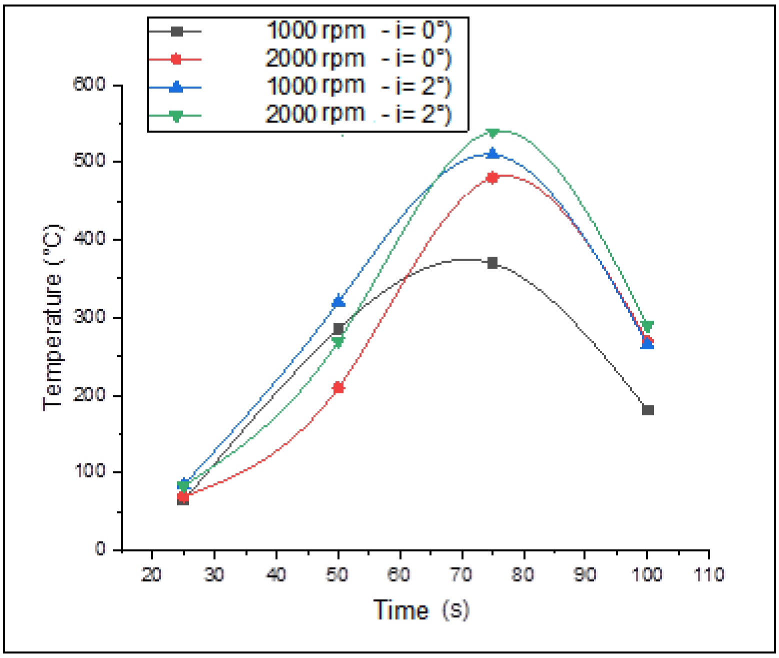


Fig.11. Evolution of the temperature during the welding of the plates linearly

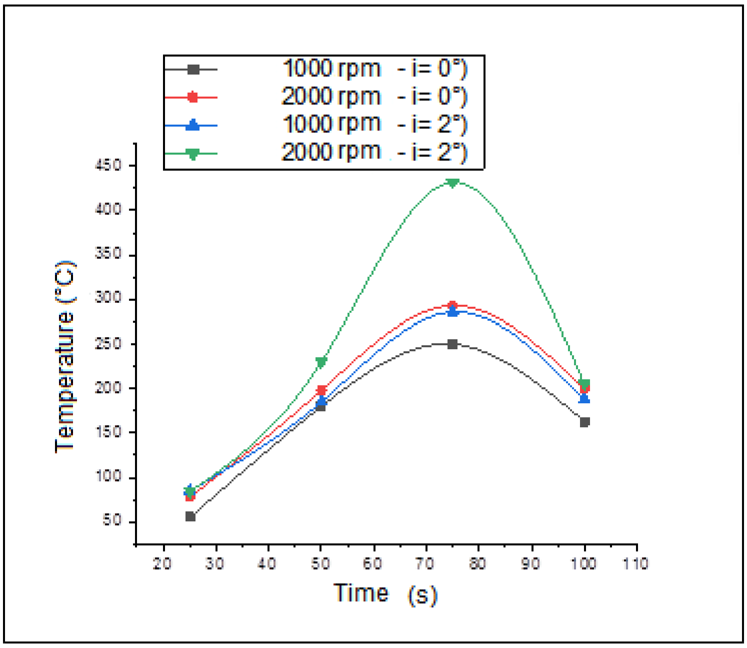


Fig.12. Evolution of the temperature during the welding of the plates inclined at 45°

Figure 12 shows the temperature profile obtained for two rotational speeds equal to 1000 and 2000 rpm. We note that the evolution is identical to that seen previously. The measurements taken show that the temperature value is maximum (420°C) for a rotation of (2000 rpm) and that the lowest are obtained by the rotation speed (1000 rpm).

4 CONCLUSION

The present work has been designed to identify the most influential and optimized FSLW (lap joint welds) process parameters on the weld joint resistance of Aluminum alloy AA3003

The following important conclusions are drawn from this study and experimental investigation

- For the welding of Aluminum alloy AA3003 the rupture strength is very sensitive around the pin during the FSLW lap joint.
- A maximum rupture strength of 9000 N has been reached for the double lap joint welded with the optimized parameters i.e a rotational speed of 1000 rpm and weld speed of 250 mm/min. Moreover, this value of the rupture strength in the SZ region for welds having an excess of the tool pin penetration is greater than the maximum value reported in the literature when the tool pin penetration is well defined.
- It is observed that the hardness value decreases from the HAZ region towards zero in the direction to the ZATM region.
- The process FSW does appeal to any external heat source. The resulting dissipation of mixing of the material and its friction on the tool is sufficient to cause a rise in temperature allowing the formation of welding in the solid state.
- The rotation speed is the factor that has greater influence on the temperature rise.

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