INVESTIGATION OF THE EFFECT OF ALUMINUM ALLOY POSITION ON RESIDUAL STRESSES IN DISSIMILAR FSW WELD BY USING THE ULTRASONIC METHOD

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Abstract. The main goal of this study is to show the effect of the advancing side (AD) and the retreating side (RT) position on the Residual stresses and local mechanical behaviour of dissimilar friction stir welds of aluminum alloys AA2024-T3 and AA7075-T6. Different samples were produced by varying the rotational speed of the tool (1200 and 1400 rpm) and the alloy position regarding the advancing side of the tool. Ultrasonic Method has been used to evaluate Residual Stresses. This method is based on the acoustoelastic effect, which measures the velocity variation of the elastic waves according to the stress state of the material. This can be achieved through a calibration test, which permits the determination of the acoustoelastic coefficient (K). The results show a tensile stress in the Nugget (N), the heat affected zone (HAZ) and a compression stress in the base metal (BM). Increasing the rotational speed reduces the amplitude of the longitudinal residual stresses with a high reduction in the case where AA7075 - T6 is in the advancing side whit 1400 rpm. This has been directly associated to the increase in the heat input and the reduction of the thermal mismatch between different areas of the weld. The microstructure effect of aluminum alloy position acts on the acoustoelastic constant K. The choice of t_0 corrects the overestimated residual stresses in the (HAZ) and (N).

1 Introduction

The Aluminum alloys are renowned for their ratio weight / high strength and their high corrosion resistance with structural applications in aeronautical, automotive and marine industries. The assembly of aluminum alloys by the Fusion welding is known to be problematic with the formation of secondary brittle phases and cracking during solidification. In addition, the thermal cycle of the weld process causes a development of the residual stresses in the weld. The presence of the residual stresses can impact mechanical and corrosion properties of the weldment, they play an important role in the strength and service life of structures [1]. FSW is in joining low weldability materials, such as AA2024 and AA7075 aluminums alloys [2], it takes place in the solid-phase, at temperatures below the melting point of the material. The reduced welding temperature during this process improves the mechanical properties and affects considerably the residual stresses [3]. Therefore, the development of several methods to measure the residual stress such as X-ray diffraction, incremental hole drilling, and more recently ultrasonic methods. The latter is based on the acoustoelastic effect, which measures the velocity variation of the elastic waves according to the stress state of the material. However, few studies on residual stresses of aluminum alloys friction stir welding through ultrasonic method have been done. Javadi et al. [4] presented in their works different experimental configuration needed to measure the longitudinal residual stresses of plates. In his work, H Jamshidi [1] used the X-ray diffraction to measure residual stress in dissimilar FSW of AA6082-T6 and AA7075-T6, it was found that the residual stress distribution at different zones is a function of the local mechanical properties and the temperature distributions. Similar studies were developed by J Zapata et al [5]. Recently, welding dissimilar aluminum alloy has been widely studied. Guo et al. [6] investigated the effect of exchanging materials location of dissimilar aluminum alloy on material flow, microstructure and tensile properties. Zhixia et al. [7] found that the location of materials has an important effect on mechanical properties and the microstructure of joints in FSW dissimilar joint of AA6013/AA7003 aluminum alloys. The motion of the tool in the dissimilar aluminum alloy, lead to local strains zones an asymmetric residual stresses distribution and mechanical properties between the advancing side (AD) and the retreating side (RT) [8]. The fracture in the dissimilar weld AA2024-T3/AA7075-T6 is located in the HAZ on the side of the aluminum alloy AA2024-T3 where the hardness is low. Maximum tensile strength of the joint was achieved when AA2024 was located on the advancing side [2]. Furthermore, by using a digital image correlation, Niu et al. study the response of the local mechanical properties to determine the global one on the aluminum alloys welded with FSW process [9]. Researchers studied the effect of the material position on the mechanical properties [10], but they did not study it on the distribution of residual stresses. Accordingly, ultrasonic method for residual stress analysis and digital image correlation (DIC) for analyses of heterogeneity deformation are performed to evaluate the effects of FSW process parameters and material position on distribution of residual stress in welded joint.

2 Experimental Procedures

2.1 Sample description

Two aluminum alloys, AA7075 and AA2024 have been tested. Different configurations of dissimilar welds obtained by friction stir welding of 5 mm thick sheets. A sheet of 200 mm length 100mm width were welded parallel to the rolling direction by employing a machine three-axis. The tool material used was AISI H11 tempered steel with 6 mm diameter threaded cylindrical pin and 20 mm shoulder and is positioned in weld line centre. In the present study, AA7075-T6 and AA2024-T3 each one positioned on the advancing side of the tool for different welding.

2.2 Measurement Device

The measurement device, shown in Figure 1, includes a wave train generator synchronized with a digital oscilloscope having a sampling frequency of 5 GHz. Measurements were performed with a piezoelectric transducer, which is composed of one emitter (E) and two receivers (R1 and R2). The nominal frequency and diameter of the piezoelectric elements are 5 MHz and 10 mm, respectively.

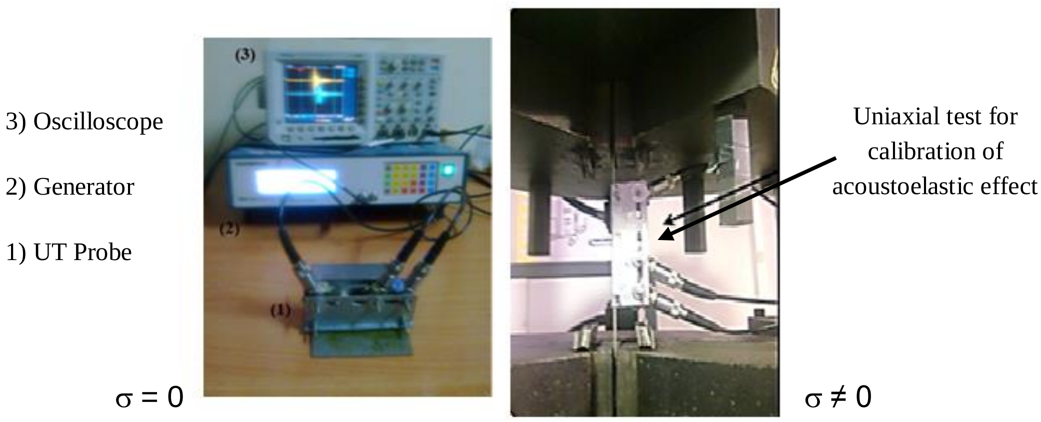


Figure 1. Schematic representation of the Lcr wave measurement setup for $\sigma = 0$ and calibration of acoustoelastic effect for $\sigma \neq 0$.

2.3 Evaluation of the Calibration Constants

The evaluation of residual stresses is based on the acoustoelastic effect [11 - 14]. The acoustoelastic constant K is deduced experimentally from a uniaxial tensile test (Figure 1). In this case, the calibration samples for tensile test were taken in the direction parallel to the weld figure 2. In this study, to show the effect of the advancing side (AD) and the retreating side (RT) position on the residual stresses, we need to evaluate the calibration constants corresponding to the BM and N, equation (1):

$$K = -1 / \sigma [(t - t_0) / t_0] \tag{1}$$

Where, t and t_0 are the time-of-flight measured between the two receivers for stressed and unstressed samples, respectively. σ is the applied stress.

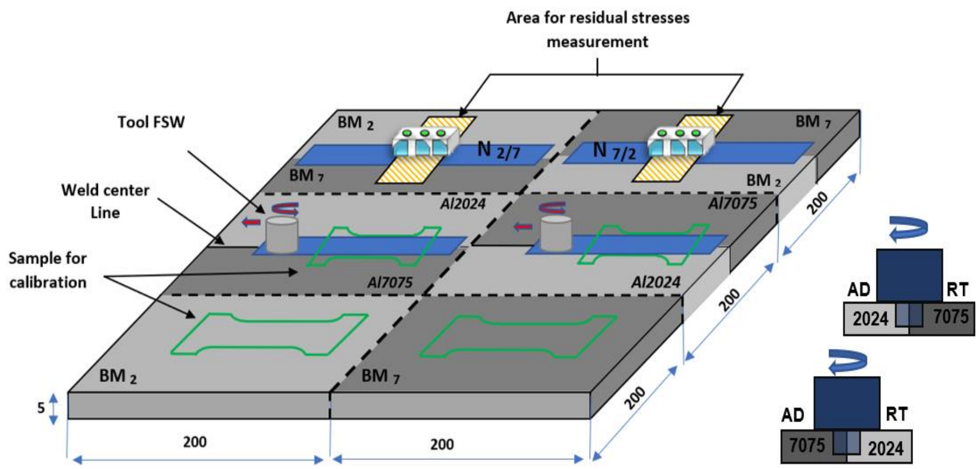


Figure 2 Positions of the calibration samples and area for residual stresses measurement on the original plate.

3. Results and Discussion

3.1 Macro and microstructures of joints

Figure 3 shows the cross section of a weld obtained with 1200 rpm and 40 mm / min. The FSW seal is characterized by four different zones: Nugget (N), affected thermomechanical zone (TMAZ) and heat affected zone (HAZ). In addition, the size of the ring flux pattern in the nugget region increases with the speed of rotation tool, due to increase in heat inputs. obviously. The microstructures of the base metals of the advancing side and retreating side are shown in Figure 3. it's consisted an elongated grain along the rolling direction with a random distribution of small black particles.

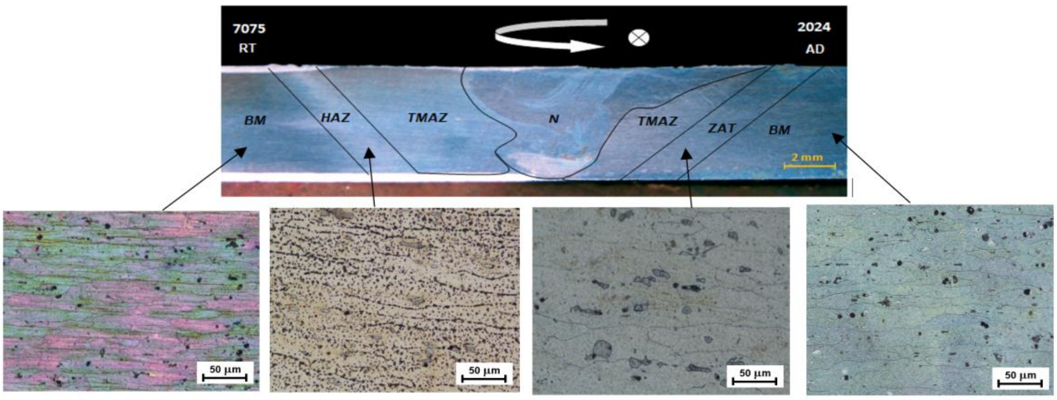


Figure 3 Macro and microstructures of the various weld zones microstructures.

3.2 Microstructure Effect on the Acoustoelastic Constant

The results of tensile test performed an BM 2024, BM 7075, N 7AD/2RT and N 7RT/2AD samples to measure acoustoelastic constant are presented in Figure 4. Linear curves were obtained during the loading and unloading phases, where the slope of the lines represents K acoustoelastic constants. Figure 4 shows that the acoustoelastic behaviour of the material is very affected by the microstructure. That is, acoustoelastic constants K (N 7AD/2RT) and K (N 7RT/2AD) are respectively different by 10%, 12% from the $K_{\mathbf{BM2}}$ constant and 17, 20% for $K_{\mathbf{BM7}}$. Furthermore, 4% of the difference between the two-nugget constant, show the weak effect of the alloy position in the nugget zone. However, is difficult to measure the constant of the HAZ because is less than 3mm.

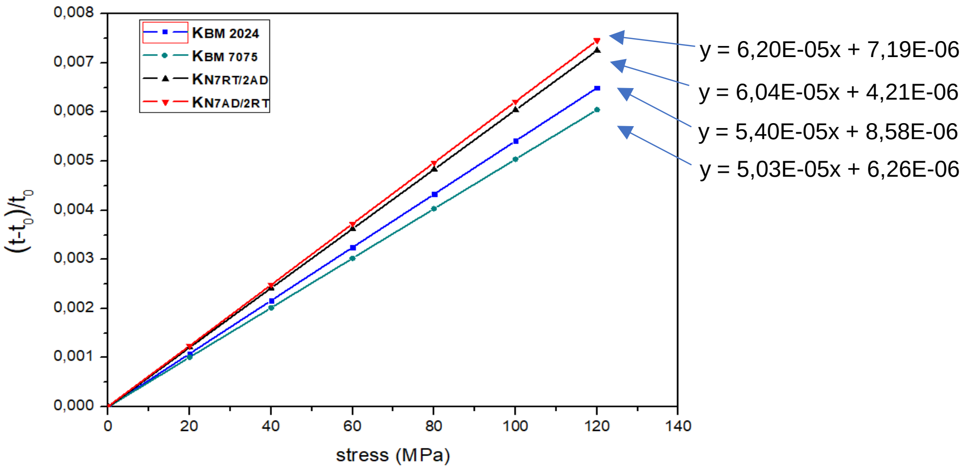


Figure 4. Influence of the microstructure on the acoustoelastic calibration constant.

3.3 Residual stresses characterization

Regarding the Figure 5, it is seen that the stress profiles displayed the characteristic "M" shape for the longitudinal residual stresses, the asymmetry between advancing and retreating stress peaks was clearly visible as already fond by H. Jamshidi et al [1]. As can be seen when AA 2024 is in advancing side, the profile shows a lower magnitude of stresses on the advancing side compare to the retreating side. in the advancing side, the direction of tangential component of tool rotation and the velocity vector associated with the welding speed coincide this causes more friction. These factors create higher temperature on AD as compared to RT.

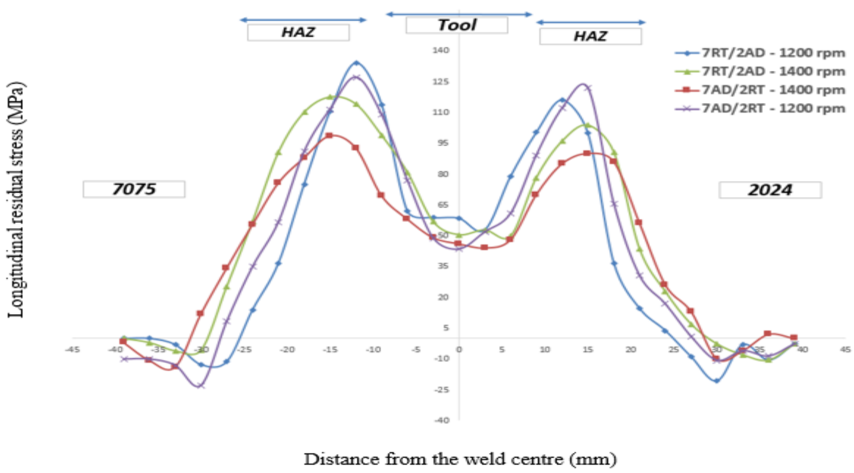
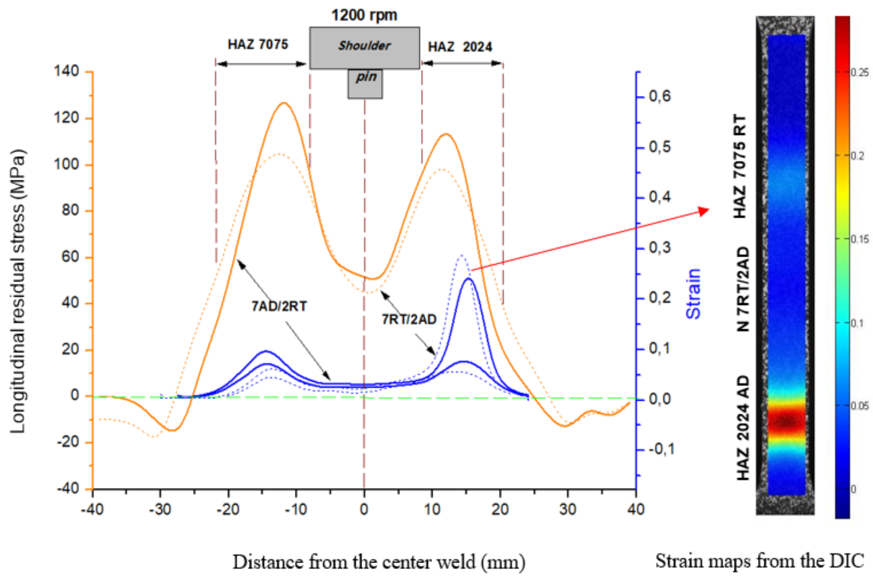


Figure 5. Longitudinal residual stress distributions.

It can be observed that the maximum value of the residual stress is located on the HAZ for both materials, whit significant variation between the different profile. However, there is very small variation in nugget zone. For the case when AA2024-T3 is in advancing side the maximum tensile residual stress occurs in the AA7075 retreating side to 135 MPa. the magnitude of the residual stresses decreases (for both side AD and RT) upon a change in velocity from 1200 to 1400 rpm whit a "M" shape increases in width. However, when AA2024-T3 located in retreating side, the residual stress peaks on the advancing and retreating sides were nearly equal. Furthermore, the magnitude of the residual stresses in AA2024 RT side is higher than AA2024 AD side. Of observations to note is the considerable reduction the magnitude of the residual stress for AA7075 advancing side upon a change in velocity from 1200 to 1400 rpm, this is related with the mechanical resistance of AA7075 which is higher compared to the AA2024. thus, causing higher heat input.
The strain maps correspond to strain distribution at maximum load is shown in Figure 7 a), and the related local mechanical properties of different welding subzones for the two case when AA2024 is in advancing side and when is in retreating side is achieved by Digital image correlation (DIC) method are shown in Figure 6 b).

a)



b)

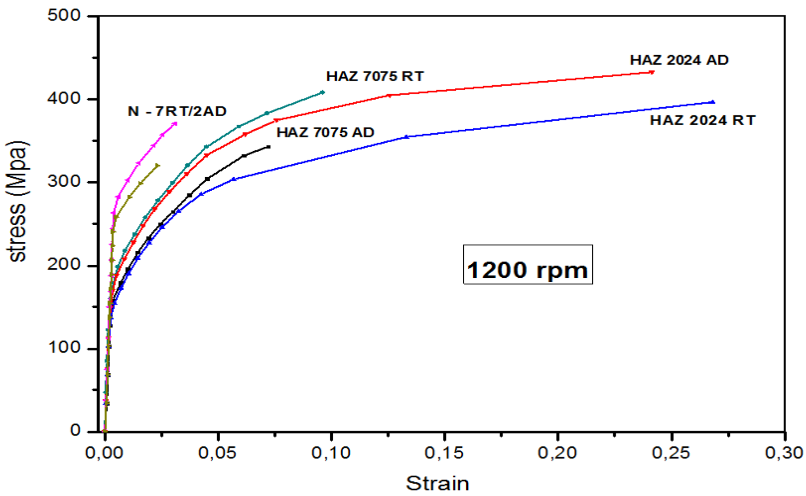


Figure 6 for the two case: AA2024 located in advancing side and in retreating side
a) Strain maps resulting from the DIC measurement according to the residual stress.
b) the local mechanical properties of different weld sub-zones.

According to the strain maps, the tensile sample fracture in the HAZ of the AA2024 side where a minimum tensile residual stress in the weld zone are observed is illustrated in Figure 6a). It can be seen that the residual stress distribution at the region HAZ 2AD and HAZ 2RT is a function of the local mechanical properties and the inhomogeneous temperature distributions during and after welding. The HAZ 2AD with lower residual stress profile show higher peak yield stress than the related region in the HAZ 2RT side (Figure 6 a).and figure 6b). furthermore, N 7RT/2AD has a rather higher yield stress than N 7AD/2RT.

4. CONCLUSION

The main goal of this study is the effect of the material position and rotational speeds on residual stresses wish is evaluated by using the ultrasonic method. The following conclusions could be drawn:

- The microstructure effect acts on both the acoustoelastic constant K.
- The increase in rotation speed results in more reduction in the amplitude of the residual stress when AA7075 is in advancing side compared to AA7075 is in retreating side.
- The residual stresses become compressive as the distance from the HAZ zone increases thus become tension stresses.
- The HAZ 2AD with lower residual stress profile show higher peak yield stress than the related region in the HAZ 2RT side.
- The maximum value of the residual stress is located on the HAZ for both materials.

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