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PROCESSING MAPS FOR FRICTION STIR WELDED JOINTS OF ALUMINUM AA7075-T6

Juan José Toro Castrillón
Universidad Nacional De Colombia Sede Medellín-Calle 59A No 63 - 20
jujtoroca@unal.edu.co

Juan Felipe Mafla García
Universidad Nacional De Colombia Sede Medellín-Calle 59A No 63 - 20
jfmaflag@unal.edu.co

Elizabeth Hoyos Pulgarín
Escuela de Ingeniería de Antioquia - Km 2 + 200 Vía al Aeropuerto José María Córdova
pfehoyos@eia.edu.co

Diana María López Ochoa
Universidad Nacional De Colombia Sede Medellín-Calle 59A No 63 - 20
dmlopez3@unal.edu.co

Abstract. *In this work the influence of the rotation and travel speed on the quality of butt joints of AA7075 T6 aluminum alloy obtained by Friction Stir Welding is studied. The tests were carried out with combinations of parameters covering 400 rpm to 650 rpm for rotation speed and 40mm/min to 65 mm/min for travel speed, using a convex shoulder tool with a concentric circle pattern and a threaded cylindrical pin. Force and torque data were obtained during the welding process and the samples were classified according to its integrity. It was found that a low rotation speed, such as 400 rpm, allowed to obtain good quality welds for almost any travel speed; with higher rotation speeds, an irregular flow of the outmost layers of the metal is observed and is related with the formation of zones of incomplete joints. It was found a direct relationship between the rotation speed and the force on the traveling and the transverse direction and between transversal force and travel speed. These relationships between forces and speeds allowing a better comprehension of the material flow mechanisms than analyze the effect of these parameters separately. Processing maps for quality and forces as a function of the rotation and travel speed were obtained to present the results.*

Keywords: *Friction stir welding, aluminum, joint quality, forces, convex shoulder tool*

1. INTRODUCTION

Aluminum alloys are characterized for having high strength to density ratio, in particular aluminums of the 7000 series, being widely used in the aerospace and transport industry, since they allows to design lighter systems, reducing the power consumption while maintaining the structural function of the component; having a positive economic and ecological impact (Guo et al. 2011).

7000 series Aluminum alloys are characterized for containing $MgZn_2$ precipitates on the aluminum matrix improving mechanical properties of the alloy (Rajakumar et al. 2011). However, their microstructures can be difficult to weld by traditional fusion methods due to the formation of dendritic structures while solidification, leading to a decrease in the mechanical properties of the joint (Su et al. 2003). Also this alloy family is prone to weld solidification cracking, heat affected zone liquation by the presence of copper; while in the other hand, the vaporization of zinc causes porosity, lack of fusion and toxic fumes (Rajakumar et al. 2011). Further, there are another common issues with the traditional fusion welding methods, sometimes causing severe distortion of the pieces being welded and relatively high residual stresses on the joint area (Cavaliere et al. 2006).

In recent years solid state welding processes has been developed to overcome the issues appointed previously. Friction stir welding were developed back in 1990 at the Welding institute. It consists on a special tool which plunges into the joint line and travels while rotating, generating heat through friction and plastic deformation of the material. The tool features two main parts: the shoulder and the pin. The shoulder keeps contact with the surface of the joint, confining the material below it, while the pin stir the metal inside the joint and extruding back the material as the tool travels, generating the joint (Cavaliere et al. 2006). As result of the heat generated and the deformation, the process generates recrystallization with strain free equiaxial grains inside the joint (Attallah 2008). Other advantages of the process includes that the welding is autogenous, the tool is non consumable and it has high joining speed (Balasubramanian 2008).

During the last years, great attention has been paid to the study of the microstructural features inside the joint and the adjacent zones and how it relates with mechanical performance of the welding (Atharifar et al. 2009). Some efforts has been made also to develop models capable of describing the phenomena involved in the process, and increase in that way the prediction capacity about this process (Atharifar et al. 2009) (Chen & Kovacevic 2004) .

In this paper, a processing map for friction stir welded joints of AA7075 T6 in terms of the speed parameters, the forces involved in the process and the quality of the welded zone is presented as a practical way of transferring knowledge to manufacturing industry. The isolated analysis of the speed parameters do not give many ideas about how the material is flowing in the stirring zone to produce the weldment, then the capacity of prediction about the occurrence of defects is very general and the understanding about it is very limited. On the other hand, load data alone is not very useful if it the loads exerted by the tool and the speed parameters can give a more complete approach to the comprehension of the mechanisms behind the defect formation.

2. MATERIALS AND METHODS

Plates of 100 x 50 x 5 mm of AA 7075-T6 aluminum alloy were welded perpendicular to the rolling direction. The nominal composition of the alloy is presented in Table 1.

Table 1. Nominal composition of AA 7075-T6

Element	Zn	Mg	Cu	Cr	Al
Content - wt.%	5.1-6.1	2.1-2.9	1.2-2	0.18-0.28	Balance

The used tool featured a 20mm diameter convex shoulder with a concentric circles pattern and a cylindrical and threaded pin with 7mm in diameter and a semispherical tip. The material used for the tool was H13 tool steel, with 55HRC of hardness on the surface. Figure 1 shows the Illustration of the tool.

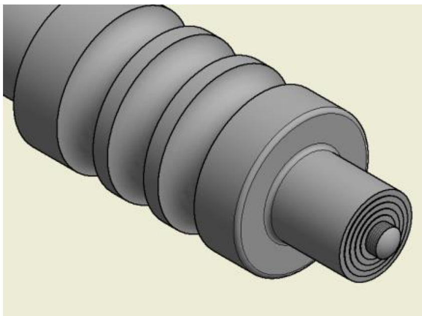

Figure 1 Drawing of the used tool

A RM1 FSW machine from Manufacturing Technologies, of the Brazilian Nanotechnology National Laboratory (LNnano) was used to weld the plates. Controlled force was the mode selected to develop the joints, being the force in the z axis (perpendicular to the welding plane) set to 10 KN. 19 different joints were developed varying the rotation speed between 400 RPM and 650 rpm and the traveling speed between 40 mm/min and 65 mm/min. A dwell time of 15 second were used for every joint. Force, torque and heat input are recorded just after the dwell time.

3. RESULTS AND DISCUSSION

3.1 Quality of the joints

Four kinds of defects were identified in the joints, and they are described as follows:

Figure 2 shows the appearence of shoulder marks. It can be seen as a succession of shiny and opaque marks with the shape of the edge of the shoulder. It can be seen mainly at rotation speeds up to 500 rpm and transverse speed less or equal to 50mm/min. Figure 3 shows a lack of fluence, it can be seen how the metal flow produces layers corresponding with the pattern on the shoulder. While inner layers seems to advance more from the advancing to the retreating side of the joint, the outer layers do not reach the retreating side of the joint. This defect was identified at rotation speeds higher than 550 rpm and transverse speed higher than 50mm/min.

In addition, the flash is identified as a portion of metal that is extruded outside the welding zone as a consequence of the excessive penetration of the tool inside the metal. The defect is present at higher rotation speeds and lower transverse speed. Figure 4 shows a joint with this defect, it can be noticed that the joint also shows some level of lack of fluence towards the end of the joint. Finally, the loss of the superior layer, showed in Fig. 5, is characterized for appearing as shiny region on the center of the joint surrounded by the opaque surface layer. This defect is different from the lack of the fluence since the extent of the exposed zone is bigger and it seems like the metal from the retreating side reach effectively the advancing side. Furthermore, as it will be seen the loads and heat input behave differently for both defects.

Figure 7 shows the distribution of defects according to the transverse speed and rotation speed used to develop the joints. As can be seen, defects appears in distinctive regions of the map, giving some idea about safe zones of processing.

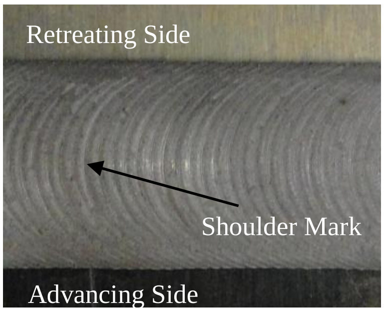

Figure 2. Shoulder mark defect at 400 RPM and 45 mm/min

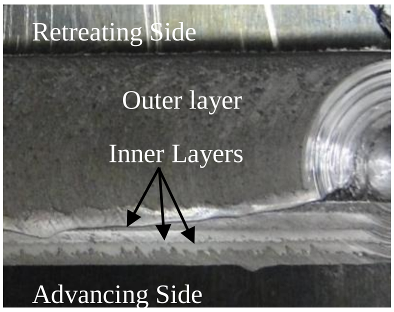

Figure 3. Lack of fluence at 600 RPM and 50mm/min

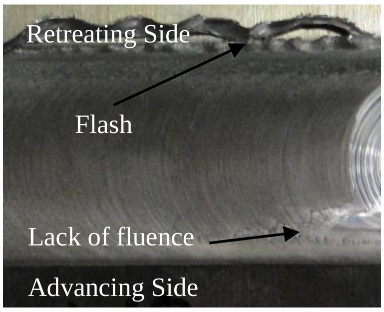

Figure 4. Flash defect at 650 RPM and 45 mm/min

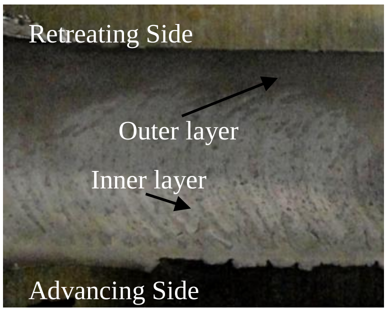

Figure 5. Loss of surface layer at 500 RPM and 65 mm/min

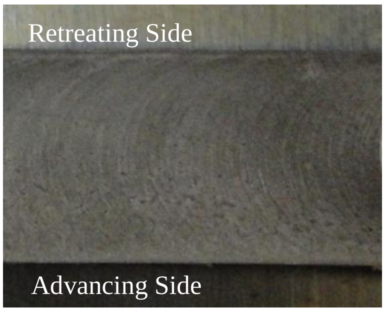

Figure 6. Good surface finishing at 550 RPM and 45 mm/min

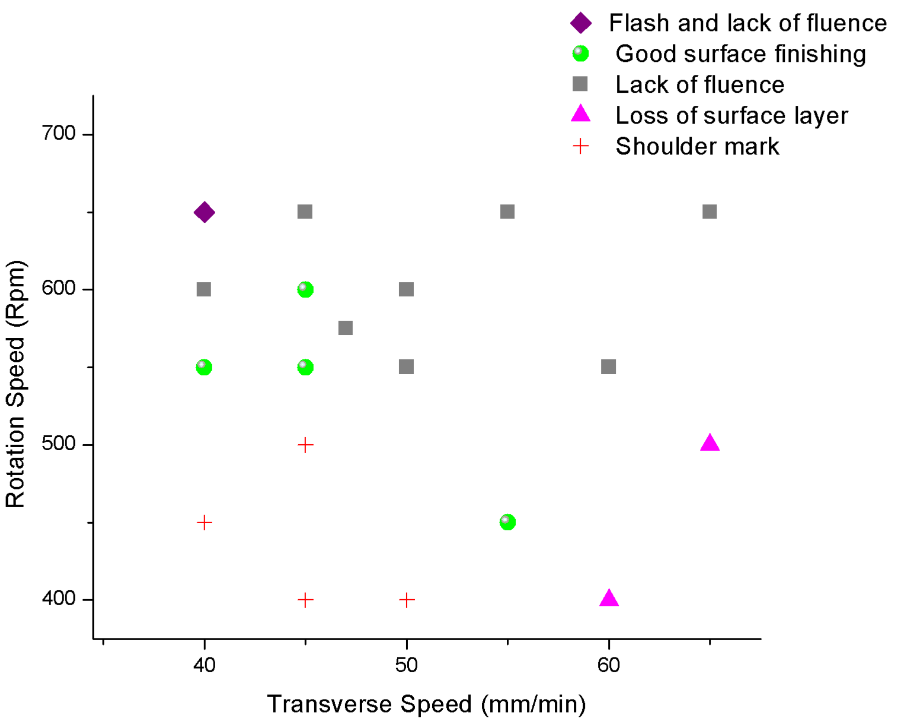

Figure 7. Processing map showing safe and defect zones according to the transverse speed (X) and rotation speed (Y)

3.2 Forces, torque and heat input

The loads sensed on the tool are the result of the interaction between the metal to be welded and the tool; this interaction implies the flow of the metal that shape the joint, and therefore it is possible to relate the occurrence of the defects for a particular tool and material with the measurements of forces, torque and heat input. Figures 8 and 9 show how the defects appears in distinctive ranges of the mean values of longitudinal (X) and especially transversal (Y) forces with the variation of transverse and rotation speed.

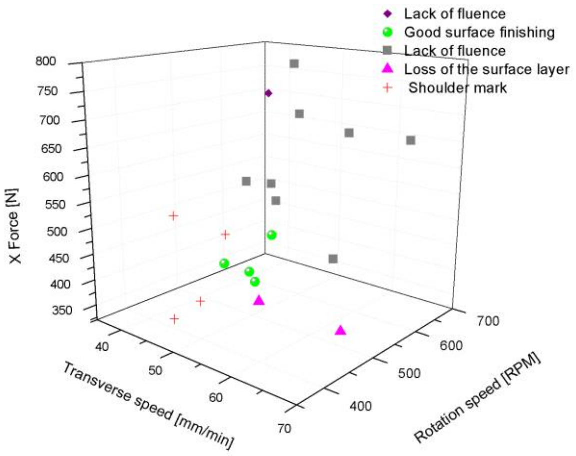

Figure 8. Scatter plot of the X Force (Z) categorized by defect in terms of transverse speed [mm/min] (X) and rotation speed [RPM](Y)

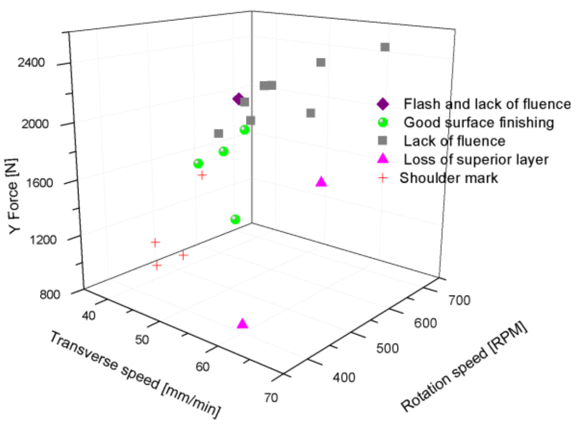

Figure 9. Scatter plot of the Y Force (Z) categorized by defect in terms of transverse speed [mm/min] (X) and rotation speed [RPM](Y)

Defects could also be characterized by the heat input and the torque developed on the stirring zone. Heat input is claimed to be one of the most important parameters in the FSW process and for the present work it is defined as the energy used by the machine per unit length of the joint (Torres & Ramirez 2011). However defects can be better categorized if they are put in terms of torque. This means that for a determinate range of torque, some defect is expected to appear in the joint, and vice-versa.

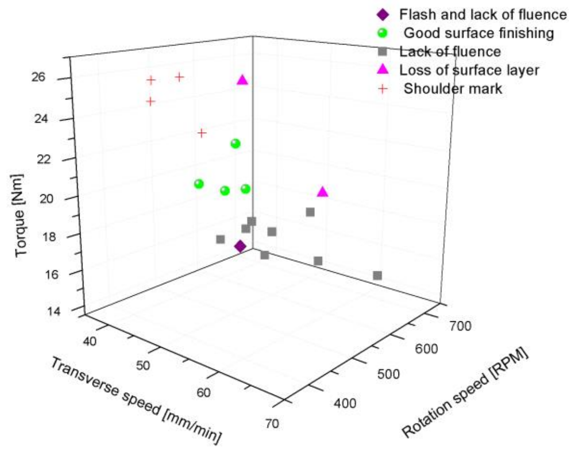

Figure 10. Scatter plot of the Torque (Z) categorized by defect in terms of transverse speed [mm/min] (X) and rotation speed [RPM](Y)

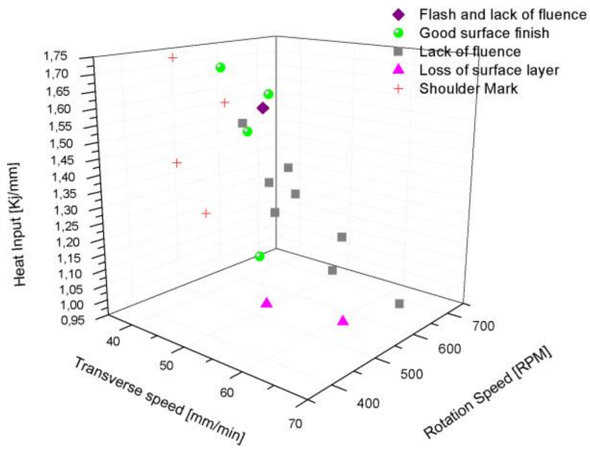

Figure 11. Scatter plot of the Heat Input (Z) categorized by defect in terms of transverse speed [mm/min] (X) and rotation speed [RPM](Y)

The lack of fluency defect is represented in the graphics as a gray square and is characterized for a high level of in plane average forces: X Force average ranges between 446.46 N and 760.66 N, while Y Force average ranges between 1755,12 N and 2502,09 N. Torque levels for this defect are relatively low, ranging from 14.8 Nm to 19.5 Nm. Heat input for this defect is on the low range of the experiment varying from 0.98 Kj/mm to 1.5 Kj/mm. Higher heat input for similar speeds parameters leads to the occurrence of flash.

Loss of surface layer defect is represented by the pink triangle and is characterized for its low heat input ranging from 1.026 Kj/mm to 1.11 Kj/mm. It also features the highest level of torque in the context of the experiment varying from 21.23 Nm to 26.61 Nm. This high levels of torque could be indicative of a particular tribological condition as sticking, between the material of the joint and the tool, which could be concordant with the apparition of the shiny inferior layer. However, more investigation about the tribology of the formation of the joint is needed. In terms of force, its mean value are among the lowest in the experiment. X force mean value ranges between 347.78 N and 429.49 N and Y force mean value ranges between 855.18N to 1733.70N.

Shoulder marks could be identified for the relatively high heat input varying from 1.32 Kj/mm to 1,74 Kj/mm, and the relatively low level of forces varying from 338.20N to 505,57 N as it can be seen in Fig. 8 and 9. This region also features high values of torque varying from 20.82 Nm to 25.41 Nm. However, further investigation is needed to determine the mechanism of formation of the shiny and opaque succession.

Finally, the zone of good surface finish can be identified for its relatively high mean torque, ranging from 19.27 Nm to 29.28 Nm. It also features high levels of mean Y force and heat input varying between 1434.38 N to 1825.77 N and 1.2 Kj/mm to 1.69 Kj/mm respectively. X force behavior for this region of the map is low for the context of the experiment fluctuating between 370.46 N to 429.9 N. In any case the values sensed are not the highest nor the lowest, meaning that secure zone of processing is delimited by speed parameters as could be seen in the Fig. 7. In a similar way, Fig. 8 to 11 show that the secure zone are not located at the limits of the parameters tested in this work, being enclosed by non-secure zones. It is worth noting that the conditions described in the present work could vary significantly according to the material and the tool design.

4. CONCLUSIONS

A process map in terms of speed parameters for FSW in 7075-T6 with convex shoulder tool was developed. Four different defects were identified and characterized in the map in terms of rotation speed and transverse speed, however load and heat input were studied for each defect. Safe zone of processing comprises some points in the range of 450 RPM to 600 RPM and 40 mm/min to 55 mm/min, however it is recommended to test zones near 450 RPM and 50 mm/min.

5. ACKNOWLEDGEMENTS

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