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Studying the distribution of hardness values in friction drilled 7075 Al-alloy sheets at different conditions

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Abstract. The thickness of sheet metal parts can be locally increased by friction drilling technology via forming of a hole with a bush by a special drilling tool. Here, a 7075 Al-alloy was drilled by friction using tool cone angles with values of 40, 45 and 50^0 under different feed rates (100, 200 and 315 mm/min) and rotational speeds (1000, 1250 and 1600 rpm). The present study investigates the hardness distribution in the thermally-formed bush and in the heat-affected zone around the bush. It was found that the hardness of the bush was slightly increased with increasing of the tool cone angle and reduction of the tool rotational speed. However, the hardness of the thermally-induced bush showed values lower than the parent metal. The hardness near the drilling surface was approximately 65±10 HV, while it recorded hardness values of 75±10 HV at 5 mm away from the drilling surface. In addition, the microstructure of the friction drilled specimens showed a very fine structure in the drilling zone due to crushing of the original structure during the friction drilling process.

1. Introduction

EN AW 7075 (Al-Zn-Mg-Cu) high strength alloy is used in many industrial applications such as aerospace components, bike parts, and building construction elements which require excellent mechanical performance. However, this alloy has a poor weldability, which limits the choices of joining methods available for 7075 Al-alloys assembly [1].

Thermal drilling is a non-traditional hole-making method used in manufacturing of thin sheet metals. It creates holes with extra height more than the base metal without generation of chips via a non-traditional tool-drill. Hence, it is a suitable technology to produce a clean hole with high efficiency and good surface quality [2, 3].

The presence of a bushing (the extra height) in thin sheets can be further threaded; therefore, temporarily joining of the thermally drilled specimens can be performed using studs or bolts [4-6]. The feed rate and spindle speeds of the tool are the most vital factors during the friction drilling process. The thermal drilling parameters directly affect the axial thrust force and torque values during the drilling process [7, 8].

Friction drilling begins when the rotary tool contacts with the work piece. Under the influence of the rotating tool, friction is induced which increases the temperature of the sheet material in contact with the drilling tool. The temperature reaches 750 °C and 380 °C during thermal drilling of austenitic stainless steels and Al-alloys respectively [9,10]. The induced temperature softens the material in front of the tool drill. The tool has a conical geometry that gradually expands the diameter of the hole and lengthens the molded bushing. The geometry of the tool affects the shape and size of the bushing [5].

On one hand, 7XXX Al-alloy series are heat-treated via T6 treatment; it produces spherodized precipitates of eutectic Si, in addition to existence of Cu-, Fe- and Mn- intermetallic compound particles which enhance the hardness, strength and ductility of these alloy-series [11-13]. On the other hand, the friction drilling of 7075 Al-alloy is expected to create thermal conditions that may affect the heat treatment influence.

The aim of the present study is to investigate the distribution of hardness values in friction drilled 7075 Al-alloy sheets at different working conditions via the manipulation of the rotational speeds, feed rates and tool cone angles.

2. Experimental setup

2.1 Materials and Methods

The chemical composition of the investigated 7075-T6 Al-alloy is 5.6 wt.% Zn, 2.3 wt.% Mg, 1.4 wt.% Cu,0.5 wt.% Fe, 0.4 wt.% Si, 03 wt.% Mn and 89.5 wt.% Al. The thickness of the drilled specimens is 4 mm. It worth mentioning that, the melting temperature of the 7075 Al-alloy is approximately 635 °C. A vertical milling machine was used to perform the friction drilling processes of the specimens.

2.2. Drilling tool

The details of the friction drilling tool were discussed in our previous work [10]. The friction angle (is also defined as the tool cone angle) and the length of the conical region are referred as β and h_n respectively. In the present study, three different friction angles of 40°, 45° and 50° are considered. The drilling tool has a diameter d equals 8 mm and a cylindrical length h_l equals to 16 mm.

2.3. Drilling conditions

Table 1. Sample codes corresponding to the different drilling parameters values.

Sample **no.**	*R, rpm*	*F, mm/min*	*β, ^o^*	*Sample* **no.**	*R, rpm*	*F, mm/min*	*β, ^o^*	*Sample* **no.**	*R, rpm*	*F, mm/min*	*B, ^o^*
S1	1000	100	40	**S10**	1250	100	40	**S19**	1600	100	40
S2	1000	100	45	**S11**	1250	100	45	**S20**	1600	100	45
S3	1000	100	50	**S12**	1250	100	50	**S21**	1600	100	50
S4	1000	200	40	**S13**	1250	200	40	**S22**	1600	200	40
S5	1000	200	45	**S14**	1250	200	45	**S23**	1600	200	45
S6	1000	200	50	**S15**	1250	200	50	**S24**	1600	200	50
S7	1000	315	40	**S16**	1250	315	40	**S25**	1600	315	40
S8	1000	315	45	**S17**	1250	315	45	**S26**	1600	315	45
S9	1000	315	50	**S18**	1250	315	50	**S27**	1600	315	50

The investigated friction drilling parameters imply the tool rotational speed R, feed rate F and tool cone angle β. The present investigation considers three values of each drilling parameter: R equals 1000, 1250 and 1600 rpm, F equals 100, 200 and 315 mm/min, and β equals 40°, 45° and 50°. The experiments were carried out based on three factors with three levels of full factorial experimental design. The developed design matrix produced 27 experiments as shown in table 1.

2.4 Vickers micro-hardness measurements.

Vickers micro-hardness test has been performed with an applied load of 100 gf at a holding time of 15 s according to the ASM standard E384 [14]. Hardness values were measured by using PHASE-Ⅱ Vickers hardness tester. The average of three readings was recorded. Hardness was measured in numerous points in the thermally-formed bush (drilling zone referred as DZ) and in the heat-affected zone (HAZ) around the bush. Figure 1 displays a schematic drawing showing the HAZ, DZ, and the edges of the friction drilled hole.

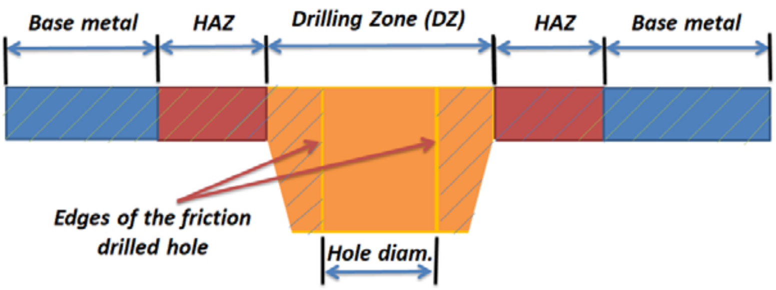

Figure 1. Schematic drawing showing a cross section after friction drilling processing at where base metal, HAZ and DZ are identified.

2.5. Microstructure analysis.

Samples for metallography were mounted, ground, polished and then etched for 5-15 s with Keller agent according to the ASTM standard E407 [15]. The microstructure was recorded with KERN optical microscope.

3. Results and discussion

3.1. Hardness results

Figure 2 shows the results of hardness values near the edge of the friction drilled bush and through a distance of 6 mm away from it with a step equals 1 mm in the 27 specimens. It is clear that, both of the DZ and the HAZ have hardness values lower than the base metal. Moreover, the hardness values increase with moving away from the edge of the induced bush.

Specimen S8 shows a maximum value of hardness (77.2 HV) near the edge of the friction drilled hole. While S21 shows a minimum value of hardness (57.3 HV) near the edge of the hole. It leads us to conclude that the hardness of the bush is a maximum when *R* equals 1000 rpm, *F* equals 315 mm/min and β equals 45º. However, the hardness of the bush is a minimum when *R* equals 1600 rpm, *F* equals 100 mm/min and β equals 50º.

On the other hand, the maximum temperature during friction drilling of S8 and S21 recorded 292 ^{0}C and 376 ^{0}C respectively [10]. It seems that the higher the induced temperature during the friction drilling process, the lower the hardness of the induced bush of the 7075 Al-alloy.

Figure 3 shows the evolution of hardness values at near the edges of the friction drilled holes at different rotational speeds, cone angles and feed rates. Clearly, when *F* equals 100 mm/min, the micro-hardness values increase with the increase of the cone angle from 40º to 45º respectively, while it decreased with the increase of the cone angle from 45^0 to 50^0 at 1000 rpm and 1600 rpm (figure 3.a). Moreover, when *F* equals 200 mm/min, the micro-hardness increased with the increase of the tool cone angles from 40° to 45°, then, it decreased with the increase of the tool cone angles from 45° to 50° (figure 3.b).

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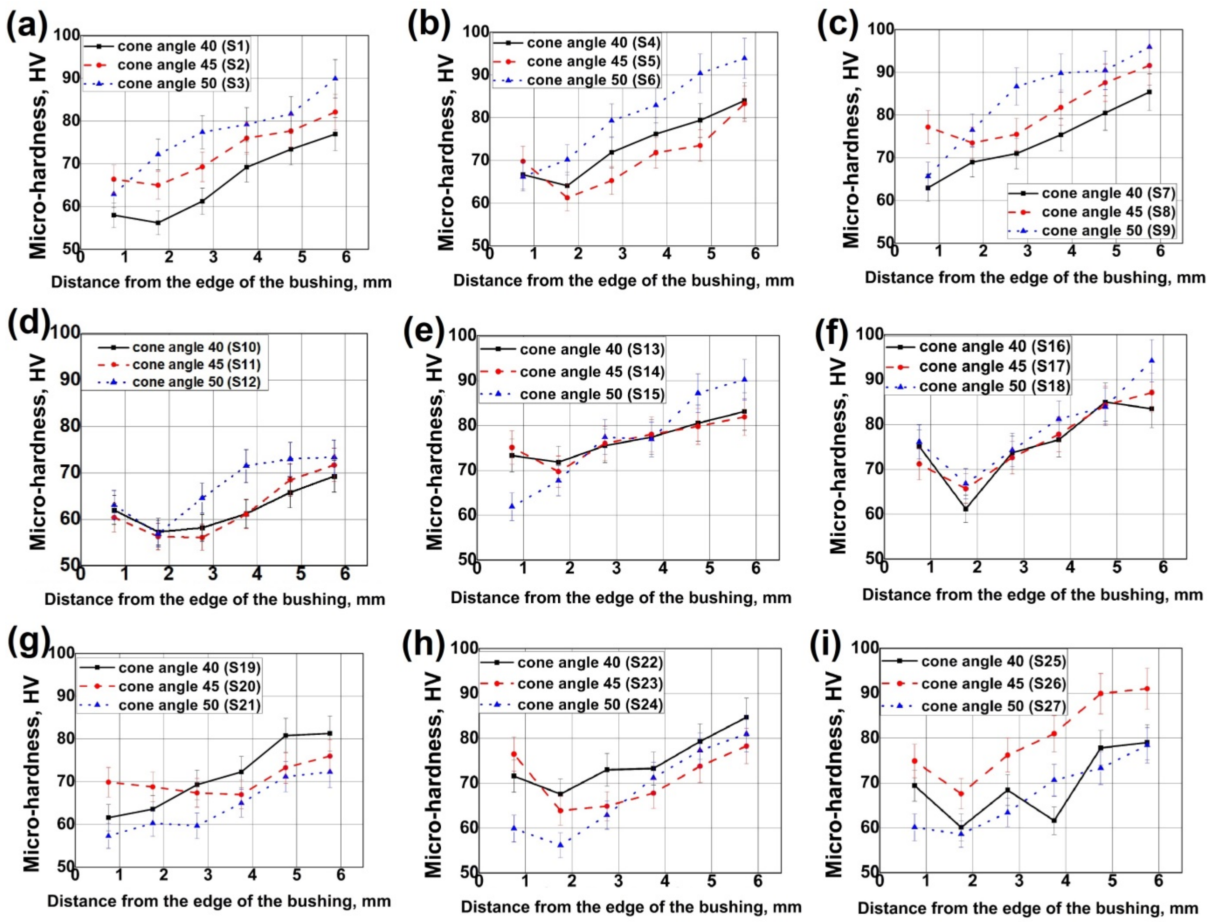

Figure 2. Micro-hardness values at different distances from the edge of the friction drilled bush under different friction drilling conditions: a) *R*=1000 rpm, *F*=100 mm/min, b) *R*=1000 rpm, *F*=200 mm/min, c) *R*=1000 rpm, *F*=315 mm/min, d) *R*=1250 rpm, *F*=100 mm/min, e) *R*=1250 rpm, *F*=200 mm/min, f) *R*=1250 rpm, *F*=315 mm/min, g) *R*=1600 rpm, *F*=100 mm/min, h) *R*=1600 rpm, *F*=200 mm/min, i) *R*=1600 rpm, *F*=315 mm/min,

Furthermore, at *F* equals 315 mm/min, the micro-hardness values increased with the increase of the tool cone angle from 40^{O} to 45^{O}, while it decreased with the increase of the cone angle from 45º to 50^{O} at 1000 rpm and 1600 rpm. However, the micro-hardness values decreased with the increase of the the cone angle from 40º to 45º, while it increased with the increase of the cone angle from 45 1250 rpm (figure 3.c). The highest value of the micro-hardness recorded at tool cone angle of 45º.

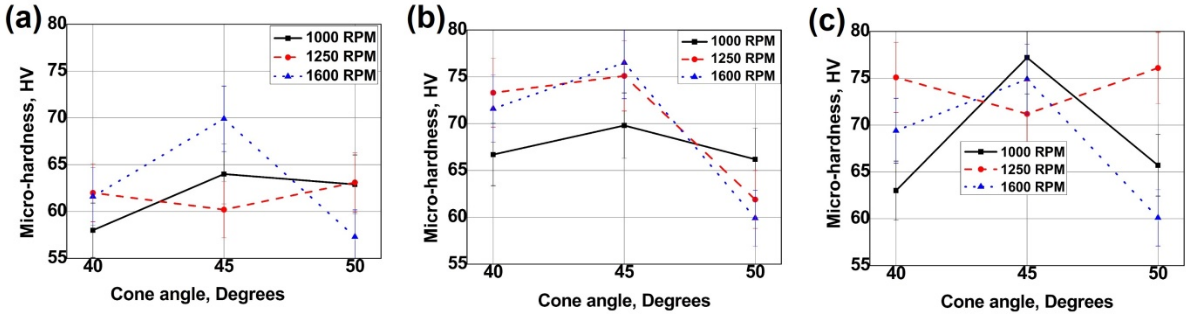

Figure 3. Hardness values at near the edges of the thermally induced bush under different tool rotational speeds and cone angles at different feed rates: a) *F*=100 mm/min, b) *F*=200 mm/min and c) *F*=315 mm/min.

3.2. Microstructure analysis

Figure 4 shows the microstructure at the edge of the induced bush and the as received condition before etching. The graphs show existence of intermetallic compound particles which mainly consists of Cu, Fe and Mn as reported in the literature [11]. It is clear the intermetallic particles are homogeneously distributed in the microstructure of the as-received condition, the average size of the particles is 8±5 µm. However, the microstructure of the induced bush shows refining of the intermetallic particles with average size of 1±0.5 µm. It leads us to conclude that the dissolution and/or fragmentation of the intermetallic particles at the drilling zone decreased the hardness of the formed bush and the HAZ in comparison with the base metal, as discussed above.

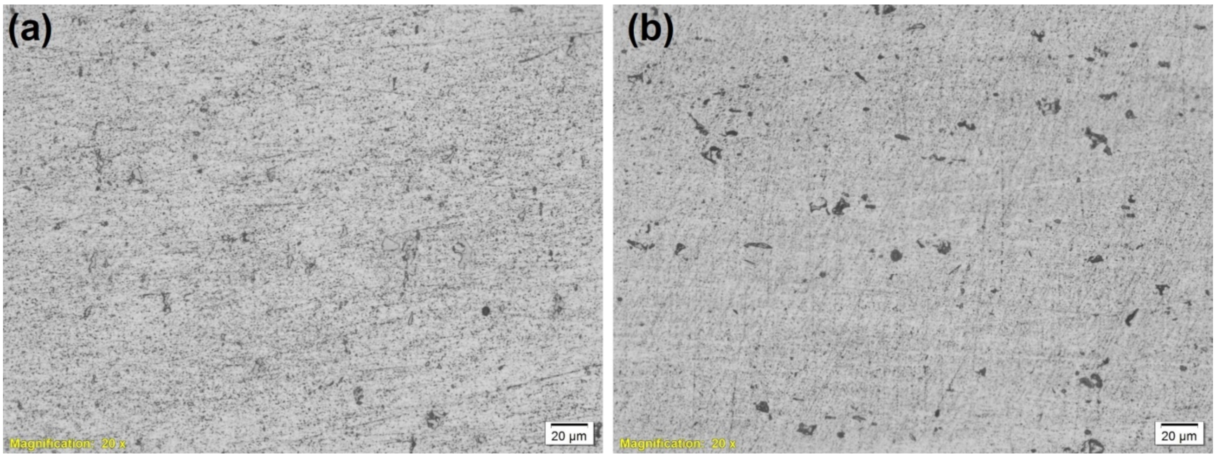

Figure 4. The microstructure of 7075 Al-alloy before etching at: (a) the induced bush, (b) the as-received condition.

Figure 5 displays the microstructures of the DZ, HAZ and the base metal after etching. It is apparent that the base metal has a grain size of approximately 50±15 µm. The grain size at the HAZ is 25±5 µm, while the grain size near the DZ is approximately 15±2 µm. The refinement of the grain size near the DZ is attributed to the dynamic recrystallization which occurs during the friction drilling process.

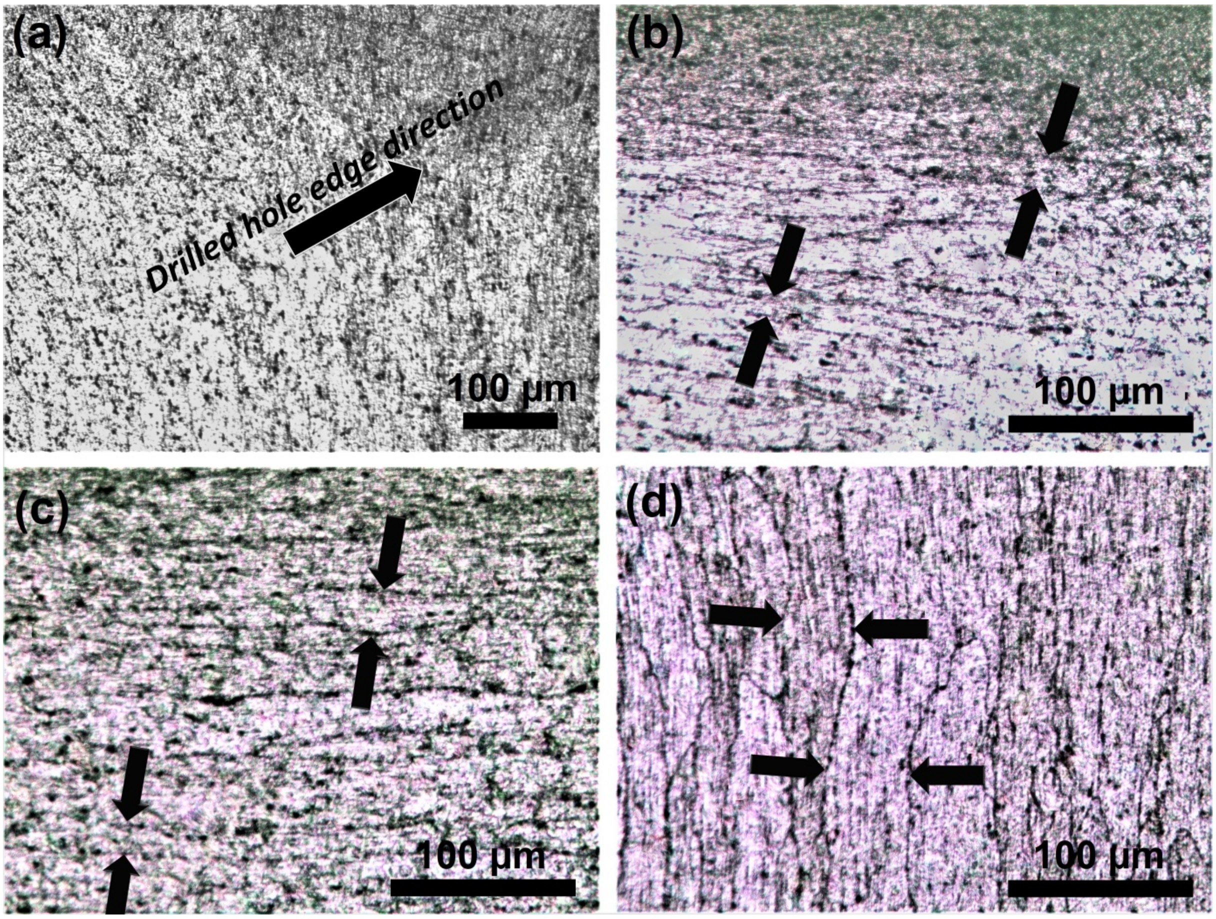

Figure 5. The microstructure of 7075 Al-Alloy after etching at: a), b) near the edge of the friction drilled specimen S21 at different magnifications, c) HAZ and d) base metal.

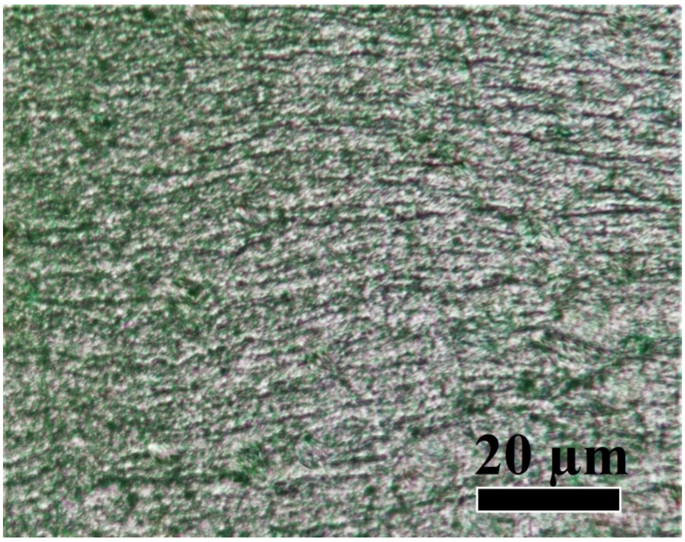

Figure 6. The microstructure at the edge of the induced bush of S21specimen.

Figure 6 exhibits the microstructure at the edge of the induced bush of S21. The grain size is approximately 2±0.5 µm. In spite of the grains refinement at the DZ and the HAZ, the hardness values of these zones are lower than the as-received condition. It seems that the existence of the intermetallic particles (figure 4.b) is the main reason behind the high values of hardness of the base metal.

The current results highlight the importance of the existing intermetallic particles in 7075 Al-alloy. The intermetallic particles are refined and/or crushed after friction drilling and consequently the friction drilled bush and the surrounding zone have hardness values lower than the base metal. On the other hand, we recommend performance of heat-treatments of 7075 Al-alloy after friction drilling processes in order to raise its hardness.

4. Conclusions

In the present study, the hardness values of thermal induced bushes of 7075 Al-alloy were investigated under different rotational speeds, feed rates and tool cone angles.

- The hardness value at the drilling zone was a maximum (77.2 HV) at *R* equals 1000 rpm, *F* equals 315 mm/min and β equals 45º. However, the hardness of the bush is a minimum (57.3 HV) when *R* equals 1600 rpm, *F* equals 100 mm/min and β equals 50º.
- The hardness values at the drilling zone and the heat affected zone are lower than that of the base metal.
- The dissolution/fragmentation of the intermetallic particles as well as material recrystallization associated with the friction drilling process are responsible for the reduction of the hardness values of the induced bush in spite of the refinement of the grain sizes at the drilling zone.

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