Investigation of Temperature Variation During Friction Drilling of 6082 and 7075 Al-Alloys

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Abstract

Friction drilling is used to process special holes with a bushing and a boss in thin sheet metals without producing chips via a non-traditional tool-drill. Friction drilling parameters involve the feed rate, rotational speed and profile dimensions of the drilling tool, which directly affect the induced bushings dimensions, as well as, the microstructure of the produced hole. In the present study, friction drilling parameters were manipulated during the performance of friction drilling of 6082 and 7075 Al-alloys, moreover, the temperature variation in the tool-work-piece interface was recorded during the drilling processes via an infrared camera and four thermocouples located at different positions near the drilling zone. During the formation of the bushing and the boss in the investigated aluminum sheet metals, the minimum measured temperature was 220 °C and the maximum measured temperature was 380 °C. It was found that the temperature in the tool-work-piece interface increased with the reduction of the feed rates and the increase of both of the rotating speeds and the tool cone angles. Furthermore, the surface roughness values of the drilled holes were found to be increased with the increase of the rotational speeds.

Keywords

Friction drilling • Temperature measurement • Surface roughness • Aluminum

Introduction

Friction drilling is a nontraditional hole-forming method. Due to the friction between a rotating conical tool and the work piece, heat is generated in the tool-work-piece interface. The generated heat enables softening, deformation, and displacement of the work material, which consequently creates a bushing and a boss through the drilled work piece [1–6].

The thickness of the produced bushing is greater than the thickness of the work piece (about three times), so that the depth for a planned threading and clamp load capability can be further increased. The existence of the bushing in thin sheets can be threaded, therefore, temporarily joining of the friction drilled specimens can be performed using studs or bolts [7]. This technique is particularly attractive for automotive industry, moreover, it is a flexible alternative method of the spot welding process which only provides joints with permanent joining [8].

During friction drilling, the extracted material from the drilled hole contributes to form the bushings, it eliminates chip generation. Thus, the friction drilling process is a chip-less hole-making process, which depends on the plastic deformation of the material [3–5]. Friction drilling is called thermal drilling, flow drilling and friction stir drilling. It is a dry drilling process and hence unlike traditional drilling; cutting fluids and coolants are not a must. However, the temperature of the tool-work-piece interface should be investigated in order to control the dimensional accuracy of the processed holes, surfaces roughness, grains size, as well as, the produced microstructure in the heat affected zones [9–11].

The aim of the present study is to investigate the temperature variation during the friction drilling of 6082 and 7075 aluminum alloys at different working conditions via the manipulation of the rotational speeds, the feed rates and the tool cone angles.

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Experimental Work

Materials

6082 and 7075-T6 Aluminum alloys were investigated for the experiments, the thicknesses of the sheets approximately were 4 mm. Table 1 shows the chemical composition of the alloys. It worth mentioning that the melting temperatures of the 6082 and the 7075 Al-alloys approximately are 575 and 635 °C respectively.

Drilling Tool

Figure 1 shows a schematic drawing of the friction drilling tool. Clearly, the tool consists of four regions; the center region, conical region, cylindrical region and shank region [11, 12]. (a) The center region: it is the region near to the tip of the tool. It has a very short length and a blunt angle (α) equals to 90°. The effect of blunting is to generate an extra force and heat at the start of the drilling. (b) The conical region: This region has an angle sharper than the angle of the center region. The drill in this region rubs against the work piece to generate the friction, then heat is produced and the work material is pushed to shape the bushing. The friction angle (is also defined here as the tool cone angle) and length of the cone-shape in the conical region are marked as β and h_n respectively. In the present study, three different friction angles of 40°, 45° and 50° are considered. (c) The cylindrical region: this region has a diameter (*d*) which is equal to the diameter of the hole. The length of this region is designated as h_l. In the present study, the drilling tool has *d* equals to 8 mm and h_1 equals to 16 mm. (d) The shank region: it is the region at where the tool is fixed in a rotating chuck.

Drilling Conditions

A vertical milling machine was used to carry out the friction drilling processes of the 6082 and 7075 Al-alloys. The selected variable parameters imply different rotational speeds (*R*) of 1000, 1250 and 1600 rpm; different feed rates (*F*) of 100, 200 and 315 mm/min, in addition to different tool cone angles (β) of 40°, 45° and 50°. Table 2 lists the drilling conditions of the current study. The total number of the performed experiments is 54; a number of 27 different drilling conditions for the 6082 Al-alloy and the same number of the drilling conditions for the 7075 Al-alloy.

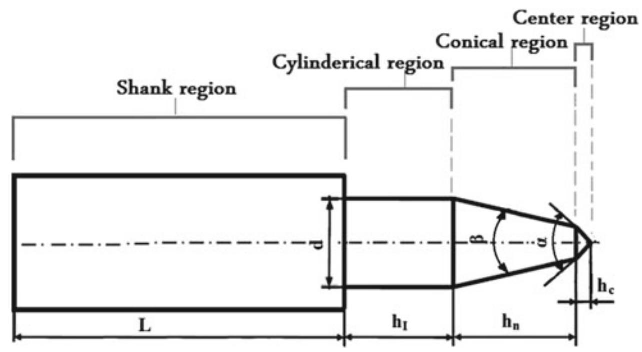

Fig. 1 Schematic drawing of the friction drilling tool

Temperature Recording

Temperature was recorded via four thermocouples located at different positions in addition to an infrared camera. The four thermocouples were located at distances of 10, 12, 20, and 24 mm from the center of the drilled holes. The thermocouples were connected with an USB-2048 Data acquisition card. The infrared camera was a FLUKE Ti32 Infra-Red camera type, it has a powerful 320 × 240 resolution and it has a thermal sensitivity of 0.045 °C and a temperature range from −20 to 600 °C.

Figure 2 displays the output of the infrared camera during the friction drilling of the 7075 S#5 specimen. It shows the temperature distribution in the drilling tool, as well as, the heat affected zone surrounding the drilled hole. All the drilling processes of the 54 specimens were recorded, the change in the temperature values are discussed in the results and discussion part.

Surface Roughness Measurements

Surface roughness values were measured by a Surf-test SJ-310 series 178-portable surface roughness tester. The measuring range of the detector was −200 μm to +160 μm with a cut-off length equals to 0.8 mm, the resolution of the detector was 0.02 μm and the measuring speed was 0.5 mm/s. The measurements of the surface roughness values of the hole-walls can be considered as an indicator of the friction drilling quality; the lower the surface roughness values, the higher the quality (finishing) of the surface.

Table 1 Chemical composition of 6082 and 7075 Al-alloys

Element, wt%	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
6082 Al-alloy	0.89	0.5	0.1	0.62	0.7	0.25	0.2	0.1	Bal.
7075 Al-alloy	0.4	0.5	1.4	0.3	2.3	0.22	5.6	0.2	Bal.

Table 2 Sample codes of the different drilling conditions

Sample number	R, rpm	F, mm/min	β, °	Sample number	R, rpm	F, mm/min	β, °	Sample number	R, rpm	F, mm/min	β, °
S#1	1000	100	40	S#10	1250	100	40	S#19	1600	100	40
S#2	1000	100	45	S#11	1250	100	45	S#20	1600	100	45
S#3	1000	100	50	S#12	1250	100	50	S#21	1600	100	50
S#4	1000	200	40	S#13	1250	200	40	S#22	1600	200	40
S#5	1000	200	45	S#14	1250	200	45	S#23	1600	200	45
S#6	1000	200	50	S#15	1250	200	50	S#24	1600	200	50
S#7	1000	315	40	S#16	1250	315	40	S#25	1600	315	40
S#8	1000	315	45	S#17	1250	315	45	S#26	1600	315	45
S#9	1000	315	50	S#18	1250	315	50	S#27	1600	315	50

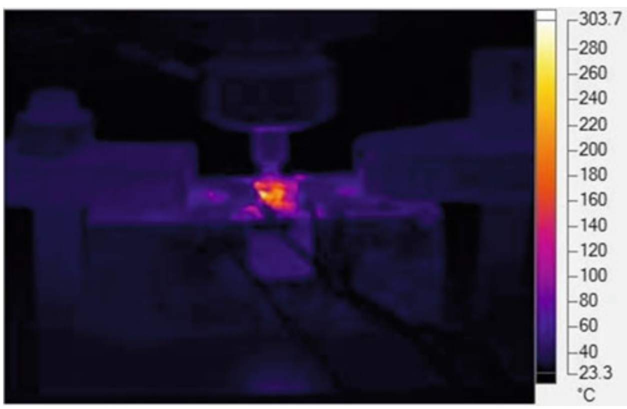

Fig. 2 The output of the infrared camera during friction drilling of the 7075 Al-alloy S#5. (Colored figure)

Results and Discussion

Figure 3a shows the drilling tool installed in the chuck of the vertical milling machine, while the aluminum sheet is fixed via studs and nuts in a special table. Figure 3b shows the cross sectional elevation of a friction drilled hole, it displays that the heights of the boss and the bush are greater than the thickness of the parent sheet.

Figure 4 shows the temperature distribution in the heat affected zone during the friction drilling of the 6082 Al-alloy at different conditions as previously illustrated in Table 2. Clearly, S#21 exhibits the maximum drilling temperature of 370 ± 20 °C which is achieved at *R* equals to 1600 rpm, *F* equals to 100 mm/min and β equals to 50°. However, S#7 shows the minimum drilling temperature of 220 ± 15° C

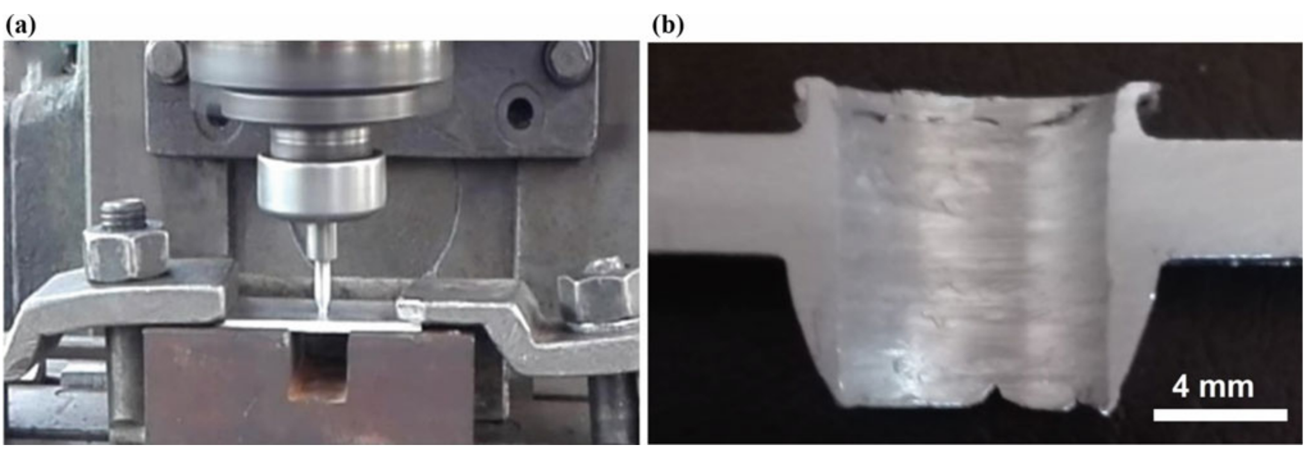

Fig. 3 **a** The setup of the drilling tool and the work piece, **b** a cross sectional elevation passing through the center of a hole produced by friction drilling

which is achieved at *R* equals to 1000 rpm, *F* equals to 315 mm/min and β equals to 40°.

Figure 5 shows the temperature distribution in the area surrounding the drilled hole during the friction drilling of the 7075 Al-alloy at different conditions. It is clear that the specimen S#21 exhibits the maximum drilling temperature of 380 ± 25 °C, which is achieved at *R* equals to 1600 rpm, *F* equals to 100 mm/min and β equals to 50° similarly to the 6082 Al-alloy. It leads us to conclude that the temperature is increased with the reduction of the feed rate and the increase of the rotational speed and the tool cone angle. On the other hand, S#6 shows the minimum temperature value of 220 ± 15 °C which is achieved at *R* equals to 1000 rpm, *F* equals to 200 mm/min and β equals to 50°.

In order to analyze the maximum temperature values (at the tool-work-piece interface) as shown in Figs. 4 and 5, the maximum temperature values were compared together. Figure 6 shows interaction plots of the maximum temperature values of the 6082 and 7075 Al-alloys. Figure 6a shows the effect of the feed rate increase on the temperature values under rotational speeds of 1000, 1250 and 1600 rpm in the 6082 and 7075 Al-alloys. It is clear that temperature values decreased with the increase of the feed rates. Figure 6b shows the effect of the tool cone angle increase on the temperature values under rotational speeds of 1000, 1250 and 1600 rpm in the 6082 and 7075 Al-alloys. Clearly, the temperature increased with the increase of the tool cone angles from 40° to 50°, however, the temperature recorded at

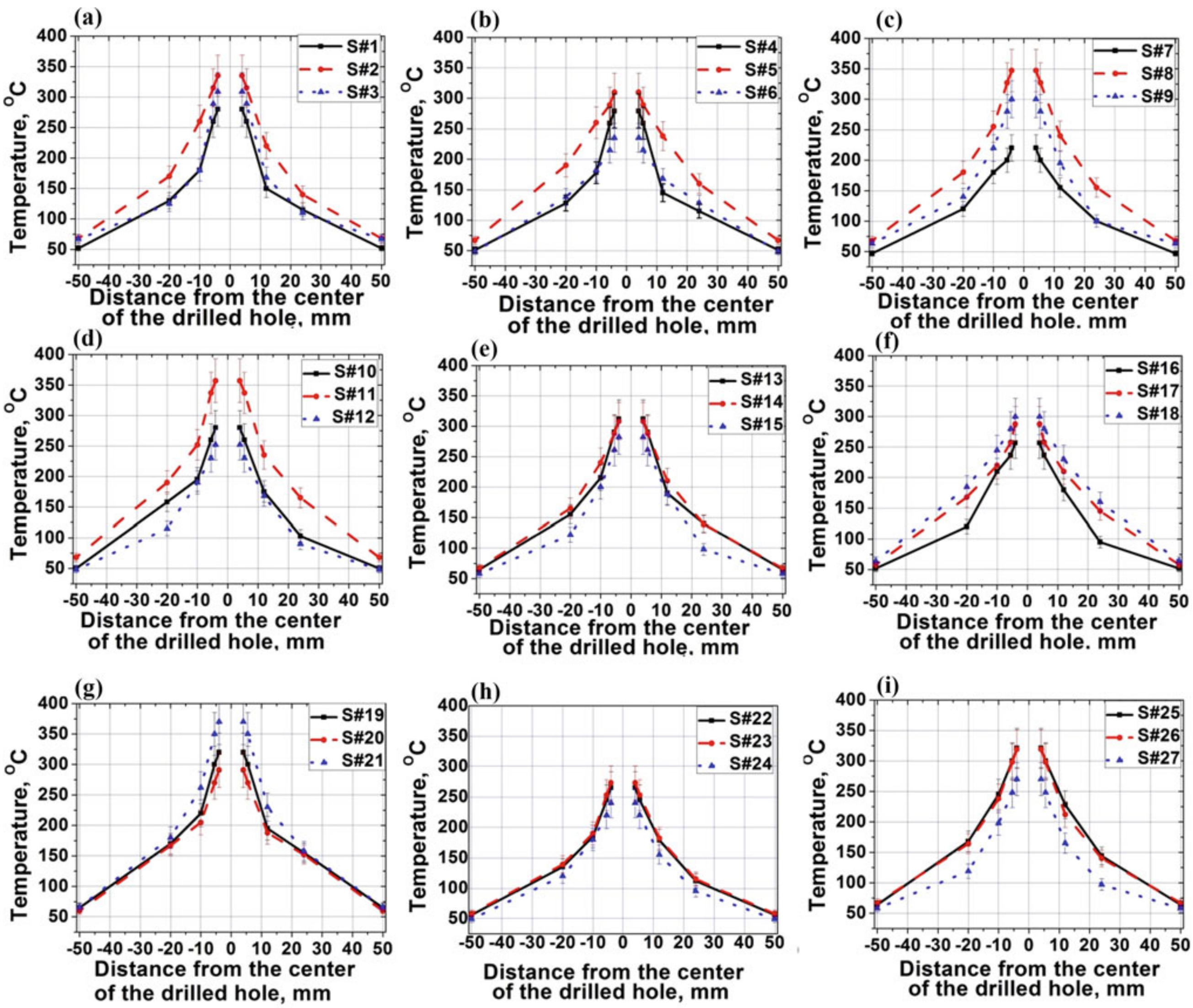

Fig. 4 The mean temperature values during the friction drilling of the 6082 Al-alloy at different conditions measured by the four thermocouples and the infrared camera

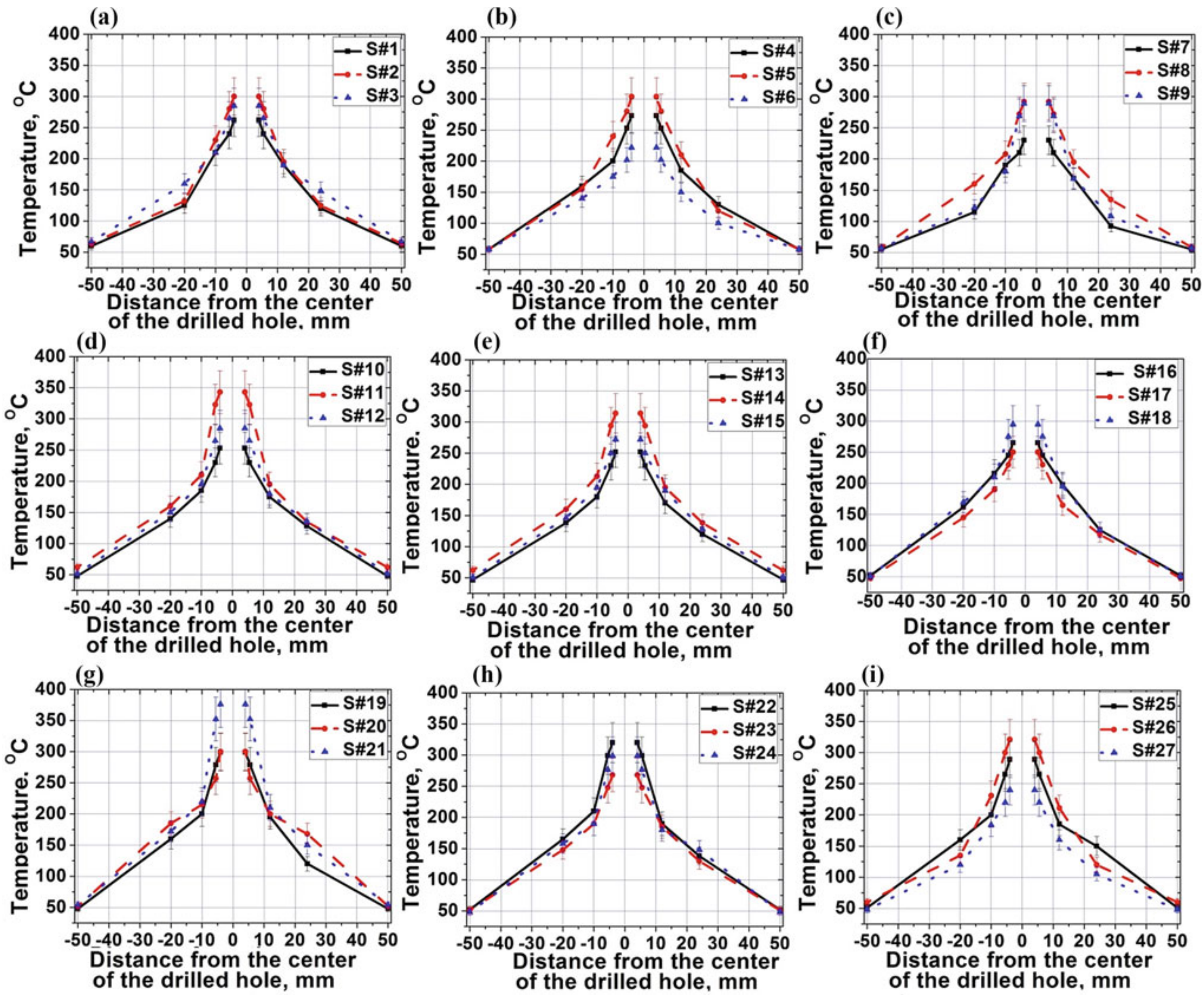

Fig. 5 The mean temperature records during the friction drilling of the 7075 Al-alloy at different conditions measured by the thermocouples and the infrared camera

β equals to 45° is higher than the temperature recorded at β equals to 50°, which will be interesting to reveal the reason behind this result in future work [Under Preparation].

The increase of the temperature during the friction drilling process refers to an increase of the accompanying friction between the tool and the work piece. The rise of the temperature directly affects the grains size of the produced microstructures, as well as, the thrust force required to carry out the drilling processes which will be discussed in future work [Under Preparation].

It is supposed that the increase of the induced heat during the friction drilling of the 6082 and 7075 Al-alloys enhance the plastic flow of the material drilled by the tool-drill, and hence, it is expected that the dimensions of the drilled holes and the bushings heights are directly affected by the induced drilling temperatures. Based on the results shown in Figs. 4, 5 and 6, a number of three conditions were selected for more investigations (S#7, S#16 and S#25). The three drilling conditions had the same feed rate (315 mm/min) and the same tool cone angle (40°), while the rotating speeds of S#7, S#16 and S#25 were 1000, 1250 and 1600 rpm respectively. Table 3 lists the dimensions of the drilled holes diameters, bushing and boss heights, as well as, the temperature recorded at the tool-work-piece interface in S#7, S#16 and S#25 for the 6082 and 7076 Al-alloys.

Table 3 shows that the temperature increased with increasing of the rotational speed in both of 6082 and 7075 Al-alloys. Clearly, with the increase of the temperature, the diameters of the drilled holes became more accurate (close to 8 mm), while the bushings heights were not seriously affected. In addition, the boss heights were increased with increasing of the temperature. It leads us to conclude that the

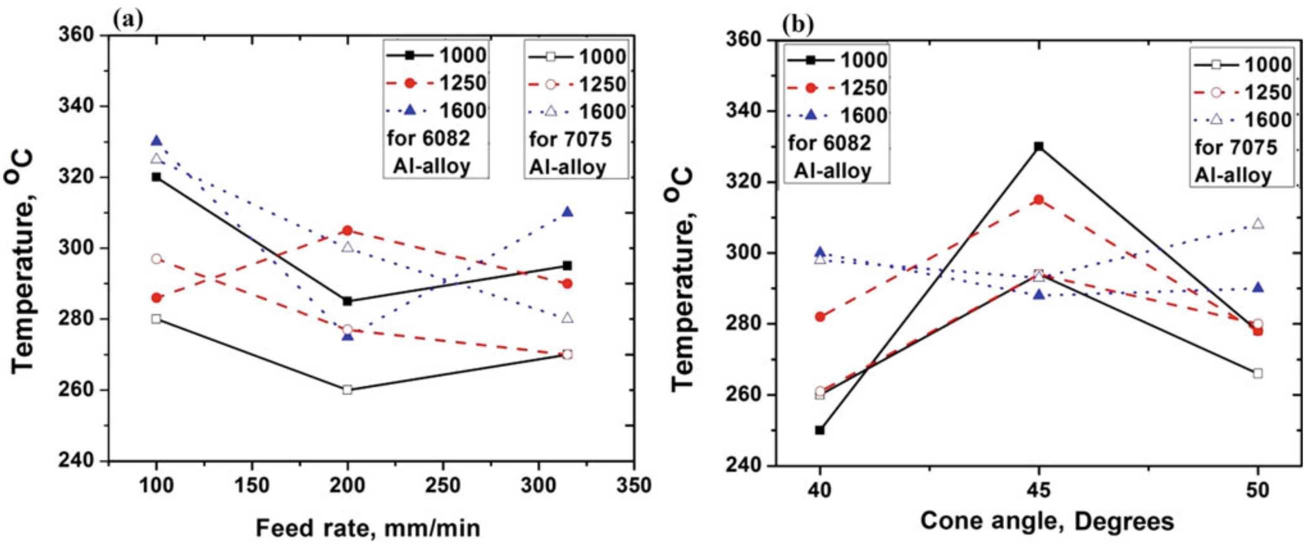

Fig. 6 The effect of changing of **a** the feed rate, **b** tool cone angle on the maximum temperature values induced at the edges of the drilled holes in 6082 and 7075 Al-alloys at different rotational speeds

Table 3 Temperature values and dimensions of the diameter, bush and boss of S#7, S#16 and S#25 for 6082 and 7075 Al-alloys

Sample number	Diameter (d), mm		Bushing height, mm		Boss height, mm		Temperature, °C	
	6082 alloy	7075 alloy	6082 alloy	7075 alloy	6082 alloy	7075 alloy	6082 alloy	7075 alloy
S#7	7.85 ± 0.05	7.79 ± 0.1	4.92 ± 0.3	4.6 ± 0.4	2.1 ± 0.1	2.66 ± 0.1	220 ± 15	230 ± 16
S#16	7.89 ± 0.06	7.82 ± 0.1	5.07 ± 0.2	5.04 ± 0.25	2.52 ± 0.18	3.35 ± 0.2	257 ± 20	265 ± 22
S#25	7.97 ± 0.03	7.93 ± 0.07	5.12 ± 0.25	5.08 ± 0.3	3.26 ± 0.3	3.51 ± 0.3	321 ± 25	289 ± 24

Table 4 Surface roughness values of S#7, S#16 and S#25 for 6082 and 7075 Al-alloys

Sample number	Surface roughness, μm	
	6082 alloy	7075 alloy
S#7	1.70 ± 0.64	1.20 ± 0.34
S#16	2.22 ± 0.9	2.00 ± 0.92
S#25	4.04 ± 1.1	4.06 ± 1

temperature rise associated with the induced frictional heat enhanced the softening and the plastic flow movement of the extracted material from the friction-drilled holes, which resulted in increasing of the boss height. As a consequence, the diameters and bushings dimensions of the drilled specimens at high temperatures showed higher accuracy than the drilled specimens at low temperatures.

The values of the surface roughness represent a strong evidence of the quality of the surface. Table 4 lists the average surface roughness values of S#7, S#16 and S#25 for both of 6082 and 7075 Al-alloys. Clearly, the surface roughness values increased with the increase of the rotational speeds, the surface roughness of the 6082 Al-alloy increased from 1.7 μm at 1000 rpm to 4.04 μm at 1600 rpm, and also the surface roughness of the 7075 Al-alloy increased from 1.2 μm at 1000 rpm to 4.06 μm at 1600 rpm. It seems that the quality of the produced surfaces by the friction drilling is negatively affected with the increase of the rotational speed from 1000 to 1600 rpm at feed rate of 315 mm/min and tool cone angle of 40°.

Conclusion

To conclude, temperature variation was recorded during the friction drilling of 6082 and 7075 Al-alloys at various rotational speeds, tool cone angles and feed rates. It was found that the temperature directly increased with the increase of the rotational speed and the tool cone angle whereas it decreased with the increase of the feed rate. The reduction of the feed rate values resulted in the increase of the contact time between the drilling tool and the work piece, which caused a temperature rise during the friction drilling of the 6082 and 7075 Al-alloys. The increases in the frictional heat directly improved the flow and plasticity of the extracted material during the friction drilling of the

Al-alloys, therefore the dimensions of the drilled holes and bushings were more accurate with the increase of the temperature. Whereas, at a feed rate of 315 mm/min and a tool cone angle of 40°, the reduction of the rotational speed from 1600 to 1000 rpm positively affected the surface roughness of the produced holes.

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