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Research article

Investigate the effect of tool conical angle on the bushing height, wall thickness and forming in friction drilling of A7075-T651 aluminum alloy

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Abstract

Friction drilling process is a non-traditional hole drilling process formed by thermal friction having the most important features such as no pollution, short machining time and long tool life. In this process conical tool is used to generate heat by friction to soften and generate a thin workpiece and create a bushing without generating chips. In this friction drilling experimental study, the selected spindle speeds were 2400 rpm, 3600 rpm, and 4800 rpm, feed rates were 50 mm/min, 75 mm/min, and 100 mm/min and tool material was HSS tool with 24°, 36°, and 48° conical angles, 8 mm, 10 mm, and 12 mm cylindrical region diameters and 16 mm tool cylindrical region lengths. The specimens were A7075-T651 with thickness of 4 mm, and 6 mm. The effect of tool conical angle on the bushing height, bushing wall thickness, and bushing shape were analyzed. It was seen that for 4 mm and 6 mm materials thicknesses, according to the bushing height, the most optimum tool conical angle was 24° for all diameters. For 4 mm material thickness according to the bushing wall thickness 48° was the most optimum conical angle in friction drilling 8 mm diameter, 24° for friction drilling 10 mm and 12 mm diameters. The most optimum tool conical angle was 36° for 8 mm diameter, 24° for 10 mm and 12 mm diameters. With decreasing tool conical angle the bushing height was increased and bushing wall thickness was decreased. In the conditional low tool conical angles the softened material flow in the direction of tool motion in friction drilling, thus bushing height increased and wall thickness decreased. With increasing both tool conical angle and spindle speed the cracks in obtained bushing were advanced and the shape of bushing formed as petal. But with increasing feed rate the bushings shapes were not changed.

Keywords: *Friction drilling, tool conical angle, bushing height*

1. Introduction

Friction drilling is a non-traditional hole making method which was introduced to the industry about three decades ago. In the process, the heat generated from friction between a rotating conical tool and workpiece to soften and generate a hole in thin workpiece. The soften material flowed in tool movement direction and forming bushing under of hole. Some of the soften material flowed in counter tool movement direction and forming flake at the top of the hole and some of the material is spread around hole with

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the effects of spindle speed, torque and feed rate. The most important purpose of friction drilling is to increase thickness for threading and available clamp load from the thin workpiece. Thus it is provided by the bushing forming at the under of the hole.

Literature survey provided very limited information about friction drilling. The high spindle speed and workpiece pre-heating were beneficial to reduce the thrust force, torque, energy, and power, but did not affect the bushing formation at the room temperature as well as on the bushing shape. Higher feed rate and shorter cycle time for hole drilling was demonstrated to be feasible with reduced thrust force, torque, and no change in bushing quality [1].

A proper geometrical shape of drill and parameters of drilling were found in order to obtain a quality hole surface after exploring the surface roughness using Taguchi Method. The friction drill had a better performance such as avoiding serious tool wears, enhancing hole quality, and prolonging the tool life significantly. The drilled surrounding area obtained fine grain size and high micro-hardness than that of area away from drilled area [2].

The tool wear was concentrated at the tool center region and at the intersection between the conical and cylindrical regions. During friction drilling, the tool tip self-sharpened which reduced the thrust force, at different stages of tool wear the torque did not display any obvious change, and adhesive, oxidative, and abrasive wear all occur. But it is difficult to determine wearing types' proportional contributions. These wearing types associated with diffusion wear, may change as the tool continues to wear out [3,4].

It is due to the adhesion of tool to workpiece material (AISI 304 stainless steel), which enhanced the tool surface roughness and raised the friction coefficient. At the same friction drilling conditions, coated tools suffered less tool wear than uncoated drills. Drill coating suffered greater tool wear and the difference in surface temperature between coated and uncoated tools diminished at higher spindle speeds. The heat generated in friction drilling was noticed to be about 1/2 to 2/3 of the workpiece melting temperature. The ratio of workpiece thickness (t) to hole diameter (d) is an important parameter that effect the bushing shape in friction drilling [9].

The thrust force and torque under constant spindle speed were measured and analyzed at the end of experimental analysis and modeling of the friction drilling process. A mathematical model based on the contact area between tool and workpiece. The model-predicted thrust force and torque had good correlation with experimental measurements. However the model will require better understanding of the tribological phenomenon, heat partition between the tool and workpiece, and prediction of coefficient of friction in both radial and axial directions [6,7].

The workpiece preheating had proven to be beneficial to reduce the thrust force, torque, energy and power for friction drilling. The micro structure and friction forces are affected by temperature. The temperature in friction drilling is dependent stress-strain properties of the work-material. The work material deformation and temperature in friction drilling could be demonstrated with using the 3D FEM (finite element method) model [8].

The microstructures are effected by friction forces and heat produced during friction drilling process. Depending on the thermal conductivity and frictional energy, the localized heating can reduce the work hardening that would occur by deformation done. The adherence of work-material to the tool increased the frictional work done and thus the energy required to create a hole. Some of the heat that produced by friction drilling process, goes into the tool, a portion transfer to the workpiece, and rest is dissipated to the around [9].

At the higher rotation speed, hardness is greater near the hole wall due to the higher temperature generated, better roundness and surface roughness could be obtained. Lower rotation speed leads to a lower wall temperature which may cause molten metal to adhere to the tool. As a result the molten melt scratches against the hole wall, thus increasing surface roughness. In addition that lower rotation speed generates less heat energy, thus cooling becomes faster, resulting in uneven contraction that yield a hole wall with poor roundness [10,11].

The bushing height which formed at the end of friction drilling processes is about 2-3 times of material thickness [12].

In literature, the bushing height, bushing wall thickness and bushing shape were less studied subjects. The purpose of this study is to analyze the bushing height, bushing wall thickness and bushing shape according to the tool conical angles.

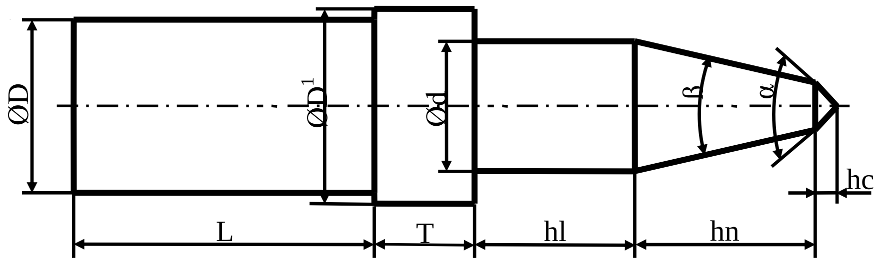
2. Experimental Setup and Procedure

A HESSAP True-Trace C-360/3D 1095 Model copy milling machine was used for friction drilling experiments of A7075-T651 material. Overview of the setup in HESSAP True-Trace C-360/3D 1095 Model copy milling machine was shown in Fig. 1. The tool was held by a standard tool holder. The tools used in this study have 8 mm, 10 mm, and 12 mm diameters, 16 mm cylindrical region lengths, 90° tools tip and 24°, 36° and 48° tools conical angles. The tool material was HSS showed in Fig. 2. The used spindle speeds were 2400 rpm, 3600 rpm, 4800 rpm, and the feed rates were 50 mm/min, 75 mm/min, and 100 mm/min respectively. 4 mm, and 6 mm thickness A7075-T651 material used for experiments in this friction drilling study. The cylindrical lengths (h_l) of the tools are 16 mm.

(a) (b)

Fig. 1 Experimental setup with tool (a) and workpiece (b)

The bushes which were formed at the end of the friction drilling were shown in Fig. 3a, b, and c. They were measured with a depth micrometer which demonstrated in Fig. 3d. Bushing height was measured in mm unite. Bushes were divided into two equal pieces [Fig. 3e, f, and g]. Then the bushing wall thickness was measured with a micrometer whose measuring limit was between 0 – 25 mm [Fig. 3h].



(a)

(b)

Fig. 2 Tool geometrical dimension, (a) tool geometry (b) tool photograph

The bushings' height were measured with a depth micrometer shown in Fig. 3. The measuring spindle of the micrometer was adjusted to contact the surface of the workpiece material and the vicinity the tip of the bushing was taken under the paddle of the micrometer. Then the height value of the bushing was clarified. The height of the bushings were measured in four different locations. And the highest value was taken into consideration.

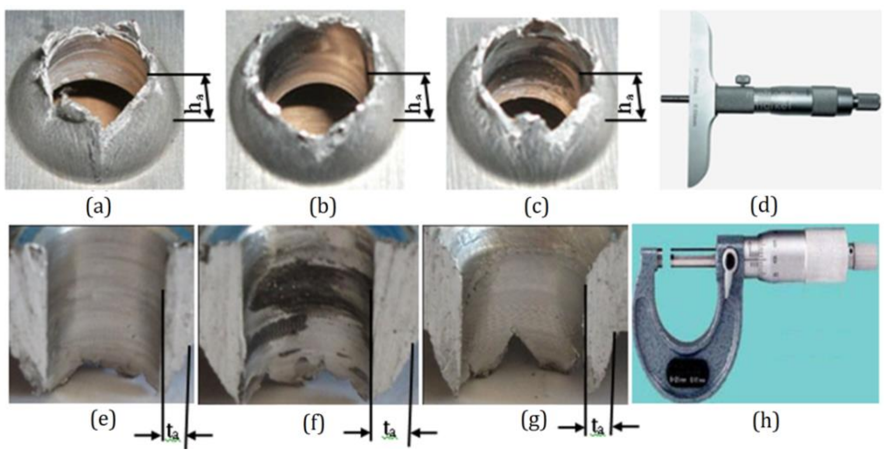


Fig. 3 Bushing height measuring style (a-c), depth micrometer (d), bushing wall thickness measuring style (e-g), and 0 – 25 mm micrometer (h)

3. Results and Discussion

Friction drilling processes are based on the frictional heat between rotating conical tool and workpiece. Therefore tool conical angle constituted the mechanism of the friction drilling process due to cross-sectional area between tool conical surface and workpiece material. The source of the temperature which was generated between tool and workpiece cross-sectional area was friction heat. Because of frictional heat formation, the tool conical angle is the most important parameter in friction drilling. The conical angle of the tool gives bushing shape when bushing formation starts. The other important parameters in friction drilling operations which affect the bushing height, bushing wall thickness, and bushing shape are t/d ratio, spindle speed, the length of the tool cylindrical section. With increasing both tool conical angle and spindle speed the cracks in obtained bushing were advanced and the shape of bushing becomes as petal. But with increasing feed rate the bushings shapes were not changed.

The effect of tool conical angle on the bushing height (Fig. 4a, b, and c) bushing wall thickness (Fig. 4a_1, b_1, and c_1), and bushing shape (Fig. 5) were demonstrated with drilling 8 mm diameter hole to the 4 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. According to the graphs shown in Fig. 4, with increasing both spindle speed and tool conical angle the bushing height increased. Decreasing the tool conical angle provided the most cross-sectional area between tool and workpiece thus cause to become more operation heat. The cross-sectional area and frictional heat were decreased with increasing the tool conical angle. In conditions both high spindle speed and tool conical angle the bushing height was increased and bushing wall thickness was decreased. The biggest bushing height became into existence in friction drilling 50 mm/min feed rate, 24° conical angle, 2400 rpm spindle speed and 48° conical angle, 4800 rpm spindle speed conditions. The biggest bushing wall thicknesses were occurred in friction drilling 100 mm/min feed rate, 48° conical angle for all spindle speeds conditions. The highest bushing was measured as 6.55 mm in friction drilling 50 mm/min feed rate, 2400 rpm spindle speed, and 48° conical angle, the most wall thickness was measured a 1.99 mm in friction drilling 48° conical angle, 100 mm/min feed rate, 4800 rpm spindle speed conditions.

The effect of tool conical angle on the bushing height (Fig. 6a, b, and c) bushing wall thickness (Fig. 6a_1, b_1, and c_1), and bushing shape (Fig. 7) were demonstrated with drilling 8 mm diameter hole to the 4 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. According to the graphs which shown in Fig. 4 with increasing both spindle speed and tool conical angle the bushing height was decreased. With increasing hole diameter from 8 mm to 10 mm the material volume, which flown in direction of tool motion, was increased. Therefore inquiry the higher heat that become into existence in friction drilling. The biggest bushing height were measured at 50 mm/min feed rate, 24° conical angle, 2400 rpm spindle speed conditions which measured as 7.56 mm. The bushing wall thickness increased with increasing spindle speed and decreased with increasing tool conical angle. The highest bushing wall thickness measured as 2.05 mm in friction drilling at 100 mm/min feed rate, 24° conical angles, 3600 rpm and 4800 rpm spindle speeds conditions. The softened, flowing and become viscose material spread around hole diameter due to spindle momentum and bushing wall thickness increased in conditions high spindle speeds.

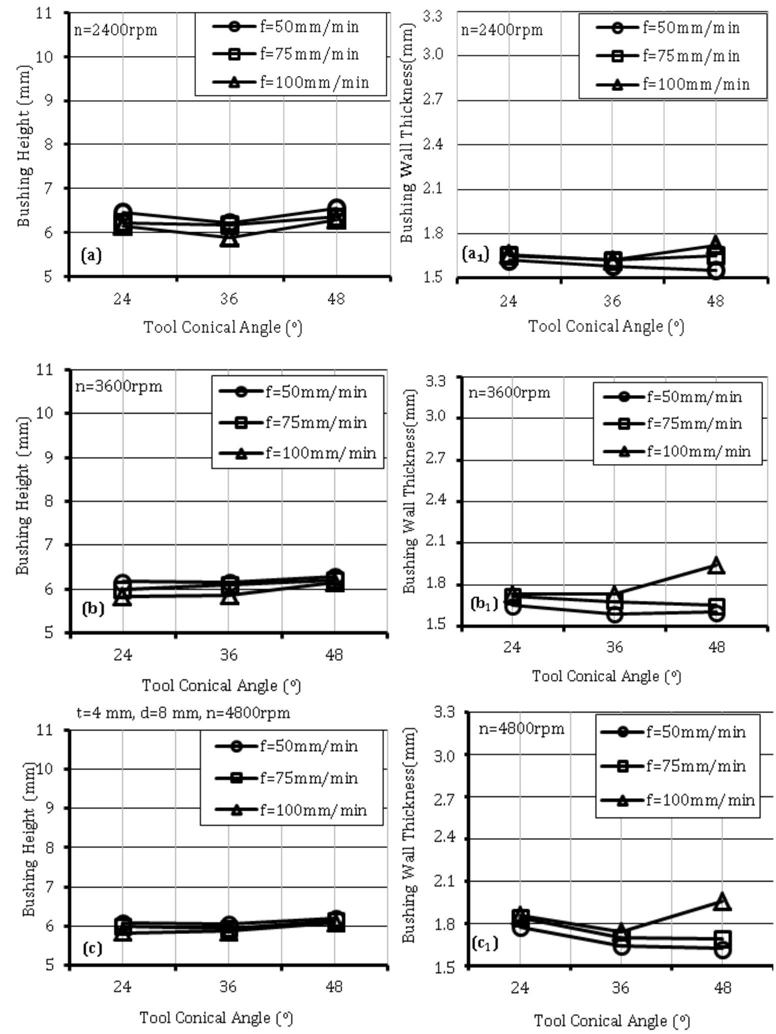


Fig. 4 For d= 8 mm, t=4 mm, h_1=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

	n=2400 rpm			n=3600 rpm			n=4800 rpm		
β ↓	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min
24°									
36°									
48°									

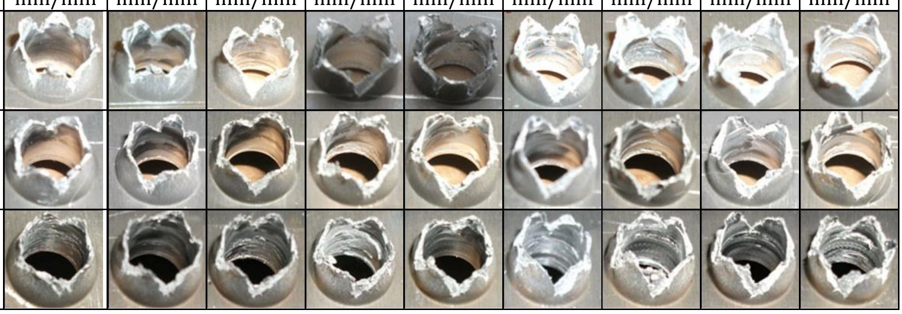


Fig. 5 Bushing shapes

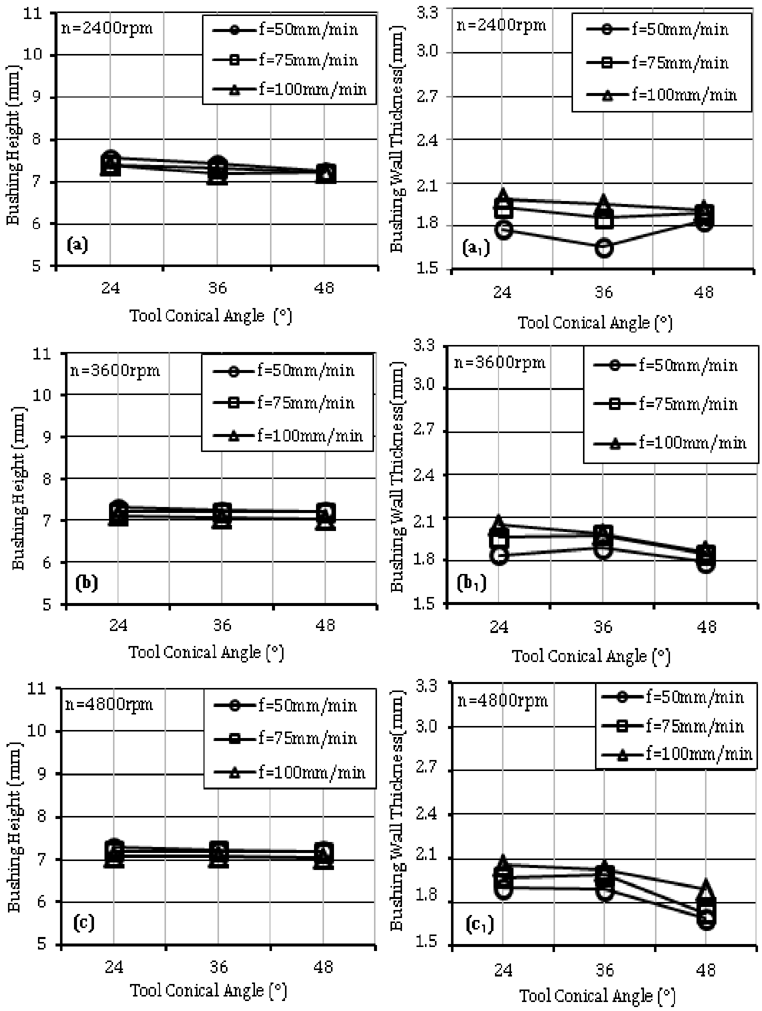


Fig. 6 For d= 10 mm, t=4 mm, h_1=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

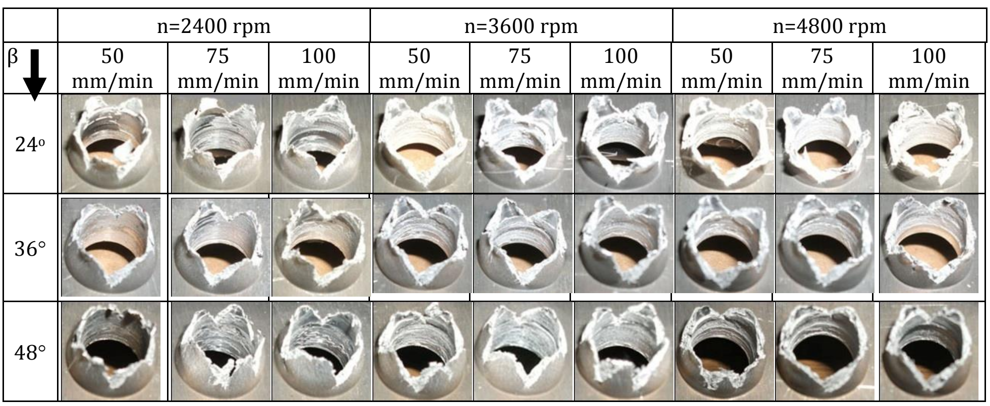


Fig. 7 Bushing shapes

The effect of tool conical angle on the bushing height (Fig. 8a, b, and c) bushing wall thickness (Fig. 8a_1, b_1, and c_1), and bushing shape (Fig. 9) were demonstrated with drilling 8 mm diameter hole to the 4 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. The raises hole diameter from 8 mm or 10 mm to 12 mm caused to increase material volume which flown in direction tool motion in friction drilling. The raised material volume inquired more heat, which softened workpiece material, provided it is flown, and increased its viscosity. When tool conical angle increased, due to the less cross sectional area between tool and workpiece material, the frictional heat decreased. At high spindle speeds conditions the operation heat, which occurred at the result of friction, increased. Increasing spindle speed exterminated the negative effect of high tool conical angle on frictional heat which occurred. The highest bushing was become into existence at 50 mm/min feed rate, 24° and 48° conical angles, for all spindle speeds conditions. According to the highest bushing criterion the optimum tool conical angles were 24° for 2400 rpm and 48° for 4800 rpm spindle speeds. At 50 mm/min feed rate, for 2400rpm and 3600rpm spindle speeds the optimum conical angles were 24° and 48°. When feed rate increased to 75 mm/min or 100 mm/min, at 2400 rpm and 3600 rpm spindle speeds, the bushing height decreased. At 4800 rpm spindle speed the bushing height increased orderly with increasing tool conical angle. The most bushing height measured as 8.93 mm at 50 mm/min feed rate, 2400 rpm spindle speed and 24° conical angle conditions. The bushing wall thickness was decreased systematically with increasing tool conical angle. But at 3600 rpm spindle speed, 50 mm/min feed rate, 48° conical angle the bushing wall thickness increased. The highest bushing wall thickness measured as 2.05 mm at 3600 rpm and 4800 rpm spindle speeds, 24° conical angle and 50 mm/min feed rate conditions.

The effect of tool conical angle on the bushing height (Fig. 10a, b, and c) bushing wall thickness (Fig. 10a_1, b_1, and c_1), and bushing shape (Fig. 11) were demonstrated with drilling 8 mm diameter hole to the 6 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. With increasing workpiece thickness from 4 mm to 6 mm the bushing height and bushing wall thickness were increased because of more material volume which become into existence in friction drilling of A7075-T651 alloy. The bushing height decreased with decreasing both spindle speed and tool conical angle. The feed rate effect on bushing height was less than the effect of spindle speed and conical angle. The highest bushing was measured at 50 mm/min federate, 2400 rpm spindle speed, 24° conical angles as 6.74 mm. The bushing wall thickness increased with increasing feed rates. The most optimum tool conical angle was 36° according to the bushing thickness criterion. The highest bushing wall thickness were measured at 100 mm/min feed rate, 2400 rpm, and 3600 rpm spindle speeds, 36° conical angle as orderly 2.42 mm and 2.47 mm. For 4800 rpm spindle speed, the 75 mm/min was seen the most optimum feed rate according to the bushing wall thickness criterion.

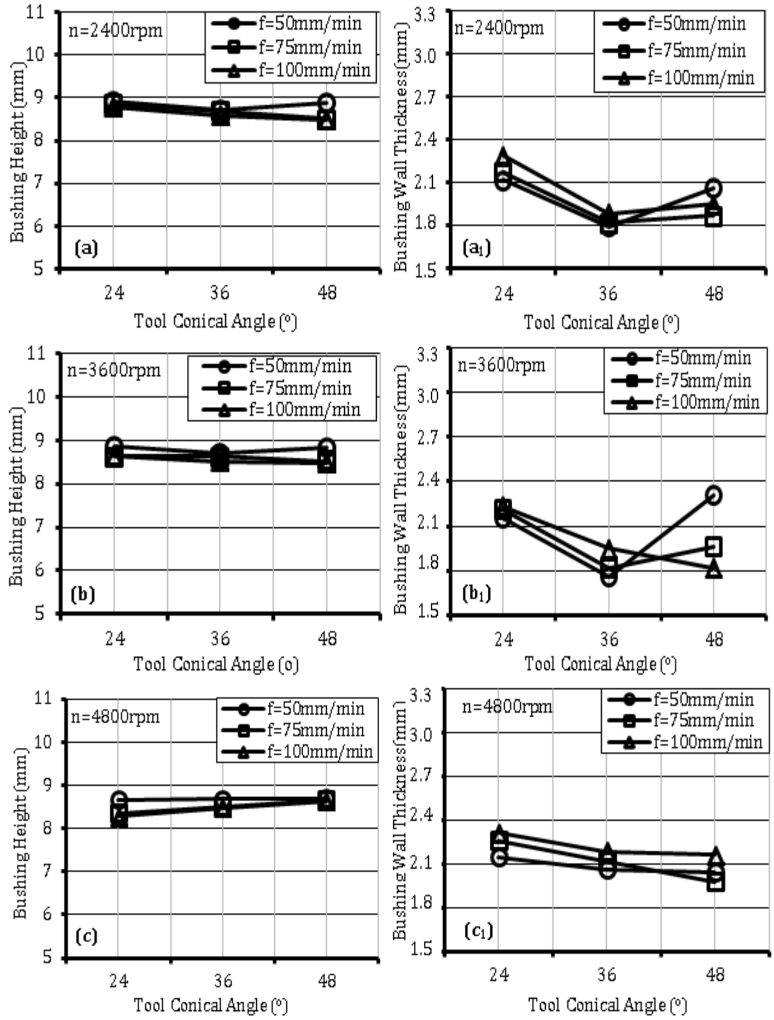


Fig. 8 For d= 12 mm, t=4 mm, h_l=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

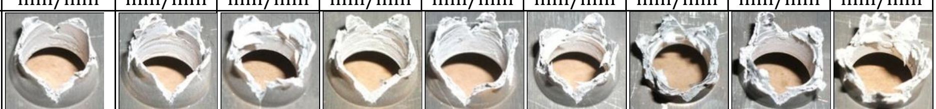
	n=2400 rpm			n=3600 rpm			n=4800 rpm		
β ↓	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min
24°									
36°									
48°									

Fig. 9 Bushing shapes

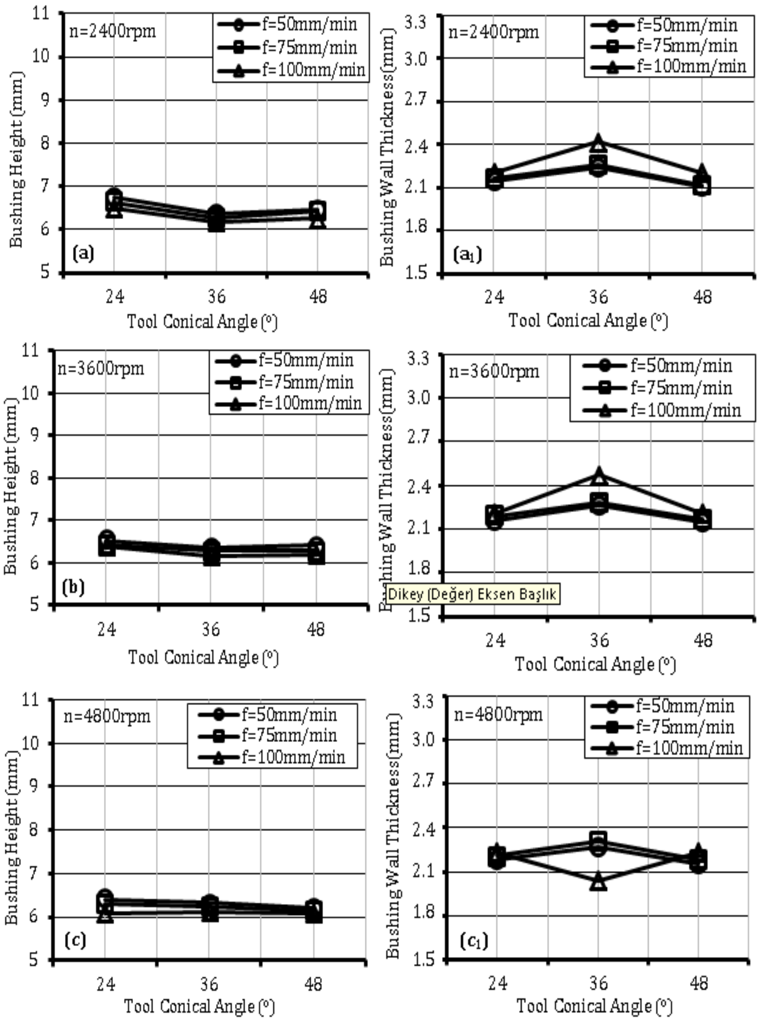


Fig. 10 For d=8 mm, t=6 mm, h_1=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

	2400 rpm			3600 rpm			4800 rpm		
β	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min
24°									
36°									
48°									

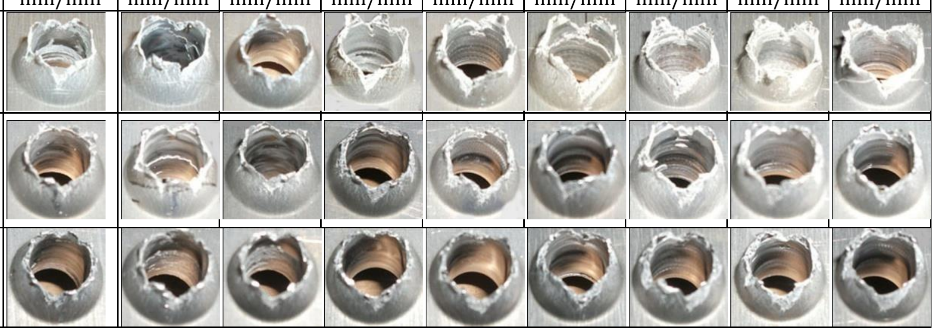


Fig. 11 Bushing shapes

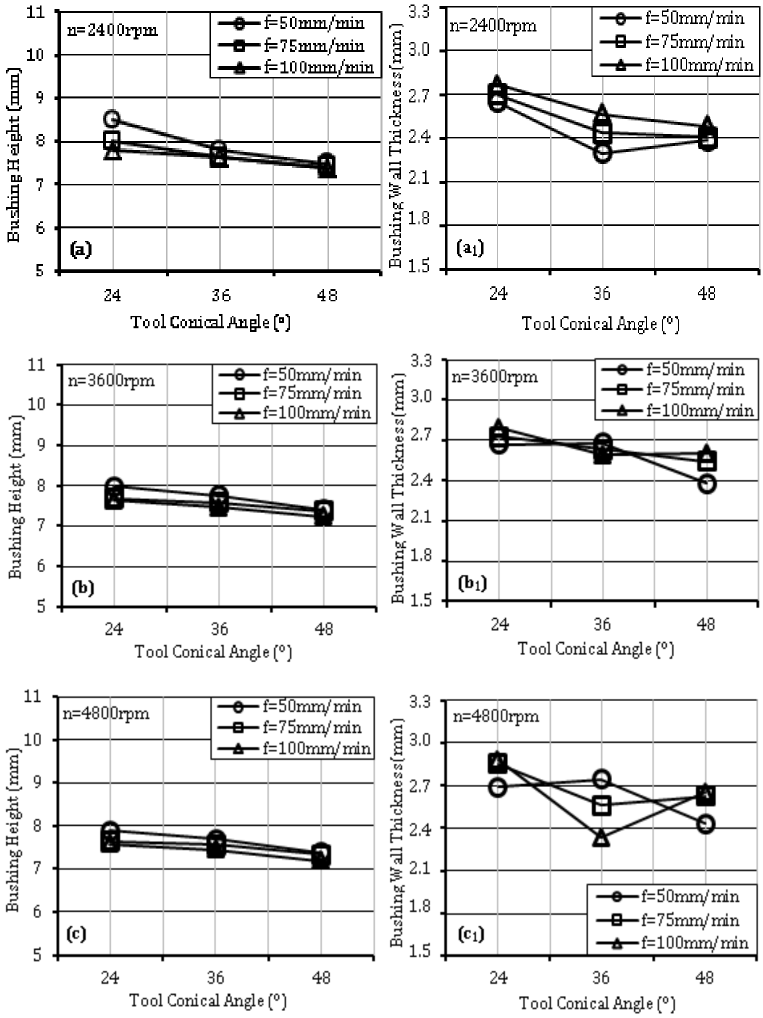


Fig. 12 For d= 10 mm, t=6 mm, h_1=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

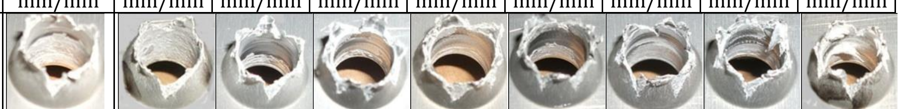
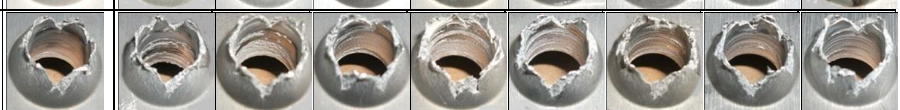
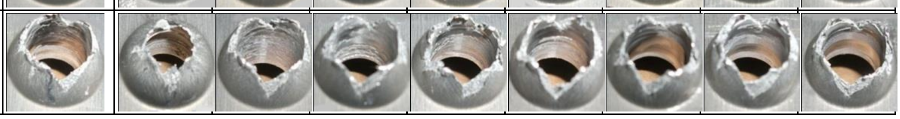
	n=2400 rpm			n=3600 rpm			n=4800 rpm		
β	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min
24°									
36°									
48°									

Fig. 13 Bushing shapes

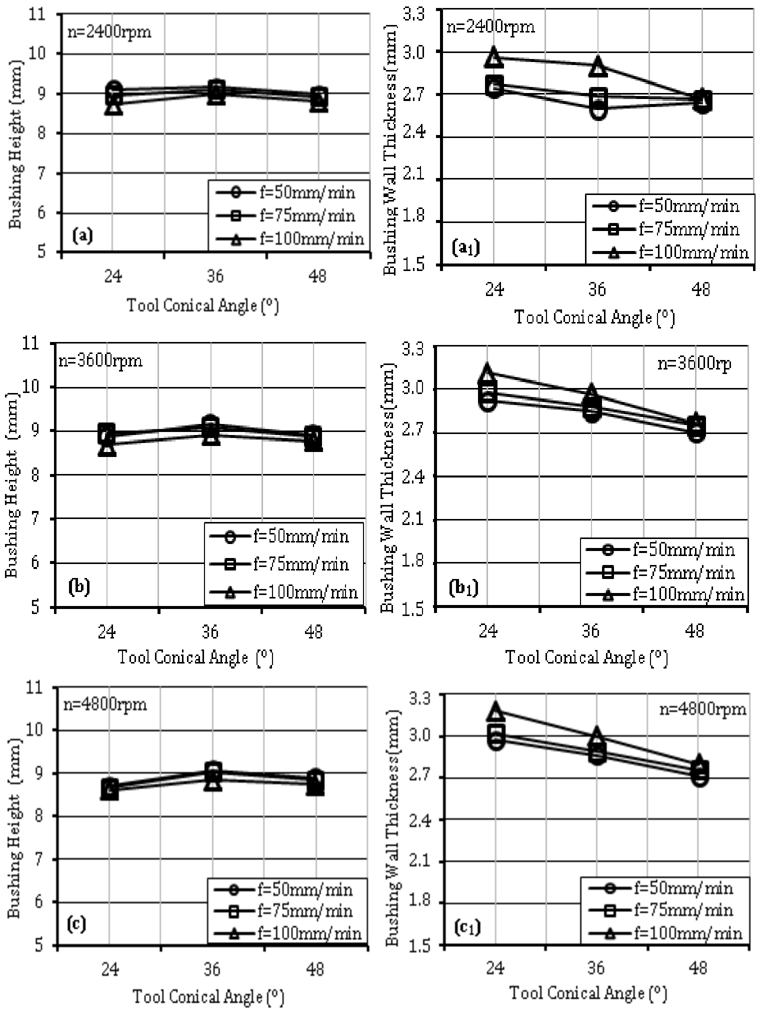


Fig. 14 For d= 12 mm, t=6 mm, h_l=16 mm the effect of tool conical angle on bushing height (a-c), bushing wall thickness (a_1-c_1)

	n=2400 rpm			n=3600 rpm			n=4800 rpm		
β	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min	50 mm/min	75 mm/min	100 mm/min
24°									
36°									
48°									

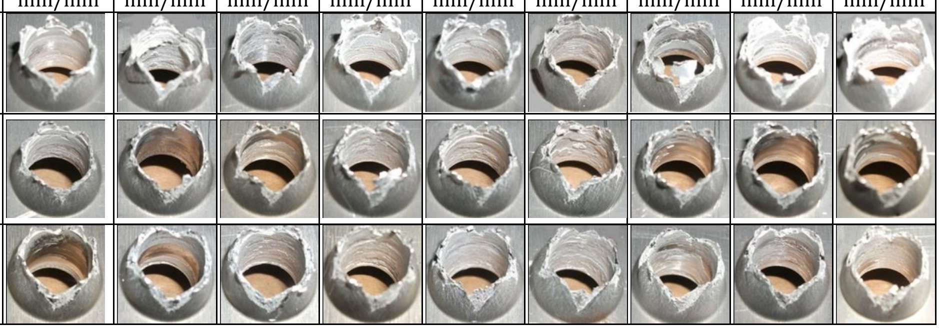


Fig. 15 Bushing shapes

The effect of tool conical angle on the bushing height (Fig. 12a, b, and c) bushing wall thickness (Fig. 12a_1, b_1, and c_1), and bushing shape (Fig. 13) were demonstrated with drilling 8 mm diameter hole to the 6 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. At the 6 mm material thickness ad 10 mm hole diameter conditions both the bushing height and the bushing wall thickness were decreased orderly with increasing both spindle speed and tool conical angle. The highest bushing were measured at 24° conical angle, 50 mm/min feed rate, and the biggest bushing wall thickness were measured at 100 mm/min feed rate, 24° conical angle. In friction drilling 6 mm thickness A7075-T651 alloy with 10 mm diameter tool, the highest bushing measured as 8.5 mm at 24° conical angles, 50 mm/min feed rate, 2400 rpm spindle speed, and the biggest bushing wall thickness measured at 100 mm/min feed rate, 24° conical angle, and 4800 rpm spindle speed as 2.88 mm.

The effect of tool conical angle on the bushing height (Fig. 14a, b, and c) bushing wall thickness (Fig. 14a_1, b_1, and c_1), and bushing shape (Fig. 15) were demonstrated with drilling 8 mm diameter hole to the 6 mm thickness of A7075-T651 alloy, in conditions 2400 rpm, 3600 rpm, and 4800 rpm spindle speeds, 50 mm/min, 75 mm/min, and 100 mm/min feed rates. In friction drilling of 6 mm thickness A7075-T651 alloy with 12 mm diameter tool, the highest bushings were measured at 36° conical angle, 75 mm/min feed rate, and 3600 rpm spindle speed. The highest bushing was 9.14 mm. The highest bushing wall thickness was measured as 3.18 mm at 100 mm/min feed rate, 24° conical angle, and 4800 rpm spindle speed. The bushing wall thickness decreased systematically with increasing tool conical angle, but increased with increasing both spindle speed and feed rate.

4. Conclusion

With increasing both tool conical angle and spindle speed the cracks in obtained bushing were advanced and the shape of bushing becomes as petal. But with increasing feed rate the bushings shapes were not changed.

The highest bushings were become in friction drilling of 4 mm thickness of A7075-T651 alloy at 24° conical angle, 50 mm/min feed rate, and 2400 rpm spindle speed. The highest bushing wall thicknesses were obtained at 48° tool conical angle, 4800 rpm spindle speed, and 100 mm/min feed rate.

Because of increasing both material thickness and hole diameter, the material volume, bushing height and bushing wall thickness were increased and therefore the bushing shape become cylindrically due to high t/d ratio. During friction drilling operation the material softened, flowing and become viscose, owing to frictional heat. With increasing material thickness and hole diameter more temperature inquired to become material softened and become viscose.

At high material thicknesses, due to increasing cross-sectional area between tool and workpiece, the effect of deformation was removed and it was seen that the most optimum conical angle was 36° in friction drilling of A7075-T651 alloy. The bushing height and bushing wall thickness were reverse values, so when bushing height was increased the bushing wall thickness was decreased and when bushing wall thickness decreased the bushing height was increased.

Nomenclature

α : Tool nose angle (°)
β : Tool conical angle (°)
D : The tool handle diameter (mm)
D_1 : The tool shoulder diameter (mm)
d : Hole diameter (mm)
f : Feed rate (mm/min)
h_a : Bushing height (mm)
h_c : Tool nose area length (mm)
h_l : Tool cylindrical area length (mm)
h_n : Tool conical area length (mm)
L : Tool handle length (mm)
n : Spindle speed (rpm)
T : The tool shoulder thickness (mm)
t : Workpiece material thickness (mm)
t/d : The ratio of material thickness to the hole diameter

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