Article

An experimental investigation on bushing geometrical properties and density, in thermal frictional drilling

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Abstract: In thermal friction drilling (TFD) operations, the geometrical dimensions of bushing shape, height and wall thickness are the most vital consequences, due to increasing the connecting length and strength. In this paper, AA7075-T651 aluminum alloys with 2, 4, 6, 8, and 10 mm in thicknesses were drilled with TFD process in order to investigate the density, the volume ratio, and height and wall thickness of the bushings. The experiments were conducted at constant spindle speed and feed rate conditions by using HSS conical tools of 5, 10, 15, and 20 mm in diameters. It was experimentally found that the bushing height and the wall thickness were tendency of increase linearly with increasing both material thickness and tool diameter. The effect of tool diameter was found to have much of influence on the measured values than the thickness of the drilled material. The density of the bushing was changed inconsiderably. Approximately 70-75 % percentages of the evacuated material composed the bushing shape, in TFD operations.

Keywords: thermal friction drilling; bushing density; bushing shape; bushing height; bushing volume ratio; bushing wall thickness.

1. Introduction

Friction drilling is a hole production method, in which the metal cast sheet materials were drilled without cutting, due to the sample material is heated up by the effect of the friction, in the area of the conical tool and material contacting. The generated temperature makes the sample softened and then it is pushed by the tool downward, where tool proceeding into the material to generate the bushing formation, increasing the connection strength in sheet materials. Therefore, investigation of the bushing formation is the main goal of the TFD operations [1]. It is generally desired to obtain only the bushings with a cylindrical shape, having no cracks and petal formations, in order to increases the connecting strength [2]. Higher bushing length leads to a more screwing area as well as increasing the connection strength in sheet materials [3]. Bushing shape, especially bushing height and wall thickness, depends on both the thickness of the drilled material (t) and the diameter of the hole (d), and hence it depends on the ratio of (t/d) [4]. Bushing shape is completed in five steps and categorized according to the geometrical regions of the conical tool and proceeding dimension of the tool into the material [5]. The bushing height is measured to be approximately 2 – 3 times of the (t) [6].

A decrease in bushing height leads to an increase in the wall thickness of the bushing formation, which provides move screwing area by connecting of sheet materials [7-10]. The height of the bushing depends on the d rather than the (t). The height of the bushing does not change with (t), for selecting constant hole diameters [11]. However, cracks and petal formations on the bushings cause to decrease the strength of the connections. Furthermore, deformation and fracture of the drilled material cause to the occurrence of petal formation and cracks on bushing shape. A better-selected tool geometry provides improving bushing formations [12].

During the TFD process, the bushing shape was generated with the help of required temperature reached at the tool – workpiece interface owing to the friction. Due to this rice in temperature, the material is thermally softened and the yielding point was decreased to help the formation of plastic deformation easily to provide the bushing formation. The appropriate process temperature is generally realized to be between 1/2 and 2/3 of the melting temperature of the drilled material [13-15].

The main purpose of this paper is to investigate the effects of t and d on the geometrical dimensions of the bushing shape, such as bushing height and its wall thickness. Furthermore, the investigation of the proportion of the volume of the bushing shape to the total volume of the evacuated material is a crucial result. Therefore, this proportion was investigated experimentally, in TFD of the A7075-T651 aluminum alloy.

2. Materials and Methods

In the TFD experiments, a FU400x1600 V/2 model a milling machine was employed. A7075-T651 aluminum alloy sheets with 2, 4, 6, 8, and 10 mm in thickness were used as target material. The experimental setup was shown in Figure 1. The thermal drilling conical tool and specimen fastening apparatus (a clamp), indicated by arrows with lines, can be clearly seen from the figure. The TFD tools were specially machined from HSS material with 36o conical angle and 5, 10, 15, and 20 mm in diameters. The geometrical dimensions of the used conical tool and its photo are given in Figure 2. The experiments were conducted at constant 1120 rpm spindle speed and 25 mm/min feed rate conditions.

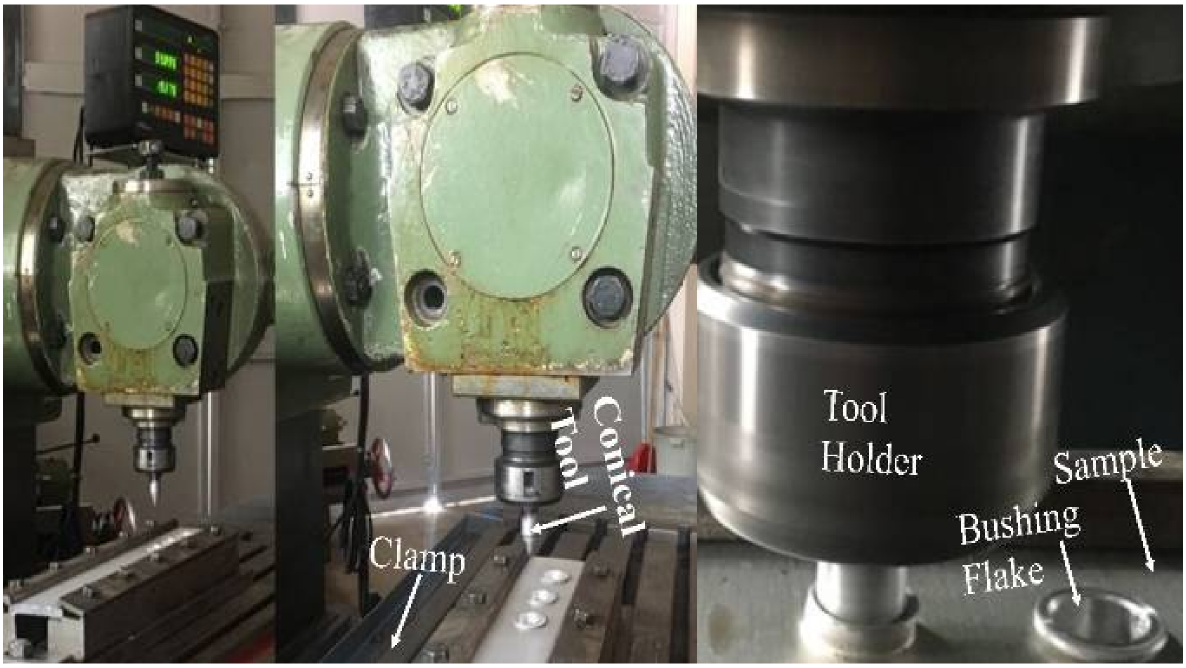

Figure 1. Experimental setup with conical tool and fastening apparatus.

A depth micrometer gauge, with 10-3 μm sensitivity was used, in order to measure the heights of the bushings. Bushing height (h_a) is a geometrical dimension measured from the under the surface of the thermal friction drilled material to the tip of the bushing formation, as seen in Figure 3. Furthermore, the bushing wall thickness is a vital geometrical dimension, affecting the processes consequences, such as connecting length and strength, with the help of threading. Also, the bushing wall thickness (t_w) dimension as demonstrated in Figure 3. The outer diameter of the bushing dimensions measured by using a digital caliper gage, with 0,02 mm precision. The bushing wall thickness values were calculated using the following equation:

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$$t_w = \frac{\text{𢓊}_B\text{-豥}}{2} \quad (1)$$

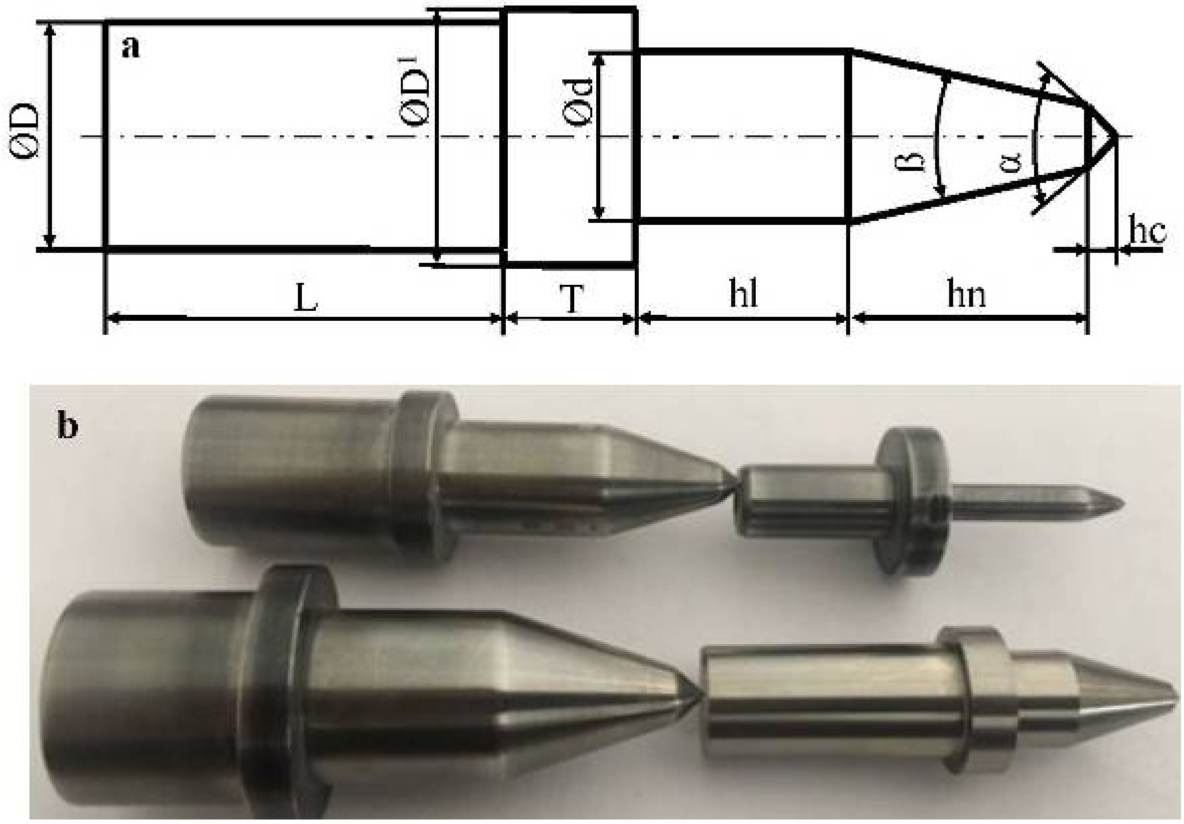

Figure 2. Conical tools a) geometrical dimensions of tools b) photos of tools.

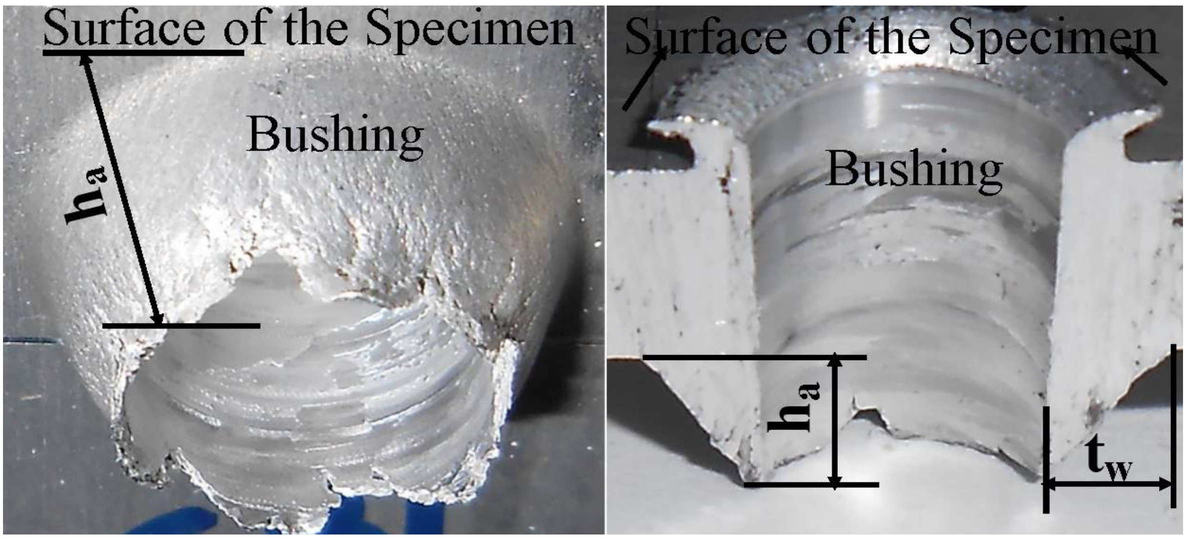

Figure 3. Bushing height on the bushing shape.

The drilled samples were divided into pieces, including thermal frictionally drilled hole and bushing shape. The volume and weight of these pieces were measured separately, by using the scaled beaker and VIBRA AJ model digital scale with 0.01 accuracy, respectively. The volumetric measurement method of the divided samples seen in Figure 4, in which beakers and water used. In the measuring method, at the first beaker was filled up at the level of integer number then the sample was placed in the beaker. The water, raised from the first level after the sample had placed into the

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beaker, was aspirated by using pipet, with 0.1 g/cm³ accuracy, until the level of the water decreased to the first level before the sample placed into the beaker. The volume of the aspirated water by the pipet was accepted as the volume of the divided samples measured. The weight of the divided samples measured with a digital scale, having 0.01 g precision, as seen in Figure 5b. The density and the volumetric ratio of the bushing shapes measured by the help of measured weight and volume of the divided samples, including bushing, as shown in Figure 5a. The volumes of the samples were measured by multiplying a, b, and t dimensions, which measured on the samples by means of a digital calipers with 0.01 mm accuracy, as seen in Figure 5a, with subtracting the volume of thermal frictional drilled hole, from the volume of the sample (V_S), without including the volume of the bushing, as demonstrated in Equation (2).

$$\rho_B = W_B - V_S$$

(2)

The weight of a sample (W_S), without including the weight of the bushing shape was calculated by multiplying the volume of the sample with the density of A7075-T651 aluminum alloy (ρ=2.7 gr/cm³), as seen in Equation (3).

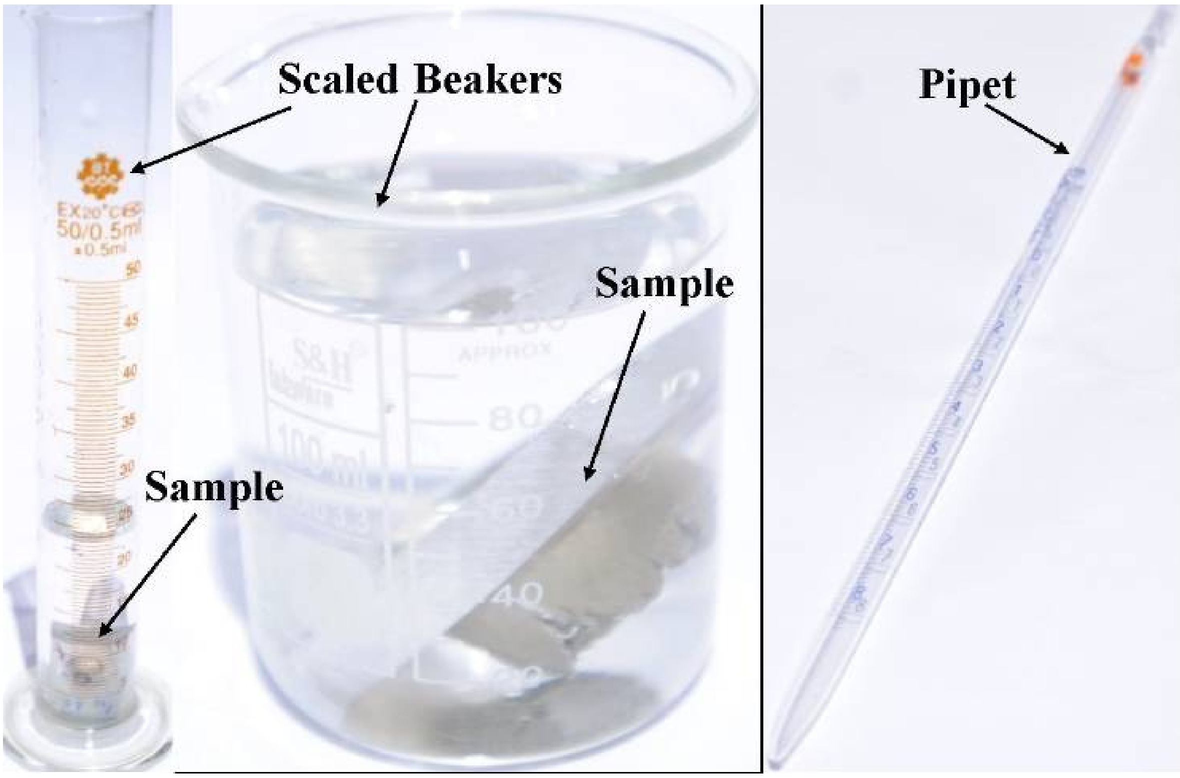

Figure 4. Beakers, pipet, and samples, whose volume measured.

$$V_S = (a.b.t - \pi.\frac{d^2}{4}.t).\rho \qquad (3)$$

The weight of a divided sample (W_S), without including the weight of the bushing shape, calculated by the help of Equation (3). The total weight of a sample (W_T), also including bushing weight, measured by using a digital scale gage, as seen in Figure 5b.

The volume of the bushing shape derived by subtracting the calculated volume of the sample (V_S) from the measured total volume of the sample (V_T), as shown in Equation (4).

$$V_B = V_T - V_S = V_T - (a.b.t - \pi.\frac{d^2}{4}.t) \qquad (4)$$

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The weight of the bushing shape can be derivable by subtracting the weight of the sample, without including bushing shape (W_S), from the measured weight of the sample (WT), as seen in Equation (5).

$$W_B = W_T - W_S = W_T - (a.b.t - \pi.\frac{d^2}{4}.t).\rho \quad (5)$$

The density of the bushing shape (ϱB) calculable by dividing the weight of the bushing (W_B) to its volume (V_B), as derived in Equation (6).

$$\rho_B = W_B - V_S \quad (6)$$

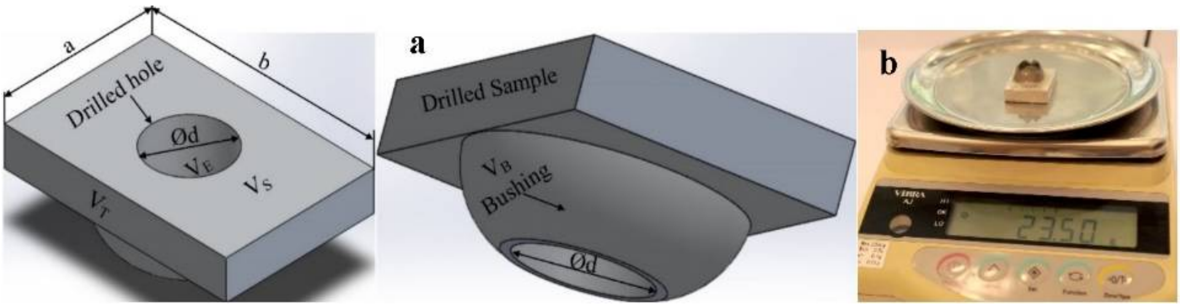

Figure 5. a) Geometrical propertied of samples, b) digital weight scale gage, with 0.01 gr precision.

3. Results and Discussion

3.1 Bushing height and wall thickness

Bushing height and wall thickness values are crucial geometrical dimensions, affecting the outcomes of the TFD operations. While bushing height is affecting the connecting length and strength by means of achieving the numbers of the threading teeth, the depth of the threading tooth is affected by the bushing wall thickness. However, these dimensions have less investigated on the neglected level, in the open literature. Nevertheless, in literature established that the bushing height is about 2 – 3 times of the frictional thermal drilled material thickness. However, this idea may be valid for thin sheet metal materials, thinner than 2 mm, but it seems not valid for sheet materials, thicker than 2 mm.

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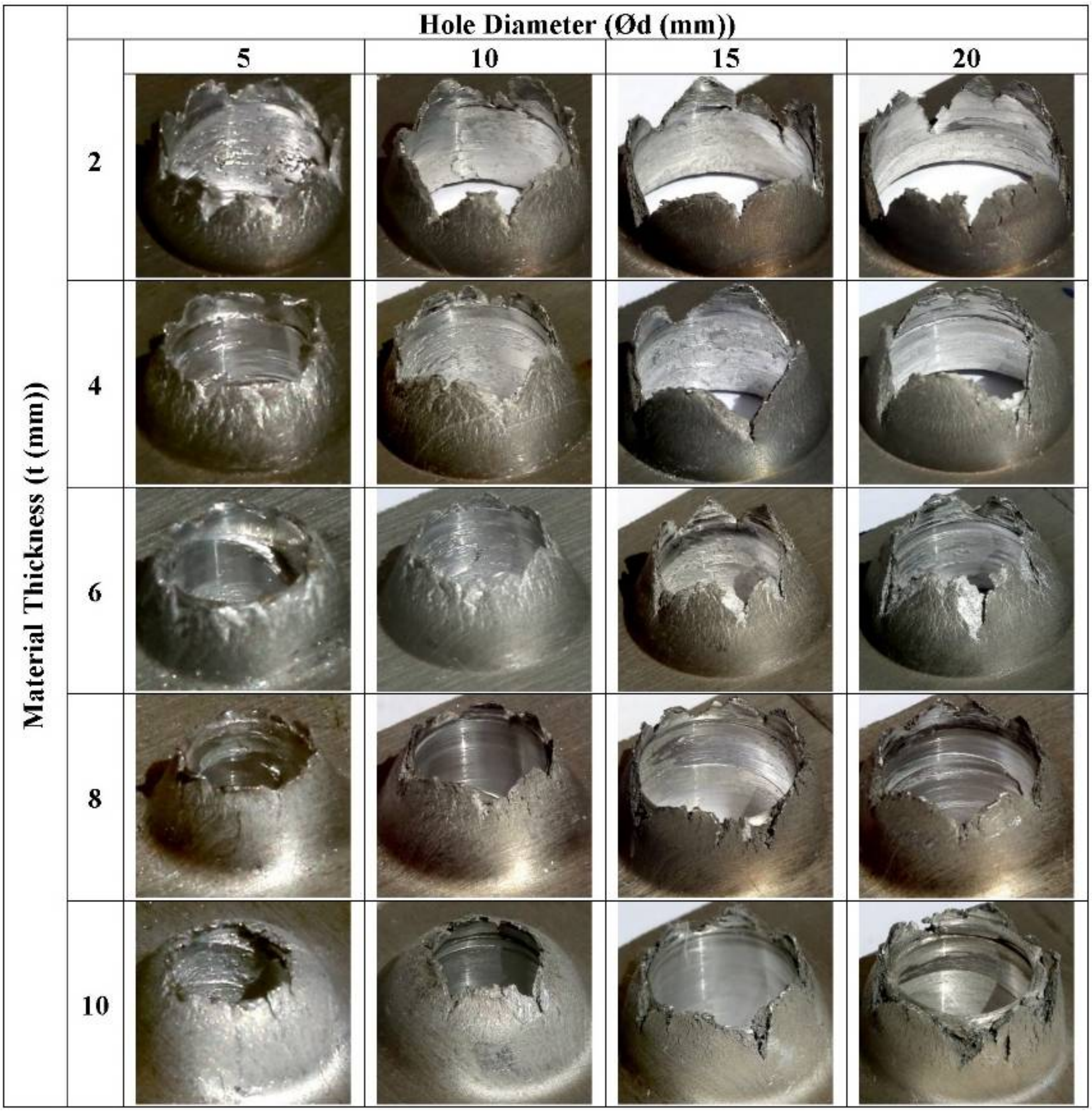

Figure 6. Bushing shape according to material thickness and hole diameter.

In TFD operations, it considered that the most influential parameter on the bushing geometrical dimensions is material thickness. However, there are other crucial parameters, such as hole diameter, spindle speed, and feed rate, affect these dimensions. Because the volume of the evacuated material from the thermal frictional drilled material shapes the bushing. Therefore, the material thickness (t) and hole diameter (Ød) are more influential parameters than the selected spindle speed and feed rate, on the shaping of the bushings. Although the effects of spindle speed and feed rate factors on the geometrical dimensions of the bushing shape are less than the material thickness and hole diameter, they may cause the cracks and petal formation generations especially in TFD of brittle sheet materials, due to rotating and proceeding motions of the conical tool.

The experimentally gained bushing shapes for different t and d values are given in Figure 6. As shown from this figure that the cracks and petal formations on the bushings were increased with higher d and lower (t) values. When (t) value was exceeded 6mm, cracks and petal formations were almost completely eliminated under the used experimental conditions. 4 and 6 mm material thicknesses were found appropriate only for hole diameters of 5 and 10 mm, according to cracks and petal formations criterion, when 2 mm material thickness was not appropriate. Therefore, in the TFD

 doi:10.20944/preprints201811.0263.v1

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of sheet materials, 2 mm in thickness, hole diameters, smaller than 5 mm, recommended being selected.

The effects of TFD parameters on the bushing height and wall thickness are given in Figure 7a-7d. Figure 7a tells us the bushing height is tendency of increase linearly with the hole diameter for all values of materials thickness. A negligible difference between 2 to 10 mm thicknesses was observed. However, the bushing wall thickness showed a nonlinear alteration with changing hole diameter from 5 mm to 20 mm, and material thickness from 2 mm to 10 mm, as demonstrated in Figure 7c, and Figure 7d. Bushing wall thicknesses values remained constant for material thicknesses greater than 6 mm, at all hole diameters. However, it showed a linear changing for 2, 4, and 6 mm thickness, at selected 5, 10, and 15 mm hole diameters. Contrary to the literature, bushing height and wall thickness dimensions increased nonlinearly with stepping up the material thickness, also bushing height is not equal to 2 -3 times of the drilled material thickness. According to the graphs in Figure 7, while hole diameter has a linear influential on bushing height, there is a little, negligible, effect of material thickness on bushing height.

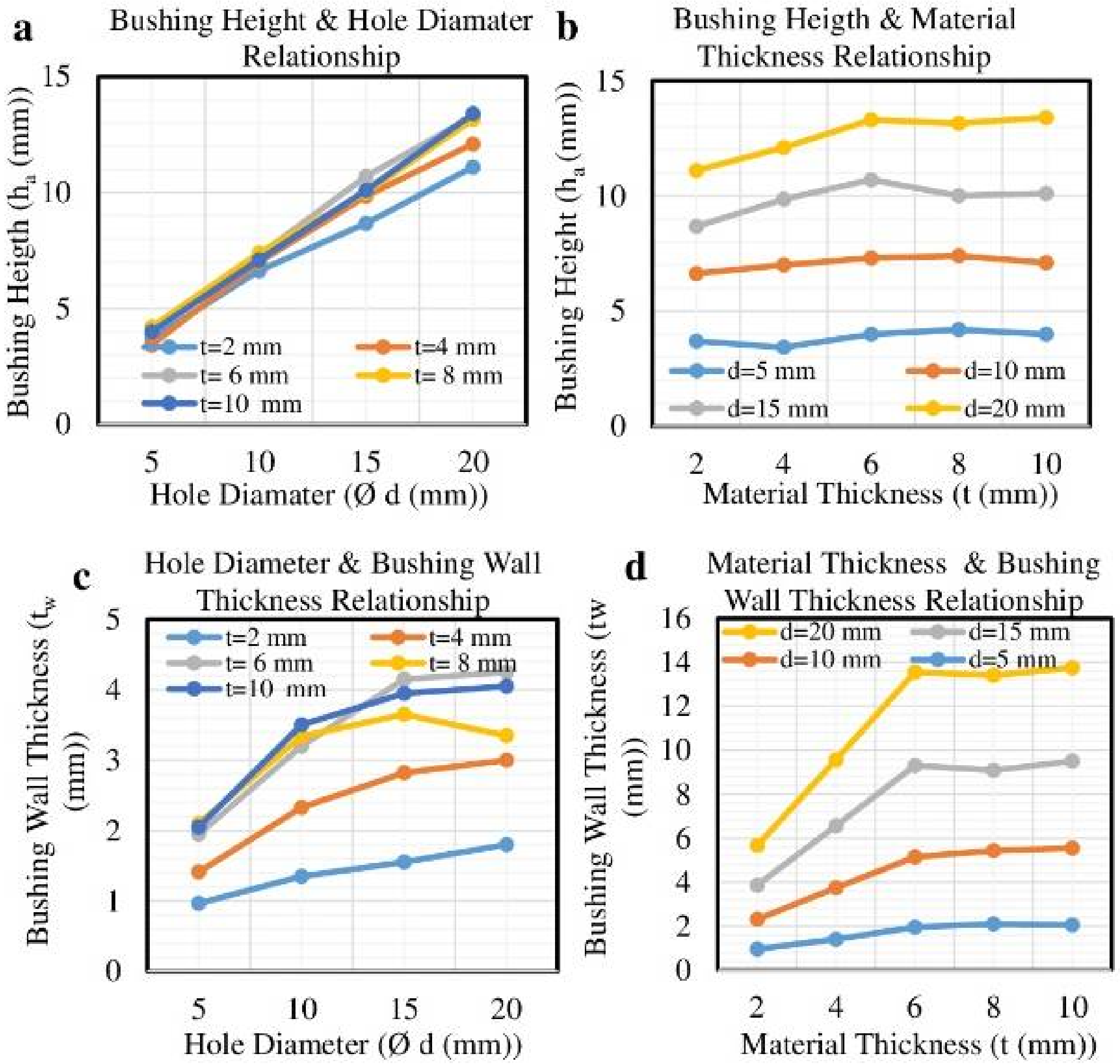

Figure 7. The effects of hole diameter and material thickness a) and b) on bushing height, c) and d) bushing wall.

Additionally, the effect of hole diameters and material thicknesses on bushing height and wall thickness was investigated by using Minitab software, as shown in Figures 8a and 8b. The main effects plots for bushing height and wall thickness can be demonstrated in Figure 8a and 8b, depending on selected hole diameters, 5, 10, 15, and 20 mm, and material thicknesses, 2, 4, 6, 8, and

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10 mm. While bushing height is increased linearly with stepping up hole diameter from 5 mm to 20 mm, it is shown a little, negligible, changing with increasing material thickness from 2 mm to 10 mm, as seen in Figure 8a. This consequence shows that contrary to the literature studies, the effect of material thickness on bushing height is smaller than the effect of hole diameter. Because increasing hole diameter provides greater volume of the evacuated material than increasing material thickness. However, the bushing wall thickness was shown a linear changing, in the direction of stepping up, with increasing both hole diameter, from 5 mm to 20 mm, and material thickness, from 2 mm to 10 mm, as demonstrated in Figure 8b.

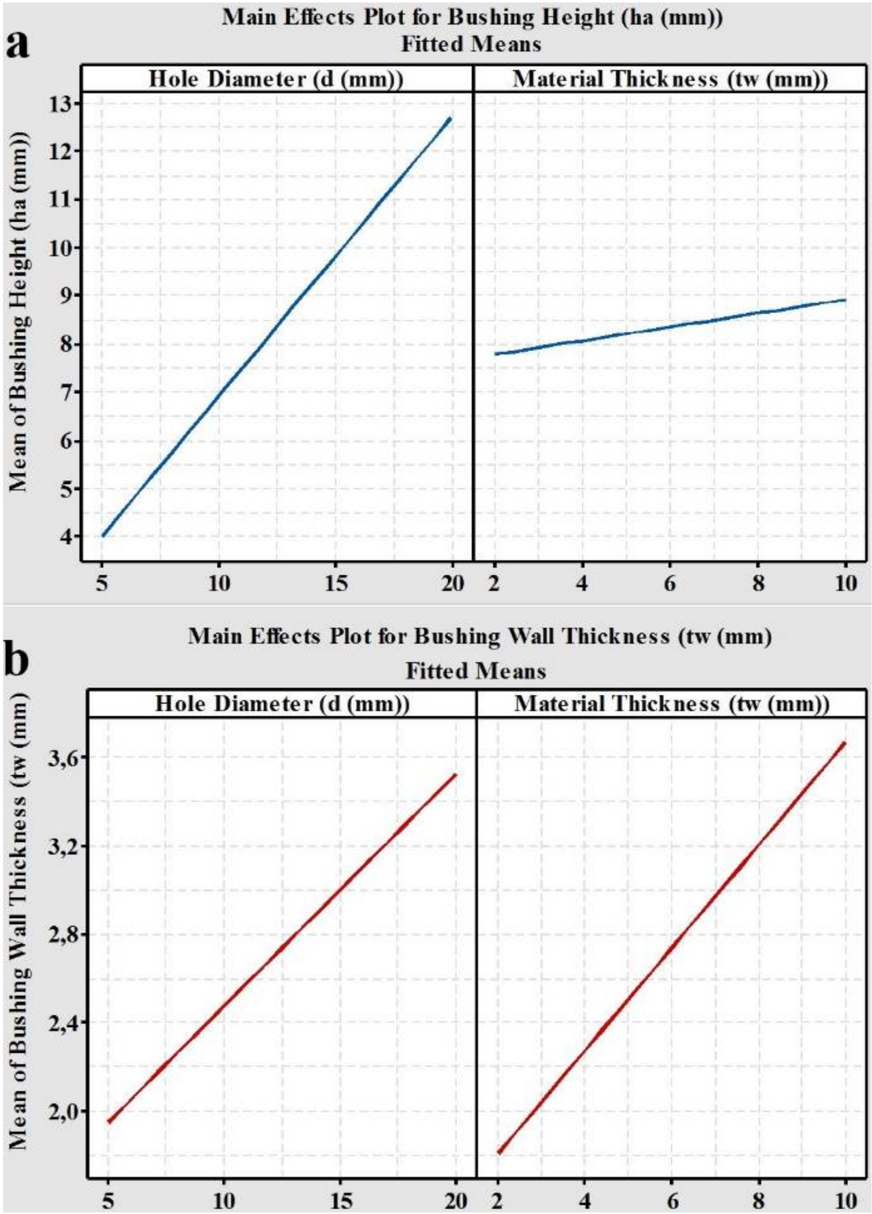

Figure 8. The effects of hole diameter and material thickness a) on mean bushing height, b) bushing wall.

3.2. The density and the volume ratio of the bushing

The volume ratio of the bushing (V_B) to the evacuated material (V_E) is a vital outcome, affecting the bushing shape, without cracks and petal formation. With decreasing the ratio means that the least flowed material to compose the bushing, on which there are cracks and petal formations, undesired outcomes in the process. Therefore, the ratio of the volume of the bushing (V_B) to the evacuated material (V_E) is desired to be high. Additionally, greater the bushing volume means less the flowed material composing the flake and dissipating into surroundings. Furthermore, the density of the bushing is changeable, due to the drilled samples, was subjected to the deformation phenomenon, causing the microstructure of the flowed material, composing bushing shape, to change.

According to the bushing shape and its geometrical dimensions, such as bushing height and wall thickness, both the ratio of the volume of the bushing (V_B) to the volume of the evacuated material (V_E) and the density of the bushing are vital outcomes in TFD operations, because of having influential on bushing shape, desiring without cracks and petal formation.

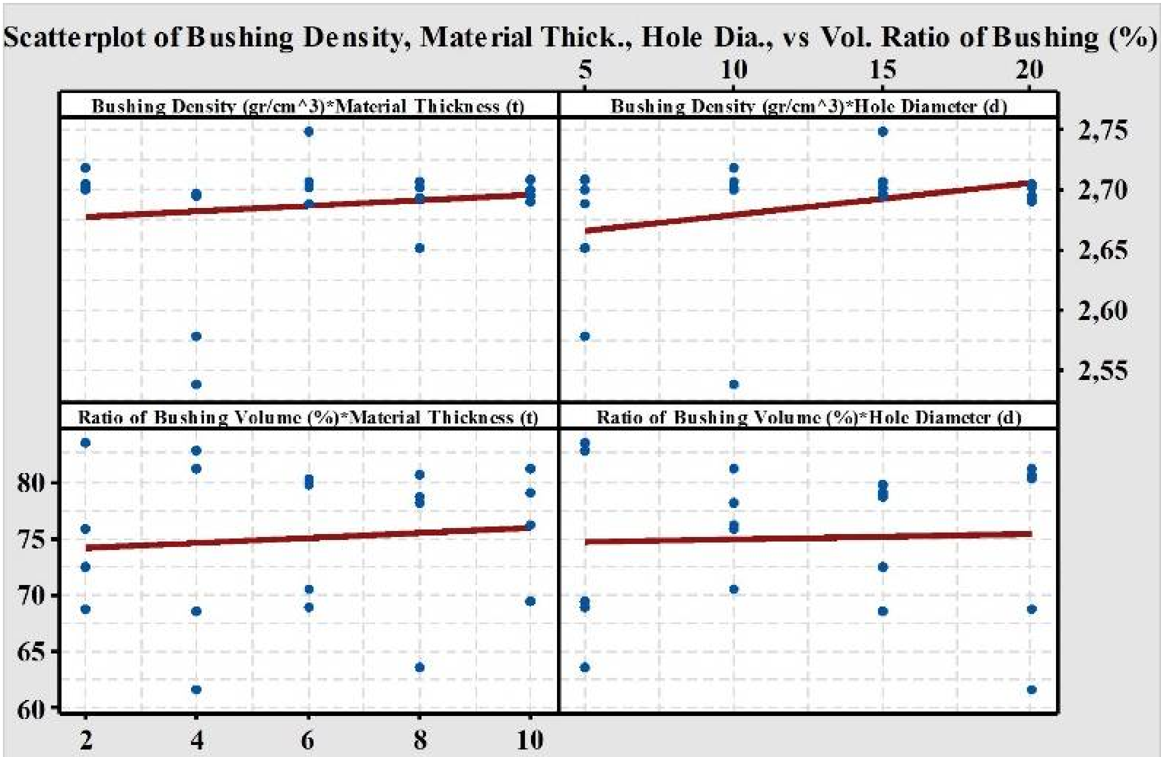

Figure 9. The effects of hole diameter and material thickness a) on mean bushing height, b) bushing wall.

The relationship between the hole diameter (d), the material thickness (t), and the bushing density (ρ), the ratio of (V_B) to (V_E) can demonstrated, as in Fig. 9. While the bushing density was changed in small quantities, between 2.54 gr/cm^3 and 2.75 g/cm^3, with increasing material thickness (t) and hole diameter (d), the ratio of (V_B) to (V_E) was substantially changed between 61% and 84 %. Therefore, the density of the bushing shape changed in small and inconsiderable quantities. This means that the substantial of the softened and flowed material composed the bushing shape.

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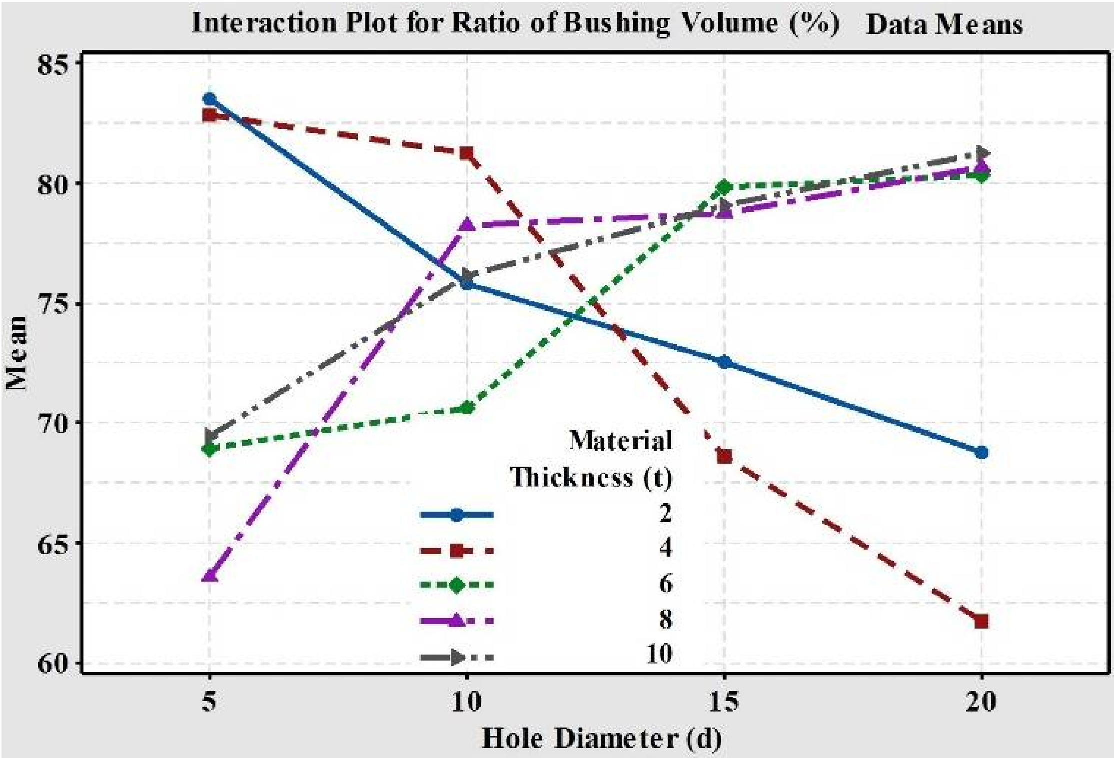

Figure 10. The interaction plot of the hole diameter, and volume ratio of the bushing.

The relationship between the ratio (r) of (V_B) to (V_E) and hole diameter (d) shown as in Figure 10. According to the graphs, the ratio (r) of the volume of the bushing increased linearly with increasing hole diameters from 5 mm to 20 mm in thermal drilling of samples with 6 mm, 8 mm and 10 mm in thicknesses, but the ratio (r) decreased linearly with increasing the hole diameters in drilling of samples with 2 mm in thickness. However, the ratio (r) decreased linearly for the selected hole diameters, bigger than 4 mm, while it has remained stable for hole diameters smaller than 4 mm, TFD of samples with 4 mm in thickness. According to achieved outcomes, it is proposed that the optimum hole diameters should select smaller than 10 mm in TFD of materials, smaller than 4 mm in thicknesses. Furthermore, the ratio (r) values of the volume of the bushing (V_B) to the softened evacuated material (V_E) recorded between 61 % and 84 %. This outcome means that approximately the 70 % percent of the evacuated material composes the bushing shape, in TFD operations. With increasing both the material thicknesses (t) and hole diameters (d) the value of the ratio (r) change from 61 % to 84 %.

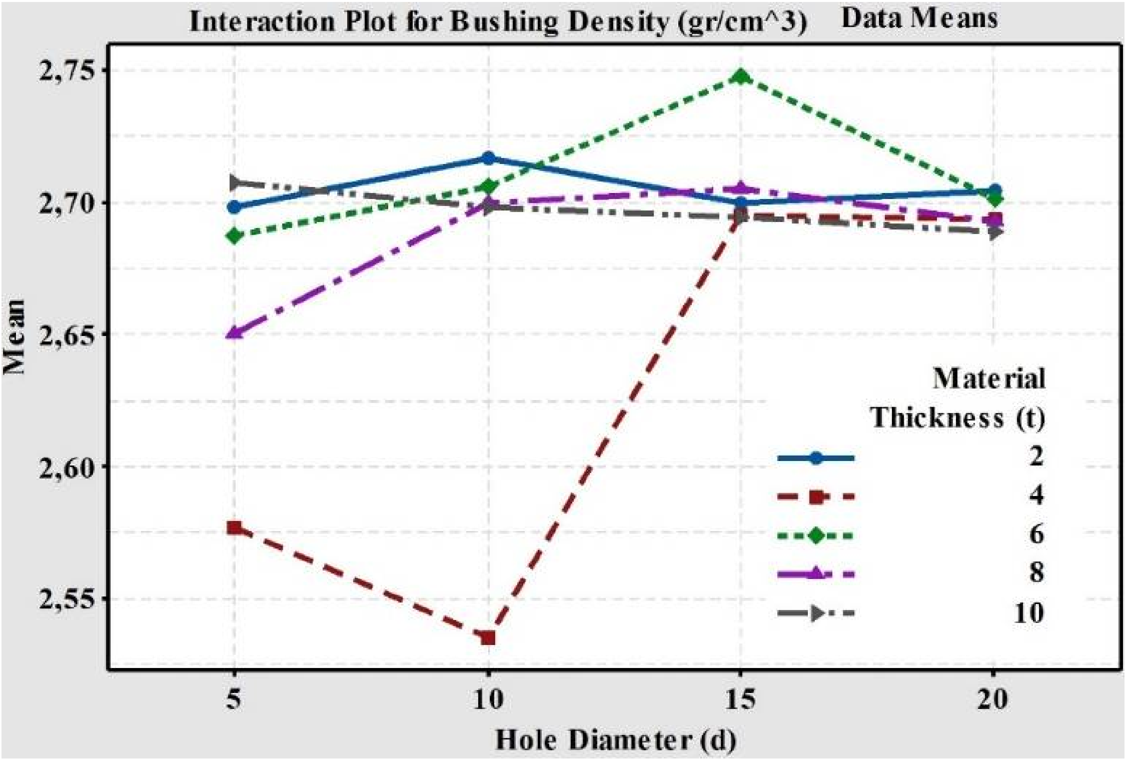

Figure 11. The interaction plot of the hole diameter, and density of the bushing.

The density values of bushings, derived from thermal friction drilling operations of A7075-T651 aluminum alloys, 2, 4, 6, 8, and 10 mm in thicknesses, changed from 2.54 g/ cm^3 to 2.75 g/ cm^3, while the density of the selected samples was 2.7 g/ cm^3. Although the density of the samples with 4 mm and 6 mm in thicknesses showed different values from the other selected samples, the density of the bushing was changed in small and inconsiderable quantity, as seen in Figure 11. Depending on the results, the density of the bushing shape demonstrated inconsiderable alteration, in TFD operations.

4. Conclusions

The bushing shape, especially the softened flowed material, composing the bushing shape, was affected by material thickness and hole diameter, together with tool geometrical dimensions, feed rate and spindle speed. Particularly, material thickness and hole diameter are the most crucial parameters on composing the bushing shape and its geometrical dimensions. Because the material quantity of the softened and flowed material, evacuated from the TFD sample, increases at selected high diameters followed by material thicknesses. The spindle speeds and feed rates provide the rotating and proceeding motions of the conical tool during the process, causing cracks and petal formation on the bushing shapes. Furthermore, the bushing height and wall thickness were altered by the material thickness and hole diameter linearly. Contrary to the literature, the bushing height values were not equal to be approximately 2-3 times of the TFD material. In the end, it was investigated that the bushing height and wall thickness values were increased linearly with increasing both material thickness and hole diameter, but the effect of the hole diameter was bigger than the material thickness.

The changing in the density of the bushing recorded in small and inconsiderable quantity. These values were around 2.7 g/cm^3, the density of A7075-T651 aluminum alloy. The ratio (r) of the volume of the bushing (V_B) to the volume of the evacuated material (V_E) was changed about from 61 % to 84 % percentages. According to the recorded values, the volume ratio of the bushing (r) is accepted to be approximately 70 %, especially, between 70 % and 75 % percentages.

Author Contributions: All authors provided individual contributions at the researching, analyzing, investigating, and preparing procedure of the paper.

Funding: This research received no external funding.

Acknowledgments: This paper was not supported by anyone, except the authors of the paper.

Conflicts of Interest: The authors declare no conflict of interest.

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