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INVESTIGATE THE BUSHING SHAPE IN MOULD SUPPORTED THERMAL FRICTION DRILLING

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Abstract

Although bushing height and wall thickness are crucial issues, cracks and petal formation on bushings affect these outcomes adversely in thermal friction drilling operations. Therefore, in this paper, bushing shapes were investigated both in traditional and mould supported thermal friction drilling of A7075-T651 aluminum alloy, 4 mm in thickness, at 2000 rpm spindle speed and 25 mm/min feed rate. The proportion of the volume cavities (VBC) of the moulds to the volume of the total evacuated material (VE) selected between 16 % and 32 %. Moreover, the gap sizes between the tool and tool proceeding cavity (CDT) were selected at 0.2 mm, 0.3 mm, and 0.4 mm. In conclusion cracks and petal formation were substantially eliminated, bushing height and wall thickness values were able to select, depending on requirements, also homogenous bushing wall thickness for threading, in moulds supporting thermal friction drilling operations.

Keywords: Friction Drilling; Bushing Shape; Threading; Connecting Length; Friction Drilling Moulds.

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1. Introduction

Friction thermal drilling operations are implemented to sheet metal materials to increase their bonding length, accordingly connecting strength, with the help of threading. The highest bushing is provided leading to more threading area, thus increasing connecting strength, in thermal friction drilling operations [1]. However, these processes are not appropriate to apply to brittle sheet metal materials due to improper bushing shapes, on which undesirable outputs, such as cracks and petal formation, are taken place, despite these negative results, this manufacturing method is inevitable to implement to brittle sheet metal materials [2]. There is scarcely any research effectuated about although bushing shape, especially geometric dimensions of the bushing, such as bushing height and wall thickness, compose the main view of the process [3]. Traditionally pre-drilling method

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substantially provides decreasing cracks and petal formation on bushings, with eliminating the initial deformation and providing an appropriate melting temperature [4]. Moreover, pre-drilling provides achieving uniform bushing wall thickness, which is a vital output to affect the threading depth, improving connecting strength [5, 6]. The process temperature, dissipating into the conical tool, drilled sample, and surroundings, affects the microstructure of the material [7]. Higher selected spindle speeds ensure higher the process temperature, in friction drilling [8]. The most appropriate the process temperature is to be approximately 1/2 – 2/3 of the melting temperature of the frictional drilled material [7].

Additionally, pre-heating, as a new idea, provides improving the bushing shape and its quality, on which fewer cracks and petal formation due to high temperature in thermal friction drilling of brittle cast sheet metal materials [3]. Furthermore, deformation and fracture of the drilled material cause to petal formation and cracks on bushing shape, but better-selected tool geometry can provide improving the bushing formation [9].

The purpose of this paper is to investigate the effect of the mould in the shaping of the bushing in thermal friction drilling. Due to this purpose, the designed then manufactured moulds employed. Therefore, the cracks and petal formation on bushing height and wall thickness adjustable according to necessities and expectations, by using a mould in thermal friction drilling. Additionally, the cracks and petal formation on bushing shape substantially eliminated.

2. Materials and Methods

A CNC vertical machine used for realising the experiments, as shown in Figure 1 a. A7075-T651 aluminium alloy, selected as experiment sample in dimensions of 4 mmx90 mmx70 mm. Samples fastened to the machine by using a clamp, connecting bolts, and supporting devices, as seen in Figure 1 b. Also, the conical tool was fastened to the spindle of CNC Vertical Milling Machine with the help of a collet chuck, as demonstrated in Figure 1 b.

Prepared moulds were fastened on the table of the CNC Vertical Milling Machine, via a clamp, under the sample material, with the help of the supporting devices. Then the samples were adjusted on the moulds, in the location of designed and fastened up by means of connection bolds, as shown in Figure 1 b. Then the samples were adjusted on the moulds, in the location of the designed and fastened up with the help of connection bolds, as shown in Figure 1 b.

Figure 1: a) CNC milling machine and its computer screen, b) experimental setup

Thermal friction drilling operations implemented to the cast sheet metal materials, due to increasing their binding length and strength, with the help of bushing shape, taken place under the face of the sample. Therefore, bushing height and wall thickness are the main dimensional quantity of the process. Bushing height is a dimensional quantity of formation, starts from the under face of the sample to the tip of the bushing shape, as seen in Figure 2 a and b, identified with ha icon. Furthermore, bushing wall thickness is the second important issue of the process, as demonstrated in Figure 2 b, specified with two icon.

Thermal friction drilling supporting moulds were manufactured from AISI 1050 steel material in dimensions 15mmx100mmx100mm, as seen in Figure 4 a. The cavities, in which bushings got their formation on the moulds, during the thermal friction drilling operation, were adjusted in different kinds of dimensions, as specified in Table 1. As demonstrated in Table 1, Ød, t, VE, ØDm, hac, VBC, (VBC/VE) %, tw, and CDT represented by a conical tool diameter, sample material thickness, total of the evacuated softened material from the sample, mould bushing cavity diameter, height of mould bushing cavity, volume of mould cavity, proportion volume of the mould cavity (VBC) to the volume of the total evacuated material (VE), bushing wall thickness, and the gap, between the mould wall and conical tool, respectively. In Figure 4 b, the cavity of the bushing formation on the moulds are demonstrated with VBC, while it is accepted the conical tool is into the moulds, during the process.

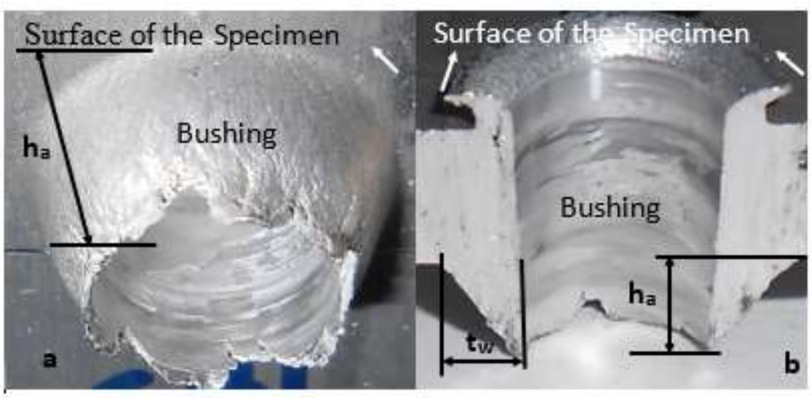

Figure 2: a) Bushing height (ha) and b) bushing wall thickness (tw), on the bushing shape

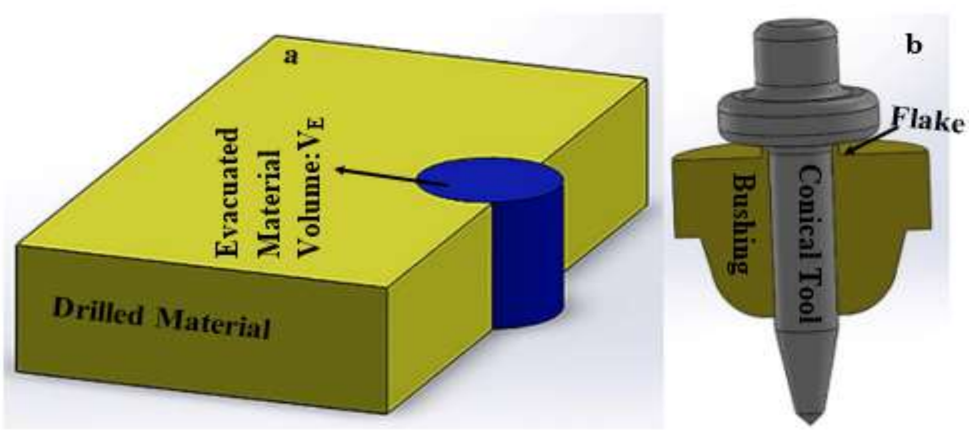

Figure 3: a) Evacuated material, b) conical tool and bushing formation, in thermal friction drilling

Table 1: Geometrical dimensions of thermal drilling mould

Example Number	Ød	t	VE	ØD	hVBC	VBC	% (VBC/VE)	tw (mm)	CDT (mm)
1	6.7	4	84.23	8.76	3.72	24.08	28.59 %	1.03	0.2
2	6.7	4	84.23	8.74	3.58	22.95	27.25 %	1.02	0.4
3	6.7	4	84.23	8.50	2.70	15.27	18.13%	0.9	0.3
4	6.7	4	84.23	8.76	3.52	22.79	27.06 %	1.03	0.4
5	6.7	4	84.23	8.66	3.52	21.68	25.74 %	0.98	0.2
6	6.7	4	84.23	8.96	1.9	13.50	16.02 %	1.13	0.4
7	6.7	4	84.23	9.08	2.8	20.94	24.87 %	1.19	0.4
8	6.7	4	84.23	9.36	2.2	18.39	21.84 %	1.33	0.4
9	8.5	4	106.86	11.58	3	29.04	27.18 %	1.54	0.2
10	8.5	4	106.86	11.26	2.5	21.69	20.29 %	1.38	0.2
11	8.5	4	106.86	11.64	2	19.74	18.47 %	1.57	0.2
12	8.5	4	106.86	11.36	3.3	29.66	27.76	1.43	0.2
13	8.5	4	106.86	11.24	4	34.45	32.24 %	1.37	0.3
14	8.5	4	106.86	11.78	2.5	25.77	24.12 %	1.64	0.2
15	8.5	4	106.86	11.32	3.6	31.91	29.86	1.41	0.2
16	8.5	4	106.86	11.3	3.76	33.09	30.96	1.4	0.3
17	8.5	4	106.86	11.2	3.92	33.26	31.13	1.35	0.2
18	10.2	4	128.23	13.62	3.4	36.55	28.50	1.72	0.2

Besides, the section A – A and top views of the moulds are shown, as in Figure 4 c and d, respectively. CDT cavities values were selected as 0.2 mm, 0.3, and 0.4 mm. Samples were thermal friction drilled Ø6.7 mm, Ø 8.5 mm, and Ø10.2 mm in diameters, according to the drill hole diameter of M8, M10, and M12 threads, respectively. Tapered tools, with 36o taper and 90o tip point angles, were made from HSS material. HSS conical tools photos demonstrated in Figure 3 c. The diameter of the cavity, on the mould, composes the bushing shape, expressed with ØDm, also

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the diameter of the hole, where the conical tool proceeding into the sample, during the operation, with Ødp in diameter. The gap CDT derived by subtracting Ød from Ødp, as seen in Equation 1.

$$C_{DT} = \O d_p - \O d \quad (1)$$

Although, as the same method, the cavity thickness of the mould, composes bushing wall thickness, twm accountable, as demonstrated in Equation 2.

$$t_{wm} = \frac{\O D_m - \O d}{2} \quad (2)$$

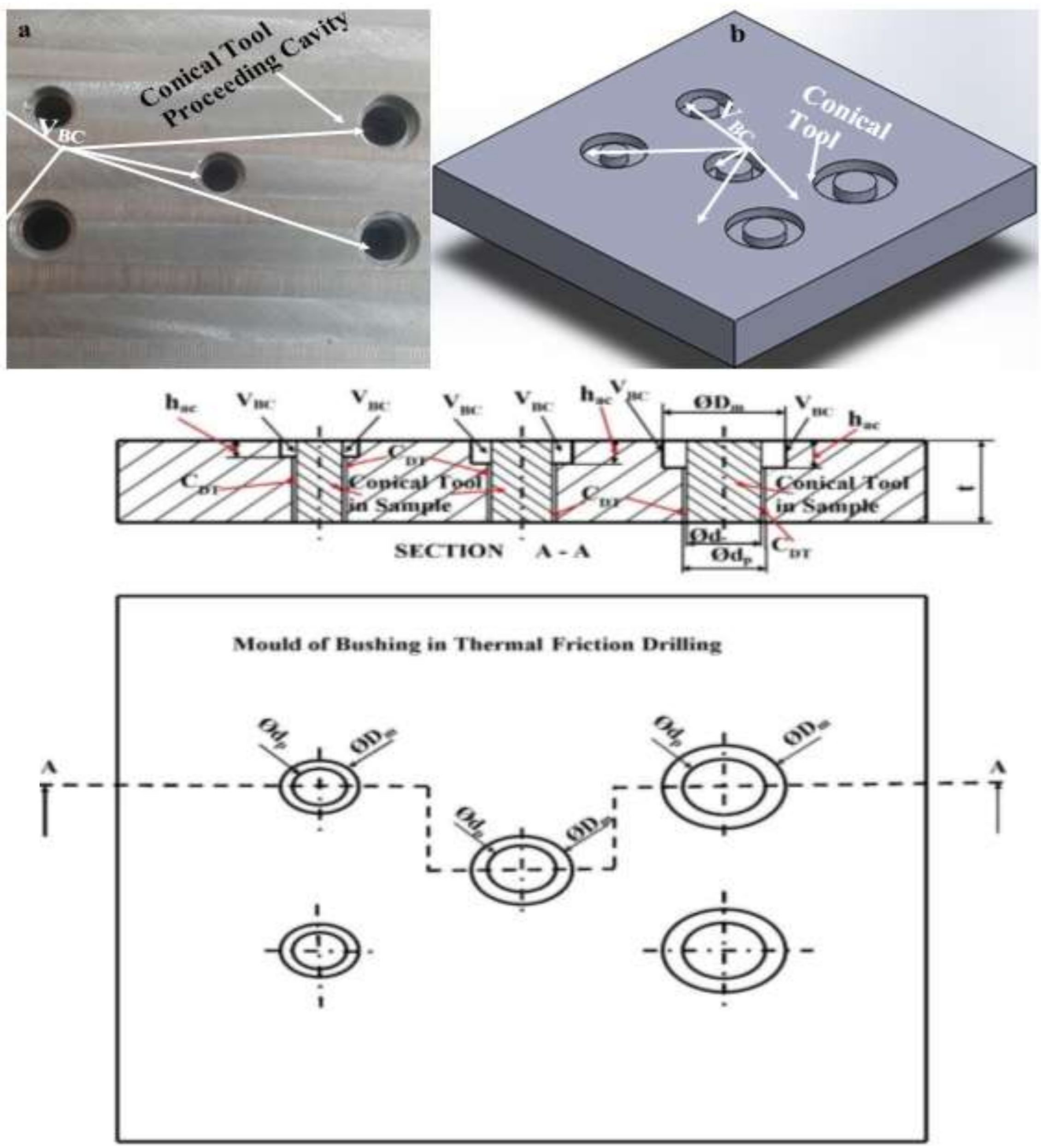

Figure 4: a) Manufactured mould, b) designed mould with conical tool, c) section view of mould, d) top view of the mould

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Bushing geometrical dimensions, such as bushing height and bushing wall thickness, were measured caliper gauge and depth micrometer, respectively. The wall thickness of the bushing shape calculated, as specified in Equation 3.

$$t_{wb} = \frac{ØD_{mb} - Ød}{2} \quad (3)$$

Bushing hollows on the models are identified with VBC, the volume of the cavity, between the wall of the mould and the tapered tool, while the tapered tools in the patterns. The height of the bushing cavity is expressed with hac, as shown in Figure 4 c while the tapered tool is in the mould, the hole, between the tapered tool and the wall of the cavity, is identified with CDT icon, as demonstrated in Figure 4 c.

3. Results and Discussions

3.1. Geometrical Properties of Obtained Bushings

Although geometrical dimensions of the bushing, such as bushing height and wall thickness, also obtaining the bushing without cracks and petal formation, are crucial outputs, affecting the quality of the process, there are fewer effectuated researches about, in negligible numbers. Brittle cast metal materials are generally accepted to not appropriate for thermal friction drilling due to cracks and petal formation on bushings, at the end of the process. However, using these materials approximately are an obligation in different kinds of manufacturing areas, including thermal friction drilling. Therefore, in some research studies, due to improving bushing formation, different kinds of supporting processes, such as pre-drilling and pre-heating, were used.

In this paper, the bushing shape and its geometrical dimensions investigated in the thermal drilling of A7075-T641 aluminum alloy, in which the processes supported by moulds. The conical tool rotates to make the sample material softened and flowed, while it proceeded into the cavity hole (CDT), under the bushing shape cavity (VBC), in the moulds. The conical tool proceeding cavity dimensions were selected as 0.2 mm, 0.3 mm, and 0.4 mm, as specified in Table 1.

The bushing shapes photos shown in Figure 5, according to selected example numbers. The selected parameters for each example as seen in Table 1 and Table 2 for moulds and bushing geometrical dimensions, respectively. In examples between 19 – 21 traditional thermal friction drilling was applied to the samples, without using patterns, but in remained examples were supported by using moulds.

Three kinds of bushing shapes gained thermal friction drilling, supported with moulds, as seen in Figure 5. The most influential parameter to make the bushing shapes differentiated is the gap dimension between the conical tool and mould wall thickness (CDT). During the processes, the softened material flowed in these gaps, at the end of each example. However, at 0.2 mm gap values, the flowed softened material was departed from the bushing shape and then it was smeared to the wall of the moulds, by the rotating and proceeding impact of the conical tool motions. With increasing the gap values from 0.2 mm to 0.4 mm, the quantity of the flowed softened material, formatting the bushing, under the main bushing shape, as its continuation formation, increased. The main bushing shapes, composed in the cavity of the moulds, are numbered with 1 and the

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adhesive formation to the main bushing shapes, as bushings, enumerated with 2, as demonstrated in Figure 5

Figure 5: Bushing shapes achieved from thermal friction drilling with mould and without mould

The cracks and petal formation on bushing shapes were substantially eliminated, in thermal friction drilling, supporting with moulds, as seen in Figure 5 with example numbers. On bushings, obtained from traditional thermal friction drilling operations without using moulds, there were cracks and petal formation, as shown in Figure 5 with example numbers between 19 and 21.

Bushings, as demonstrated in Figure 5, in examples, shown with numbers of 1, 9, 14, and 15, bushings shapes received in cylindrical shapes, in homogenous wall thickness, without cracks and petal formation, in moulds, supported thermal friction drilling, with 0.2 mm gap size (CDT). However, in examples, shown with numbers of 2, 3, 7, 8, and 13, bushing shapes has an adhering formation to the main bushing shape as its continuation.

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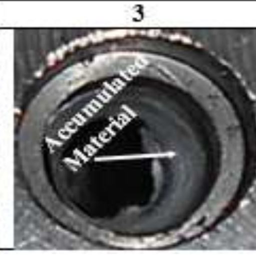
3.2. Moulds Geometrical Properties

Moulds were manufactured from AISI 1050 steel alloy, in dimensions demonstrated, as specified in Table 1. VE is the total volume of the evacuated material from the sample, during the process. VBC is the volume of the cavity of the mould, composing the bushing geometrical dimensions, such as bushing height and wall thickness. The volume of the cavity of the moulds (VBC) selected between at 16.02 % (minimum) and 32.24 % (maximum) percentages of the total volume of the evacuated material (VE). The height (hac) and outer diameter of the cavity (ØDm), composing the wall thickness of the bushing shape, were selected in different kinds of values, between 1.9 mm – 4 mm and Ø8.50 mm – Ø13.62 mm, respectively. Therefore, the cavities, composing to the bushing wall thicknesses (twm), were selected between 0.9 mm – 1.72 mm.

At the end of some examples, in which the gaps (CDT) selected as 0.2 mm, the flowed softened material smeared to the wall of the moulds by the effects of the conical tool rotating and proceeding motions, as seen in Figure 6, moulds photos demonstrated with example numbers 9, 11, and 18. In some moulds cavities, in which the gap (CDT) values selected as 0.2 mm, the flowed softened material accumulated in moulds, as seen in Figure6, in which photos are shown with example numbers 1 and 3. However, at selected 0.3 mm and 0.4 mm gap of moulds (CDT), the flowed softened material was neither smeared on the wall of the moulds nor accumulated in the mould cavities. Therefore, the softened residual material flowed into the mould, as a bushing and a continuation of the main bushing shape, adhesive to the main bushing formation, by this way the cavities of the moulds were free of the softened residual material, as seen in Figure 6, in which photos demonstrated with example numbers 2, 7, 8, and 16.

Although the gap (CDT) selected as 0.2 mm in small value, the softened material flowed in downwards and smeared to the moulds walls, by the effect of the motions of the tool. The flowing of the softened material downwards in the gap (CDT) can attribute to the selected volume size of bushing cavity. Probably, the size of the mould cavity is selected smaller than the volume size of the material, composing the bushing shape. Therefore, the residual material
flowed downwards through the impact motions of the conical tool.

With selecting the volume size of bushing cavity on moulds as close as to the volume size, composing the bushing, the residual material, flowing downwards, in the gap (CDT), will be able to eliminate. Additionally, selecting the accurate gap value (CDT) will be contributed to preventing the flowing of softened material. As a matter of fact, the prevented material can be contributed to composing of bushing shape.

Exam. No	1	2	3
Moulds Cavities After Processes			

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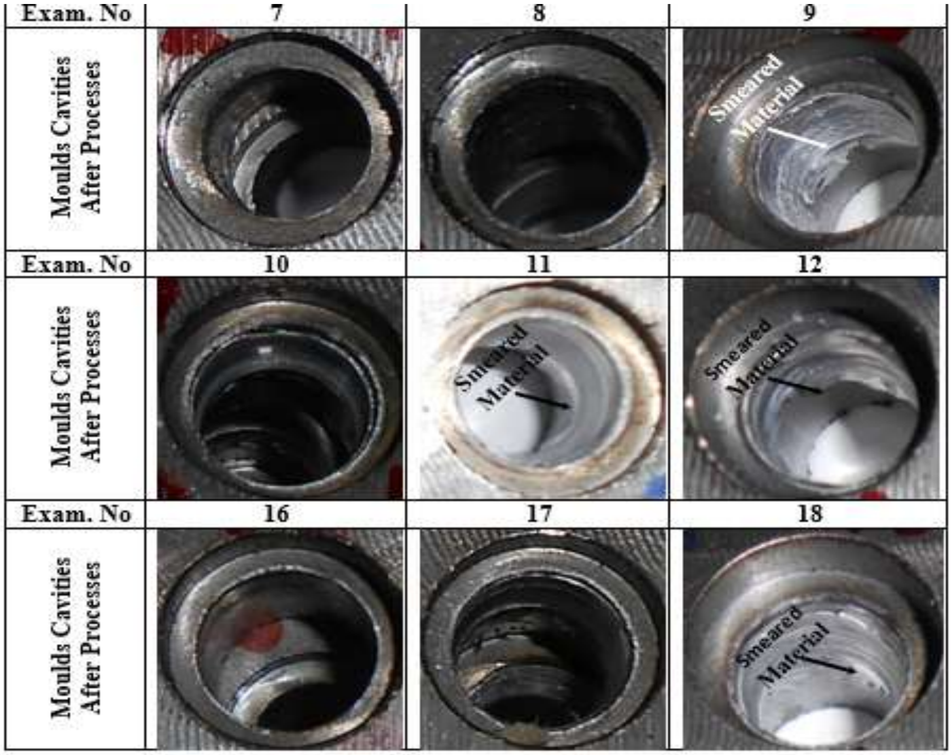

Figure 6: Moulds cavities after thermal friction drilling operations

3.3. Threading Properties of Bushings

The obtained bushings threaded in metric union, according to the holes diameters, Ø6.7 mm, Ø8.5 mm, and Ø10.2 mm in diameters. The bushing wall thickness is bushing formation geometrical dimension, affecting the depth of threading thereby the strength of connecting of sheet cast metal materials. The bushing wall thickness values were obtained between 0.995 mm and 1.31 mm for Ø6.7 mm in diameter of bushing hole, between 1.36 mm and 1.66 mm for Ø8.5 mm in diameter, and 1.69 mm for Ø10.2 mm in diameter. The thickness and height values of bushings were adjusted, depending on moulds cavities, arbitrarily. The measured size of both bushing height and wall thickness values were obtained, closed to the cavity sizes on the moulds, as seen in Table 2.

The tooth depth of M8, M10, and M12 threads are 0.77 mm, 0.92 mm, and 1.074 mm respectively. According to the bushing height and wall thickness values, threaded bushing formations provide the connection length and its strength. While higher bushing heights provide more threading length, bushing wall thickness affects the strength of the connection, depending on the depth of threading.

Table 2: Geometrical dimensions of obtained bushing shapes.

Example Number	**Ød**	**ØD**	**ha**	**VBC**	**% (VBC/VE)**	**tw (mm)**	**CDT (mm)**
1	6.7	8.69	3.74	24.08	28.59 %	0.995	0.2
2	6.7	8.71	3.56	22.95	27.25 %	1.005	0.4
3	6.7	8.68	3.02	15.27	18.13%	0.99	0.3
4	6.7	8.74	3.56	22.79	27.06 %	1.02	0.4

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5	6.7	8.62	3.54	21.68	25.74 %	0.96	0.2
6	6.7	8.94	2.32	13.50	16.02 %	1.12	0.4
7	6.7	9.04	2.86	20.94	24.87 %	1.17	0.4
8	6.7	9.32	2.34	18.39	21.84 %	1.31	0.4
9	8.5	11.56	3.16	29.04	27.18 %	1.53	0.2
10	8.5	11.22	2.72	21.69	20.29 %	1.36	0.2
11	8.5	11.52	2.28	19.74	18.47 %	1.51	0.2
12	8.5	11.32	3.46	29.66	27.76	1.41	0.2
13	8.5	11.2	4.1	34.45	32.24 %	1.35	0.3
14	8.5	11.82	2.98	25.77	24.12 %	1.66	0.2
15	8.5	11.3	3.68	31.91	29.86	1.4	0.2
16	8.5	11.26	3.88	33.09	30.96	1.38	0.3
17	8.5	11.24	3.96	33.26	31.13	1.37	0.2
18	10.2	11.88	3.48	36.55	28.50	1.69	0.2
19	6.7	8.86	5.23			1.08	
20	8.5	10.98	6.46			1.24	
21	10.2	13.54	7.42			1.67	

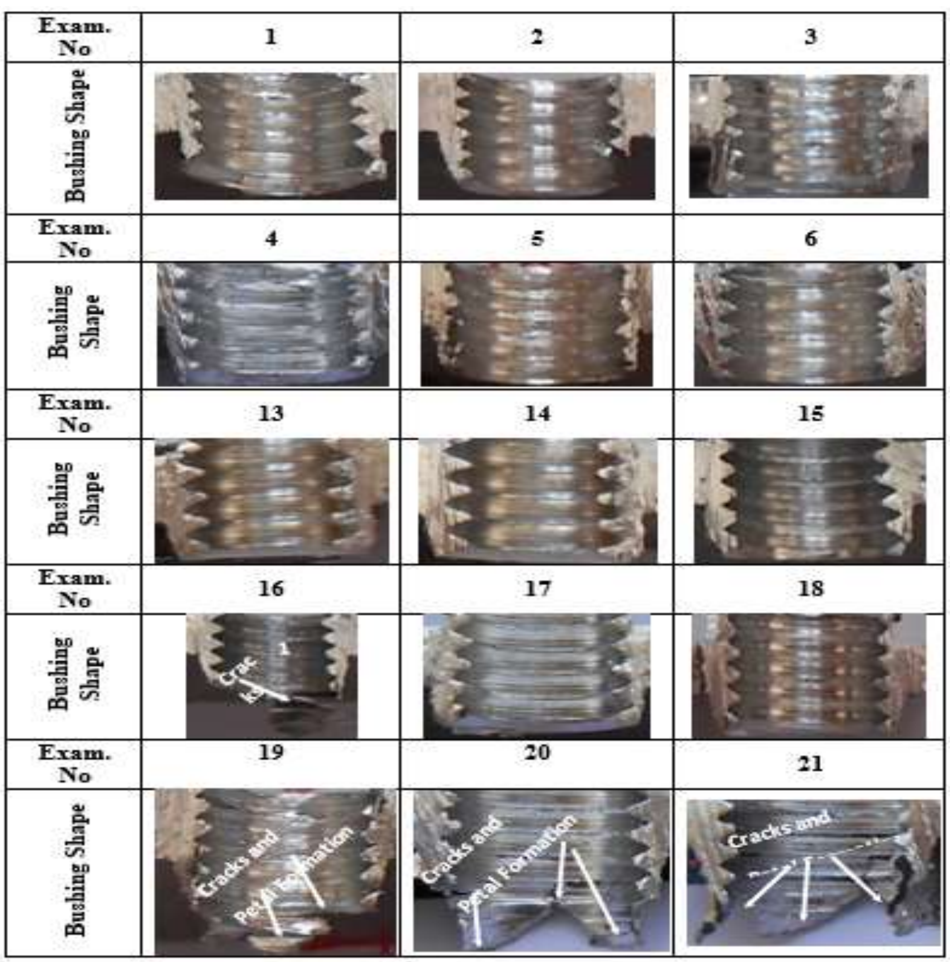

Figure 7: Threading of bushing shapes, achieved from thermal friction drilling with mould and without mould

Bushings, with homogenous bushing wall thickness, without cracks and petal formation, obtained in thermal friction drilling operations, supported with moulds, as observed in Figure 7. Due to the thickness of the formation, adhering to the main bushing shape as its continuation, from the moulds cavities borders, was smaller than the depth of threading teeth, it removed from the main bushing formation during threading. However, on threaded bushing shape, demonstrated with 16 example number, a small part of this formation remained to adhere to the main bushing shape, as cracks and petal formation, as seen in Figure 7.

Although traditional thermal friction drilling provided higher bushing heights and thicker wall thicknesses, threading was not homogenous along the bushing shape due to cracks and petal formation on threaded bushings photos, as seen in Figure 7, specified with example numbers from 19 to 21. Furthermore, bushing wall thickness became thinner from the root of the bushings to their tip points. Therefore, it estimated that threading is not contributed to the connecting strength of bushings, obtaining from traditional thermal friction drilling operations.

4. Conclusions and Recommendations

4.1. Conclusion

Bushing formation is a vital problem in the thermal drilling of brittle cast metal materials due to the cracks and petal formation. Therefore, in this paper, thermal friction drilling of A7075-T651, as a brittle aluminum alloy, was supported with moulds, during the operations made the softened material flowed in the cavities of the models. Thus cracks and petal formation on the bushings were substantially eliminated, bushing height and wall thickness values could be adjusted, according to the requirements expectations, and bushings geometrical dimensions were shown homogenous along the bushing formation. Thus the most appropriate threading was achievable in mould supported thermal friction drilling operations.

4.2. Proposals

The proportion volume of the material, composing the bushing shape to the total evacuated material from the sample is a crucial parameter for moulds, mould supported thermal friction drilling operations. Therefore, the proportion of the material, composing the bushing shape, must be identified, depending on the volume of the total evacuated material, in percentage unit. Because how accuracy selected the mould cavity volume, the most precision bushing shapes can be obtained without softened residual material, flowing in the gap (C_{DT}). Furthermore, the mould gap size (C_{DT}) must be selected smaller than 0.2 mm, also moulds are recommended to hot work steel alloys.

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Competing interests

The authors declare that they have not any competing interest for the paper.

Authors' contributions

All authors contributed to the results reviewed, and all authors have approved the manuscript for submission.

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