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Influence of The Thermal Drilling Process Parameters on The Dimensional Characteristics of AA6082 Aluminum Alloys

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***Abstract*:- In the present investigation, holes were manufactured in AA6082 aluminum alloy sheets using thermal drilling (TD) process. The effect of the TD process parameters, namely, the tool rotational speed (TRS), tool feed rate (TFR) as well as the tool's conical angle (TCA) on the generated hole dimensional characteristics, typically, hole diameter (HD), bushing height (BH) and bushing thickness (BT) were studied. The analysis of variance (ANOVA) was used to evaluate the significance of the investigated TD process parameters. The results revealed that the interaction effect of TRS, TFR and TCA found to have significant influence on the hole dimensional characteristics, like, HD, BH and BT. The ANOVA calculations showed that the TFR is the most influential parameter that affects the HD, followed by TRS and then TCA. While for the BH and BT, the TRS is the most influential parameter that affects the BH and BT, followed by TFR and then TCA. The TFD process parameters is the least parameter that influence on the hole dimensional characteristics.**

1. INTRODUCTION

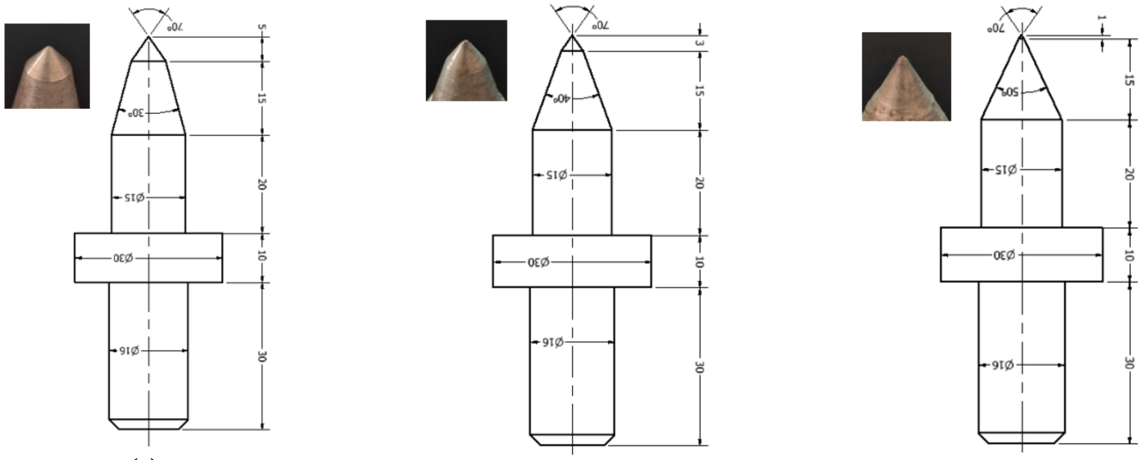
Thermal drilling (TD) process, known also as friction frilling, is a non-traditional, hole shaping process that produces bushing without the formation of chips [1,2]. In TD process the heat developed due to the friction between the drilling tool and the workpiece is used for drilling the holes and forms a bushing on the workpiece due to the plastic deformation of the workpiece material [3]. The bushing in TFD process is formed in situ from the workpiece. The FTD is clean, no-chip and dry manufacturing process, in which no coolants or cutting fluids are necessary [4,5]

There are several FTD important process parameters that influencing the final hole dimensional characteristics as well as the hole quality. These parameters, include, the tool rotational speed (TRS), tool feed rate (TFR), the drilling tool geometry and size, the hole diameter and sheet thickness and the type of the workpiece material [6-9]. Studying the influence of these process parameters is very important to obtain the holes with the required dimensions characteristics and quality. *Krishna et al.* [10] investigated the mechanical aspects of TD of AA6351 Al alloy sheet having 1 mm thickness. They showed that a highly burnished surface is obtained at low and medium speeds, however, at high-speed discolorations is observed. Moreover, they reported that the TCA is a critical parameter, and it is affecting both torque and trust force. *Sami et al.* [11] investigated the influence of TD process parameters and predrill diameter on drilling force, generated temperature, BH and BT of A6063-T6 Al alloy. They showed that adding a pre-hole to the plate helps in attaining uniform BT and reduces the force and heat required to perform the TD process. *Ozek* and *Demir* [12] investigated the TD of 4 mm thickness A1050, A6061, A5083, and A7075 Al alloy sheets with different thermal coefficients of conductivity. The generated frictional heat, surface roughness, and BH according to TFR, TRS, and thermal conductivity coefficient of the materials were investigated. The results showed that, at the high TRS and low TFR, increasing thermal conductivity coefficients, the frictional heat was increased. The greater BH were achieved at lower TRS and high TFR.

In the present investigation, holes were drilled in 3 mm sheets made from AA6082 Al alloys using TFD process. The influence of the TFD process parameters, namely, the TRS, TFR and TCA on the manufactured hole dimensional characteristics, including the HD, BH and BT were investigated. The analysis of variance (ANOVA) statistical approach was adopted to assess the significance of the TFD process parameters and their influence on the aforementioned hole dimensional characteristics.

2. EXPERIMENTAL PROCEDURES

The workpiece material chosen was the AA6082 Al alloy sheets having 3 mm thickness. The chemical compositions of the AA6082 alloys are (wt.-%): 0.1% Cu, 0.5% Fe, 0.62% Mn, 0.7% Mg, 0.89% Si, 0.2% Zn, 0.25% Cr, 0.1% Ti and 96.64% Al. The TD process was carried out using three different tools with three different conical angles (β), typically, 30º, 40º and 50º as shown in Fig. 1. The TD tool is made from H13 tool steel with chemical composition as follows (wt.-%): 5.21% Cr, 1.1% Si, 0.39% C, 0.4% Mn, 1.37% Mo, 0.9% V and 90.63% Fe.



(a) (b) (c)

Figure 1. A schematic illustration of Photographs of the tools with different tool conical angles (β): (a) 30º, (b) 40º, and (c) 50º.

The holes were drilled using computerized numerically controlled (CNC) machine. The TD process was carried out using three different feed rates, typically, 100, 200 and 300 mm/min and three different spindle speeds of 2000, 2500 and 3000 rpm. Table 1 lists the studied TD process parameters and their levels.

Table 1. The studied TD process parameters and their levels.

Parameter	Symbol	Unit	Level		
			Min.	Avg.	Max.
Tool Conical Angle	TCA	Degree	30	40	50
Tool Rotational Speed	TRS	rpm	2000	2500	3000
Tool Feed Rate	TFR	mm/min.	100	200	300

After drilling, the workpieces were cut, from the center of the hole, using wire cut machine and the HD and BT and BH were measured. The BT was measured at the middle of the bushing height (BH/2). Figure 2 shows a schematic illustration of the HD, BT and BH dimension hole characteristics. The dimensions of these hole characteristics were measured using image analyzing techniques.

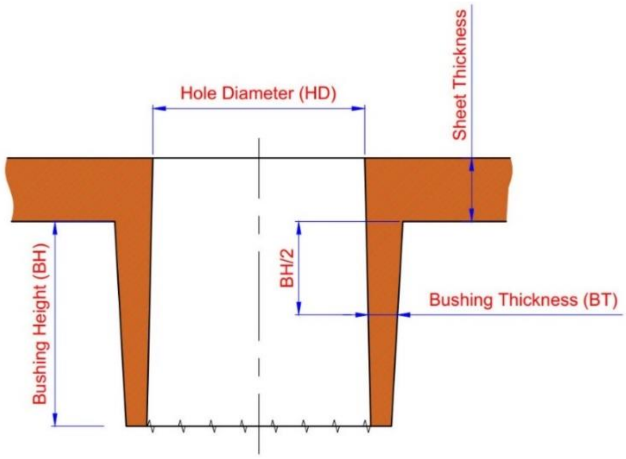


Figure 2. Bushing height, bushing thickness, and hole diameter.

The TD experiments were designed using full factorial design of experiments (DOE) technique. The full factorial design was applied for examining three parameters at three levels with total run of 27 (3^3). The analysis of variance (ANOVA) statistical approach was used to obtain the influence of the TD process parameters (i.e., TCA, TRS and TFR) on the developed hole dimensional characteristics (i.e., HD, BT and BH).

3. RESULTS AND DISCUSSION

3.1. The Formation of Bushing

Figure 3 show photographs of typical bushes formed after TD of AA6082 Al alloy sheets using different TRS, TCA and constant TFR of 200 mm/min. The photographs show the views of bushing from bottom of the sheets. Typical photographs of the cross-sections of bushes formed in thermal frictional drilling of the AA6082 aluminum sheets using different TRS, TFR and TCA are shown in Fig. 4. Cracks and petal formation in bushing were noticed in some samples. The formation of the petals and the

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generation of cracks are unfavorable features. These undesirable features affect the effective height and the strength for threading. The presence of cracks and petals may destroy the useful surface area and restrict the load carrying capacity of the holes during threading.

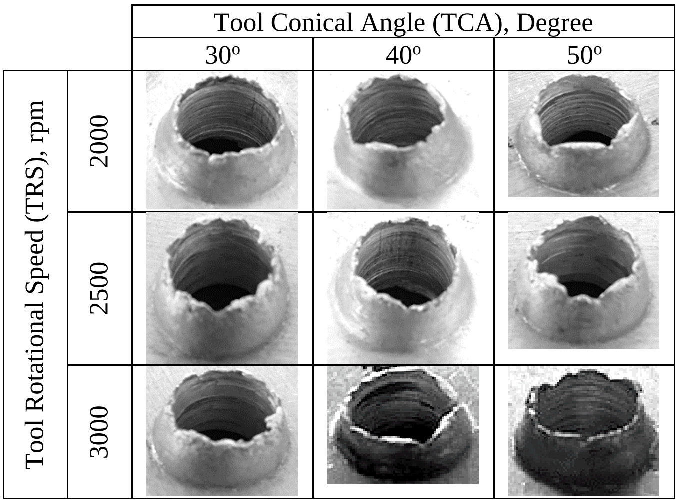

Figure 3. Bushes formed in AA6082 aluminum alloy sheets after TD using constant TFR of 200 mm/min and different TRS and TCA.

In TD process, it is considered that the sheet thickness and the hole diameter have significant influence on the bushing geometrical dimensions. Although, there are other crucial process parameters, like TCA, TRS, and TFR exhibit a significant influence on the bushing geometrical dimensions. It is because the volume of the evacuated material from the TD material shapes the bushing. The TFR and TRS process parameters may cause the creation of cracks and petal formation, especially in TD of brittle sheet materials, like A356 aluminum alloy, due to rotating and proceeding motions of the conical tool [4].

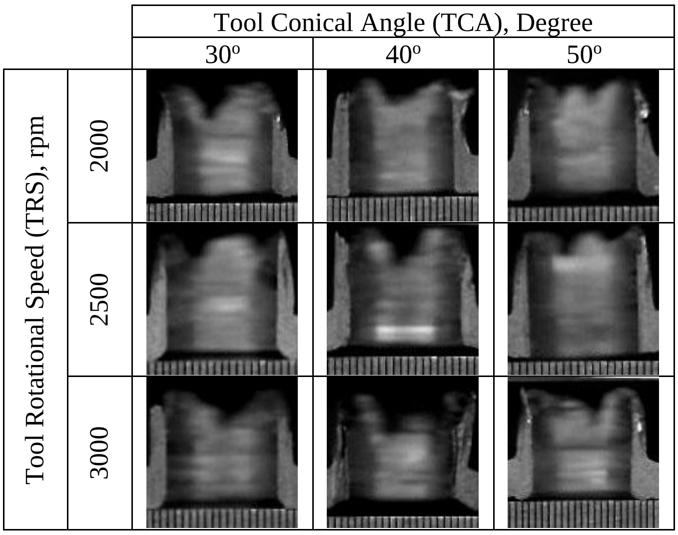

Figure 4. Cross-sections of bushes formed after thermal frictional drilling at constant TFR of 100 mm/min and different TRS and TCA.

3.2. Hole Diameter Measurements

Figure 5 shows the variation of the HD with the TRS at different TCA, and TFS. The results revealed that the TD process parameters have significant influence on the developed HD. At TFR of 100 mm/min (see Fig. 5a), and/or constant TCA, increasing the TRS reduces the developed HD. For example, TCA of 30°, increasing the TRS from 2000 rpm to 3000 rpm reduced the developed 15.296 mm to 15.149 mm, respectively. At TFR of 100 mm/min and constant TRS, the holes drilled using a tool with 30° exhibited larger HD when compared with holes drilled using tools with 40° and 50°.

The reduction of the HD with increasing the TRS was also observed for those holes drilled using constant TFR of 300 mm/min and the tools having different TCA (see Fig. 5c). For example, at constant TFR of 300 mm/min and the TCA of 40°, increasing the TRS from 2000 to 3000 rpm reduced the drilled HD from 15.273 mm to 15.161 mm, respectively. The results revealed also that the largest HD (15.296 mm) was obtained at TRS, TFR and TCA of 2000 rpm, 100 mm/min and 30°,

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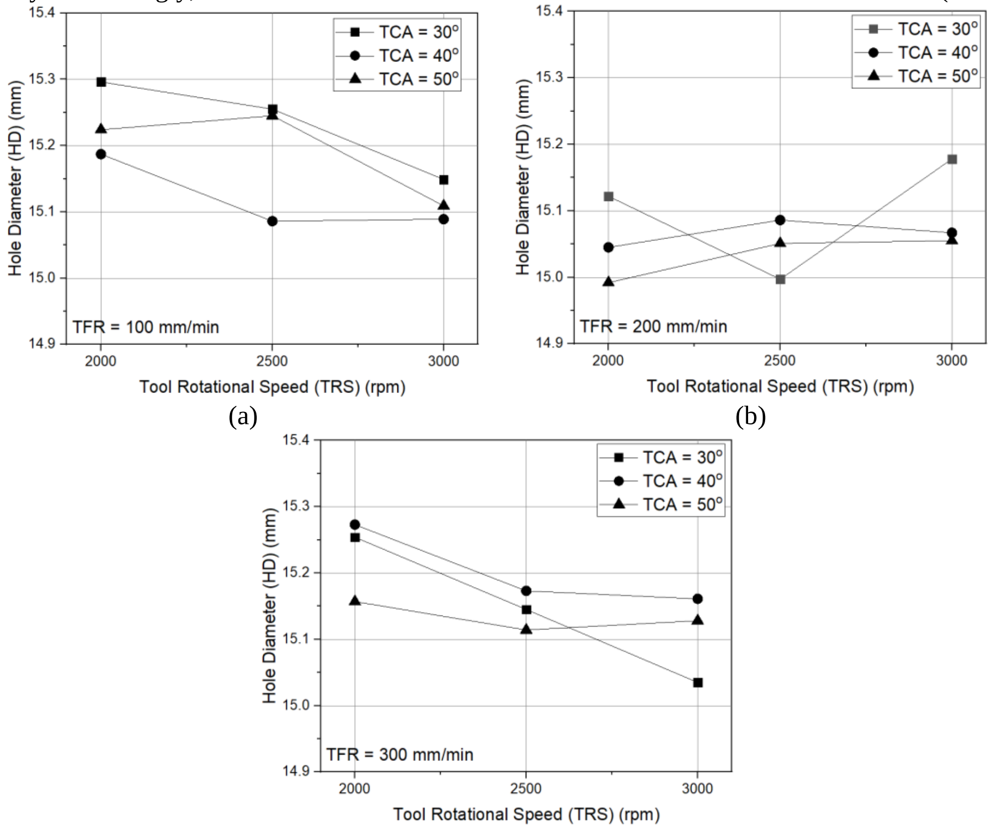
respectively. While the smallest HD (14.992 mm) was obtained at TRS, TFR and TCA of 2000 rpm, 200 mm/min and 60°, respectively.

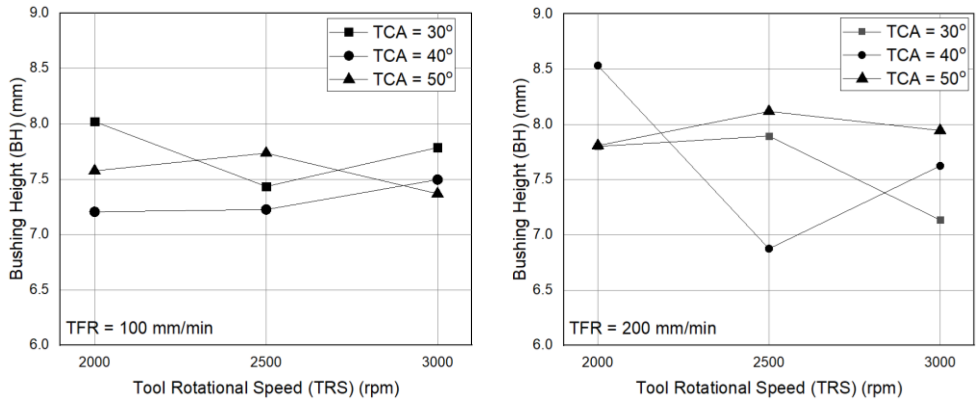
3.3. The Bushing Height and Thickness Measurements

Figures 6 and 7 show the variation of the BH and BT with the TRS at different TCA and TFR, respectively. The maximum BH was about 8.532 mm and obtained for hole drilled using TCA, TRS and TFR of 40°, 2000 rpm and 200 mm/min, respectively. While the minimum BH was about 6.875 mm and obtained for hole drilled using TCA, TRS and TFR of 40°, 2500 rpm and 200 mm/min, respectively. Accordingly, the BH of the drilled holes is about 2.29 to 2.844 times the thickness (3 mm) of the sheet.

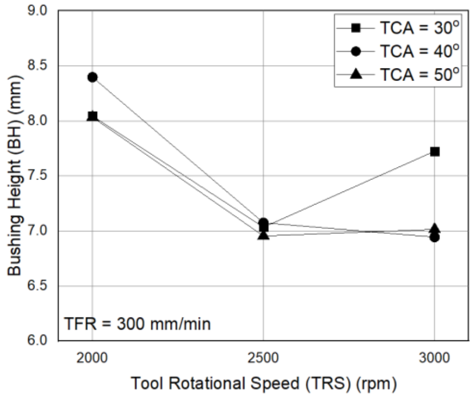


(c)

Figure 5. Variation of the HD with the TRS at different TCA, and TFS of (a) 100, (b) 200 and (c) 300 mm/min.

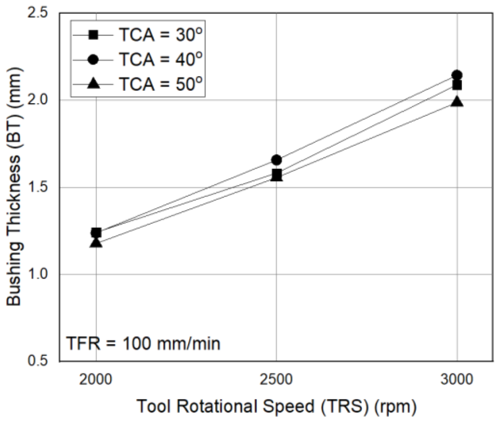


(a) (b)

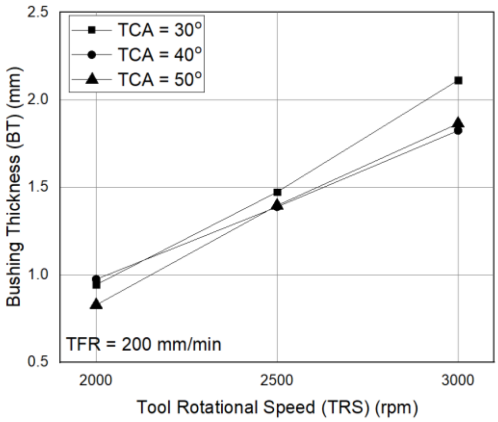


(c)

Figure 6. Variation of the BH with the TRS at different TCA, and TFS of (a) 100, (b) 200 and (c) 300 mm/min.



(a)



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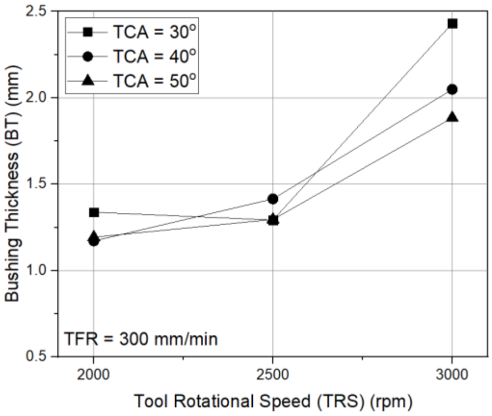

(c)

Figure 7. Variation of the BT with the TRS at different TCA, and TFS of (a) 100, (b) 200 and (c) 300 mm/min.

The maximum BT was about 2.431 mm and obtained for hole drilled using TCA, TRS and TFR of 30°, 3000 rpm and 300 mm/min, respectively. While the minimum BT was about 0.829 mm and obtained for hole drilled using TCA, TRS and TFR of 50°, 2000 rpm and 200 mm/min, respectively. It has been found that the BT of the drilled holes increases with increasing the TRS from 2000 rpm to 3000 rpm. For example, at constant TFR and TCA of 300 mm/min and 50°, respectively, increasing the TRS from 2000 rpm to 3000 rpm increased the BT from 1.194 mm to 1.884 mm, respectively. At constant TRS and TFR, increasing the TCA has slight influence on the BT, especially at the lower TRS of 2000 rpm and 2500 rpm. For example, at constant TRS and TFR of 2000 rpm and 100 mm/min, increasing the TCA from 30° to 60° produced holes with BT of 1.242 mm and 1.178 mm, respectively. The results showed that, at constant TRS (2000-3000 rpm) and TFR (100-300 mm/min), changing the TCA from 30° to 50° has no significant influence on BT of the TD holes. For example, at constant TRS and TFR of 3000 rpm and 100 mm/min, increasing the TCA from 30° to 50° reduced the BT from 2.088 mm to 1.987 mm (about 4.83% reduction), respectively.

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3.5. *The ANOVA Results*

Tables 2 to 4 shows response table for S/N ratios, based on the larger-is-better criteria for D, BH and BT, hole characteristics resulted from ANOVA calculations. The results revealed that, for the HD, the TFR is the most influential parameter (rank 1, see Table 2) that affects the HD, followed by TRS and then TCA. For the BH and BT, the TFS is the most influential parameter (rank 1, see Tables 3 and 4) that affects the BH and BT, followed by TFR and then TCA. Among all investigated thermal friction drilling process parameters, the TCA is the least influential parameter that affects the hole dimensional characteristics.

Table 2. Response Table for S/N Ratios for HD.

Level	TCA	TRS	TFR
1	23.61	23.62	23.62
2	23.59	23.59	23.56
3	23.59	23.58	23.61
Delta	0.02	0.04	0.07
Rank	3	2	1

Larger is better

Table 3. Response Table for S/N Ratios for BH.

Level	TCA	TRS	TFR
1	17.67	17.98	17.54
2	17.46	17.34	17.77
3	17.62	17.43	17.44
Delta	0.21	0.64	0.32
Rank	3	1	2

Larger is better

Table 4. Response Table for S/N Ratios for BT.

Level	TCA	TRS	TFR
1	3.7905	0.9204	4.0396
2	3.4846	3.2042	2.6593
3	3.0233	6.1738	3.5995
Delta	0.7672	5.2534	1.3803
Rank	3	1	2

Larger is better

Figures 8 to 10 show the interaction plots for HD, BH and BT hole dimensional characteristics. Parallel lines in an interactions plot indicate no interaction. The greater the departure of the lines from the parallel state, the higher the degree of interaction. It is clear from these graphs that the interaction effect of TRS, TFR and TCA found to have significant influence on HD, BH and BT hole dimensional characteristics.

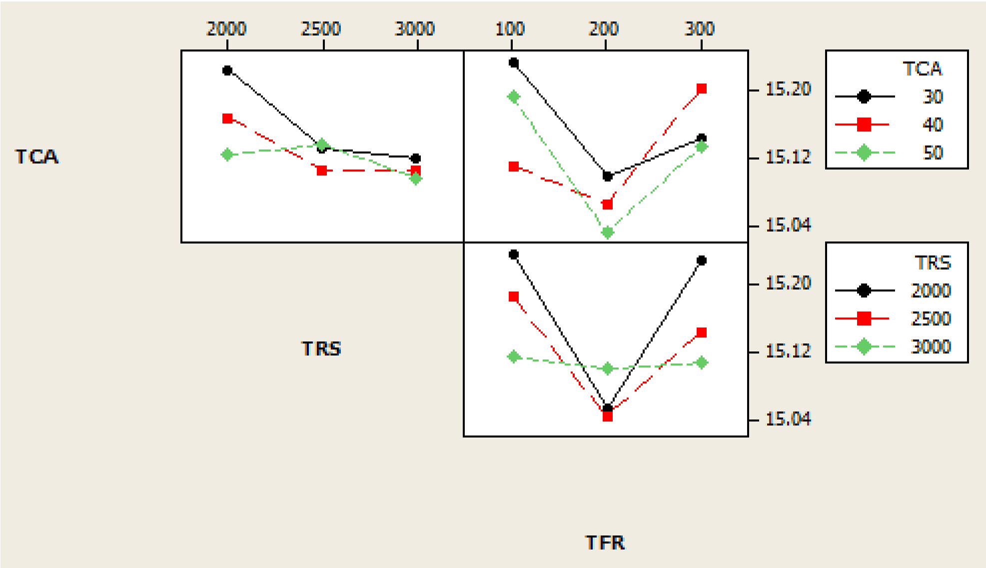

Figure 8. The interaction plot for HD.

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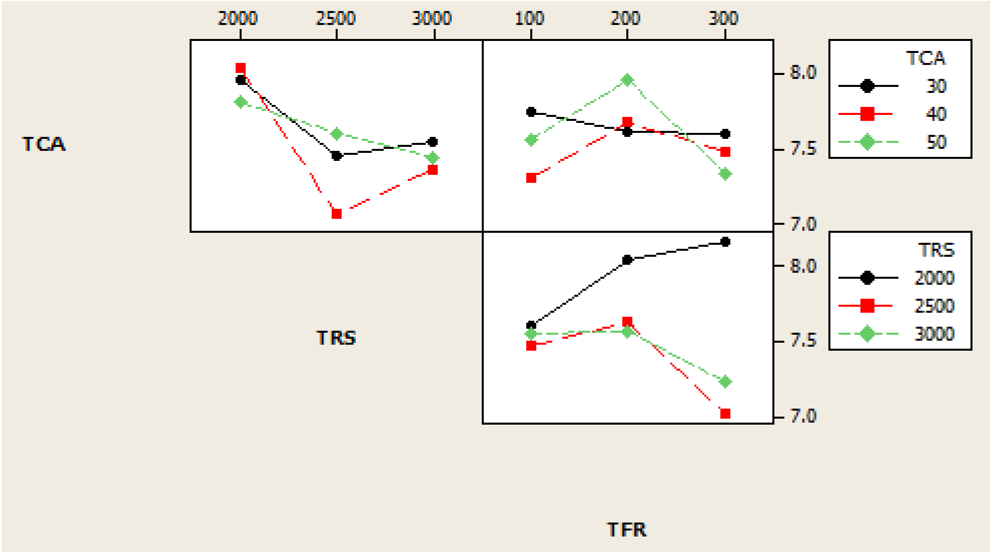

Figure 9. The interaction plot for BH.

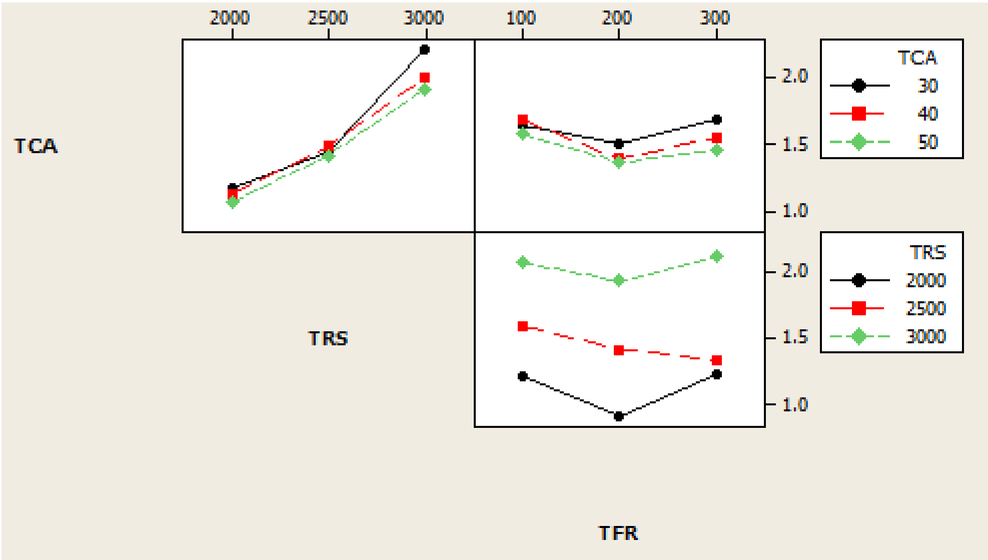

Figure 10. The interaction plot for BT.

4. CONCLUSIONS

Based on the aforementioned results, the following conclusions can be represented:

1. The TD was successfully used to manufacture holes with bushing in 3 mm thickness AA6082 Al alloy sheets. The interaction effect of TRS, TFR and TCA found to have significant influence on the drilled hole dimensional characteristics HD, BH and BT.
2. At constant TFR and TCA, the BT of the drilled holes increases with increasing the TRS from 2000 rpm to 3000 rpm. While at constant TRS and TFR, increasing the TCA has slight influence on the BT, especially at the lower TRS of 2000 rpm and 2500 rpm.
3. The ANOVA results showed that the TFR is the most influential parameter that affects the HD, followed by TRS and then TCA. While for the BH and BT, the TRS is the most influential parameter that affects both BH and BT, followed by TFR and then TCA. Among all investigated TD process parameters, the TCA is the least influential parameter that affects the hole dimensional characteristics.

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