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BURR HEIGHT ASSESSMENT: A CASE STUDY DURING THE DRILLING PROCESS OF THIN ALUMINUM SHEETS

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Abstract: The study of the burr height generated in the drilling of thin aluminum sheets emerged during the creation of the ROBOCETI project chassis, where it was necessary to drill 2 mm thick aluminum sheets and the formation of large burrs was noticed. Preliminary tests were carried out in order to identify the parameters that influenced the burr height, and from them it was decided to evaluate the effects of cutting speed, feed and pre-hole, and to determine the necessary tests, factorial planning was used. with three variables at two levels. To carry out the tests, a CNC milling machine, high speed steel drills, and the CAD-CAM – NX4® software performed the simulation of the holes that were performed in random order, in all holes, alcohol was used as cutting fluid. hydrated ethyl. The burr measurement was performed indirectly, where the resin was used to form the burr replica. To obtain the images of the samples of the burr replicas, a photographic camera and a scale were used. With the scale in the photo, it was possible to measure the samples using AutoCAD® software, where the scale served as a parameter for the measurement. The analysis of the results was performed using the DOE4u software complement, where the effects were analyzed both individually and in combination, and showed that the most influential parameter was the pre-hole, when the burr was reduced in size. Another parameter that proved to be important was the advance, in which its increment increases the size of the burr. The cutting speeds used did not show significant effects.
Keywords: Aluminum, drilling, experiment design, burr.

INTRODUCTION

According to Carvalho *et al.* (2009) the ROBOCETi project (Robotics as a Training Instrument for Federal Institutes in Science, Education, Technology and Innovation) was developed in the Federal Network of Professional and Technological Education, linked to the Ministry of Education, in the area of educational robotics, with the objectives of training of teachers from the Federal Network and the motivation of students to choose careers linked to engineering and technology. During the construction of the chassis of the ROBOCETI project, it was necessary to drill 2 mm thick aluminum sheets. During the making of these holes, the problem of formation of large burrs was encountered, which required finishing (deburring).

Aluminum has many advantages over other materials, however, the generation of large burrs is a common problem when machining this metal. The study of experimental processes makes it possible to develop new technologies and improve existing ones. According to ABAL – Associação Brasileira do Alumínio (2017), the characteristics of aluminum allow it to have a diverse range of applications, so the metal is one of the most used worldwide. It is a lightweight, durable and beautiful material, as well as showing excellent performance and superior properties in most applications. For this reason, the study carried out in this work is important.

According to Stemmer (1992); Diniz, Marcondes and Coppini (2003), feed, cutting speed and hole diameter are influential parameters in burr formation, so a complete factorial statistical experiment was used to evaluate the drilling process.

The understanding and control of burr formation in parts obtained by machining processes has shown relevant interest in the academic and industrial sector (KILICKAP, 2010; REZENDE *et al.*, 2016). In the review work by Dornfeld and Mil (2010), the authors point out that the costs with labor and processes associated with the removal of these burrs are substantial, reaching up to 30% for components that require high surface finish and precision, such as aircraft engines.. In medium complexity components, such as the automotive segment, the total deburring cost value for a part is concentrated in the range of 15 to 20% of manufacturing expenses. Therefore, industrial practice has shown that the real investment in deburring systems increases with the complexity of the part and that studies aimed at controlling cutting parameters that reduce burr formation as a result of machining help to reduce the cost of devices and labor.

Preliminary drilling tests on commercially pure aluminum were performed. During the tests, the cutting and feed speed values were changed, in addition to the pre-hole. The cutting fluid used was ethyl alcohol. However, the use of the same did not show relevant influence. After carrying out preliminary tests, the parameters were defined and the holes were drilled. Then, the burr generated indirectly was measured and the results were analyzed using the DOE4u *software* complement developed by Resende, Silva (2017).

METHODOLOGY

This section presents the methodology used during the tests, in addition to the equipment, materials and tools used during the work.

MATERIALS

To carry out the tests, the DIPLOMAT NARDINI brand milling machine, model Petrus 50100R, with HEIDENHAIN control was used. The tools used were 2 mm and 4 mm diameter high speed steel twist drills, both with original sharpening, that is, a tip angle equal to 118º.

The specimens used in the tests were commercially pure aluminum plates with dimensions of: 175.9 mm in length; 64.9 mm wide; and 2 mm thick. These dimensions were defined during the execution of the robotics kit of the ROBOCETI project, as the part is part of the mechanical structure of the robotic car chassis.

To fix the part in the CNC milling machine, an MDF (medium-densityfiberboard – medium density fiberboard), with holes 8 mm long and 6 mm in diameter so that the burr could form freely. Hydrated ethyl alcohol 46^0 INPM / 54^0 GL was used as cutting fluid.

To form the burr replica, Optosil ® condensation silicone was used comfortPutty and its activator, both branded by HeareusKulzer ®. According to preliminary tests, the best concentration for this purpose is found in the proportion of 4 ml of silicone and 0.1 ml of activator. Because, under these conditions, the complete hardening time is 180 seconds, which is enough time to handle it.

To maintain the standard of the photographs, a support with height variation, support for a cell phone, a potentiometer and lighting with LEDs were used. The camera used was an iPhone ® 6, with a resolution of 8 megapixels.

Still to maintain the standard, a small box was used to deposit the resin, in addition to a cutting template so that the samples at the height of the burr kept the same thickness. To cut the resin (mold with burr negative), a stylet was used.

HURRICANE

To carry out the tests, there was a concern to determine the input parameters that would be controlled during the test and their influence on the machining of the material. Feed, cutting speed and pre-hole diameter were defined as input variables, and burr height as output variable. With the parameters already defined, according to Montgomery et al. (2004), “when there are several factors of interest in an experiment, a factorial design must be carried out”. For this purpose, we used the planning of three input variables with two values each, that is, 2^3, as shown in Table (1).

Assays 1 to 4 were performed using a 4mm diameter drill, without any prior preparation. Tests 5 to 8 were initially performed with a 2mm drill and later with a 4mm drill. The 2mm holes are called pre-holes.

To minimize errors, it was defined that the holes would be drilled in random order and *CAD* -CAM NX-4 software would be used to generate CNC code for the machine tool. It is worth mentioning that the parts, after the burr studies, will receive more holes, to finally integrate the mobile car chassis kit of the ROBOCETI project. Therefore, holes in the wrong places could compromise their future use, which shows the need to use the UGS NX 4.0 as a tool to eliminate possible errors in hole positioning.

In order to define the random order of the holes, two draws were carried out, the first to define the order of the holes for tests 1 to 4, and the second for tests 5 to 8. The tests were divided this way, as it was It is necessary to generate two codes in the NX-4 *software, one for the tests without* pre-hole and the other for the tests with pre-hole.

Then, the CNC code was created in the NX-4 *software,* for this, a drawing of the part was made in SolidWorks, which was later exported to the NX-4, and this, through the *blank,* which is a blank, marked the holes in the order previously defined by drawing lots.

After programming the machine, the aluminum plate was fixed on the previously prepared MDF board, and then the holes of tests 1, 2, 3, and 4 were made, with four repetitions each, modifying the speed parameters of cutting and feeding, using the 4 mm drill bit. The same procedure for programming and fixing the plate was performed for tests 5, 6, 7, and 8, also with four repetitions for each one, modifying: cutting speed, feed, using the 2 mm drill for the pre-hole and then using the 4 mm drill bit.

The plates after drilling can be seen in figures (1a) and (1b).

MEASUREMENT

First, the activator and silicone were manually mixed until a homogeneous mixture was obtained. This mixture was placed inside the device (Figure 2a). Then, the mold (small box) with the resin was placed, carefully, on the aluminum plate, as shown in figure (2b), then the curing and hardening time was allowed. After this period, the resin was removed from the mold, (Figure 2c), and fitted to the cutting template, (Figures 2d and 2e), then it was cut into pieces, with a thickness of 1 mm, with the aid of a stylet, in four samples for each repetition.

To perform the measurement with AutoCAD ®, the methodology described by Rodrigues and Siqueira (2007) was used. In this method, the image of the sample with a scale on the side was obtained using a photographic camera, then the image was transferred to a computer and exported to AutoCAD ® *software.* Thus, it was possible to adjust the image scale for the measurements, as shown in Figure (3).

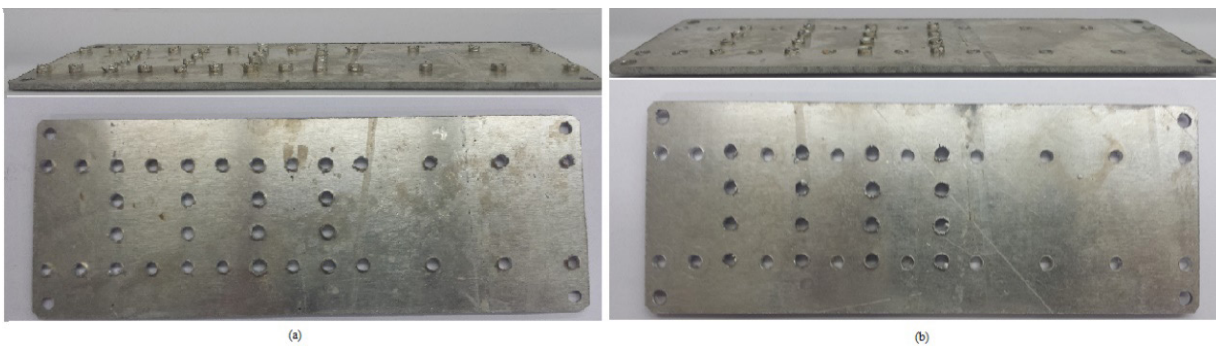
Data analysis was performed using the complete factorial planning tool - DOE4u, free to use in the LibreOffice ® Calc Worksheet, developed by Resende e Silva (2017), where the parameters used and the height of the measured burrs were released, and the *Software* add-on generated the results in the form of tables and graphs.

RESULTS

Based on the results presented in the DOE4u *software complement,* it was possible to analyze

Experiment No.	Cutting speed (V) [m/min]	Advance (fz) [mm/ rev]	pre-hole [mm]
1	40	0.02	0
two	80	0.02	0
3	40	0.08	0
4	80	0.08	0
5	40	0.02	two
6	80	0.02	two
7	40	0.08	two
8	80	0.08	two

Table 1. Factorial design (2^3) with three variables.



(The) (B)

Figure 1. Plate after drilling: (a) Tests 1 to 4; (b) Tests from 5 to 8

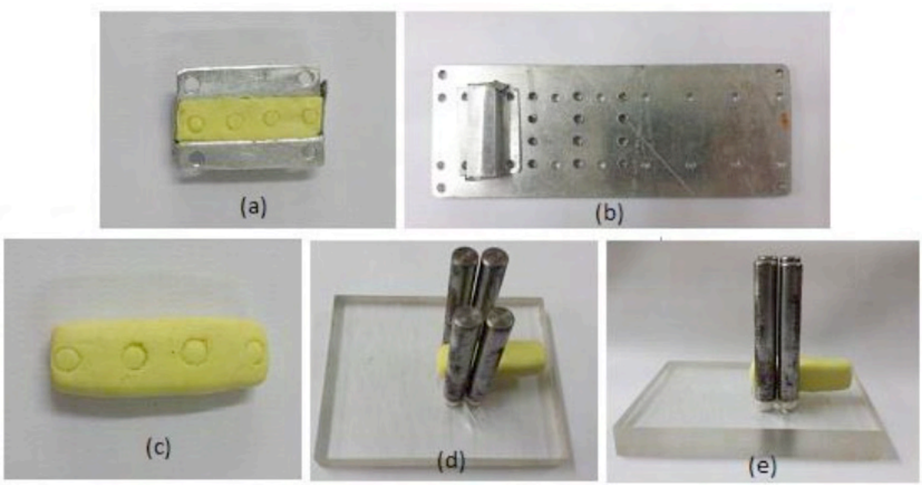


Figure 2. Resin modeling: (a) Resin inside the device; (b) Device embedded in the aluminum plate; (c) Resin after curing; (d) Top view of the resin in the cutting template; (e) Side view of the resin in the cutting template.

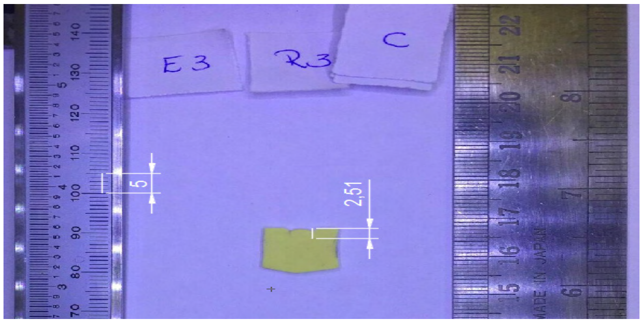


Figure 3. Sample with measurement in AutoCAD ®.

Matriz ANOVA						
Fatores	**GL**	**SQ**	**Contribuição Percentual**	**MQ**	**Fo**	**P**
Vc	1	0,0045125	0,03%	0,0045125	0,08	0,7787
fz	1	4,83605	31,22%	4,83605	86,58	0,0000
Vc+ fz	1	1,25E-05	0,00%	1,25E-05	0,00	0,9882
pré furo	1	6,1075125	39,43%	6,1075125	109,35	0,0000
Vc + pré furo	1	0,0032	0,02%	0,0032	0,06	0,8129
Fz + pré furo	1	3,1878125	20,58%	3,1878125	57,07	0,0000
Vc+ fz + pré furo	1	0,0098	0,06%	0,0098	0,18	0,6790
Erro	24	1,34049999999998	8,65%	0,05585417		
Total	31	15,4894	100,00%			

Figure 4. ANOVA matrix.

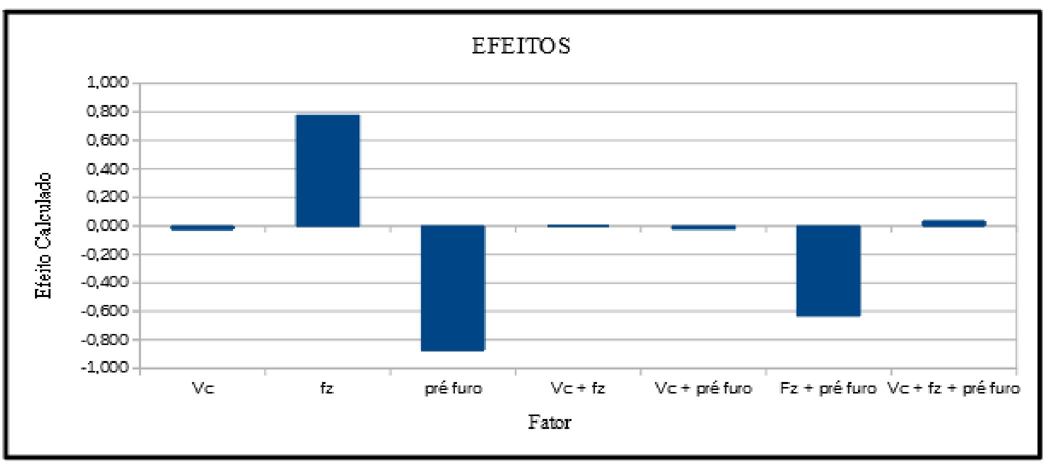


Figure 5. Graphic representation of the influence of s parameters.

the data obtained in the experiments, and observe which ones significantly influenced the height of the formed burr.

Using these data, the DOE4u *software* complement generated the ANOVA matrix, Figure (4), which shows the percentage contribution of each parameter, namely: cutting speed, feed and drilling using pre-hole.

According to the results obtained in the ANOVA matrix, the highest percentage contribution in this experiment was from the pre-hole, which presented 39.43% and the lowest was from the combination of the cutting speed with the pre-hole, which was 0.02 %. According to Resende and Silva (2017), the reliability adopted in the DOE4u is 95%, that is, for any p-value less than 0.05, the effect is considered to be relevant.

To facilitate the visualization of the cut parameters and their effects, a graph was also generated, in DOE4u, as shown in figure (5). In view of the graph presented, it is possible to observe that the factor " fz ", which represents the feed, the factor " pre-hole ", which represents the 2 mm hole, which was made before the 4 mm hole, and their combination are factors that had the greatest effect on burr formation. The factor " Vc ", which is the cutting speed, and the other combinations have no influence on the burr height.

Analyzing Figure (5), which represents the calculated effects, by the DOE4u *software* complement, it was possible to observe that the pre-hole factor was more important in the burr height, followed by the advance (fz). The cutting speed (Vc) had the least importance in this experiment. As the pre-hole was negative in the graph, the output, that is, the burr height, decreased when the pre-hole had its value increased from 0 mm (zero, that is, without pre-hole) to 2 mm. On the other hand, the advance caused the height of the burr to be higher, when using the advance of 0.08 mm/ rev, and lower when using the advance of 0.02 mm/ rev, that is, as the advance increased, the height of the burr also increased. increased.

CONCLUSION

In view of the results presented, in figures (4) and (5), it is possible to observe that the burr height is inversely proportional to the pre-hole size and the cutting speed, and directly proportional to the feed.

The variables influencing the burr height were pre-hole, followed by feed and a combination of the two. Cutting speed and other combinations had negligible effects.

With this, it is possible to conclude that, in a process of drilling thin aluminum sheets, the use of pre-hole is an important solution for a lower burr height. Progress is also important. Therefore, lower feeds and larger pre-holes would result in lower burr height values, according to the required materials and specifications.

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