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DETERMINATION OF TOOL WEAR DRILLING PROCESS OF ALUMINUM 6061 AND BRASS C3604 BY USING CNC ROBODRILL MACHINE

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ABSTRACT

Hole making process is a stimulating process as it impacts the drilling tool's performance and wear. The main objective of this paper is to determine the drilling tool wear by using step-by-step drilling approaches used by most of the manufacturing companies. Two types of materials involved; Aluminum 6061 & Brass C3604. Firstly, the raw material grade was confirmed by testing it using an Oxford Spectrometer. Four types of drilling tools are used; center drill diameter 3.00 mm; drill diameter 10.00, 13.00 and 14.50 mm. The drilling tool material used is High-Speed Steel (HSS). The cutting parameter used is stated in detail in the methodology section. Two approach are used to determine the tool life; measuring the holes diameter produced by using Vernier caliper; graphical form with the help of the camera. The major finding of this research is the understanding on how the cutting process react with the drilling tool during the cutting process as discussed in the results and discussions. The tool life of a center drill, drilling tool diameter 10.00 mm, 13.00 mm and 14.50 mm in drilling Aluminum 6061 is 476, 250, 485 and 499 holes while for Brass C3604 is 360, 190, 360 and 375 holes.

Keywords: Tool wear; aluminum 6061; brass C3604; drilling process

INTRODUCTION

The primary purpose of creating holes is to be used to tightened using rivets, screws and bolts before small parts can be turn into a complete product. The most common products with many holes in the automotive industries are engine block where it consists of many holes for various purposes. Hole making is the most critical process in assembly a product because failure to produce a good quality of holes will lead to lost assembled product functions [1]. The force that occurs during drilling operations is cutting force (F_c), Thrust force (F_f) and Radial force (F_r) [1]. These three forces and raw material characteristics sometimes make drilling challenging, impacting the drilling tool's wear. The main objective of this paper is to determine the drilling tool wear and understanding the mechanism which leads to the tool wear, while the scope of this study is by using the step drilling approaches such being used in industry.

Drilling operations is a cutting process to produce a circular hole using a drilling tool [2]. Tolouei-Rad [3] added that holes are created when cylindrical tools rotate against a workpiece, where the tool is called a drill bit. On the other hand, Kalpakjian & Schmid [4] added that drill-cutting tools have a high length-to-diameter ratio; they can produce a relatively deep hole during the cutting process.

According to Kumar el al., [2], Kalpakjian & Schmid [4], drilling operations can produce holes by using various tool such as straight-fluted drill, twist drill, double-fluted, step drill, spade drill, gun drill and etc. The most common drilling tool in the manufacturing industry is a standard twist drill cutting tool [5]. Kalpakjian and Schmid [4] also seconded that the standard twist drill is widely used in manufacturing industries, as shown in Figure 1 [4]. The twist drill cutting tools have four main features: point angle, helix angle, chisel angle and lip-relief angle. Generally, there are two types of twist drills commonly used; two and three-flutes (grooves) twist drills. These flutes run the length of the drill and guide the chips produced during the drilling process upward out from the drilled hole. According to Alting [6], a point angle is the angle between two lips when projected on a plane parallel to the axis where the normal value of a point angle is 118 degree. Alting [6] also stated that the helix angle is the angle of the flute concerning the work surface. The values varied between 18 - 45 degrees, and the standard value used is 30 degrees. The chisel angle is the angle between the chisel edge and the lip of the twist drill when measuring on a normal plane to the axis. Lastly, the lip-relief angle is formed by the flank. A plane perpendicular to the axis lip-relief angle is given to the cutting edges to allow the drill to enter the workpiece without hindrance.

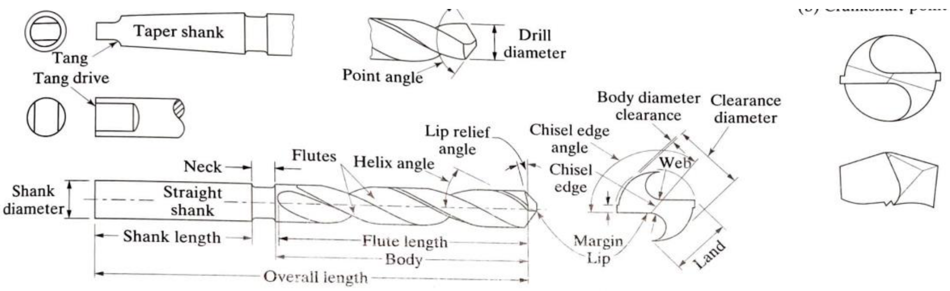


Figure 1. Twist drill part name [4].

The twist drill design was improvised by adding chip-breaker feature ground along the cutting edges, allowing the chip produced to be short in length. Besides that, some drill has internal longitudinal through holes that enable cutting fluids to go through them, improving the lubrication and cooling as long as washing away the chips effectively.

Table 1 Summary of Aluminum 6061 and Brass C3604 compositions.

Materials	Aluminum 6061 (% content)	Brass C3604 (% content)
Aluminum (Al)	95.8-96.8	0
Chromium (Cr)	0.04 – 0.35	0
Copper (Cu)	0.15 – 0.40	57.0 – 61.0
Ferum (Fe)	Max 0.7	Max 0.5
Magnesium (Mg)	0.08 – 1.20	0
Mangan (Mn)	Max 0.15	0
Silicon (Si)	0.40 – 0.80	0
Plumbum (Pb)	0	1.80 – 3.70
Tin (Sn)	0	Max 0.5
Zinc (Zn)	0	34.3 – 41.2

Table 1 shows the summary of Aluminum 6061 and Brass C3604 composition provided by ASM Aerospace Specifiction Metal Inc [9] and Daechang Co. [10]. Aluminium 6061 and

Brass C3604 are commonly used in the manufacturing industry [7]. Among the factors contributing to its popularity are Aluminium 6061, a light material with good machinability. In contrast, Brass C3604 have high corrosive resistance and can stand up in saltwater environments better than other materials [8].

The most common method researchers use to conduct drilling cutting tool life is by using one specific drilling tool diameter and determining the tool life [7]. Salaam added if the diameter of the holes needed to be produced is bigger, this method seems not very practical, especially when experimenting according to the industry needs [7]. In the manufacturing industry, for example, creating 13.00 mm diameter holes is done step by step in a few stages; for example, it starts with a center drill diameter of 3.00 mm, followed by drilling of diameter 7.00 mm, 10.00 mm and 13.00 mm holes. By doing this, theoretically, the tool life will be longer because a minimum amount of force is needed to perform the drilling process for each hole's diameter. However, it takes a longer time to be completed.

Researchers used many methods to determine the tool life of a drilling tool [7]. Among them is determining the number of holes produced until the drilling tool fails or breaks, the total machining time used until the drilling tool breaks, chips formation, force signal, condition of drilling tool by using scanning electron microscope (SEM) [8] [17] [18]. The total time they are being used until the drilling tool is broken is sometimes challenging to be used when involving problems during the machining process, where there is a possibility researcher tend to forget to record the machining time before the problems occur. The other methods are based on performance measurements such as the surface roughness of the hole produced, the drilling force measured during the drilling process [11], the cylindricity of the hole created and drilling tool image capture before and after the drilling process with the help of Scanning Electron Microscope (SEM)[12], torque produce during the drilling process [13], burr height produced during the machining process and minimum and maximum diameter deviation being measured after the machining process take place [8], [16].

METHODOLOGY

This study is a part of the sustainability assessment study to evaluate the pneumatic connector sustainability assessments. The depth of the pneumatic connector hole is 55.00 mm and the actual machined product are shown in Figure 2.

Figure 2. Actual case study product with hole depth 55.00mm.

This project starts with identification of materials commonly used to produce pneumatic connectors, suitable cutting parameters used to perform experiments, drilling strategies being used and methods other researchers used to determine the drilling tool life. There are three types of common material being used to produce the pneumatic connector; Aluminum 6061, Brass C3604 and Stainless steel.

The raw material being selected in this study are Aluminum 6061 and Brass C3604 because they are widely used to produce the pneumatic connector and the cheaper compared to stainless steel material. The size of raw materials being used is 200.00 mm x 200.00 mm x 55.00 mm. The 55.00 mm represents the hole's depth that needs to be drilled.

Before the experiment is conducted, all the raw material undergoes material grade identification tests using an Oxford Spectrometer in the Foundry Laboratory, FTKMA, UMPSA. The raw material is cut into a small piece one for each, sized 15.00 mm x 15.00 mm x 15.00 mm. Then, the samples undergo three steps sanding process at Material Laboratory, FTKMA, UMPSA until flat and even surfaces being produced. This step is important because the preciseness of the raw material grade results is depending to the flatness & evenness of the sample when the electron shoot to the sample surface. The sample being shoot with electron for three times and the average results were calculated.

Four types of drilling cutting tools are used in this study: centre drill diameter 3.00 mm; drill diameter 10.00 mm, 13.00 mm and 14.50 mm. The drilling tools material is High Speed Steel (HSS), and the cutting speed being used is 9.426 m/min, federate of 0.10 mm/rev and depth of cut of 0.10 mm for centre drill and 30.00 m/min cutting speed, federate of 0.10 mm/rev and depth of cut of 0.10 mm for the rest of drilling tools as suggested by Kalpakjian & Schmid [4] which suitable to be used for both materials. The machine used for this study is the CNC Robodrill Center located at CNC Laboratory FTKMA, UMPSA.

The machining method being used in this study is the step drill method, which starts with a center drill and then is followed by drilling holes of diameter 10.00 mm, 13.00 mm and 14.50 mm until through holes are achieved. This method is adopted because it mimics how the industry produced the holes rather than the straight forwardly used diameter of 14.50 mm after the center drill process. Another reason is that, based on the literature survey, the step drill method makes the tool life longer than a straight drill diameter of 14.50 mm. Although the required hole depth is 55.00 mm, the maximum depth to be machine is 60.00 mm to achieve a through hole.

Two methods are being used to determine the center drill's and drilling tools' tool life. The first method is measuring the diameter of the holes produced using a Vernier caliper. The second method uses the graphical form of the center drill and the drilling cutting tool by using the camera.

RESULTS AND DISCUSSIONS

The average results of the raw material grade identification test are shown in Table 2, where both Aluminum 6061 and Brass C3604 materials are in the range of their compositions compared with Table 1. When conducting this experiment, it is compulsory to grind the surface to obtain a flat and even surface because it will make sure the electron movement is at the right angle to obtain a good result.

Table 2 Summary of Aluminum 6061 and Brass C3604 composition results

Materials	Aluminum 6061 (% content)	Brass C3604 (% content)
Aluminum (Al)	96.8	0
Chromium (Cr)	0.0855	0
Copper (Cu)	0.271	58.5
Ferrum (Fe)	0.205	0.319
Magnesium(Mg)	0.855	0
Mangan (Mn)	0.0075	0
Silicon (Si)	0.617	0
Plumbum (Pb)	0	3.37
Tin (Sn)	0	0.466
Zinc (Zn)	0	35.8

Table 3 shows the tool life results of the center drill diameter 3.00 mm cutting tool drilled on Aluminum 6061 and Brass C3604. During the experiment, it is found that the tool life of the center drill is 476 holes for Aluminum 6061 and 360 holes for Brass C3604. From the observation of drilling Aluminum 6061, when drilling at hole number 470th, the drilling process produces abnormal sounds compared to the first hole. When drilling the 477th holes, the center drill tool broke down and stuck at the raw material, as shown in Figure 3. As for Brass C3604, the same situations were observed where an abnormal drilling process sound produced, and after completing holes 360, the cutting tool broke down but was not stuck in the workpiece. Brass produced small number of holes being drilled compared to Aluminum 6061 because it is harder than Aluminum. Before broken down, it is observed that the center drill bends a bit due to the pressure applied during the drilling process.

Table 3 Summary of Average holes diameter when performing center drill 3.00 mm
(a) Aluminum 6061.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	3.000	3.000	3.000	3.000
50th	3.010	3.009	3.011	3.010
100th	3.013	3.014	3.012	3.013
150th	3.017	3.015	3.016	3.016
200th	3.018	3.019	3.016	3.018
250th	3.024	3.025	3.025	3.025
300th	3.026	3.028	3.028	3.027
350th	3.032	3.034	3.031	3.032
400th	3.038	3.046	3.037	3.037
450th	3.043	3.047	3.046	3.045
476th	3.046	3.045	3.048	3.046

(b) Brass C3604.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	3.000	3.000	3.000	3.000
50th	3.015	3.017	3.015	3.015
100th	3.017	3.016	3.019	3.017
150th	3.020	3.019	3.021	3.020
200th	3.025	3.024	3.026	3.025
250th	3.028	3.026	3.028	3.027
300th	3.038	3.037	3.036	3.037
350th	3.040	3.042	3.041	3.041
360th	3.050	3.049	3.050	3.050

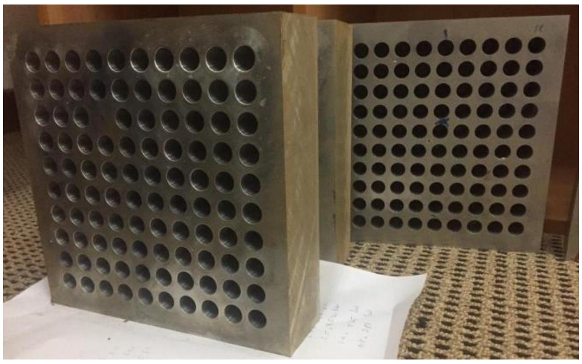


Figure 3. One hole cannot be drilled because the center drill 3.00 mm diameter tool broke down in the Aluminum 6061 workpiece.

Table 4 to 6 shows the drilling tool life (number of holes) based on the holes' diameter. The tolerance used in this study is 0.05 mm based on the hole size requirements. The first drilling tool life is 10.00 mm in diameter, the tool life usually not very long due to build-up edge and the high force needed during the drilling process to ensure the part of the drilling tool remains in the workpiece [13]. Besides that, the tendency for the drilling tool to be chipped off at the tip of the tool also can cause the drilling tool to break down, as shown in Figure 4(a) which Ghasemi et al. [13], Aamir et al. [14] & Sharif [15] also reported. The other observation is that, the holes produced before the tool broke down are slightly larger than required due to the bending phenomenon of the high force for both materials.

The tool life of 10.00 mm drill diameter is 250th holes for Aluminum 6061, while for the Brass C3604 is 190 holes. The tool life of diameter 13.00 mm drill is 485 holes for Aluminum 6061 and 360 holes for Brass C3604. Based on the Figure 4(b), it shows that the tip is free from machining defects; thus, the absence of a tool worn around the tip of the drilling tool is observed; but not at the other area. There is a noticeable bending phenomenon occur due to high force applied during drilling process.

Lastly, the tool life for diameter 14.50 mm drilling tool is 499 holes for Aluminum 6061 and 375 holes for Brass C3604 before the drilling tools started to produce an abnormal sound and the holes dimension became larger. The same phenomenon occurs for diameter 14.50 mm compared to diameter 13.00 mm but at a different place such as shown in Figure 4(c); but at the other area. There is also noticeable scratching surface can be seen outer the tip of the drilling tool which also occur due to high force applied during drilling process. Overall, the findings of this project is similar to Ghasemi et al. [13] findings such as shown in Figure 5 and Dahnel et al. [16].

Overall, the tool life obtained from Aluminium 6061 drilling process is longer compared to Brass C3604. This is because the characteristics of Brass C3604 material is harder compared to Aluminum 6061which is softer and require less force to perform drilling process.

Table 4 Summary of Average diameter holes when drilling holes diameter 10.00 mm on
(a) Aluminum 6061.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	10.000	10.000	10.000	10.000
50th	10.015	10.014	10.016	10.015
100th	10.018	10.023	10.023	10.021
150th	10.025	10.024	10.026	10.025
200th	10.039	10.035	10.036	10.037
250th	10.050	10.050	10.050	10.050

(b) Brass C3604.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	10.000	10.000	10.000	10.000
50th	10.019	10.023	10.022	10.021
100th	10.027	10.024	10.025	10.025
150th	10.035	10.038	10.039	10.037
190th	10.050	10.049	10.050	10.050

Table 5 Summary of Average diameter holes when drilling holes diameter 13.00 mm on
(a) Aluminum 6061.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	13.000	13.000	13.000	13.000
50th	13.005	13.003	13.007	13.005
100th	13.010	13.011	13.009	13.010
150th	13.015	13.016	13.018	13.016
200th	13.020	13.022	13.021	13.021
250th	13.025	13.025	13.024	13.025
300th	13.031	13.029	13.034	13.031
350th	13.036	13.037	13.035	13.036
400th	13.041	13.037	13.042	13.040
450th	13.042	13.045	13.047	13.045
485th	13.050	13.050	13.049	13.050

(b) Brass C3604.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	13.000	13.000	13.000	13.000
50th	13.009	13.008	13.007	13.008
100th	13.014	13.013	13.015	13.014
150th	13.021	13.023	13.019	13.021
200th	13.025	13.025	13.025	13.025
250th	13.034	13.035	13.034	13.034
300th	13.038	13.040	13.041	13.040
350th	13.048	13.044	13.043	13.045
360th	13.049	13.049	13.048	13.049

Table 6 Summary of Average diameter holes when drilling holes diameter 14.50 mm on
(a) Aluminum 6061.

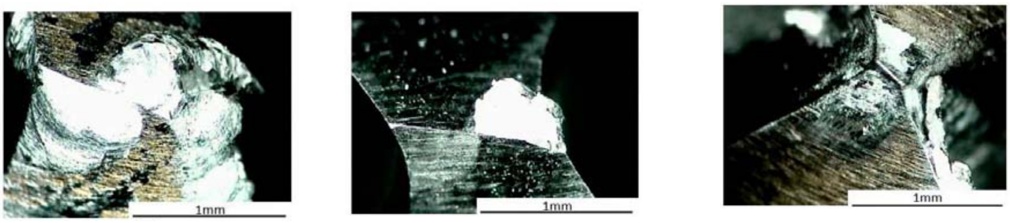
Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	14.500	14.500	14.500	14.500
50th	14.505	14.508	14.504	14.506
100th	14.510	14.507	14.509	14.509
150th	14.514	14.516	14.518	14.516
200th	14.520	14.528	14.531	14.520
250th	14.525	14.523	14.526	14.525
300th	14.530	14.528	14.531	14.530
350th	14.535	14.536	14.533	14.535
400th	14.540	14.541	14.538	14.540
450th	14.545	14.546	14.545	14.545
499th	14.550	14.549	14.550	14.550

(b) Brass C3604.

Pass	1st Reading	2nd Reading	3rd Reading	Average
1st	14.500	14.500	14.500	14.500
50th	14.507	14.509	14.509	14.508
100th	14.513	14.512	14.514	14.513
150th	14.520	14.525	14.521	14.522
200th	14.527	14.526	14.536	14.526
250th	14.533	14.530	14.535	14.533
300th	14.540	14.539	14.541	14.540
350th	14.547	14.547	14.545	14.546
375th	14.550	14.550	14.549	14.550

(a) (b) (c)

Figure 4. The drill cutting tool conditions after the drilling process. (a) Diameter 10.00 mm; (b) Diameter 13.00 mm, and (c) Diameter 14.50 mm.



(a) (b) (c)

Figure 5. Ghasemi et al. [13] reported the drilling tool worn at the tip.

CONCLUSIONS

In conclusion, the main objective of this study to determine the tool wear of High-Speed Steel drilling tools when drilling Aluminum 6061 and Brass C3604 have been achieved. The tool wear for center drill 3.00 mm in diameter, 10.00 mm, 13.00 mm, and 14.50 mm drilling tool for Aluminum 6061 is 476, 250, 485 and 499 holes respectively. For Brass C3604, the tool life is 360, 190, 360 and 375 holes. Another finding obtain from this study is the behavior of drilling tool before and when it is near to failure where abnormal machining sound appeared. Besides that, it is found that when preforming step-by-step drilling process, the area appears to cause failure is different. For center drill diameter 3.00 and drill bit diameter 10.00, the cause of failure is at the tip of the bit while for drill bits diameter 13.00 and 14.50 mm the failure is usually along the drill lip and at the end of drill lip.

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