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An Experimental Investigation on Drilling of Aluminum Alloy (Al 7075) using High Speed Steel Cutting Tools

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Abstract:

Aluminum alloys 7075 have been increasingly chosen as a main part in aerospace industry due to its property which is low in weight but having high strength. This paper focuses on the effect of cutting parameters and cutting condition when drilling Aluminum alloy 7075 in terms of tool wear, surface roughness and hole circularity. The drilling was conducted using high speed steel (HSS) having point angle of 118 ° and 6 mm tool diameter. The drilling test was conducted with a constant feed rate of 0.15 mm/min, cutting speeds of 22,44 and 66 m/min, and different cutting conditions (dry and cutting fluid). Drilling Aluminum Alloy 7075 with presence of cutting fluid and low cutting speed (22 m/min) resulted in reduced tool wear by 20 to 30 % and improved surface roughness by 30 % as compared to drilling in dry condition with same cutting parameter..

Keywords: *aluminum alloy, drilling, tool wear, hole quality.*

I. INTRODUCTION

The demand of high strength and low weight materials which contributed to low fuel consumption and less maintenance cost made aluminum alloys always used as a main component in aircraft and automotive part. Furthermore, the properties of the aluminum alloy can be tailored by the alloying element inside them. One of the promising aluminum alloy which is aluminum 7075 (Al 7075) is one of the strongest alloy that is available and is comparable to many types of steel. Al 7075 can be heat treated to increase the strength of the alloy. Al 7075 comprises aluminum alloys as a main element and zinc alloys as the primary alloying element. The composition of aluminum 7075 includes 5.6 - 6.1 % zinc, 2.1 - 2.5 % magnesium, 1.2 - 1.6 % copper, and less than half a percent of silicon, iron, manganese, titanium, chromium, and other metals. Al 7075 are extensively used in aeronautical structures as fuselage, wing and support structures due to their unique properties such as low density and high mechanical properties [1, 2].

To assemble parts, machining operation such as drilling are needed for making a hole for bolt, rivets and nut. Drilling is the most critical machining process as it is usually performed at the final stages of manufacturing operations. However, problems such as rapid tool wear and poor hole quality due to improper drilling operation may result in additional finishing operation and part rejection which leads to the increase in the production cost and time. The low melting point of the Al 7075 and high temperature during drilling could lead to adhesive tool wear, affect the hole quality and promote tolerance errors.

Several studies have been carried out to investigate the effect of cutting parameter on the machinability of the Al 7075. The effect of cutting parameter cutting speed, feed rate etc. have been extensively investigated by many researchers. Tool wear is a major concern when drilling Al 7075 due to it low melting point. As drilling process progresses, the tool wear increase due to an increase temperature at the interface of cutting edges of the drill and the workpiece, as well as increases the shear plane deformation [3, 4]. The increasing of cutting speed significantly increased the tool wear. It was observed that increasing of cutting speed increased the flank wear of the cutting tool. Sultan et. al [2] compared between 18 m/min and 30m/min cutting speed at 0.045 mm/rev where they found that at lower cutting speed the cutting tool can drilled up to 14 hole compare with 7 hole (30m/min) before it reached maximum wear.

The implementation of cutting fluid during machining significantly improved the machinability as well as enhanced the quality of the machined parts. Kilickap et. al [5] study the effect of different cutting condition when drilling Al 7075. They observed that the presence of MQL as a coolant reduced the tool wear and improved the surface roughness as compared when drilling Al 7075 in dry condition. The improvement of the surface roughness and hole circularity during drilling of Al 7075 can be explained that chip formation can be modified during drilling with present of cutting fluid. The long and continuous chip produced during drilling can affect the quality of the drilled hole [3]. High friction coefficient in dry machining of Al 7075 also contributed to rapid tool wear of the cutting tool as well as the deterioration of the drilled surface and quality of the machined part [6].

In this study the effect of cutting speed and cutting condition during drilling Aluminum alloy 7075 (Al 7075) was experimentally investigated. The machinability was investigated in terms of tool wear, surface roughness and hole circularity.

II. METHODOLOGY AND EXPERIMENTAL SET-UP

A. Drilling of Aluminum Alloy using HSS

Drilling of Aluminum alloy 7075 (Al 7075) was conducted on Gate ECM-1 CNC Milling machine using a 6 mm diameter high speed steel (HSS) drilling tool with two cutting flute and 118 ° point angle, as in Figure 1. The workpiece materials employed in this study was aluminum alloy 7075 which comprises 5.6 % zinc alloy as a primary alloying element. The mechanical properties of the Al 7075 employed in this research was tabulated in Table 1. The workpiece material was cut into rectangular plates of 200 x 150 x 13 mm and clamped on the machine table using a special fixture to perform the drilling test.

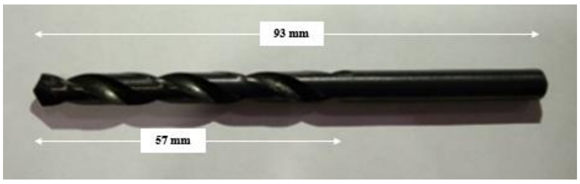

Figure 1 6 mm high speed steel (HSS) cutting tool

Table 1 Aluminum 7075 mechanical properties

Property	Value
Modulus Of Elasticity (Gpa)	71.7
Density (Kg/M^3)	2810
Hardness (Bhn)	150
Ultimate Tensile Strength (Mpa)	572

The conventional cutting fluid type X-Ten C30 cutting fluid which is fully-synthetic metalworking fluid manufactured by Belling was supplied through a nozzle directly to the cutting edge. Figure 2 shows the overall set up for this experimental study.

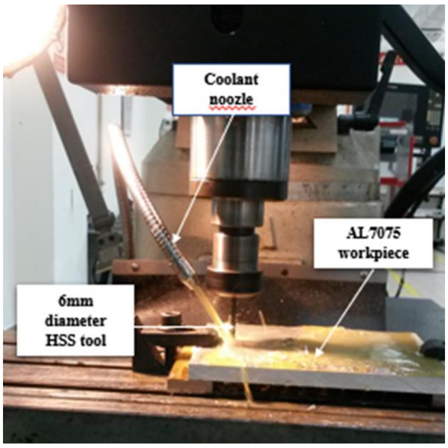

Figure 2 Experimental set up for drilling Al 7075 in dry and CCF cutting condition.

The progression of tool wear during drilling was measured at every 10th holes using as optical microscope equipped with an Optical Analog CCD camera. The camera then was connected to a personal computer running ViS digital imaging and measurement software for the tool wear analysis. The tool wear was measured at every flute of the cutting tool and the average was taken for analysis.

A Mitutoyo Surftest SV-3200 Series 178 surface roughness tester, was employed for surface roughness measurement with 0.8 mm cut off length and 4 mm evaluation length. Prior to measure the surface roughness, the drilled hole was sectioned into two part and the average surface roughness (Ra) was taken from three different point along the holes. In terms of hole circularity, it was measured using micrometer at every 10th hole and the result was compared with nominal size of the drilling tool diameter.

In this experimental study, constant feed rate of 0.15 mm/min with three different cutting speeds were employed for both dry and cutting fluid cutting condition. The Sanwa SE300, digital tachometer was employed prior the experimental work to measure the actual spindle speed. It detects the speed as the irradiation light passes on the reflective sticker attached on the spindle. The overall cutting and machining parameter employed in this study was tabulated as in Table 2.

Table 2 Cutting parameters during drilling Al 7075

Parameters	Value/Details
Feed rate (mm/min)	0.15
Cutting Speed (m/min)	22 44 66
Cutting conditions	Dry Conventional cutting fluid (CCF)

III. RESULTS AND DISCUSSIONS

A. Effect of cutting speed and cutting condition on tool wear

Figure 3 shows the progression of tool wear of cutting tool when drilling Al 7075 in dry and cutting fluid. Referring to the Figure 3 (a) and (b) the trend of the tool wear progression for 22, 44 and 66 m/min cutting speed is similar when drilling in dry and cutting fluid condition. For both cutting condition, dry and cutting fluid, the highest tool wear was found on 66 m/min cutting speed followed by 44 m/min and 22 m/min cutting speed. This trend can be explained by the increasing of cutting speed resulted in increasing the heat generated between the cutting edge and workpiece. Thus, as a result the tool wear increases. It was also found the materials sticking at the edge of cutting tool when machining at high cutting speed (66m/min, dry condition), suggested that the heat generated soften the workpiece.

When comparing the effect of the cutting condition, the tool wear obtained from cutting fluid cutting condition is lower 20 to 30 % when similar cutting speed and feed rate was employed. The tool wear measured at 50th drilled hole when drilling with 66 m/min for dry was 0.169 mm and CCF was 0.117 mm which is 30 % higher when drilling in dry condition. Higher tool wear obtained in dry drilling can be explained by the interaction between the cutting tool and the workpiece increase the heat generated and affect the tool wear. Whereas, the presence of cutting fluid removed the heat generated during drilling and aided the disposal of the chip produced [7].

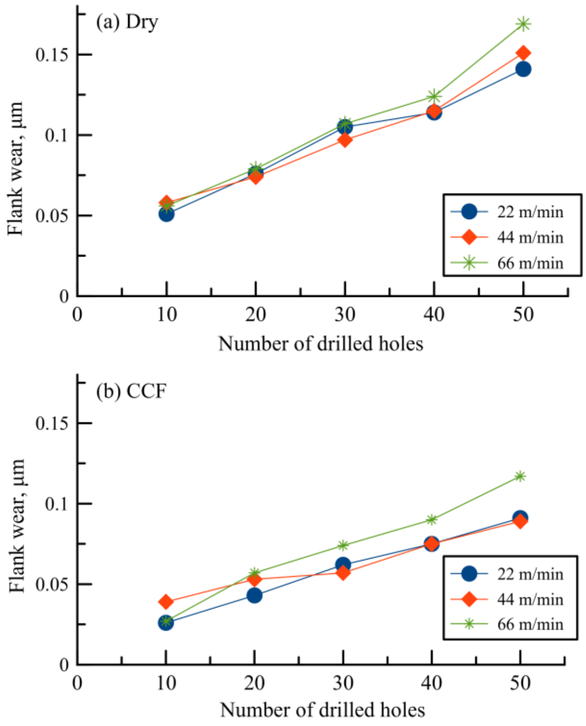

Figure 3 Progression of flank wear during drilling Al 7075 in dry and conventional cutting fluid (CCF) condition.

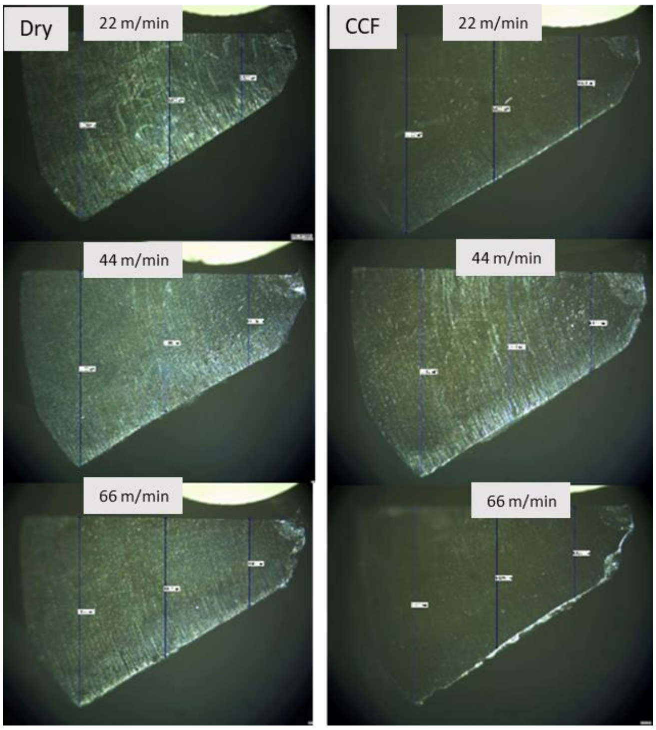

Figure 4 Microscopic images of tool wear after drilled 50th holes when drilling Al 7075 in dry and conventional cutting fluid conditions.

Figure 4 illustrates the photos of drill bit's cutting edges after 50th holes for each combination of spindle speed in dry and wet condition. Noticeable wear on the flank face such as abrasive and chipping can be seen in all parameters due to the immediate loss of sharp cutting edge [2]. Additionally, at 66 m/min cutting speed for dry and cutting fluid cutting condition shows chipping at the cutting edges was found.

B. Effect of cutting speed and cutting condition on surface roughness

Figure 5 shows the progression of the surface roughness when drilling Al 7075 in dry and cutting fluid conditions. The increasing of the surface roughness value for both cutting condition shows similar trend. The surface roughness increases as the number or hole increases. This can be explained by the increasing of the tool wear of the cutting tool as in Figure 5 for both dry and conventional cutting fluid cutting condition. In terms of cutting speed, in both condition, highest surface roughness was obtained by 66 m/min.

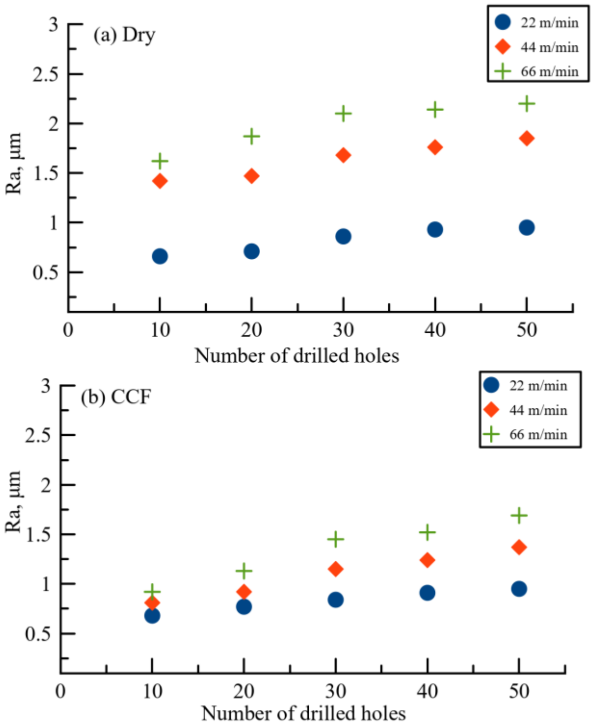

Figure 5 Progression of surface roughness during drilling Al 7075 in dry and CCF condition

The surface roughness obtained when drilling with cutting speed of 22 m/min at 30th hole in dry condition was 0.86 µm which is 59 % lower than the highest spindle speed of 66 m/min (2.2 µm). The increasing of surface roughness with increasing cutting speed can be explained by thermal softening. This argument can be supported by a statement from [8], who state that the cutting heat from the cutting temperature would lead to higher thermal stress and deformation, resulting in increased roughness of the hole. When the cutting speed increases, the contact temperature increase and thus, thermal softening occur which lead to the material to attach at the tool edge and deform it. This also supported by Bagci et. al [9] where they found that increasing of spindle speed have significant effect on the increasing of heat generated during drilling. When the number of holes drilled is increased, the surface roughness values gradually increase due to the increase of the tool wear. From this study, the surface roughness when drilling with presence of cutting fluid at 50th hole was 1.69 µm which is 23 % lower than that dry condition. The presence of cutting fluid aided in prolonged the tool life of the cutting tool as well as improve the surface roughness of the drilled hole.

C. Effect of cutting speed and cutting condition on hole circularity

Figure 6 shows the hole circularity after drilling Al 7075 in dry and CCF cutting condition. Generally, as the cutting speed increases, the diameter of the hole drilled errors also increase. It is suggested that the increasing of the vibration of the spindle as the cutting speed increases [2]. In this experiment, no clear trend can be observed which was possibly due to the adhesion on the cutting edges by the chips produced. It also can be affected by the increasing of the tool wear as the number of the drilled hole was increasing as well as chipping at the cutting edges that affected the hole circularity. Although there was no clear pattern of the hole circularity most of the diameter of the drilled hole was within the range such as the tolerance for 10th is 0.00 mm / +0.015 mm which considered as acceptable hole diameter.

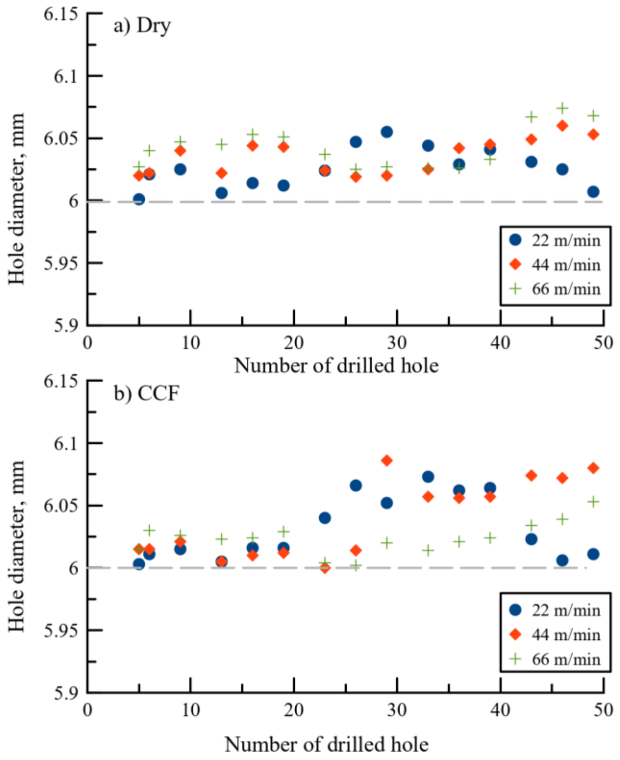

Figure 6 Hole circularity after drilling Al 7075 in dry and CCF cutting condition

The produced hole should have maximum of 1.5% difference in diameter as the accepted tolerance is under 0.015 mm. From the graph it shows that all the drilled holes are within the range except for hole 33 in dry machining with cutting speed of 44 m/min. It is suspected that there are chips attached to the cutting tool during drilling and thus, affecting the accuracy of the hole diameter.

IV. CONCLUSION

Drilling of Aluminum Alloy 7075 is very crucial since its always performs prior to the assembly operation. In this experimental study, drilling aluminum alloy Al 7075 using high speed steel tool with diameter of 6 mm with point angle of 118° and feed rate of 0.15 mm/rev. The tool wear, surface roughness and hole diameter are mostly influenced by the cutting speed and the cutting condition. Lower cutting speed of 22 m/min and the usage of cutting fluid will give improved result for the tool wear and surface roughness. As the number of drilled holes increased, the tool wear increases as well as the surface roughness for all cutting parameters and conditions. The highest surface roughness, 2.2 µm was observed when the test was conducted at highest cutting speed of 66 m/min in dry condition while the lowest cutting speed of 22 m/min in wet condition produced the minimum roughness of 0.68 µm. Hence, the use of lower cutting speed of 22 m/min and cutting fluid is recommended to minimize the surface roughness. In this experiment, it was observed the pattern for the hole circularity is not similar, however, the minimum percentage error was achieved when the holes are drilled with 44 m/min in cutting fluid condition. Most of the measured holes diameter is within the accepted range between 6.00 mm to 6.015 mm as recommended in industry. In conclusion, the use of lower cutting speed and cutting fluid is preferred to produce a better hole during drilling process of aluminum Al 7075.

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