

The Effect of Chilled Air on Burr Formation When Drilling Aluminium Alloy in Manufacturing Industry

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Abstract— Burr formation is a major challenge during drilling which could cause poor assembly and may lead to part rejection. One of the factors which could result in an increment of burr height and deteriorating the hole quality is poor selection of cutting parameters and drilling environment. aluminium alloy (Al7075) is usually drilled in dry condition due to the concern over the use and disposal of cutting fluid which could lead to environmental pollution. However, dry drilling can cause high heat generation which can highly influence the burr formation. Therefore, this research aims to investigate the effectiveness of chilled air as a cooling medium in drilling Al7075 to improve the machined surface integrity in aspects of burr formation. Drilling operations of Al7075 were performed at cutting speeds and feed rates of 82 - 123 m/min and 0.01 - 0.1 mm/rev. The lowest burr height was obtained when drilling using the higher cutting speed and feed rate of 123 m/min and 0.01 mm/rev. Whereas, the lowest burr thickness was obtained when drilling using the lower cutting speed and feed rate of 82 m/min and 0.01 mm/rev. This indicates that the use of chilled air when drilling Al7075 is favorable to reduce the burr formation at higher cutting speed and feed rate hence improving the productivity.

Keywords— Burr; Drilling; Chilled Air; Aluminium Alloy.

I. INTRODUCTION

Burr formation is one of the challenges in drilling operation where the existence of burr can delay the assembly operation of automobile parts and result in additional cost for deburring to ensure the good hole quality for assembly. Burr can be assessed through the height, thickness, and radius. The main factor in affecting the shape of burr is the heat generated from the friction between cutting tool and workpiece in drilling operation [1]. In dry drilling, the major challenge is the high heat generated between the tool and workpiece interface. This often causes material adhesion on cutting edges, built-up edge, accelerated tool wear, shorter tool life and poor drilled hole quality. A proper selection of cutting parameters is important in reducing burr formation during drilling aluminium alloys. At higher cutting speed and feed rate, burr formation tends to become larger due to higher heat generation that cause increase in aluminium alloy ductility which then led to higher plastic deformation, hence, larger burr size [2]. This is consistent with the finding by [3] where during drilling aluminium 6061 in dry condition, it had been found that burr size increase by 54% as the feed rate increases from 0.04 to 0.08 mm/rev. In addition, the higher thrust force generated at higher feed rate also led to higher plastic deformation, hence, resulting in larger burr formation. Therefore, it is suggested to choose lower cutting parameters combination for minimizing burr formation which can reduce the production cost for burr removal also results in better hole quality.

Moreover, [4] found that the smallest exit burr size with 75% burr heights reduction was obtained when drilling aluminium alloy 7010 at intermediate feed rate of 0.16 mm/rev and cutting speed of 150 m/min. In contrast, the larger burr size of 0.06 mm was found when drilling at a lower feed rate of 0.08 mm/rev. At lower feed rate, the material removal rate is lower which results in greater chip accumulation and material adhesion at the cutting edge, hence, the increase in material deformation led to higher burr formation at the hole exit. Therefore, in reducing burr formation, the combination of higher cutting speed and intermediate feed rate was preferable. It is suggested that the burr formation in drilling Al7075 can be reduced when the temperature is low. [1] showed that this can be achieved by drilling Al7075 using low cutting speed and feed rate of 31 m/min and 0.1 mm/rev, the formation of burr height was the lowest. This is due to the lower heat generation at lower cutting speed where the change in ductility of the workpiece is reduced. Higher cutting speed was known to increase the burr height due to the increase in plastic deformation when there is higher heat generation. In addition, the result of contribution percentage in ANOVA also showed that feed rate was the significant parameter that affects the burr formation.

Burr height increases with feed rate where a possible explanation for this is due to the amount of removed material increases which led to chip overflow [5]. When chips accumulated extensively at the tool-workpiece interface, this led to higher deformation at the cutting area, hence, results in upsurge of the burr height [6]. For that reason, the combination of higher cutting speed and feed rate in drilling aluminium alloy at dry condition is not recommended in reducing the burr formation. Most studies ([7], [8]) showed that lower cutting speed and lower feed rate is preferable due to lower heat generation and lower material removal rate. When the heat generated at tool-workpiece interface and material removal rate is lower, the material adhesion and formation of built-up edge is lesser. Thus, the rate of tool wear is reduced, and the quality of machined surface is improved. However, the cutting parameters suggested in previous studies is mostly applicable to aluminium alloys 2xxx to 6xxx series. Thus, the purpose of this research is to fill in the gap regarding optimum cutting parameters in reducing the burr formation during drilling Al7075 specifically for automotive industries application.

II. EXPERIMENTAL METHODOLOGY

Drilling operations of aluminium 7075 alloy were performed using MAZAK Vertical Centre Nexus 410A-II machine that is equipped with the Mazatrol Matrix Nexus CNC controller, in dry and with chilled air (10°C). The drilling setup is shown in Figure 1.

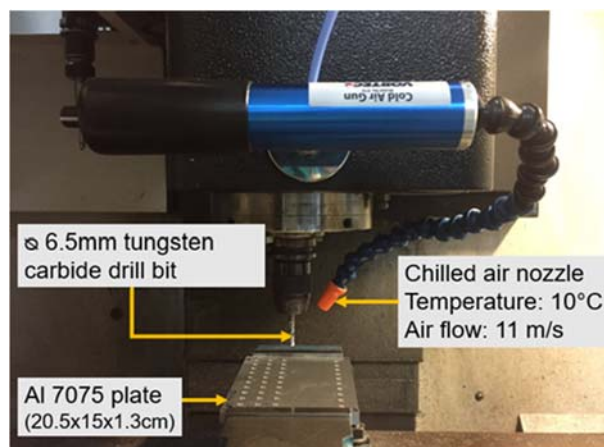


Figure 1: Drilling setup of Al7075

Aluminum 7075 plates with the composition as shown in Table 1, and a thickness of 13 mm were used throughout the drilling operations. This aluminium alloy grade (7xxx series) has been widely used in the automotive industry, specifically for assembly operation of automobile parts due to its high strength to weight ratio properties. The uncoated tungsten carbide drills with the geometry as shown in Table 2 were used in drilling experiments. Drilling operations were conducted at cutting speeds and feed rates of 82 - 123 m/min and 0.01 - 0.10 mm/rev. The burr was examined and measured using Mitutoyo Holtest micrometer and Dino-Lite Digital Microscope Premier with magnification up to 250x.

Table 1. Aluminium 7075 composition (weight percentage)

Zn	Mg	Cu	Fe	Si	Mn	Ti	Cr	Al
5.1	2.1	1.2					0.18	
–	–	–	0.5	0.4	0.3	0.2	–	remainder
6.1	2.9	2.0					0.26	

Table 2. Cutting tool geometry

Diameter	No. of flutes	Helix angle	Point angle	Flute length	Total length
6.5 mm	2	30°	118°	31 mm	70 mm

III. RESULTS AND DISCUSSION

The burr formed at the drilled hole exit was assessed and compared based on their height and thickness. The burr is detrimental to the operators since they are sharp and could jeopardise the assembly parts. The results of the average burr height of Al7075 after drilling in dry condition using cutting speeds of 82 and 123 m/min, and feed rates of 0.01, 0.05 and 0.10 mm/rev are discussed in the following sections. The burr data when drilling using the highest cutting speed of 163 m/min is not included as all cutting tools broke after drilling 1 to 10 holes.

Burr Height

From Figures 2 and 3, it can be seen that the lowest burr height within the range of 0.108 – 0.624 mm were formed when drilling using the higher cutting speed and feed rate of 123 m/min and 0.01 mm/rev, respectively. This could be due to lower material removal rate and it is in correlation with tool wear data in which there is minimal wear with minor chipping at the cutting edge as shown in Figure 4. In addition, at lower feed rate, the contact time is longer, so, the material removal rate is lower, hence, resulting in lower thrust force which led to the decrease in the formation of burr height [8]. The lowest feed rate (0.01 mm/rev) when drilling Al7075 is favourable to produce the least burr due to the least material removal rate per rotation. This causes slower removal of material where the tool was able to remove the workpiece efficiently since the material were able to be sheared instead of being pushed which resulted in burr at the hole exit. When material were sheared smoothly, no or less burr was formed. The present finding is consistent with [5] which found that exit burr was the smallest when aluminium 7075-T6 alloy was drilled at lower feed rate of 0.015 mm/rev with cutting speed of 37.5 m/min. This shows that feed rate is the main factor that control the removal rate of material which consequently influence the burr formation.

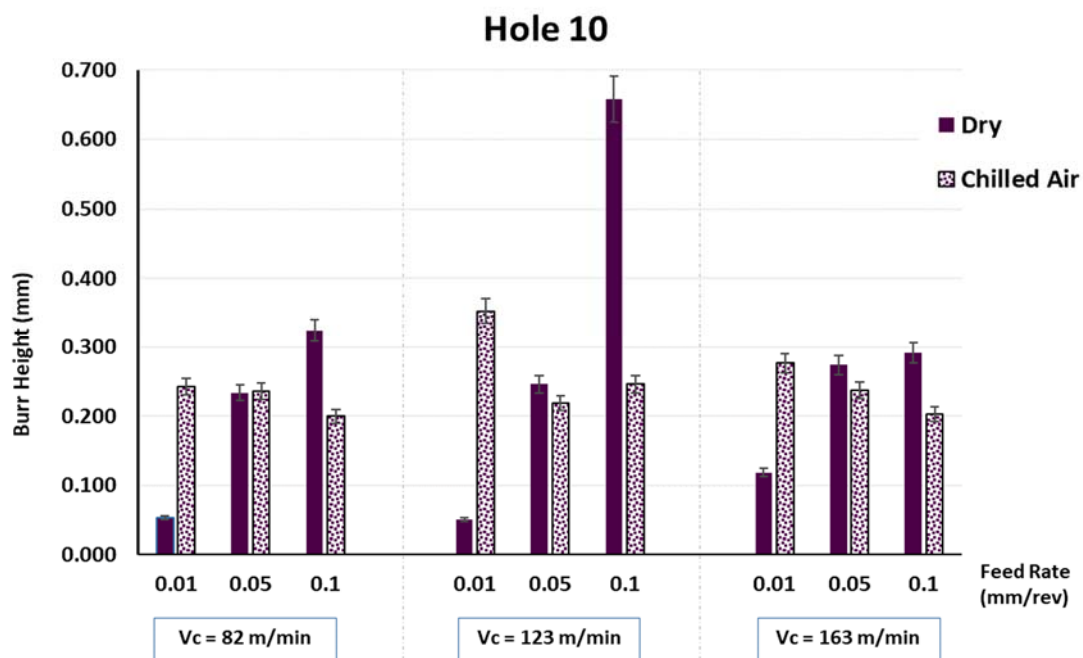


Figure 2: Average burr height at the exit of 10th holes after drilling of Al7075

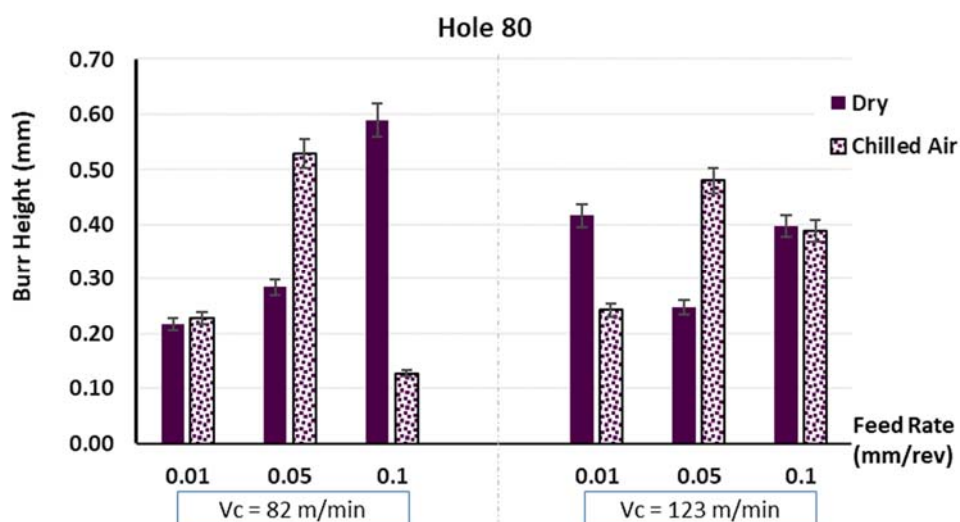


Figure 3: Average burr height at the exit of 80th holes after drilling of Al7075

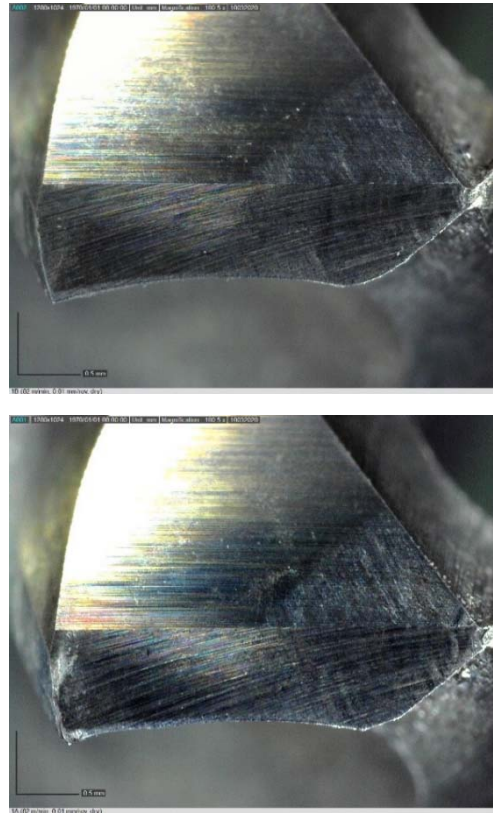


Figure 4: Cutting tool conditions after drilling 140 holes at the cutting speed and feed rate of 123 m/min and 0.01 mm/rev

In contrast, as seen in Figure 5, in comparison to hole 10 with no burr, at hole 80, as tool wear increases by 81%, the burr height increases by 88%. A possible explanation for this could be attributed to the higher cutting speed usage at dry condition which increase the malleability of the workpiece due to increment in heat generation. When the malleability of the workpiece increases, the plastic deformation also increases and as a result, burrs were formed since the workpiece was pushed out by the cutting tool rather than being cut [1]. Moreover, at lower feed rate, the material removal rate is lower and this cause ploughing at the cutting edge which results in higher plastic deformation. This is supported by [4] which reported that in dry drilling of aluminium alloy, when the feed rate was lower, material adhesion and chips accumulation was bound to increase due to the lower material removal rate which then resulted in higher burr size.



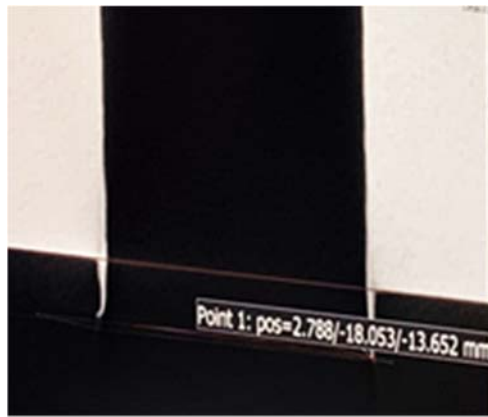


Figure 5: X-ray scan of the highest burr height in drilling Al7075

Interestingly, during drilling at chilled air condition, the lowest burr height with range of 0.114 – 0.172 mm was achieved at cutting speed of 82 m/min and feed rate of 0.10 mm/rev, as shown at hole 10 in Figure 2. As the tool wear increases, it can be seen that at hole 80 the burr height reduced by 36%. In comparison to dry drilling, although the cutting speed is lower, it can be seen that the feed rate applied was higher. In this study, the application of chilled air was able to result in lesser material adhesion in between tool-workpiece interface though at higher feed rate the MRR is higher.

This is consistent with the [9] findings on air based coolant where chilled air improved the machined surface integrity of aluminium 6061 alloy when drilling at higher feed rate of 0.08 mm/min [10] findings also observed formation of lowest burr height when drilling aluminium alloy with assistance of water at standard temperature of 25°C. This is due to the less ductility of aluminium alloy since water was acting as a cooling medium during drilling, hence, plastic deformation was reduced and result in lower burr height formation. The burr formation is also defined by its thickness and the results as discussed in the next section.

Burr Thickness

Burr thickness is the leading cause of deteriorate and poor hole quality when drilling Al7075 and it can affect the original diameter of the holes produced. A primary concern of burr thickness is the heat that was generated due to the friction at tool-workpiece interface [2]. Therefore, burr thickness had been measured in addressing the objective of studying the effect of cutting parameters and conditions that give results as shown in Figure 6. It can be seen in Figure 7 that the lowest burr thickness within the range of 0.035 – 0.052 mm were formed when drilling in dry condition using the lower cutting speed and feed rate of 82 m/min and 0.01 mm/rev. It is possible to hypothesise that at lower cutting speed, the heat generation reduces in which this resulted in lesser thermal softening, hence, lesser plastic deformation that is the crucial factor in reducing the burr size. This finding can be supported by [6] study where during drilling aluminium 6061, the burrs produced were minimal for lower cutting speed of 60 m/min and feed rate of 0.10 mm/rev. This proved that the combination of these cutting parameters in dry drilling is good since this had resulted in lower aluminium 6061 plasticity in which led to thinner and smaller burrs formation.

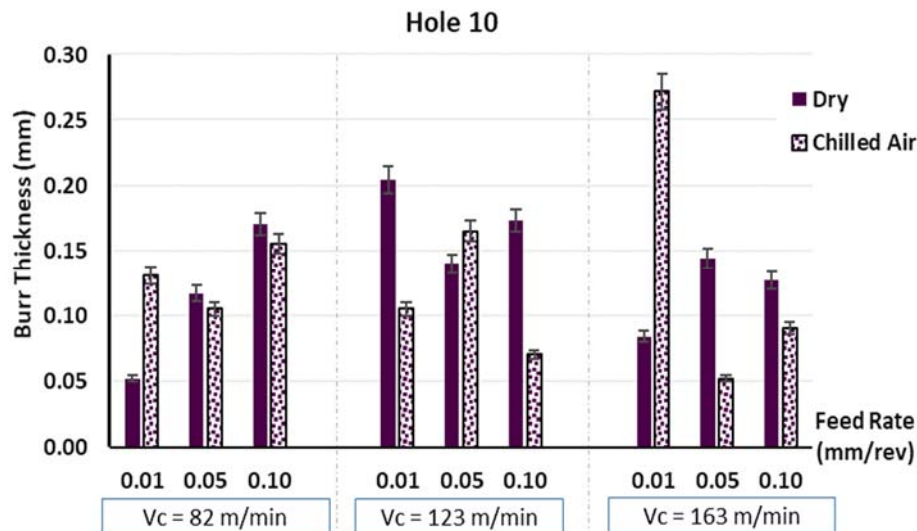


Figure 6: Average burr thickness at the 10th holes after drilling of Al7075

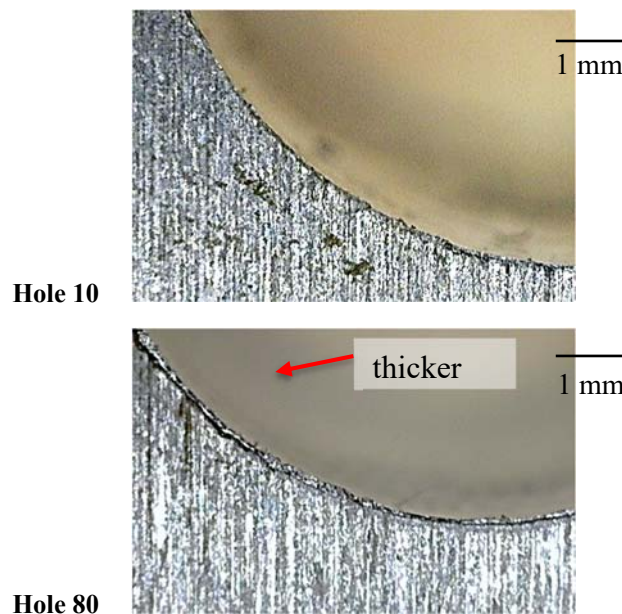


Figure 7: Burr thickness at the hole exit after dry drilling Al7075 with cutting speed and feed rate of 82 m/min and 0.01 mm/rev

As the tool wear increases, at hole 80 as shown in Figure 8, the burr thickness increases by 46%. This might be due to the dry cutting condition that increase the tool wear by 97% as number of holes increases, hence, the plastic deformation of Al7075 is higher which lead to formation of thicker and bigger burrs. Moreover, at lower cutting speed, the burr thickness is larger due to the material adhesion at the cutting tool which increase the tearing of workpiece at the exit of the hole [11]. Furthermore, previous studies of [12] found that drilling ductile material generated lower thrust force, hence, lower stress in the cutting zone. Thus, there is no sufficient of stress in order to break and removed the burrs at the hole exit which led into production of larger burrs. At lower feed rate, the contact time between the cutting edge and workpiece was longer. Thus, the drilling time became longer, and this led to increase in ductility properties which would affect the plasticity of the workpiece, hence, resulted in wider burr thickness as can be seen in Figure 8 of hole 80.

From Figure 9, it can be seen that at hole 10 for chilled air condition, the lowest burr thickness with range of 0.043 – 0.07 mm were obtained when drilling at the higher cutting speed and higher feed rate of 123 m/min and 0.10 mm/rev. As the number of holes and tool wear increases at hole 80 as shown in Figure 9, the burr thickness increased by 28% which indicates lower increment as compared to dry drilling. The trend of burr thickness shows for chilled air and dry condition are contradict. As cutting speed increases, the burr thickness decreased for chilled air and vice versa for dry condition. This is due to the 50% to 71% higher heat generation as the cutting speed increases. However, the presence of chilled air had managed to reduce heat generation by 50% and result in smaller burr thickness by 60%. The effect of feed rate is not significant for burr thickness since there is only small differences for each run regardless of which cutting conditions applied in drilling Al7075.

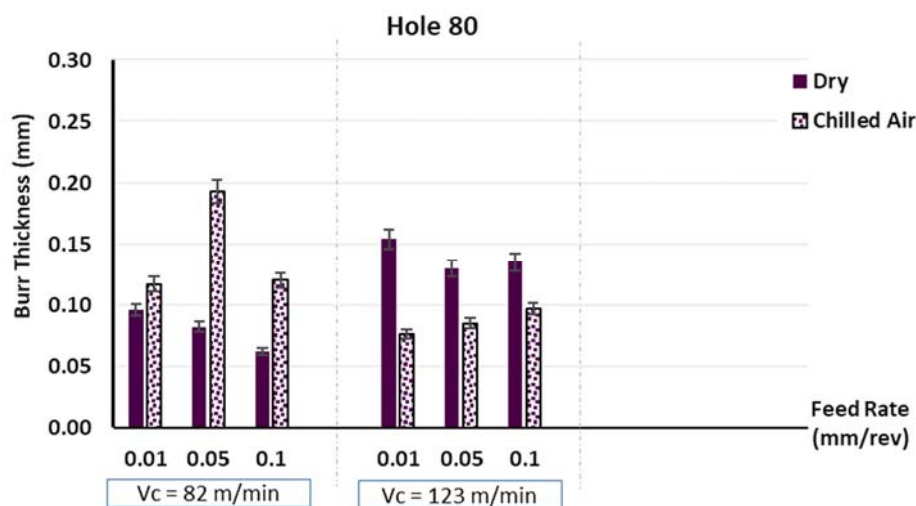


Figure 8: Average burr thickness for hole 80 after drilling of Al7075

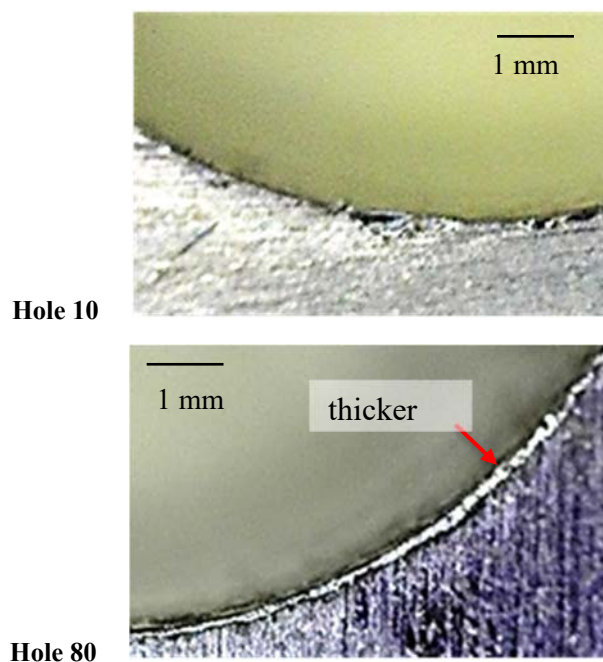


Figure 9: Burr thickness at the hole exit after dry drilling Al7075 with cutting speed and feed rate of 123 m/min and 0.10 mm/rev

IV. CONCLUSIONS

As a conclusion, this study shows that the application of chilled air was able to reduce the burr height by 36% at higher feed rate. This is due to the less ductility of aluminium alloy since chilled air was acting as a cooling medium during drilling, hence, plastic deformation was reduced and result in lower burr height formation. Therefore, the usage of chilled air as a cooling medium during drilling of Al7075 at cutting speed of 82 m/min and feed rate of 0.10 mm/rev is beneficial since it resulted in burr height reduction, hence, improving the product integrity. Meanwhile, it can be seen that the burr thickness was influenced by cutting speed. With the application of chilled air in drilling operation, higher cutting speed can be used since the presence of chilled air had managed to reduce heat generation by 50% and result in smaller burr thickness by 60%. Hence, the reduction of burr formation could improve the machined surface integrity and increase the productivity of drilling operation.

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