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PERFORMANCE EVALUATION ON DRILLING OF AUSTENITIC STAINLESS STEEL 316L USING HSS TOOL

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ABSTRACT

This paper presents the effect of drilling parameters on tool wear, tool life, surface roughness, dimensional accuracy and roundness when drilling austenitic stainless steel 316L using HSS tool. Experimental trials were conducted at different cutting speeds of 10, 16 and 22 m/min with constant feed rates of 0.05 and 0.075 mm/rev and under dry and coolant conditions. Results showed that the number of drilled holes was significantly influenced by the cutting speed whereby increasing cutting speed decreases the number of holes. Surface roughness measurement showed that better surface finish was obtained at lower cutting speed and feed rate. Results also showed that the dimensional accuracy at lower feed rate is better than at higher feed rate. From the roundness aspect, it was found that the new tool contribute to the good roundness compared to the worn tool.

Keywords: *Drilling, Tool wear, Surface roughness, Dimensional accuracy, Roundness*

1.0 INTRODUCTION

Drilling is an operation of making a circular hole or cutting process by removing a volume of metal from the solid materials using cutting tool called drill bit [1]. Nowadays, drilling is considered as one of the most fundamental technologies that is used towards getting high precision for productivity enhancement. The drills play an important role in increasing the productivity and the quality of the cutting process. This is because, broken drill bit during the drilling process, will result in poor quality of workpiece finishing. As a result, additional process is needed to repair the product and this will cause higher cost per unit compared with the good quality product. Therefore, in order to increase the productivity and the quality of drilling process, a study on the effect of incremental feed rate in drilling of stainless steel will be conducted. This research also will give additional advantage in cost perspective which will reduce the cause of tool failures. Although the price of cutting tools is low but the effect of tool failures on the cost is considerably high.Lee Joo Hong [2] had conducted the research about drilling of titanium alloy Ti-6Al-4V using uncoated and coated carbide drills on surface integrity. He found that drilling Ti-6Al-4V produced crown shape burrs whereby the last holes had higher burrs than the first holes. He also found that thicker workpiece material beneath the drill undergoes plastic deformation and was pushed out to create thicker burrs at last holes. He also concluded that hardness variation occurred at the sub surface of drilled holes. Low conductivity of Ti-6Al-4V prevents quick dissipation of heat during drilling process and causes work hardening. From the research, the hardness values near the surface holes drilled at 55 m/min were found to be higher than those drilled at 25 m/min. The hardness variation for drilling at 55 m/min was observed to be higher than those drilled at 25 m/min. Ahmad Afzan bin Ahmad Alwi [3] had conducted a research about drilling of stainless steel AISI 630 H1075 using different type of TiAIN carbide drill.

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The objective of the research is to evaluate the drill performance of TiAlN coated carbide tools when drilling stainless steel 630 (17Cr-14Ni-H1075) and to study the effect of drilling parameters and edge geometry on tool life, tool wear and burr formation. The finding of the research shows that tool wear has a significant effect on the tool geometry. It shows that S shape has longer tool wear compared to straight shape drills. Result also shows that burr height was significantly influenced by tool wear where the straight shape geometry has higher burrs compared to S shape drill. Surface roughness and burr heights were also significantly effect by the drill geometry. He also found that drills with S shape cutting geometry produce better surface integrity and longer tool life compared to straight cutting geometry.

Ali Akhavan Farid [4] had conducted the research on surface integrity of Inconel 718 during drilling operation. The objective of the study is to evaluate the machined hole quality and surface integrity of a Inconel 718 when drilling using carbide drill with respect to surface roughness, microhardness, microstructure defects. The second objective of the study is to study the influence of the cutting conditions on the surface roughness, microstructure defects and burr formation when drilling of Inconel 718. From the study, Ali Akhavan found that the surface roughness values were between 0.6 and 1.1 µm Ra at all condition investigated. Smoother surface finish was obtained at higher cutting speed and lower feed rate (V=18 m/min, f= 0.05 mm/rev, point angle= 130 deg). He also found that the burrs created during drilling are burrs with drill caps which is the burr height in last holes were higher than those obtained during the initial cut. He also found that by increasing point angle, it can reduce the burr height. It can be conclude that subsurface microstructural damage was very obvious in holes produced using worn tools, consist of deformed grain boundaries in the direction of drilling and a formation white layer. The white layer progressively increases with flank wear and cutting speed.

Asmar Suid [5] had conducted the research on investigation of the microscopic deformation behavior and surface quality of austenitic stainless steel plate during holes piercing process. The objective of the research is to investigate the effect of cutting clearances on the microscopic deformation behavior of a pierced hole and to evaluate the cutting clearances effect on stress and index failure using computer aided engineering analysis. From the experimental results, he found that the burr, smooth sheared region and punch force greatly influenced by the clearance value between the die and punch. It is means that when the cutting clearance value decreases, the smooth sheared and punch force value increases. The relationship between burr height and cutting clearance is when the burr height increase, cutting clearance also increase. The results are in agreement with the previous theoretical and experimental works in the literature.

Hasrul Shafiq Kamaruzaman [6] had conducted the research about surface integrity study when drilling Inconel 718 using coated Carbide tool. The objective of his research are to study the effect of drilling parameters on the surface integrity of the drilled hole of Inconel 718 when using coated carbide tools and burr formation. From the research that conducted, he found that the burrs created during drilling are homogenous burrs or rollover-type burrs. Burr height increases with increase in tool wear. Increase in point angle and decrease in feed rate tend to reduce the burr height. He also concluded that no effective methods to control the white layer formations. All cutting condition was obtained to the white layer. Drilling process alone cannot reduced the white layer formation thus requires finishing processes such as reaming and horning.

In this research, the experiment of drilling process will be conducted in order to evaluate the drill performance of High Speed Steel tools when drilling stainless steel 316L. The main purpose of perform this research is to study the tool wear of the drill bit. Besides that, this research also likes to study about the surface roughness of the workpiece that will be drilled. This research will give advantages in cost aspect which will reduce cost cause of tool failures. As known, the price of cutting tools is low but the cost caused by tool failures is considerably higher. The method of the research was by drilling the workpiece which is austenitic 316L stainless steel using HSS tool bit until it failed. Then performance the tool life, tool wear and surface roughness test. The experiment was repeated by increasing the feed rate.

2.0 EXPERIMENTAL DESIGN

The drilling experiment is conducted using CNC Milling Machine Anayak Anak-Manti-7 at UniKL-MSI Kulim. There are two machining parameters that were considered in the experiment which is cutting speed and feed rate. These parameters have large influences on the investigation result in the previous researches. High Speed Steel (HSS) drilling tool bit coated with TiAlN is used in this research with diameter 5.5mm. Cutting speeds of 10, 16 and 22 m/min were selected as rotation drilling cutting speed and the feed rate was set as 0.05, 0.075 mm/rev. Austenitic 316L was used as work material in this experiment with alloy composition consists of chromium, nickel and molybdenum. The material selected is based on their characteristic such as corrosion resistance, improves resistance to pitting from chloride ion solutions, and provides increased strength at elevated temperatures.

The block size of austenitic 316L is 120mm x 60mm x 12mm for length, width and thickness respectively. The experiment was divided into two type which is labeled as Tool A and B. For Tool A, the feed rate was set at 0.05 mm/rev for the first 4mm and the other 8mm of thickness was set at 0.075 mm/rev. The cutting speed was set at 10, 16 and 22 m/min. Coolant will be used during the drilling until the average flank wear reaches 0.1mm or achieve the maximum flank wear which is 0.3mm or until the tool fails. Same goes to Tool B but the difference between Tool A and Tool B is that coolant was not used on Tool B.

The performance of drilled holes was measured in term of surface roughness, tool wear and dimensional accuracy. In order to observes and measure the tool wear and quality of surface finish on the machined surface, Sometech Video microscope (SV-35) were used. The surface roughness is a term used to describe the geometry quality of a mechanical surface. The quality of the surface roughness is important in the evaluation of the machined surface. There are two method of measuring the surface roughness of material which is the arithmetic mean value and the root mean square value. Only the Arithmetical Mean Roughness, *Ra* parameter is selected to be measured the surface roughness. The *Ra* is an average or centre line average of value. It is based on the schematic illustration of a rough surface. The arithmetic mean value is defined as [7]:

$$Ra = (a + b + c + d + \ldots\ldots.. + n) / N \qquad (1)$$

Where all coordinate, a,b,c,…..,n are absolute value, and the N is the number of reading. The lowest value of *Ra* means that the surface is smoother.

3.0 RESULTS AND DISCUSSION

3.1 *Tool Wear*

Tool wear describes the gradual failure of cutting tools due to regular operation. In this research, the operation that conducted was drilling. There are several types of tool wear included flank wear, crater wear, glazing and edge wear. The effect of tool wear is increased cutting forces, increased cutting temperature, poor surface finish and decreased accuracy of finished part. Besides that, it also may lead to tool breakage and causes change in tool geometry.

Figures 1a, 1b and 1c shows the progression of flank wear curve for Tool A (with coolant) and Tool B (no coolant) when drilling Austenitic 316L stainless steel at various cutting speed of 10, 16 and 22 m/min. From the figures, it shows that the tool wear progression follows the normal trend of tool wear during machining. However, the slope of the line graph for Tool B was higher than Tool A for the three cutting condition. This shows that Tool A contribute to more drilled hole compared with Tool B. The Figures also show that the cutting conditions with coolant give extra drill rate compared to without coolant. The higher drilled hole was from Tool A with 10m/min cutting speed which is gives 24 drilled holes. Tool B with 22 m/min cutting speed gives the lowest drilled hole which is just 4 holes. The contact length of the drill bit with cutting speed 10 m/min was higher as compared to the others. This phenomenon might contribute to the lower rate of low cutting speed tool.

Figure 1d and 1e show the comparison of Tool Wear for Tool A and B at three different cutting speeds. From the figures, the pattern of both graphs almost the same which is the low cutting speed gives long machining time. The longest machining time goes to Tool A with10 m/min cutting speed which is 15.888 minutes for 24 holes. In contrast, the shortest machining time goes to Tool B with 22m/min cutting speed which is just 1.508 minutes for 4 holes. It shows that the lower cutting speed give higher wear rate compare to the other two cutting speed.

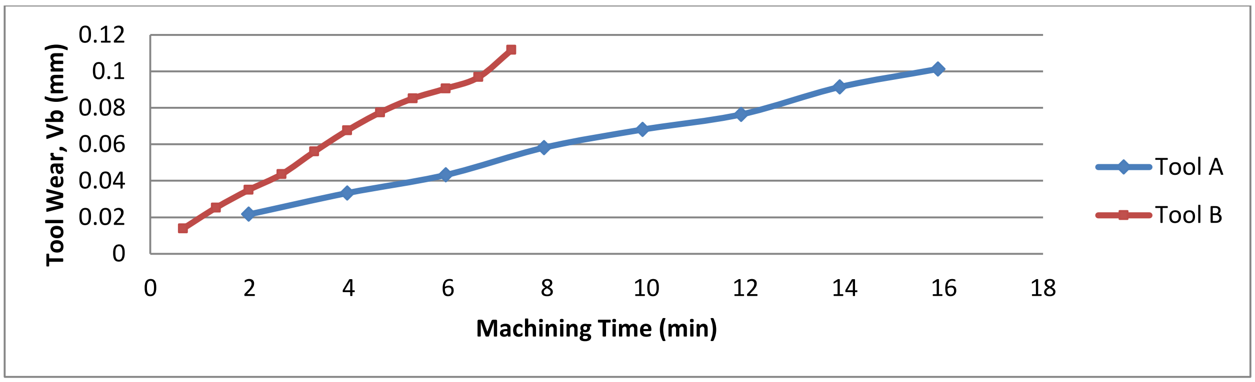

Figure 1a: Tool Wear of Tool A and Tool B at 10 m/min Cutting Speed.

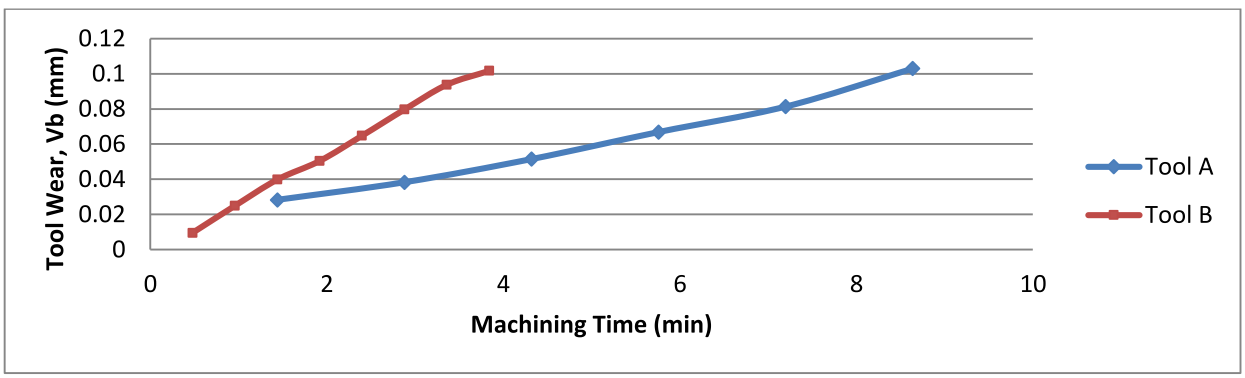

Figure 1b: Tool Wear of Tool A and Tool B at 16 m/min Cutting Speed.

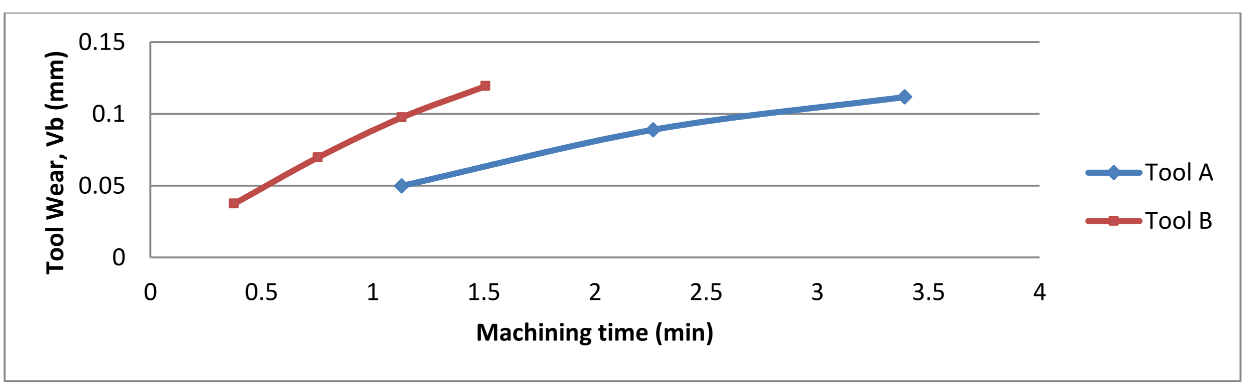

Figure 1c: Tool Wear of Tool A and Tool B at 22 m/min Cutting Speed.

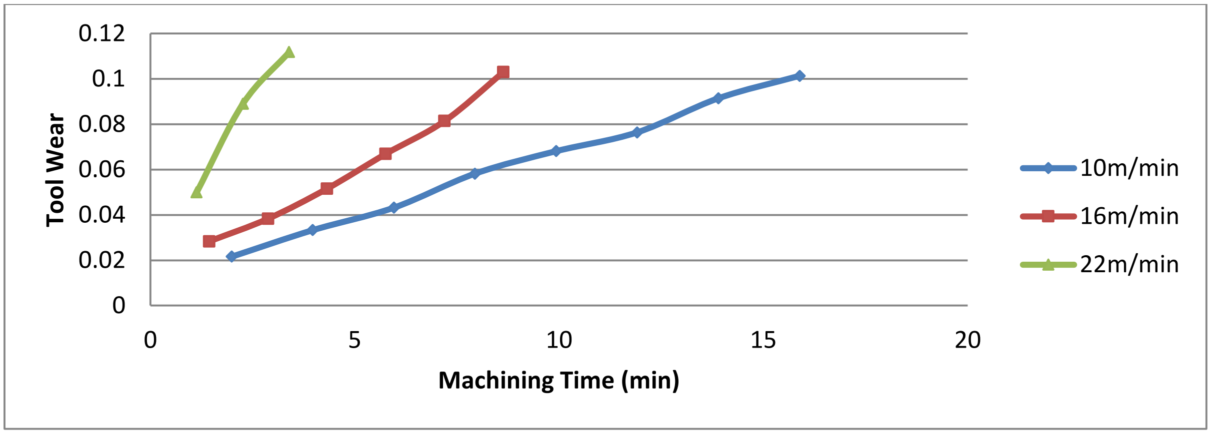

Figure 1d: Comparison of Tool Wear of Tool A at various Cutting Speed.

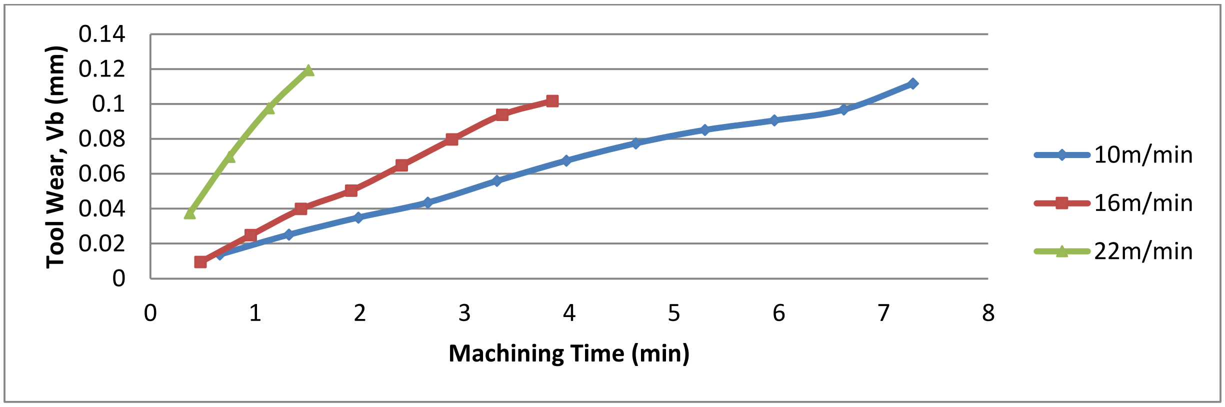

Figure 1e: Comparison of Tool Wear of Tool B at various Cutting Speed.

From the cutting speed perspective, the pattern of the curve show that the lower cutting speed contributes to the higher number of holes that drilled. Its same goes to the trial that with coolant is in off mode. From the both figures, it can be concluded that when cutting speed increase, the number of holes will be decrease.

3.2 Built Up Edge

Adhesion of the workpiece on the cutting edge was prominent for Tool B (no coolant) as shown in Figure 2. This results to a build up edge (b.u.e) formation which affected the tool performance. The b.u.e happens because of the high temperature of drill bit and the workpiece when both were in contact for the long time. This situation does not happen at Tool A (with coolant) because Tool A were running with coolant is in on mode. From the observation, it can be conclude that coolant playing an important characteristic in prevent from b.u.e occur because coolant was cooled the temperature of drill bit and workpiece when they were in contact each other.

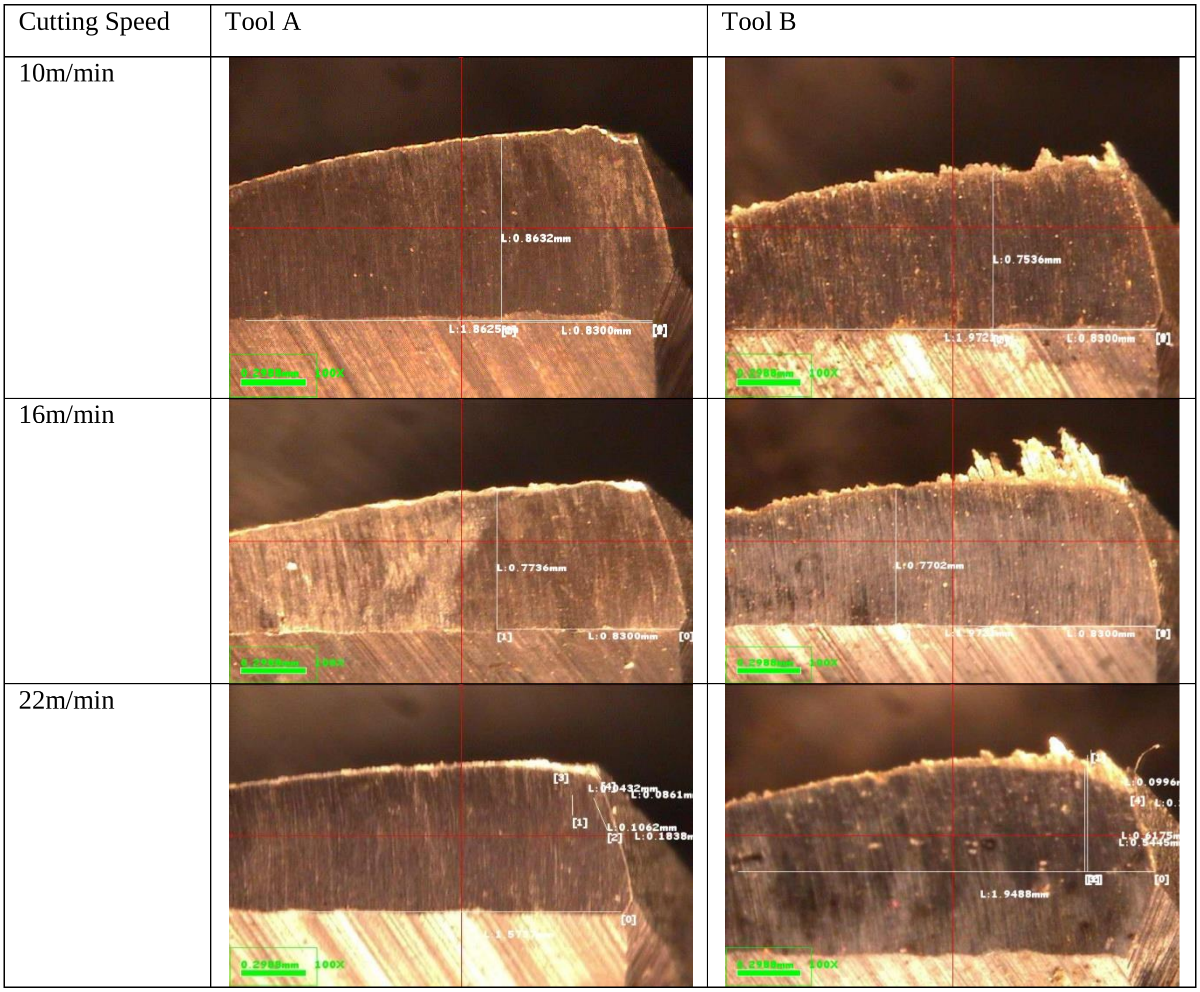

Figure 2: Image of worn tools at initial drilling stage

3.3 Tool Life

The tool life is define by how long the tool bit can perform before failed or breakage. In this research, the tool bit consider fail if it achieve Vb_{ave} = 0.1mm or Vb_{max} = 0.3mm and also if it broken. When the drill bit achieves one of those three criteria, the machining time were calculated to estimate the tool life performance. The tool life performance of Tool A and Tool B during drilling Austenitic 316L Stainless Steel is shown in Table 1.

Table 1: Number of holes drilled under different conditions

Experiment No.	Cutting Speed (m/min)	Feed Rate (mm/rev)	Number of holes
Tool A (Coolant)	10	0.05 and 0.075	24
	16		18
	22		9
Tool B (No Coolant)	10		11
	16		8
	22		4

From the table, it can be seem that the tool life performance of drill bit with 10m/min cutting speed for both tool that running with coolant in on mode drilling more holes than other cutting speed. Tool A with 10m/min cutting speed manage to drill until 24 holes compared with Tool B which just can drill about 11 holes. The different of drilled hole for Tool A and Tool B at 10m/min cutting speed is more the a half. The lowest holes that drilled are at 22m/min cutting speed. This situation also same for the trials that running with coolant is in off mode.

In general, it can be suggested that Tool A outperformed Tool B respect to tool life and tool wear at all cutting speed investigated. It can be conclude that coolant give an adverse effect on the tool life and tool wear performance of the drilling process.

3.4 Surface Roughness

Surface roughness is considered to be the primary indicator of the quality of the machined surface finish. The temperatures created during drilling Austenitic 316L Stainless Steel were found to play a major role in tool wear which as a significant factor in surface roughness of the drilled holes. Figures 3a and 3b show the surface roughness values (Ra) of each drilled hole for Tool A and Tool B according to the cutting parameters. It is evident that drilling using coolant produced better surface finish at most cutting conditions when compared to drilling without using coolant. The Ra values obtained for Tool A that drilling with coolant lied between 0.455µm to 2.668µm.

The Ra values obtained for Tool B that drilling without coolant lied between 1.216µm to 3.617µm. From the both figures, it also show that the 10m/min cutting speed with 0.05mm/rev feed rates for both tool gives the good surface roughness. It can be conclude that smoother surface finish has been obtained at lower cutting speed and feed rate.

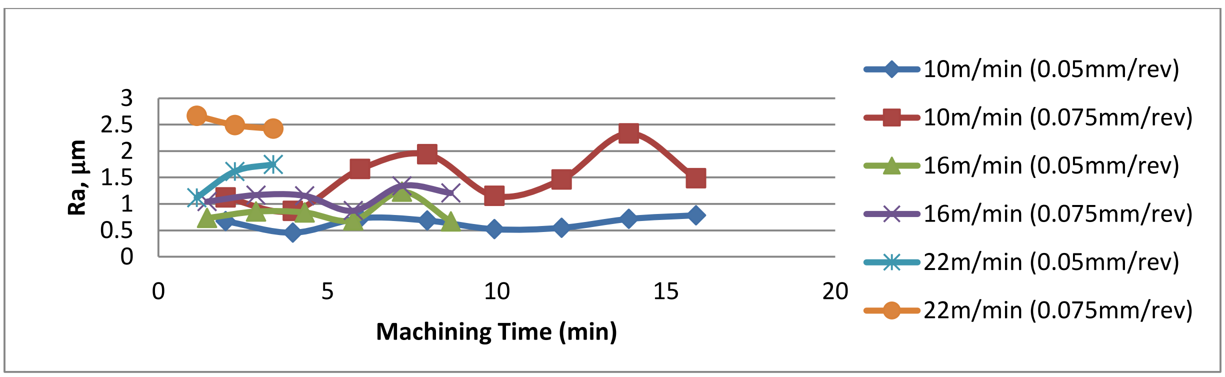

Figure 3a: Surface Roughness for Tool A at various cutting speed

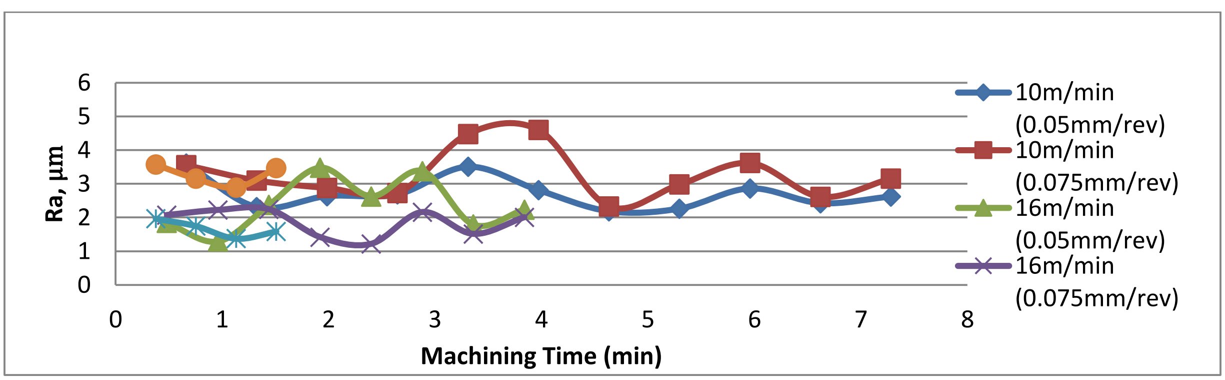

Figure 3b: Surface Roughness for Tool B at various cutting speed

3.5 Dimensional Accuracy

In this research, dimensional accuracy is measured in order to define how accurate diameter of the holes that drilled. The entire drilled holes diameter was measured using a Computer Measuring Machine (CMM). For this experiment, the first measure is at 3mm depth of hole from the upper surface. The second point of the same hole was taken at 9mm depth from the upper surface. At each depth, there are four points that calibrate which is at 0°, 90°, 180° and 270°. The reason of taken two different depth of a hole because each holes has two different feed rate which are 0.05mm/rev and 0.075mm/rev.

Recorded values at every three hole of the drilled diameters for the Tool A were subtracted from the actual diameter at each experimental and the results are shown graphically in Figure 4a. It shows the trend of dimensional accuracy of Tool A. It can be seen that the pattern of the line is moving upward while drilling more holes. It shown that, when drilling more holes, the dimensional diameter accuracy of the hole become less accurate compared to the first hole.

Figure 4b shows the graph of Dimensional Accuracy for Tool B. The trend of the plotted line graph show the same result as Tool A which is the line move upward when drilling more holes. The situation shows that the more holes are drilled, the less accurate the diameter of the hole. The result may be influenced by the flank wear that happen during the drilling process. It can be concluded for the both tool that the flank wear have direct proportional with the dimensional accuracy. It can be seen that this variation in the holes diameter produced using worn drills are higher than those obtained using new drill. It also can be concluded that the dimensional accuracy of the lower feed rate is better than the higher feed rate. The heat generated by the drilling process can lead to thermal expansion of the drill and workpiece which may affect the size and quality of the drilled holes leading to oversized holes [16].

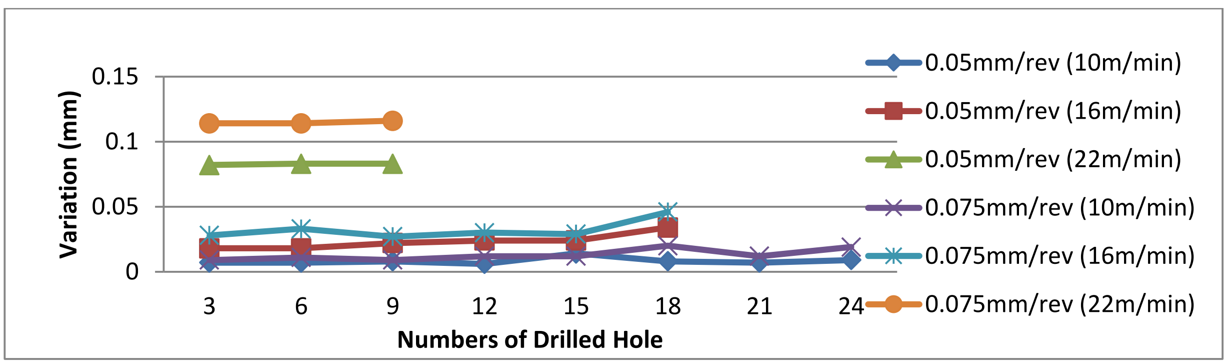

Figure 4a: Dimensional Accuracy for Tool A (Coolant)

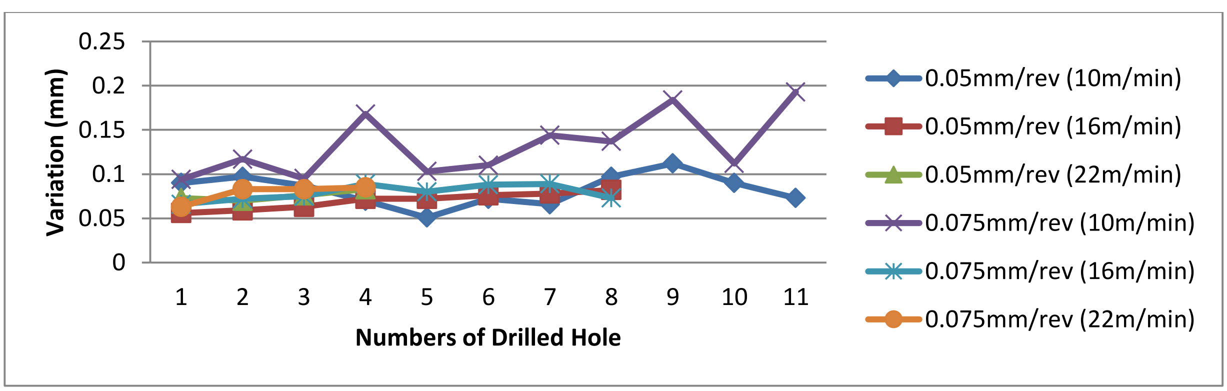

Figure 4b: Dimensional Accuracy for Tool B (No Coolant)

3.6 Roundness

Roundness can be defined as the measure of sharpness of a particle's corners. In this research, roundness is the circle of the hole that drilled. It measured how roundness is the hole that was drilled. Roundness can be measure using Computer Measuring Machine (CMM), the same machine that used to measured dimensional accuracy. The result of the roundness in this research was shown graphically in Figures 5a and 5b. Figure 5a shows the roundness measurement for Tool A which is running with the coolant is in on mode. Roundness measurement is in good condition if the measurement is near to or equal to zero. From the figure, it can be conclude that the good roundness is the higher cutting speed which is goes to 22 m/min. It also can be seen from the graph that there are two points that suddenly high which is at 10m/min with 0.075mm/rev feed rate. This result may due to the error doing the measurement or the surface of the hole is not clean properly.

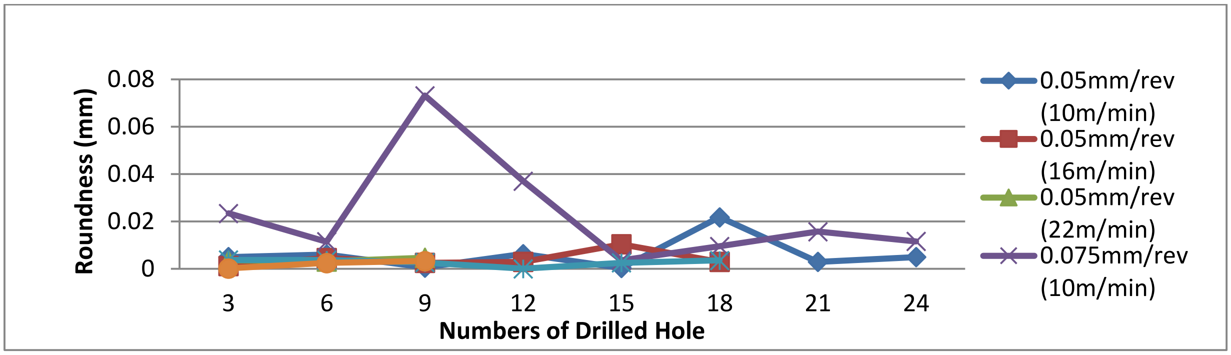

Figure 5a: Roundness of Drilled Holes for Tool A (Coolant).

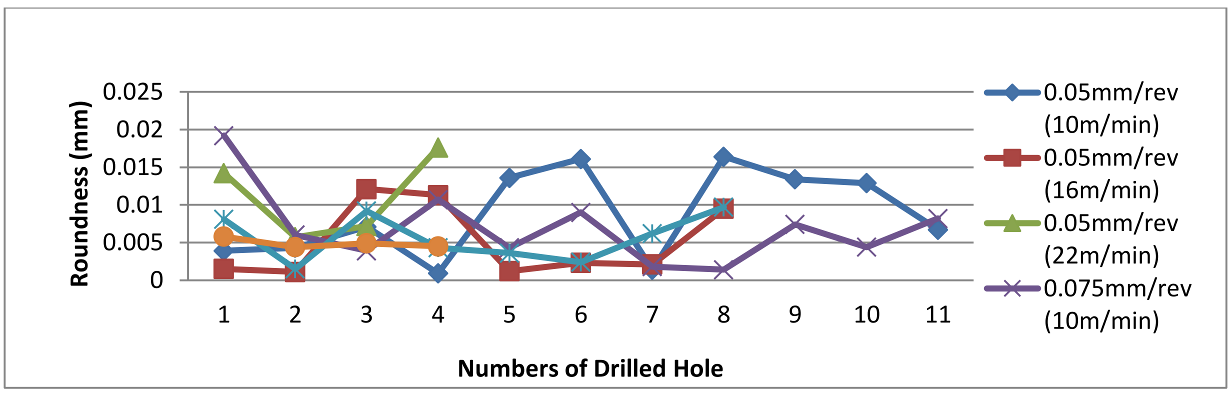

Figure 5b: Roundness of Drilled Holes for Tool B (No Coolant).

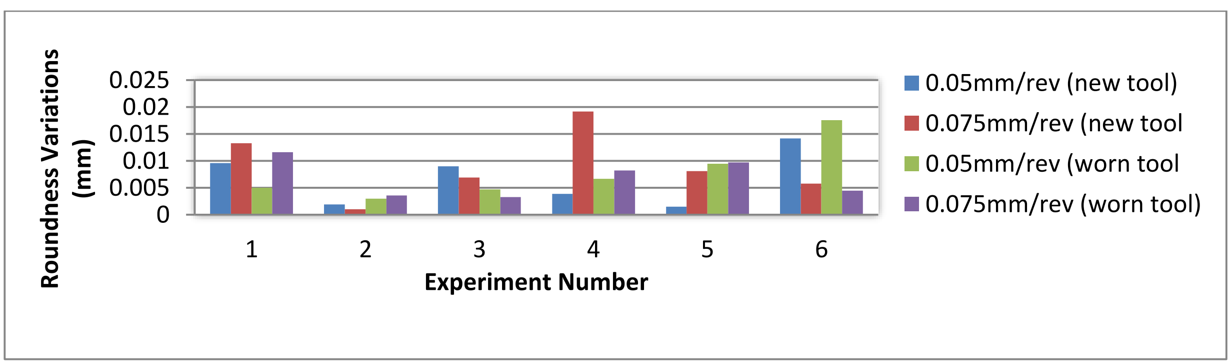

Figure 5c: Roundness of Drilled Holes for New and Worn tool.

Figure 5b shows the Roundness measurement for Tool B which is running with no coolant. The output of the graph for Tool B show a bit different from Tool A which is Tool A graph look more linearly compared to Tool B where is the graph curve look more fluctuated. The different of two graphs may be due to the usage of coolant. As mention earlier, Tool A was running with coolant is in on mode but Tool B was running with coolant in off mode. From the figure, it show that the 22m/min cutting speed with 0.075mm/rev feed rate is more linear compared to the other two. The others two cutting speed shows the fluctuated lines. It shows that, if cutting speed is higher, it will contribute to the good roundness. This is due to the stability of the spindle during drilling operation which is less vibrating cause of high cutting speed. From the figure 5c, it can be concluded that the new tool contribute to the good roundness compared to the worn tool. This is because the vibration of worn tool is more than new tool. The vibration of first hole is less if compared to the last hole. This situation will influence the roundness measurement result.

4.0 CONCLUSIONS

This research focused on the study of the effect of incremental feed rate in drilling of Austenitic 316L stainless steel. The evaluating aspects that take into consideration in this research is tool wear, surface roughness, tool life, machining time, dimensional accuracy and roundness of the holes. All these aspects were obtained based on different type of cutting condition. The research also running with two feed rate in each drilled hole which is 0.05 and 0.075mm/rev. From the obtained results, the following conclusions can be drawn:

i. From the tool wear perspective, the higher cutting speed contributes to the higher tool wear. It also can be concluded that the cutting speed is inverse proportional with the number of drilled hole.

ii. The finding from the research also shows the character or the function of coolant. Coolant played an important role in this experiment. The trials that running with coolant show the high number of drilled hole compared to the trials running without coolant at various cutting speed.

iii. Built up edge just occur at the trial that running without coolant. This situation happened because the coolant playing an important role it to decrease the temperature between the drills bits with the workpiece when they contact each other.

iv. The graph pattern of tool wear versus machining time for Tool A and Tool B show that the lower cutting speed give the lower slope of line plotted while the higher cutting speed give high slope. This conditions same as previous study.

v. The experiment shows that the 10m/min cutting speed with 0.05mm/rev feed rates for both tool gives the good surface roughness. It can be conclude that smoother surface finish has been obtained at lower cutting speed and feed rate.

vi. From the dimensional accuracy view, it can be concluded that the dimensional accuracy of the lower feed rate is better than the higher feed rate. It can be seen that the variation in the holes diameter produced using worn drills are higher than those obtained using new drill.

vii. The result of roundness measurement show that the new tool contributes to the good roundness compared to the worn tool. This is because the vibration of worn tool is more than new tool. The vibration of first hole is less if compared to the last hole. This situation will influence the roundness measurement result.

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