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Experimental study on the cutting temperature, vibration and chip formation in machining of 316L under dry and flood process

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ABSTRACT

This research aim at providing information of the cutting temperature, vibration and chip formation on machining stainless steel 316 under dry and flood coolant. The chosen material for the workpiece was a stainless steel, 316L. The milling performance was evaluated respectively by cutting temperature, chip thickness and vibration. The tools to measure cutting parameters were thermal camera, micrometer and accelerometer transducer. Various machining conditions were tried involving two different cutting tools T1 and T2, then measured on the parameters of interest. The results showed that the highest temperature used for slot milling on dry cutting tool T2 was 146 ^{o}C compared to dry condition cutting tool T1, 117 ^{o}C. The chip thickness for cutting tool T2 was lower compared to T1. The chip thickness for T1 in slot milling was recorded 0.0469 mm while T2 measured as 0.0208. For the vibrations, cutting tool T2 also showed lower vibrations compared to that in T1. The vibration for T1 in slot milling was recorded 0.055372 g while T2 was a bit lower as indicated by its acceleration 0.055168 g.

Key words: Stainless steel, cutting edge preparation, cutting tool, cutting temperature.

1. INTRODUCTION

Milling is the method of removing extra material from the workpiece using a rotating multi-point cutting tool, called a cutter [1]. This study is important in improving the milling performance and it is the easiest way to reduce production costs and improve the quality of the products. Usually tool gets damaged and broken due to several factors such as overheated and high vibration produced during machining. Since the cutting tool is the basic requirement in milling process, the study of the cutting tool structure, in particular the cutting edge, is a breakthrough point to enhance the milling performance [2]. In order to get a smoother cutting edge after the preparation process, the cutting radius needs to be enlarged. The second method in improving the milling performance is the utilization of cutting fluid and in this study, flood cutting has been used as the cutting fluid. In conjunction, cutting edge preparation was applied in both side milling as well as slot milling.

Milling is one of the methods of machining. CNC machining is now a popular machine used in all processes of industrial production where pre-programmed computer software controls the movement of factory tools and machinery. A variety of complex machinery can be operated through the process, from grinders and lathes to mills and routers. Three-dimensional cutting tasks can be done in a single set of prompts with CNC machining.

Stainless steel type 316 is an austenitic chromium-nickel and heat-resisting stainless steel with superior corrosion resistance compared to other chromium-nickel steels especially when exposed to corrosive chemicals such as sea water, brine solutions and others. Form 316L is durable, easy to manufacture, clean, welded, and finished. It is much more resistant to high temperature solutions such as sulphuric acid, chlorides, bromides, iodides and fatty acids. In the manufacture of certain pharmaceuticals, stainless steels containing molybdenum are required to prevent excessive metallic contamination.

The milling process is conduct using Vertical Center Nexus 410A-II CNC machine and take some data of cutting temperature, cutting force, vibration, and chip formation. Whereby each parameters will use flood cooling and dry machining. Cutting fluids are employed in machining operations to improve the tribology process, which occur when two surfaces, tool work-piece make contact [3]. The application of cutting coolant increases tool life as well as the surface topography of the work-piece.

The use of cutting lubricants in the manufacturing of metal cutting has become additional challenge for the physical and environmental condition of the employee. Manufacturing and research institutions are looking for advanced tools or are either the need or use of fluid cutting in terms of cost effectiveness and environmental issues [4]. It was found flood cooling assisted results were more efficient than the results of dry machining.

2. METHODOLOGY

Two workpieces were used in the experiment; one for slot milling and another one for slide milling. Figure 1 shows the workpiece for experiment using stainless steel 316L. Both workpieces have different size. The side milling workpiece have been divided into several section. The reason size of workpiece of side milling is divided into several section and smaller than slot milling is to save time cost and to make sure the experimental process is going smoothly without to make a new surface for new parameter.

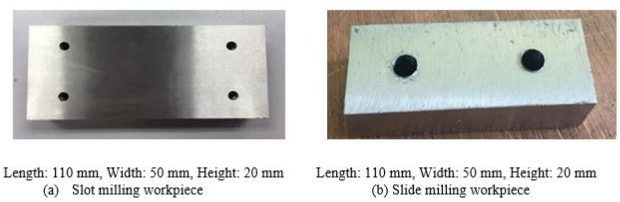

Figure 1:. Two different workpieces

Testing and experimentations were conducted by using two different cutting tools namely T1 and T2 to see the performance or the measured parameters. Table 1 shows the specification of the tool used for the experimental works.

Table 1: Cutting tool specification

	T1	T2
Type	Square	Square
Flutes	4	4
Design	Fake OD, DP	Eccentric OD, DPDH

Three different measurements were conducted to the temperature, vibration and chip thickness. The setup for each experiment involved different setup arrangement related to the measurement gauges.

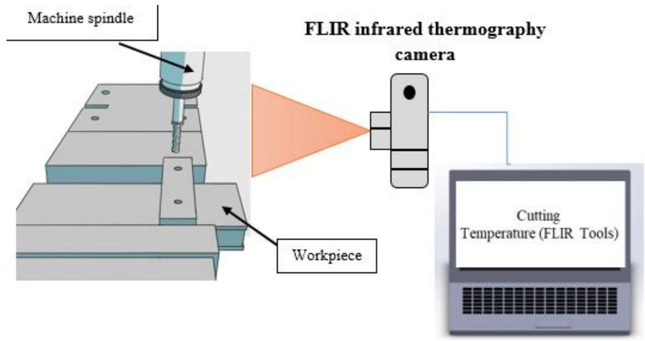

Figure 2: Experimental setup of cutting temperature using thermography camera

2.1 Cutting Temperature Setup

Figure 2 shows the experimental setup for cutting temperature where the camera was connected to the laptop. The temperature can be displayed by using Forward Looking Infrared (FLIR) camera application. The camera was pointing to the cutting tools and the temperature can be taken during the cutting process.

2.2 Vibration Setup

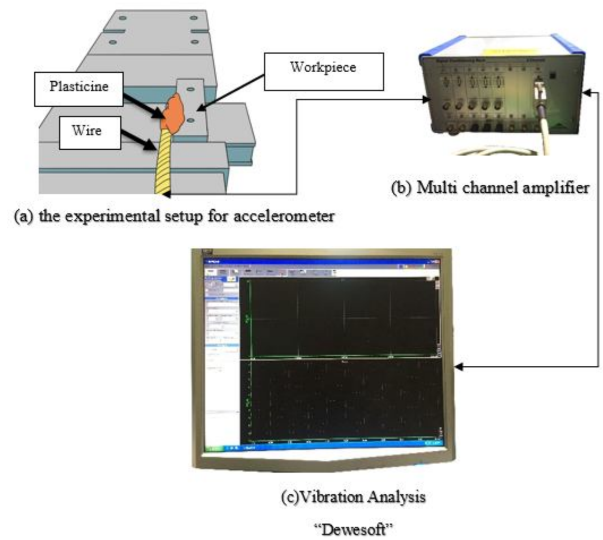

Figure 3: Experimental setup for vibration

In order to pickup the vibration, a single vibration transducer known as accelerometer was connected to a multi-channel vibration data acquisition and then sending the vibration response to a computer controller to plot the vibration data

2.3 Chip Thickness

Measuring the chip thickness used digital micrometer. Figure 4 shows the micrometer to measure the chip thickness in the experimental. For constant measurement, the chip was measured consistently in the middle. The value of the chip thickness was displayed at the digital view. The unit of micrometer was in millimeter. There were 10 sample chips of dry condition and 5 sample chips of flood condition.

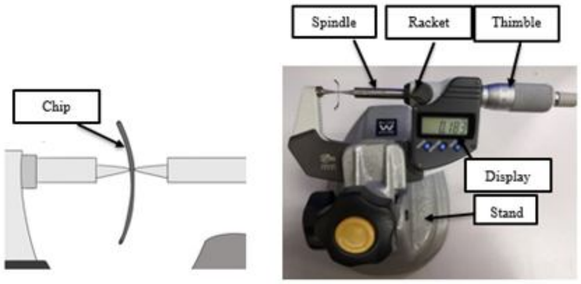

Figure 4: Experimental setup for vibration

3. RESULTS AND DISCUSSION

3.1 Cutting Temperature

There were a few problems occurred while taking the temperature where the temperature results were not constant while focusing on the tool. Thus, the highest temperature was taken to use in the experiment. Next, while running the flood milling, the camera was not focusing perfectly on the tool and the work piece because the tool was covered by the coolant. The experimental measurement results were collated in Table 2.

Table 2: Cutting temperature in dry and flood milling

	Dry Milling		Flood Milling	
Slotting	T1	117°C	T1	38.5°C
	T2	146°C	T2	46.3°C
Side Milling (standard)	T1	113°C	T1	32.5°C
	T2	127°C	T2	38°C
Side Milling (Roughing)	T1	115°C	T1	42°C
	T2	130°C	T2	43°C
Side Milling (Finishing)	T1	104°C	T1	36°C
	T2	107°C	T2	40°C

The results show that the temperature record is higher in dry milling than the temperature record in flooding in all milling processes. When using T2 cutting tool, the temperatures generated are also higher compared to machining process when using T1 cutting tool.

Slotting

It can be explained that the T1 cutting tool without cutting edge preparation and chamfer is wear-resistant compared to T2, which results in a higher cutting force for the chamfered tool [5].In the same size as the cutting tool, the radial cut was also 6 mm. The greater the cutting force, the higher the temperature. The use of fluid cutting was thought to improve the efficiency of the tool. There was a slight difference between T1 and T2 in flood cutting. It is noticed that the slot milling under dry condition, there were no cutting fluid to flush the formed chips that left at machined slot geometry since more chips with smaller size generated by chamfer geometry of edge prepared tool [4].The temperature capture in dry condition in T1 and T2 cutting tools are shown in Figure 2.

Figure 5: T1 and T2 in dry condition

Side Milling (Standard)

The cutting performance of T2 was lower compared to T1 cutting tool in side milling (standard). Both tools however showed the same performance in slotting milling. The temperature for side milling (standard) was lower than the slotting. The radial of cut was not occur in side milling standard. The cutting tool T2 with edge preparation and chamfered was not suitable for the slotting and side milling (standard). More chips with smaller size generated by chamfer geometry of the edge prepared tool [4], the smaller chips located at the cutting area can caused rise cutting temperature during machining process.

Side Milling Roughing and Finishing

In this milling condition, the cutting tool T1 without cutting edge has low wear resistance [6] and hence, it caused a high cutting force in dry cutting under the high temperature. While tools with cutting edge preparation T2, can keep its high performance in wear resistance due to lower cutting temperature even in dry cutting[7].

The temperature for the finishing is a bit lower compared to roughing due to low feed rate. In side milling (finishing), the cutting tool T1 without cutting edge was at low wear resistance [6] and hence, caused a high cutting force in dry cutting under the high temperature. While tools with cutting edge preparation T2, can keep its high performance in wear resistance due to lower cutting temperature even in dry cutting [7].

3.2 Chip Thickness

A device call micrometer was used to measure the chip thickness for every cutting. In order to hold the small chip, a clip was used to hold the chip when measuring the thickness. However, there were a bit problems while taking the chip for flood cutting. It was difficult to pick up the chip after the flood cutting was done. The measurement results of the chips in dry condition are shown in Table 3, while for flood condition are collated in Table 4.

Table 3: Chip thickness in dry condition

	Slotting		Standard		Roughing		Finishing	
	T1	T2	T1	T2	T1	T2	T1	T2
Average (mm)	0.0469	0.0208	0.0355	0.0336	0.02601	0.0154	0.0318	0.0271

Table 4: Chip thickness in flood condition

	Slotting		Standard		Roughing		Finishing	
	T1	T2	T1	T2	T1	T2	T1	T2
Average (mm)	0.0222	0.0186	0.0242	0.0176	0.0256	0.025	0.0506	0.023

Slot Milling

Since the cutting tool T1 was in lower performance compared to T2 in slot milling. This performance was due to the cutting edge preparation. T1 has no edge preparation so that it was lower resistance[6]. Flood cutting utilization did not bring significant effects to the thickness development of the chip.

Side Milling (Standard and Roughing)

The use of flood cutting makes the chip thickness become thinner compared to dry cutting. The smooth and less resistance in cutting process is contributing to the thin of chip development. When the process was in roughing, the chip thickness is even smaller.

Side Milling (Finishing)

In finishing process, the usage of flood cutting technique did not show significant effect to chip thickness.

Table 5: Average of vibration in dry condition

	T1	T2
Slot milling	0.055372	0.055168
Side Milling (Standard)	0.06568	0.057391
Side milling (Roughing)	0.070509	0.062316
Side Milling (Finishing)	0.057163	0.043886

Table 6: Average of vibration in flood condition

	T1	T2
Slot milling	0.053926	0.058716
Side Milling (Standard)	0.056897	0.097811
Side milling (Roughing)	0.053549	0.047197
Side Milling (Finishing)	0.058218	0.055594

3.3 Vibration

A vibration measurement system Dewesoft was used to capture vibration response during the machining processes. The vibration transducer, accelerometer attached to the workpiece read the vibration and plot the vibration graph on the computer screen through its Dewetron software. The vibration was measured in g as the unit of the vibration.

Slot Milling

For cutting tools without edge preparation T1, the vibration are recorded 0.055372 g for dry cutting (Table 5) and 0.053926 g for flood cutting (Table 6), respectively. As for the cutting edge-prepared endmill T2, the vibration for dry cutting are 0.055168 g and 0.058716 g for flood cutting. For each condition, T2 generated lower vibration than T1 and the reduction of vibration are 0.37% in dry condition and 8.15% in flood condition. Higher improvement on vibration assisted by flood cutting for both T1 and T2 [3].

Side Milling (Standard)

For side milling (standard), the vibration for cutting tool T1 without cutting edge preparation and T2 which is with cutting edge-prepared endmill in dry condition and flood condition did not show much difference with the slot milling except for the cutting tool T1 in flood condition for slot milling which was higher than side milling (standard).

The vibration for cutting tool T1 are 74 g for dry condition and 54.04 g for flood condition. For cutting tool T2 are 35.36 g for dry condition and 15 g for flood condition respectively. Besides, the study has shown that the reduction for dry condition between cutting tool T1 and T2 is 52.2% and for the flood condition is 72%.

Side Milling (Roughing)

The vibration in side milling (roughing) for cutting tool T1 without cutting edge preparation and T2 with cutting edge-prepared endmill in dry condition and flood condition was slightly higher than the slot milling and side milling (standard). This is due to cutting speed for side milling (roughing) was a bit lower compared to slotting and side milling (standard) 50 mm/min [8].

The vibration for cutting tool T1 were captured 0.070509 g for dry condition and 0.053549 g for flood condition. For cutting tool T2 **showed** 0.062316 g for dry condition and 0.047197 g for flood condition respectively. Moreover, the reduction for dry condition between cutting tool T1 and T2 was calculated as high as 11.62% and for the flood condition was about the same, 11.86%. Sharp cutting edge believed has lower strength that leads to lower wear resistant [9]. The sharp edge can be removed by cutting edge preparation by increasing the cutting radius to strengthen the edge geometry [10].

Side Milling (Finishing)

For side milling (finishing), the vibration for cutting tool T1 which was without cutting edge preparation and T2 which was with cutting edge-prepared endmill in dry condition and flood condition was higher than the slot milling and the other side milling. This is due to cutting speed for side milling (finishing) was higher which was 70 mm/min [8].

Moreover, the cutting tool T2 kept in its best performance which had lower vibration compared to cutting T1. The vibration for cutting tool T1 was 70 g in dry condition and 10.22 g in flood condition. As for the cutting tool T2 was recorded 35.36 g in dry condition and 8.8 g in flood condition respectively. The reduction for dry condition between cutting tool T1 and T2 was recorded 49.48% while for the flood condition was only 13.89%.

In cutting temperature test, for slot milling and side milling (standard), T2 generate high temperature compare with cutting tool T1 which is different with side milling (roughing) and side milling (finishing) [11]. For chip thickness, cutting tool T2 shows the lower chip thickness for both dry and flood condition [12]. Moreover, same as for the vibration experiment, cutting tool T2 keep it performance which is has lower vibration compare with cutting tool T1 that has no cutting edge preparation [13].

An improvement of machining performance in terms of cutting temperature, chip thickness and vibration of stainless steel 316L has been observed by utilizing of flood cutting in almost every machining processes [14]. Further research should consider some other parameters that could have effect in machining accuracy [15-17].

5. CONCLUSION

The machining performance of stainless steel 316L was investigated using experiments. The cutting tool end mill with diameter of 6 mm with cutting edge preparation (namely T2) in general produced lower cutting temperature. This type of cutting tool produced also thin chip thickness compared to T1 type.

The vibration showed similar characteristics that T2 produced lower vibration in machining process on stainless steel 316L. Cutting fluid can act as coolant and lubricant during cutting process, which helps to decrease the cutting temperature and vibration.

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