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In-situ worn geometry effect over the surface roughness propagation during micro milling process

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ABSTRACT

High-precision miniaturized components for micro-machining operations has an increasingly demand for numerous developing sectors such as medical instrumentations, electronics components, computer manufacturing, aerospace and automotive engineering. Micro-milling has known as a flexible micro machining process and the most familiar micro mechanical machining method. Due to overcome a few difficulties in micro fabrication, micro milling is picked as an alternative way as it has potential and imperative for high accuracy machining. However, micro tools have low tool life as it is unpredictably and wear quickly. Furthermore, it also has tendency to break easily due to its micro size dimension. The study observe the behaviour of micro milling worn geometry during machining and includes a non-conventional method to measure surface roughness resulted by micro milling process in machining of mild steel AISI1045. The workpiece is prepared by using CNC milling machine with facing and slotting process. Then, the mild steel AISI1045 will undergo a machining process by a 1 mm size end mill diameter with different set of parameters which are of cutting speed. Once the best cutting speed is obtained based on surface roughness result, the tool life performance is teste. From the study, it is known that higher cutting speed gave better surface roughness, as limited for the study at 3000 rpm (7.53m/min). Meanwhile, higher cutting speed gave tool limited tool life, there is not much different with lower cutting speed for micro end milling process probably due to geometrical effect.

INTRODUCTION

A worldwide phenomenon in expanding request for miniaturization technologies was experienced during the previous two decades. This miniature components and micro-parts for high-accuracy technology witnessed an increment growth in numerous sectors of industries, including biotechnology, media communications, medical, electronic components, aerospace engineering, and automotive engineering. Due to this consistently expanding interest, the micro manufacturing technology is automatically boosted [1] [2].

Micro manufacturing indicates the manufacture of high-precision three-dimensional products on an assortment of materials with specification whose sizes range between ten micrometres to a couple of millimetres [3]. Evolvement of micromachining technologies is significant to reach the specification of micro-innovation basic products like a printed circuit board, switches, micro-sensors, microchip, chemical micro-reactors, micro-electromechanical, microfluidic systems, for instance, inkjet printers and more [3]. Micro products have picked up acknowledgment in societies because of simply taking care of and settlement in constrained space. Additionally, micromachining advances ease in sparing material and energy while merging enhanced functionality inside constrained space [4] [5].

Over the past few years, the study about monitoring of machining operations has got a seriously led as this issue importantly adds to the process of automation of machining and limits human cause [6] [7]. Expanding requests of an automation process for no humans' help in manufacturing pulled in numerous research workers in the field of an online monitoring machining process. In perspective of this issue, broad study work is occurring worldwide in the zone of an online tool condition monitoring (TCM) system [8]. Tool breaking is a significant issue in a situation of extremely unstable pressure, for example interfered with turning [9]. In all of a sudden, the tool may go wrong although the tool failure is normally come before another sign like tool wear and tool edges crack or chipping in advance of the ruined failure. All the signs are able to be utilized for forecasting thoroughly the tool failure achieved. Apart from that, downtime which affected by the failure of the tool could be diminished by monitoring system even though foreseeing it is particularly troublesome in interfered cutting because of greatly changeable stress causing risen tool wear [10]. Therefore, with an efficient monitoring system, it can help to avoid the damage to the machine apparatus, downtime and rejected components [7] [8].

In increasing of supreme demand for high-precision miniature components, micro milling is known as an adjustable micro machining process and one of the most familiar micro mechanical machining methods. Due to overcome a few difficulties in micro fabrication, micro milling is picked as an alternative way as it has potential to fulfil the demands. However, micro milling has low tool life as it is easy to break. The tendency for the tool to break is higher due to its micro size dimension. Nevertheless, micro milling is imperative for high accuracy machining.

In the study, the behaviour of surface roughness propagation will be observed and related to in-situ geometry wear of micro geometry of end mill tool during machining process of mild steel AISI1045. This study will related towards the utilization of online monitoring system for the application of micro milling, where it is able to determine the condition and prevent the tool breakage or severe the condition beforehand through the artificial intelligent analysis.

METHODOLOGY

CHOICE OF TOOL

Milling cutters are the cutting tools which are commonly utilized to conduct the operations of removing material from a flat 3 dimensional shape of workpiece. The materials are eliminated by the movement of cutting tools within the machine or instantly from the shape of cutters. As the cutting tools must have specific qualities to operate properly during the machining process, the cutter used must be tougher than the material of workpiece. This is to ensure that the cutter have sufficient strength to withstand the pressure generated during the cutting operation. In this study, 4 flutes tungsten carbide flat end mill of Ø1.0 mm diameter as shown in Figure 1 is chosen as the cutting tool. Tungsten carbide is known to have high hardness, high stiffness and resistant to high cutting temperatures. These physical aspects enable hard metal applications to run at greater speeds and feeds and enhance production speed while having long machine tools.

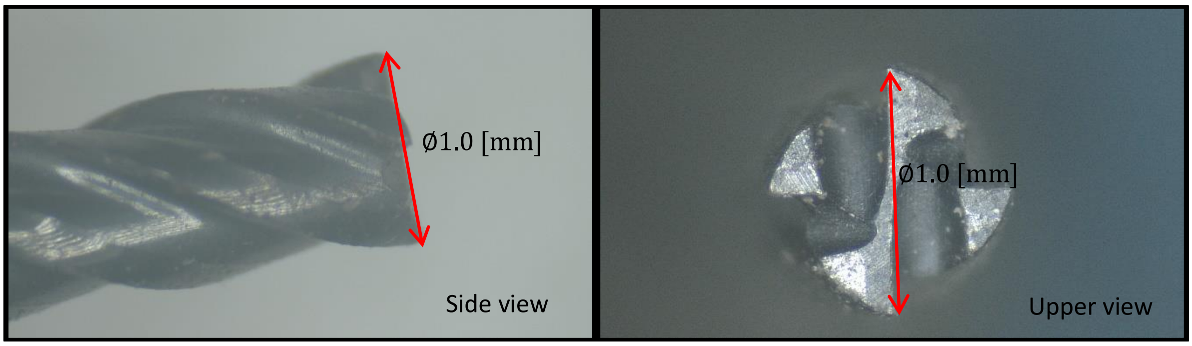

Figure 1: 4 flutes 1 mm diameter tungsten carbide tool

DESIGN OF WORKPIECE

For the workpiece preparation, the mild steel AISI1045 block is used to conduct the experiments. In milling operations, mild steel is a common form of steel as it has a relatively low price and provides the material properties which can be acceptable for many applications. The material of AISI 1045 mild steel is a medium tensile steel which is transferred in the black hot rolled or normalized condition. The tensile strength of the mild steel is between 570 to 700 MPa and it has a Brinell hardness with range from 170 to 210. Furthermore, the material of mild steel AISI 1045 has a good machinability in normalized as well as the hot rolled condition. Based on the recommendations from the manufacturers of machine, machine operations such as milling, drilling, tapping, turning and other applications can be applied on mild steel AISI 1045 by using suitable feeds, tool type and speeds. For this research, a rectangular block of mild steel workpiece is design into the shape as shown in the Figure 2 below to easier the process of cutting. The dimension of the workpiece is 100 mm in length, 20 mm in height and 40 mm in width.

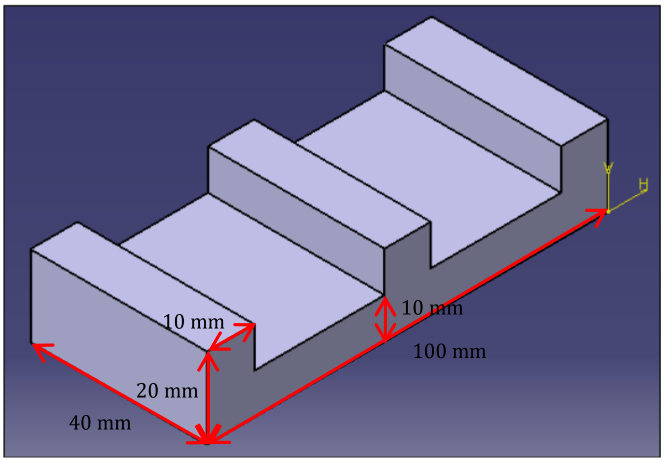

Figure 2: Workpiece design for micromachining purpose

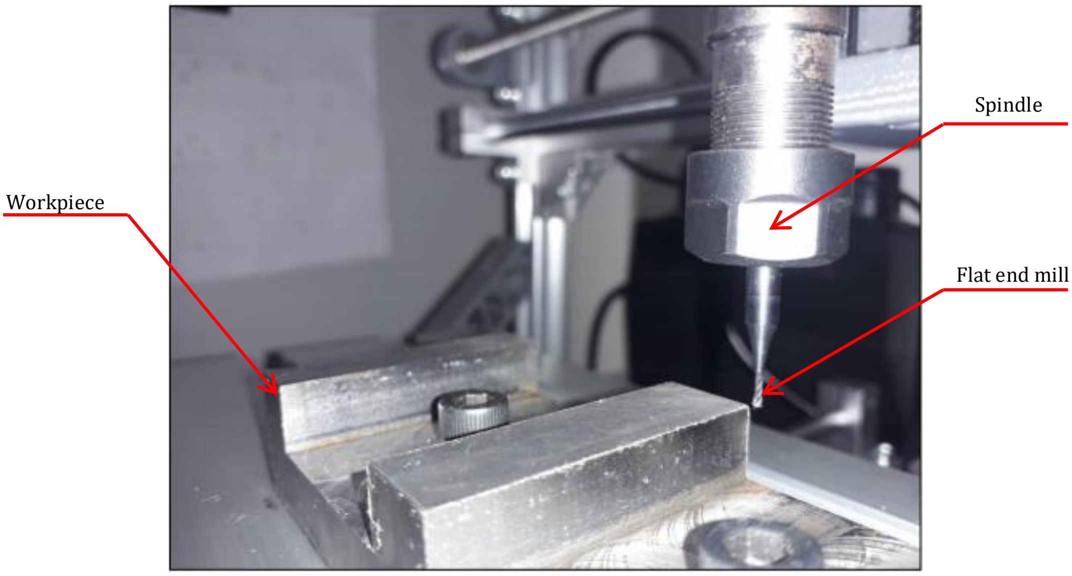

Figure 3: Experimental setup

MICROMILLING PARAMETER

For this research, the experiments are run to explore and discover the behaviour of micro milling machine during the milling operations. There are eight number of testing set with different tools are conducted with different parameters. Two main parameters, cutting speed and cutting length are chosen for this experiment. From the value of the parameters, the cutting speed for each testing set can be calculated. The parameters are chosen based on the maximum capability of NC milling lathe available at the lab. The cutting speed of the metal can also be defined as the speed, in meters per minute (m/min) where the metal can be machined effectively. The milling cutter can be reduced to a specific number or revolutions per minute (rpm) during the machining of the workpiece. It is depending on the size of its diameter to reach the correct cutting speed.

The cutting speed is calculated by using the Eq. (1):

$$V = \frac{\pi DN}{1000} \tag{1}$$

Where;

V: Cutting speed (m/min)
D: Tool diameter (mm)
N: Spindle speed (RPM)

Additionally, all the parameters related to relationship of cutting speed and surface roughness is shown in Table 1, while the parameters related to relationship of tool wear and surface roughness is shown in Table 2.

Table 1: Micromachining parameters for cutting speed relationship towards surface roughness

Parameter	**Number of Testing Set**							
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Spindle Speed (rpm)	1000	1200	1400	1600	1800	2000	2200	2400
Feed Rate (mm/min)	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
Axial Depth (mm)	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Radial Depth (mm)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Cutting Speed (m/min)	3.14	3.77	4.39	5.03	5.65	6.28	6.91	7.53

Table 2: Micromachining parameters for tool wear relationship towards surface roughness

Parameter	**Number of Testing Set**	
	1	**2**
Spindle Speed (rpm)	1000	2400
Feed Rate (mm/min)	5.0	5.0
Axial Depth (mm)	2.0	2.0
Radial Depth (mm)	0.5	0.5
Cutting Speed (m/min)	3.14	7.53

RESULTS AND DISCUSSION

SURFACE ROUGHNESS TEST

Figure 4 shows the results of the surface roughness by the micro end milling process. From the graph, it can be seen that the higher the cutting speed applied, the lower the value of surface roughness obtained. This also means, the better quality of the machined surface will be achieved by applying the high cutting speed during the micro milling operations. Surface roughness is an important characteristic parameter that reflects the rough surface performance, and it is a measure of the surface quality of a workpiece. In the machining industry, surface roughness can affect the performance and quality of the product, which is mainly reflected in its impact on the product wear, resistance, and fatigue resistance. Therefore, it is significant to evaluate the surface roughness accurately [11].

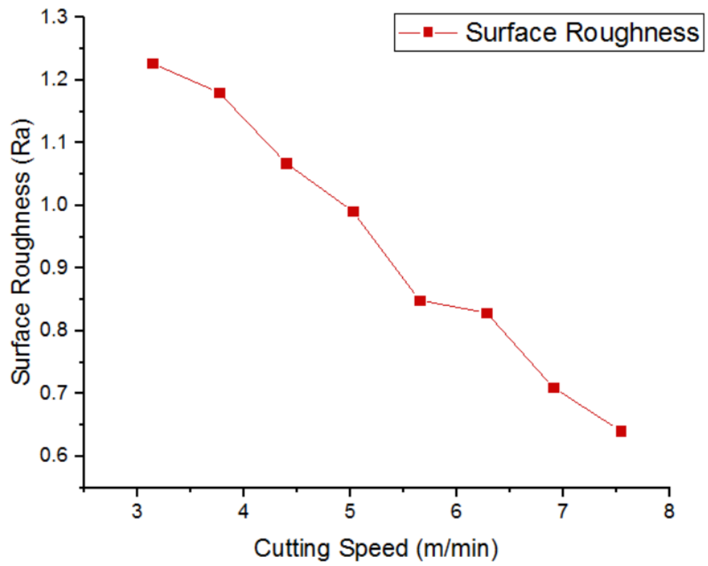

Figure 4: Relationship of average surface roughness and micro end milling cutting speed

PROPAGATED TOOL WEAR

Continually, 2 parameters had been chosen from the previous condition and set as Tool 1 and Tool 2, which will undergo a process of milling cutting with a low and high cutting speed, respectively. The sizes of the tool wear for each flute are observed properly under the video measuring system. From Figure 5, the graph illustrates that the higher the cutting speed the greater the wear length for each tools. Furthermore, as the high cutting speed applied on tool 2 the mean wear has a largest value of wear length compared to tool 1 which undergo under low cutting speed.

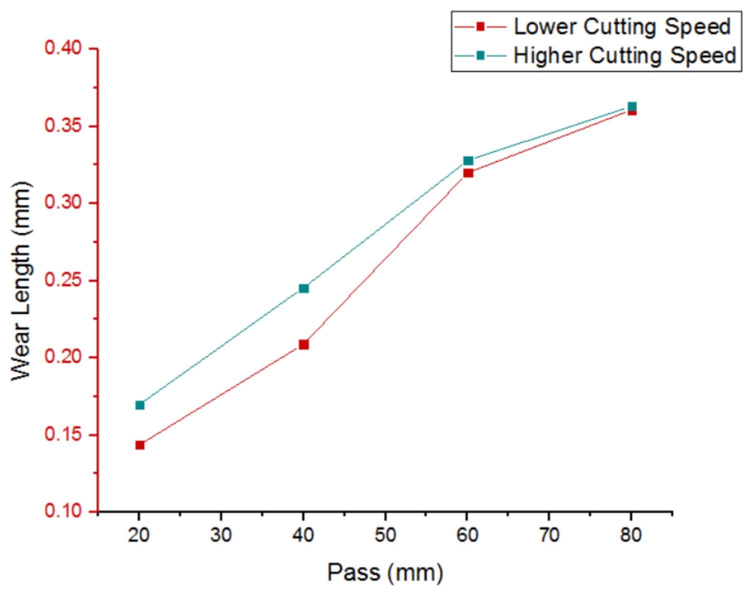

Figure 5: Propagation of tool wear length as the cutting pass increases

WORN TOOL GEOMETRY

The condition of tool geometry from top view and side view are observed properly as Figure 6. After a pass of 20 mm, the tool conditions are viewed under the optical microscope with display and video measuring system to study the shape of geometry. The conditions of the carbide flat end mill tool before and after the experiment are illustrated in the following section.

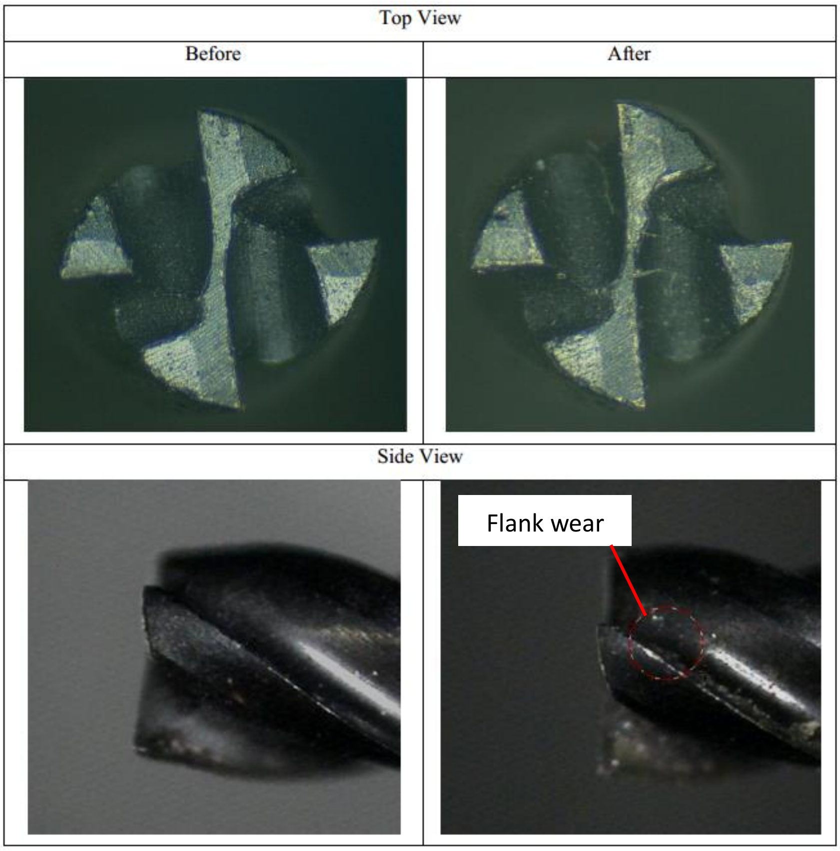

Figure 6: Tool geometry before and after 20.0 [mm] pass used

In milling process, both material and geometry of the cutting tools play important roles on their performances in achieving effectiveness, efficiency and overall economy of machining. Based on the Figure 6 above, it clearly indicates the shapes of the tool from the side and top view of the tool. The images are taken after a cutting process 20 mm length of pass with depth of cut 0.5 mm. From the top view, it is illustrated that the tool has a flank type of wear. Flank wear is usually which the portion of the tool in contact with the finished part erodes. This wear can be caused by the spindle speed or cutting speed that is too low or a feed rate that is too high.

From the side view, the wear also can be seen as the shape of the tool is slightly changes compared to the shape of tool before. Geometry of a cutting tool is the shape and angles to which cutting portion of a cutting tool are grounds. It can influence the quality of the finished part and the life of the cutting tool. The cutting portion consists of the working surfaces which includes the top surface along which the chips come off, and the side surfaces which face the machined surface of the workpiece. Then, the intersections of the working surfaces form the cutting edges.

CONCLUSION

Micro milling is commonly utilized in sectors of industry for the production of micro components but poorly predict the tool wear is usually the reason for a short tool life of the micro cutting tools frequently occurred. Therefore, this research is done to investigate the behavior of micro milling cutting process to help improve the prediction of the tool wear behavior for micro tools.

After conducting the experiments, the parameters setups is conclude as one of the crucial things need to be carefully focused in order to help increase the tool life of micro cutting tools. Furthermore, this research is done to clarify the effect of micro geometry onto tool and machining quality. The experiments are conducted to study the wear of tool after the cutting process due to help predict the tool life of the micro tools and several conclusion can be made as following:

1. For micro milling process, as higher cutting speed applied, lower surface roughness and low tool life are able to be obtained.

2. It is similar to conventional milling machine but as the micro milling act differently compare to the conventional milling, it provides a high impact from geometrical effect and frictional behaviour. Therefore, micro tools wear quickly due to its micro size dimension.

3. In order to extend the micro tool life, the cutting tool must be harder and tougher than the material of workpiece as it will ensure the tool to withstand the pressure during the process of cutting.

4. Besides, the materials chosen might also influence the probability for the tool to wear and break during the milling operations.

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