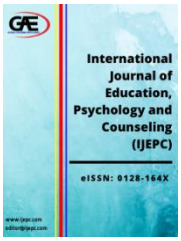
International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 9 Issue 53 (March 2024) PP. 584-590
DOI 10.35631/IJEPC.953044



INTERNATIONAL JOURNAL OF EDUCATION, PSYCHOLOGY AND COUNSELLING (IJEPC)
www.ijepc.com

INVESTIGATION ON THE END MILLING CUTTING IN MACHINING POLYVINYL CHLORIDE (PVC) FOAM BOARD FOR ISLAMIC ART

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Article Info:

Article history:
Received date: 12.12.2023
Revised date: 19.01.2024
Accepted date: 28.03.2024
Published date: 31.03.2024

To cite this document:

Abbas, N. M., Azahari, M. A. H., Mat Zaki, M. N. I., & Ahmad, Z. (2024). Investigation on the End Milling Cutting in Machining Polyvinyl Chloride (PVC) Foam Board for Islamic Art. *International Journal of Education, Psychology and Counseling*, *9* (53), 584-590.

Abstract:

The polyvinyl chloride (PVC) foam board is utilized for decorative purpose such as a backdrop stand or three-dimensional (3-D) model. Some of the advantages are lightweight, mobile and ease in adding realistic details through printing or machining. The Selangor Islamic International Arts Complex employs the PVC foam board to create 3-D Islamic art for mosque ornamentation. However, the quality of the product produced does not meet the required quality and rework need to be done when the two flutes end mill cutting tool is used. This study focuses on identifying the reason of the unexpected surface finish and proposing method to improve the quality of the pattern produced. The investigation was done by comparing the pattern exhibits after a four continuous hours of machining between two flutes and single flute of end mill tool under the same parameter setting. It was found that, the single flute end milling yielded good surface finish compared to the two flutes which exhibit burrs and rough surface finish. This is because the single flute end mill tool gives lower friction and less heat during machining and facilitating proper chip removal in comparison to the two flutes end mill tool.

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Keywords:

Cutting Tool, End Milling, Foam Board, Polyvinyl Chloride (PVC), Surface Finish

Introduction

End milling is a material removal process by shear deformation. The desired finished products including complex-shaped components (Reddy, N.S.K. and Rao, P.V., 2005) can be achieved by grooving, slotting or pocketing a workpiece by utilizing different types of tool bits (Prasad K. and Chakraborty S., 2016). The machining parameters are feed rate, depth of cut and cutting speed and the tool life depends on the speed and depth of cut. An increase in the average roughness (Ra) was caused by the increase in spindle speed and feed rate (Omer Cerlek et al., 2023). Tool flute geometry also has a minimal effect on cutting forces (N.A Norrdin et al., 2018). The width and the length of the contact area are influenced by both radial and axial depths of cut (Wen-Hsiang Lai, 2000). Therefore, the method used to ease the burden of tool life is by having a smaller depth of cut and multiple machining process. To gain a much lower error margin of the design, the industry used a roughing and finishing end milling process.

One of the most important criteria of a good product creation is the surface finish. An appropriate selection of end milling tool can reduce the roughness of the surface (Prasad K. and Chakraborty S., 2016), defeat the need for post processing machining process and thus increasing the productivity (T. U. Jagtap and H. A. Mandave, 2015). The surface defect usually in term of chip formation, rough surface finish, burr, chipping and chattering (Carbide Depot, 2023). In selecting the end milling cutting tool, flute number is one of the selection criteria. This flute number depends on the workpiece where the lower the number of flute is used for lower heat tolerance of the workpiece (MSC Industrial Supply Co, 2023). Single flute allows more chip space for high volume material removal (Bob Warfield, 2023; MSC Industrial Supply Co, 2023)

Polyvinyl chloride (PVC) foam board is widely used for advertisement and decoration drops as replacement for wood (Xin Xu and Quan Jiang, 2019). It is a soft material with low heat tolerance at 65^{o}C to 70^{o}C. In order to avoid melting while machining, quick removal of heat from the contact area between the tool and the workpiece is required (Harvey Performance Company, 2017). To reduce the temperature due to the friction between the cutting tool and the workpiece, the cutting tool can be lifted for a brief moment (Umut Karaguzel et al., 2017). However, this may lead to longer machining time. J.Y Byun et al., 2015 revealed that machining PVC in dry condition resulted in better performance in terms of the cutting time than in the wet condition. The burr formation in milling is known to be influenced by chip flow angle and exit order (Masayuki Hashimura and David A Dornfeld, 1998).

The Selangor Islamic International Arts Complex uses PVC foam board to produce Islamic ornamentation which is used as wall panels in the mosque. The ornament was machined by two flutes end milling cutting tool. Rework is needed after machining because of burr and poor surface finish causing late completion of work and extra manpower. The study aims is to investigate the surface finish of the PVC foam board by comparing the one flute with two flutes of end milling cutting tool under the same machining parameter.

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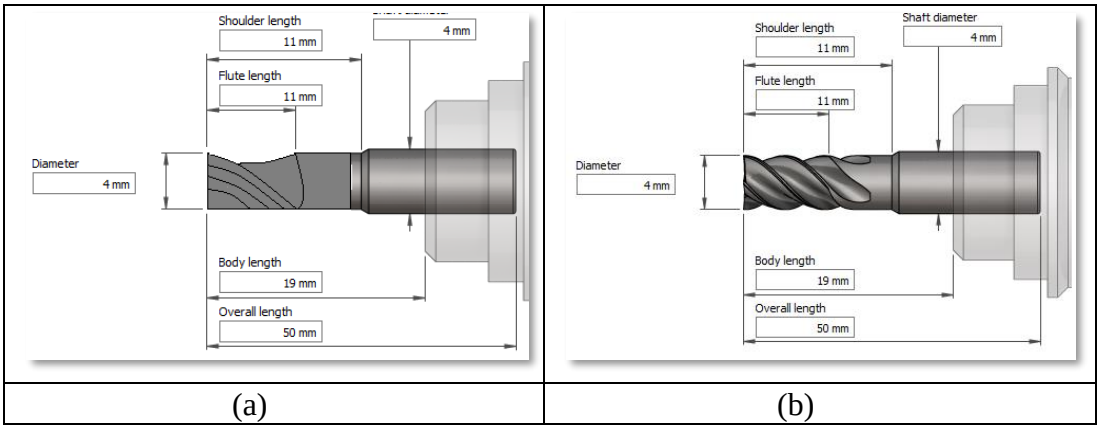
Methodology

Preliminary Observation

The study started by observing the machining process and the outcome of the common practice implemented by the industry. The industry was using a commercial PVC foam board and two flutes end milling cutting tool with aluminium titanium nitride (AlTiN) as the coating. The dimension of the two end milling tool is given in Figure 1 and the machining parameter is shown in Table 1. Then, by using a thermal imager the temperature of the milling cutting tool was observed and recorded when machining of the same pattern was performed. This is to identify the temperature of continuous machining. The observation was done for five hours and the temperature was recorded in every 30 minutes of machining.



(a) (b)

Figure 1: Dimension of (a) Single Flute and (b) Two Flutes End Milling Tool

Table 1: Machining Parameter

Parameter	Value
Feed rate	100 mm/s
Cutting speed	18000 rpm
Depth of cut	4 mm

Machining

By using the same commercial PVC foam board material and machining parameter as in Table 1, the machining was done by using two different end mill tools; single and two flutes. Both of the end milling cutting tool was coated by aluminium titanium nitride (AlTiN). The PVC foam board and the machining dimension are given in Table 2. For the experiment, the design was simplified and the cutting tool path selected was helix as shown in Figure 2. Simulation was done by using Autodesk Fusion 360 software to estimate the machining time and machining process in order to imitate the actual machining process. The machining was performed for four hours and the surface finish together with the chip formation were observed in every 30 minutes.

Table 2: PVC Foam Board and Machining Dimension

Parameter	PVC foam board dimension	Machining dimension
Width	1.22 m	1.10 m
Length	2.44 m	1.10 m
Thickness	10 mm	4 mm

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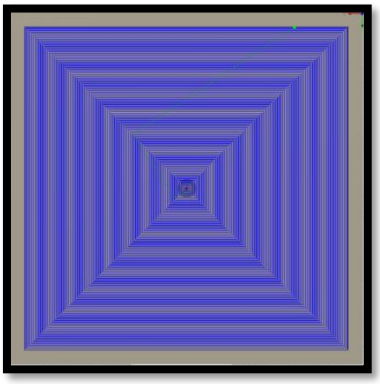

Figure 2: Simulation on Helix Cutting Tool Path

Results and Discussions

Preliminary Observation

From the initial observation, it was found that extreme burr exhibits along the edge of the of the pattern and the trace of cutting tool path was obvious. This can be seen in Figure 3. It was estimated that the temperature increases during the machining due to friction between the tool and the PVC foam board causing the extreme burr and the cutting tool path pattern. To confirm this, the cutting tool temperature was observed. The result shows that the temperature range during the machining process was from 39.6^{o}C to 55.0^{o}C with an average of 49.9^{o}C. Figure 4 shows the observation results. This temperature is below the temperature where the PVC foam board begins to soften, which is around 65^{o}C.

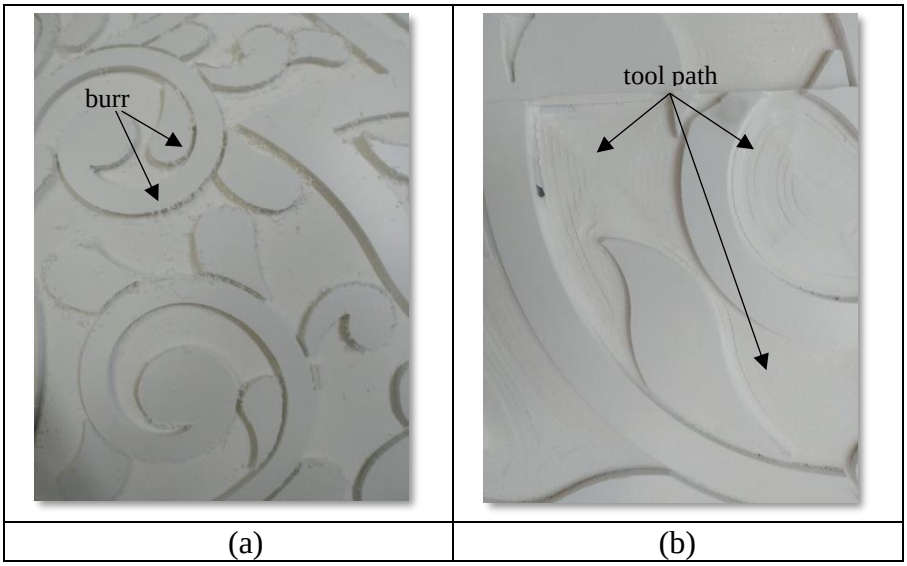

Figure 3: (a) Burr at the Edges of the Machined Pattern, (b) Trace of Cutting Tool Path

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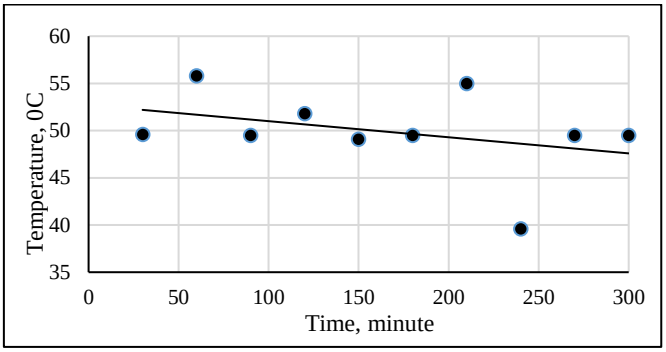

Figure 4: Temperature of Two Flutes End Milling During Machining

Machining

From the preliminary observation, a primary analysis was done. The extreme burr exhibits due to temperature build up during machining by using the two flutes end milling cutting tool. If the cutting speed is reduced in order to reduce the temperature, the machining time will increase causing delay in completing the machining process. Therefore, single flute end milling tool was selected as the potential solution. This is because, the single flute end mill can help to reduce the friction in one rotation compared to two flutes and consequently reduce the temperature during machining. Comparison on the surface finish between the two machining methods are given in Figure 5.

The figure shows that the surface finish of the PVC foam board is good with single flute end milling tool compared to two flutes throughout the machining duration of 240 minutes. In the case of two flutes end milling tool, burr on the edge of the material can be seen at 180 minutes of machining process. These defects are becoming much rougher and coarser when the duration of the machining process increases which can be caused by temperature. In the case of single flute, there was lower process force for even more number of features no cutting edge in engagement (J. Schmidt et al., 2023). Thus, since the friction between the tool and the workpiece can be reduced, the temperature between the two surfaces can be controlled resulting in a better surface finish.

Chip Formation

Chip is the unwanted material removed from the PVC foam board during machining. Figure 6 shows the chip formation for single flute and two flutes, respectively. The single flute has a discontinuous fine shape and almost constant throughout the process. This is because the single flute has a larger flute valley which allows the bigger chip creation and more heat can be removed from the workpiece without melting (Harvey Performance Company, 2017).

Conclusions

A preliminary observation was done to identify the machining behavior when a PVC foam board was machined with two flutes end milling tool to create an Islamic art wall panel ornament. Other than the information about the end milling tool and the machining parameter, temperature during the machining was measured for every 30 minutes. It was found that the average of the cutting tool temperature during machining was 49.9^{o}C which is below the melting temperature of a PVC foam board. However, because machining with lower number of flute can reduce the friction between the tool and the workpiece leading to reduction of temperature during machining, comparison between single flute end milling cutting tool was done with two flutes. The machining pattern was simplified but, the machining parameters

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were the same. It was found that single flute end milling cutting tool resulted in good surface finish compared to two flutes end milling cutting tool. In addition, machining the PVC foam board with single flute exhibits larger size and discontinue type of chip which shows that the cutting process occurs without melting.

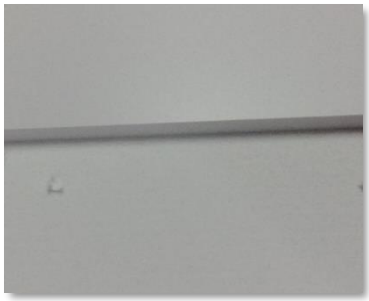
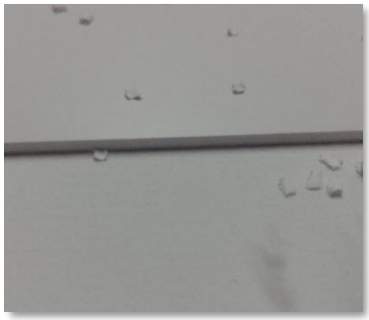
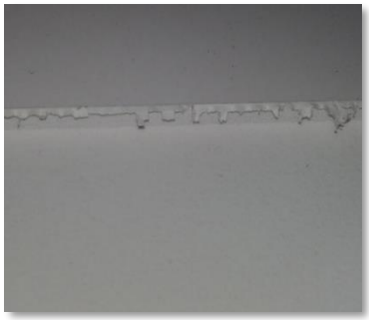
Time (minute)	Single flute	Two flutes
30		
180		
210		
240		

Figure 5: Machined Surface Comparison between Single and Two Flutes End Milling Tool

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Acknowledgements

The authors are grateful to the members of Yayasan Restu for the collaboration and cooperation in completing the study.

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