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The Impact of Tool Path Strategy on Tool Wear and Surface Quality During Milling Process

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Abstract: The use of a variety of cutter path techniques and positionings during milling is crucial in the manufacturing and machining industries. Appropriate choice can result in considerable cost savings in the enhancement of workpiece surface quality and tool life, consequently resulting in lower overall costs and increased productivity. The purpose of this work is to investigate the influence of different tool path techniques on tool wear and surface roughness during ball milling of a mould core component. Three tool strategies; lace, spiral, and concentration are discussed in relation to various milling operations.

Keywords: *Milling Operation, Tool Path Strategies, CAD/CAM, Surface Quality, Tool Wear*

1. Introduction

Numerous constraints in terms of the material of the workpieces, the machine equipment, and the cutting tools are present in machining processes. To increase the desired level of machinability, these constraints must be optimised [1]. They are classified according to material selection, tool geometry, cooling conditions, and material properties.

Due to the significance of the finishing phase in machining process, milling is the most efficient way to attain high surface superiority and precision in a short period of time. It is also necessary to look at the tool path techniques in order to achieve high quality for the intended parts. The most popular milling cutter path techniques when using a computer-aided manufacturing system (CAM) are zig-zag, and contour. Moreover, the manufacture of tool paths is the primary issue in various phases of Numerical Control machining, which affects not only the quality of the required geometry but also the efficiency of the manufacturing process [2]–[4].

The quality of the workpiece and how well the tool works are affected not only by the design and parameters of the tool, but also by its path and orientation. Tool path and position have a major effect on the machining process. This is especially true when making parts for the aerospace industry, which require high quality machining and have complicated tool paths and position for hard-to-machine materials [5]. Therefore, the objective of this paper is to study the impact of tool path strategy on tool wear and surface quality in milling operation.

2. Literature review

Over the past three decades, numerous cutter path techniques have evolved into machining convex and concave surface. They can typically be divided into 3 distinct categories: offset, single-direction raster, and raster. According to Dragomatz and Mann [6], majority of earlier work on CAD/CAM systems in manufacturing concentrated on the geometric aspects of tool path development. One of the tool path strategies is raster strategy. This is an approach in which the cutter traverses the workpiece in the X–Y plane in a back-and-forth motion.The raster strategy causes the cutter to mill alternately in the direction of the spindle and the other way, resulting in up and down milling respectively [7]. Another advantage of using raster strategy is that the

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machining time can be reduced tremendously and much simpler computation can be executed [8]. Offset milling is a process in which the cutter starts at the edge of the face and spirals inward [2]. The biggest factor affecting the quality of machining is how tool wear appears on the tool path, and some representative studies have been conducted in this area. Farhadi et al. [9] conducted a theoretical study on how tool path influences tool wear and proposed a tool path improvement method for slot milling by optimising tool path, which makes tool wear even and improves the consistency of the cutting surface. Liu et al. [5] discussed the impact of tool path and posture on the issue of tool wear; this study makes use of their description of the shapes and postures of the undeformed machining part under various tool paths and postures. A three-dimensional wear matrix ergodic approach is suggested to determine the spatial variation properties of tool wear under arbitrary tool path, posture, and machined surface.

3. Methodology

Using Inventor Autodesk, the final convex shape component is geometrically represented. The DXF format is then used to send the CAD information to the CAM environments. Edge CAM was used as the CAM software for this investigation. After the graphical representation of the machining operation has been processed by CAM, a CNC part programme is generated by means of a part processor. Aluminum workpieces are machined using a ball nose milling tool and a CNC milling machine (in this case, a Bridgeport VMC 530). After each machining test, the tool wear and surface roughness were measured. The flow chart and Table 1.0 below illustrate the experimental planning for this research.

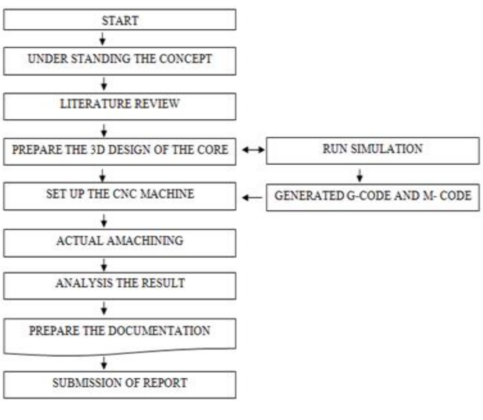


Figure 1.0: Diagram of experimental processes

The preliminary design forms the basis for the trials. All the geometrical forms of the core component are developed using the inventor's software. The Edge Cam Software was utilised to construct the simulation of the machining. All the tool path strategies are investigated using these simulations. Spiral, lace, and concentric are the three distinct approaches to tool path planning that are available. The investigations focused on determining how the three different types of tool path techniques affect the amount of tool wear as well as the surface roughness. For the cutting operation, the feed rate was set to 0.04 mm/tooth and the cutting speed was set to 67.86 m/min.

The tool wear of the cutting tool was measured using a Zeiss Axiotech high-powered optical microscope with image processing. The surface roughness of the machined core component was measured using a Mitutoyo Formtracer CS-5000 surface roughness gauge.

Table 1.0: Experimental setup

Machine	3 Axis Milling Bridgeport VMC 530
Cutting Tool	Ball Nose Milling
Workpieces Material	Aluminium 6061
Tool Path Strategies	1) Spiral method 2) Lace method 3) Concentration method
Milling Mode	1) Climb machining 2) Conventional machining
Feed Rate	0.04 mm per tooth
Cutting Speed	67.86 meter per minute

4. Results and discussion

4.1 Tool wear

Figures 1.2 and 1.3 illustrate the tool wear when machining aluminium 6061 at different tool path strategies. In the figure, it can be seen that during conventional milling using the lace strategy, the flank face of the cutting tool exhibits minor chipping at the flank edge, whereas during climb milling, the flank face exhibits less visible damage for all tool path strategies. This is because conventional milling involves rotating the cutter counterclockwise to the feed direction while simultaneously moving the work piece clockwise. As the cutters move away from the workpieces, the thickness of the chips gradually increases from zero at the start of the cutting process. A previous study by Hadi et al., [10] stated that when the depth of cut, cutting speed, and feed rates increased, the tool wear also increases rapidly when an conventional milling operation was applied during the machining of Inconel 718. Figure 1.3 illustrates severe damage on the chisel edge. This damage may be caused by severe friction during the cutting process. The high heat in the cutting area causes wear on the surface of the tool tip to occur quickly.

Strategy	Conventional	Climb
Concentration		
Spiral		
Lace		

Figure 1.2: Flank wear at different types of tool path strategy

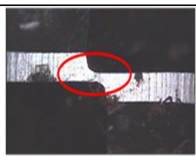
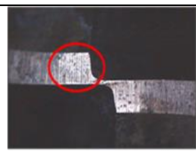
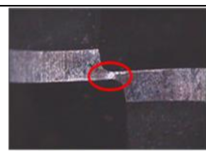
Strategy	Conventional	Climb
Concentration		
Spiral		
Lace		

Figure 1.3: Chisel edge at different types of tool path strategy

4.2 Surface finish

The surface roughness equipment was used to measure the surface roughness of the work piece. A stylus-type profile metre was used to measure the surface. Based on the data presented in Figure 1.4, the lace strategies exhibited higher surface roughness value. The best surface roughness of 5.924 microns is achieved by utilising the spiral strategy using climb machining. When using conventional machining, the higher surface roughness value is 8.817 microns under lace strategies and the lowest surface roughness value is 5.925 microns when using spiral technique. In climb machining, the difference between the highest and lowest surface roughness is 82.6%, whereas for the conventional method, it is 48.8%. Overall, climb machining, which is a part of the spiral strategy, yields good surface quality compared to conventional machining. Based on the results of the surface roughness, it was found that the high value of the surface roughness in conventional machining is due to the damage of the tool tip during the cutting process.

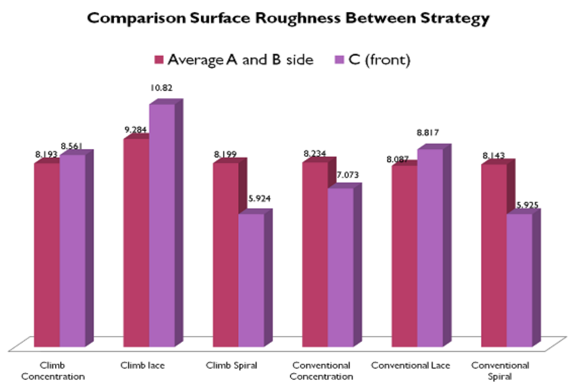


Fig 1.4: Comparison between surface roughness for different strategies

5. Conclusion

Investigations were done into how cutting path strategies affected tool wear and surface finish when machining aluminium 6061. The following conclusions can be drawn from this study:

(i) In climb milling, less damage is visible on the flank face for all tool path strategies, whereas small chipping appeared at the flank edge of the cutting tool during machining using the lace strategy under conventional milling.

(ii) Cutting path strategies impact on the surface finish of the machining of aluminium 6061.

(iii) Spiral cutting path strategy produced the best surface finish on the machining of aluminium 6061 block under climb milling mode and the worst surface finish was recorded when using the lace strategy.

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