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## Effect of High-speed Milling tool path strategies on the surface roughness of Stavax ESR mold insert machining

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**Abstract.** High speed milling is one of the recent technologies used to produce mould inserts due to the need for high surface finish. It is a faster machining process where it uses a small side step and a small down step combined with very high spindle speed and feed rate. In order to effectively use the HSM capabilities, optimizing the tool path strategies and machining parameters is an important issue. In this paper, six different tool path strategies have been investigated on the surface finish and machining time of a rectangular cavities of ESR Stavax material. CAD/CAM application of CATIA V5 machining module for pocket milling of the cavities was used for process planning.

*Keywords:* CAD/CAM, CATIA, High speed machining, Inserts, tool path strategies, Surface finish

### 1.0 Introduction

High speed machining (HSM) is one of the promising technologies which are typical for a reduced machining time by applying a small side and down step combined with a high spindle speed and feed rate. It has been used in the machining processes of moulds and dies which require a high surface finish and geometric accuracy. However, it was only the spindle speed, cutting speed and other cutting parameters that have been the subject of previous researches [1, 2]. Due to the high market demand and competition, mould and die makers are facing the stringy requirement to meet the customers' expectations in terms of surface quality.

Machining Stavax ESR (AISI 420 modified) used for mold insert is a topic of great interest in plastic industries and scientific research [1]. It is a corrosion resistant mold steel, with very good polishability. For example, STAVAX plastic mold stainless steel is one of the mold materials that play an essential role in the forming and shaping processes due to its high hardness, toughness, corrosion resistance, and wear resistance [2]. The precision and the surface quality of the mold are the primary concerns because they directly affect on the appearance of the plastic products.

Main applications can be found as insert material for blow molds inserts with demands on high surface finish and where low maintenance is needed. A high proportion of production costs are involved in machining, as large volumes of metal are generally removed and finishing cuts must meet strict work piece surface roughness and dimensional accuracy requirements. As such, the use of high speed milling (HSM) for the production of moulds and dies is becoming more widespread. Significant advantages of HSM are high metal removal rates, good surface finish since high cutting speed avoids built-up edges, low cutting forces, minimal work piece distortion, labour reduction by unattended machining [3], reduced part counts into a monolithic component, ability to machine thin-walled sections and simple fixturing. Other advantages include product repeatability, improved assembly techniques, comparable

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mass and reduced production costs. To achieve a significant impact on overall machining efficiency and process reliability, the selection of cutting tools, cutter path strategies and machining parameters is critical [4-6].

In a pocket milling there are mainly two tool path strategies called contour parallel and direction parallel which are used to generate some features [6]. The contour parallel tool paths are generated by successive offsets of input profiles whereas, the direction parallel path line segments are parallel to an initially selected reference line. Any of the tool path strategies do have the effect on the machining time, cutting forces, length of tool paths and surface roughness. Due to the need for a high performance machining of free form surfaces with optimized CNC, application of CAD/CAM software has become vital for the design and process planning. In this paper, CATIA software was used for generating the process plan to make a pocket. Three types of tool path strategies were used to study the effect on the surface roughness of the machined surface.

## 2.0 Experimental procedure

### 2.1 Work piece material and tooling

The work piece material used in this experiment was Stavax stainless tool steel. It is a premium grade stainless tool steel with a nominal composition of 0.38% C, 0.9% Si, 0.5% Mn, 13.6.0% Cr, 0.30% V and Fe balance. Prior to milling process, the work piece was wire electro discharge cut in a rectangular shape of 100x60x30 mm<sup>3</sup>. A 4-flute ultra-fine grain solid bulls end mills were used coated with a mono-layer (Al,Ti)N film with a thickness of about 2.5  $\mu$ m. The cutter has a diameter of 6 mm, helix angle of 45 and a radial rake angle of 14.

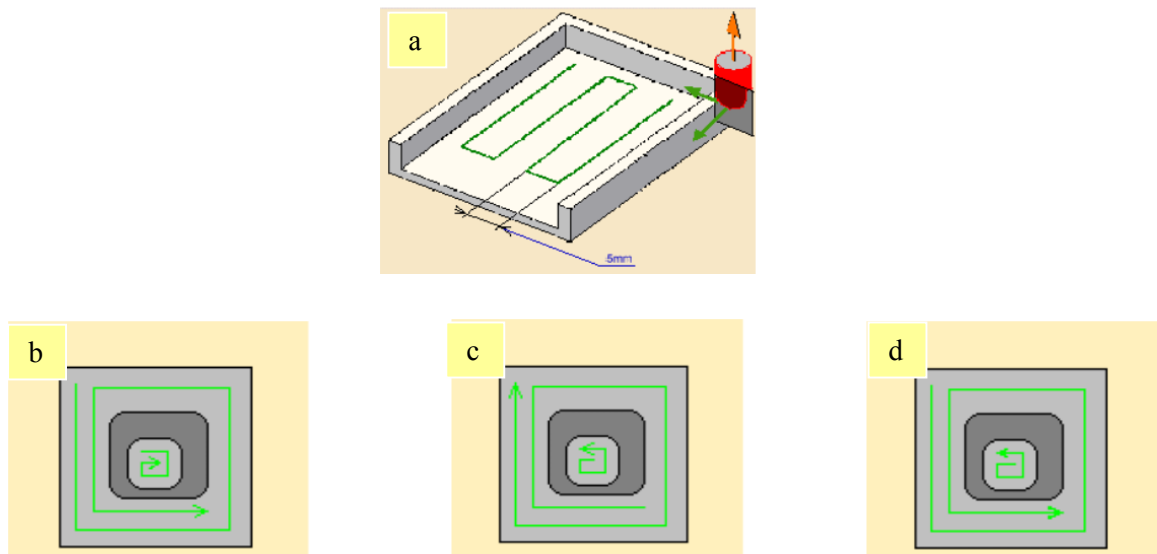
### 2.2 Equipment setup

The experimental studies were performed on a 3-axis vertical prismatic high speed machining centre from Roders RXP 300. This has a continuously variable speed of 200–20,000 rpm with a maximum spindle power of 15 kW and variable feed rates up to 15 m/min. All machining tests were conducted dry. In addition, high-pressure air blast delivered through a nozzle was directed at the cutting zone for all machining tests conducted. For this experiment the spindle, feed rate and depth of cut were fixed at 7196 RPM, 120.88IPM and 0.2 mm respectively. All cutters were checked prior to machining to ensure a tool run out of less than 10  $\mu$ m [6]. These were assessed using a dial indicator with a resolution of 0.001 mm [6].

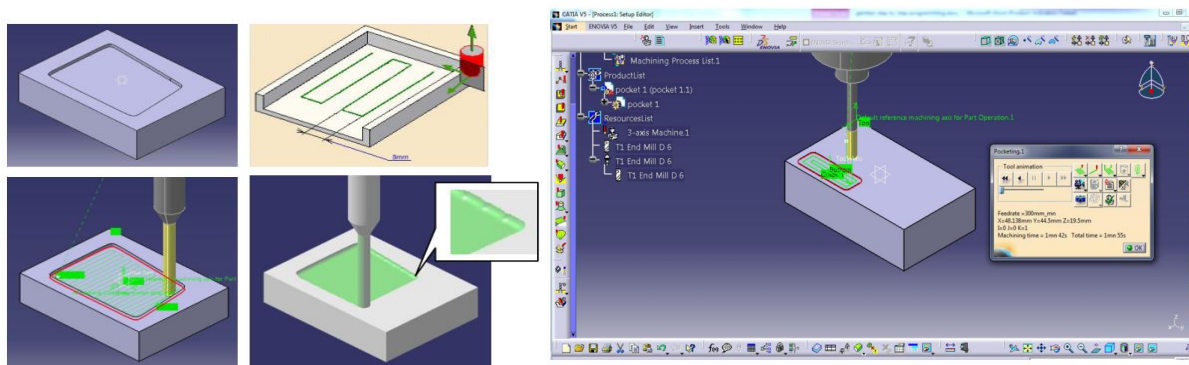
### 2.3 Tool path strategies using CATIA machining workbench

The challenge to the CAD/CAM system is to make passes with very small stepovers at very high feed rates. And this must be accomplished without forcing the tool to make sharp turns, because the look-ahead features of HSM controls will automatically reduce the feed rate when they detect a corner approaching.

In this work, three of the tool path strategies namely; inward helical, outward helical and back and forth was used. Helical or spirall milling as shown in Figure 1a, is a strategy divided into two different way of cutting where in the outward the cutter may start at the center then proceeds spirally outwards. In inward helical as shown in Figure 1b, the cutter starts at the edge of the pocket and proceeds spirally inwards. In back and forth milling as shown in Figure 1c, the cutter draws a zigzag cutter path by moving back and forth across the work piece in the xy plane. The machining planning and tool path selection was used suing CATIA machining work bench as shown in Figure 2.



**Figure 1.** Tool path strategies (a)Back and Forth (b)Inward Helical (c)Outward helical (d) Both Inward and outward helical



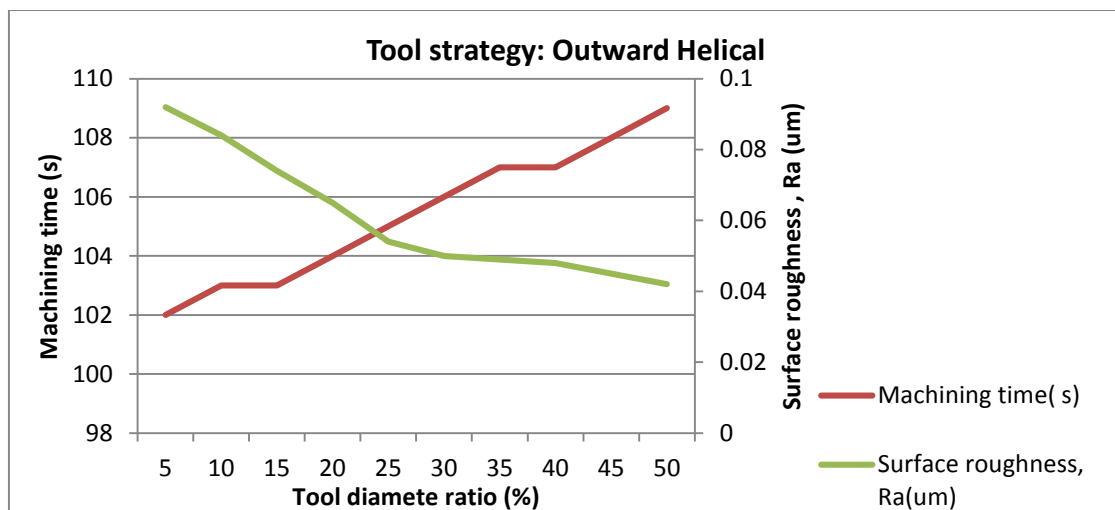
**Figure 2.** Machining simulation using CATIA

One factor at a time (OFAT) approach is a method in design of experiment where all the machining parameters are kept constant and one parameter has been fluctuated from minimum to maximum values. It is very useful in analyzing the optimum condition of parameters, main effect, and the significance of specified parameter to surface integrity. In this experiment for each tool path strategy, kipping the cutting parameters constant, the tool diameter ratio was varied from 5- 50% at five percent interval while the machining time and surface roughens (Ra) was measured.

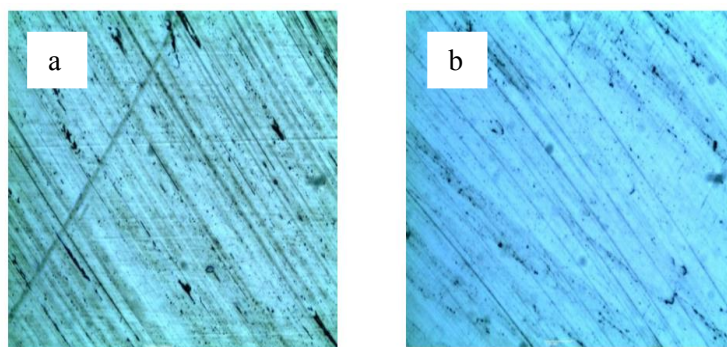
The surface roughness of the machined surface of each specimen was measured using Perthometer ZEISS (SURFCOM 130/480 A). Specimens surface were cleaned before any surface roughness measurement is done. This is because oil sticking on specimen surface may disturb surface roughness reading thus producing wrong surface roughness value. The surface roughness which is measured by the central line average (Ra) was used to assess the surface quality of the machined surface. Each specimen will have three surface roughness values and the average from those three reading was taken. The microstructure of machined surface was viewed also by using a metallurgical microscope. Each specimen is undergoing through this process for each element that are machined for each tool path strategies.

### 3.0 Results and discussion

In die or mold manufacturing, the main purpose of high-speed milling is to reduce or even eliminate manual polishing and reduce the time for surface finish machining. An improved surface finish can be achieved through selection of the best tool path strategy and appropriate tool diameter ratio. Figure 3, 5 and 7 show the change in surface roughness and machining time when used the outward helical tool path strategy. The tool diameter was varied from 5-50% tool diameter ratio so that it covered the whole range of passes during machining. It can be observed that as the tool diameter ratio increased, the surface roughness value decreased and the machining time was increased at high rate. This is due to the fact that, as higher tool diameter ratio removes small size of the surface, cutting forces will be reduced and hence leading to better surface finish. The trade-off between the surface roughness and the machining time was between 20-25% tool diameter ratio. However, as the surface microstructure in Figure 4 of the pockets at the different overlap ratio shown, none of this optimum combination (20-25%) has the better surface. The 40% tool diameter ratio is better smoother than the optimum ranges of tool diameter ratio.

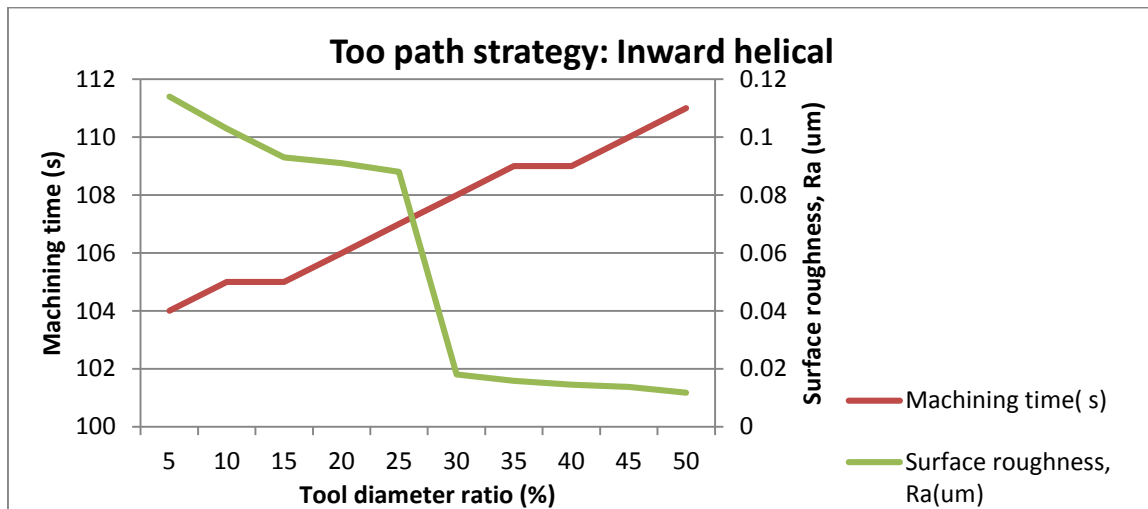


**Figure 3.** Effect of tool diameter ratio on the machining time and surface roughness using the outward helical strategy

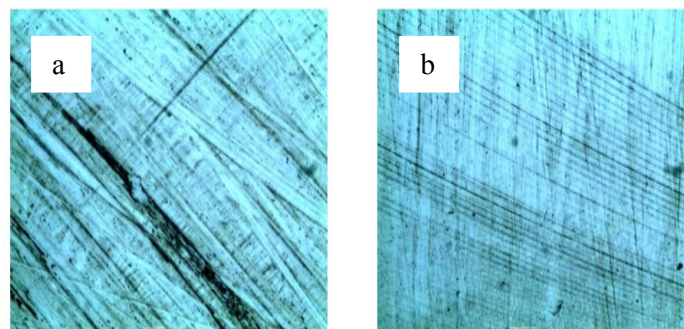


**Figure 4.** Outer surface using optical microscope for the outward helical machined surface  
(a) overlap ratio at 20% (b) overlap ratio at 30%

The effect of inward helical pocketing on the surface finish value and machining time is shown in Figure 5. The trend is the same as the outward helical but the range of the optimum percentage for both machining time and surface roughness is a bit higher of 5-10 percent. Around the same percentage of tool diameter ratio (30%), it showed the lowest surface roughness smoother surface as shown in Figure 6. This phenomena may be due to the constant force applied along the inward direction of the tool path.



**Figure 5.** Effect of tool diameter ratio on the machining time and surface roughness using the inward helical strategy



**Figure 6.** Outer surface using optical microscope for the inward helical machined surface (a) overlap ratio at 20% (b) overlap ratio at 30%

The general trend of the effect of tool path strategy on the surface roughness of the back and forth also showed the same trend as the previous methods. However, the back and forth tool path showed the lowest surface roughness and poor microstructure at any combination of tool diameter ratio compared to the tow methods as shown in Figure 7 and 8 respectively. This is because the back and forth tool path strategy may not create a stable cutting force along the paths.

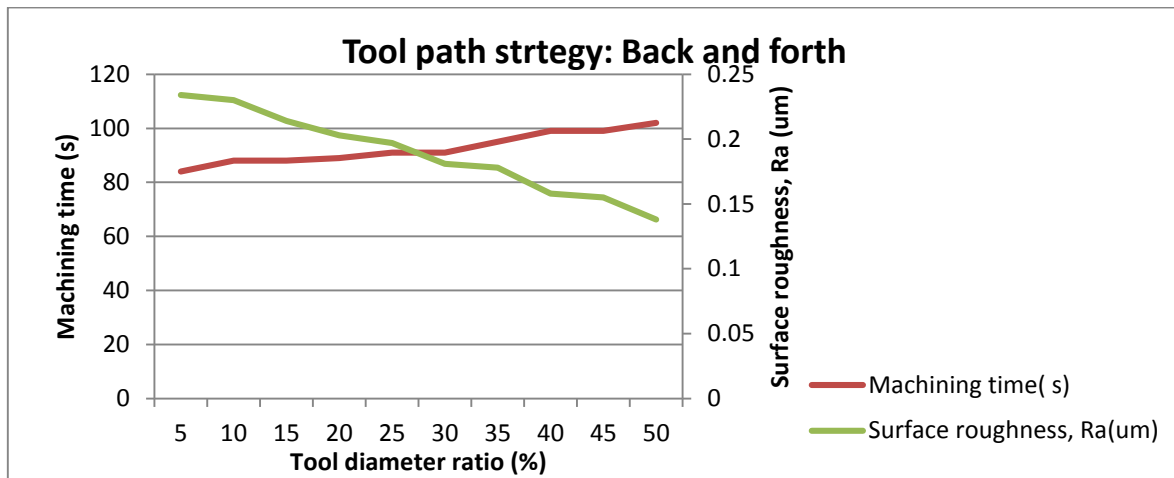


Figure 7. Effect of tool diameter ratio on the machining time and surface roughness using the back and forth strategy

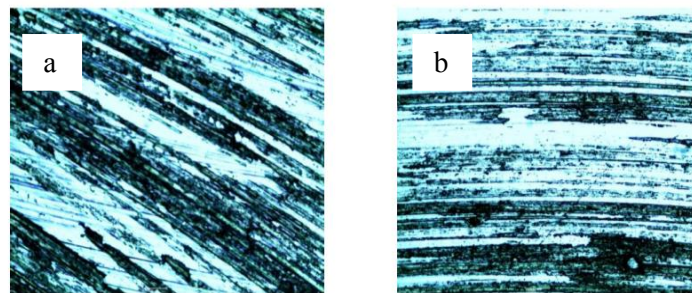


Figure 8. Outer surface using optical microscope for the back and forth machined surface (a) overlap ratio at 20 % (b) overlap ratio at 30%

#### 4.0 Conclusions

From the experiment, it was shown that different tool path strategies, with different tool diameter ration resulted in to different surface roughness values. Using the inward helical, the finest surface roughness was observed better when the tool path ratio was 30%. However, this strategy takes a high amount of time which may incur higher manufacturing cost for the mold inset companies. In moulding industry, the most critical parameter is cavity and core insert of the mold surface finish, hence this experimental work can the indicator for selecting the best surface finish with the type of tool path strategy implemented.

#### Acknowledgment

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