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THE EFFECT OF CUTTER PATH STRATEGIES ON SURFACE ROUGHNESS WHEN MACHINING TITANIUM ALLOY

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Abstract: *The article deals with the comparison and evaluation of finishing cutter path strategies when applied to one of the difficult to cut material such as Ti-alloy. The titanium alloy has been increasingly used for high performance application for oil and gas, aerospace, energy, medical and automotive industries. The importance of milling strategies outgoing from their impact on the economic aspects of production, realized using CNC machines. A planar sample was designed for the purposes of the experiment, enabling finishing cutter path strategies for shaped surfaces. Three cutting strategies were involved and compared- spiral, constant Z and line feed. For assessment of the effect of the cutting strategies three different feed rate were used. Comparison of simulated cutter path strategies and machined surface were visually inspected as well as measured surface roughness were evaluated. The constant Z cutting path strategy was found as suitable cutting strategy from point of view of surface roughness.*
Key words: *3 cutting path strategy, surface roughness, titanium alloy.*

Uticaj strategije putanje alata na hrapavost površine pri mašinskoj obradi legure titanijuma. *Članak se bavi poređenjem i procenom strategija završne putanje alata kada se primenjuju na jedan od materijala koji se teško reže kao što je Ti-legura. Legura titanijuma se sve više koristi za primenu visokih performansi u naftnoj i gasnoj, vazduhoplovnoj, energetskoj, medicinskoj i automobilskoj industriji. Značaj strategije glodanja proizilazi iz njihovog uticaja na ekonomske aspekte proizvodnje, realizovane korišćenjem CNC mašina. Planarni uzorak je dizajniran za potrebe eksperimenta, omogućavajući doradu strategije putanje alata za oblikovane površine. Uključene su i upoređene tri strategije rezanja – spiralna, konstantna Z i linijsko pomicanje. Za procenu efekta strategija rezanja korišćene su tri različite brzine pomaka. Poređenje simuliranih strategija putanje alata i obrađene površine je vizuelno pregledano, kao i procenjena izmerena hrapavost površine. Konstantna Z strategija putanje rezanja je pronađena kao pogodna strategija sa stanovišta hrapavosti površine.*
Ključne reči: *3 strategije putanje rezanja, hrapavost površine, legura titanijuma.*

1. INTRODUCTION

Research on cutter path generation techniques has been plentiful over the past decade. Nevertheless, the implementation of the cutter path techniques has been strictly limited to machining the so-called easy-to-machine workpiece materials. Proper selection of cutter path strategy is crucial for achieving desired machined surfaces [1].

One of the fundamental metal cutting processes is end milling which is very often utilized in various industry.

Surface roughness is one of the most important quality characteristics in the machining. However, surface roughness is also affected by the cutter path strategies. For minimizing the surface roughness, the proper selection of cutter path strategies is very important. Machining with optimum parameters and path strategies will contribute to lower energy consumptions and hence, will lead to lower production costs. This leads to the widespread of applying specific pre-determined machining strategy and product design mainly in the automotive and aerospace industry [2].

One of the current trends is utilization high-strength and metal materials in different designs. A common feature of these materials is difficult to machine. Materials that are difficult to machine and advanced materials such as Ti6Al4V have been increasingly used for high-performance applications in industries such as oil and gas, aerospace, energy, medical, and automotive. These types of material are characterised by factors such as limited tool life, high generated forces, torque, and temperature in the cutting zone caused by low thermal conductivity, as well as chemical reactivity with the cutting tool. In this study different cutting path strategy were chosen and surface roughness were measured and compared for various feed per tooth and tool path strategy, as well as simulated and machined surface topography were compared.

2. METHODOLOGY

2.1 Workpiece and machining process

The machining process was performed on titanium alloy TiAl6V4 due to its widespread application for oil and gas, aerospace, energy, medical and automotive industries. Solid block of Ti alloy with a dimension of 70x70x28 mm was used as the stock was machined into shape as shown in Fig 1 for each cutting path strategy. Solid Works software was used to model the block and assign the cutting path strategies. SolidCAM software was used to generate cutting tool path and the

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appropriate codes which where compactible with the CNC machine controller. Grooves were made by milling on the semi-finished product, creating nine surfaces for the application of finishing cutting path strategies. The cutting path strategies chosen were constant Z, cross linear and spiral. The cutting path strategies that were used for this study were chosen the available strategies from the software commonly used in industry SolidCAM. Machining operation were done by a DMG Mori EcoMill 50equiped with Sinumerik 840D controller. Cutting fluid with 6% of oil content was supplied with high pressure, which helped to remove the chips from the cutting lip and avoid built-up edge formation as well as minimise heat generation in the share zone (cutting tool/work piece interface), where high mechanical and thermal loading occurs. When machining Ti and its alloys, the contact length between the chip and tool is extremely short (less than one-third of the contact length of steel with the same feed rate and depth of cut [3]. This implies that the high cutting temperature and stress are simultaneously concentrated near the cutting edge (within 0.5 mm) [4].

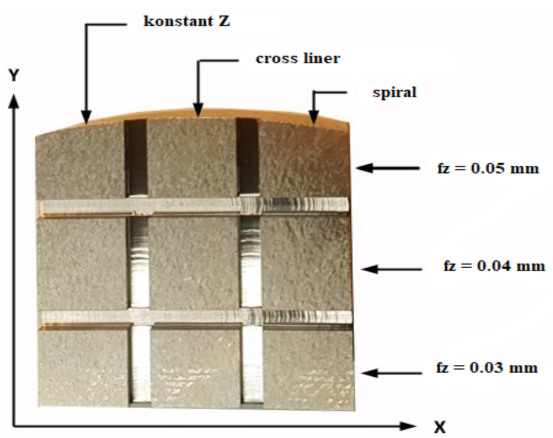


Fig. 1. View on work-piece with used cutter path strategies and feed per tooth

Cutting tools – a 3–fluted ball-nose end-mills - applied in experiments with diameter of 8 mm were from tungsten carbide type WC/Co, S type, suitable for machining of titanium alloys, Fig. 2.

Fig. 2. Ball-nose end mill cutter used in machining

Experiment were performed using constant cutting speed 100 m/min, depth of cut 0.3 mm and three feed per tooth 0.03 mm, 0.04 mm and 0.05 mm. Cutting parameters were chosen according to cutting tool producer recommendation.

2.2 Cutting path strategies design

Figures 3, 4 and 5 show schematic of cutting path strategies used in this study. The cutting path strategies chosen were constant Z, cross liner and spiral These strategies are recommended for shaped surface finishing (concave or convex). Flat work piece was inclined by 45 degrees around the X axis of the machine tool coordinate system. To avoid that ball-nose end mill center will not be in contact with the work piece at a zero resp. low cutting speed. Fig. 3 shows cutting path strategy constant Z.

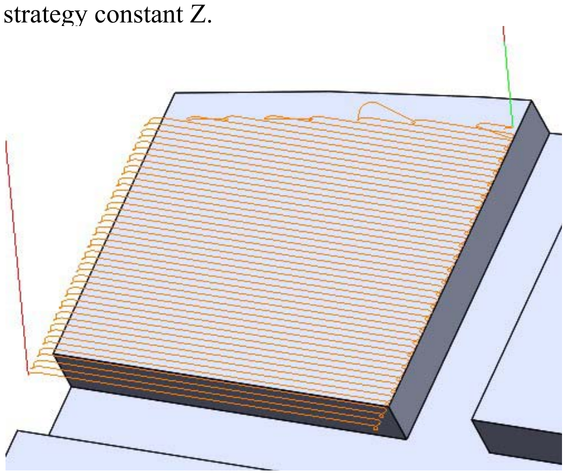


Fig. 3. The cutting path strategy: constant Z

The path is parallel with the X axis of machine tool coordinate system and the minimal occurrence of non-productive pathways without cutting is detectable.
Fig. 4 shows cutting path strategy cross liner. In this strategy, liner was chosen with the additional option completion to cross. The basic strategy generates parallel paths in the selected direction and the choice to cross will ensure the generation of the second set of tracks in a direction rotated by 90 °. The surface is in this case, passed the tool twice. Even with this strategy, the occurrence of non-productive tool path is minimized.

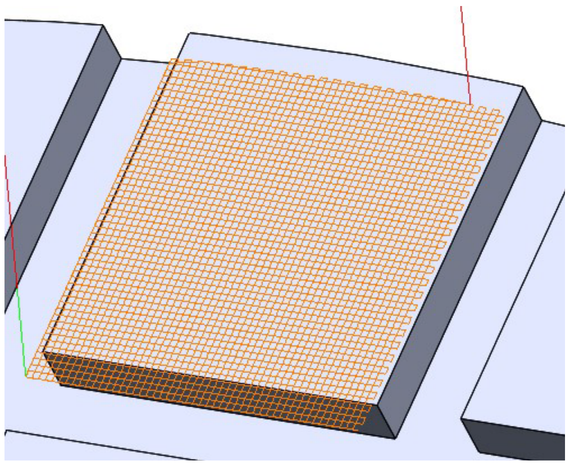


Fig. 4. Cutting path strategy: cross liner

The third strategy considered is the spiral, see Fig 5. Its advantage is a continuous uninterrupted cut at suitable shape of the machined surface. Usually spiral milling is a strategy where the cutter may start at the center of the surface and then proceeds spirally outwards. The cuter recurs to the starting point in each cycle and then cuts outwards to the next outer cycle. On the other hand, at rectangular shape, the cut is interrupted at the edge of the surface, then the tool is raised above the surface, it is moved and starts at the beginning of the next path element. The consequence is a high incidence of non-productive tool pathways.

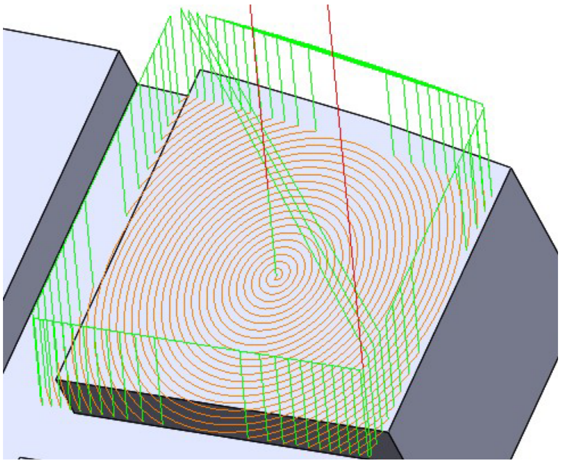


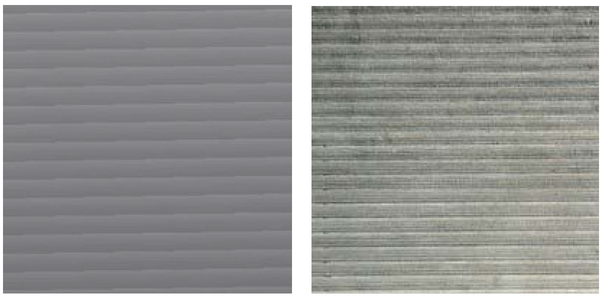
Fig. 5. The cutting path strategy: spiral

The high of scallops (SH) defined by the CAM programmer controlling was set constant: SH = 0.005 mm for all used strategies.

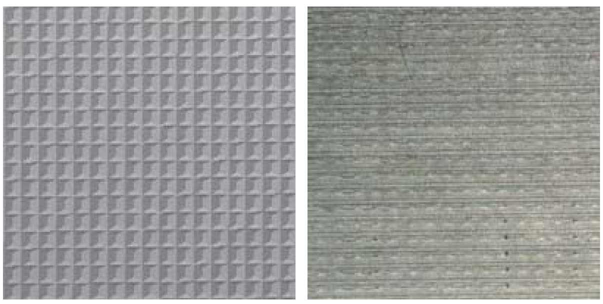
3. RESULTS AND DISCUSSION

3.1 Comparison of simulated and machined surface

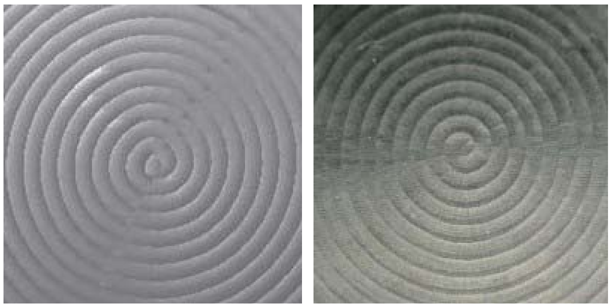
The surface texture was documented using an optical microscope. Surface texture was visually compared to the virtual machined surface simulated in the system SolidCAM. The comparison for the Constant Z strategy is Fig. 6a. Traces of the tool are visible in the distance selected by the programming system based on the specified SH. Fig- 6b and 6c show simulated and real machined surface for cross liner strategy and spiral, respectively.



a)



b)



c)

Fig. 6. Comparison of simulated (left side) and machined surface texture for cutting path a) constant Z b) cross liner and c) spiral

3.2 Measuring surface roughness

All machined surfaces were tested using Mitutoyo SJ-301 Surftest surface roughness testing equipment. The test includes testing the surface roughness travelling distance direction along both x-axis and y-axis of the surface, see Fig.1. The surface profile of each test was compared and the average surface profile Ra and Rz for each cutting path strategy was obtained and compared.

Influence of feed per tooth was compared. Average Ra and Rz was calculated from 3 measurements in each direction. Fig. 7, 8, 9 and 10 show relation among tool path strategy and feed per tooth in x and y directions.

In Fig. 7 the Ra value in y-axis direction for spiral strategy is smaller than for constant Z for all used feed. However, comparing with x-axis direction measurement the best roughness Ra is for constant Z strategy against spiral one, Fig 8. Again, the clear dependence of the feed on roughness was not confirmed.

The same results can be concluded for surface roughness Rz, see Fig. 9 and 10. Again, the best Rz was for constant Z strategy in x-axis directions on the other hand, in y-axis direction the spiral strategy show better result than other two strategies.

Comparing influence of feed per tooth on surface roughness quality the lowest Ra was observed for feed 0.4 mm for each used tool path strategy.

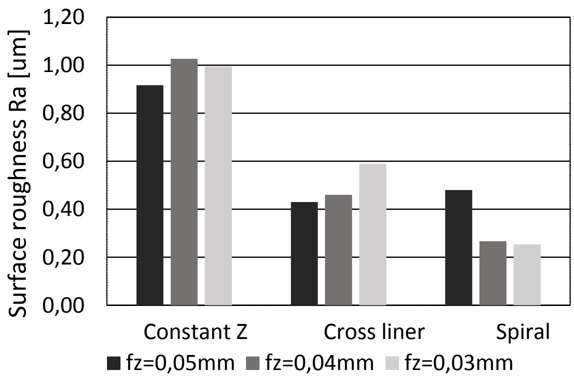


Fig. 7. The roughness Ra for each cutting strategy and various feed per tooth in Y-axis direction

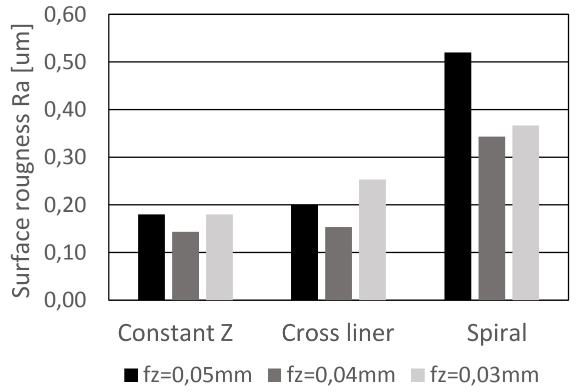


Fig. 8. The roughness Ra for each cutting strategy and various feed per tooth in X-axis direction

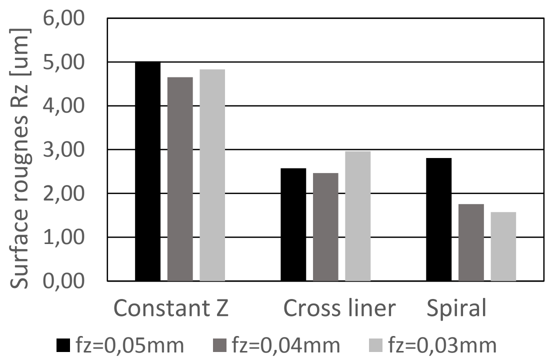


Fig. 9. The roughness Rz for each cutting strategy and various feed per tooth in Y-axis direction

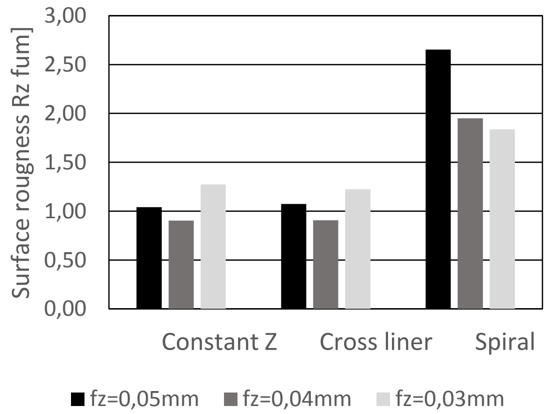


Fig. 10. The roughness Rz for each cutting strategy and various feed per tooth in X-axis direction

4. CONCLUSIONS

The effect of cutting path strategies on surface finish roughness when milling Ti alloy were investigated. In this study, the following points can be concluded:

- Cutting path strategies do influence the surface finish of the surface of titanium alloy.
- Evaluations of surface roughness were not confirmed clear rule that with decreasing of feed surface roughness decease too.
- The lowest value of Ra roughness was observed for feed 0.4 mm for each used tool path strategy.
- From the above results, it is not possible to state clearly the advantages of the used strategies from the point of view of achieving surface roughness.

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