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GENERATING AND CHARACTERISTIC OF SURFACES IN MECHANICAL MACHINING OF MICRO-PARTS

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Abstract: *Development of micro-devices parts is intensified with developments in medical device and energetic industry. In production of micro-parts (micro-pump, micro-gears, micro-manipulators, etc.), a wide range of engineering materials is encountered. Strict requirements are set in terms of characteristic of micro-parts machined surfaces, such are low surface roughness, advanced tribological characteristic, etc. In this paper is analysed possibilities of different metallic materials mechanical micro-machining. The analysis includes the analysis of the generating and characteristics of the machined surfaces, and influence of a whole set of parameters on surface characteristic. The results showed the benefits of mechanical micro-machining and proved that it can achieve satisfactory results of the surface characteristics indicators.*

Keywords: *micro-parts, surfaces, machining, analysing*

1. INTRODUCTION

Micro-parts surface characteristic is the important properties regard to its functionality. The big problem in production of micro-parts is getting the appropriate machined surface roughness, because there are disproportion in range between dimensions, tolerations and surface roughness parameters. Industry of micro-devices and micro-parts is in expansion with growth of energetic sector, medical sector and automotive and aero industry. There are many mechanical and thermal methods for machining surface on metallic micro-parts, such are: laser beam machining, electro-discharge machining, forming, cutting, grinding, casting, and etc. Each of them have advantages and disadvantages.

In cutting technology, as mechanical method for production of metallic micro-parts, mains problem is caused by size effect. Size effect is caused by ratio between process parameters, tool geometry, workpiece structure and mechanical properties (Fig. 1).

Micro-milling, as mechanical micro-cutting technology, is increasingly used in tool and die industry because it can produce complex geometry with high-dimensional accuracy. Process of micro-cutting is done in range of elasticity of workpiece materials, which results in ploughing and sliding. This phenomena has big influence on generation and surface roughness on micro-parts. In this paper is analysed influence of different process parameters and workpiece properties on surface characteristic. Focus is on metallic materials such micro-milling of chromium-molybdenum tool steel AISI D2 (for production of mold and die) and Inconel 718 (for production of functional temperature loaded mechanical parts).

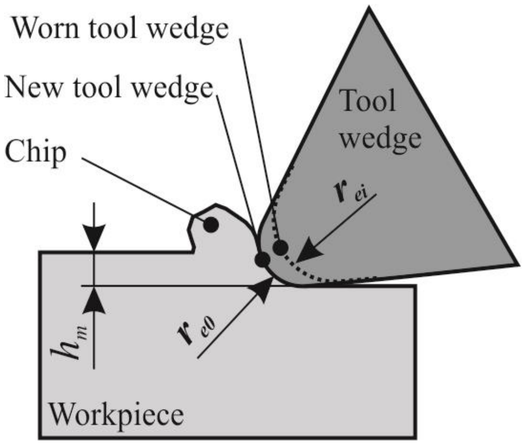

Figure 1. Size effect in mechanical machining

Bissasco et al. [1] analysed influence of tool geometric characteristics on surface roughness, in micro-milling of martensitic stainless steel, due the size effect. Aramcharoen et al. [2] analysed influence of size effect in micro-milling of hardened tool steel H13. Li [3] analysed tool wear and surface roughness in micro milling of SKD 61 steel (38 HRC), under different lubrication condition. They improved machinability by using MQL. Lee et al. [4], analyzed influence of cutting parameters on surface roughness and burrs. Based on experimental research, it was shown that the appropriate choice of parameters can reduce the surface roughness, and burrs on workpiece edge also. Similar studies are shown in [5]. In studies [6, 7] by Ucun et al., was investigated effect of cutting parameters, coating material and the built-up edge on the surface roughness in micro-milling of Inconel 718. They are concluded that coated tools are given better surface roughness performance. Kuram et al. [8] investigated the influences of cutting parameters on surface roughness and cutting forces, in micro-milling of Ti6Al4V alloy and Inconel 718. Lu et al. [9], analyzed the influencing of cutting condition and tool coats on output parameters in micro-milling of Inconel 718. Vazquez et al. [10] investegated influence of cooling and lubrication techniques in micro-milling of special alloy.

2. EXPERIMENTATION

Experiment measurement was performed on the tree axis high speed micro-milling centre Sodick MC430L (Figure 2) with hybrid bearing high speed spindle (maximum revolution 40.000 min^{-1}). The linear machine motors has resolution of 100 nm and accelerate up to 1 G. Machine is equipped MQL system. Cutting tool was two flute flat-end-mill by SECO, TiAlN layer coated. It has diameter is 600 µm, corner radius 0.05 mm, neck 8 mm and mounting diameter is 3 mm. Helix revolution angle is 7.25°, height 0.8 mm.

Figure 2. Experimental setup

In this analyse research was used two different workpiece materials. First, nickel-chromium based Inconel 718 supper-alloy, was used. This oxidation and high temperature resistant super-alloy has tensile strength 1350 MPa and hardness 40 HRc. Second workpiece material was cold work tool steel AISI D2, hardened to 62 HRC, with tensile strength 1100 MPa. Both materials are intended for micro-parts exposed to high temperature and mechanical loads.

Surface roughness was measured with optical 3D non-contact measuring device ALICONA InfiniteFocus (Figure 3). Measurement was based on photo recording of horizontal layers for every 10 nm, recognized the sharpest parts of captured image, and proceed the 3D micro-surface relief (Figure 4).

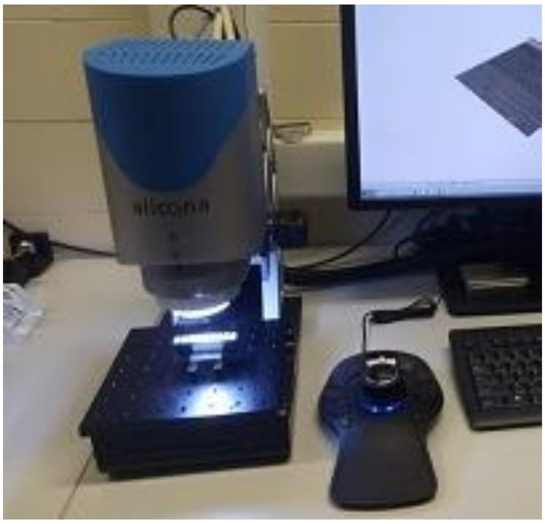

Figure 3. ALICONA measuring device

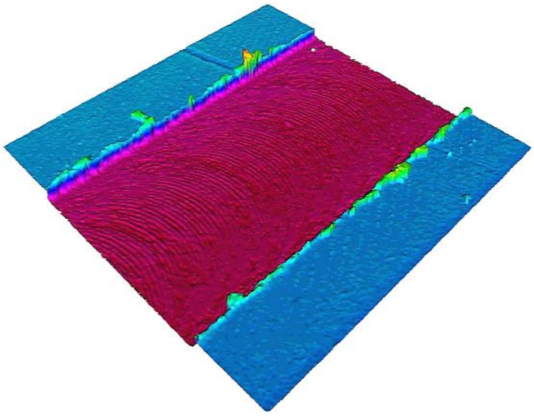

Figure 4. Formed measurable 3D model of micro-surface relief

Experiment was performed under MQL condition of lubricating. For all experiments cutting speed was v_c = 40 m/min. Other cutting parameters range was adopted by cutting tool manufactures.

3. RESULTS AND DISSCUSIONS

On Figure 5 is shown 3D scans of micro-machined channel in Inconel 718. On the same figure, on picture a) is shown relief of microchannel milled by use feed per tooth f_z = 0.012 mm and depth a_p = 0.01 mm, and b) micro-milled surface by same feed but depth a_p = 0.02 mm. Can be noted differences in generated surface on channel bottom. On bottoms can be noted cutting tool trace, and build-up edge on channel side. Height of build-up edge is higher on side where micro-mill cutter exits outside the channel. Also, can be concluded that generated surface is more plunged for higher values of cutting depth. Along channel, more intensive plunging of the workpiece material occurred at the entrance and exit of the milling micro-tool teeth. The reason for this is the reduction in the chip cross-section, which has the result of dominating the size effect. This phenomenon is caused by proportions of the thickness of the affected workpiece material by cutting wedge and cutting wedge radius, because edge is not ideal sharp. In this paper, follow up analysing of the parameters that describing the condition of the generated surface, such as the surface roughness and height of build on edge.

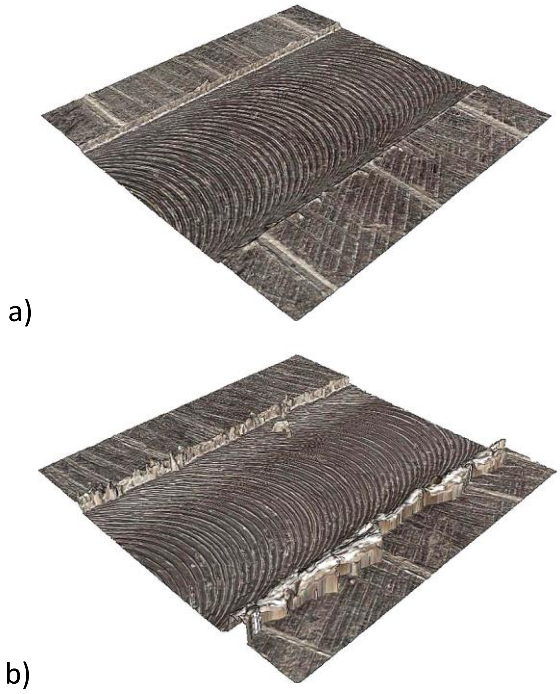

Figure 5. Scanned channel in Inconel 718

For both workpiece material is analysed the average surface roughness (R_a) and mean peak to valley height in ten points of roughness profile (R_z). This two surface roughness parameters was measured on four different points in each channel, after which their mean value was calculated. On each measuring point in channel, reference length was set along the channel.

On Figure 6 is shown influence of feed and depth of cutting on surface roughness parameters in micro-milling of Inconel 718. Can be concluded that surface roughness increase with increase of cutting parameters, except for set of lower cutting parameter values. High values of surface roughness for lower values of depth of cutting and feed were caused by phenomenon of size effect. In that case, values of feed wasn't provide a sufficient value of minimum chip cross-section that can be removed by cutting tool wedge. Similar conclusions can be obtained for the values of R_z (Figure 7).

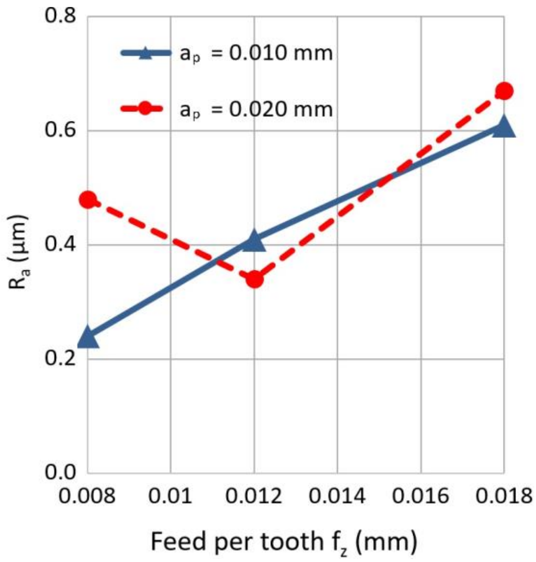

Figure 6. Average surface roughness (Ra) for Inconel 718

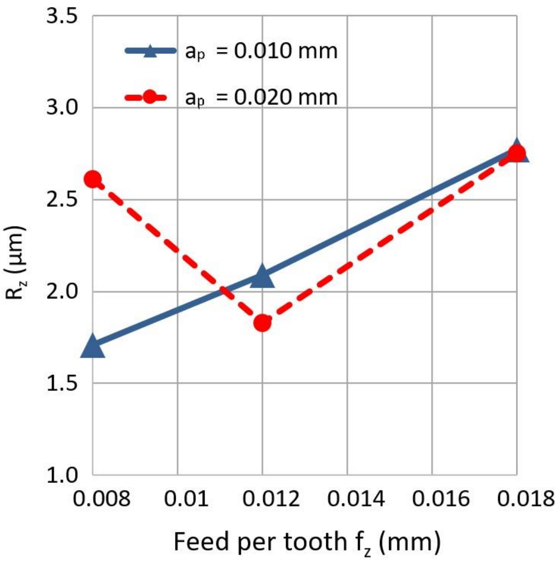

Figure 7. Average surface roughness in ten points (R_z) for Inconel 718

Based on graphs can be concluded that surface roughness parameters intensively increase with changing of feed, while the changing of depth of cutting leads to less change in values of surface roughness parameters. This variation of values is intensively for parameter R_a relative to parameter R_z.

On Figures 8 and 9 is shown values of surface roughness parameters after micro-milling of AISI D2. Can be concluded that R_a and R_z increase with increasing of feed and depth of cutting.

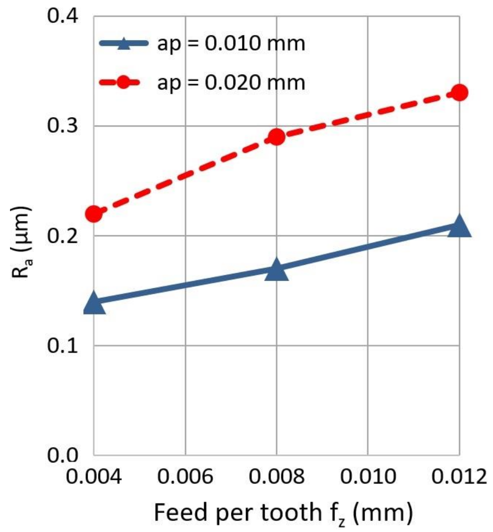

Figure 8. Average surface roughness (Ra) for AISI D2

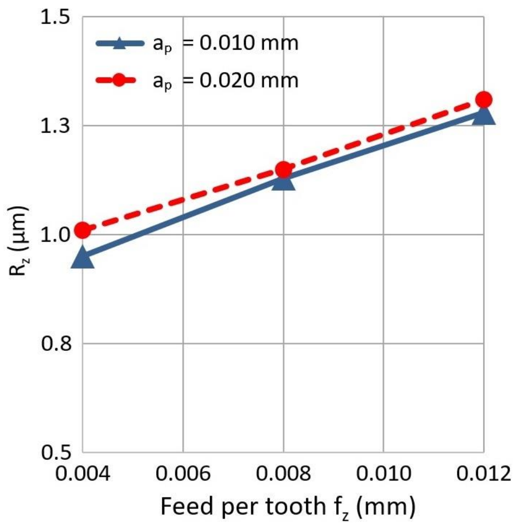

Figure 9. Average surface roughness in ten points (R_z) for AISI D2

In the case of micro-milling of AISI D2, fluctuations in the values of the surface roughness parameter at the lower values of feed are absent. Based on graphs can be concluded similar finding for this material. Values of both surface roughness parameters increase with increasing of depth of cutting and feed. In case of micro-milling of AISI D2, parameter R_a intensively increase with depth of cutting changing, while increasing of feed leads to relative lower increasing of R_a.

On Figure 10 is shown comparison of R_z parameters for different cutting conditions and different workpiece materials. Can be conclude that during micro-milling of AISI D2 obtained relative lower values of surface roughness than Inconel 718. The reason for this is a smaller workpiece material grain size, thereby avoiding the effect of the size effect and material ploughing.

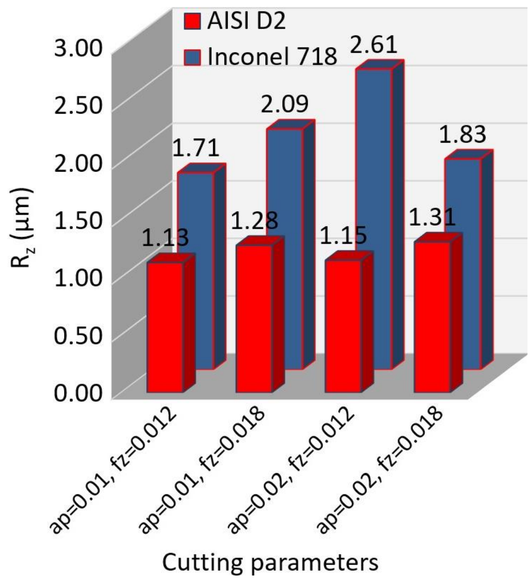

Figure 10. Surface roughness parameters for different workpiece materials

Variation of surface roughness during micro-milling, for different cutting condition and different material is shown on Figure 11.

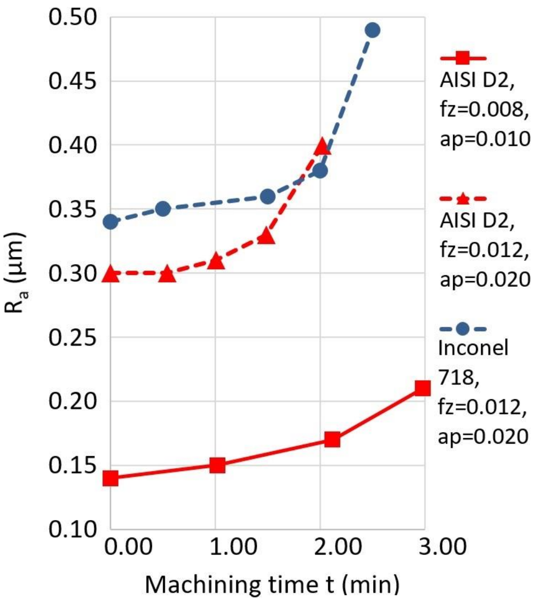

Figure 11. Increasing of surface roughness parameters during machining

Based on graph, can be concluded that surface roughness increases during machining time. Using of higher cutting parameters values leads to intensive tool wedge wear, and relative intensive decreasing of surface roughness. Increasing of surface roughness is results of intensive workpiece material ploughing, which caused with size effect. In that case, cutting tool tip was worn and its measure reaches values of minimal chip thickness.

Build up edge participates in the evaluation of the functionality of micro-part. For both materials height of build-up edge (B_w) was measured in for different points along channel, on its edge vertical side, where micro-milling tool tooth leaves the channel. Different points of measuring were coincided with the surface roughness measurement points. After evaluation, an arithmetic mean of heights was found.

On Figure 12 is shown values of build-up edge height (B_w) for different materials and cutting condition. Based on graph can be concluded that values of B_w increase with increasing of depth of cutting and feed. More intensive growth occurs with increasing of depth of cutting. Comparing the values for different materials, it is clearly noticed that there are higher values when micro-milling of AISI D2. Reason for this is relative higher tough of this material.

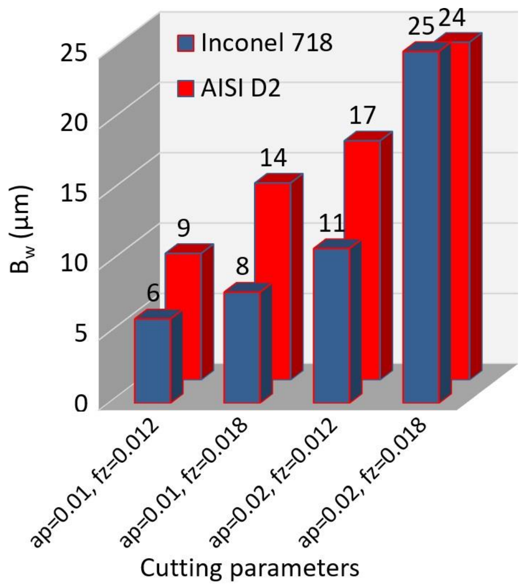

Figure 12. Built up edge for different workpiece materials

4. CONCLUSION

In this paper is presented study on characteristic of mechanical micro-machined surface for high alloyed metallic materials: AISI D2 hardened steel and nickel-chromium alloy Inconel 718. Both of workpiece materials are intended for production of high mechanical and temperature loaded micro-parts (micro-die, micro-pumps, micro-gears, etc.).

Generally, based on the presented research, can be concluded that micro-milling with, as mechanical process, can be used in production of micro-parts with very high surface quality. During micro-milling of AISI D2 obtained lower surface roughness, but during micro-milling of Inconel 718 obtained lower built-up edge high on workpiece. Greater impact on increasing of surface roughness, in micro-milling of Inconel 718, has feed. Greater impact on increasing of surface roughness, in micro-milling AISI D2, has depth of cutting. In fact, in micro-milling of Inconel 718, minimal values of analyzed surface roughness parameters R_a = 0.24 µm and R_z = 1.71 µm was reached with a_p = 0.010 mm and f_z = 0.008 mm. In micro-milling of AISI D2, for same cutting parameters, reached values of analyzed surface roughness parameters was R_a = 0.17 µm and R_z = 1.13 µm.

In future, will be performed additional research on mechanical micro-processing of different engineering materials. Aim of this research is development of database of adopted cutting condition in flexible micro-production of geometry complex, high quality and ultra-precision micro-parts.

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