

STUDY OF THE INFLUENCE OF AXIAL CONTACT POINTS ON THE ROUGHNESS OF END-MILLED SURFACE

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Abstract: Milling is usually one of the initial and basic operations of the manufacturing process. Although the surface quality obtained by this method has been greatly improved over time, its improvement remains an important task. This article analyses results of an experimental study of the influence of cutting data on surface quality during boss milling operation. 7075 aluminium alloy was machined. A solid carbide DLC coated end mill was used. Stability of the milling process was analysed by optimal values of axial depth of cut using the axial contact points (ACP) method. Arithmetic average roughness parameter R_a was measured both in direction parallel and perpendicular to the feed direction. It is established that surface roughness parameter R_a decreases with increase of ACP value.

Keywords: end milling, surface roughness, aluminium alloy, axial contact points, axial depth of cut.

1 INTRODUCTION

Manufacturing parts require obtaining certain dimensions, tolerances, and surface finishes. Even though the technologies nowadays get more and more advanced and new kind of manufacturing techniques were created such as laser cutting, waterjet cutting, ultrasonic, electrical discharge machining (EDM), 3D printing, and many more, milling is still one of the most commonly employed manufacturing operations in industry because of its flexibility and potential to produce high quality parts (Koca, 2012; Ozkirimli, 2011).

Using the conventional machine tools operated by humans introduces human errors, the part quality highly depends on operator's experience and overall machine precision is relatively low. Moreover, more and more complex parts are required, which cannot be machining using the conventional machine tools. That's why nowadays machines are controlled using CNC (Computer Numerical Control), which provides an incredible accuracy, repeatability and allows to machine very complex parts with extreme precision. This kind of machines are known for rigidity and very efficient for mass manufacturing since one part program can be used repeatedly to produce exact same parts every time without human errors. Although, they must be programmed accordingly. All the cutting data, tools and their movements must be selected and programmed by humans. That's why a lot of test runs is required to reach the best results and produce the most

consistent and precise parts. However, despite the high rigidity of the CNC machine tools, the rigidity of the tool is not always sufficient, which leads to vibrations and degraded quality of machined surface.

Cutting force is one of the main factors that affect the performance of the milling process, tool life, and quality of machined surface (Kull Neto et al., 2016). Cutting force is related to tool wear, surface roughness, and tool deflection, which may cause dimensional errors of up to 100 μm depending on the tool and toolholder stiffness (Kull Neto et al., 2016). Large cutting forces are often a constraining factor for improving productivity as they increase tool wear and deflection force (Savilov et al., 2021). For this reason, many authors have studied cutting forces in the milling cutting process. According to Kecelj et al. (2004), the main problem with roughness of the machined surface in the finish milling of cavities using long mills with high length-to-diameter ratio occurs near vertical walls, where the radial force is higher and tool deflection affects the surface roughness and dimensional accuracy of the part. According to the authors (Salgado et al., 2005) whose studied correlation between rigidity of the tool and its deflection in the finish milling of complex shapes of molds and dies using ball nose end mills, in stable conditions, tool deflection can be calculated in the same way as for a cantilever beam subjected to a force at its extremity.

In order to improve quality of milled surface and optimize process parameters, it is very important to study the formation mechanism of machined surface topography and achieve accurate surface topography prediction. In recent years, researchers have carried out relevant numerical and experimental studies on the milled surface topography, and carried out optimization of cutting parameters (Xu et al., 2023).

The ACP (Axial Contact Points) method is the one of the effective technological vibration suppression methods (Savilov et al., 2021; Mueller, 2022; iMachining for NX presentation, 2023). According to it, the optimal number of contact points of the tool and the material machined should be achieved. The number of ACP is calculated as the ratio of axial cutting depth to the spiral pitch of the end mill. ACP method does not strictly regulate other cutting parameters, such as feed per tooth and cutting speed and is efficient for end milling with large axial cutting depth (Savilov et al., 2021). An analysis of numerical and experimental studies of the end milling processes shows that the milling method with an optimal value of the ACP is understudied (Savilov et al., 2021; Nikitenko et al., 2021).

Some CAM (Computer Aided Manufacturing) systems provide recommendations for optimal ACP values, which can reduce vibrations and improve cutting conditions (iMachining for NX presentation, 2023; Dudukovic & Ogrizovic, 2013). In a favorable zone, more aggressive cutting modes can be selected without increasing the level of vibrations. However, CAM systems take into account only geometric aspects of this method and ignore features of a specific technological system and materials being machined (Nikitenko et al., 2021). Thus, it is necessary to evaluate the effectiveness of vibration reduction methods in specific technological situations (Nikitenko et al., 2021).

This article aims to study the influence of axial cutting depth on the roughness of end milled surface. In this work the emphasis is made to evaluate how axial contact points influence surface quality of the part machined.

2 MATERIALS AND METHODS

The block with dimensions 78×78×39 mm (Figure 1) made from aluminium 7075 T6 grade was machined to evaluate the ACP (axial contact points) influence on the quality of milled surface.

ACP in milling reflect the number of contact points the tool has with the vertical wall when it cuts, measured along a vertical line (Figure 2). The axial contact points are the areas where the cutting

edges engage with the workpiece, creating the cut. These contact points are critical to the milling process, as they determine the depth and width of the cuts made by the end mill.

Figure 2 presents a scheme of boss milling operation. The red dots roughly indicate where contact with the workpiece takes place.

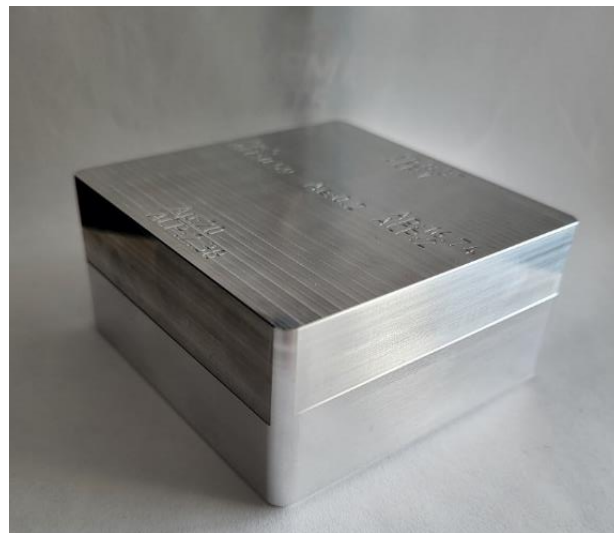


Fig. 1 Machined aluminium block

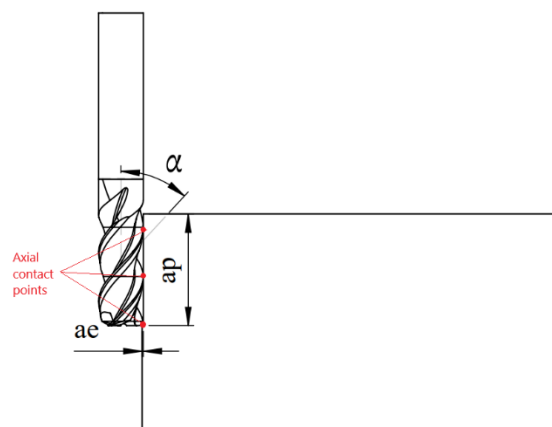


Fig. 2 Scheme of the boss milling with axial contact points indicated (a_p is the axial depth of cut, a_e is the radial depth of cut, α is the flute helix angle)

To calculate number of ACP, the following formula is used:

$$ACP = \frac{za_p}{P} \quad (1)$$

where: z is the number of cutting edges; a_p is the axial cutting depth, mm; P is the teeth pitch, mm.

Datron Neo high-speed CNC milling machine was used in all the experiments.

Standard 3-flute coated carbide end mill was chosen to machine aluminum alloy. When machining aluminum, it is best to use end mills that have a sharp cutting edge and a high helix angle, such as those made from high-speed steel or carbide. These types of end mills cut more

efficiently and produce a better surface finish on the aluminum surface. Geometrical parameters of the end mill are presented in Figure 3a and described in Table 1. Image of the tool is presented in Figure 3b.

Cutting part of the end mill was coated with DLC coating. DLC, or Diamond-Like Carbon, is a hard, amorphous carbon that is often applied on end mills, which are used in various machining operations. The DLC coating is applied to the

surface of the end mill using a process called Physical Vapor Deposition (PVD).

The parts after milling process were cleaned and deburred to avoid any contaminants and sharp corners for accuracy and safety.

In all the cases we used profilometer SJ-410 from Mitutoyo to measure the arithmetic average roughness parameter Ra. This equipment is shown in Figure 4.

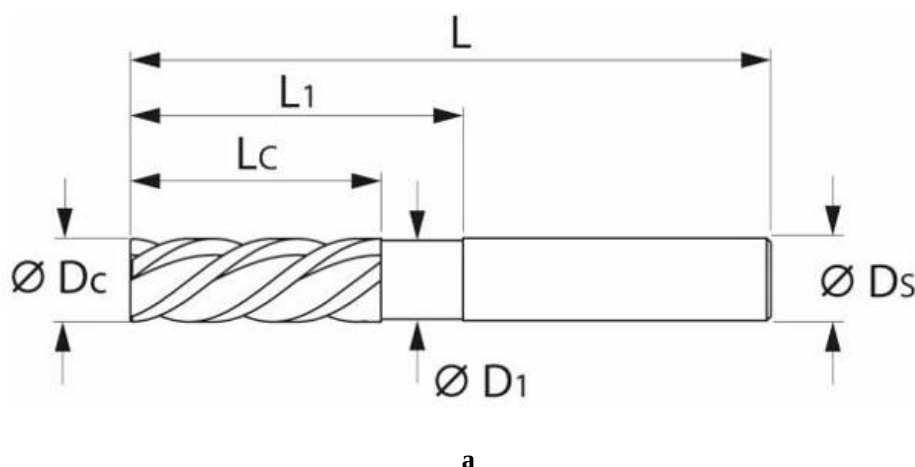


Fig. 3 Sketch (a) and image (b) of the end mill used to machine a vertical wall

Table 1. Geometrical parameters of the end mill used (Figure 3a)

Dc, mm	D1, mm	Ds, mm	Lc, mm	L1, mm	L, mm	Number of flutes z	Helix angle $\alpha, ^\circ$	Pitch P, mm
8	7.4	8	21	25	63	3	45	25.13



Fig. 4 Mitutoyo profilometer model SJ-410

To get more accurate results, several measurements at different places were taken. In

this case 6 spots at different heights and places were chosen (Figure 5). Then results were averaged. In the first case, the roughness measuring direction was parallel with tool feed direction as it is shown in Figure 5a. It means the measuring stylus was moved same direction as the part was being machined with end mill.

In the second case, measurement direction was changed to the perpendicular (Figure 5b). It means that roughness was measured in direction from the bottom of the wall towards the top. The measurement scheme for this case is presented in Figure 5b.

Axial cutting depths and ACP calculated according formula (1) and used in experiments are presented in Table 2.

Other cutting data selected or calculated according to the tool manufacturer recommendations is presented in Table 3

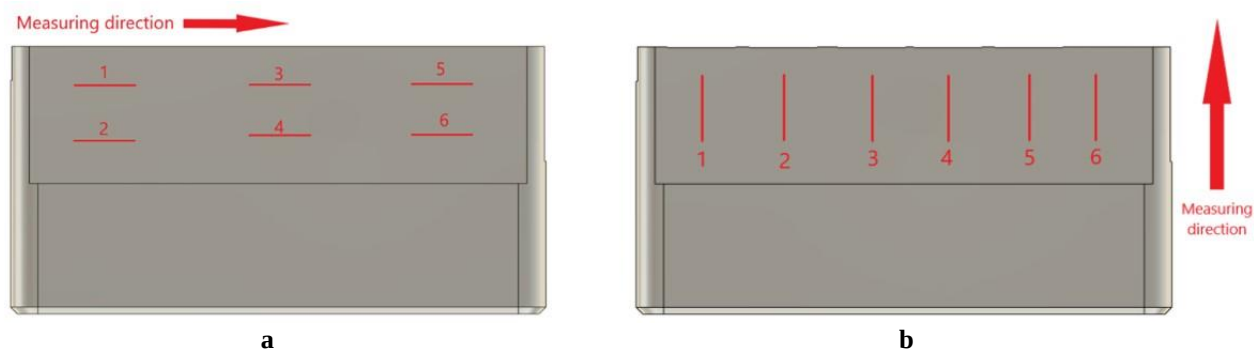


Fig. 5 Surface roughness measurement scheme: a – horizontal direction (parallel to the feed direction); b – vertical direction (perpendicular to the feed direction)

Table 2. Axial depth of cut according to ACP

Experiment Nr.	a_p (Figure 2), mm	ACP
1	5	0.59
2	8.37	1
3	16.74	2
4	20	2.38

Table 3. Parameters for test cuts

Experiment Nr.	Surface speed, m/min	Feed rate, mm/min	Axial depth of cut, mm	Radial depth of cut, mm	Tool overhang, mm
1	400	1500	5	0.2	31
2	400	1500	8.37	0.2	31
3	400	1500	16.74	0.2	31
4	400	1500	20	0.2	31

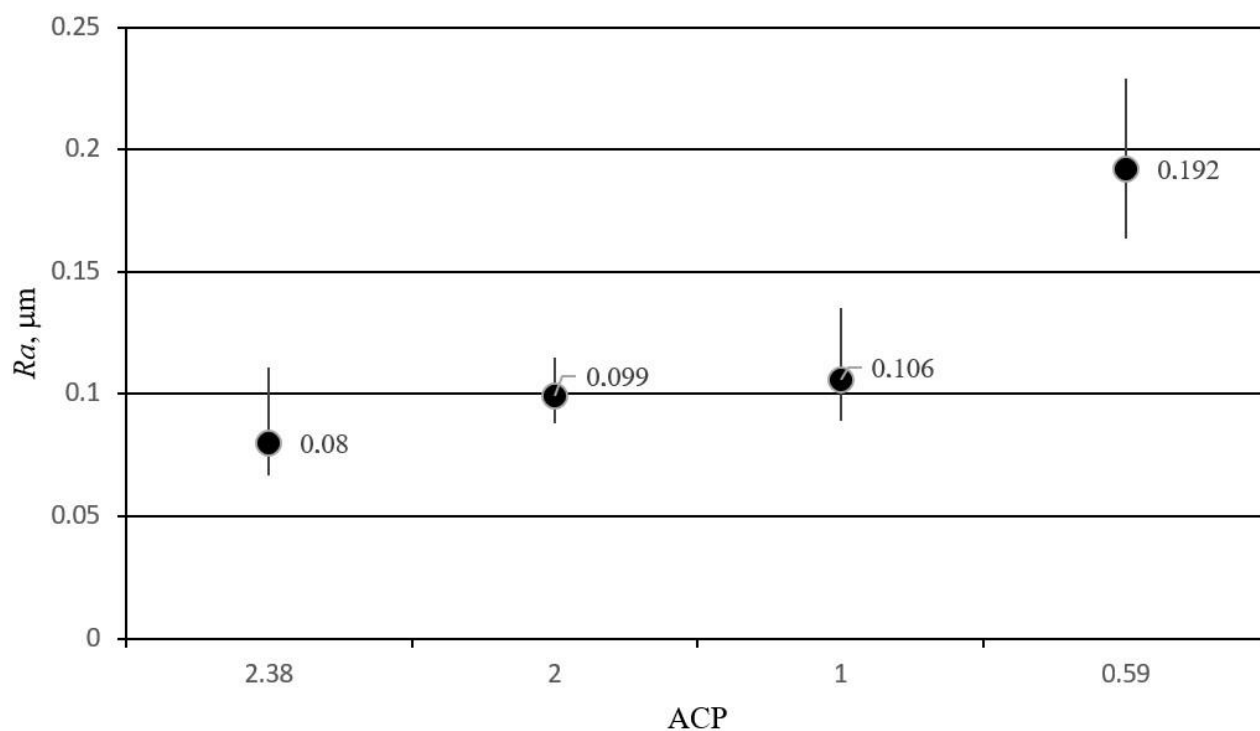


Fig. 6 Average R_a values vs ACP obtained for horizontal measurement direction

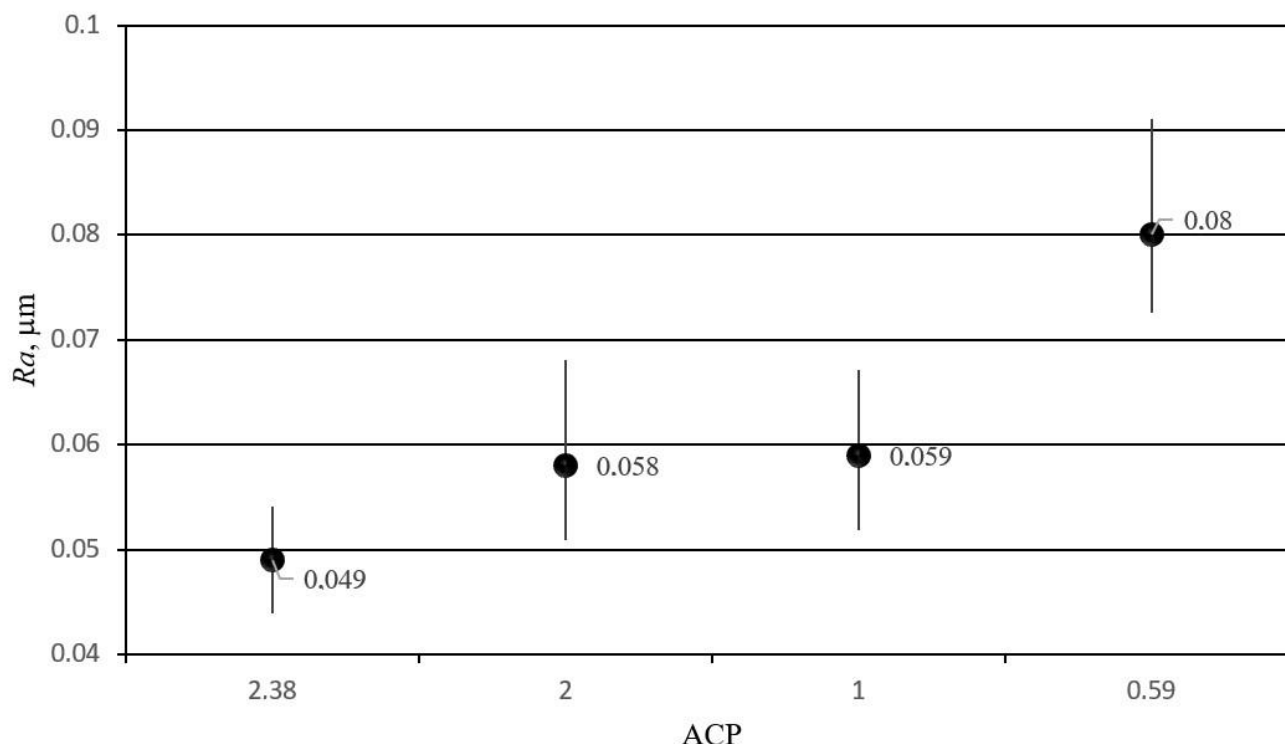


Fig. 7 Average Ra values vs ACP obtained for vertical measurement direction

3 RESULTS AND DISCUSSION

Results of surface roughness measurement are presented in Figures 6 and 7.

It can be seen from Figure 6 that the quality of the machined surface significantly reduces in case of ACP value less than 1. On the other hand, there is no sufficient difference between results obtained for ACP values 1 and 2 as the roughness parameter Ra is almost the same. The smoothest surface was measured when ACP is equal to 2.38. The correlation between the ACP and surface roughness parameter Ra is evident.

The results of measurements in vertical direction (Figure 7) shows same pattern as compared to results obtained for horizontal direction (Figure 6). Although, it is worth to mention that Ra values are smaller than obtained in case of horizontal measurement direction. The smoothest surface was measured again when ACP equal to 2.38 with Ra being 0.049 μm and the roughest surface was obtained at ACP value 0.59 with Ra = 0.080 μm. Even though Ra values presented in Figure 7 show the same pattern as the results obtained for horizontal direction, they are almost twice lower than measured in parallel direction.

4 CONCLUDING REMARKS

Experimental dependences of surface roughness parameter Ra on ACP were obtained for aluminium alloy end milling case. These dependences show

that with a decrease in ACP value, the Ra parameter of milled surface increases.

The results show that the most consistent surface finish with almost identical roughness was reached when ACP was equal to integer numbers 1 and 2. The Ra values obtained in both measuring directions horizontally and vertically were very close, i.e., 0.099 and 0.106 (horizontally), 0.058 and 0.059 (vertically).

The character of the dependence of the surface roughness parameter Ra on number of ACP remains the same regardless of the roughness measurement direction. The more active contact points there is, the better the surface finish seems to be reached. The lowest roughness value was measured in horizontal direction when ACP value is 2.38 (Ra = 0.080 μm) and the roughest surface was obtained with ACP value 0.59 (Ra = 0.192 μm). In case of vertical measurement direction, the lowest Ra value was measured when ACP value is 2.38 (Ra = 0.049 μm) and the roughest surface was obtained with ACP value of 0.59 (Ra = 0.080 μm).

The results obtained can be used for optimizing process productivity and cutting conditions when milling the 7075 aluminium alloy.

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