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ROUGHNESS OF ALUMINUM SURFACES FACE MILLED WITH A DIAMOND TOOL

Abstract. *This article describes the results of face milling experiments. The roughness parameters of machined surfaces with diamond were examined. Measurements were made in three planes parallel to the feed direction. Changes in the roughness profile diagram and roughness values as a function of the feed rate were analyzed.*

Keywords: *face milling; aluminum; diamond insert; surface roughness.*

1. INTRODUCTION

Research into the quality and accuracy of surfaces that are machined under various conditions is a constantly highlighted area of machining. This is motivated by the desire to meet the functional requirements of the connecting surfaces of built-in components and the cutting ability of newly developed tools, tool materials, as well as the machinability of new, high quality materials.

Vehicle manufacturers' effort to achieve optimum strength characteristics with the lowest mass of components also constantly addresses the issue of machinability of aluminum alloys. Aluminum surface can typically be machined with a diamond tool by cold forming [1] or machining [2]. Both methods can improve the surface quality of machined parts [3]. In this paper we studied the milling of aluminum. In this field, too, there is a wide variety of research directions and results from publications on diamond cutting.

Niu et al. [4] investigated the chip formation process in micro-milling aluminum with a natural diamond insert. The chip morphology and the milling processes were analyzed in correlation with the cutting force. They found that the formed chips are affected jointly by the tool-workpiece material pair and the cutting edge radius. Also, the chips were intact and separate. Moreover, the cutting force and thrust force are of the same order, as the cutting edge radius cannot be ignored.

Bai et al. [5] presented a new attempt to manufacture a small-diameter tool with a PCD diamond tool edge used for micro-machining for a better understanding of the wear and breakage behaviors of the downsized PCD tool. Stress distribution and crack propagation of the tool were revealed by FEM analysis.

Thereafter, wear characteristics of the rake face and flank face were analyzed during machining experiments of aluminum alloy. Results showed that abrasive, adhesive and oxidative wear were the dominant characteristics in the damage region of the tool.

Different designs of chip breakers made in a metal-matrix polycrystalline diamond (MMPCD) insert used for milling aluminum alloy were studied by Elkaseer et al. [6]. The profiles of the generated traces under different cutting conditions and the thickness of the chips were analyzed. They observed that the creation of the chip breakers with laser was successful in terms of high surface quality and tight dimensional accuracy.

Bourlet et al. [7] investigated burr formation in milling. A new methodology was proposed to simulate burr height along any part edge and for most face milling trajectories. New 3D aspects of face milling in relation with exit order sequence were developed.

Wang et al. [8] used a three-dimensional simulation model to analyze the surface topography of an ultra-precision machined aluminum alloy with a single crystal diamond tool. Results showed that the simulation model can properly simulate the surface profile and the predicted surface roughness under the cutting conditions.

Many articles deal with the milling of SiC particle reinforced aluminum matrix composites with diamond tools. Huang et al. [9] analyzed milling of composites with SiC particles of larger volume ratio and size. Tool wear, milling force and surface roughness were examined. They found that the main tool-wear mechanism in machining of this type of material was abrasion on the flank face. Studying the effect of cutting speed, feed rate and PCD particle size on tool wear (Wang et al. [10]) has shown that tool wear has increased significantly with increasing cutting speed, but that feed rate is less affected. Huang et al. [11] investigated the effects of volume fraction of SiC particles on tool wear morphology, wear resistance, cutting force and surface roughness in high-speed milling with a single PCD insert in the milling cutter. The research results showed that volume fraction has a negligible effect on tool wear morphology but a large effect on the wear amount and rate. With a low volume of SiC particles, the tool wear amount is small and increases slowly. However, tool wear amount is much greater and increases significantly with the increase of cutting distance. The surface roughness is larger when the volume fraction of SiC particles is higher. When the cutting distance increases to a certain length, the surface roughness decreases and becomes constant.

Brinksmeier et al. [12] carried out fly-cutting experiments for studying cutting forces, tool wear and surface roughness in high speed turning and milling aluminum workpiece with diamond and carbide tools. They found that an improved surface roughness can be achieved with a PCD tool rather than a carbide tool in high speed machining. This also offers several advantages, especially a major reduction of machining time.

In this work, we show the roughness of a diamond-milled aluminum surface in three measurement planes parallel to the feed direction, using different feed rates.

2. EXPERIMENTAL SETUP AND PROCEDURE

The milling of the aluminum alloy was carried out under the following conditions.

Machine tool: Perfect Jet MCV-M8 (H) vertical machining center

Cutting edge: Sandvik R590-1105H-PS2-NL CD10 uncoated diamond insert
 $\kappa_r = 90^\circ$; chamfer $0.25 \times 45^\circ$

Milling tool: Sandvik R590-080027A-11M milling head, $D=80$ mm (Figure 1)

Workpiece: AlSi9Cu3(Fe) aluminum alloy, size of the cut surface: 58×50 mm

The cutting data are indicated in Table 1.

Table 1 – Cutting data

Constant parameters					
$v_c=2513.3$ m/min		$n=10000$ 1/min		$a_p=1.5$ mm	
Changing parameter					
Feed per tooth (mm/tooth)					
f_{z1}	f_{z2}	f_{z3}	f_{z4}	f_{z5}	f_{z6}
0.06	0.09	0.12	0.15	0.18	0.21

The roughness values were measured on AltiSurf 520 three-dimensional surface roughness measuring equipment with a CL2 confocal probe.

Measurements were made in the symmetry plane and in other planes 20-20 mm bidirectionally from the first one, as indicated in Figure 2. Plane y_3 is the nearest to the entry side of the tool and it exits close to Plane y_1 .



Figure 1 – The applied milling head with one diamond insert

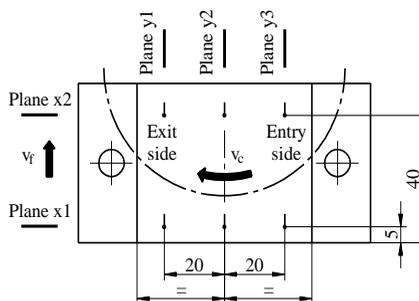


Figure 2 – Places (start points) of surface roughness measurement

3. RESULTS AND DISCUSSION

The measurements were repeated three times at each point, and their mean values are summarized in Table 2. The values in one plane are averaged for each feed rate, and those are given separately in Table 3.

Table 2 – Measured values of surface roughness at feed $f_z=0.12$ mm/tooth

$f_z=0.12$ mm/tooth						
	Plane y_1		Plane y_2		Plane y_3	
	R_a (μm)	R_z (μm)	R_a (μm)	R_z (μm)	R_a (μm)	R_z (μm)
Plane x_1	0.25	1.66	0.19	1.29	0.20	1.48
Plane x_2	0.25	1.63	0.22	1.65	0.19	1.21
Average	0.25	1.645	0.205	1.47	0.195	1.345

Roughness profile charts were also recorded for each measurement and are shown in Table 4 for the point defined by Planes x_1 - y_2 .

Table 3 – Summary of average measured values of surface roughness at different feed per tooth

Feed per tooth f_z (mm/tooth)	Plane y_1		Plane y_2		Plane y_3	
	R_a (μm)	R_z (μm)	R_a (μm)	R_z (μm)	R_a (μm)	R_z (μm)
0.06	0.235	1.740	0.180	1.635	0.215	1.605
0.09	0.270	2.105	0.210	1.575	0.220	1.480
0.12	0.250	1.645	0.205	1.470	0.195	1.345
0.15	0.295	2.305	0.265	2.295	0.285	2.725
0.18	0.325	2.475	0.315	2.795	0.290	2.380
0.21	0.320	2.400	0.280	2.385	0.290	2.165

Table 4 – Surface roughness profile diagrams at different feed per tooth at Planes x_1 and y_2

<p>Roughness profile, Gaussian Filter, cut-off 0.2500 mm</p>	$f_z = 0.06$ mm/tooth
<p>Roughness profile, Gaussian Filter, cut-off 0.2500 mm</p>	$f_z = 0.09$ mm/tooth
<p>Roughness profile, Gaussian Filter, cut-off 0.2500 mm</p>	$f_z = 0.12$ mm/tooth
<p>Roughness profile, Gaussian Filter, cut-off 0.8000 mm</p>	$f_z = 0.15$ mm/tooth
<p>Roughness profile, Gaussian Filter, cut-off 0.8000 mm</p>	$f_z = 0.18$ mm/tooth
<p>Roughness profile, Gaussian Filter, cut-off 0.8000 mm</p>	$f_z = 0.21$ mm/tooth

Plotting the measured values in diagrams shows that there are significant differences between the values not only for the feed rate but also for the measuring points (Figures 3 and 4).

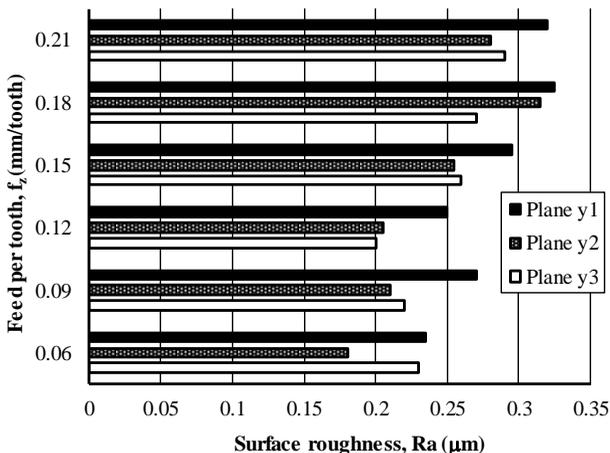


Figure 3 – Surface roughness R_a at different feed per tooth values and Planes y_1 , y_2 and y_3

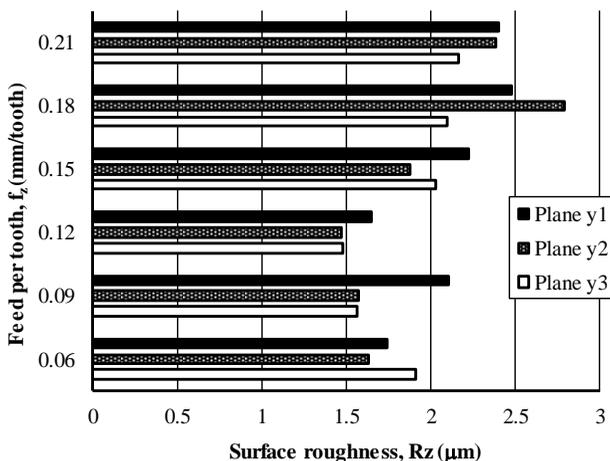


Figure 4 – Surface roughness R_z at different feed per tooth values and Planes y_1 , y_2 and y_3

As shown in Figure 3, the R_a values of the measurements vary between 0.18 and 0.325 μm . In almost all cases, the smallest average roughness value for each feed rate was observed in the y_2 symmetry plane. Furthermore, in each case, the mean roughness values measured on the entry side (Plane y_3) are greater than on the exit side. The values of R_z (Fig. 4) show similar characteristics to those of R_a . Measured R_z values range from 1.47 to 2.795 μm .

Figures 5 and 6 show the change in mean values of R_a and R_z for the whole face-milled surface as a function of increasing the feed per tooth. We found that both roughness parameters increase in value as a trend with increasing feed per tooth.

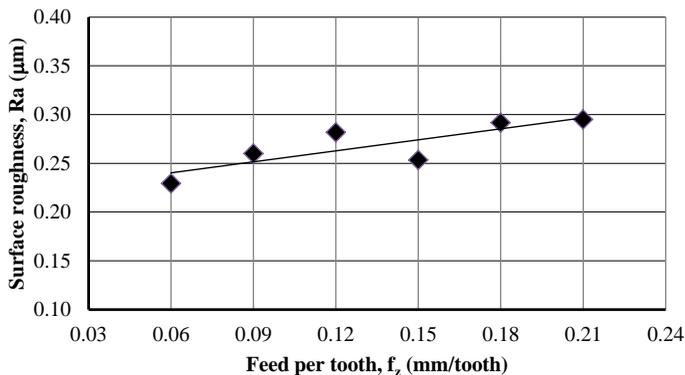


Figure 5 – Variation of surface roughness R_a as a function of feed rate

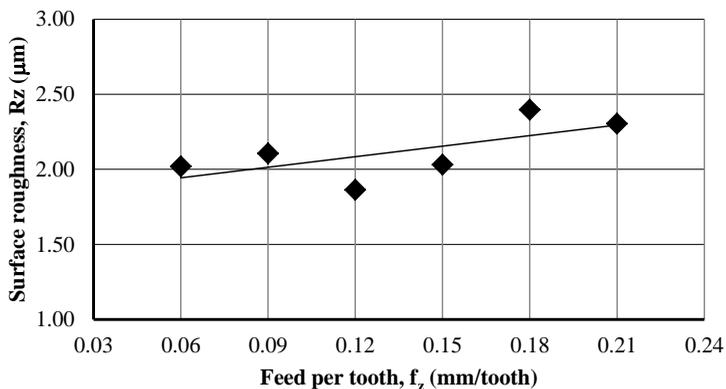


Figure 6 – Variation of surface roughness R_z as a function of feed rate

Applying linear and power function approximation, there is no significant difference in the shape of the trend curve. Therefore, trend lines are plotted using linear regression in Figures 5 and 6. Under the cutting conditions used, the change in R_a (Figure 5) is described by the trend equation of $y=0.38x+0.22$, and the change in R_z (Figure 6) by $y=2.35x+1.8$.

4. CONCLUSIONS

In our experiments, we used a diamond tool for milling an aluminum alloy specimen used in the automotive industry. With constant depth of cut and cutting speed, the change of surface roughness parameters with increasing feed rate per tooth was examined. Roughness measurements were made at six points. Based on the experimental results described in this article, the roughness of the face milled surface is different in each point. The effect of the feed rate appears as a trend, increasing the feed rate causes the increase of the values of the roughness parameters. It is also worth pointing out that the roughness values measured on the symmetry plane and on sides of the entrance and exit of the cutting edge also show different characteristics (effect of up-milling and down-milling). The measured values are within a standard deviation range. Thus, in order to achieve the required roughness values for the whole surface, the effect of this should also be considered when selecting the technological parameters. The spread of the roughness parameters is also influenced by the material structure homogeneity of the machined surface. It was also found from the experimental results that despite the distribution, the maximum values of R_a and R_z are also significantly lower than the values measured in [13] for face milling with a carbide tool at similar feed rates. In the latter case, the cutting speed (and thus the productivity of the machining) was only 10-12% that of the diamond tool.

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ШОРСТКІСТЬ ПОВЕРХНІ ДЕТАЛІ З АЛЮМІНІЮ ПІСЛЯ ТОРЦЕВОГО ФРЕЗЕРУВАННЯ АЛМАЗНИМ ІНСТРУМЕНТОМ

Анотація. *Виробники транспортних засобів докладають великі зусилля по досягненню оптимальних характеристик агрегатів з найменшою масою їх компонентів і постійно вирішують проблему оброблюваності, наприклад, алюмінієвих сплавів. У статті були вивчені питання фрезерування алюмінію. У цій області існує безліч напрямків досліджень і публікацій результатів з алмазної обробки. У цій роботі досліджено шорсткість поверхні алюмінієвої заготовки після алмазного фрезерування в трьох площинах виміру, паралельних напрямку подачі при варіюванні різними швидкостями подачі. Вимірювання проводилися в площині симетрії яка проходить через геометричну вісь фрези і збігається з напрямком вектору подачі й в інших двох паралельних площинах, розташованих в 20 мм в двох напрямках від осі симетрії. Зміна параметрів шорсткості поверхні при постійній глибині різання і швидкості різання вивчалася зі збільшенням швидкості подачі на зуб. Вимірювання шорсткості були зроблені в шести точках. Грунтуючись на експериментальних результатах, видно що шорсткість фрезерованої поверхні різна в кожній точці. Вплив швидкості подачі виглядає як тенденція: збільшення швидкості подачі викликає збільшення значень параметрів шорсткості. Варто також зазначити, що значення шорсткості, виміряні на площині симетрії і на сторонах входу і виходу ріжучої кромки, також показують різні характеристики (ефект фрезерування вгору і фрезерування вниз). Виміряні значення знаходяться в межах стандартного відхилення. Таким чином, щоб досягти необхідних значень шорсткості для всієї поверхні, цей ефект слід враховувати при виборі технологічних параметрів. На розкид параметрів шорсткості впливає також однорідність структури оброблюваного матеріалу. Також з експериментальних результатів було виявлено, що максимальні значення Ra і Rz також значно нижчі, ніж значення, обмірювані раніше для торцевого фрезерування з твердосплавним інструментом при аналогічних швидкостях подачі. В останньому випадку швидкість різання (і, отже, продуктивність обробки) становила всього 10-12% від швидкості алмазного інструменту.*

Ключові слова: *торцеве фрезерування; алюміній; алмазна вставка; шорсткість поверхні.*