

Effects of technological parameters on surface characteristics in face milling

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Abstract. The experimental and theoretic examination of conventional manufacturing procedures continue to be a topic of modern research. It is assisted, to a great extent, by the spread and the possibility of the application of high level software and more accurate measuring equipment. The research results obtained by the use of new equipment can open new ways for further development of conventional manufacturing procedures and their more intensive, more productive application. In this paper, an experimental method is used for examination of the surface features (e.g. flatness, 2D and 3D surface roughness parameters) of face milled aluminium parts. The aim of experiments was to determine the effect of change of the technological parameters (feed rate and cutting speed) on flatness and surface roughness features in of face milling of aluminium parts.

Introduction

A constant intention in the automobile and airplane industry is to find substitution materials of whose application allows the mass of the parts to be reduced and/or their strength to be increased. That is why, the proportion of aluminium parts is rapidly increasing. In practice the effective utilization of the cutting ability of cutting tools, including, for production is an important task.

The machining of the flat surfaces examined in the study is done, first of all, by face milling. As most of the mentioned parts are precision ones, the parts and/or surfaces of parts should satisfy high level requirements of accuracy and surface topography. Good surface quality (e.g. surface roughness and flatness) plays an important role in the wear resistance, tensile strength and fatigue enduring ability of machined surfaces.

When creating parts that contain machining operations the choice of appropriate manufacturing systems, such as flexible systems [1], is a determining factor. However, production is highly affected by cost factors as well [2]. When process planning, the technologist has to determine some cost-effective decisions such as choosing the appropriate machine tools and cutting tools for manufacturing and monitoring [3] and in the time of “Industry 4.0” the use of digital manufacturing can also reduce manufacturing costs [4].

In the examination of surface quality, the surface roughness (topography) is analysed extensively [5]. Muñoz-Escalona and Maropoulos [6] give information about the preparing of a geometrical model for surface roughness prediction for the examination of face milling. Their model was validated with experiments as well for high speed milling of aluminium alloy executed by Taguchi experiment design. Their research parameters were: cutting speed, feed per tooth, axial depth of cut and different values of tool nose radius.

Sheth and George [7] dealt with the experimental investigation and prediction of flatness and surface roughness during face milling operation. They found that the values of flatness and surface roughness have an effect on the leakage of a dual plate check valve. In order to achieve a properly operating valve they had to control the technological parameters when machining the valves, having appropriate measured flatness and surface roughness. Clauß et al. [8] investigated the surface properties in the milling of SiC particle reinforced aluminium matrix composites (AMCs). For executing the experiments they applied the fractional factorial experiment design. During their experiments they used CVD diamond tipped tools and they investigated the effects of cutting

parameters (cutting speed, feed per tooth) on the surface structure (roughness, imperfections) and on the residual stress state. Matras et al. [9] dealt with the precision milling of hardened steel with CBN tools while Jersak et al. [10] investigated the surface integrity of hardened steel after milling. Mikó [11] predicted the surface quality in case of steep free form surface milling and Beno et al. [12] also dealt with the milling of free-form surface fragments.

The following papers also examined the flatness. Nadolny and Kapolnek [13] dealt with the analysis of flatness deviations for stainless steel workpieces after efficient surface machining. Chen Lu [14] studied the prediction of surface quality of machining process, reviewing the methodologies and practice employed for the prediction of surface profile, roughness and flatness. He summarizes the advantages and disadvantages of each approach. Chen Lu uses RBF neural network prediction of surface profile and introduced future trends.

Some researchers investigated machinability of materials [15] while others (among them e.g. Vereschaka) are examining the working efficiency of cutting tools [16]. Durakbasa et al. [17] investigated the optimization of end milling parameters and determination of the effects of edge profile for obtaining high surface quality in the case of AISI H13 steel.

Milling examinations

Aim of milling examinations. The aim of the experiments is examining the change of feed and cutting speed on flatness and features of surface roughness in face milling of aluminium alloy.

Examination conditions. Face milling experiments were done on aluminium Al 6070 (UNS A96070) prismatic parts (dimensions: 120x64x64 mm), whose chemical composition can be found in Table 1.

Table 1. Chemical composition of examined specimen

Elements At [%]							
Al	Si	Mg	Fe	Mn	Cu	S	Zn
96.77	1.04	0.74	0.65	0.37	0.25	0.08	0.04

The ordering information of the milling cutter used for the milling experiments performed on a PERFECT-JET MCV-M8 milling machine: milling head R252.44-080027-1SM; insert: R215.44-1ST308M-WL GC4030.

Applied cutting data can be found in Table 2.

Table 2. Cutting data

Feed rate (mm/rev)	$f_1=0.1$	$f_2=0.2$	$f_3=0.4$
Cutting speed (m/min)	$v_{c1}=250$	$v_{c2}=300$	
Depth of cut (mm)	$a=0.4$		

The 2D and 3D surface roughness measurements were executed on AltiSurf[®]520 type 3D surface roughness measuring machine while for flatness measurements Talyrond 365 type shape error and position examining equipment was used.

Measuring method. As well-known when creating a face milled surface the edge of the cutting tool, determined by the applied kinematics, machines along curtate epicycloids. As a consequence of this different topography is created on the surface in different directions and different places. In the planes, parallel to the feed rate direction (A, B, C, D, E) (Fig. 1a) the roughness theoretically is the same in the planes at a similar distance (B-D, A-E) from the symmetric plane (C). 2D surface roughness parameters were measured in planes (a, b, c, d, e) perpendicular to the (C) symmetric plane (Fig. 1a), and average of the measured values were calculated. The average of the 3D measurements was

calculated in three places (a, c, e) perpendicular to the directions of (A-C-E) (Fig. 1b). So, on the specimen manufactured by different technological parameters the 2D surface roughness measurements were executed in the 25 different places shown in Fig. 1a ($l_1=14$ mm, $l_2=51$ mm) while 3D measurements were performed in 9 places ($l_3=25.5$ mm) (Fig 1b). The measuring lengths and territories were determined according to the DIN EN ISO 4288: 1998 and DIN EN ISO 3274: 1998 standards. The multi plane flatness measurements were done along concentric circles. The milling cutter enters the surface on side (A) and leaves it on side (E) and (a) marks the beginning of cutting, while (e) marks the end of it in longitudinal direction.

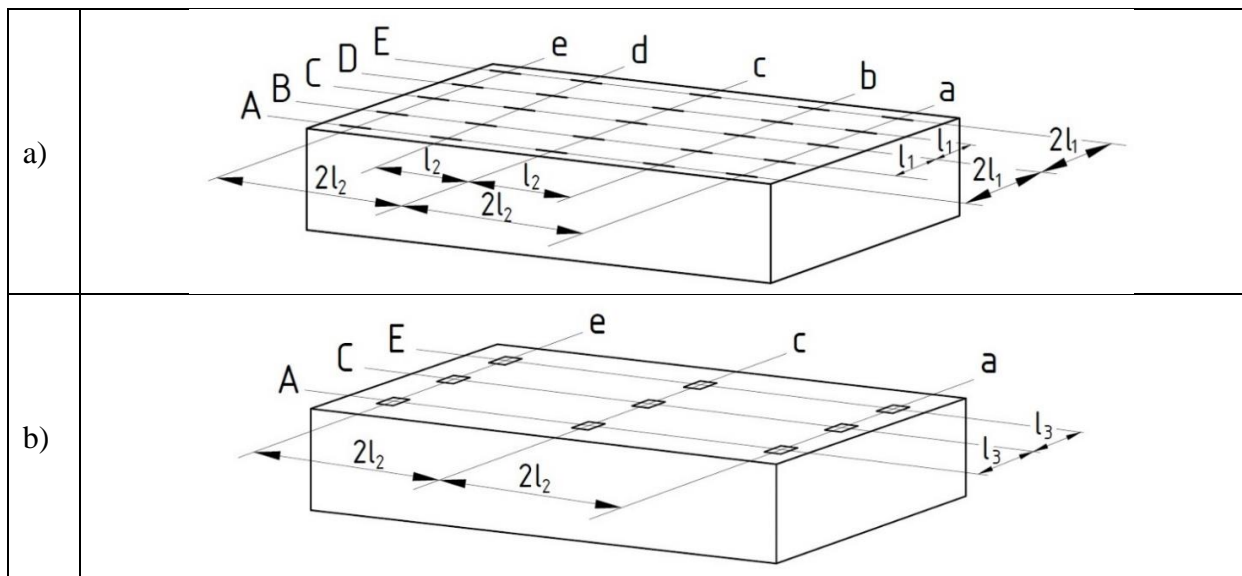


Figure 1. Measuring places on the specimen

a) for 2-dimensional roughness measurements; b) for 3-dimensional roughness measurements

Measuring results and their evaluation

We recorded the profile diagrams (in all 25 measuring places) with the measured standardized roughness values in the milling experiments performed at all three different feed rates ($f_1=0.1$ mm/rev; $f_2=0.2$ mm/rev; $f_3=0.4$ mm/rev). In Fig. 2. the 2D roughness profile is shown in perpendicular direction of feed rate ($f_2=0.2$ mm/rev) in middle (c). It can be seen well that the profile heights are the highest in plane (C), and farther away from it their value is reducing. Figure 2 also shows that in planes a similar distance from plane (C) planes and parallel to it in planes (B, D) and (A, E) the shape of the roughness profile is almost the same. If we examine numerically the values of roughness in all measuring points (Table 4) in that case the similarities and differences can be examined more precisely. Among the 2D roughness parameters we examined the values of Arithmetical mean deviation of the profile (R_a), Maximum height of the profile (R_t), Ten-point height of irregularities (R_z) or other words (Peak-to-valley height) and Root-mean-square roughness (R_q).

The average making activity (Table 3) is shown on the base of measuring results (a, b, c, d, and e) of plane (A). Similarly, from the 5-5 measuring results the averages were created in the planes (B), (C), (D) and (E). The average values are contained in Table 4 for different feed rate values and shown in Fig. 3a.

In the case of 3D roughness parameters, the averaging system was the same. Figure 3b and Table 5 contain the changes in the average values of the Arithmetical mean height of the surface (S_a) and Root mean square height of the surface (S_q) parameters, among the 3D roughness parameters in the planes (A, C, E). From Fig. 3a it is evident that all the examined 2D parameters, but especially R_t , are the highest perpendicular to the direction of the feed rate in the middle plane (C).

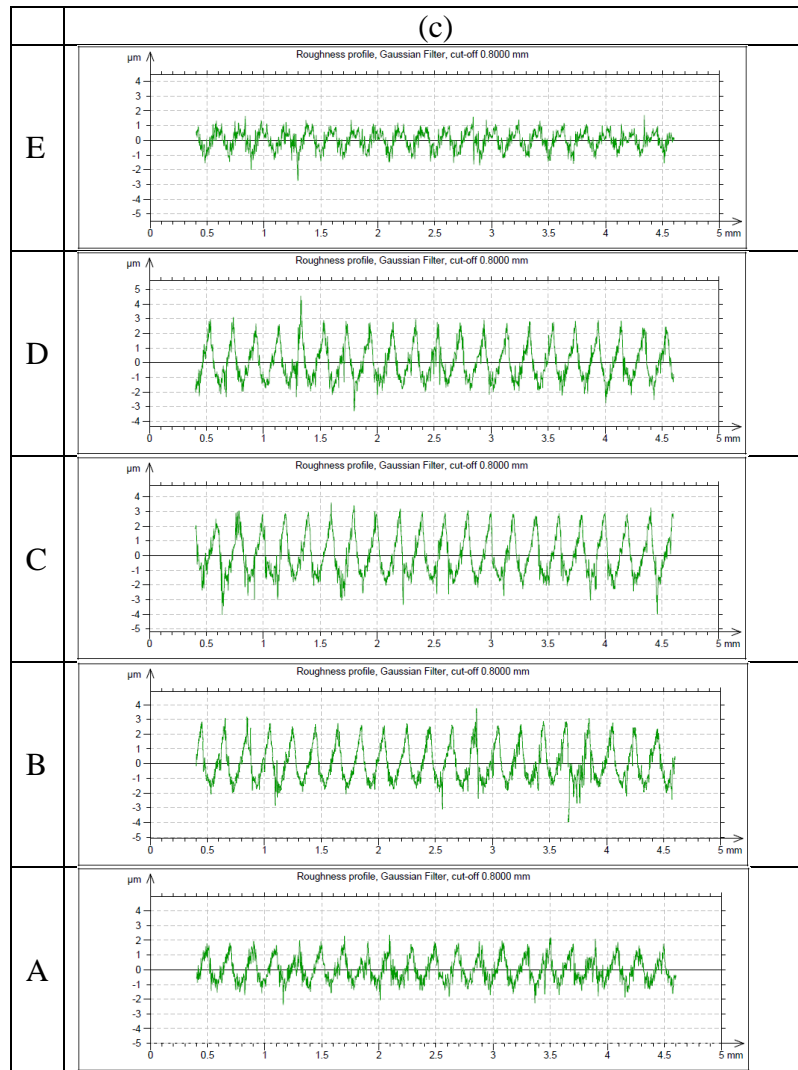


Figure 2. 2D surface roughness profiles in middle of the specimen (c) perpendicular to the direction of feed ($f_2=0.2$ mm/rev, $v_{c1}=250$ m/min)

Furthermore, it can be noticed that values of roughness are higher at the entering place of the milling cutter in plane (A) than the leaving plane (E). A similar statement can be made for Fig. 4b as well; however, only in the case when the feed rate is higher ($f_3=0.4$ mm/rev) is there is a little discrepancy between the entering and leaving planes. Numerically this difference is as follows: the Ra average value is 5% higher in plane (B) than in plane (D), and 25% higher in plane (A) than in plane (E). The average value of Rz in plane (B) is 4% higher than in plane (D) and 10.4 % higher in plane (A) than in plane (E).

The traces of milling insert and the pictures of 3D surface topography are shown in Fig. 4 in the middle (vertically) of specimen (plane c) in the leaving side of the specimen, that is in plane (E) in case of different feed rates. In Fig. 4 it can be seen well that by increasing the values of feed rate the traces of machining are higher, or traces are more distinctive, as the shank of the milling cutter was not tilted.

Table 3. Measured values and average of Ra surface roughness parameter ($f_1= 0.1$ mm/rev)

Ra, μm		e	d	c	b	a	Average
f ₁ =0.1 mm/rev	E	0.44	0.42	0.37	0.33	0.39	0.39
	D	0.44	0.46	0.42	0.39	0.46	0.50
	C	0.43	0.46	0.61	0.53	0.48	0.50
	B	0.47	0.46	0.55	0.55	0.48	0.43
	A	0.37	0.36	0.38	0.41	0.43	0.39

Table 4. Average values of 2D surface roughness parameters in case of different feed rates

	Ra	Rt	Rz	Rq	Ra	Rt	Rz	Rq	Ra	Rt	Rz	Rq
	$f_1=0.1$ mm/rev				$f_2=0.2$ mm/rev				$f_3=0.4$ mm/rev			
E	0.39	4.36	3.28	0.49	0.57	5.89	4.20	0.70	1.45	8.77	7.68	1.72
D	0.50	6.18	4.28	0.64	1.01	7.47	5.59	1.20	2.21	8.77	10.78	2.61
C	0.50	6.30	4.23	0.64	1.20	9.30	6.90	1.43	2.93	15.45	13.17	3.42
B	0.43	5.33	3.87	0.56	1.09	7.24	5.78	1.28	2.32	12.90	11.21	2.68
A	0.39	5.10	3.87	0.51	0.73	5.71	4.68	0.88	1.81	10.34	8.48	2.09

Table 5. Average values of 3D surface roughness parameters at different feed rates

	Sa	Sq	Sa	Sq	Sa	Sq
	$f_1=0.1$ mm/rev		$f_2=0.2$ mm/rev		$f_3=0.4$ mm/rev	
E	0.48	0.62	0.80	0.97	1.64	1.99
C	0.66	0.92	1.25	1.51	2.88	3.39
A	0.46	0.64	0.83	1.01	1.98	2.30

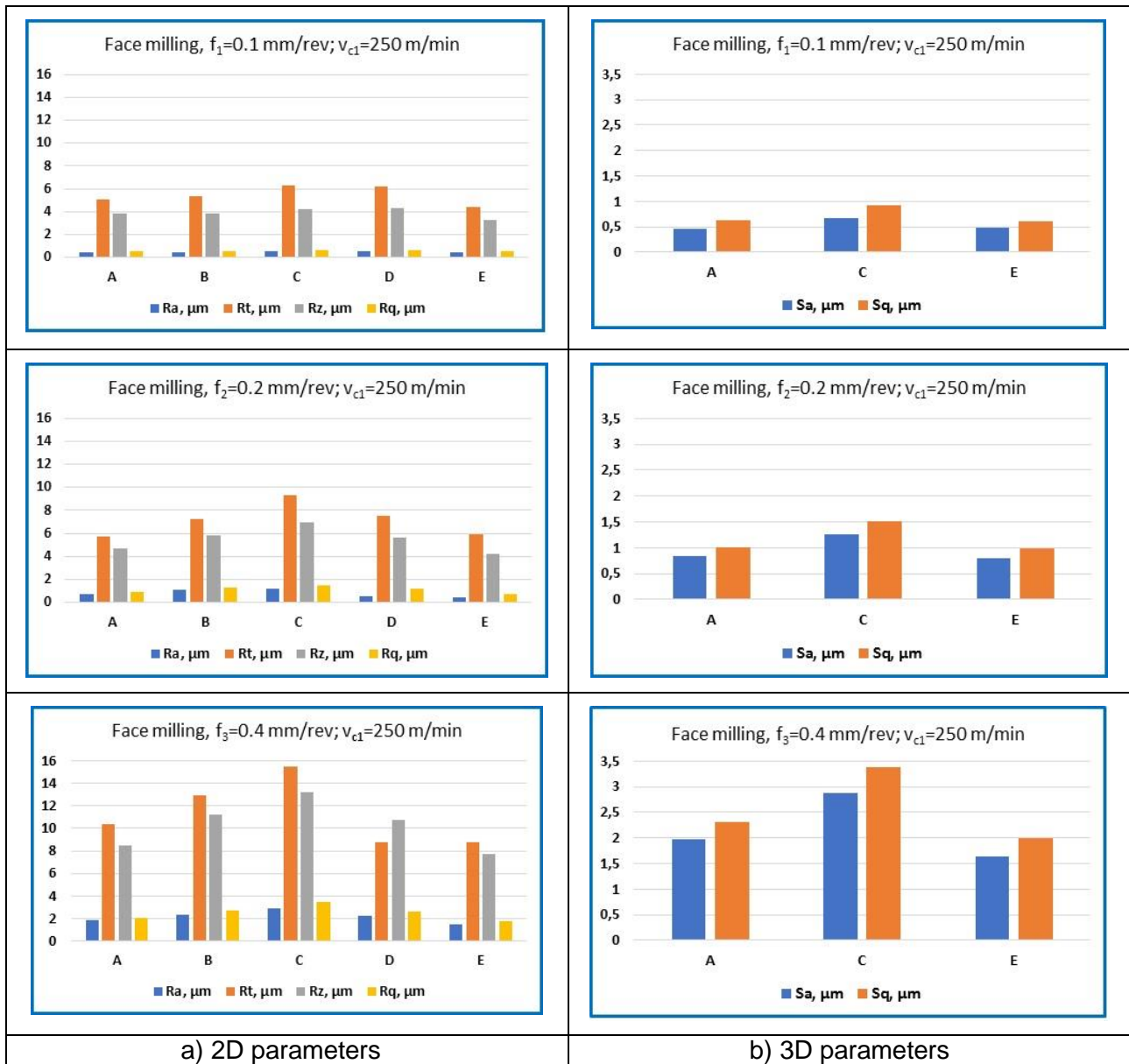


Figure 3. Average values of 2D and 3D roughness parameters in the planes parallel to feed rates

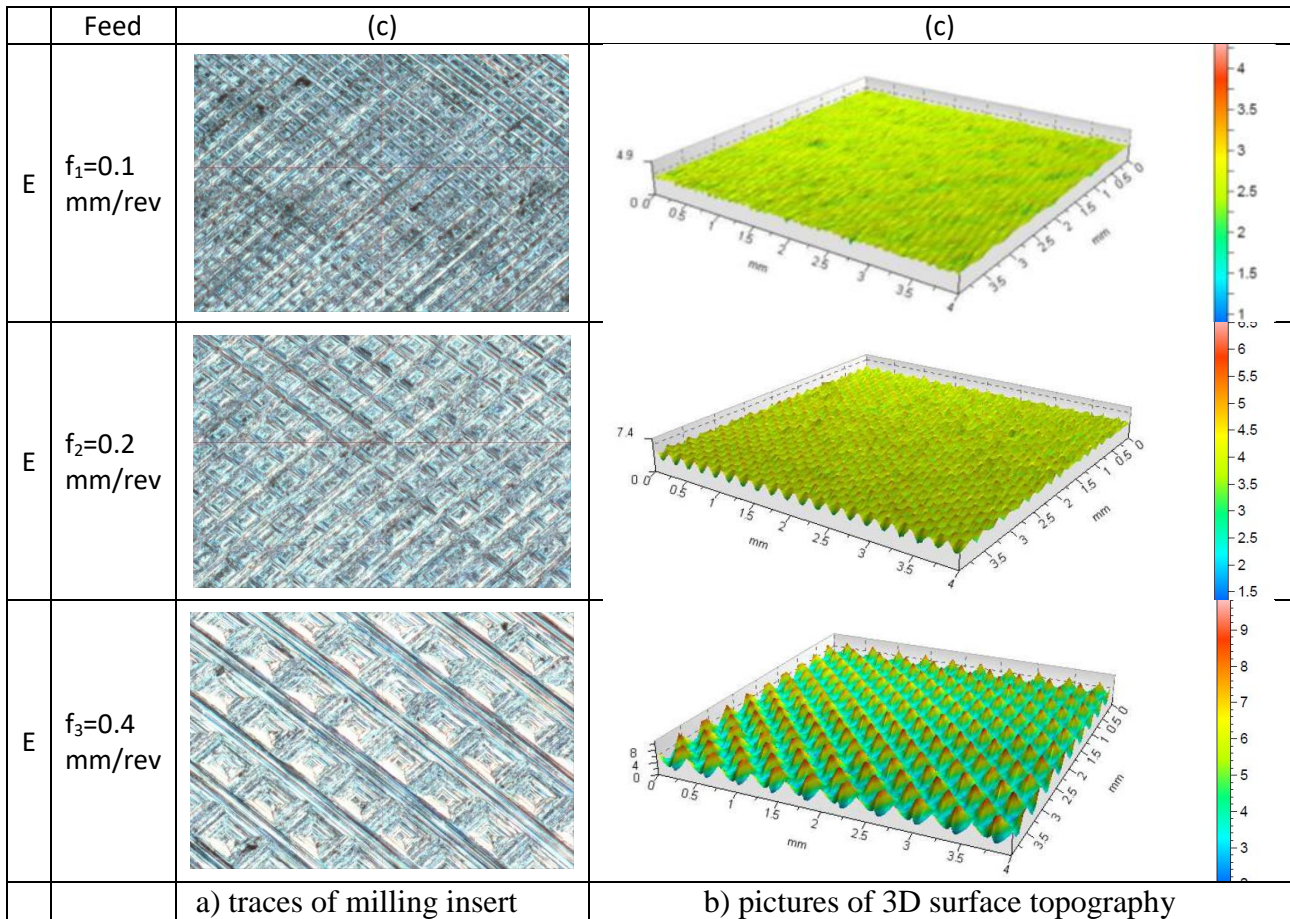


Figure 4. Traces of milling insert on the specimen's surface and 3D surface topography in the middle of specimen (c) when the insert leaves the plane (E) as a function of feed rate, ($v_{c1}=250$ m/min)

Measurements of flatness. Flatness, that is the deviation from the ideal flat plane was measured by Talyrond 365 type shape error and position examining equipment. This is done by rotation of specimen and the stylus deflection is in a vertical (Z) direction (perpendicular to the surface). The discrete points of the surface were recorded not along a straight line, but a circle. The places of these points on the x-y plane, that is on the surface to be measured, could be clearly identified.

For characterization of deviation of flatness, the standard ISO/TS 12781-1:2003 defines several parameters such as:

- FLTt (peak-to-valley flatness deviation (MZPL), (LSPL)),
- FLTp (peak-to-reference flatness deviation (LSPL)),
- FLTv (reference-to-valley flatness deviation (LSPL))
- FLTq (root mean square flatness deviation (LSPL)).

All four characteristic-feature can be created using a reference plane determined by the least squares method (LSPL – Least Squares Reference Plane), furthermore the first one, that is the FLTt parameter with the use of a reference plane determined by the minimum zone method (MZPL – Minimum Zone Reference Plane) as well.

Real production experience shows that from a metrological point of view the FLTt (peak-to-valley flatness deviation) parameter is the most useful parameter of those above [13]. This parameter is defined as the highest peak to valley normal to this reference plane (Fig. 5), establishing that the reference plane was determined by the Least Squares Method (LSM) or the Minimum Zone Method (MZM).

The MZM is characterized by higher accuracy; however, LSM is the more frequently applied method for characterizing deviation from flatness as determination of reference plane is done in a relatively simpler way [13]. Several measuring machines use this method. Using reference plane determined by LSM method the flatness deviation can be written in the form [13]:

$$FLT_t = FLT_p + FLT_v \quad (1)$$

where: FLT_p - value of the largest positive local flatness deviation from the reference plane determined by least squares method (LSPL),
 FLT_v – value of the largest negative local flatness deviation from the reference plane determined by least squares method (LSPL).

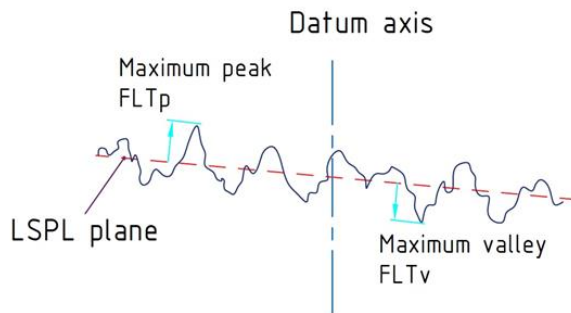


Figure 5. The FLT_t peak-to-valley flatness deviation parameter is perpendicular to the reference plane

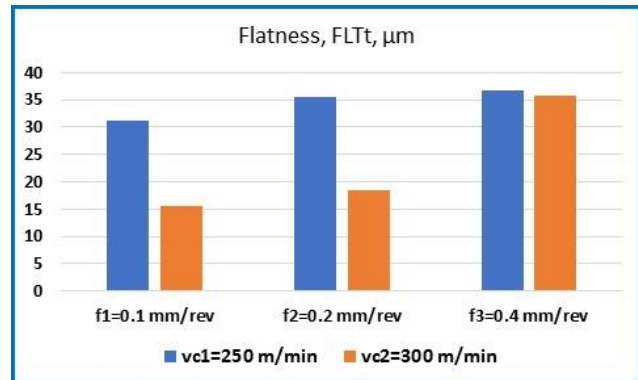


Figure 6. Measured flatness deviation values (FLT_t) as the function of feed rate and cutting speed

Examination of flatness deviation was performed on milled surfaces produced at 3 different feed rates and 2 different cutting speeds. When using both cutting speed parameters flatness deviation shows increasing trends when the feed rate is higher, and the measured values of flatness deviations were in a similar scale which could be found in the literature when machining steel. At smaller feed rate values ($f_1=0.1$ mm/rev; $f_2=0.2$ mm/rev) the increase of cutting speed effectively reduced the value of flatness deviation while at the value of feed rate $f_3=0.4$ mm/rev the value of flatness deviation is almost the same when machining at the two-different cutting speeds. It is unclear why FLT_t for $v_c = 300$ m/min increases almost twice as much from $f = 0.2$ mm/rev to 0.4mm/rev, in comparison to FLT_t for $v_c = 250$ m/min. It will be analysed in our following paper.

Summary

This paper deals with an experimental analysis of milling of aluminium workpieces. 2D roughness profiles and average values of 2D and 3D surface roughness parameters were introduced in 5 planes parallel to feed direction.

The highest values of roughness were found in the middle plane, and when we examine a parallel plane to it at a longer distance, the value of its roughness will be lower. In our case, for the distance 28 mm – generally – at low feed rate ($f_1=0.1$ mm/rev) both R_a and R_z decreased by 22%, while in case of high feed rate ($f_3=0.4$ mm/rev) R_a was reduced by 50.5%, and R_z by 41.7% at the insert's leaving side. For 28 mm from the middle plane, at the leaving side of the specimen at low feed ($f_1=0.1$ mm/rev) S_a decreased by 27.3 % and S_q by 33.6%, while in case of high feed rate ($f_3=0.4$ mm/rev) S_a was reduced by 43.1 % and S_q by 41.3%.

We showed the traces of the milling cutter and the measured 3D surface topography at the tool's leaving side. We examined the values of flatness deviation (FLT_t) as a function of feed rate and cutting speed. At the low cutting speed ($v_{c1}=250$ m/min) flatness deviation did not change significantly as a function of feed, while at the higher cutting speed ($v_{c2}=300$ m/min) when increasing the feed rate from $f_1=0.1$ mm/rev to $f_3=0.4$ mm/rev the flatness deviation increased to almost double.

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