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Evaluation of the Effect of Machining Technologies on the Surface Texture Analysis of Ertacetal C Polymer

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The surface created by machining significantly affects the service life and functional reliability of the component. As part of this study, four different chip machining technologies were evaluated on the surface texture of the polymer material Ertacetal C. The samples were processed by turning, milling, grinding and polishing technologies, 5 samples for each technology. Within the given technology, different cutting conditions were chosen to compare the effect of cutting conditions on the resulting surface roughness. The machined surfaces were comprehensively evaluated on the basis of 16 profile and surface roughness parameters due to the practical use of the tested material. Surface texture measurements were performed on a Talysurf CCI Lite device. A non-contact method using a coherence correlation interferometer was used for the measurement. The obtained data were evaluated using TalyMap Platinum software. Graphical documentation of the machined surfaces was made using an Olympus DSX500 opto-digital metallographic microscope.

Keywords: Machining, Technical Plastics, Polymers, Surface Texture, Surface Roughness, Profile Parameters, Area Parameters

1 Introduction

In the case of small production volumes, conventional chip machining is a fast and economical option to achieve a very precise plastic part. Plastic materials are different from metal materials in many ways, which needs to be kept in mind even in the case of their machining. Simply put, the basic principles of metal machining do not apply when machining plastics. The surface created by machining significantly affects the service life and functional reliability of the component. After machining, the surface layer of the material acquires its specific character and different properties from the inner mass of the component material. The processes of failures, cracks, fatigue, material degradation etc. begin on the surface or just below it. One of the evaluation elements of the machined surface is its roughness. The surface roughness has a significant effect on the functional surfaces of the part and their friction, sealing, vibration or lubrication properties [1]. Technical uses for plastic materials include not only the automotive and engineering industries, but also the food, pharmaceutical, chemical, construction, electrical, nuclear, aerospace and space industries. The machined material Ertacetal C (POM-C) is a thermoplastic acetal copolymer from the construction plastics group. Polyoxymethylene copolymer (POM-C) is an engineering thermoplastic that used in many industries due to its physical, mechanical, self-lubricating and chemical properties [2, 3, 4]. Final properties of polymer materials, i. e. improvement of mechanical, thermal and chemical properties, can provide ionic and ionizing radiation [5]. It is highly resistant to hydrolysis, strong alkalis and heat-oxidative degradation.) Changing the viscoelastic properties of glass fiber polymers with respect to their molecular structure affects the rate and depth of environment-induced degradation [6]. This material has high mechanical strength and hardness, very good dimensional stability, creep resistance and good sliding properties. It is machined very well and is suitable for the production of precision mechanical parts [7, 8]. Polymeric materials are replacing conventional materials, but due to the growing demand for these materials, the amount of their waste is also increasing [9]. Majerník et al. (2017) focus on the reuse of waste and examine the tensile properties of test specimen according to the selected percentage of additives in the volume of the basic granulate.

2 Machining of Ertacetal C (POM-C)

Turning unreinforced polyoxymethylene copolymer material POM-C with a polycrystalline diamond (PCD) cutting tool results in a correlation between cutting parameters and cutting energy or specific cutting energy varying due to the viscoelastic behaviour of the workpiece material and also leads to a high-quality machined surface with roughness degrees ISO N6 and N7 [10]. A study on turning polyoxymethylene polymer POM C using a cemented carbide cutting tool showed that surface roughness is significantly affected by feed rate with a large contribution, followed by depth of cut, while cutting speed has no effect [11].

This article [12] deals with the roughness of surfaces obtained during drilling of three polymeric materials: polyamide – PA6, polyacetal – POM-C and high-density polyamide – HDPE 1000. The existence of micro-uniformities on the surface of the part results in worse functional conditions and causes a number of disadvantages. Based on the results, we can state that visually at a scale of 500 μm, the POM-C and HDPE materials have a better-defined surface state compared to PA 6, where exfoliation of the material with the effect of plastic deformation on the generated surface can be observed [12].

The purpose of this article is to present a comparative analysis of four bore cleaning technologies commonly used for machining POM C polymer. To achieve high dimensional accuracy, the authors recommend using either boring or reaming. The tribological behaviour of the surface obtained by spiral milling and boring is better than by reaming or contour milling, because it holds the lubricating film better and has a higher bearing capacity [13].

The results [14] of the experiment that dealt with the influence of seven different polymer contact rollers on the belt ground surface texture (PS-R, POM C-R, PA 6-R, PPC-R, PPH-R, HDPE-R, and LDPE-R) indicate that they indicate a better surface texture obtained with a PA 6 polyamide roll (hardness = 60 Shore D) compared to that obtained with other rolls of the same or different hardness [14].

The study focuses on the effect of cutting parameters on surface roughness, cutting force, cutting performance and productivity in turning polyoxymethylene polymer (POM-C). Productivity maximization recommended for roughing machining is effective cutting parameters vc = 628 m.min^{-1}, f = 0.08 mm.rev^{-1} and ap = 3 mm. But if we also consider the combination of productivity and quality, the resulting optimal conditions are vc = 628 m.min^{-1}, f = 0.097 mm.rev^{-1} and ap = 1.80 mm [15].

Testing the processability of laser texturing on polyoxymethylene (POM) in comparison to creating surface texturing by computer numerical control (CNC) machining techniques concluded that laser surface texturing of polymeric materials causes thermal damage such as melting and creep and severe bulging and burring [16]. The effect of different machining positions on the surface quality of FDM products was investigated, where machining position was shown to have a large effect on surface roughness and the results of this study point to the fact that the surface quality of parts intended for 3D printing can be improved [17].

The authors of Tabacaru et al. (2020) proposed a neural model that is able to predict surface roughness not only with regard to cutting parameters, but also to the type of material when drilling polymeric materials in dry conditions – high-density polyethylene (class HDPE 1000), polyamide (class PA6) and polyacetal (class POM - C). The final conclusion from this study can be stated that POM-C has the best machinability of all materials studied, the second-best being HDPE 1000 and PA6 [18].

Gehlen et al. (2021) addressed the tribological behavior of POM-C subjected to sliding on a gray cast iron disk at different temperatures and the results clearly point to the fact that the pressure-velocity limit (PVL) of POM-C is strongly affected by temperature.

3 Machining of other polymeric materials

Erenkov et al. (2019) confirmed the effectiveness of incorporating preliminary burnishing of billets into the technological process of machining polymeric materials due to the reduction of the strength of the surface layer and the improvement of the performance of subsequent turning processing. Turning of polymer material polyethylene terephthalate (PET) reinforced with carbon fibers is described in the article [21]. Carbide insert TPGN 16 03 04 H13A was used for turning. The samples were machined under the following conditions: vc = 75 m.min^{-1}, f = 0.05 mm.rev^{-1}, ap = 0.5 mm. As the resulting evaluation parameter of the surface roughness, this article states the average arithmetic deviation of the profile Ra = 0.91 μm [21]. Inclusion in the machining production process for polymer materials of an operation of prior burnishing of workpieces prevents a reduction in the operational properties of the material and ensures the operational efficiency and reliability of the components [22].

Milling of the polymer onyx® (nylon) is described in article [23]. A tungsten carbide cutter with an AlTiN coating with a diameter of 3.175 mm was used for milling. The samples were machined dry and with the use of coolant under the following conditions: n = 6000 min^{-1}, f = 600 mm.min^{-1}, ap = 1.25 mm. The resulting surface roughness value was for dry machining Ra = 2.78 μm (face milling) and Ra = 2.87 μm (cylindrical milling). Using a cooling liquid, the results of Ra

= 3.40 μm (face milling) and Ra = 3.60 μm (cylindrical milling) were achieved [23].

Turning of polyamide polymer is described in article [24]. A VCMT 16T304 cemented carbide insert was used for turning. The samples were machined under the following conditions: vc = 127.2 m.min^{-1}, f = 0.21 mm.rev^{-1}, ap = 0.15 mm. The resulting surface roughness value was Ra = 2.53 μm [24]. During turning of polyamide PA-6 using two different materials of cutting tools – polycrystalline diamond (PCD) and sintered carbide K 15, the effect of cutting conditions (cutting speed and feed) on the surface roughness of polyamide PA-6 was investigated (Mata). Feed was found to have the greatest influence on roughness [24]. Turning of the high-performance polymer PEEK CF30 is described in the article [25]. A TiN-coated insert (WNMG080408-TF) was used for turning. Samples of ∅ 50 mm were machined under the following conditions: uncooled, f = 0.1 mm.rev^{-1}, ap = 0.5 mm, vc_1 = 50 m.min^{-1}, vc_2 = 200 m.min^{-1}, vc_3 = 500 m.min^{-1}. As roughness measurement outputs, this article reports the average arithmetic deviation Ra and the highest profile height Rz with the following values: Ra1 = 0.69 μm, Rz1 = 3.70 μm; Ra2 = 0.54 μm, Rz2 = 2.88 μm; Ra3 = 1.18μm, Rz3 = 5.50 μm [26].

Grinding of the high-performance polymer polyether ether ketone (PEEK) is described in the article [27]. A SiC grinding wheel (10C100H12VQ) was used for grinding. Grinding took place under the following conditions: cooled by compressed air, f = 2000 mm.min^{-1}, ap = 30 μm, vc_1 = 5 m.s^{-1}, vc_2 = 10 m.s^{-1}, vc_3 = 15 m.s^{-1}. The resulting average arithmetic deviations of the roughness profile reached the following values: Ra1 = 1.7 μm, Ra2 = 1.6 μm, Ra3 = 2.5 μm [27]. A comparative study [28] of the machining characteristics of carbon/PI and carbon/PEEK composites under different cutting conditions evaluated drilling force, machining temperature, delamination damage, surface morphology, hole dimensional accuracy and tool wear. The results indicate that carbon/PEEK composites generally exhibit much poorer machinability than carbon/PI composites [28].

Milling of the high-performance polymer TECAPEEK is described in the article [29]. A double-edged end carbide end mill of ∅10 mm was used for milling. A plate with dimensions of 160 x 50 x 15 mm was used as a sample. Machining took place under the following conditions: n_1 = 4000 min^{-1}, f_1 = 0.2 mm.tooth^{-1}, ap_1 = 4 mm; n_2 = 8000 min^{-1}, f_2 = 0.3 mm.tooth^{-1}, ap_2 = 8 mm. The resulting average arithmetic deviations of the roughness profile reached the following values: Ra1 = 0.69 μm, Ra2 = 3.5 μm [29].

The results of the study, where a wide range of different types of modern structural polymer materials used for tooling, prototyping and manufacturing of machine parts were machined, show the results: the values of the surface roughness parameters were almost independent of the tool type and feed direction, and the lowest values of the surface roughness parameters occurred after high density polymer machining materials, especially composites [30].

The current state of knowledge about the effect of machining on the surface texture of polymeric materials includes only a few types of plastics from the vast amount of these materials. Also, most studies evaluate the roughness of the machined surface only using the basic parameters Ra and Rz, and therefore do not evaluate it as a whole. The purpose of this study was to deepen knowledge about another very useful material for practice with a comprehensive assessment of surface texture using a whole range of profile and area parameters.

4 Samble preparation

The samples for the experiment were made of the thermoplastic acetal polymer Ertacetal C (POM – C). The material was obtained in the form of a bar semi-finished product with a diameter of 30 mm and 1000 mm long. Semi-finished products are produced by extrusion technology from molten granulate and subsequently heat-treated to reduce the internal stress caused by uneven cooling of the semi-finished product. This material is very easy to machine and is suitable for manufacturing that specializes in precision mechanical parts (e.g. gears with a small modulus). The manufacturer of this material states the following properties: density 1.41 g.cm^{-3}, melting point 165 °C, maximum operating temperature 140 °C, minimum operating temperature -50 °C, yield strength 67 MPa, hardness 150 N.mm^{-2} and modulus of elasticity in tensile strength 2800 MPa [31]. The bar was cut with a band saw into 20 samples of 50 mm length. The samples were further turned, milled, ground and polished (always 5 samples for each technology).

The turned samples were processed on a classic SV 18 RD lathe. The samples were clamped in a chuck and longitudinally turned to a length of 30 mm. A high-speed steel (HSS) knife with a chip former was used for machining. All turning was done without cooling. Turning parameters are listed in Tab. 1.

Tab. 1 *Turning parameters*

Sample	Revolutions *(n)* [min^{-1}]	Cutting speed *(vc)* [$m.min^{-1}$]	Feed *(f)* [$mm.rev^{-1}$]	Depth of cut *(ap)* [mm]
1.	2100	198	0.05	2
2.	2300	217	0.05	2
3.	2450	231	0.05	2
4.	2600	245	0.05	2
5.	2700	255	0.05	2

The milled samples were processed on a FV 25 CNC A milling machine. A cylindrical end mill with two cutting edges made of cobalt-alloyed high-speed steel (HSS Co8) with a diameter of 20 mm was used for machining. Sample preparation consisted of milling a 30 mm long area along its perimeter in two passes without using process liquid. Subsequently, the test sample was rotated, on which an analogous operation was performed while applying the same cutting conditions with the use of a process liquid.

The samples were clamped in a vise and a 30 mm long surface was milled around the perimeter in two passes of the cutter. Milling took place without cooling. Then the sample was turned over and a second surface was milled on the opposite side under the same cutting conditions using cooling. Milling parameters are listed in Tab. 2.

Tab. 2 *Milling parameters*

Sample	Revolutions *(n)* [min^{-1}]	Cutting speed *(vc)* [$m.min^{-1}$]	Feed *(f)* [$mm.rev^{-1}$]	Depth of cut *(ap)* [mm]
1.	3200	201	0.05	3
2.	3425	217	0.05	3
3.	3650	229	0.05	3
4.	3900	245	0.05	3
5.	4100	258	0.05	3

The samples were ground on a Kellenberger KEL-VISTA UR 175/1000 CNC grinder. The samples were clamped in a chuck and longitudinally ground into a round 30 mm length to a diameter of 29 mm. A 400 mm diameter, 50 mm wide Norton sanding wheel with a medium grit (P = 60) was used for grinding. During the entire process, the grinding wheel performed an axial oscillating movement with a frequency of 90 mm.min^{-1}. All grinding was done with cooling. Grinding parameters are listed in Tab. 3.

Tab. 3 *Grinding parameters*

Sample	Revolutions of the grinding wheel *(n_1)* [min^{-1}]	Spindle revolutions *(n_2)* [min^{-1}]	Cutting speed *(vc)* [$m.s^{-1}$]	Tangential feed rate *(vft)* [$m.min^{-1}$]	Radial depth of cut *(ap)* [mm]
1.	1000	270	20	25.5	0.015
2.	1300	270	26	25.5	0.015
3.	1600	270	33	25.5	0.015
4.	1900	270	39	25.5	0.015
5.	2200	270	45	25.5	0.015

The samples were polished manually on a Struers LaboPol 60 polisher. Four abrasive papers with different grain sizes were used for polishing. FEPA P 220 grit paper was used first, followed by FEPA P 500, then FEPA P 1000 and finally FEPA P 2400. Water was used as the cooling medium. Polishing parameters are listed in Tab. 4.

Tab. 4 *Polishing parameters*

Sample	Revolutions (*n*) [min^{-1}]	Polishing time (*t*) [s]
1.	100	240 (4 x 60)
2.	150	240 (4 x 60)
3.	200	240 (4 x 60)
4.	250	240 (4 x 60)
5.	300	240 (4 x 60)

5 Sample measurement

Surface texture measurements were performed on a Talysurf CCI Lite device. A non-contact method using a coherence correlation interferometer was used for the measurement. The obtained data were evaluated using TalyMap Platinum software. Graphical documentation of the machined surfaces was made using an Olympus DSX500 opto-digital metallographic microscope. A Gaussian filter was used to distinguish the profiles. From the point of view of the comparability of the evaluated parameters, one type of sensor and the same conditions were used for measuring all samples. The measurement conditions are listed in Tab. 5.

Tab. 5 *Basic conditions for surface texture measurement*

Measured area	Number of measured profiles	Basic length	Evaluated length	Filtration
0.8 x 0.8 [mm]	1024 x 1024	0.8 [mm]	4 [mm]	Gauss – 0,8

6 Evaluation of achieved results

Selected detailed images of the machined surfaces can be seen in Fig. 1. The images were taken on an Olympus DSX500 opto-digital metallographic microscope. The images show the different surface topography created by individual machining technologies. In Fig. 1, a certain similarity can be observed between the periodic profiles of the turned and milled sample, due to machining with a tool with a defined geometry. Likewise, a similarity can be observed between the ground and polished samples, which were machined with a tool of undefined geometry, resulting in a non-periodic profile.

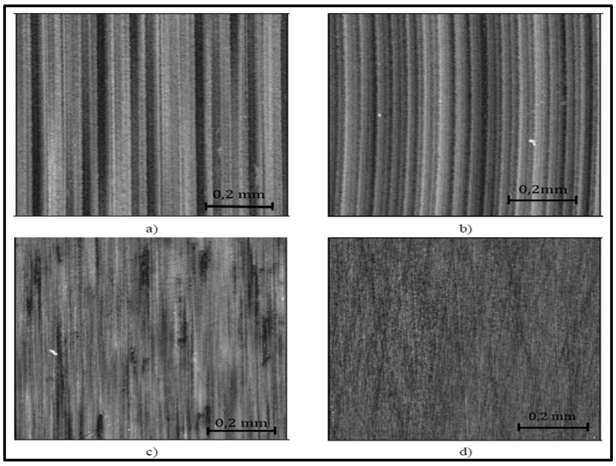

Fig. 1 *Images of machined surfaces (0.8 x 0.8 mm, magnified 500x): a) turned, b) milled, c) ground, d) polished*

For a more comprehensive idea of the appearance of real surfaces created by individual machining technologies, 3D visualizations of the surface texture are shown in Fig. 2 to Fig. 5.

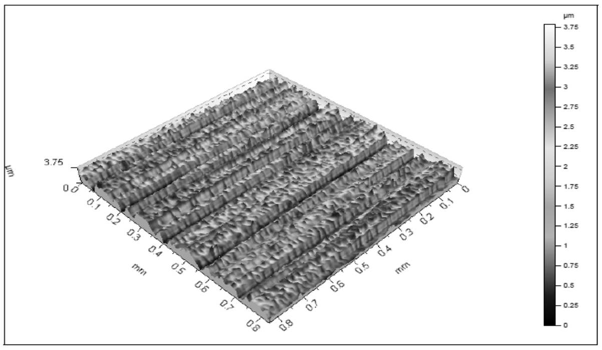

Fig. 2 *3D visualization of surface texture – turned*

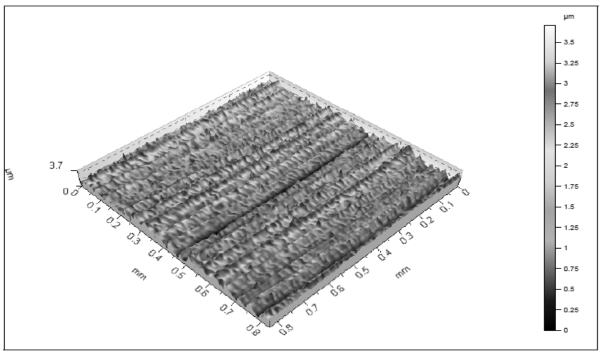

Fig. 3 *3D visualization of surface texture – milled*

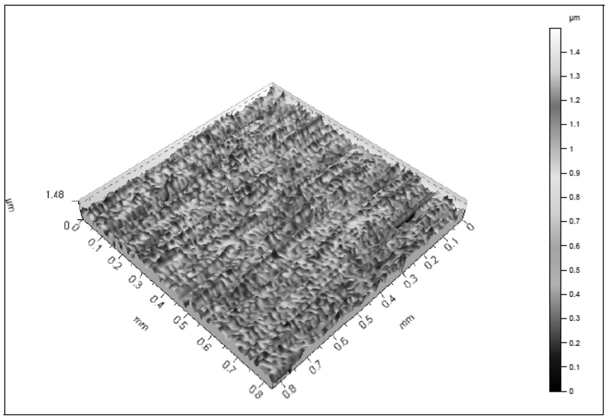

Fig. 4 *3D visualization of surface texture – grinded*

A simplified form of 3D visualization is the representation of the surface texture as a graphical dependence of the 2D roughness profile. The profile displayed in this way can be imagined as a perpendicular section at the selected point of the evaluated surface. The resulting profile was measured at an evaluated length of 4 mm. For better clarity, the roughness profile has been zoomed in and displayed on a base length of 0.8 mm (x-axis). Fig. 6 to Fig. 9 show the 2D surface roughness profiles for each machining technology.

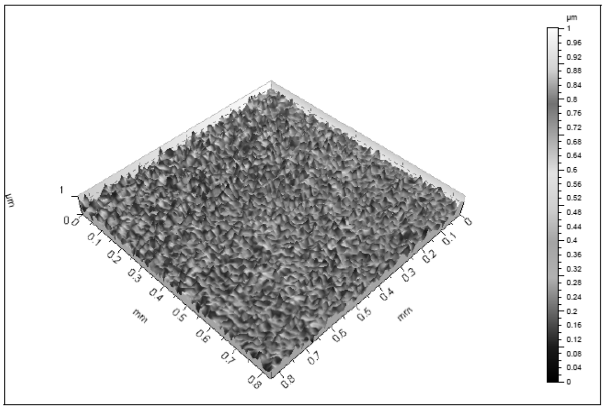

Fig. 5 *3D visualization of surface texture – polished*

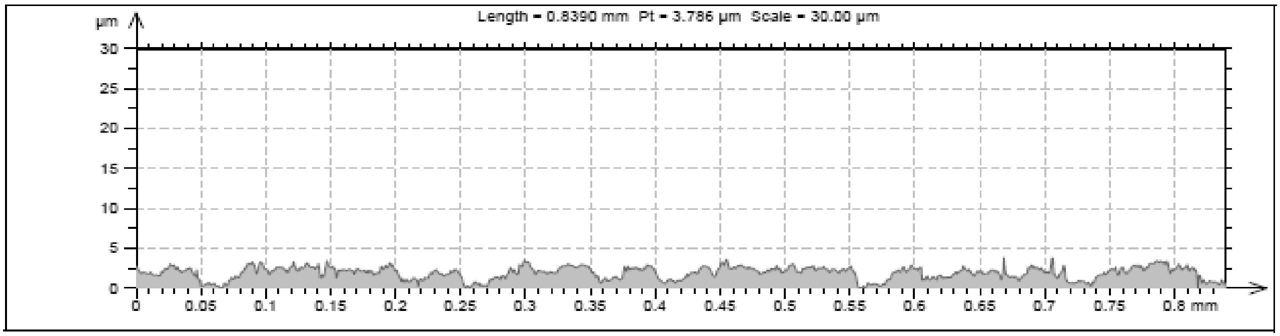

Fig. 6 *2D roughness profile – turned*

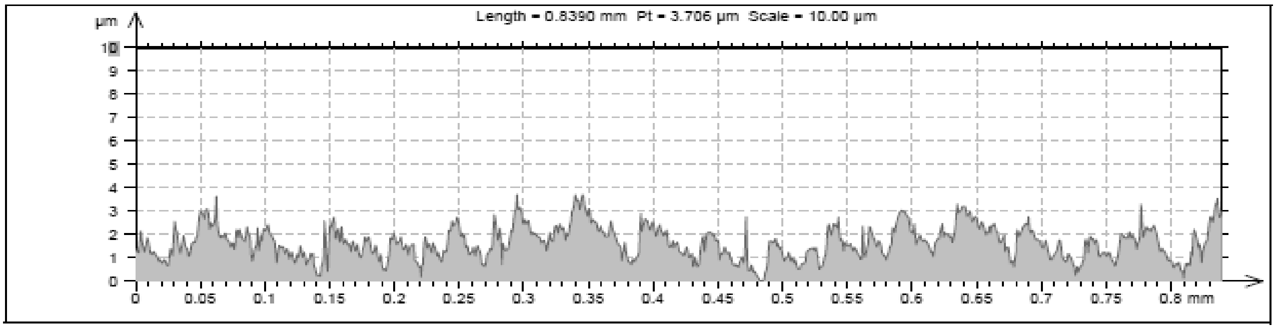

Fig. 7 *2D roughness profile – milled*

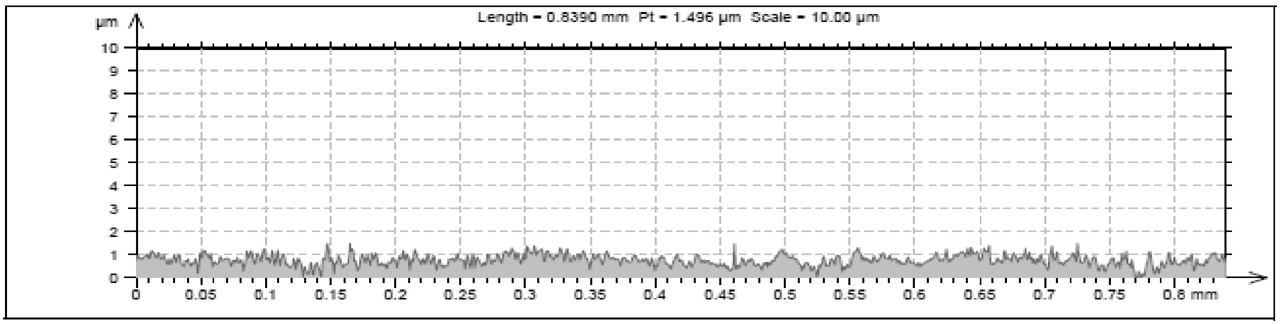

Fig. 8 *2D roughness profile – grinded*

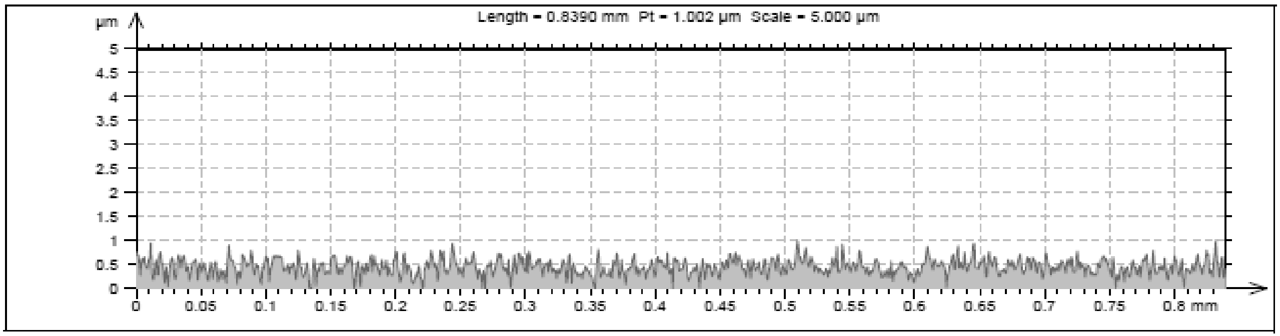

***Fig. 9** 2D roughness profile – polished*

This is followed by an evaluation of the measured profile and area surface roughness parameters. The following parameters were selected for evaluation (Tab. 6).

***Tab. 6** Overview of evaluated parameters*

g		
Sz	The greatest height of the limited scale of the surface	[µm]
Sa	Arithmetic mean deviation of the limited scale of the surface	[µm]
3D functional parameters		
Svk	Reduced depth deepens the limited scale of the surface	[µm]
Spk	Reduced peak height of limited surface scale	[µm]
Sk	The basic roughness core depth of the limited surface scale	[µm]
Sr2	The fraction of material below the roughness core of the limited surface scale	[%]
Sr1	The fraction of material above the roughness core of the limited surface scale	[%]
2D profile parameters		
Rz	The greatest height of the roughness profile	[µm]
Ra	Arithmetic mean deviation of the roughness profile	[µm]
Rdq	Root mean square slope of the roughness profile	[°]
RSm	The average width of the roughness profile element	[mm]
2D functional parameters		
Rvk	Reduced depth of roughness profile depressions	[µm]
Rpk	Reduced height of roughness profile peaks	[µm]
Rk	Basic roughness profile core depth	[µm]
Mr2	The proportion of material below the core of the roughness profile	[%]
Mr1	The proportion of material above the core of the roughness profile	[%]

Tab. 7 shows the measured values of surface and profile parameters of the surface roughness of five turned samples. When looking at the data, one can see low differences in the measured values of the parameters, while no regularity can be seen, where, for example, the quality of the surface increases or decreases significantly with increasing revolutions. The values of the average arithmetic deviation parameters (Sa, Ra) are approximately the same, within a tolerance of ± 0.1 µm.

Tab. 7 *Ertacetal C – turned samples*

Sample	1.	2.	3.	4.	5.
Revolutions *(n)*	2100 [min^{-1}]	2280 [min^{-1}]	2450 [min^{-1}]	2600 [min^{-1}]	2700 [min^{-1}]
3D amplitude parameters					
Sz [µm]	5.53	3.88	3.78	3.83	3.37
Sa [µm]	0.61	0.53	0.63	0.62	0.54
3D functional parameters					
Svk [µm]	0.67	0.63	0.84	0.64	0.63
Spk [µm]	0.81	0.53	0.53	0.57	0.48
Sk [µm]	2.02	1.61	1.62	1.63	1.63
Sr2 [%]	91.11	87.12	86.33	88.58	88.71
Sr1 [%]	7.01	5.89	5.93	8.28	10.11
2D profile parameters					
Rz [µm]	4.26	3.32	3.48	3.58	3.13
Ra [µm]	0.57	0.52	0.61	0.61	0.49
Rdq [°]	14.39	11.98	11.58	10.41	9.68
RSm [mm]	0.029	0.028	0.032	0.038	0.031
2D functional parameters					
Rvk [µm]	0.51	0.72	0.82	0.78	0.78
Rpk [µm]	0.53	0.47	0.39	0.56	0.44
Rk [µm]	1.93	1.55	1.79	1.78	1.49
Mr2 [%]	91.17	84.37	87.68	86.99	88.01
Mr1 [%]	7.02	7.97	6.08	9.26	10.81

Tab. 8 shows the measured values of surface and profile parameters of the surface roughness of five milled samples. As in case of turning, also in milling, the change in cutting speed had no significant effect on the values of the arithmetic average deviation parameters (Sa, Ra). The effect of cooling on the quality of the machined surface was also not recorded. The values of the average arithmetic deviation parameters, in case of dry and wet machining, differ within a tolerance of ± 0.1 µm. Only one sample (No. 4, cooled) had significantly different values compared to the others. No deformation was visible on the image of the material, so it can be concluded that this deviation was probably caused by poor clamping of the workpiece or dirt on the tool.

Tab. 8 *Ertacetal C – milled samples*

Sample	1.		2.		3.		4.		5.	
Revolutions *(n)*	3200 [min^{-1}]		3425 [min^{-1}]		3650 [min^{-1}]		3900 [min^{-1}]		4100 [min^{-1}]	
Cooled	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES
3D amplitude parameters										
Sz [µm]	3.11	3.08	4.19	4.53	2.82	3.09	3.71	17.88	3.96	4.58
Sa [µm]	0.43	0.49	0.43	0.53	0.42	0.48	0.53	1.07	0.54	0.56
3D functional parameters										
Svk [µm]	0.52	0.43	0.49	0.56	0.37	0.56	0.48	2.08	0.51	1.12
Spk [µm]	0.67	0.51	0.59	0.69	0.38	0.78	0.61	2.97	0.53	0.52
Sk [µm]	1.38	1.58	1.22	1.28	1.29	1.33	1.49	2.34	1.94	1.64
Sr2 [%]	90.04	88.44	90.14	90.36	91.44	90.97	92.26	86.39	92.31	84.47
Sr1 [%]	10.69	6.09	10.39	10.76	8.54	10.62	12.21	9.14	5.81	9.17
2D profile parameters										
Rz [µm]	3.03	2.57	3.43	4.49	2.61	2.97	3.43	14.89	3.41	3.94
Ra [µm]	0.43	0.43	0.43	0.51	0.43	0.47	0.52	1.02	0.52	0.54
Rdq [°]	8.18	8.62	11.43	10.12	8.23	8.34	11.11	46.81	12.32	14.88
RSm [mm]	0.028	0.034	0.028	0.026	0.029	0.028	0.028	0.028	0.027	0.028
2D functional parameters										
Rvk [µm]	0.66	0.51	0.48	0.47	0.58	0.46	0.48	2.27	0.53	1.03
Rpk [µm]	0.63	0.33	0.48	0.58	0.49	0.53	0.74	1.98	0.51	0.48
Rk [µm]	1.34	1.52	1.29	1.23	1.23	1.33	1.68	2.39	1.89	1.71
Mr2 [%]	89.67	88.72	88.28	88.98	87.57	89.13	90.94	83.53	92.48	84.83
Mr1 [%]	10.13	6.22	8.68	8.78	10.47	9.02	9.67	11.32	7.37	7.93

Tab. 9 shows the measured values of the area and profile parameters of the surface roughness of five ground samples. Looking at the data, it can be seen that very similar values are achieved for 1, 2 and 4 samples. For sample 5, the measured values deteriorated, therefore it can be concluded that the selected grinding conditions for sample 5 are unsuitable for this material.

Tab. 9 *Ertacetal C – ground samples*

Sample	1.	2.	3.	4.	5.
Revolutions *(n)*	1000 [min^{-1}]	1300 [min^{-1}]	1600 [min^{-1}]	1900 [min^{-1}]	2200 [min^{-1}]
3D amplitude parameters					
Sz [µm]	2.21	2.13	1.51	2.28	3.28
Sa [µm]	0.23	0.22	0.18	0.24	0.31
3D functional parameters					
Svk [µm]	0.54	0.49	0.27	0.38	0.85
Spk [µm]	0.28	0.31	0.24	0.23	0.31
Sk [µm]	0.64	0.69	0.56	0.58	0.75
Sr2 [%]	86.43	88.34	89.84	88.14	86.28
Sr1 [%]	9.73	10.24	10.14	9.59	9.18
2D profile parameters					
Rz [µm]	1.94	1.98	1.28	1.72	2.81
Ra [µm]	0.23	0.23	0.18	0.18	0.32
Rdq [°]	6.97	6.58	5.74	5.96	6.63
RSm [mm]	0.022	0.024	0.019	0.018	0.033
2D functional parameters					
Rvk [µm]	0.56	0.52	0.31	0.38	1.24
Rpk [µm]	0.23	0.23	0.18	0.24	0.26
Rk [µm]	0.62	0.69	0.54	0.47	0.77
Mr2 [%]	84.33	84.78	87.24	86.78	82.59
Mr1 [%]	9.28	8.38	10.39	10.49	9.11

Tab. 10 shows the measured values of the area and profile parameters of the surface roughness of five polished samples. Looking at the data, it can be concluded that the differences in the values of the roughness parameters were probably caused by the different forces and angles with which the samples were pressed against the polishing paper during manual polishing.

Tab. 10 *Ertacetal C – polished samples*

Sample	1.	2.	3.	4.	5.
Revolutions *(n)*	100 [min^{-1}]	150 [min^{-1}]	200 [min^{-1}]	250 [min^{-1}]	300 [min^{-1}]
3D amplitude parameters					
Sz [µm]	1.01	1.48	5.61	1.57	1.53
Sa [µm]	0.14	0.18	0.33	0.16	0.13
3D functional parameters					
Svk [µm]	0.18	0.24	0.78	0.21	0.26
Spk [µm]	0.21	0.26	0.78	0.28	0.23
Sk [µm]	0.41	0.43	0.84	0.43	0.42
Sr2 [%]	90.33	89.81	86.88	89.64	88.62
Sr1 [%]	10.93	10.96	11.53	10.99	10.57
2D profile parameters					
Rz [µm]	0.88	1.44	4.11	1.08	1.18
Ra [µm]	0.12	0.16	0.24	0.13	0.14
Rdq [°]	5.62	6.02	14.48	6.32	6.37
RSm [mm]	0.013	0.014	0.018	0.014	0.013
2D functional parameters					
Rvk [µm]	0.14	0.19	0.61	0.17	0.22
Rpk [µm]	0.13	0.18	0.38	0.18	0.17
Rk [µm]	0.35	0.36	0.58	0.38	0.39
Mr2 [%]	90.38	89.83	86.47	90.01	89.73
Mr1 [%]	11.03	10.53	10.62	11.06	11.13

To compare the individual machining technologies with each other, the evaluated parameters of the measured samples were averaged within the given machining technology. The averaged measurement results of all machining technologies are shown in Tab. 11. For a more objective comparison, the values of the samples that were significantly different from the values of the others were not included in the calculated average. Furthermore, the evaluation of individual surface and profile parameters of the surface roughness with regard to practical use is given.

***Tab. 11** Ertacetral C – comparison of machining technologies*

	Turned	Milled (on dry)	Milled (cooled)	Grinded	Polished
3D amplitude parameters					
Sz [μm]	4.09	3.56	3.84	2.29	1.38
Sa [μm]	0.58	0.48	0.52	0.23	0.16
3D functional parameters					
Svk [μm]	0.69	0.48	0.66	0.51	0.22
Spk [μm]	0.59	0.56	0.63	0.27	0.23
Sk [μm]	1.68	1.46	1.46	0.64	0.43
Sr2 [%]	88.39	91.24	88.56	87.81	89.58
Sr1 [%]	7.46	9.53	9.16	9.78	10.86
2D profile parameters					
Rz [μm]	3.53	3.19	3.49	1.93	1.13
Ra [μm]	0.56	0.47	0.49	0.23	0.14
Rdq [°]	11.61	10.26	10.48	6.38	6.08
RSm [mm]	0.032	0.029	0.028	0.024	0.014
2D functional parameters					
Rvk [μm]	0.73	0.53	0.62	0.58	0.18
Rpk [μm]	0.48	0.57	0.48	0.23	0.18
Rk [μm]	1.71	1.49	1.46	0.62	0.37
Mr2 [%]	87.64	89.79	87.92	85.13	89.97
Mr1 [%]	8.23	9.27	7.99	9.53	10.94

The use of area parameters to evaluate the surface is similar to the case of profile parameters, with the advantage that area parameters evaluate the entire measured area, while profile parameters describe only part of the measured area. From this, it can be assumed that the area parameters will reach mainly higher values than the profile parameters, which was also confirmed in the previous measurement. Area parameters generally have a higher ability to tell about the functional properties of the examined surface, because they evaluate the surface as a whole. The use of the surface parameter Sa instead of the profile Ra is particularly suitable in the case of measuring non-periodic surfaces, which are created, for example, by grinding and polishing technologies.

From Tab. 11, it may be seen the different values of the measured roughness of surfaces produced by individual chip machining technologies, even though for turning technologies and milling, the same cutting conditions were chosen. The average arithmetic deviation of the Sa surface in the case of turning is higher by 0.12 μm than in the case of milling. Such a difference could be due to the poor geometry of the turning knife or its insufficient sharpness. During milling, no significant effect of the use of cooling on the resulting roughness of the machined surface was noted. The Sa parameter of the cooled and uncooled surface differs by only 0.04 μm. As expected, the best results were achieved with polishing and grinding technologies, which depend on the grit of the abrasive tool. Using the parameters of the highest height of the profile Rz and the evaluated area Sz, the susceptibility of the surface to the formation of cracks can be evaluated. High values of these parameters also indicate faster surface wear and worse sealing properties caused by large distances between protrusions and depressions. A surface with high Sz and Rz values also has a negative effect on the wear of the applied lubricating film. The highest values of the Rz parameter were achieved by turning technology. A graphical representation of these parameters is shown in Fig. 10.

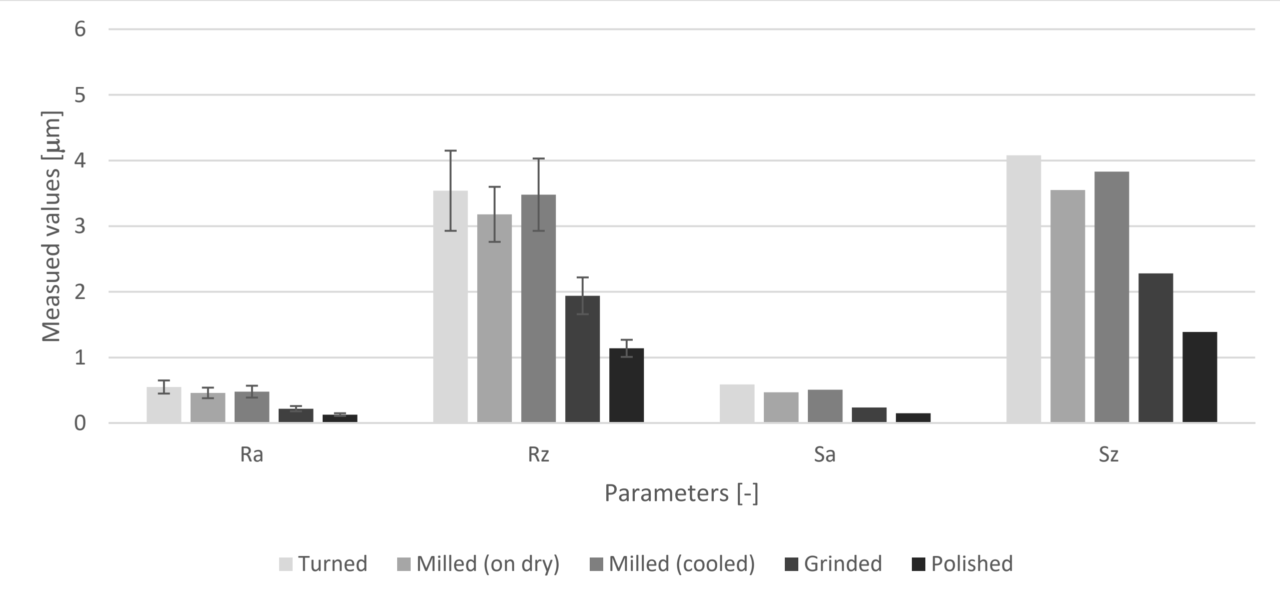

Fig. 10 *Comparison of parameters – Ertacetal C*

7 Discussion on the results achieved

The parameter describing the average width of the element of the roughness profile RSm is assumed to be numerically equal to the selected feed during machining and can be monitored e.g. to check the condition of the cutting tool. This assumption was not confirmed in the measurements. Turning and milling technologies achieved approximately the same RSm value, but lower, than the selected feed (by approximately 0.02 mm). Polishing of the samples was carried out manually, and therefore it is not possible to evaluate the connection between the parameter RSm and the feed during machining.

Another evaluation parameter is the average quadratic slope of the Rdq profile. This parameter is particularly suitable for very fine surfaces. A greater slope means higher friction of the material, easier deformation under load and overall greater wear of the material. The main advantage of a greater slope is the adhesion of the material. The slope of the profile also has a significant effect on the vibrations generated on the surface. The smaller the slope, the lower the vibrations. A low slope is typical for good surface reflectivity. According to the assumption, the lowest slope value was achieved by grinding and polishing technologies. The highest slope value was achieved with the turning technology, 1.35° more than the milling technology.

The last parameters measured were the so-called functional parameters of surface roughness. The output of these parameters is the bearing share of the material, which is characteristic for individual machining technologies. Functional parameters have a significant influence for assessing loaded functional surfaces, solving problems of friction, lubrication and wear. The parameter Rk and its area equivalent Sk, which describe the width of the material's core, have the most important meaning for functional properties. The smaller the width of the core, the flatter the surface and the less material wear on the contact surfaces. The low values of the core width are mainly achieved by fine finishing machining operations (grinding, polishing), which was confirmed in the measurements. Turned and milled samples again achieved similar values. The parameter Rpk (Svk) expresses the proportion of the height of the profiles that is above the basic core of the profile Rk (Sk). Exceptionally high protrusions are not included in the value of this parameter. The highest values of Rpk (Spk) parameters were achieved by milling technology, therefore the milled surface will wear out the fastest. Conversely, ground and polished surfaces will be more resistant to wear and tearing of the lubricating film. The parameter of the reduced height of depressions Rvk (Svk) expresses the proportion of the height of the profiles below the basic core of the profile Rk (Sk), reduced by the isolated high values of the depressions. The Rvk parameter has a significant influence in terms of assessing the sustainability of the applied lubricant on the contact surface. From a practical point of view, a surface with a higher value of the Rvk parameter will better hold the applied lubricant at the point of contact of the surfaces. From the measured data, it can be seen that in the case of turning and grinding technologies, depressions prevail over protrusions on the resulting surface. In the case of milling and polishing, the distribution of protrusions and depressions is balanced. The proportion of material above and below the core is expressed as a percentage by the parameters Mr1 and Mr2 (Sr1 and Sr2). The smaller the distance between the Mr1 and Mr2 values, the smaller the contact reliability of the surface under load. The proportional distribution of the material is almost equal for all technologies. The best values of the material share were achieved by milling technology (81.7 %), the worst result was the ground surface (78 %) [32].

From the results, it can be noted that each machining technology will have certain advantages and disadvantages for different practical applications, and therefore it is necessary to choose the machining technology depending on what purpose the surface will serve. Therefore, it is not possible to clearly determine which technology is the best.

8 Conclusion

The contribution deals with the issue of evaluating the influence of conventional methods of chip machining (turning, milling, grinding and polishing) on the surface texture of functional surfaces for the plastic material Ertacetal C and at the same time discusses the effect of cooling during machining. A total of 20 samples were prepared, which were machined with selected technologies, measured and evaluated based on surface and profile parameters of surface roughness. In the contribution, statistical processing of the measured data, graphical comparison of individual chip machining methods and evaluation of the measured surface roughness parameters with regard to practical use, which is evaluated in the discussion, were performed.

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