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SURFACE ROUGHNESS OF STRUCTURAL POLYMER MATERIALS AFTER MILLING

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Abstract: *The work was made to determine the technological conditions of milling of modern structural polymer construction materials due to the micro-geometrical structure of the machined surface (surface roughness). Wide spectrum of different type of modern structural polymer materials, used for toolmaking, prototyping and machine parts making application were machined. Five, commonly used, surface roughness parameters were specified, using MarSurf GD 120 PC - Based Roughness Measuring Unit. Original results of the experiment related to comparison of material and roughness with the use of two different milling tools were presented and discussed.*

Keywords: surface roughness, milling, structural polymer materials

1. Introduction

The milling process, thanks to the possibility of high-elastic processing workpieces of very different materials, shapes and dimensions, has found wide application in the field of machining materials. The increase of application areas of this type of machining, especially in area of polymers machining, required broadening the scope of knowledge on this subject (Byrne et al., 2003). The dynamic development of this technique has enabled machining of products with very high dimensional accuracy as well as the highest quality surface layer. Cutting of polymeric materials, especially composites, places special demands on the properties of the workpiece. Difficult heat dissipation can lead to melting of the workpiece. Proper selection of the tool and parameters is also important due to the phenomenon of delamination (Teti, 2002, Sheikh-Ahmad et al., 2012). The condition (state) of the machined surface is particularly important due to the functional properties of the objects. This is particularly important when it is necessary to obtain surfaces with specific characteristics, e.g. significant adhesion (Ligaj et al., 2018) of in case of cooperating pairs (Musiał et al., 2017). Determining the optimal conditions for machining can be done using automated process control systems. Knowledge of the relationship between machining conditions and the condition of the machined surface is important for determining the boundary conditions of automatic process control systems (Mikołajczyk et al., 2016). The surface condition can be determined, for instance, by the surface roughness parameters values. It is important to manage rational machining so as to obtain the required condition of the processed surface while maintaining high machining efficiency (Musiał et al., 2018).

2. Experimental methods

Research involved milling seven samples made of structural polymer materials. Samples were profile (side) milled; in-cut and out-cut. The surface roughness parameters after milling were determined, which allowed conclusions to be formulated, regarding milling modern structural polymer materials with various tools and parameters. Milling parameters and other conditions were, as follows:

- cutting speed: 25.56 m/min (at 710 rev/min and 12 mm tool diameter),
- tool federate: 200 mm/min,

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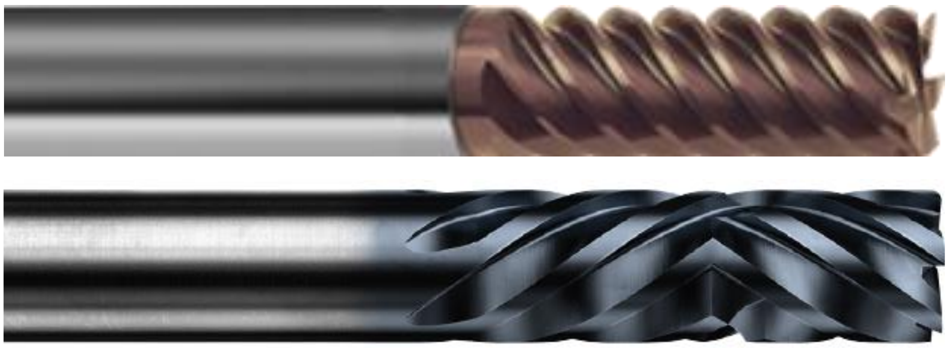
- mill no.1: Guhring 3715 cutter - for hardened steel (Fig. 1a). The outer diameter of the tool: 12 mm, the length of the cutting edge: 26 mm, the angle of the cutting edge: 55 degrees, the number of edges – 6, details can be found at: https://guehring.com,
- mill no.2: specialized milling cutter for composite materials: Sandvik CoroMill Plura 2P460-1200-NA (Fig. 1b). The outer diameter of the tool: 12 mm, the length of the cutting edge: 38mm, the angle of the cutting edge: 30 degrees, the number of edges – 6, details can be found at: https://www.sandvik.coromant.com.
- TOS OLOMOUC FB 25 numerical control milling machine,
- in-cut and out-cut milling at 3 repetitions (for each case),
- dry milling (without coolant).



a)

b)

Fig. 1: Tools, used in experiment: a) mill no. 1. - Guhring 3715;
b) mill no. 2. - Sandvik CoroMill Plura 2P460-1200-NA,

Seven samples of different polymer materials were used for the experiment. Main material properties are summarized in Tab. 1. TCF; phenolic cotton laminated plastic (laminate) is common used for high durability parts and constructions, especially wear resistant ones, RenShape® materials are mostly used for prototyping processes and light structures constructions. Cibatool® polymer materials are used for mold making, tool making and modelling.

Tab. 1: Material properties.

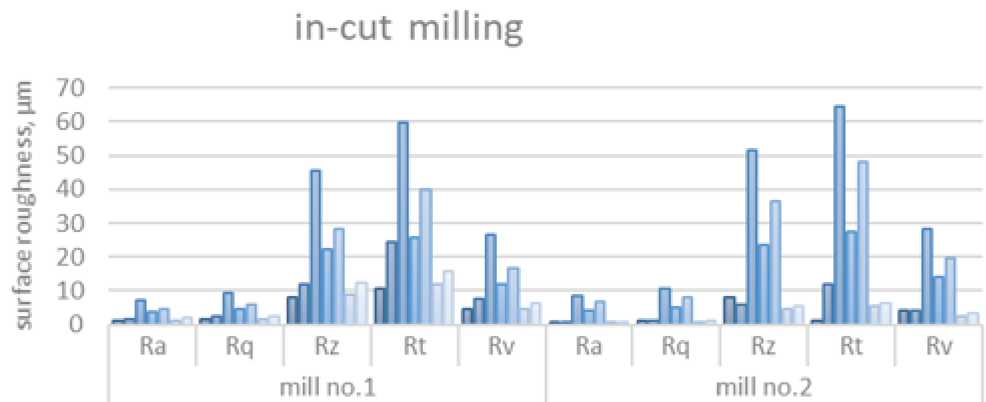
material	**ρ [g/cm^3]**	**σ [MPa]**	**Shore D**
TCF (Tekstolit)	1.5	80	85
RenShape® BM5273	1.4	90	120
RenShape® BM5035	0.45	0,02	48
Cibatool® BM5005	0.56	25	68
RenShape® BM5185	0.5	15	-
Cibatool® BM5272	1.4	80	85
Cibatool® BM5168	1.4	90	85

Surface roughness parameters; Ra, Rq, Rz, Rt and Rv were measured, using MarSurf GD 120 PC-Based Roughness Measuring Unit.

3. Results and discussion

The obtained results of measurements of the micro-geometrical structure of the surface (surface roughness parameters) were analyzed. The influence of the type of tool used and material type applied to the values of the individual roughness parameters - for mean values.

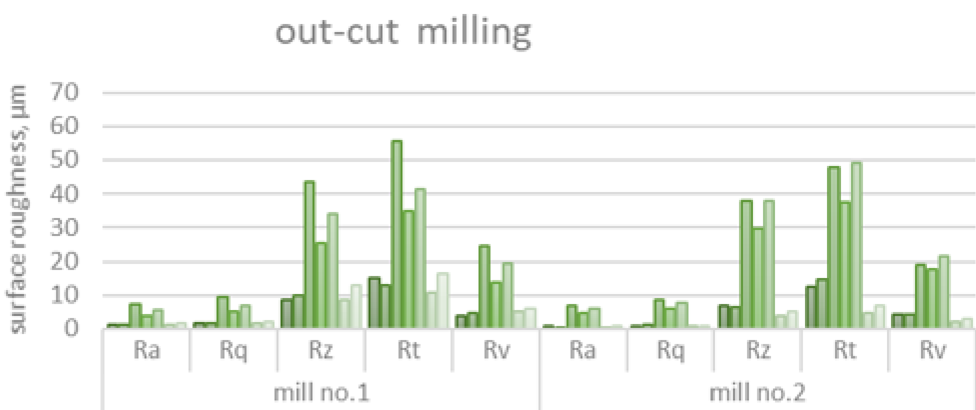
The results of the analyses were presented in the form of graphs. Averaged values determined on the basis of measurements from 3 replicates are presented in Figs. 2 and 3 in graphic form and the given values.



	mill no.1 Ra	mill no.1 Rq	mill no.1 Rz	mill no.1 Rt	mill no.1 Rv	mill no.2 Ra	mill no.2 Rq	mill no.2 Rz	mill no.2 Rt	mill no.2 Rv
Tekstolit TCF	1,23	1.58	8.06	10,49	4.56	0.81	1.25	8.12	1.20	4.27
Renshape BM 5273	1,51	2,32	11,89	24,26	7.48	0,59	0.99	5.71	12,03	3,91
Renshape BM 5035	7.16	9,36	45.36	59.54	26.43	8.22	10.47	51.40	64.33	28.34
Cibatool BM 5005	3,49	4,42	22,06	25.63	11.73	4.00	5,09	23,58	27.53	14,23
Renshape BM 5185	4.67	5.88	28.47	40.08	16.63	6.60	8.12	36.27	48.25	19.43
Cibatool BM 5272	1.28	1.65	8.78	11.83	4.57	0.65	0.83	4.63	5.33	2.59
Renshape BM 5168	1.85	2.35	12.39	15.92	6.22	0.77	0.96	5.44	6.39	3.19

Fig. 2: Surface roughness in µm for in-cut milling for mill no.1 (left side, roughness parameters from Ra to Rv) and mill no.2 (right side, roughness parameters from Ra to Rv); adequate values below.

When observing the milled surface of the samples, no significant differences in the surface roughness of the material were noticed; all samples had a similar geometrical surface structure of the surface and traces remaining on it after machining. Low values of surface roughness parameters were observed after in-cut and out-cut machining TCF, Renshape® BM 5273, Renshape® BM5168 and Cibatool® BM5272 in a case of use of booth milling tools. Lower values of surface roughness under the same conditions for all materials were observed using mill no. 2. The lowest values of surface roughness parameters were observed after machining TCF with mill no.1 and Cibatool® BM5277 with mill no. 2. Other materials (Renshape® BM 5035, Renshape® BM 5185 and Cibatool® BM5005). Analyzing the measurements of roughness, it was observed that lower roughness values for given parameters occurred mostly on the surface of counter-milled samples, in particular milling cutter no. 2; mill with opposing cutting edges. The highest value of the Ra parameter occurs during down (in-cut) milling with tool no. 2; was 8,22µm, for Renshape® BM 5035. The lowest value of the same parameter occurred during up (out-cut) milling with cutter no. 2, its value was 0.54 µm for Cibatool® BM 5272. 10.4733µm was the highest value of the Rq parameter. It occurred during milling of Renshape® BM 5035 with mill no. 2. The lowest value of the Rq; 0.6877 µm parameter was obtained during machining with tool no. 2 of the sample from the Cibatool® BM 5272. The next analyzed parameter was Rz. The highest value - 45.3583 µm - of this parameter was observed for the Renshape® BM 5035 material, which was milled with tool no. 1. The lowest value of Rz parameter was 3.70 µm. The Cibatool® BM 5272; it was milled in the opposite direction with tool no. 2. Analyzing the total height of the profile Rt, it was noticed that the highest value of this parameter occurred during the co-milling of Renshape® BM 5035 material with tool no. 2, its value was 64.33µm. The lowest value of the total height of the profile; 4.67 µm was observed when testing the Cibatool® BM 5272 sample, milled with counter-cutter no. 1. The last parameter to analyze was the depth of the lowest pit Rv. Its highest value was 28.34 µm, it occurred on the surface of the Renshape® BM 5035 sample, which was in-cut milled with tool no. 2. The lowest value of this parameter was 1.97 µm for the Cibatool® BM 5272, which was out-cut milled with tool no. 2.



	mill no.1					mill no.2				
	Ra	Rq	Rz	Rt	Rv	Ra	Rq	Rz	Rt	Rv
Tekstolit TCF	1.18	1.56	8.47	15.09	4.06	0.68	0.94	6.93	12.63	4.37
Renshape BM 5273	1.34	1.74	9.78	13.11	4.57	0.61	1.08	6.37	14.75	4.07
Renshape BM 5035	7.41	9.27	43.48	55.39	24.65	6.91	8.47	38.09	47.62	18.82
Cibatool BM 5005	3.88	5.03	25.35	35.01	13.62	4.78	5.96	29.52	37.37	17.81
Renshape BM 5185	5.54	7.08	34.14	41.43	19.49	5.94	7.58	37.80	48.90	21.35
Cibatool BM 5272	1.28	1.64	8.80	10.91	5.16	0.54	0.69	3.70	4.69	1.97
Renshape BM 5168	1.66	2.25	12.95	16.18	6.19	0.65	0.85	5.33	6.82	3.14

Fig. 3: Surface roughness in µm for out-cut milling for mill no.1 (left side, roughness parameters from Ra to Rv) and mill no.2 (right side, roughness parameters from Ra to Rv); adequate values below.

4. Conclusions

The conducted research, including wide range of different structural polymer materials and analysis of the available literature in the field of the study enabled the formulation of the following conclusions:

- surface roughness parameters values were nearly independent on tool type and feed direction,
- lowest values of surface roughness parameters occurred after machining high-density polymer materials, especially composites,
- largest values of surface roughness parameters occurred after machining low-density polymer materials, probably due to the superimposition of the material's internal structure on the surface structure,
- further investigations are needed, especially in the area of diversified machining parameters and other environmental conditions (e.g. cooling, cryogenic cooling, MQL and others).

References

Byrne, G., Dornefeld, D., Denkena, B. (2003) Advancing cutting technology. Annals of CIRP, No.2/2003.

Ligaj, B., Wirwicki, M., Karolewska, K., Jasinska, A. (2018) Experimental studies of glued Aluminum-glass joints, 3rd International Conference on Science, Technology, and Interdisciplinary Research (IC-Star), Book Series: IOP Conference Series-Materials Science and Engineering, vol: 344, no. UNSP 012014, DOI: 10.1088/1757-899X/344/1/012014.

Mikołajczyk, T., Fąs, T., Kłodowski, A., Matuszewski, M., Olaru, A., Olaru, S. (2016) Computer Aided System for Superfinishing Process Control. Proceedings 9th International Conference Interdisciplinarity in Engineering, INTER-ENG 2015, Book Series: Procedia Technology, vol. 22, 2016, 48-54.

Musiał, J., Polasik, R., Kałaczyński, T., Szczutkowski, M., Łukasiewicz, M. (2018) Milling efficiency aspects during machining of 7075 aluminium alloy with reference to the surface geometrical structure. 24th International Conference on Engineering Mechanics, Engineering Mechanics vol. 24, 2018, pp. 569-572.

Musiał, J., Szczutkowski, M., Polasik, R., Kałaczyński, T. (2017) The Influence of Hardness of Cooperating Elements on Performance Parameters of Rolling Kinematic Pairs. Proceedings of 58th International Conference of Machine Design Departments - ICMD 2017 pp. 260-265.

Sheikh-Ahmad, J., Davim, P. J. (2012) Cutting and Machining of Polymer Composites, in book: Wiley Encyclopedia of Composites, DOI: 10.1002/9781118097298.weoc061.

Teti, R. (2002) Machining of Composite Materials, Annals of the CIRP 51/2:611-634.