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EXPERIMENTAL RESEARCH ON MILLING OF THE POLYETHERETHERKETONES (TECAPEEK NATURAL)-WHIT BALL-NOSE END MILL

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Abstract: *The use of composite biomaterials has become a common necessity in medical practices. From this extensive range of materials, the group of polymers stands out due to the advantages they have from the point of mechanical properties, chemical resistance and compatibility. Polyetheretherketone is a kind polymer material with similar elasticity to bone and one of the most promising engineering plastics. For this reason, a lot of research concludes that polyetheretherketone has good processability. It will be a great advantage to be used frequently in medical technique for trauma, orthopedic, dental reconstruction and spinal implants. The shape of those elements used to replace some human or animal parts are very complex by the point of component surfaces. The roughness of those surfaces has a major influence in the success of the medical intervention and its durability. For this reason, experimental research to optimize the processability process is needed.*
Key words: *Surface roughness, inclination angle, cutting speed, milling, polyetheretherketones (Tecapeek natural).*

1. INTRODUCTION

Following numerous researchers upon biomaterials, PEEK and related composites can be used for different implants applications because of wide range of physical, mechanical, and surface properties [1].

Different forms of PEEK materials have been applied in surgical fields like spine surgery, maxillo-facial surgery, and orthopedic surgery (figure 1). A lot of PEEK based materials is used in the variety of medical fields like an important group of biomaterials for bone and cartilage replacement [2]. The bio-medical technique for different types of trauma is using the group PEEK materials because the result was better in comparison with another material. Compared with titanium in treatment of intervertebral height and cervical lordosis, the cage from PEEK offers better clinical results in analysis made for long period of use [3]. Because of its advantage of wear rates in the functioning of the human body, particularly on ceramic bearing, the particle size of Peek materials results from tribological process represent an important reason for using against different elements made from metal-on-metal or polyetilene-on-CoCr used in TDRs [4]. Also, in cervical discectomy and fusion, a lot of researchers concludes that the cage made from PEEK is the most widely used in anterior cervical discectomy and fusion [5,6].

Recent studies shows that in the dental market the PEEK material can be a non-metallic alternative material for removable partial denture framework construction with superior mechanical properties [7]. The urgent need of space maintainers with a good biocompatibility with human body but also thanks for its dimensional stability, the PEEK it is recommended as a very good material [8]. In order to make different shape and parts for cranial implants, with very complex surfaces, are necessary some steps from scanning of skull of the patience to CAD/CAM system and in the end to effective machining of parts by milling or injection process systems [9]. In tribological process of artificial joint system used for clinical applications, the wear particle generated by friction between two parties, which remain in contact zone, influences the lifetime of implants [10]. The wear particles lead in general to clinical complications or the worst to loosening of prosthesis because wear particles are not supported by human body. The type and the size of wear particles are influenced by a several factors like the surface roughness.

Fig. 1. Applications of polyetheretherketone materials [1], [8], [9], [11].

The PEEK bio composite have applicability like an orthopedic implant material in bone repair and bone tissue engineering applications with condition that the parties must have favorable value of surface roughness [12]. A great number of research shows that the surface roughness value has an important influence upon integration of implants in human or animal body.

One of the most used methods for machining complex shapes for different implants elements is ball nose end milling. To control the results of this process and the surface quality, it is needed to establish the optimal combination of technological parameters that are necessary to grow the machining performance [13].

2. THE TOOL AXIS INCLINATION

The ball nose end milling process is a special method for machining of complex surfaces. Because the cutting edge is distributed on a circular arc, the area of uncut chip in cross section is variable [14].

The ball end milling process are a most used method in multi-axis finishing machining of curved surfaces. The tool orientation has a significant impact on the milling process and surface quality [15].

Although, in PhD thesis,"Surface quality in ball end milling", Pasca and Lobontiu conclude that the best value of surface roughness resulted when the surfaces are machined with the tool axis inclined around Y axis in counterclockwise direction with 15°. Research in biomedical field shows that not all the time the smaller value of roughness is optimal for biocompatibility and bio integration. In this situation is needed to know how the tool axis inclination can influence the surface quality [16].

The effective cutting speed is one of the most important parameters in ball nose end milling process. Because of specific features of ball nose end milling process it is not enough to analyze the influence of each technological parameters but the optimization of the conditions by correlation between al parameters. [16].

In this situation, the best quality of surface, characterized by surface roughness, it depends by correlation between tilt angle and spindle speed.

The cutting and geometrical parameters, specifical for ball nose end milling process, used in our research are presented in table 1.

In accordance with the diameter of ball end mill, spindle speed and inclination angle, the variation of effective cutting speed, for values of tilting angle used in research, are presented in the first columns of table 3 and 4.

Table 1

The used cutting parameters

Parameter	Units	Value
Tool radius	[mm]	5
Feed per tooth	[mm]	0.15
Radial depth	[mm]	0.15
Axial depth	[mm]	0.15

3. EXPERIMENTAL SETUP AND WORK CONDITIONS

The cutting parameters represented by tilt angle and spindle speed are the most influential parameters upon effective cutting speed and implicit upon milling process in ball nose end milling. The identification of some values for each parameter that can be combined in order to obtain the best condition of the process will lead

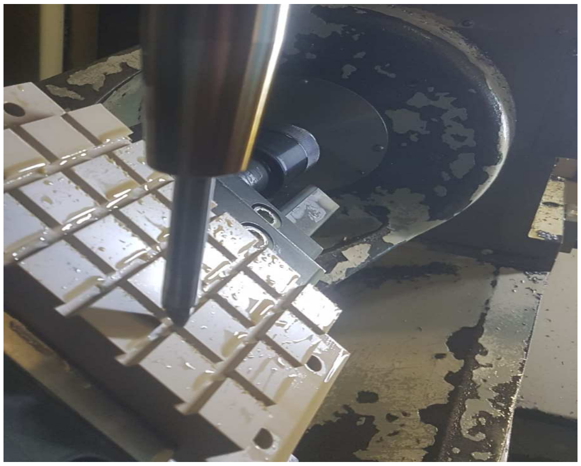

Fig. 2. Tool axis inclination.

to the smaller value of surface roughness.

The effective cutting speed is defined by the values of tilt angle and spindle speed.
Because the cutting speed values are higher it coolant was used to reduce the possibilities of heating the work-piece, chip and tool.

3.1 The experimental equipment

The experiments are concerned with a 5 axis CNC machine tool, Okuma MU-400VA.

The tools used in experiments are manufactured by ISCAR LTD (table 2).

Table 2

Tools used in experiments

No.	**Type**	**Code**
1.	Tool holder	MM TS-A-L080-C10-T06
2.	Inserts	MM EBA100B07-2T06 IC08

3.2 Workpiece material

Mechanical and physical properties of Polyetheretherketones (Tecapeek-natural), produced by Ensinger Gmbh are describe in table 3. The workpiece was a plate with 25 mm thickness, length of 195 mm and with of 95 mm. Also, a matrix structure with 4 columns for different value of spindle speed and 6 rows for different values of tilting angle was created.

3.3 Experimental conditions

With respect of parameters indicated in table 1,2,3,4 and 5, and by practice the milling in feed direction, indicated by the most researchers to be the best strategy in ball end milling the experiments took place in good conditions.

Table 3

Properties of polyetheretherketone

Properties	**Value**	**Unit**
Young Modulus	3.5 - 3.9	GPa
Density	1.26 - 1.32	g/cm^3
Elongation at break	30 - 150	%
Thermal conductivity	0.25	W/m.k
Toughness	80 - 94	J/m
Flexibility	3.7-4	GPa

3.4 Surface roughness measurements

To obtain a clear characterization of surface, the measurements of surface roughness were made for R_a and R_Z. The device TR200 with the related software was used. The topography of surface machined can be predicted only if the analysis is made in direction of tilt angle and perpendicular to tilt angle.

3.5 Experimental results

Experimental data for surface roughness were measured and presented in table 4 and table 5.

The topography of surface for each value of tilting angle is presented in figure 4. In these conditions it is obvious that the smallest value for surface roughness were obtained also for an angle with the value of 15°.

4. ANALYSIS OF EXPERIMENTAL RESULTS

The influence of tool axis tilting angle on surface roughness, in B positive direction, was analyzed in the first part of research by researcher Pasca et all for spindle speed of 7500 [rot/min] [16].

Analysis of surface roughness values, when using spindle speed of 10.000 [rot/min] indicate that the best results were obtained also for tilting angle with 15° value, but with good condition also until 30° value (figure 4,6). The higher values of surface roughness were obtained between 45° and 60° values, but also when tilting angle value is near 90° (figures 5,7). For values of tilting angle smaller that 30°, a higher value of spindle speed and implicit of effective cutting speed lead to smaller value of surface roughness. If it is necessary to use tilting angle bigger that 30° it is recommended not to increase the spindle speed because the roughness value is getting worse.

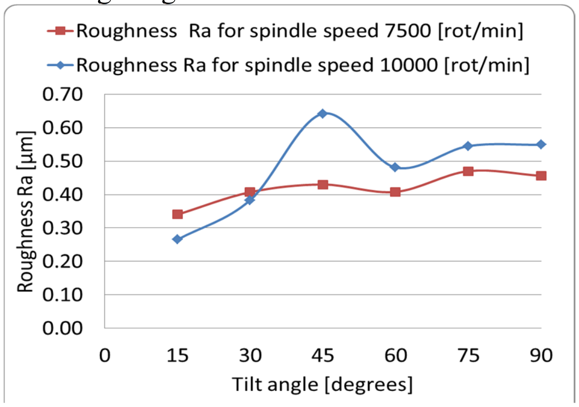

Fig. 4. The variation of surface roughness R_a for measurement in feed direction

The fact that it is noticeable is that for tilting angle with 15° value the improvement of surface quality by increasing the spindle speed from 7500 [rot/min] to 10000 [rot/min] it is possible to reduce the roughness by almost 50% from 0.574 [μm] to 0.316 [μm].

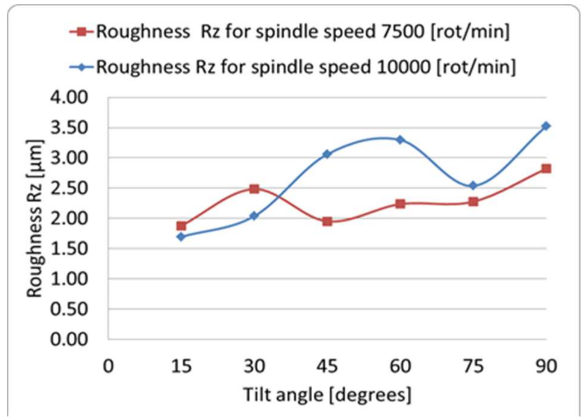

Fig. 5. Variation of surface roughness R_z for measurement in feed direction

For tilting angle between 60° and 90° increasing of spindle speed does not significantly influence the surface roughness, fact revealed by the results obtained for measurements made in tilting direction..

Table 4

Surface roughness measured parallel whit the feed direction

No.	**Spindle speed**	**Tilt angle**	**Effective cutting speed**	Surface quality [μm]			
	[rpm]	[degrees]	**[m/min]**	**R_a**	**R_z**	**R_a**	**R_z**
1	7500	15	114.22	0.574	2.992		
2	10000		151.35			0.316	1.943
3	7500	30	163.67	0.519	3.363		
4	10000		217.4			0.378	2.14
5	7500	45	202.05	0.594	2.807		
6	10000		268.5			0.512	2.932
7	7500	60	226.31	0.525	2.623		
8	10000		301.44			0.504	2.74
9	7500	75	235.26	0.573	3.267		
10	10000		313.68			0.548	3.156
11	7500	90	235.55	0.603	3.376		
12	10000		314			0.538	3.236

Table 5

Surface roughness measured perpendicular on the feed direction.

No.	**Spindle speed**	**Tilt angle**	**Effective cutting speed**	**Surface quality [μm]**			
	[rpm]	**[degrees]**	**[m/min]**	**R_a**	**R_z**	**R_a**	**R_z**
1	7500	15	114.22	0.34	1.88		
2	10000		151.35			0.265	1.696
3	7500	30	163.67	0.407	2.483		
4	10000		217.4			0.383	2.036
5	7500	45	202.05	0.43	1.952		
6	10000		268.5			0.642	3.059
7	7500	60	226.31	0.408	2.236		
8	10000		301.44			0.481	3.296
9	7500	75	235.26	0.47	2.276		
10	10000		313.68			0.545	2.536
11	7500	90	235.55	0.456	2.819		
12	10000		314			0.549	3.519

Higher values of surface roughness were obtained for tilting angle with 45° value, where it is recommended to decrease the spindle speed value. In ball nose and milling of Tekapeek, the favorable values of inclination angle, by point of surface roughness, are situated in intervals between 15° to 30°

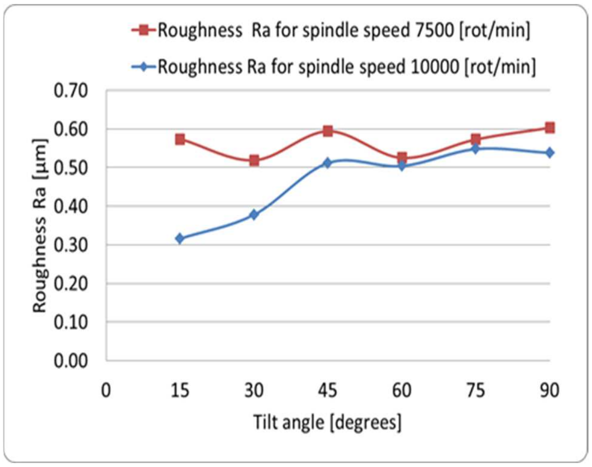

Fig.6. Variation of surface roughness R_a measured perpendicular to the feed direction.

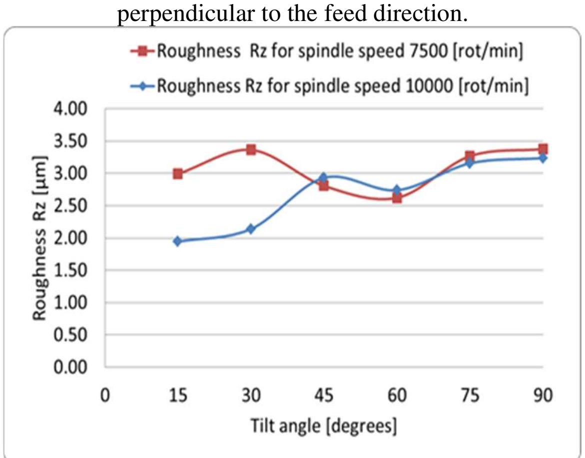

Fig.7. Variation of surface roughness R_z measured perpendicular to feed direction.

5. CONCLUSIONS

The surface roughness is influenced significantly by the inclination angle of tool axis but also by the effective cutting speed ib case of milling whit ball nose end milling cutter the polyetheretherketone (Tecapeek-natural).

By optimizing these parameters, it is possible to obtain the desired value for surface roughness but also certain topography that in medical practice is very important in order to ensure the integration of different parts in the human or animal body. In medical application of polyetheretherketone the most favorable value of surface roughness indicated by clinical research is situated between 0.2 µm and 0.3 µm. The present paper indicate only one situation when it is possible to obtain the desire value of surface roughness equal with 0,265, are when we are using tilting angle with 15° and effective cutting speed with 151.35 m/min.

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CERCETAREA EXPERIMENTALĂ A INFLUENȚEI UNGHIULUI DE ÎNCLINATIE AL AXEI SCULEI, ASUPRA RUGOZITĂŢII SUPRAFEŢEI, LA FREZAREA CU FREZĂ CU CAP SFERIC, A MATERIALULUI POLYETHERETHERKETONES (TECAPEEK NATURAL)

Rezumat: Utilizarea biomaterialelor compozite a devenit o necesitate uzuală în practicile medicale. Din această grupă extinsă de materiale, grupa polimerilor se remarcă prin avantajele pe care le prezintă din punct de vedere al proprietăților mecanice, rezistenței chimice și compatibilității. Polyetheretherketone este un material polimer cu o elasticitate asemănătoare oaselor şi unul dintre cele mai promițătoare materiale plastice industriale. Din acest motiv, mulți cercetători au indicat faptul că materialul polyetheretherketone are o bună prelucrabilitate. Acesta este un mare avantaj în vederea utilizării frecvente în tehnica medicală pentru diferite traume, în ortopedie, reconstrucția dentară şi implanturi spinale. Forma elementelor utilizate în scopul înlocuirii unor elemente umane sau animale, este foarte complexă din punct de vedere al suprafețelor componente. Rugozitatea acelor suprafețe are o mare influență asupra succesului intervențiilor și durabilității. Din acest motiv se impun cercetări experimentale în scopul optimizării procesului de prelucrare.

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