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THE DEVELOPMENT OF NEW HSS MILLING CUTTER WITH NEGATIVE GEOMETRY FOR ROUGHING OPERATIONS

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Abstract: This article deals with construction of HSS milling cutter for roughing operations. New milling cutter is constructed as a three edges milling cutter with negative geometry. Each edge is composed from two special compensation edges which are used for reducing tensile stress in heel of tooth. Autodesk Inventor Professional 2013 was used for construction the tool. New geometry of cutting tool was tested during machining artificial wood SikaBlock M610 and aluminium alloy $AlCu_4MgSi$. HSS milling cutter (producer ZPS-Frézovací Nástroje a.s., Zlín, Czech Republic) was used for comparison results. The milling process was carried out without using process liquid, so it was dry machining. Monitored parameters were force loading and tensile stress. Dynamometer Kistler was used for measuring force loading and for stress analysis was used data obtained during machining.
Keywords: high speed steel (HSS), milling, milling cutter, force loading, stress analysis

1. INTRODUCTION

There are a lot of cutting materials which are used for production cutting tools, for example, sintered carbides, high speed steel (HSS), ceramics, cermets, etc. The most widely used materials for production milling cutters are sintered carbides and HSS. Carbides are used in the form of indexable inserts or as monolithic cutting tools. HSS tools are produced as monolithic end or plug milling cutters with positive or negative geometry. Most of the tools are deposited by PVD or CVD coatings [1,2].

The milling cutters with straight teeth are prone to shocks that occur when the tool is going into the cut. For this reason, the vast majority of end milling cutters is constructed with helical teeth. Conventional cutting tools with positive geometry are prone to axial tensile stress. Axial tensile stress causes that cutting tools are pulled out of the cut and leads to generating vibrations and undercutting the surface. Cutting tools with negative geometry are susceptible to axial compressive stress [1]. For these reasons is obvious that it is difficult to find optimal geometry of cutting tool.

The new cutting tool is constructed like as three edges milling cutter with straight cylindrical shank for roughing operations. One of the main parts of this article deals with reducing the axial tensile stress. For this reason each edge is composed from two special compensation edges. These compensation edges are used for reducing tensile stress in heel of tooth. High Speed Steel ČSN 41 9830 was chosen as a cutting material.

2. TECHNOLOGY OF PRODUCTION

Autodesk Inventor Professional 2013 was used for creating 3D model of cutting tool and this model was converted into stl. format which was necessary for 3D printing. Technology Fused Deposition Modelling (FDM) was used for obtaining real plastic 3D model. This plastic prototype was used for visualizing and evaluating the designed geometry and then it is used for creating silicone mold which is important for creating wax models.

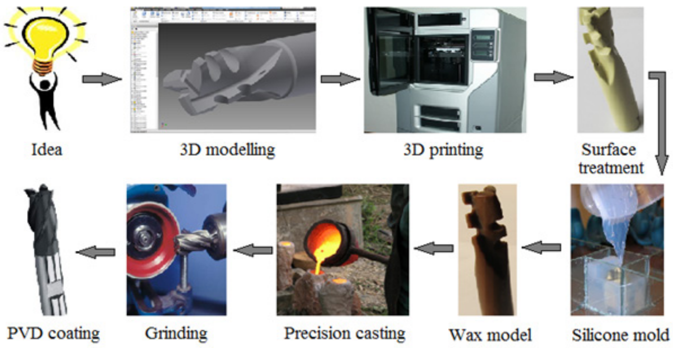

Figure 1: Designed technology of production of new cutting tool with compensation edges

The wax models are used for making shell mold. The final metal prototype is produced by precision casting method. Final adjustment will be grinding of functional part of the tool, heat treatment and deposition of PVD coating. Designed technology of the new milling cutter with negative geometry is shown in Figure1.

3. DESIGNED 3D MODEL

The first step for creating new geometry of milling cutter is to decide which method will be used for production the tool (cylindrical grinding, precision casting etc.). In case of cylindrical grinding it is necessary to know the dimensions of grinding wheel, because they are important for machining helical groove. Methods of precision casting are not limited by dimensions of grinding wheels, after casting, only functional parts are regrinded [3,4,5].

There are two basic methods for creating a new geometry of cutting tool. First method is based on the mathematical description of end milling cutter groove whose rotation and moving along and around the tool axis, the cutting part with helical groove is created. Second method has opposite procedure. In the case when dimensions of grinding wheel, dimensions of workpiece and helical groove parameters are known, then on the basis of "machining simulation" can be obtained the transverse profile of helical groove which is important for creating 3D model.

The machining simulation was chosen for modelling of new cutting tool with negative geometry. First segment of helical groove was made to the workpiece material by fictional grinding wheel (Figure 2a-b). The first created segment was copied using spiral curve and helical groove was made (Figure 2c). Copying of created helical groove was used for obtaining three edges milling cutter (Figure 2d-f).

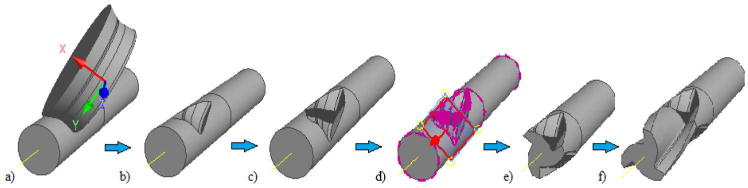

Figure 2: Construction of helical groove

The next step was creating face surfaces on the cutting tool. Machining simulation method was again used for creating these surfaces. In Figure 3a are shown the dimensions of used grinding wheel and in Figure 3b are shown created face surfaces. One edge is sharpened through the centre.

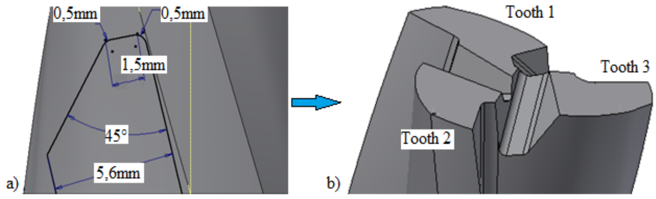

Figure 3: Sketch of used grinding wheel and finished face surfaces

Construction of flank surfaces was performed by removing of material (extruding sketch). After creating the first flank surface, the circular field was used for creating three edges milling cutter. Used sketch is shown in Figure 4a and created flank surfaces are shown in Figure 4b.

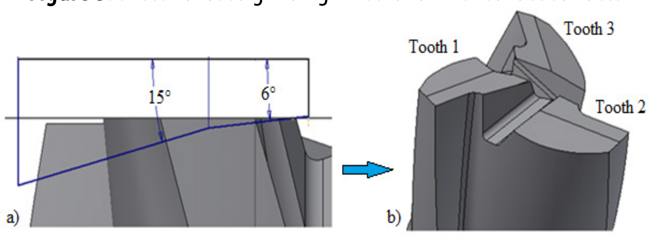

Figure 4: Sketch used for extruding and finished flank surfaces

The final step was construction of compensation edges (each edge is composed of two special compensation edges). These special edges are used for reducing tensile stress in heel of tooth. Rotation of cone (Figure 5) was used for modelling these compensations edges.

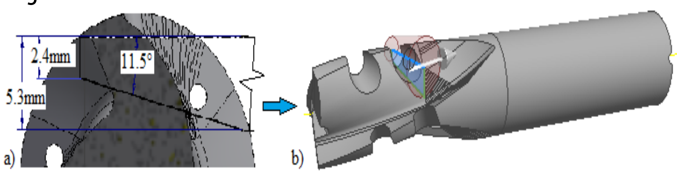

Figure 5: Used cone for rotation and finished compensation edges

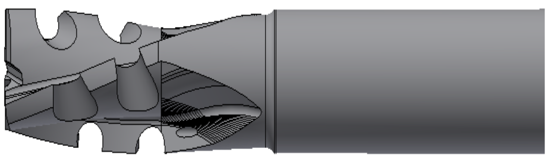

Figure 6. Finished 3D model of designed cutting tool

In Figure 6 is shown finished 3D model of three edges end milling cutter with negative geometry with compensation edges.

4. EXPERIMENTAL PROCEDURE

New designed geometry of milling cutter was used for machining artificial wood and aluminium alloy. HSS milling cutter (producer ZPS-Frézovací Nástroje a.s., Zlín, Czech Republic) was used for comparison results. Monitored parameters were force loading and tensile stress.

4.1. Materials of workpieces

Artificial wood SikaBlock M610 was used for this experiment. Dimensions of workpiece were 70x50-300mm. Aluminium alloy $AlCu_4MgSi$ (ČSN 42 4201) was chosen for comparison of the measured force loadings. Dimensions of workpiece were 40x40-80mm. Chemical composition of aluminium alloy is shown in Table 1.

Table 1: Chemical composition of aluminium alloy $AlCu_4MgSi$.

Chemical composition	Si [%]	Fe [%]	Cu [%]	Mn [%]	Mg [%]	Cr [%]	Zn [%]	Ni [%]	Al [%]
42 4201	< 0,7	< 0,7	3,80- 4,80	0,40- 0,80	0,40- 0,80	< 0,1	< 0,3	< 0,1	the rest

4.2. Tools

The new tool will be made by precision casting methods. One prototype (Ø14x92 mm) was produced by milling and grinding and this prototype was used for this experiment. HSS 19830.3 (ČSN 41 9830) was used as a tooling material. Chemical composition of tooling material is shown in Table 2. End milling cutter (Ø14x83 mm) with 3 flutes and straight cylindrical shanks (producer ZPS – Frézovací Nástroje, Zlín, Czech Republic) was used for comparison the results.

Table 2: Chemical composition of tooling material.

Chemical composition	C [%]	Mn [%]	Si [%]	Cr [%]	Ni [%]	Mo [%]	W [%]	V [%]	Cu [%]	P [%]	S [%]
19 830	0,78-1,05	0,15-0,40	0,20- 0,45	3,75- 4,50	0,30	4,50-5,50	5,50-6,75	1,75-2,20	0,25	0,30	0,30

New designed milling cutter is shown in Figure 7a and milling cutter used for comparison results is shown in Figure 7b. Both used milling cutters were not deposited by PVD coating.

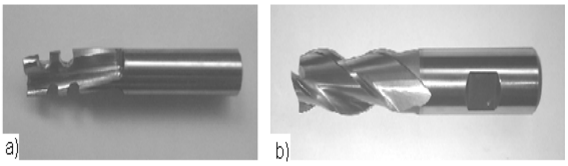

Figure 7: Tested milling cutters: a) with compensation edges; b) tool made by ZPS-FN

4.3. Cutting conditions and the experiment

As already noted, milling was carried out in dry conditions. Feed per tooth, radial depth of cut, axial depth of cut, cutting speed and feed speed were the same during the experiment. Cutting conditions for machining artificial wood SikaBlock M610 are shown in Table 3 and for machining aluminium alloy in Table 4.

Table 3: Cutting conditions used for machining artificial wood SikaBlock M610.

Cutting conditions	Marking	Value	Unit
Cutting speed	vc	44	m/min
Feed speed	vf	160	mm/min
Feed per tooth	fz	0,05	mm
Axial depth of cut	ap	24	mm
Radial depth of cut	ae	9	mm

Table 4: Cutting conditions used for machining aluminium alloy $AlCu_4MgSi$.

Cutting conditions	Marking	Value	Unit
Cutting speed	vc	22	m/min
Feed speed	vf	112	mm/min
Feed per tooth	fz	0,04	mm
Axial depth of cut	ap	24	mm
Radial depth of cut	ae	3	mm

The experiment was carried out on three-axes milling machine FGH 32. The workpiece clamping of both machining materials are shown in Figure 9. Force loading of the tool was measured by the piezoelectrical dynamometer Kistler 9257B, equipped with the charge amplifier 5070A and Dynoware software was used for data processing (Figure 8). The force loading was measured in three axes.

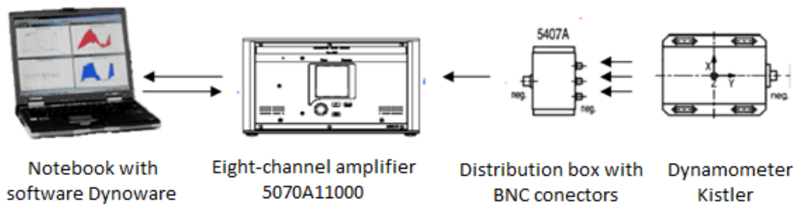

Figure 8: The Kistler data acquisition and processing [6]

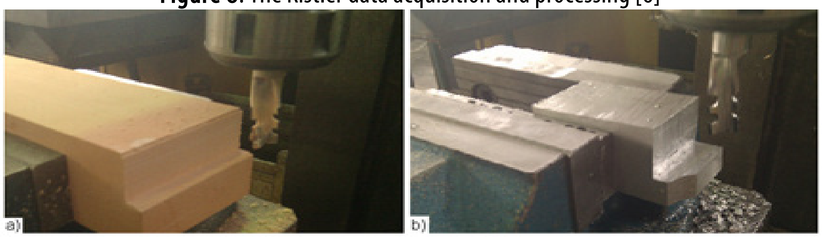

Figure 9: Workpiece and tool clamping

5. RESULTS

Four passes were performed when machining artificial wood SikaBlock M610 and one pass was performed when machining aluminium alloy AlCu4MgSi.

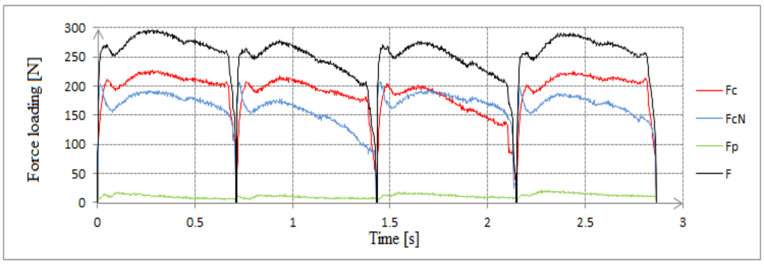

Figure 10: Time series of the force loading for the new designed milling cutter; machining of artificial wood SikaBlock M610.

The best results were achieved with both types of workpiece material when standard milling cutter with positive geometry was used. The maximum cutting force value Fc=240N was reached (when new designed tool was used) and Fc=60N (when ZPS-FN milling cutter was used) during machining of artificial wood. The cutting force reached maximum value Fc=1200N (when new designed tool was used) and Fc=400N (when ZPS-FN milling cutter was used) during machining of aluminium alloy.

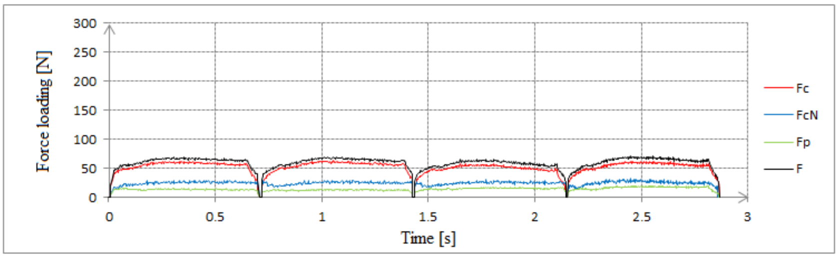

Figure 11: Time series of the force loading for the milling cutter (producer ZPS-FN, Zlín, CZ); machining of artificial wood SikaBlock M610.

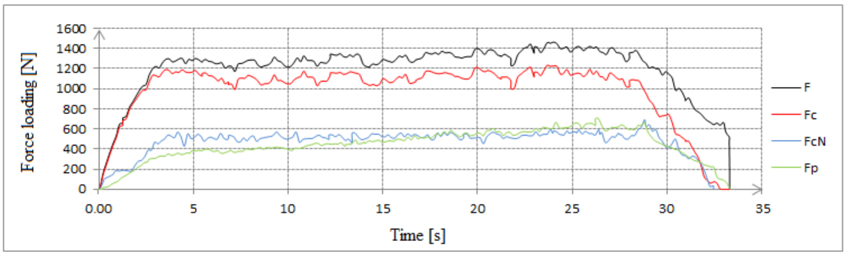

Figure 12: Time series of the force loading for the new designed milling cutter; machining of aluminium alloy AlCu4MgSi.

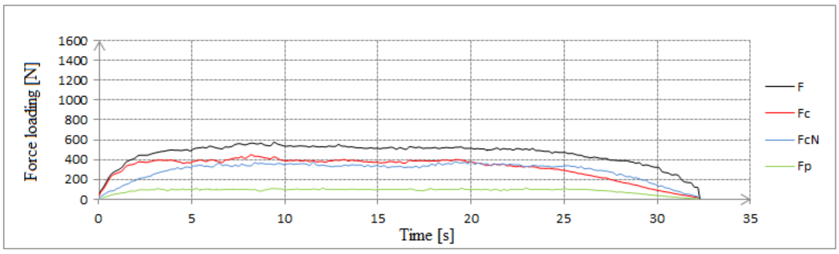

Figure 13: Time series of the force loading for the milling cutter (producer ZPS-FN, Zlín, CZ); machining of aluminium alloy AlCu4MgSi.

Force loading for machining artificial wood is shown in Figures 10-11 and for machining aluminium alloy in Figures 12-13.

The measured data were used for stress analysis (Figure 14), which was carried out in Autodesk Inventor Professional 2013 software. Reduced stress conditions by HMH (von Misses) reached maximal value 43.67MPA at the beginning of machining and 50MPa at the end of machining (after four passes) when data obtained during milling of artificial wood were used. The maximum value reached 352.6MPa during machining of aluminium alloy.

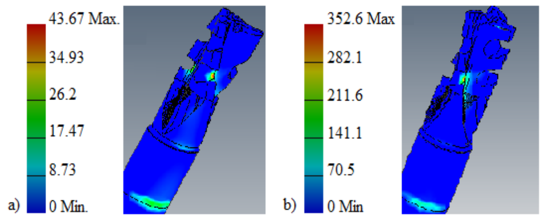

Figure 14: Stress analysis: a) for data measured during machining of artificial wood; b) for data measured during machining of aluminium alloy.

6. CONCLUSION

Force analysis shows that cutting force was 4 times smaller compared to newly designed milling cutter with compensations edges for milling artificial wood and 3 times smaller for milling aluminium alloy. Two major points with stress concentration were found by stress analysis, in the place of compensations edges and in tool clamping. Compensation edges are the most stressed place on the tool (Figure 14), the consequence is sharp face surface which makes stress notch. It would be better to deposit the new designed milling cutter with negative geometry by some kind of PVD coating (for example AlTiN) and choose better heat treatment.

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REFERENCES

[1.] FOREJT, M., PÍŠKA, M.: Theory of Machining, Forming and Cutting tools, pp.226, CERM, Brno, 2006.
[2.] HUMÁR, A.: Materials for Cutting Tools, pp.235, MM publishing, Prague, 2008.
[3.] KIM, J.H., PARK, J.W. and KO, T.J.: End mill design and machining via cutting simulation. Computer-Aided Design. 2008, vol. 40, issue. 3, pp. 324-333.
[4.] TANDON, P., RAJIK KHAN. P.: Three dimensional modelling and finite element simulation of a generic end mill. Computer-Aided Design. 2009, vol. 41, issue. 2, pp. 106-114.
[5.] MADAJ, M., PÍŠKA, M. and ZOUHAR, J.: Modern methods for designing cutting tools using CAD / CAM / CAE. FRVŠ 2636, 2009.
[6.] DVOŘÁČEK, J., MATUŠKA, M. and SEDLÁK, J.: On the application of PVD hard coatings for milling of hardened steel. In: Newtech 2011: New technologies in manufacturing. pp. 93-98.