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IMPACT OF TOOL WEAR ON THE QUALITY OF THE SURFACE IN ROUTING OF MDF BOARDS BY MILLING MACHINES WITH REVERSIBLE BLADES

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ABSTRACT

The article deals with the impact of tool wear on the quality of the surfaces when routing MDF board. It describes an experiment in which the milled MDF board with thickness of 22 mm was milled with miller machine with diameter of 50 mm and with replaceable reversible blades on 5-axes CNC machining center.

The article describes the dependence of the quality of the surface, namely the parameter of the arithmetical mean deviation of the roughness profile, on milled distance (0 m, 35 m, 70 m, to final tool wear) - stage of tool wear, i.e. alleviation of the cutting edge of reversible blades. The given dependence was observed for the three most widely used types of sintered carbides (T04F, T03SMG and T10MG).

Article points out that it has not been proven a direct relationship between the tool wear and the quality of the surface. Significant deterioration was recorded at the end of the durability of the cutting edge due to direct damage of the cutting edge and due to forming of ridges that were formed on the given surface. Throughout the entire period of durability of the cutting edges of the reversible razor blades, surface of good quality was produced with an average value of the arithmetical mean deviation of the roughness profile below 11.1 microns.

Key words: milling, reversible blades, surface roughness, tool wear, cutting edge.

INTRODUCTION

As optimization criterion for choice of technological parameters has become a quality of the manufactured product, as determinants for success of products on the market, in other words in a competitive environment, are factors of quality and price.

An objective indicator of the quality of the product is considered to be accuracy of work piece and the quality of the work piece's surface. Under the precision of work piece we understand the degree of proximity of the work piece to the geometry values indicated on the drawings. We consider the shape and dimensional accuracy. The question of sufficient accuracy with CNC machining centers is solved by design of the machine itself and more important question is the quality of finished surface. Surface quality can be precisely defined by surface roughness parameters. Surface roughness has a kinematic, technical and technological reason.

Kinematic causes of inequality (causes of waviness) lie in the cycloid shape of relative movement of the cutting edge of the knife in the wood, which makes absolutely flat surface created by rotary tool unreachable even on a theoretical level.

Technological inequality causes (causes of roughness) lie for example in cutting of vessels, fibers, annual rings, moisture, milling along the fiber and against it, type of wood and so on.

Technical causes of inequality (causes of roughness and waviness) lie in the precision of setting of knives in the cutter head (or in precision of grinding of disc cutters to equal perimeter of all cutting edges) in the state of wear of the cutting edges of blades and in the vibration and movement of milling tool. These cause both, uprooting of fibers (because of edge wear) and irregularities in the distance ripples on a milled surface.

Most of the above variables are considered stable or randomly changing. But there are also variables directly dependent on milling distance, like for example the wear of the cutting edge. Wear is an expression of the resistance of the material – wood against penetration of the cutting tool (KRILEK *at al*. 2013). This resistance is due to the strength of wood material during cutting of wood particles by cutting edge, bending deformation of cutting material, friction of material to forehead of tooth and friction of back part of the cutting edge to the machined surface (SIKLIENKA and MIŠURA 2008).

The purpose of this article is to map the impact of wear of the cutting edge on the quality of the surface, more specifically on roughness of surface in routing of MDF boards by rotary cutter with reversible knives with sintered carbides of different composition.

METHODOLOGY

The characteristics of used material:

In the experiment were used **raw, medium hard boards** (MDF) supplied by Bučina DDD, ltd., Zvolen, Slovakia. MDF boards were delivered in the **thickness of 22 mm**, and the **format 2800 / 2070 mm**. Basic technical parameters provided by the manufacturer are in Table 1.

Tab. 1 Technical parameters of raw medium hard MDF board.

Property	Test method	Request
Density	STN EN 322	730 ÷780 $kg.m^{-3}$
Thickness tolerance	STN EN 324-1	± 0,3 mm
Dimensions tolerance	STN EN 324-1	± 5,0 mm
Squareness tolerance	STN EN 324-2	± 2 mm / m
Humidity	STN EN 322	4 % ÷ 11 %
Formaldehyde release	STN EN 120	< 8 mg / 100 g a.s. samples
Thickness range		> 6 >19 >12 >19 >30
		< 9 <12 <19 <30 <45
Bending strength	STN EN 310 (MPa)	23 22 20 18 17
Tensile strength	STN EN 319 (MPa)	0,65 0,60 0,55 0,55 0,50
Swelling after 24 hours	STN EN 317	17 15 12 10 8
Modulus of elasticity	STN EN 310 (MPa)	2800 2500 2200 2150 1900

Characteristics of the machine:

The experiment was conducted at 5 axes **CNC machining center SCM Tech Z5** (Figure 1). Basic technical and technological parameters provided by the manufacturer are in Table 2.

Fig. 1 CNC machining center SCM Tech Z5.

Tab. 2 Technical and technological parameters of CNC machining center SCM Tech Z5.

Technical parameters of CNC machining center SCM Tech Z5	
Useful desktop	x= 3050mm , y= 1300mm, z=300mm
Speed X axis	0 ÷ 70 m·min^{-1}
Speed Y axis	0 ÷ 40 m·min^{-1}
Speed Z axis	0 ÷ 15 m·min^{-1}
Vector rate	0 ÷ 83 m·min^{-1}
Parameters of the main spindle	
electric spindle with HSK F63 connection	
Rotation axis C	640°
Rotation axis B	320°
Revolutions	600 ÷ 24 000 ot·min^{-1}
Power	11 kW 24 000 ot·min^{-1}
	7,5kW 10 000 ot·min^{-1}
Maximum tool diameter	D = 160 mmm
	L = 180 mm

Characteristics of the tool:

The experiment was used **milling head** under the type designation **01B1481004 MEC** (Figure 2) from the manufacturer BOTO, ltd., Nové Zámky, Slovakia. Basic technical and technological parameters stated by the manufacturer are provided by Table 3.

Fig. 2 Milling head 01B1481004 MEC.

Tab. 3 Technical and technological parameters of milling head 01B1481004 MEC.

Technical and technological parameters of milling head "301B1481004 MEC"	
The total length of the tool	80 mm
Cutter body diameter	50 mm
Shank diameter	20 mm
Height of the cutter body	30 mm
Number of blades	2 ks
Max. revolutions	12000 min^{-1}
Feed rate	7,2 $m \cdot min^{-1}$
α - clearance angle	35 ˚
β - cutting wedge angle	35 ˚
γ - rake angle	20 ˚

During the experiment **reversible blades HW30/12/1.5** (Figure 3, Table 4) were mounted in the milling head from different classes of sintered carbides TIGRA from BOTO, ltd., Nové Zámky, Slovakia. Specifically:

- **T04F** considered as a universal material,
- **T03SMG** considered the standard material in the machining of HDF, MDF and DTD.
- **T10MG** considered the standard material in the machining of hard and soft wood.

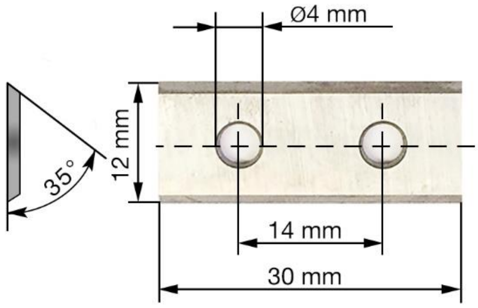

Fig. 3 Razor HW30/12/1.5.

Tab. 4 Technical data of razors HW30/12/1.5.

Technical characteristics of blades HW/30/12/1.5	
Blade length	30 mm
Blade width	12 mm
Blade thickness	1,5 mm
Number of clamping holes	2 ks
Bore diameter	4 mm
Fixing hole spacing	14 mm
Cutting wedge angle	35 °

Basic technical parameters of sintered carbides TIGRA provided by manufacturer is in Table 5.

Tab. 5 Technical Specifications of sintered carbides Tigra.

Classes of TIGRA	**ISO CODE**	**US CODE**	**Binder%**	**Hardness**		**Bending strength**	
				HV10	**HRA±0.2**	**N/mm^2**	**psi**
T03SMG	K1	C4++	3.5	2100	94.6	2400	348.000
T04F	K1	C4	4.0	1750	92.8	2350	341.000
T10MG	K10–K40	C3+	10.0	1650	92.3	3600	522.000

METHOD

The experiment was conducted in the following steps:

1. The milling head mounted with a first type of razor blades was inserted into the hydraulic clamping SOBO. 302680291 GM 300 HSK 63F from Gühring KG Albstadt, Germany. And then inserted into a magazine of CNC machine.
2. The input format of MDF board (2750 * 1840 mm) was divided in half (2 * 2750 * 868 mm);
3. Half-format MDF board was placed in a CNC machining center so that the longer side was alignment in the X-axis and the shorter side in the Y-axis, attaching the MDF was provided 12 evenly placed suction cups measuring 120 x 120 x 35 mm (set the vacuum 0.9 bar) (distance from the cutting head suction cups no more than 50 mm). Since the format of MDF board during experiment dwindled, locations of suction cups have been corrected if the distance from the edge of routing was less than 20 mm.

4. The experiment was carried out so that the experimental milling head took 2 mm thick layer from the long sides of MDF in the process with parameters given in the Table 6.

Tab. 6 milling parameters.

Milling process parameters	
Revolutions of main spindle	12000 min^{-1}
Milling type	Opposed
Sliding speed	3 $m \cdot min^{-1}$
Abstracted layer thickness	2 mm

5. After the desired milled distance (0, 35, 70, 105, ..., to milled distance which caused wear on the cutting edge, with the naked eye observable deterioration in the quality of the surface like - burning of surface, pulling the fiber material or scratches on the surface) was sawed-off 5 mm thick strip from which samples were taken for determination of surface roughness. Samples were taken according to the methodology by SIKLENKA and ADAMCOVA (2012) look at the diagram in Figure 4.

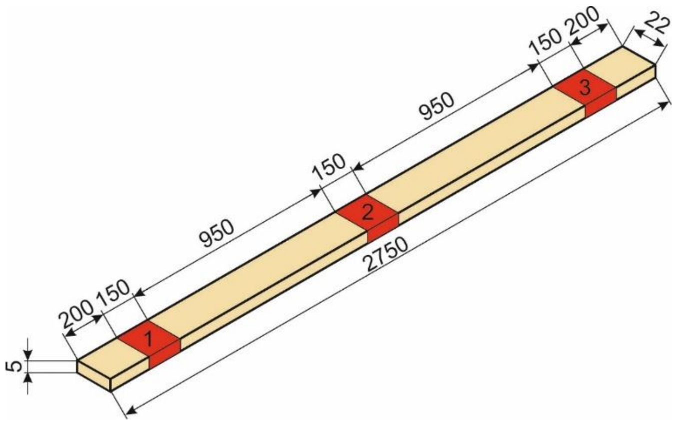

Fig. 4 Method for extraction and manipulation of test samples for the determination of surface roughness (SIKLIENKA and ADAMCOVA 2012)

6. After reaching the final milled distance, another type of razor blades was exchanged in milling head and the process was repeated.

Determination of surface roughness

The inequality of the surface of the test piece was measured with a **laser profilometer LPM-4** (Figure 5) from KVANT Ltd., Slovak Republic. Profilometer uses laser triangulation principle of laser profilometry. The image of the laser line is recorded from an angle by digital camera. Scanned image is then analyzed and object profile is evaluated in cross-section. The data obtained are mathematically filtered and indicators are provided for each primary profile, the profile of waviness and roughness profile as well (KMINIAK and GAFF 2015).

During measuring of the surface roughness a methodology by SIKLENKA and ADAMCOVA (2012) was used regarding norms STN EN ISO 4287. On each test sample, measurements were performed on three tracks located in the middle of samples, evenly spaced across the width of the sample (5, 11 and 17 mm from region of the sample), line length was 60 mm and was oriented in the direction of displacement of the spindle in the process of milling (Figure 6). Surface roughness was evaluated using a parameter of arithmetic mean deviation of roughness profile Ra.

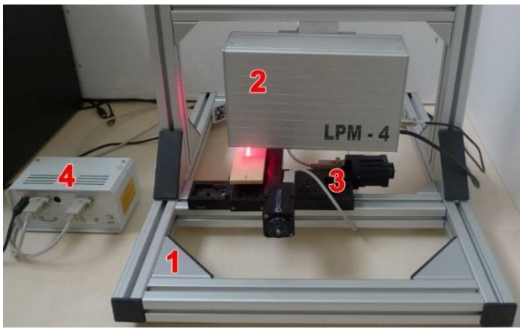

Fig. 5 Laser Surface Profilometer LPM - 4 1 - frameworks enabling manual preset of working distance and mounting of profilometric head and trolley system, 2 - Profilometric head, 3 - feed system for XZ axis, 4 - controller for shift system of working desks (KMINIAK and GAFF 2015).

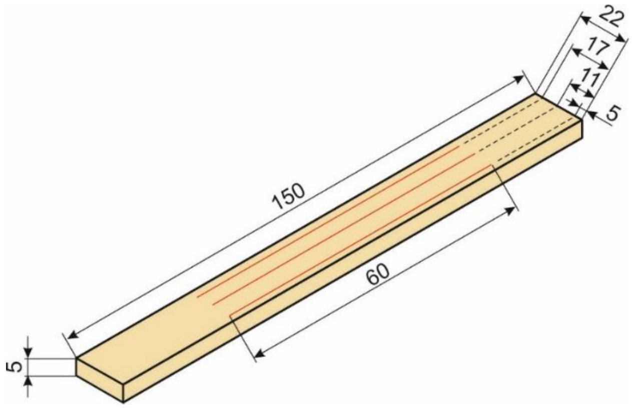

Fig. 6 Distribution of lines of measuring surface roughness across the width of the sample (SIKLIENKA and ADAMCOVA 2012).

Determination of wear of the cutting wedge

The rate of wear of cutting wedge is evaluated by the alleviation parameter of the cutting edge SV (Figure 7). In the experiment, the microscopic method by ŠUSTEK and SIKLIENKA (2012) is used.

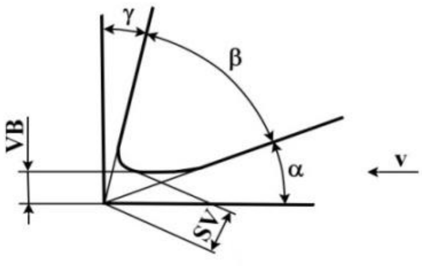

Fig. 7 subsided cutting edge α - back angle, β - cutting wedge angle, γ - rake, NE - subsidence of cutting edge BV - back retreat (ŠUSTEK and SIKLIENKA 2012).

Reversible blades were removed from the cutter head. Using assemble of microscope and digital camera (in this case the **microscope 100 HC-L** from the German company HITEC and digital camera **Canon PowerShot A520** from Canon controlled by focusing **ZoomBrowser EX 5.0** software from Canon as well) recorded images of cutting edge at 100 times magnification were made. To determine the real dimensions, the image was generated on a reference scale which was used to calculate the real dimensions. At 100 times magnification, it was possible to cover only half of the cutting edge and therefore pictures of left half and right half were taken and then evaluated separately. Cutting wedge image was then evaluated in the program **AutoCAD 2009**. Evaluation was carried out in a way, that into cutting wedge images, tangents were drawn to the cutting edge and a line passing through the reference points was created on the blade by sparking and subsequently distance of tangents and a reference line was measured and the figure has been adjusted on an appropriate scale.

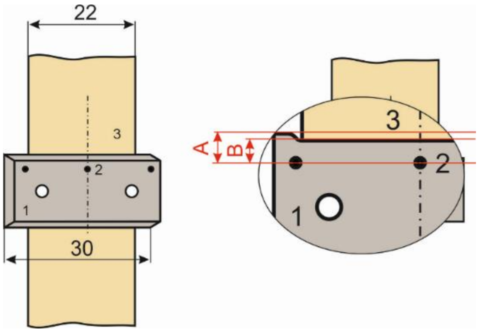

Fig. 8 Method for measuring alleviation of cutting edge 1 - reversible blade, 2 - sparking reference point 3 - MDF board, A - the distance between the straight line passing through sparking points and tangent to the cutting edge at the front of the milling, B - distance between the straight line passing through sparking points and tangent to the cutting edge after milling.

RESULTS

Because of test requirements (500 bm were milled an average of an hour, including the necessary handling operations) experiment was performed on one sets of knives. The course of cutting wedge tool wear was monitored using the "alleviation of Cutting Edge (SV)." The quality of the surface was monitored by parameter "arithmetic mean deviation of the profile roughness (Ra)".

The data obtained were subjected to statistical analysis that failed to demonstrate the interdependence of impact alleviation of cutting edge and the arithmetic mean deviation of the roughness profile. Graphical representation of the arithmetical mean deviation of the roughness profile, depending on the alleviation of cutting edge is expresses on Figure 9.

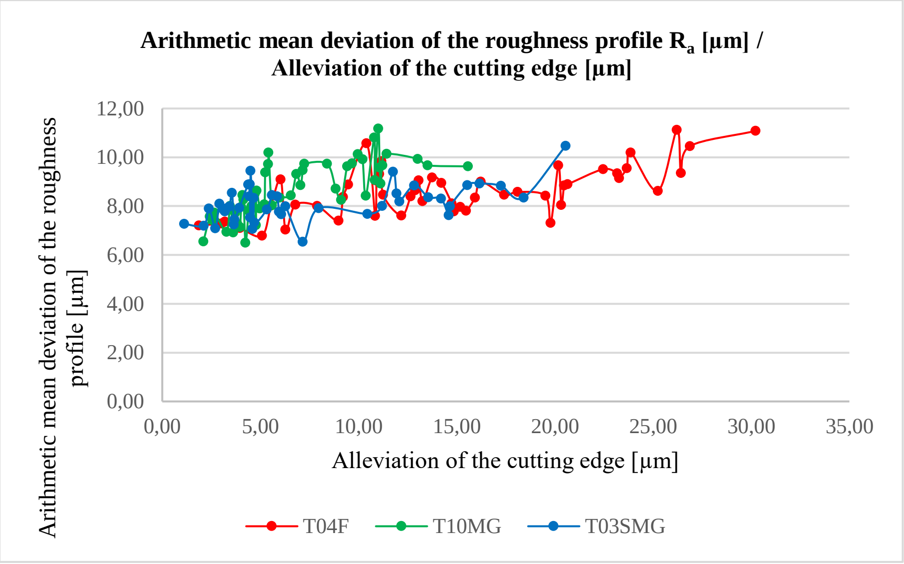

Fig. 9 Dependence of the arithmetical mean deviation of the roughness profile on the alleviation of the cutting edge.

Statistical comparison of these indexes we transferred indirectly by common factors like class of sintered carbide and milling distance. Statistics (Table 7) show, that on the alleviation of the cutting edge has a statistically significant effect milled distance and class of sintered carbide. The statistics further showed that the impact of cemented carbide grade is 11 times greater than that of milled distance.

Tab. 7 Statistical analysis of impact of milled distance and grade of sintered carbide on the alleviation of the cutting edge.

Alleviation of the cutting edge	SS	Degr. of Freedom	MS	F	p
Intercept	32664,79	1	32664,79	1908,079	0,000000
Milled distance [m]	7452,56	43	173,32	10,124	0,000000
Grade of sintered carbide	3921,20	2	1960,60	114,526	0,000000
Milled distance [m] * Grade of sintered carbide	599,13	86	6,97	0,407	0,999999
Error	4519,47	264	17,12		

However statistics (Table 8) shows that arithmetical mean deviation of the roughness profile has failed to demonstrate the impact of even one of the factors to be considered.

Average values of cutting edge alleviation together with an interval of measured values for given materials of razor blades - carbide class graphically presents Figure 10. The average value of the arithmetical mean deviation of the roughness profile along with an interval of measured values for various materials of razor blades graphically presents Figure 11.

Tab. 8 Statistical analysis of the impact of sawed distance and grade of sintered carbide on arithmetic mean deviation of the roughness profile.

Arithmetic mean deviation of the roughness profile	SS	Degr. of Freedom	MS	F	p
Intercept	29748,83	1	29748,83	2895,228	0,000000
Milled distance [m]	234,58	43	5,46	0,531	0,993061
Grade of sintered carbide	14,70	2	7,35	0,715	0,490002
Milled distance [m] * Grade of sintered carbide	237,97	86	2,77	0,269	1,000000
Error	2712,63	264	10,28		

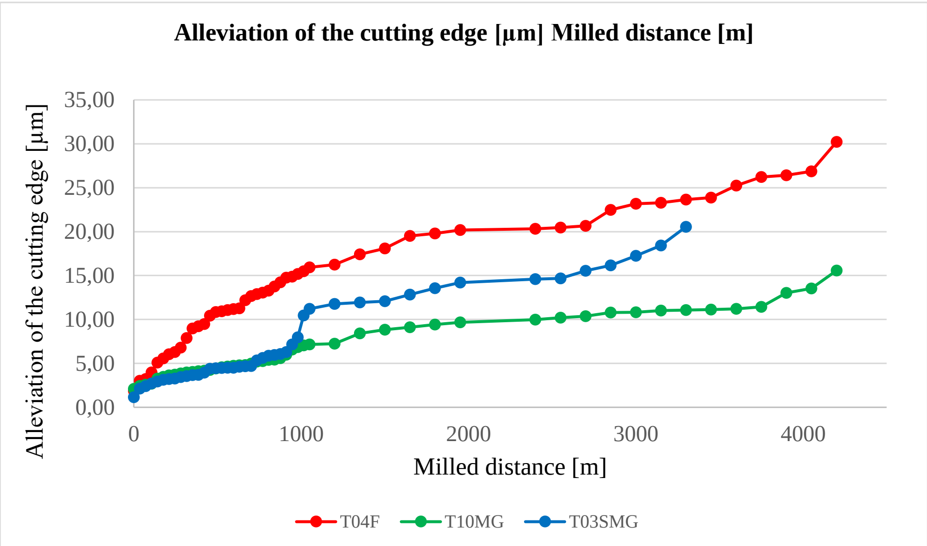

Fig. 10 Dependence of alleviation of the cutting edge on milled distance.

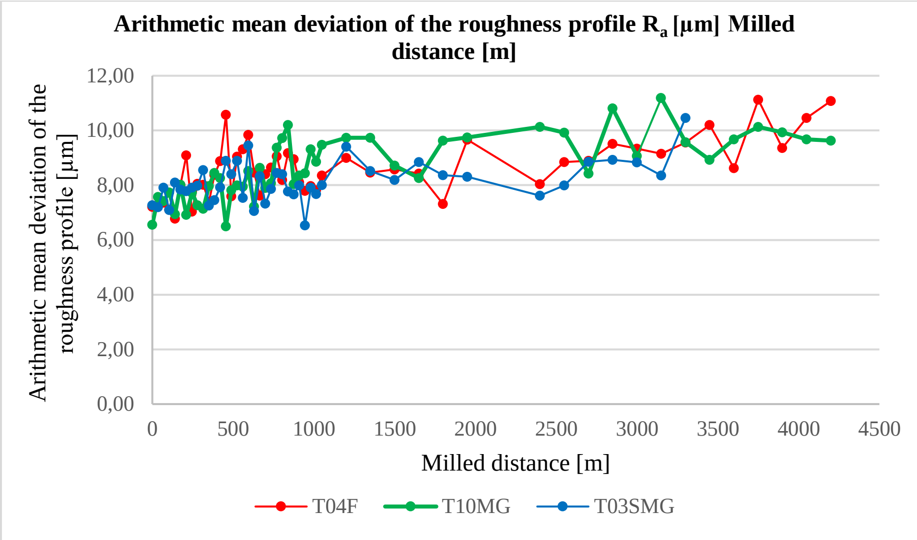

Fig. 11 Dependence of the arithmetical mean deviation of the roughness profile on milled distance.

Termination of the use of razor blades came, when formed surface showed the naked eye observable defects of quality in this case scratches due to damage to the cutting edge of reversible blades.

As for the second observed parameter - middle arithmetic mean deviation of the roughness profile at the time of terminating the use of the particular razor the average values did not exceed 11.1 microns, while the usual requirement for a maximum average values of the arithmetical mean deviation of the roughness profile depending on how the final surface treatment is done ranges from 15 to 20 microns (DZURENDA *et al*. 2008).

Impact on the values of arithmetic mean deviation of the surface by therefore mentioned grooves has not been recorded because from technological standpoint, roughness measurement makes sense only in the direction along the cutting speed of the sample and direction of grooves on the surface are longitudinally as well thus it would affect only the roughness in the transverse direction.

Data presented on Figure 10 show the durability of the cutting edge in cemented carbide grade T04F and T10MG reached 4200 meter (with sliding speed 3 m .min^{-1} it is 23.33 hours of real milling). In case of cemented carbide grade T03SMG only 3300 meter (what is 18.33 hours of real milling). At the same time Figure 10 clearly shows that the intensity of alleviation cutting edge - tool wear rises in the classes T10MG, T03SMG and T04F.

At the same time, we can read from the presented data that there is intensifying deterioration in the last 150 meters before the actual cessation of the use of all three types of cemented carbides.

We can express dependence of cutting edge alleviation on milled distance, regardless of solid carbide grade by following equation:

$$SV = 0,0048 * L + 4,0215 \ (R^2 = 0,93)$$

SV - cutting edge alleviation (µm)
L- milled distance (m)

Taking into account the class of carbide result is:

- for **T04F**

$$SV = 0,0054 * L + 7,3096 \ (R^2 = 0,93)$$

- for **T03SMG**

$$SV = 0{,}0055 * L + 2{,}0519\ (R^2 = 0{,}94)$$

- for **T10MG**

$$SV = 0{,}0026 * L + 3{,}324\ (R^2 = 0{,}95)$$

The evaluation of the impact of milled distance to the alleviation of the cutting edge can lead us to conclusion that for a given model situation, milling MDF with thickness of 22 mm and under constant material removal at 2 mm the most suitable cemented carbide grade is T 10MG then T04F and least suitable is T03SMG.

DISCUSSION

The presented results do not contradict the generally known definition of the problems of working with wood and wood materials. Similarly like AGUILERA *et al*. (2016), SANJEEV *et al*. (2012) or KOVAČ and KRILEK (2012) confirm only minimal links between the quality of the surface and tool wear. Progress of tool wear is consistent with the generally defined course of tool wear SIKLIENKA *et al*. (2015) or PROKEŠ (1980). Quality values of the surface are comparable to those in work published by DZURENDA *et al*. (2008).

Against expectations acquired in study of literature in preparation of the experiment, only one error occurred. Based on data provided by the manufacturer of sintered carbide expectation was that the most suitable carbide is T03SMG but our testing did not confirm that and we named as the most suitable T10MG.

CONCLUSION

Given experiment shows as follow:

1. Has not been established direct relationship between the tool wear and the quality of the surface, and therefore there is no need for quality correction of the surface by changing the process parameters due to a change in the quality of the tool due to wear.
2. Significant deterioration was observed at the end of the durability of the cutting edge due to direct damage to the cutting edge and forming ridges on the surface. Any interference with the process parameters at given moment does not improve the quality and grooving damage remains.
3. Throughout the period of durability of the cutting edges of the reversible razor blades produced surface had good quality with an average value of the arithmetical mean deviation of the roughness profile below 11.1 microns.

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