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INFLUENCE OF THE THICKNESS OF REMOVED LAYER ON THE QUALITY OF CREATED SURFACE DURING MILLING THE MDF ON CNC MACHINING CENTERS

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ABSTRACT

The article deals with the issue of MDF boards milling on CNC machining centers. Specifically, there is analyzed the dependence of roughness of created surface on the change of the layer thickness of removed material. The article is based on an experiment which follows milling of 18mm thick MDF board at the 5 axis CNC machining center using a miller with one reversible blade and then a miller with two reversible blades. The experiment is performed at the intervals recommended by manufacturer regarding cutting and feeding speeds and machining strategies.

The roughness of created surface is presented by a parameter - arithmetic mean deviation of the surface roughness Ra. The article highlights the fact, that thickness of removed material layer does not have a statistically significant influence on the surface roughness. At the same time, it points out the fact that there is not the same dependence of the roughness of created surface on the nominal thickness of the chips during milling of the MDF boards, as we would expect on the basis of general assumptions.

Key words: MDF milling, machining strategy, surface roughness, nominal thickness of the chips, milling cutters with replaceable blades.

INTRODUCTION

The workpiece accuracy and the quality of a created surface can be regarded as an objective indicator of the quality of the created product. The workpiece accuracy presents the degree of approaching of the geometric values of the workpiece to the values set in the drawing, as the shape and dimensional accuracy is considered. An adequate accuracy is solved by CNC machining centers by the machine itself, therefore the quality of the worked out surface seems to be more important issue. The surface quality can be exactly defined by surface roughness parameters.

The surface shows some surface roughness during milling as well, such as microscopic changes (roughness) or macroscopic changes (waviness, grooves, elevations, partially drawn fibers). The occurrence of these changes (except waviness) on the workpiece surface is irregular (KORKUT *et al*. 2013). The waviness consists of almost regular repetitive elevations and depressions of approximately the same shape and size (GÜNDÜZ *et al*. 2008, NOVAK *et al*. 2011).

Roughness and waviness are, in fact, very small deviations from the desired shape, but they significantly affect the further processing of the workpiece, in particular its surface treatment (AYDIN and COLAKOGLU 2005, HIZIROGLU and KOSONKORN 2006, OČKAJOVÁ *et al*. 2016); as there is reported that the degree of the MDF surface roughness plays an important role, since all surface irregularities may show through thin layers and thus decrease the final quality of the panel. MARIAN *et al*. (1954), FAUST (1978) and RICHTER *et al*. (1995) claim in their works that smooth surfaces need relatively less paint coat and the paint is more adhesive to the surface. Roughness and waviness depend on the kinematic conditions of cutting and are mainly influenced by the following factors (KARAGOZ *et al*. 2011):

- The way of separating chips, which depends not only on the method of machining, but also on the accuracy of a tool and its geometry
- Cutting conditions (cutting speed, feeding rate, thickness of the removed layer, etc.).
- Microgeometry (dulling the cutting edge of the tool).
- Physical and mechanical characteristics of machined material (its density, hardness and structure).

The programmer needs to choose the optimal process parameters based on the requirements on the quality of created surface. The thickness of the removed layer plays an important role as well. Based on the thickness of removed layer, the programmer of the CNC machining center, either reduces it through several steps or modifies the technological parameters - the change of the feeding speed (with the assumption - the thicker the layer is, the worse is the quality and thus the feeding speed has to be reduced to achieve the required quality). Therefore, this article reveals to what extent the machine adjustment is needed from the point of view of the roughness of created surface.

METHODOLOGY

The characteristics of used material:

Raw medium hardboards (MDF) supplied by Bučina Ltd. Zvolen, Slovakia were used in the experiment. MDF boards have **thickness h = 18 mm** , width w = 2800, length l = 2070 mm. Basic technical parameters provided by manufacturer are presented in *Table 1*.

Tab. 1 Technical parameters of raw medium-density fiberboard (Bučina Ltd. Zvolen, 2017).

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

Characteristics of the machine:

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

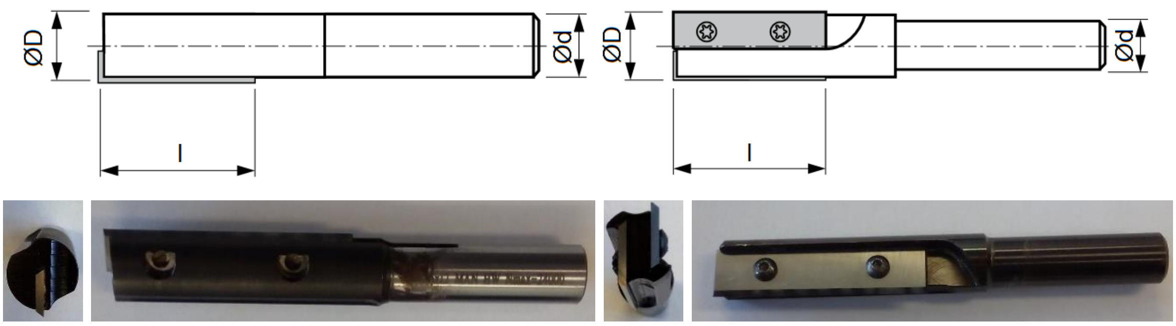
Fig. 1 CNC machining center SCM Tech Z5.

Tab. 2 Technical and technological parameters of CNC machining center SCM Tech Z5 (SCM Group, 2017).

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

Characteristics of the tool:

The experiment made use of a milling cutter with one reversible razor blade – type **KARNED 4451** *(Figure 2/a)* and a milling cutter with two reversible razor blades – type **KARNED 4551** *(Figure 2/b)* both by manufacturer Karned Tools Ltd., Prague, Czech Republic. Basic technical and technological parameters provided by the manufacturer are in *Table 3*. The milling cutters were equipped with reversible blades **HW 49.5 / 9 / 1.5** and **HW 50/12 / 1.5** made from sintered carbide **T03SMG** (standard material used when working on HDF, and MDF DTD), by BOTO Ltd., Nové Zámky, Slovakia. Basic technical parameters of sintered carbide provided by the manufacturer are presented in *Table 4*.



a) b)

Fig. 2 milling cutter used in the experiment a) with one reversible blade b) with two interchangeable blades (ØD - diameter operation, I - working length, Ød - clamping diameter).

Tab. 3 Technical and technological parameters of milling cutter (Karned Tools Ltd, 2017).

Miller	Working diameter ØD [mm]	Working length l [mm]	Diameter of the chucking shank Ød [mm]	Dimensions of used razor blades L × š × h [mm]	Blades material
KARNED 4451	16	49.5	12	49.5 × 9 × 1.5	**T03SMG**
KARNED 4551	16	50	12	50 × 12 × 1.5	**T03SMG**

Tab. 4 Technical data of cemented carbide (Karned Tools Ltd, 2017).

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

Methodology:

The experiment was based on the methodology by KMINIAK and ŠUSTEK (2016) in the following steps:

1. A milling cutter was fitted into the hydraulic clamp **SOBO. 302680291 GM 300 HSK 63F** from Gühring KG Albstadt company, Germany and then inserted into a CNC machine.
2. The input format of MDF board (2750 * 1840 mm) was divided in a half (2 * 2750 * 868 mm).
3. Half- formatted MDF boards were placed in a CNC machining center so that the longer side was in the X-axis and the shorter side was in the Y-axis, attaching the MDF board was provided by 12 evenly placed vacuum shoes with parameters 120 × 120 × 35 mm (vacuum set was 0.9 bar) (distance of vacuum shoes from the edge of the MDF board was not more than 50 mm) (see *Figure 3*). Since the MDF board was reduced during the experiment, the location of vacuum shoes should be corrected when the distance from the edge of the MDF board was less than 20 mm.

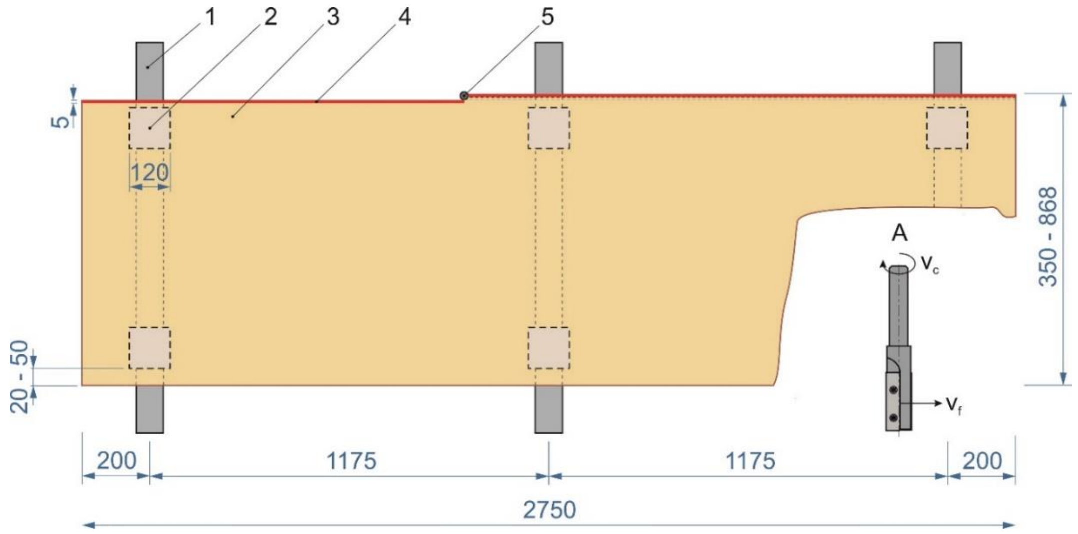


Fig. 3 Scheme of samples preparation (1 - CNC machining center transverse beam , 2 - vacuum shoe, 3 - MDF board, 4 – sample, 5 – shank cutter, v_c - direction cutting speed, v_f - direction of feed speed, A - conventional milling).

4. The experiment proceeded as follows: CNC machining center was fastened with a shank cutter (KARNED 4451 or KARNED 4551) and divided by using the given strategy – **per pass**, kind of milling – **conventional milling** and required thickness of the removed layer – **4 mm**, **8mm**, **12mm** or **16mm**. Then CNC machine tool fastened a circular saw with a diameter 250 mm and separated 5 mm thick strip of MDF board from the format. After separation of required samples, the MDF board was released and pushed to the end stop and the process was repeated with a different combination of technological parameters. The process was carried out at constant operation speed of **shank cutter n = 20,000** min^{-1} and changing **feeding speed from** v_f **= 1** $m.min^{-1}$ **to** v_f **= 5** $m.min^{-1}$ representing a maximum feeding speed recommended by the manufacturer of the tools.

5. There were extracted samples from 5 mm thick strips of MDF board to determine surface roughness. Samples were extracted according to the methodology by SIKLIENKA and ADAMCOVA (2012) see the diagram on *Figure 4*.

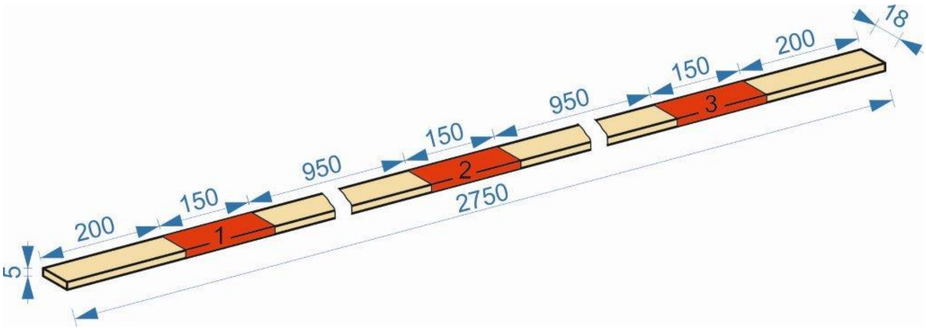


Fig. 4 Method of extracting of test samples for the determination of surface roughness (SIKLIENKA and ADAMCOVA 2012).

Determination of surface roughness:

The surface roughness of the samples was measured with a laser profilometer LPM-4 (*Figure 5*) by the manufacturer Kvant Ltd. Slovak Republic. The profilometer uses a triangulation principle of laser profilometry. The image of the laser line is scanned at an angle by digital camera. Afterwards, an object profile in cross-section is evaluated from scanned image. Obtained data are mathematically filtered and there are set individual indicators of the primary profile, profile of waviness and profile of roughness (KMINIAK and GAFF 2015).

There was used a methodology by SIKLENKA and ADAMCOVA (2012) for measuring of the surface roughness that fulfills the standard EN ISO 4287. Within each sample, there were realized measurements in three tracks, located in the middle of the sample, evenly located across the width of the sample (4.5 / 7.5 / 10.5 / 13.5 from the sample edge), track length was 60 mm and the track was oriented in the direction of displacement of the spindle in a milling process (*Figure 6*). Surface roughness was evaluated by using parameter of arithmetic mean deviation of roughness profile Ra.

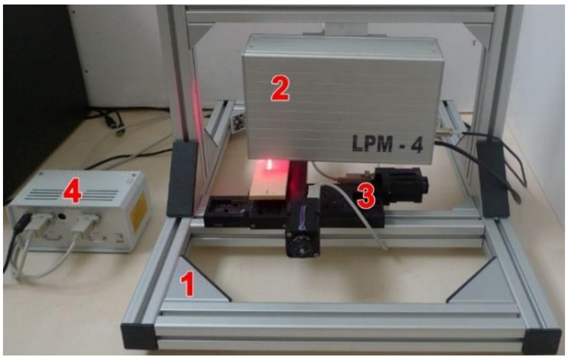


Fig. 5 Laser Profilometer LPM - 4 (1 - supporting structure allowing manual setting of working distance and fitting of profilometric head and trolley system, 2 - profilometric head, 3 - feed system of the XZ axis, 4 - control system of working desk shifts) (KMINIAK and GAFF 2015).

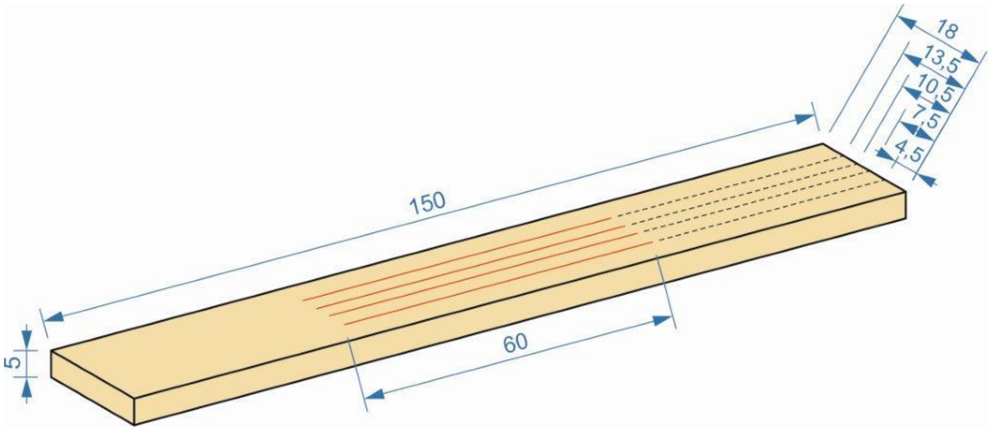


Fig. 6 Placement of surface roughness measuring tracks across the width of the sample (SIKLIENKA and ADAMCOVA 2012).

Summary:

The experiment followed the impact of three parameters (selected parameters are the basic ones that a CNC programmer needs to know in order to choose the right machining strategy). The parameters were summarized for further connection in next analyzes as follows:

- **type of milling cutter** (there are available two technical options of reversible razor blades for different instrument diameters) with one reversible razor blade and two reversible razor blades,
- **thickness of the removed layer "e",** specificaly 4 mm (e = 1/4 of a tool diameter), 8 mm (e = 2/4 of a tool diameter), 12 mm (e = 3/4 of a tool diameter) and 16 mm (e = a tool diameter)
- **feeding speed "v_f"** , specifically 1 m·min^{-1}, 2 m·min^{-1}, 3 m·min^{-1}, 4 m·min^{-1} and 5 m·min^{-1} (which represents the maximum sliding speed for a given type of a tool recommended by a manufacturer when milling agglomerated materials) and cutting speed was kept constant at 62.8 m·s^{-1} (set speed corresponds to the manufacturer's recommended tool revolutions n = 20,000 min^{-1}).

RESULTS AND DISCUSSION

The quality of the created surface was evaluated from the point of view of the surface roughness (the roughness of created surface was chosen because it is a parameter depending on the interaction of a tool with a workpiece, while in the case of waviness it is a parameter given mainly by the kinematics of the cut) and specifically of parameter the mean arithmetic deviation of the roughness profile **Ra**.

Experimental data were subjected to a multifactor analysis of scattering in the first step (*Table 5*). The analysis revealed that the factors such as type of milling cutter and feeding speed are statistically significant. Regarding the factor - thickness of the removed layer - the statistic significance was not proven, which refutes the generally accepted assumption that the increased thickness of the removed layer increases the surface roughness (as a result of increasing the internal tension in the cutting zone, which should results in cracks in the cutting zone).

Tab. 5 Multifactor analysis of dispersion of the removed layer, feeding speed and type of milling cutter on the mean arithmetic deviation of the roughness profile.

	SS	Degr. of freedom	MS	F	p
Intercept	24886.08	1	24886.08	4843.854	0.000000
thickness of the removed layer	39.16	3	13.05	2.540	0.059663
feeding speed	257.71	4	64.43	12.540	0.000000
type of milling cutter	496.45	1	496.45	96.629	0.000000
thickness of the...*feeding speed	59.05	12	4.92	0.958	0.492846
thickness of the...*type of milling ...	9.19	3	3.06	0.596	0.618660
feeding speed*type of milling...	70.08	4	17.52	3.410	0.011152
thickness of the..*feeding..*type of milling...	65.95	12	5.50	1.070	0.391597
Error	616.52	120	5.14		

The graph in *Figure 7* represents a comprehensive look at the addiction of an arithmetic mean deviation of a profile roughness on the examined parameters.

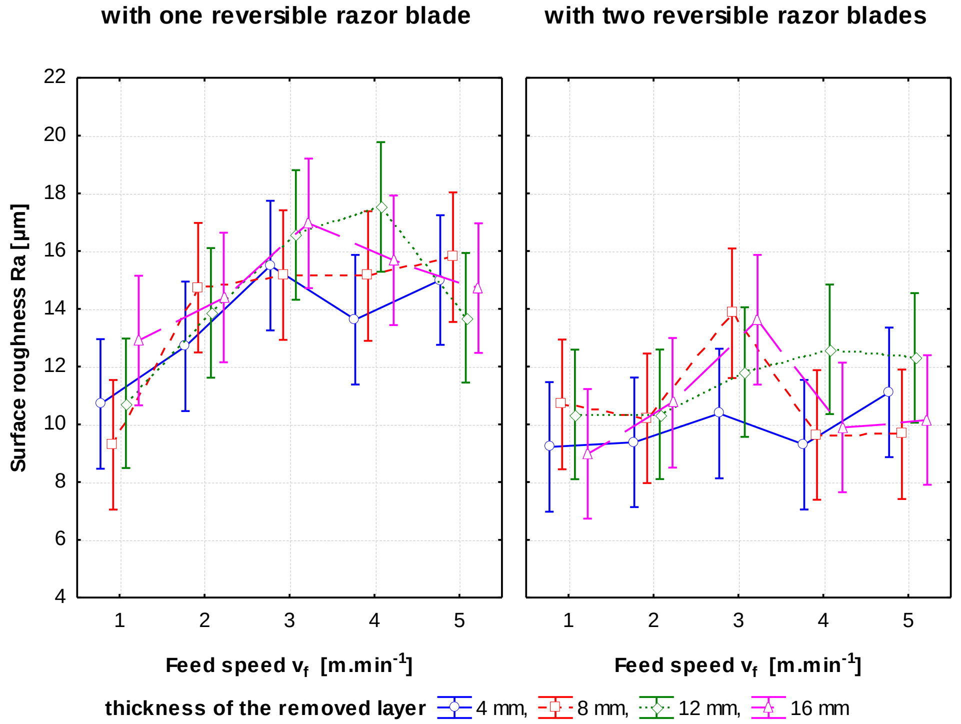


Fig. 7 Dependence of the mean arithmetic deviation of the profile roughness on the of thickness of the removed layer, feeding speed and type of milling cutter

The graph in the Figure 7 shows that the surface formed by a milling cutter with two reversible razor blades has an average roughness of 10.71 µm. At the same time, the usage of the milling cutter with two reversible blades has no statistically significant effect of the feeding speed on the surface roughness.

By using a milling cutter with one reversible razor blade, it is possible to see that the roughness increases as the feeding speed rises up to 3 m.min^{-1}, while the increase can be considered as linear. The roughness is stabilized at an average value of 15.2 µm when the feeding speed exceeds 3 m.min^{-1}. Based on generally assumptions (it must be stated that the assumptions are mainly based on theories built especially for machining solid wood) we have expected a closer correlation with the nominal thickness of the chips h_D (see *Figure 8*) which was calculated on the basis of the relationship:

$$h_D = h_{D/str} = f_z . \sin \varphi_{2/str}$$

$$\varphi_{2/str} = \frac{1}{2} \arccos \frac{R-e}{R}$$

f_z – feed per tooth [mm],
R – tool radius [mm],
e – cutting height [mm].

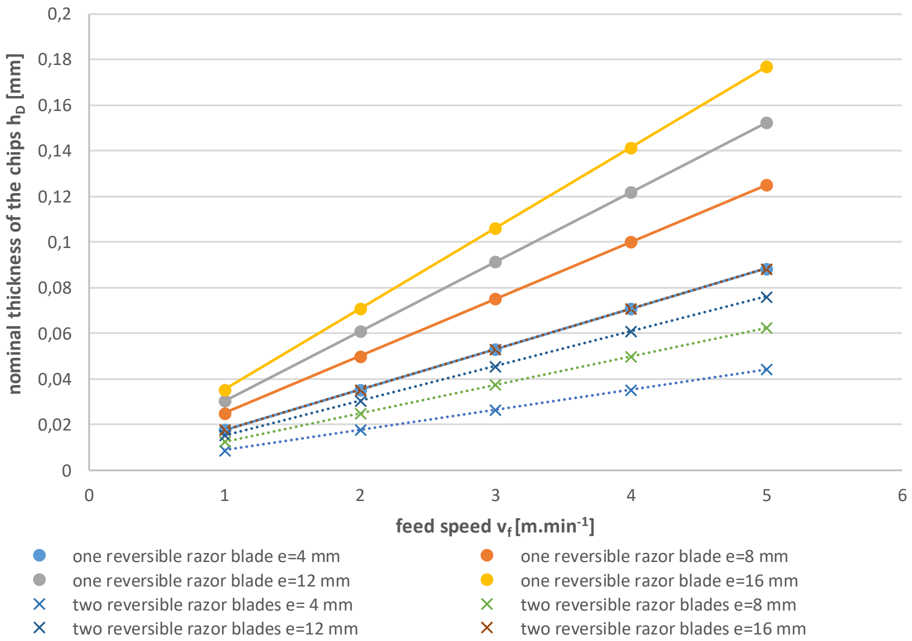


Fig. 8 Dependence of the nominal thickness of the chips on the of thickness of the removed layer, feeding speed and type of milling cutter

The expectation was that the thicker nominal thickness of the chip means the greater surface roughness (higher feeding speed means greater surface roughness and more cutting edges means smaller surface roughness). Regarding the number of cutting edges - the number of reversible razor blades the assumption was confirmed. However considering the feeding speed, the given assumption was not fulfilled, because of the inner structure of the material. The inner structure of the material is fine grain and the chips are separated easier, with the different decomposition of the forces in the surface forming zone as it is within the fibrous materials.

In order to make conclusions from the results, it is necessary to apply the optimization criterion which is the value of the required quality of the created surface. The required quality of the created surface is not defined by the standard, but based on our research on the MDF processors dispensed in KMINIAK and ŠUSTEK (2016), we can determine its value to Ra = 16 μm. From that point of view, it can be concluded that a cutter with two reversible razor blades meets the given criterion across the whole range of applicable feeding speeds. Taking into account a cutter with one reversible razor blade, this optimization criterion limits us to feeding speeds below 3 m.min^{-1}, which would results in a reduction of machine capacity.

Worth mentioned is as well the comparison of the results that have been published with the results from KMINIAK and BANSKI (2017). In both cases, there is used an identical methodology within the experiment with the only difference, which is that the one article deals with an open milling and the second article describes a milling in the groove. In both cases there was found a similar progress of dependence on the feeding speeds. However, the essential difference was within values of achieved roughness. It can be concluded from the comparison of obtained results that by using an open milling a smaller surface roughness was achieved, e.g. using a milling cutter with two reversible razor blades the difference was in average 2 μm. With respect to human perception of the surface roughness, the difference of 2–3 μm in average is considered as imperceptible, and therefore it is not necessary to realize technological interventions (to reduce the feeding speed) when changing an open milling to a milling in the groove.

CONCLUSION

Based on these results it can be said that the relationship between the roughness of created surface and thickness of the removed layer there has not been proven and therefore there is no need for programmers as well to adjust the feeding speed. Considering the economic efficiency of production processes it is appropriate to use a milling cutter with two reversible razor blades because then it is possible to make use the maximum recommended feeding speeds and the roughness of the formed surface does not exceed 16 μm.

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