ACTA FACULTATIS XYLOLOGIAE ZVOLEN, 59(1): 121−130, 2017
Zvolen, Technická univerzita vo Zvolene
DOI: 10.17423/afx.2017.59.1.12

VARIABILITY OF SURFACE QUALITY OF MDF BOARDS AT NESTING MILLING ON CNC MACHINING CENTERS

Richard Kminiak – Adrian Banski

ABSTRACT

The article deals with the issue of nesting milling of agglomerated materials on CNC machining centers. Specifically assess the quality of the surface around the perimeter of the workpiece with the view of relative changes of feed speeds direction as a result of different positions of tools and materials. Article based on experiments in which was at 5 axis CNC machining center nesting milled 18 mm thick MDF board. In the milling process they were used router bit with one or two reversible razor blades. The experiment was carried out at manufacturer recommended intervals of cutting and feeding speeds and machining strategies.

The findings of the experiment are presented via parameter arithmetic mean deviation of the surface roughness Ra. Article points out that the relative change of cutting speed direction affects this indicator. It notes that the change is average 3.4 microns in the router bit with one reversible razor blade and 1.6 microns in router bit with two reversible razor blades. Given discovery of point of view of perception of surface roughness by people can be considered negligible but in exact perception cause a need for correcting the technological parameters of the process.

Key words: machined surface inequalities, MDF machining, milling direction, nesting milling, router bit with reversible razors.

INTRODUCTION

The application of CNC technology offers a variety of machining possibilities of the given material. In machining of agglomerated materials, so called nesting milling is becoming extremely popular. Nesting milling is process when workpiece is extracted from the input material by router bits milling while distribution of the individual workpiece within given material determinates optimization software and created surface is considered as final and therefore no further working with exception of grinding is necessary (LASZEWICZ *et al*. 2013).

HIZIROGLU and KOSONKORN (2006), OČKAJOVÁ *et al*. (2016) state that the degree of roughness of the surface of the MDF plays an important role, since all surface irregularities may show through through a thin pad, reduce the final quality of the panel. MARIAN *et al*. (1954), FAUST (1987) and RICHTER *et al*. (1995) in his work they showed that smooth surfaces need relatively little primer and paint to cover better adhere to the surface.

As is apparent from the work GAFF *et al*. (2015) and SIKLIENKA *et al*. (2016). The surface roughness can have the following causes:

Kinematic cause unevenness (waviness) lie in cycloid shape relative movement of the cutting edge of the knife in the wood, which make absolutely flat surface rotary tool even theoretically cannot reach.

Technological causes unevenness (roughness) consist for example. transection of vessels or fibers, annual rings, moisture, conventional milling or climb milling, type of wood, etc.

Technical causes of inequality lie in the precision setting of knives of the cutter head (or. In precision grinding disc cutters to equal the average of all cutting edges) in the state of wear of the cutting edge of the blade, of vibration and throwing of the milling tool. They are expressed both in uprooting fibers (edge wear) and irregularities of ripples distance on a milled surface. In the present method of machining is called into question the quality of the surface homogeneity, because the tool during its trajectory changes its position relative to the workpiece - quadrant of formation resulting surface (see *Figure 1*).

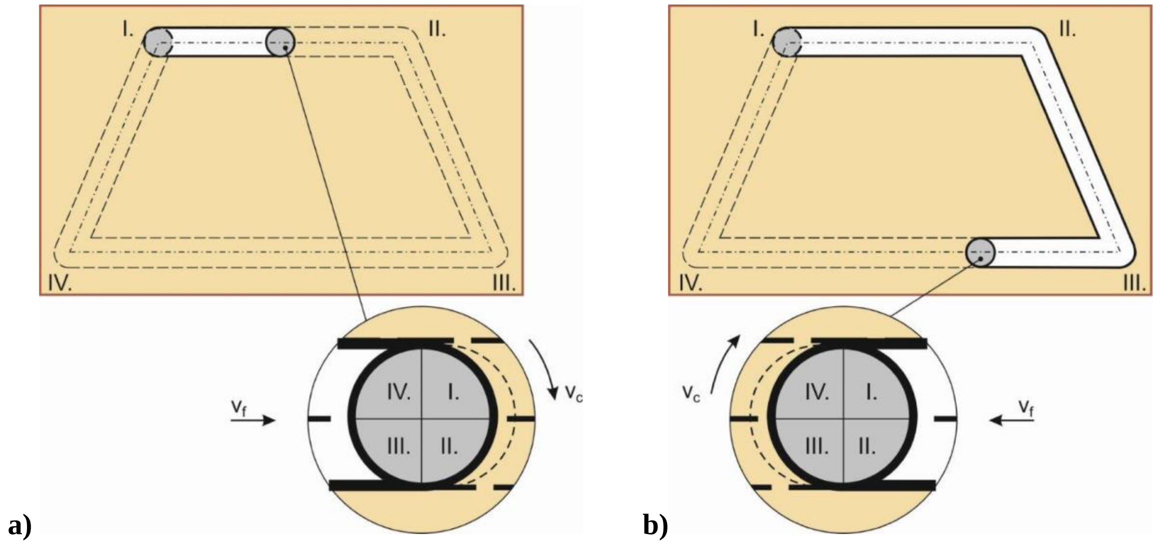

Fig. 1 The position of the tool relative to the workpiece and quadrant of the machining a) conventional milling b) climb milling.

Changing quadrant of forming surface from I to IV with a point of view of forming chips - surface finish means a change of the conventional milling on climb milling. Through common knowledge of this should be reflected in the quality of the generated surface - concrete surface roughness.

This article is intended to confirm or refute a given hypothesis and in case of confirmation to point out possible solutions to the problem.

METHODOLOGY

Material:

Characteristics of used material:

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

Tab. 1 Technical parameters of raw medium-density fiberboard.

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·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 2*) supplied by BOTO Ltd., Nové Zámky, Slovakia. Basic technical and technological parameters provided by the manufacturer are presented in *Table 2*.

Fig. 2 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}
Technical 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}
Maximum tool diameter	D = 160 mm
	L = 180 mm

Characteristics of tools:

For experiment, router bit with one reversible razor blade type designation **KARNED 4451** (*Figure 3/a*) and router bit with two reversible razor blade type designation **KARNED 4551** (*Figure 3/b*) were used, both by manufacturer Karned Tools Ltd., Prague, Czech Republic. Basic technical and technological parameters provided by the manufacturer are in *Table 3*.

Router bits were equipped with reversible blades **HW 49.5 / 9 / 1.5** and **HW 50/12 / 1.5** from sintered carbide **T03SMG** (standard material used for the treatment of HDF, and MDF DTD), from BOTO Ltd., Nové Zámky, Slovakia. Basic technical parameters provided by the manufacturer of sintered carbide provide *Table 4*.

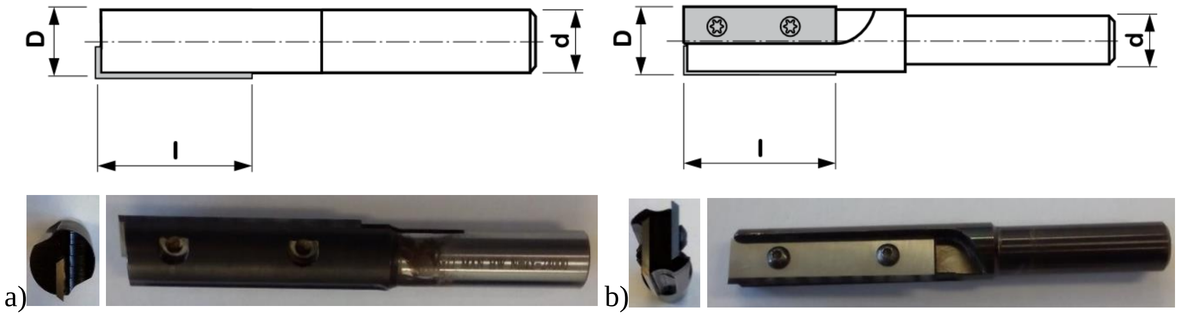

Fig. 3 router bits used in the experiment a) with one replaceable knife b) with two interchangeable cutting knifes (D - diameter operation, I - working length, d - clamping diameter).

Tab. 3 Technical and technological parameters of router bits.

Miller	Working diameter	Working length	Diameter of the chucking shank	Dimensions of used razor blades	Blades material
	D [mm]	l [mm]	d [mm]	L × š × h [mm]	
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.

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

Method:

The experiment was conducted according to the methodology KMINIAK and ŠUSTEK (2017) in the following steps:

1. Router bit was fitted with the hydraulic clamp **SOBO. 302680291 GM 300 HSK 63F** from Gühring KG Albstadt company, Germany and then inserted into a CNC machine magazine.
2. The input format of MDF board (2750 * 1840 mm) was divided in half (2 * 2750 * 868 mm).
3. Half- formatted MDF board was 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 was provided by 12 evenly placed suction cups measuring 120 × 120 × 35 mm (vacuum set was 0.9 bar) (suction cups distance from the edge of the MDF board was not more than 50 mm) (see *Figure 4*). Since the MDF board format dwindled during the experiment, suction cups location was corrected till the distance from the edge of the MDF board was less than 20 mm.
4. The experiment was carried out in a way that a router bit was gripped by CNC machining center (KARNED 4451 or KARNED 4551) and by using the given strategy (**per pass "I" E = H, the two transitions "II" e = 1 / 2h or three transitions "III", e = 1 / 3** (see *Figure 5*) **and kind of milling IA - conventional milling, IB - climb milling** (see *Figure 4*) 5 mm thick strip of MDF board was cut off (ie. sample "L" as the left). Then CNC machine tool gripped circular saw with 250 mm diameter and separated another 5 mm thick strip of MDF boards (ie. Sample

"P" as the right) 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 **router bit 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 instruments.

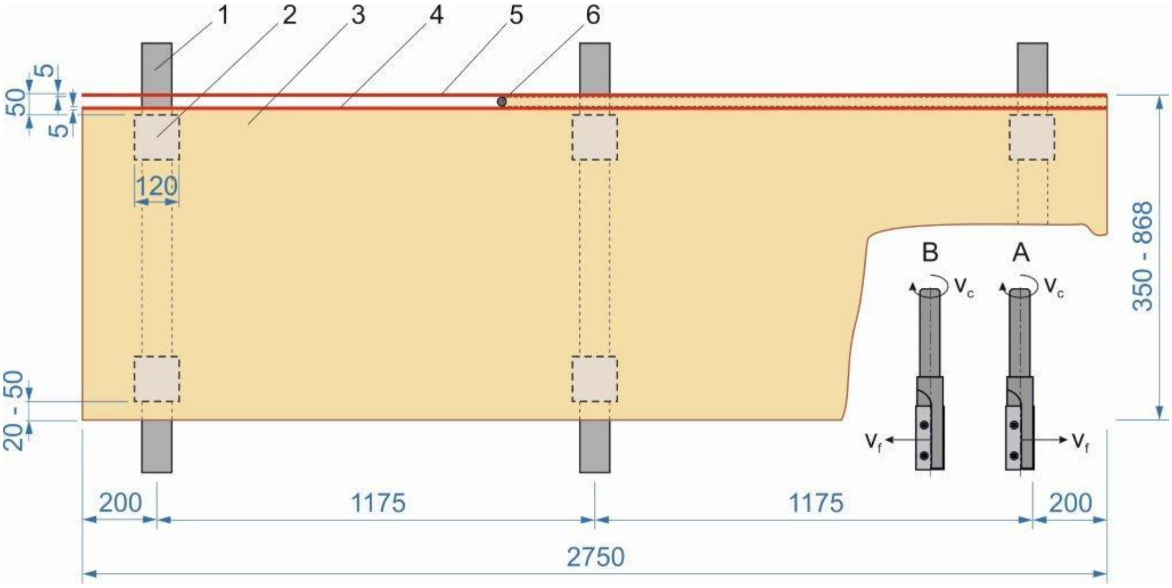

Fig. 4 Scheme of samples preparation (1 - CNC machining center transverse beam, 2 - vacuum suction cup, 3 - MDF board, 4 - sample "P", 5 - sample "L", 6 - router bit, v_c **- direction cutting speed,** v_f **- direction of sliding velocity A - conventional milling, B - climb milling).**

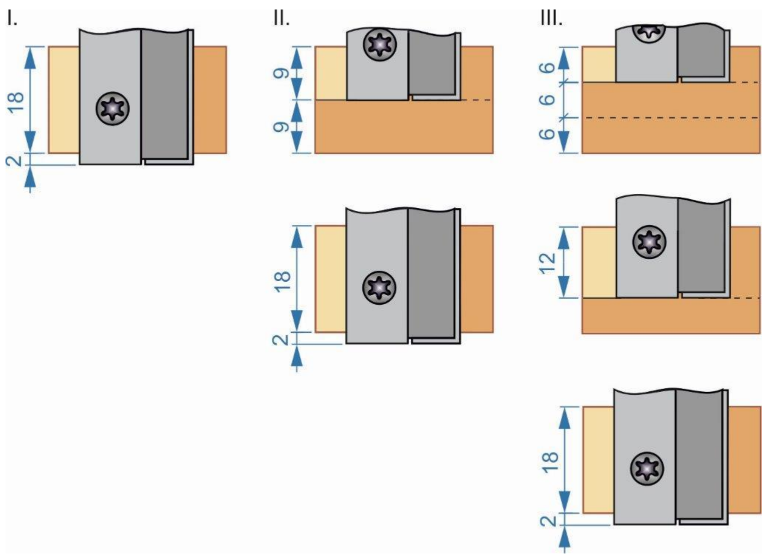

Fig. 5 Machining strategy a) on the first transition, b) on two transitions, c) on three transitions (KMINIAK and ŠUSTEK 2017).

5. L. sample was left for further evaluation, and there were extracted samples from P sample in order to determine surface roughness. Samples were extracted according to the methodology by *SIKLIENKA* and *ADAMCOVA* (*2012*) see diagram on *Figure 6*.

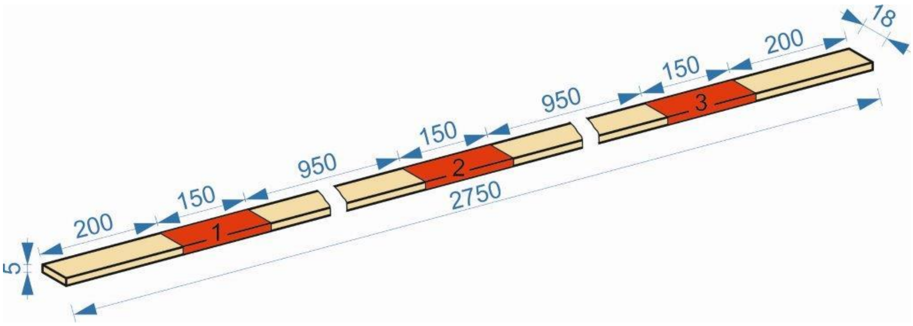

Fig. 6 Extracting method of test samples for the determination of surface roughness (SIKLIENKA and ADAMCOVA 2012)

Determination of surface roughness:

The inequality of the surface of the test piece was measured with a laser profilometer LPM-4 (*Figure 7*) from the Kvant Ltd. Slovak Republic. Profilometer uses triangulation principle of laser profilometry. The image of the laser line is scanned at an angle by digital camera. Then an object profile in cross-section is evaluated from scanned image. Obtained data are mathematically filtered and individual indicators of primary profile are set, profile of waviness and roughness profile (*KMINIAK* and *GAFF, 2015*)

For measuring surface roughness, methodology by *SIKLENKA* and *ADAMCOVA* (*2012*) was used reflecting the standard 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 (4.5 / 7.5 / 10.5 / 13.5 from the edge of the sample), line length was 60 mm and the track being oriented in the direction of displacement of the spindle in a milling process (*Figure 8*). Surface roughness was evaluated using parameter of arithmetic mean deviation of roughness profile R_a.

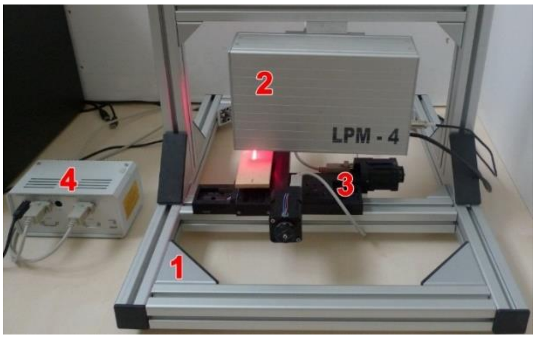

Fig. 7 Laser Surface Profile LPM - 4 (1 - supporting structure allowing manual preset of working distance and mounting of profilometric head and trolley system, 2 - profilometric head, 3 - feed system of the XZ axis, 4 - control system of working desk shifts).

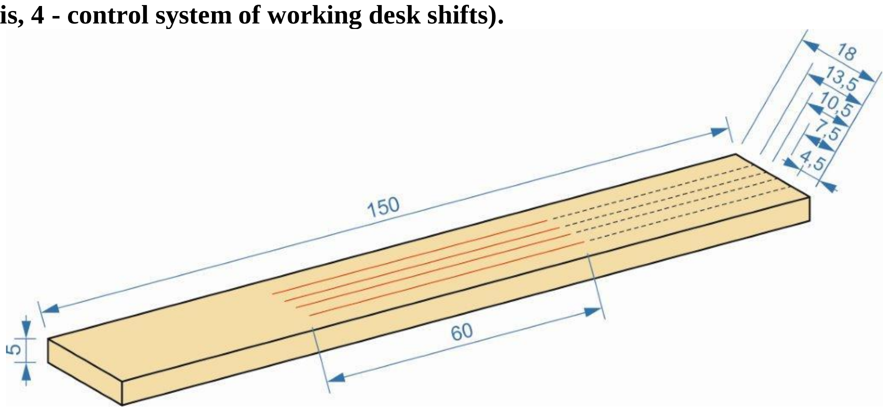

Fig. 8 Placement of surface roughness measuring tracks across the width of the sample (SIKLIENKA and ADAMCOVA 2012).

RESULTS AND DISCUSSION

Surface roughness was evaluated by criteria arithmetical mean deviation of the roughness profile R_a. The first step was the analysis of values distribution of the arithmetical mean deviation of the roughness profile along the height of cut - material thickness, because in multiple transition of working tool, the tool is in contact with surface multiple times and that may affect the surface quality in the area of machining. The statistical evaluation indicated that **the arithmetic mean deviation of the roughness profile is dependent on the track in which it was measured, but it was not demonstrated on the machining strategy** - the number of transitions of working tool through the working zone whether it was a conventional milling, or climb milling (see *Figure 9*). Since it was not proved the effect of machining strategies on the distribution of the arithmetical mean deviation of the roughness profile along the height of the cut, in the further evaluation, we will not select its value by the number of passes through working zone, but we will evaluate it as a whole.

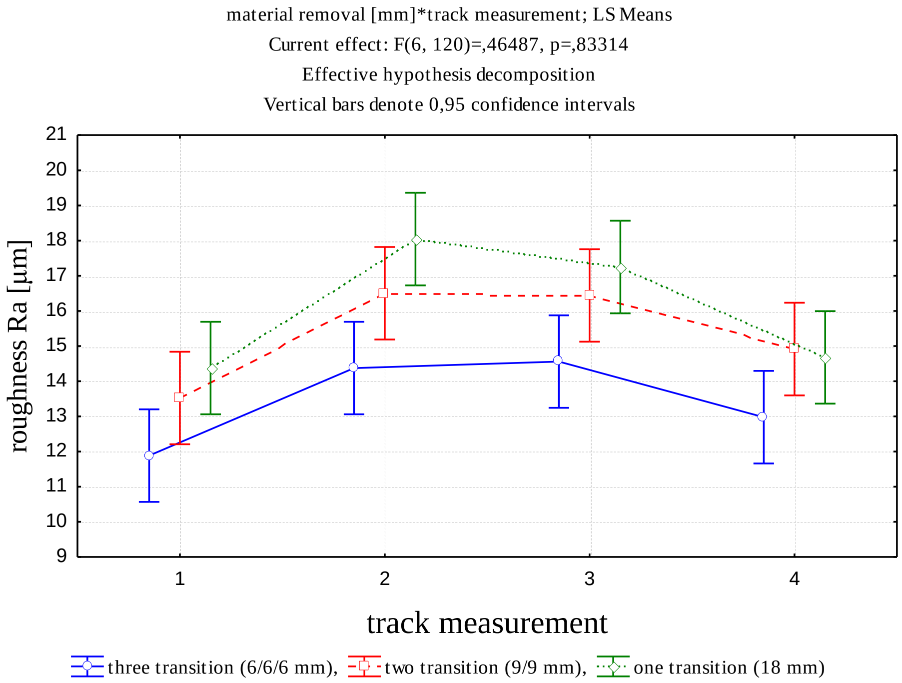

Fig. 9 Dependence of arithmetical deviation of roughness profile on the track in which it was measured for different machining strategies.

If we put into the context dependence of arithmetical deviation of roughness profile on the track in which it was measured with the density profile of MDF and generally applicable dependencies quality on the density of the agglomerated material, we can make a logical conclusion that **the quality of the surface is directly related to the density profile of the material and its value will increase symmetrically towards the axis of symmetry of the material.**

Statistical evaluation of the obtained data clearly demonstrates the difference between conventional and climb methods of forming chips - new surfaces (see *Figure 10* and *Table 5*).

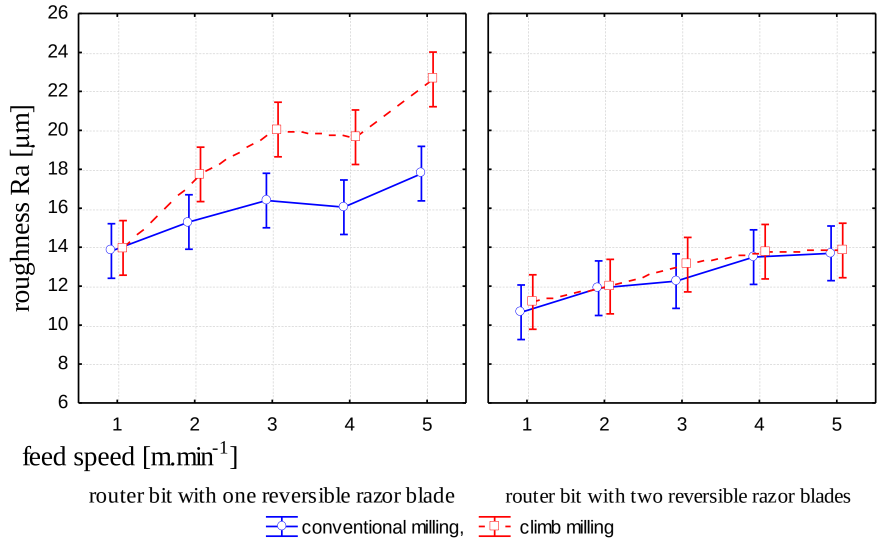

Fig. 10 Comparison of surface roughness formed at even conventional and climb method of forming chips - new surfaces.

Tab. 5 Summary of measured values in various Machining strategy.

feed speed [m·min^{-1}]	type of Endmills	milling direction	arithmetic mean deviation of roughness profile R_a [µm]				
			Mean	Std.Err.	-95,00%	95,00%	N
1	A - KARNED 4451	conventional milling	13.81	0.86	12.11	15.50	120
1	A - KARNED 4451	climb milling	13.96	0.86	12.27	15.66	120
1	B - KARNED 4551	conventional milling	10.66	0.86	8.96	12.36	120
1	B - KARNED 4551	climb milling	11.18	0.86	9.48	12.88	120
2	A - KARNED 4451	conventional milling	15.29	0.86	13.60	16.99	120
2	A - KARNED 4451	climb milling	17.74	0.86	16.04	19.44	120
2	B - KARNED 4551	conventional milling	11.90	0.86	10.20	13.59	120
2	B - KARNED 4551	climb milling	11.98	0.86	10.28	13.68	120
3	A - KARNED 4451	conventional milling	16.40	0.86	14.70	18.10	120
3	A - KARNED 4451	climb milling	20.04	0.86	18.34	21.74	120
3	B - KARNED 4551	conventional milling	12.26	0.86	10.56	13.96	120
3	B - KARNED 4551	climb milling	13.10	0.86	11.40	14.80	120
4	A - KARNED 4451	conventional milling	16.06	0.86	14.36	17.75	120
4	A - KARNED 4451	climb milling	19.65	0.86	17.95	21.35	120
4	B - KARNED 4551	conventional milling	13.49	0.86	11.79	15.19	120
4	B - KARNED 4551	climb milling	13.77	0.86	12.07	15.47	120
5	A - KARNED 4451	conventional milling	17.78	0.86	16.08	19.48	120
5	A - KARNED 4451	climb milling	22.62	0.86	20.92	24.32	120
5	B - KARNED 4551	conventional milling	13.69	0.86	11.99	15.39	120
5	B - KARNED 4551	climb milling	13.83	0.86	12.13	15.53	120

From the comparison of the data obtained shows that:

- at the router bit with one reversible razor blade the average difference in quality between the generated surface conventional and climb method of forming chips - new surfaces is 3.4 microns.
- at the router bit with two reversible razor blades the average difference in quality between the generated surface conventional and climb method of forming chips - new surfaces is 1.6 microns.

The findings correspond with the statement that the roughness of the surface has substantially the technological causes of inequality. As the point of view of agglomerated material is MDF board belongs among the most homogeneous materials we can develop this theory even deeper and identify the causes of differences in the quality of the surface on the level nominal chip thickness which in the case of the conventional milling increases from zero to maximum and in the case of the climb milling decreases from a maximum to zero. In that claims assures us almost linear dependence of surface roughness on the number of blades. Increasing the number of blades at unchanged technological parameters means a reduction of the nominal chip thickness which is within the presented data can be clearly observed.

With the ability to view the perception of inequality created surfaces the difference in average roughness 3,4 μm at the router bit with one reversible razor blade and 1,6 μm at the router bit with two reversible razor blades we consider an ordinary person imperceptible. Another case may be processors of MDF. The required quality of the surface is not defined the norm but based on our survey at processors of MDF published in the Article Kminiak, Šustek (2016) its value can be set at a level Ra = 16 μm. strict compliance with given criterion would not allow use the router bit with one reversible razor blade because would not be possible in the case of climb milling achieve quality below a given value. In the case of the router bit with two reversible razor blades suited both ways milling. If we want to achieve homogeneity of the surface roughness over the whole travel this would imply the need for corrections machining parameters. During the milling tracks I. - II. and. - III. (See Figure 1) we can use maximum feeding speed 5 $m.min^{-1}$ and during the milling tracks III. – IV. a IV. – I. we must reduce feeding speed by 50%.

CONCLUSION

The performed experiment has shown that the quality of the surface depends on the quadrant where the cutting tool takes place to the formation of particles. Based on published measurements we can state that the difference in the measured surface roughness is an average of 3.4 microns in router bit with one reversible razor blade and 1.6 microns in router bit with two reversible razor blades. Based on the process analysis, we have identified the cause as the current method of separating particles, conventional milling and climb milling. With regards the possibility of perception the quality of the surface by the user the difference considered negligible. In case, if there is to optimize cutting conditions based on the quality of the surface (Ra = 16 μm) this causes the router bit with one reversible razor blade will be considered inappropriate and in the case of router bit with two reversible razor blades will have to be corrected sliding speed by 50% to ½ of trucks. In conclusion it should be emphasized that in the case of MDF is one of the most homogenous materials and thus the effect of that phenomenon is minimal in the case of materials which predominates at a greater growth structure of product will deepened this phenomenon.

LITERATURE

FAUST, TD. 1987. Real time measurement of veneer surface roughness by image analysis. Forest Prod J. 37(6): 34–40.

GAFF, M. - KVIETKOVÁ, M. - GAŠPARÍK, M. - KAPLAN, L. - BARCÍK, Š. 2015. Effect of selected parameters on the surface waviness in plane milling of thermally modified birch wood. BioResources. 2015. 10(4): 7618–7626. URL: http://www.ncsu.edu/bioresources/BioRes_10/

BioRes_10_4_7618_Gaff_KGKB_Effect_Selected_Parameters_Surface%20waviness_Milling_Birch_7644.pdf. Project no. B05/15. WOS.
HIZIROGLU, S., KOSONKORN, P. 2006. Evaluation of surface roughness of Thai medium density fiberboard. Build Environ 41: 527–533.
KMINIAK, R. - GAFF, M. 2015. Roughness of surface created by transversal sawing of spruce, beech, and oak wood. BioResources. 2015. 10(2): 2873–2887. URL: http://www.ncsu.edu/bioresources/BioRes_10/BioRes_10_2_2873_Kminiak_G_Surface_Unevenness_Created_Transversal_Sawing_6794.pdf.
KMINIAK, R. - ŠUSTEK, J. 2016. The suitability of repeated machining in nesting milling on CNC machining centers. In Chip and chipless woodworking processes 2016: 10th international science conference, September 8–10, 2016, Zvolen : Technical University in Zvolen. 2016, s. 101–114.
LASZEWICZ, K. - GÓRSKI, J. - WILKOWSKI, J. 2013. Long-term accuracy of MDF milling process—development of adaptive control system corresponding to progression of tool wear. Eur. J. Wood Prod. (2013) 71: 383. doi:10.1007/s00107-013-0679-2
MARIAN, JE., STUMBO, DA., MAXEY, CW. 1958. Surface texture of wood as related to glue-joint strength. Forest Prod. J. (12): 345–351.
OČKAJOVÁ, A., KUČERKA, M., KRIŠŤÁK, Ľ., RUŽIAK, I., GAFF, M. 2016. Efficiency of sanding belts for beech and oak sanding. In Bioresources. Raleigh: North Carolina State university. ISSN 1930-2126. Vol. 11, no. 2, pp. 5242-5254.
Očkajová, A., Kučerka, M. 2009. Granular analysis of dust particles from profiling and sanding process of MDF. In Woodworking techniques : 3rd International Scientific Conference - Zagreb, Croatia : Faculty of Forestry, 187-192. ISBN 978-953-292-009-3
RICHTER, K., FEIST, WC., KNABE, MT. 1995. The effect of surface roughness on the performance of finishes. Part 1 Roughness characterization and strain performance. Forest Prod J. 45(7/8): 91–97.
SIKLIENKA, M. - ADAMCOVÁ, E. 2012. Výskum vplyvu materiálu reverzibilných nožov stopkových nástrojov na kvalitu opracovaného povrchu MDF. In Chip and chipless woodworking processes 2012 : 8th international science conference, September 6–8, 2012, Zvolen : Technical University in Zvolen. 2012, s. 315–323. ISBN 978-80-228-2385-2.
SIKLIENKA, M. - JANDA, P. - JANKECH, A. 2016. The influence of milling heads on the quality of created surface. Acta Facultatis Xylologiae Zvolen. 2016. (2): 81–88. ISSN 1336-3824.

ACKNOWLEDGEMENT

This work was supported by VEGA Grant No. 1/0725/16 "Prediction of the quality of the generated surface during milling solid wood by razor endmills using CNC milling machines."

AUTHORS ADDRESS

Ing. Richard Kminiak, PhD.
Ing. Adrián Banski. PhD.
Technical University in Zvolen
Faculty of Wood Sciences and Technology
Department of Woodworking
T. G. Masaryka 24
960 53 Zvolen
Slovakia
richard.kminiak@tuzvo.sk, banski@tuzvo.sk