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THE INFLUENCE OF TECHNICAL AND TECHNOLOGICAL PARAMETERS OF CNC MILLING ON THE SURFACE QUALITY OF BEECH PLYWOOD

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ABSTRACT

The milling process is one of the most used methods for machining wood and wood-based materials. This paper is focused on the analysis of the effect of technical and technological parameters on the surface quality of plywood. Beech plywood was used in the experiment, and the samples were machined using a 5-axis CNC machining centre under different feed speed settings and tool variations. Surface roughness (*Ra, Rz, Rp,* and *Rv)* was measured using a Keyence VHX-7000 digital microscope. The results show that by an appropriate combination of technical and technological parameters, it is possible to minimise surface roughness and eliminate defects such as fibre pull-out, fuzziness or surface irregularities. The paper contributes to a better understanding of the relation between CNC milling parameters and the resulting surface quality, thereby providing valuable information for optimising the production process in the woodworking industry.

Keywords: surface roughness; CNC milling; Keyence VHX microscope; plywood; feed speed; tool geometry.

INTRODUCTION

CNC wood milling is currently a key research topic in the field of wood science (Atanasov, 2021). With technological advancements, this woodworking method is being increasingly applied in industry, resulting in a growing number of CNC machines in woodworking enterprises (Hanincová *et al.,* 2024a).

A wide range of adjustable parameters requires optimisation, which can be aimed at, for example, reducing the energy consumption of CNC machining (Bal *et al.,* 2022). The key factor remains primarily the surface quality of the material after milling (Aras and Sofuoğlu, 2024, Demir *et al.,* 2022). Research by Hanincová *et al.* (2024b) demonstrated that the optimal combination of cutting tools and correctly set milling parameters results in reduced cutting forces, leading to less tool wear, lower energy consumption, and improved surface quality. One of the most important adjustable factors affecting the quality of machining is the feed speed, as noted by Bendikiene and Keturakis (2016), Smajic and Jovanovic (2021), and Çakiroğlu *et al.* (2019), as well as the tool speed. These then act on parameters such as cutting speed (Sedlecký *et al.,* 2018) and feed per tooth (Demir *et al.,* 2022). The most significant influences on the quality of the milled surface are feed speed and rotational speed (Pinkowski *et al.,* 2018; Singer and Özşahin, 2022). At the same time, research has shown that at higher feed speeds, there is an increase in surface roughness

(Csanády *et al.,* 2015; Yang *et al.,* 2023). In addition to these parameters, however, some factors cannot be directly regulated but have a significant impact on the final quality of the milled surface. These include cutting-edge wear Djurković *et al.* (2019), Koleda *et al.* (2019), as well as the natural physical properties of wood, such as its hardness and moisture content Benkreif *et al.* (2021).

In addition to surface roughness, a significant defect is delamination, which negatively impacts the quality of wood material processing. In production, it represents an error, often leading to the exclusion of the workpiece. It manifests as the separation or tearing of material layers, most often in the area of the edges, which leads to a violation of the product's structural integrity and aesthetic properties. (Pérez-Salinas *et al.,* 2023). This phenomenon is particularly critical when machining multi-layer materials such as plywood, where individual veneers can separate due to the action of cutting forces (Pérez-Salinas *et al.,* 2023). Increased tool wear and inappropriate settings of milling parameters can lead to an increase in the rate of delamination (de Castro Saiki and Gomes, 2024; Szwajka and Trzepieciński, 2016).

This paper is focused on evaluating the processing quality unevenness that would be acceptable for downstream operations. The aim is to achieve a level of unevenness that is acceptable for downstream operations, such as sanding. The objective of setting the technological parameters of the CNC machining centre correctly is to minimise the formation of torn fibres, which can lead to the delamination of layered materials, surface fuzziness, and tool traces. In the paper, the roughness of the milled surface of 11-ply beech plywood was quantified at different CNC feed speed settings of a 5-axis machining centre and with three types of tool-shank spiral milling cutters featuring positive, negative, and positive-negative helix.

MATERIALS AND METHODS

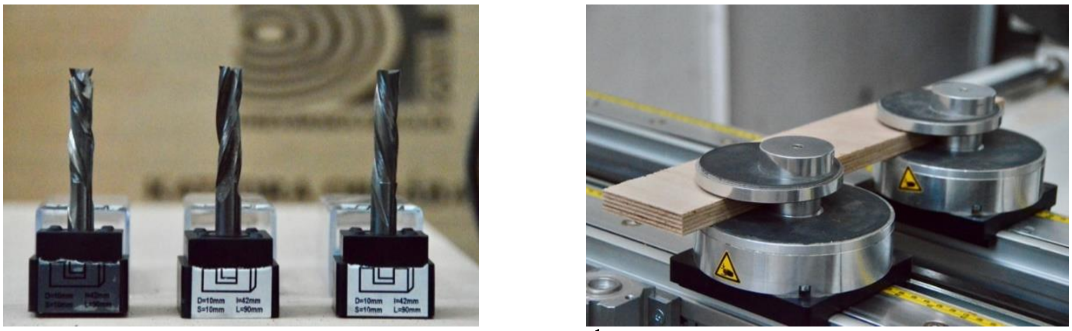
Sample preparation before CNC milling

The material used in this experiment was beech (*Fagus sylvatica* L.) 11-layer plywood (JAF HOLZ Slovakia s.r.o., Špačince, Slovakia) with dimensions of 15 mm × 1 250 mm × 2 500 mm (thickness × width × length). The plywood used was of BB quality, i.e. with a repaired surface and occasional fused lumps. Before cutting, the plywood was stored indoors, achieving an equilibrium moisture content of between 8 and 10 % (measured by the gravimetric method). The samples were cut using a sliding table saw with a scoring blade, and their dimensions (were 15 × 70 × 400 mm). The purpose of using a scoring blade was to achieve saw blade cut quality on both sides (i.e. no torn fibers on the underside of the sample). Dimensions were selected in consideration of the clamping system of the CNC machining centre. The aim was to ensure clamping stability and reduce the vibration of the loose ends of the samples during machining. A total of 36 samples were prepared.

CNC Sample Milling

The samples were milled using a 5-axis CNC machining centre SCM Tech Z5 (SCM Group S.p.A., Rimini, Italy). The samples were fixed with the VCMC-S4 12-80 combined mechanical-vacuum clamping system (Schmalz GmbH, Glatten, Germany), which ensured stable clamping during machining (Fig. 1 b)). Three types of IGM (IGM nástroje a stroje s.r.o., Praha, Czech republic) shank spiral milling cutters were used for machining: with a positive helix (IGM 193, HWM; Z3), with a negative helix (IGM 194, HWM; Z3) and with a combined positive-negative helix (IGM 190; HWM Z2) (Fig. 1 a)). All tools had a diameter of 10 mm, with the positive and negative cutters having three teeth, while the positive-negative cutter had two teeth. The position of the positive-negative helix geometry was varied in the middle of the plywood edge (to achieve the best possible quality on both sides). All tools had a total length of 90 mm, with a cutting edge length of 42 mm, and were made of tungsten carbide. It is well known from studies that the final quality of the milled surface is also affected by the number of teeth (Budakçı *et al.,* 2011, Kminiak 2014). The tools were clamped in a GM 300 HSK63F hydrodynamic chuck (Gühring KG, Albstadt, Germany). This chuck features higher tool clamping accuracy, which reduces tool run-out, improves machining accuracy, and minimises surface unevenness. Each tool was first run-in by milling so that the results were not distorted by the initial wear of the cutting edge (stabilisation).

Climb (down) milling was chosen due to the setting of the CNC machine and the direction of the movement of the cutter. In the case of climb milling, the tool rotates in the direction of the workpiece's feed (Kopecký *et al.,* 2019a, Korčok *et al.,* 2018). According to the study by Śmietańska *et al.* (2020), however, climb milling can cause higher delamination. According to Siklienka *et al.* (2017), climb milling has a beneficial effect on cutting stability, as cutting forces are directed into the material, reducing the occurrence of vibrations and the risk of workpiece deformation. According to (Darmawan *et al.,* 2018), the surface roughness is lower in climb milling compared to conventional milling due to lower cutting forces. Each sample was machined in two tool passes with a layer thickness of ae = 1 mm, which corresponds to the finishing milling process. The first pass of the milling cutter was equalising (removing unevenness after sawing and creating a flat surface), and the second pass removed a constant layer, making the unevenness characteristic of milling. With the removed material, the thickness of the cutting forces is reduced, resulting in a smoother surface. The susceptibility to fibre chipping is also reduced. The set feed speeds were 6, 10, 14 and 18 $m \cdot min^{-1}$, while the rotational speed was fixed at 20,000 rpm – the maximum value defined by the CNC machine and the tools used. This speed was selected to achieve the smallest feed per tooth and the smallest chip thickness, which, together with the amount of material removed, also affects the cutting force. The lower the cutting force, the lower the assumption of unevenness on the surface (Guo *et al.,* 2021).



a b

Fig. 1 Finishing spiral milling cutters with positive-negative, positive and negative helix (a); VCMC-S4 mechanical-vacuum clamps with clamped sample (b).

Surface Roughness Measurement

The roughness was evaluated with a Keyence VHX-7000 digital microscope (Keyence Corporation, Osaka, Japan). The milled edge of the samples was scanned using five evenly spaced scans, each measuring 4 mm × 18 mm. All scans were taken at 100× zoom using a VH-Z100R lens. First, the longer side of the scanning area was oriented perpendicular to the plane of the board (Fig. 2). From previous experiments, it was found that unevenness in this direction is primarily due to height differences between veneers milled differently.

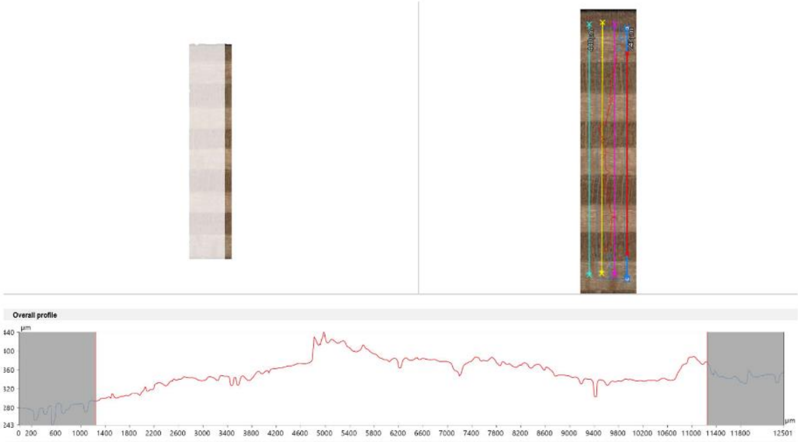


Fig. 2 Folding Lines in the direction perpendicular to the plane of the board.

Subsequently, the same area was analysed in the direction of movement of the instrument, with the lines interposed across two transverse and two longitudinal layers of veneer in the images (Fig. 3). This procedure aimed to identify the traces of the passage of the cutter in more detail.

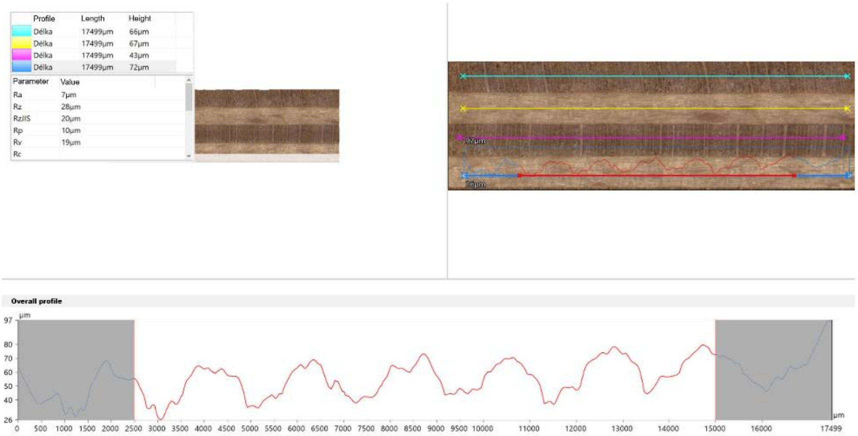


Fig. 3 Folding Lines in the direction of tool movement.

Four profile traces were evaluated from each image, resulting in a total of 20 measurements performed for each parameter in two directions: perpendicular to the board plane and parallel to the tool feed. The evaluation length of the profile was 12.5 mm. Filters according to the STN EN ISO 21920: 2022 standard were applied for the filtration of the roughness profile: L-filter (λc) with a value of 2.5 mm and an S-filter (λs) with a value of 8 µm. The evaluation of the roughness of the milled surface was conducted based on an analysis of roughness parameters, specifically *R*a and *R*z. Parameter *R*a was elected because of its relative stability and widespread use in the scientific literature, allowing comparison with the results of other studies. Since profiles with different shapes (due to varying unevenness) can have the same *R*a value (Musolff and Malburg, 2021), the amplitude parameter *R*z was also included in the analysis. This was used to capture the differences between the highest and lowest points on the surface, thus expressing the total height of unevenness.

Measurement of the delamination of plywood veneers

Again, the Keyence VHX-7000 digital microscope with a magnification of 200× was used to analyse the degree of delamination after milling. The delamination measurement was always performed on the side with the worst quality. In each case, a horizontal line perpendicular to the edge was determined, and the average profile function was applied, evaluating five profiles on both sides at a spacing of 250 μm. The scanned area was 20 × 5 mm in size (Fig. 4).

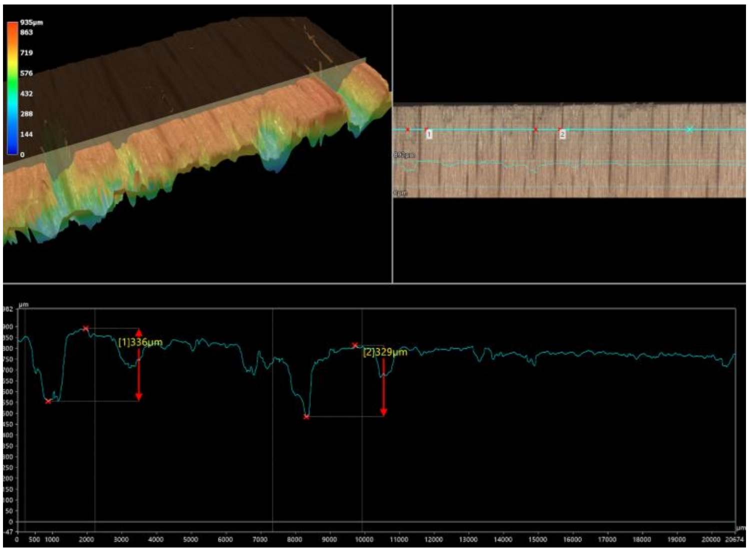


Fig. 4 3D visualisation and surface profile with marked damaged edge.

Two indicators were evaluated from the profiles: the depth of delamination (the difference between the undamaged surface of the plywood and the deepest point of the crack) and the length of delamination (the extent of damage in the horizontal plane). For each tool and feed combination, one scan was analysed at the point of most significant damage. The results were classified into four categories according to the severity of the damage (Tab. 1).

Tab. 1 Categorisation of the degree of edge delamination.

Score	Depth of damage [μm]	Length of damage [μm]	Description
0	0 – 100	0 – 500	No visible damage, clean edge
1	101 – 300	501 – 1500	Slight fuzziness or minor damage to the edge
2	301 – 500	1501 – 3000	Bright cracks or local tearing off of the veneer
3	>500	> 3000	Significant delamination, deep and extensive damage

RESULTS AND DISCUSSION

Influence of feed speed on surface roughness

Before the actual descriptive and inductive statistical analysis, outliers, which could negatively affect the reliability of the results and, thus, the conclusions of hypothesis testing, were removed from the dataset. These extreme values represent measured values that differ from the group average by several standard deviations. They most often arise due to local steep elevations of the surface (surface contamination) or incorrect conditions for scanning the surface with a digital microscope. The Z-score method was used to identify these values. Statistical analyses were performed using STATISTICA 14 software (TIBCO Software Inc., Palo Alto, California). The hypotheses were tested at a significance level of $\alpha = 5$ %. After removing the outliers, descriptive statistics were performed, specifically arithmetic averages and standard deviations for the *R*a parameter, which is the most widely used roughness parameter. Analysis of variance was used as part of the inductive statistics. The results confirmed that the technological parameters of milling – feed speed and tool geometry – have a statistically significant influence on all monitored surface roughness parameters (*R*a, *R*z, *R*p, *R*v; p-level = 0.000).

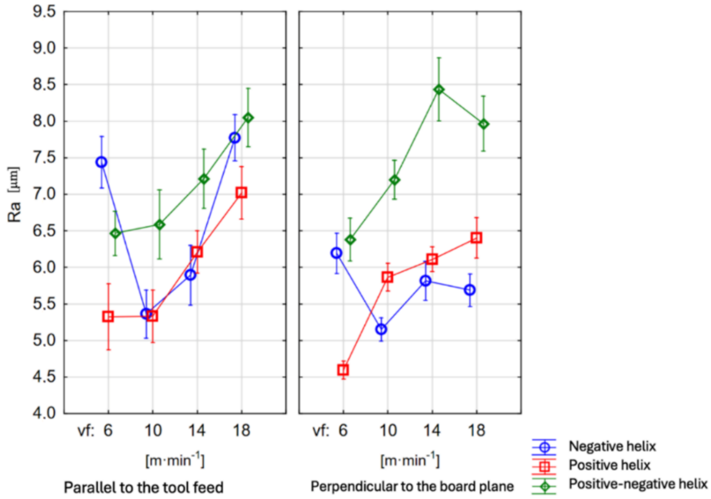


Fig. 5 Development of the *R*a roughness parameter depending on feed speed and the inclination of the tool helix in different measurement directions.

Fig. 5 shows the change in the Ra parameter due to varying feed speeds when using three different tool geometries (Bendikiene and Keturakis, 2016; Smajic and Jovanovic, 2021). The results show that the negative spiral milling cutter formed the lowest roughness at the mean feed speed values (10 and 14 $m \cdot min^{-1}$), while at the lowest speed of 6 $m \cdot min^{-1}$ there is a significant increase in roughness. This effect can be attributed to lower cutting stability and increased fibre crushing at slower feed speeds, resulting in surface disruption. As the feed speed increases, the cut becomes smoother, reducing surface roughness. Similar trends have been observed in the works of Csanády *et al.* (2015) and Demir *et al.* (2022), where it has been demonstrated that increasing the feed speed in CNC machining increases the likelihood of vibration and disruption of cutting smoothness, resulting in higher surface roughness values.

The negative cutter showed the lowest roughness values at medium feeds (10 – 14 $m \cdot min^{-1}$), while the lowest (6 $m \cdot min^{-1}$) and the highest feed speed (18 $m \cdot min^{-1}$) led to an increase in surface roughness. The positive cutter generally formed the lowest roughness among all tools, especially at low feed speeds. On the contrary, the positive-negative cutter showed the highest values of *R*a, with roughness increasing significantly as the feed speed increased, especially in the direction perpendicular to the board plane. Microscopic analysis shows that the surface roughness of the edge of the plywood is caused by torn fibers, crack formation, surface fuzziness and differences in heights between transverse and longitudinally milled veneers (Fig. 6).

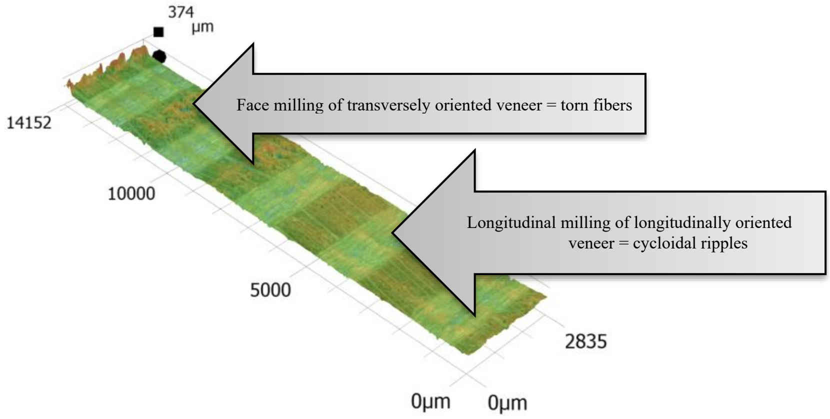


Fig. 6 Microscopic image of a surface milled with a positive milling cutter at a feed speed 18 m·min^{-1}. Lens zoom 100×.

According to the study by Ibrisevic *et al.* (2023a), one of the leading causes of the observed unevenness of the surface is the construction of the plywood itself. Alternating the layering of veneers with the direction of the fibres changing causes the orientation of the cutting edge to change relative to the fibres during milling. As a result, two distinct cutting models are applied in machining – the face-cutting model and the longitudinal-cutting model. With a face-cutting model, up to three times the cutting force is required (Curti *et al.,* 2021, Wang *et al.,* 2021), leading to more intense fibre pulling and a rougher surface. A study by Guo *et al.* (2021) shows that cutting force and wood roughness are correlated with each other. A higher cutting force leads to a rougher surface under standard conditions. A similar relationship was confirmed by (Guo *et al.*, 2018) in plywood milling. It follows that with the face-cutting model, the higher cutting force during milling will cause a greater roughness of the cross-section of plywood veneers. In the case of a longitudinal cutting model in the direction of wood fibres, the cutter creates a smoother surface with fine but distinct cycloidal waves – undulations (Brenci and Gurău 2024, Kopecký *et al.,* 2019b), which can also be seen in Fig. 6.

Authors Wei *et al.* (2021) report that at a higher feed speed, the cutting edge removes a larger volume of material, increasing the average cutting depth. This leads to a higher load on the tool, an increase in vibration amplitude, and, consequently, higher surface unevenness. By increasing the rotational speed, the surface roughness is expected to be reduced; however, according to studies by Li *et al.* (2014) and Pelit *et al.* (2021), it has been shown that increasing the speed from 12,000 rpm to 18,000 rpm can reduce roughness by 8 to 12%. In this analysed case, however, at high speeds (18,000 rpm), the opposite effect occurs – an increase in roughness, which can be attributed to the increased level of vibration of the tool. This phenomenon does not contradict previous studies, as the vibration reduction effect is particularly evident in the optimised feed per tooth. If the feed speed or rotational speed is too high, the process can be destabilised, and the machining quality deteriorates. Fig. 5 shows that as the feed speed increases; the roughness tends to increase. The same results are presented in the thesis (Ibrisevic *et al.,* 2023b, Smajic and Jovanovic 2021).

A positive tool produced lower roughness at the lowest feed speed compared to a negative one, as addressed by research by Karim *et al.* (2013), which investigated the effect of positive and negative tool face angles on tool wear and surface quality. With increasing feed speed, there was a slight increase in roughness. This trend is related to the rise in chip volume and an increase in feed per tooth, which, according to a study by Pinkowski *et al.* (2024), has led to a deterioration in surface quality. When using a positive-negative tool, the highest values of the parameter were measured in the direction of movement of the tool *R*a compared to other tool geometries. The roughness increased significantly with the feed speed, with the highest values being achieved at a feed of 18 m·min^{-1}. A similar trend was observed in measurements perpendicular to the plane of the board. It indicates that this helix inclination is less suitable for the final surface treatment at higher feeds in terms of the roughness of the machined surface. Analogous trends observed for the *R*a parameter were also evident for the *R*z parameter (Fig. 7).

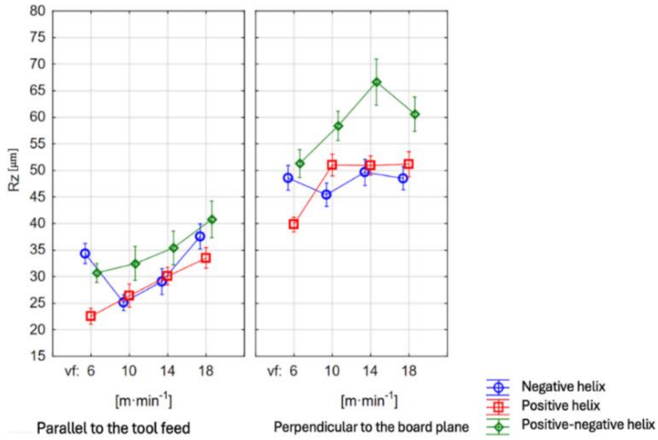


Fig. 5 Development of the *Rz* roughness parameter depending on feed speed and the inclination of the tool helix in different measurement directions.

Influence of Feed Speed and Cutter Geometry as Independent Factors on External Veneer Delamination Rate

As can be seen from the results presented in Table 2, most of the samples did not show extensive or continuous surface damage and were classified in category 0. In many cases, this was not a typical delamination in the form of tearing off part of the top veneer but rather fuzziness caused by the orientation and protrusion of the fibres. Such damage can usually be easily removed by sanding.

In the production of furniture parts, edges with a radius of 2 mm are rounded, and in children's furniture, even a radius of 4-5 mm is used, which not only increases safety but also makes it easier to remove minor damages, such as delamination or fuzziness. Such modifications follow applicable technical standards.

Tab. 2 Evaluation of the degree of delamination of upper veneer depending on milling parameters.

Tool geometry	Feed speed [m·min⁻¹]	Score	Max. depth [μm]	Max. length [μm]
Positive	6	0	< 100	< 100
Positive	10	1	172	2 332
Positive	14	3	485	4135
Positive	18	3	722	3288
Negative	6	0	< 100	< 100
Negative	10	0	< 100	< 100
Negative	14	2	501	3 224
Negative	18	3	659	3 838
Positive-negative	6	0	< 100	< 100
Positive-negative	10	0	< 100	< 100
Positive-negative	14	0	< 100	< 100
Positive-negative	18	0	< 100	< 100

With a feed speed of 6 m·min^{-1} and the use of a positive spiral milling cutter, no significant cracks or delamination occurred. However, the surface showed fuzziness in places due to the plucking of fibres. Similar findings are confirmed by the research of (de

Moura and Hernández 2006); knives with a positive spiral in face milling showed "only slightly slender fibres" without deeper cracks. These surface defects could be easily removed by fine sanding. Even in this experiment, the damage is mainly characterised by bent fibres (protruding fibres) rather than cracks at the material's depth, so we do not consider this damage to be severe.

The feed speed of 10 m·min^{-1} deteriorated the surface quality compared to the lower speed. Cracks up to 172 µm deep and 2,332 µm long are present on the scan. The surface exhibits a tendency to delaminate and tear off the fibres, which can be attributed to higher dynamic stress on the material. Rounding the edge to a minimum radius of 2 mm can be an effective way to remove this damage in this case.

With a feed speed of 14 m·min^{-1} and a positive milling cutter helix, the damage reached a maximum depth of 485 µm and a maximum length of 4135 µm. Although the depth corresponds to the second degree, the length exceeds the limit for the score of 3 assigned to this section and corresponds to significant delamination. At the same time, the scan revealed a split under the surface veneer, representing severe damage that significantly reduces the product quality. Likewise, when rounding the edge to a minimum radius of fillet of 2 mm, the damage to the edge would be preserved, which is not desirable from a qualitative point of view.

At a feed speed of 18 m·min^{-1}, a maximum depth of damage of 722 µm and a maximum length of 3288 µm were recorded, which corresponds to the highest degree of damage (score 3) – significant delamination and extensive edge disruption (Fig. 8). The damage extends beyond the thickness of the surface veneer and extends into the deeper parts of the veneer, making it impossible to remove it by sanding. In this case, the damage goes beyond the area of the radius of curvature, and a significant part would be preserved, which still ranks it as unacceptable from a qualitative point of view.

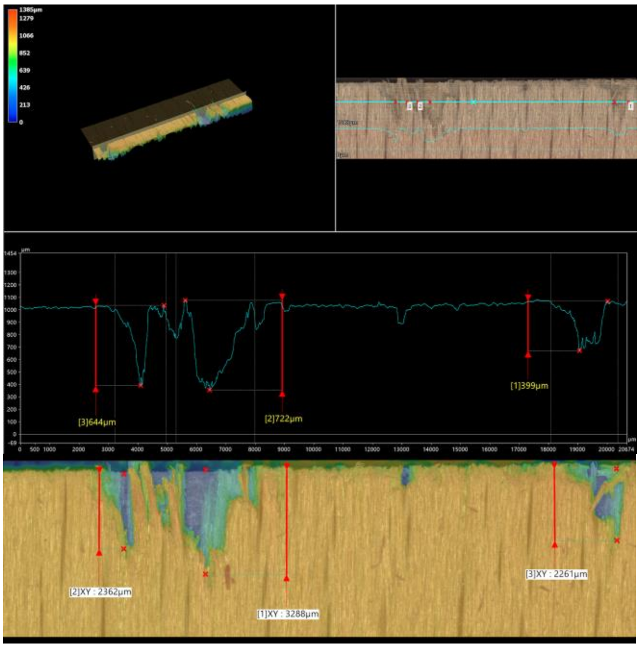


Fig. 8 3D sample scan at vf = 18 m·min^{-1} and positive cutter used.

At a feed speed of 6 m·min^{-1} for the negative cutter, the quality of the machined edge was slightly lower than that of the positive cutter at the same speed, while similar results were reported by Śmietańska *et al.* (2020). They found that with minor to moderate tool wear, positive milling with melamine-coated MDF was significantly more favourable than with a negative milling cutter in terms of delamination. The edges remained clean, without continuous cracks. The surface remains compact and uniform, without cracks, which corresponds to a damage category of 0.

With a feed speed of 10 m·min^{-1} and the use of a negative cutter, increased edge fuzziness was observed. From the microscopic measurement, an irregular line with frequent protrusions up to 350 μm is visible. The profile exhibits significant fluctuations in height, indicating an insufficiently clean cut but without any visible cracks. Such an edge is classified in damage category 0 in terms of quality, although it visually appears rough and frayed. These defects are easily removed by sanding.

With a feed speed of 14 m·min^{-1} and a negative spiral milling cutter, the quality of the machined surface was reduced compared to lower speeds. Significant defects, with a depth of up to 501 μm and a length of 3224 μm, are visible on the scanned profile, indicating a violation of the edge zone. The occurrence of fibre plucking is observed, which may be a consequence of increased dynamic loading of the material at higher feed speed. This combination of parameters appears to be less favourable in terms of machining quality, as damage could remain present even in subsequent edge rounding and sanding operations.

With a feed speed of 18 m·min^{-1} and a negative spiral milling cutter, a maximum damage depth of 659 μm and a length of 3838 μm were measured. These values represent the most significant degree of edge disruption, characterised by significant delamination and extensive material damage (Fig. 9). The defect extends deeper than just the surface layer. When rounding the edge and then sanding, the damage can be partially eliminated; however, in this case, it exceeds the minimum radius of 2 mm, so a significant part of the defect would remain even after rounding. For this reason, the quality of such an edge is still rated as unsatisfactory.

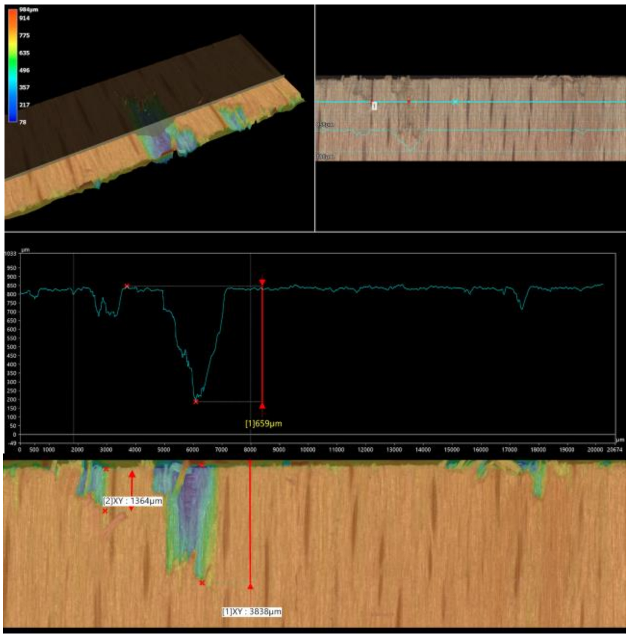


Fig. 9 3D sample scan at vf = 18 m·min^{-1} and negative cutter used.

When using a positive-negative spiral milling cutter, the quality of the machined edges was very high at all investigated feed speeds (6, 10, 14 and 18 m·min^{-1}). In cases with a lower feed speed (6 and 10 m·min^{-1}), there was no visible damage – the value of both the depth and length of the violation remained below 100 μm, which corresponds to the lowest degree of damage (score 0). At higher speeds (14 and 18 m·min^{-1}), a slight fuzziness of the marginal zone appeared, but it was not delamination in the true sense of the word. The damage was limited to protruding fibers on the surface and did not exhibit the characteristics of a crack or a torn layer of veneer. Therefore, it was still rated as a score of 0 (Fig. 10).

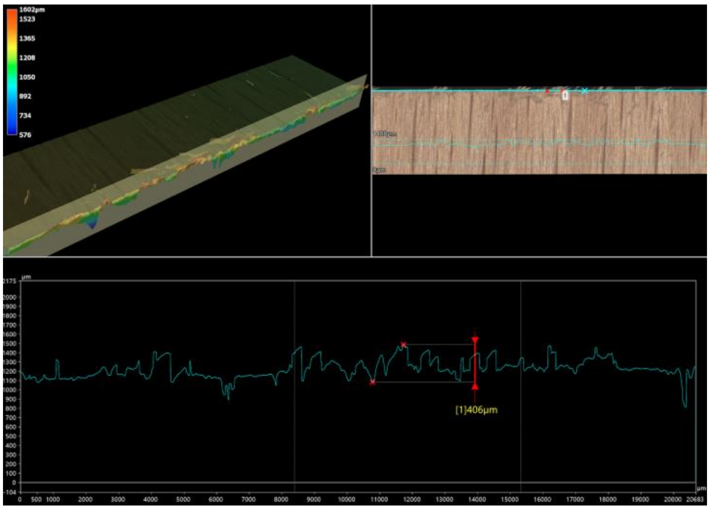


Fig. 10 3D sample scan at vf = 18 m·min⁻¹ and positive-negative cutter used.

The measurement result can be directly attributed to the specific geometry of the positive-negative cutter. This combined helix has a positive inclination of the cutting edge at the bottom (chips point upwards) and a negative slope at the top (chips point downwards), eliminating torn fibres around the edge. This geometry reduces the risk of tearing out the fibres at both the top and bottom edges of the machined material, resulting in a symmetrical and even cut based on our measurements.

These observations correlate well with the review study of Trzepieciński *et al.* (2025), which highlights that the lowest delamination coefficients are achieved at lower feeds and/or in cutting geometries where the chip is compressed back into the material. At the same time, the authors state that even a slight increase in feed speed leads to an increase in traction forces and the risk of pulling out the fibres. Our finding that the positive-negative cutter virtually eliminates delamination even at 18 m·min^{-1} feeds is in line with the work of Śmietańska *et al.* (2020), where climb and conventional milling of melamine-coated MDF was compared.

CONCLUSION

Based on the experiments conducted, it can be stated that the quality of processing the beech plywood edge is significantly influenced by the technological parameters of CNC milling, particularly by the geometry of the tool used and the feed speed. The results showed that the lowest surface roughness values (both *R*a and *R*z) were achieved when using a positive spiral milling cutter at low feed speeds (6 – 10 m·min^{-1}), confirming its suitability for applications where high quality of the edge is important. The negative cutter performed best at medium feeds (10 – 14 m·min^{-1}), while the positive-negative cutter showed the highest surface roughness, especially at higher feed rates. Microscopic analysis reveals that surface unevenness primarily results from the plucking of fibres and variations in the orientation of the veneers. The combination of the face and longitudinal cutting models, characteristic of the multilayer composition of plywood, leads to irregular loading of the cutting tool and the formation of micro-defects. As the feed speed increases, the tool load, the amplitude of vibration, and thus the surface unevenness increase. In terms of eliminating delamination and plucking of fibres, the positive-negative cutter proved to be the most effective, thanks to the combined inclination of the spirals, which minimised damage to the edges. At all speeds, it was in the score category of 0 – with no visible damage. On the contrary, with positive and negative cutters, defects occurred at higher feeds, which in some cases exceeded the 2 mm rounding limit, making it impossible to eliminate them during machining. The results confirm that to achieve optimal processing quality of the side surfaces of plywood, it is advisable to choose a lower to medium feed speed and choose tools with a stable cutting geometry. From a comprehensive perspective, it can be concluded that a positive tool is best suited for machining the edge, while a positive-negative cutter is optimal for edge processing. Where the highest visual and structural quality of the entire viewing area is required, a positive-negative milling cutter is the most versatile solution, as it provides consistent results without significant damage, even at higher feeds.

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