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WEAR CHARACTERISTICS OF CUTTING TEETH OF THE TOOL IN MILLING RECTANGULAR GROOVES IN MEDIUM-DENSITY COMPOSITE WOOD MATERIALS

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Abstract: The article investigates the wear characteristics of the cutting teeth of disc-type milling cutters used for milling rectangular grooves in medium-density composite wood materials, considering their dependence on material density and cutting speed. Empirical formulas were derived by constructing comparative graphs of the relationships between the quantitative deformation parameters of the cutter teeth during the milling of composite wood samples with varying densities. Using these formulas, the wear parameters of the disc-type cutter teeth were theoretically calculated. The obtained results were compared with experimental data from the study, and changes in wear characteristics during repeated wear cycles were analyzed. The research also established that the anisotropy of composite wood materials, alongside other technological factors, causes uneven wear of the cutter teeth. The anisotropy is attributed to variations in the physical-mechanical properties within the wood particles, uneven distribution of resin adhesive compositions, and the formation of voids in areas with high resin accumulation during the drying stage of the board production process. Furthermore, the use of diverse raw materials such as different wood species and other wood/non-wood waste materials in composite wood production accentuates anisotropic properties. During cutting, the cutter teeth continuously encounter surfaces with varying characteristics, exacerbating the non-uniform wear process. Additionally, it was observed that the cutting speed of the milling cutter varies depending on environmental conditions. Increased cutting speed leads to uneven wear of the cutter teeth, resulting in tool vibration and, consequently, greater geometric dimensional inaccuracies in the milled grooves.

Keywords: *composite material, wood, disk-type milling tool, rectangular groove, wear of teeth.*

Introduction.

In various industrial sectors, including aviation, machinery manufacturing, shipbuilding, and furniture production, composite materials are widely used to manufacture components and household items [1]. The quality of furniture, which is utilized in domestic and other settings, heavily depends on the geometric and dimensional precision of grooves milled into composite wood materials during the assembly of individual parts into a unified structure. In furniture production, composite wood panels (made from wood-based composites) exhibit varying densities, leading to differences in the wear characteristics of the cutting teeth of disc-type milling cutters employed for machining rectangular grooves [2]. Therefore, investigating tool wear during the processing of composite wood panels with differing densities remains a pressing issue [3].

Composite wood panels used in furniture production are classified by density as low-density (up to $550\,kg/m^3$), medium-density $550-750\,kg/m^3$, and high-density (above $750\,kg/m^3$) [4].

Low-density composite wood boards are mainly used as insulation elements in industry. High-hardness composite wood boards are used in the structures of specialized equipment [5].

Medium-density composite wood boards are primarily used in various fields. Therefore, by investigating the wear of the cutting teeth of tools during the milling of rectangular grooves in medium-density composite wood boards, it is possible to increase the efficiency of furniture production [6].

In furniture production, rectangular grooves milled into composite wood panels vary in geometric dimensions depending on the structural design of the furniture.

Research conducted at the "HASANOGLU" Furniture Plant revealed that rectangular grooves milled into composite wood panels have a width of 3 mm and a depth of up to 10 mm, oriented both longitudinally and transversely relative to the panel. These grooves serve as assembly reference surfaces for joining other panels. The rigidity and quality of the assembled product depend on factors such as groove surface quality, geometric dimensional accuracy, machined surface roughness, form errors, and waviness. The formation of these factors during milling is highly influenced by the composite panel's density, cutting parameters (e.g., speed, feed rate), and wear of the disc-type milling cutter [7]. Uneven wear of the cutter teeth during composite panel machining leads to variations in the geometric dimensions of the teeth (e.g., cutting edge length, rake and clearance angles), causing tool vibration. Consequently, the geometric dimensions and angular deviations of the milled grooves change, compromising assembly precision [8].

Purpose of the Study: This study investigates the wear behavior of disc-type milling cutters during the machining of rectangular grooves in medium-density composite wood panels, as influenced by cutting parameters and material characteristics. The primary objective is to develop insights that contribute to enhancing the dimensional accuracy and overall quality of the manufactured product.

Research methodology: Experiments were conducted on particleboards (PB) made of wood with three different composite material densities $550, 650 and\, 750 kg/m^3$ during the milling of rectangular grooves [9]. The experimental research was carried out at the "HASANOGLU" furniture factory using a CNC-controlled "WEEKE-HOMAG OPTIMAT BHT-500" model milling machine. Grooves with dimensions of $b \times h = 3 \times 10 mm$ were machined on the particleboards along the longitudinal feed direction using a straight-type milling cutter with a diameter $D = 125 mm,\ Z = 24 teeth$, and a thickness of $b = 3mm$. During the groove milling process, the cutting depth was set to $t = 5mm$ and the longitudinal feed rate was $S_{uz} = 12\, m/\min$. The study investigated the deformation, impact, and flank wear characteristics of the cutting teeth under varying processing lengths and spindle rotational speeds.

The deformation of the milling cutter teeth was measured using a dial indicator with a measurement accuracy of ± 1 µm, mounted on a specialized device. The flank wear on the teeth was documented by capturing photographs via a tool microscope. The experiments were designed based on a multifactorial experimental plan, and the results were processed using IT applications within Microsoft Excel software, where graphical curves were plotted.

Dıscussıon of results: Based on the methodology and experimental design outlined above, the deformation of the teeth of the straight-type milling cutter was studied in relation to changes in the density of the composite material. The conducted research revealed that during the machining of grooves in composite materials using straight-type milling cutters, the wear characteristics of the cutting teeth depend on the deformation caused by the cutting forces acting on them. The deformation of the cutting teeth during groove milling arises from the kinematic and dynamic characteristics of the cutting process. Specifically, when machining rectangular grooves with straight type milling cutters, the cutting tooth interacts with the material being cut not only along the front face but also along both side surfaces and the flank face.

During machining, since the high-speed rotating teeth of the milling cutter engage with the composite material in the direction opposite to the feed movement, the thickness of the removed chip layer starts at a maximum. Significant cutting forces act on the front face of the cutting teeth, as well as on other contact surfaces. During the rotation of the milling cutter, the direction of the kinematic forces acting on the teeth continuously changes depending on chip formation and the anisotropy of the material. Consequently, the cutting teeth of the milling cutter undergo deformation in multiple directions within a single tool cycle. Research has shown that during the cutting process of a 125*mm* diameter milling cutter with $N = 24 teeth$, the teeth experience deformation of varying magnitudes.

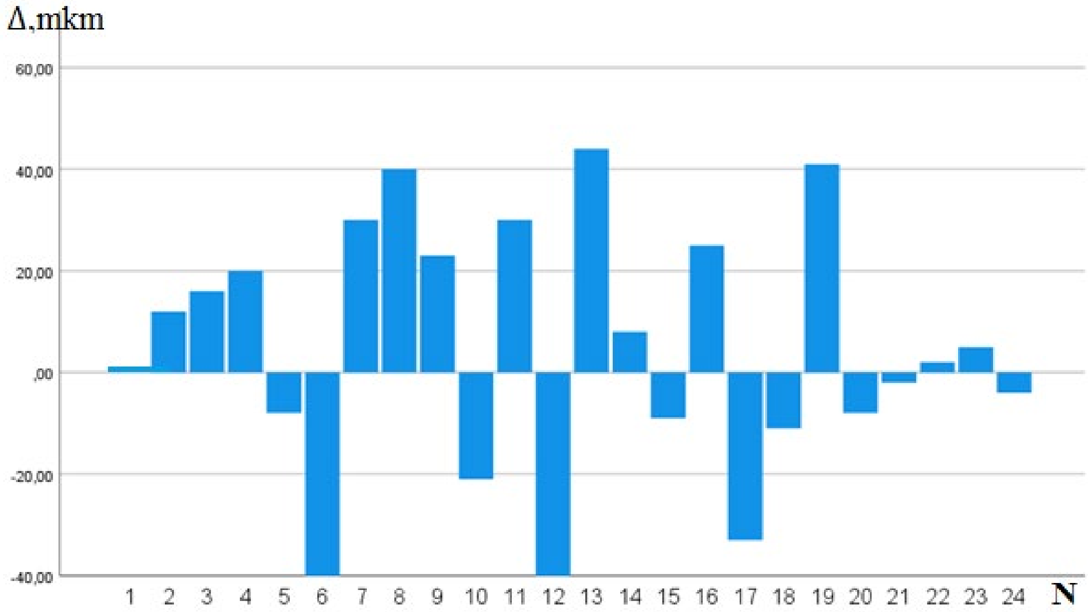

Fig. 1. Deformation of milling cutter teeth

Fig. 1 illustrates the deformation limits of the teeth of a BK6-grade straight-type milling cutter during the machining of a rectangular groove (width =3 mm, depth =5 mm) in a composite material with a density of $650\, kg/m^3$ .Measurements revealed that the cutter teeth undergo asymmetrical deformation. For example, while the deformation value for Tooth 1 was +2 μm (assuming the teeth are numbered sequentially), Tooth 2 exhibited+15 μm, and Tooth 3 showed+18 μm. The highest positive deformation was observed in Teeth 7, 8, 13, and 19, while the highest negative deformation occurred in Teeth 6, 10, 12, 17, and 23. The asymmetrical deformation of the teeth stems from the dynamic effects of the cutting process. During the milling of rectangular grooves, the cutting teeth experience uneven loading, resulting in variable directions of cutting force application. As shown in Fig.1, the deformation of the teeth occurs in multiple directions, leading to distinct wear characteristics and patterns on the front and flank faces of adjacent teeth. For instance, the wear mechanisms on the flank faces of neighboring teeth differ significantly in form and intensity. The results of the study are further supported by Fig. 2, which provides photographic evidence of flank wear on two adjacent teeth.

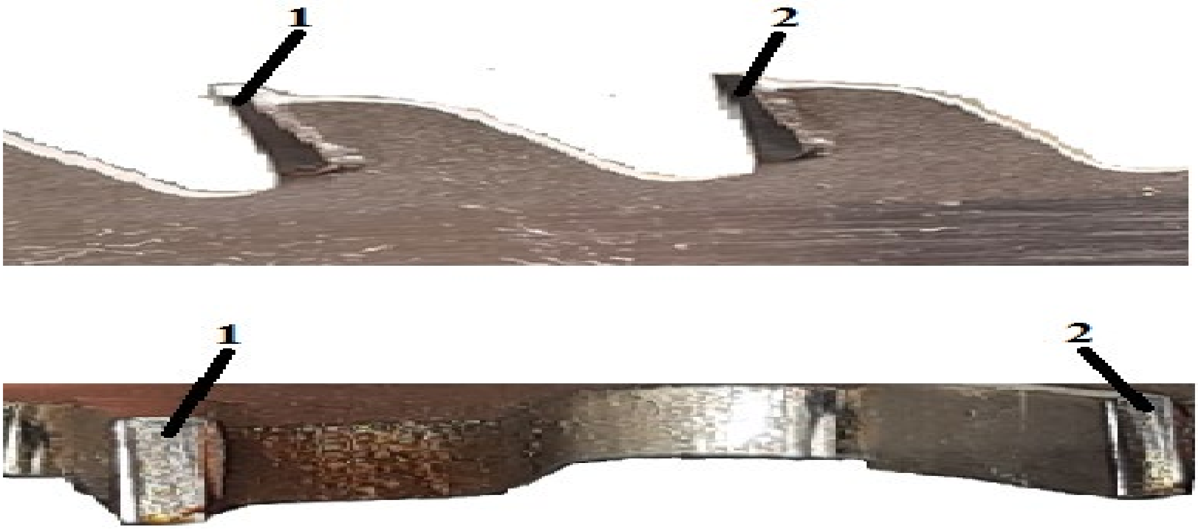

Fig. 2. Flank wear of milling cutter

Analysis of the worn surfaces reveals that flank wear on both teeth occurs in varying magnitudes and forms. Although the surface roughness of the milling cutter teeth after sharpening ranges between $R_a = 0,32$ to $0,63 \mu$m, the flank wear topography of the teeth does not remain uniform under machining conditions of feed rate S_{uz}=12 $m/\min$, cutting speed $V_f = 1570\, m/\min$, depth of cut $t = 5mm$ and machining length $L = 3000m$. This discrepancy is attributed to the anisotropy (Fig. 3) and structural heterogeneity of the composite wood boards being machined, which create variable friction conditions along the flank face of the cutting tool.

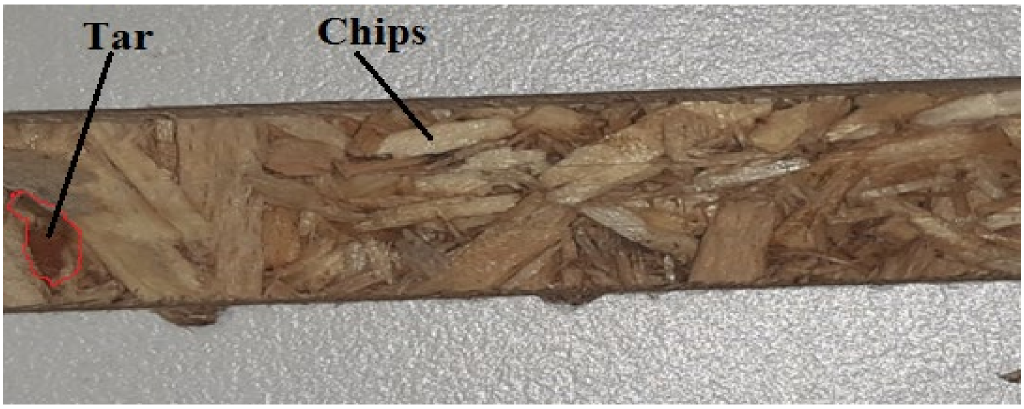

Fig. 3. Groove machined in composite wood board

In composite wood panels (Particle Boards – PB), the particle size of the wood chips distributed across a uniform surface varies significantly (see Fig. 3), resulting in non-uniform distribution of the resin that binds the particles. Consequently, the physical nature of the interaction—namely, the friction process—between the machined composite wood panel and the cutter teeth during chip formation proceeds under highly complex conditions. This, in turn, causes uneven wear on the rake face of individual cutting teeth. As a result, the chip formation process during the milling of rectangular grooves in composite wood materials using multi-tooth disc-type milling cutters is characterized by a complex technological environment. The frictional contact between the cutter teeth and the machined material is inherently unstable. Due to the continuous variations in both the magnitude and direction of cutting forces acting simultaneously on the cutting edges, forced vibrations are induced during the milling process. These forced vibrations lead to uneven wear patterns on the contact surfaces of the cutter teeth. An example of such wear, exhibiting varying topographical features on the rake face, is illustrated in Fig. 2.

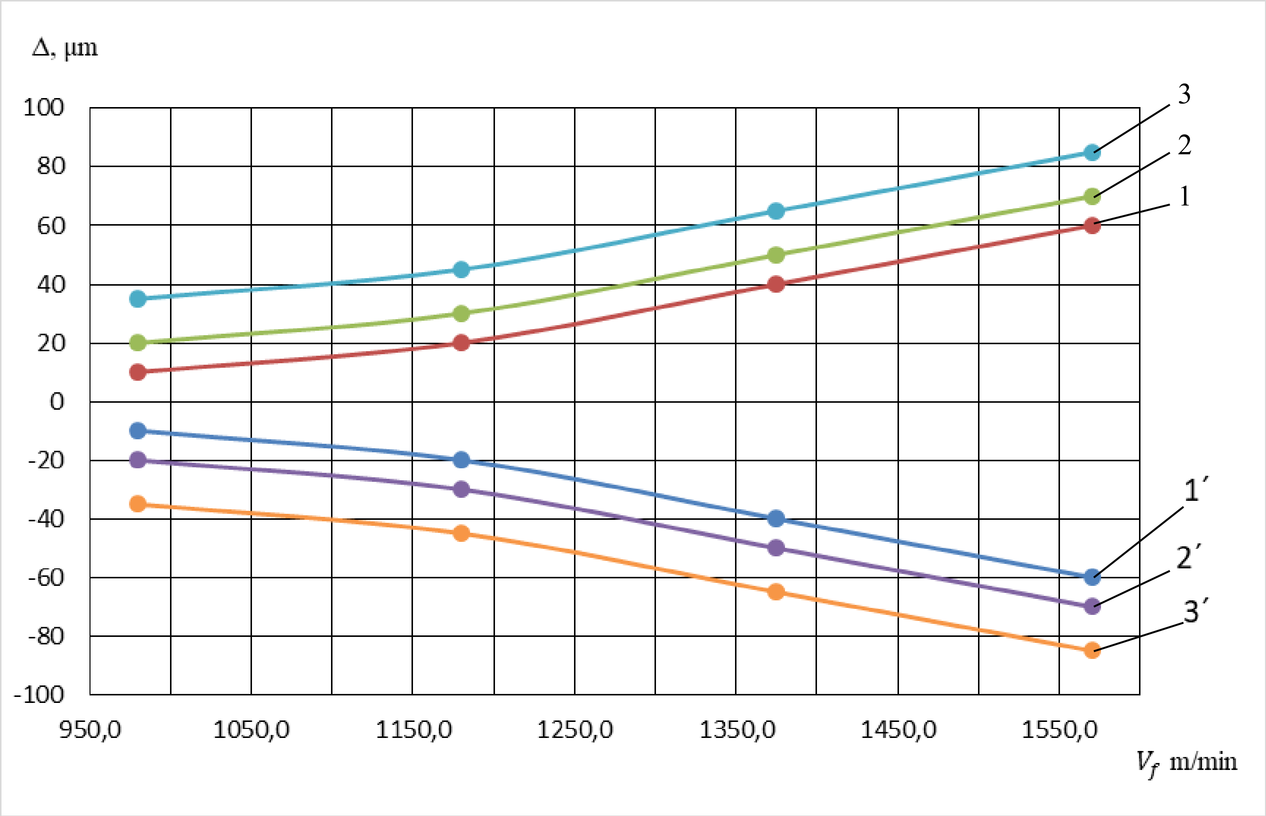

Fig. 4. Deformation of milling tool teeth depending on density and cutting speed of composite wood material

$1,1' - 550\,kg/m^3$; $2,2' - 650\,kg/m^3$; $3,3' - 750\,kg/m^3$;

Experimental studies have revealed that during the milling of rectangular grooves in composite materials, the deformation of milling cutter teeth in various directions varies depending on the cutting speed and the density of the composite wood material. Tests were conducted on composite wood panels with densities of $550, 650$ and $750\,kg/m^3$, in which grooves with dimensions $b \times h = 3 \times S$ mm were milled at different cutting speeds up to a cutting length of 3000 meters. The graphs in Fig. 4 show the variations in the average values of the resulting deformations of the cutter teeth in terms of bending (positive sign) and bulging (negative sign). The milling process was carried out at a feed speed of $S_{uz} = 12\,m/\min$. The curves located above the zero line (1, 2, 3) represent positive deformation values (bending), while the curves below the zero line (1′, 2′, 3′) indicate negative deformation values (bulging) of the cutter teeth.

The equations obtained through mathematical resolution of the graphs using IT applications are provided in (1):

$$\left.\begin{aligned}
&Equation\ of\ the\ Curve\ 1\ y = 0{,}000007x^2 - 0{,}0858x + 28{,}687\\
&Equation\ of\ the\ Curve\ 2\ y = 0{,}000007x^2 - 0{,}0858x + 38{,}687\\
&Equation\ of\ the\ Curve\ 3\ y = 0{,}000007x^2 - 0{,}0858x + 53{,}687\\
&Equation\ of\ the\ Curve\ 1'\ y = 0{,}000007x^2 + 0{,}0858x - 28{,}687\\
&Equation\ of\ the\ Curve\ 2'\ y = 0{,}000007x^2 + 0{,}0858x - 38{,}687\\
&Equation\ of\ the\ Curve\ 3'\ y = 0{,}000007x^2 + 0{,}0858x - 53{,}687
\end{aligned}\right\} \quad (1)$$

Studies have shown that as the density of the machined composite wood material increases, the deformation of the milling cutter teeth also increases. For instance, the 1st and 1′ curves demonstrate that, in the cutting of composite wood panels with a density of $550\,kg/m^3$, the deformation of the cutter teeth varies from, $\pm 16\mu m$ to $\pm 35\ \mu$m depending on the cutting speed. Fig. 4 compares the 1st, 2nd, and 3rd curves, showing that as the density of the machined composite wood material increases from 550 to $750\,kg/m^3$, the deformation of the cutter teeth during milling increases 2 to 3 times. This increase in density results in a rise in the cutting forces, which in turn elevates the level of vibrations in the contact zone. Consequently, both the bending and bulging of the cutter teeth increase.

Studies have shown that as the rotational speed of the milling cutter increases, the contact temperature affecting the wear of the cutter teeth also rises. As a result, the amount of wear on both the front and rear faces of the cutting teeth increases. Moreover, due to the uneven wear of the teeth, the length of the cutting edge changes, leading to varying values. The difference in the length of the cutting edge and the deformation of the teeth in different directions increase the impact of the disc-type milling cutters, which in turn amplifies the errors in the geometric dimensions of the milled grooves.

A critical issue in machining rectangular cutter bodies with disk-type milling cutters is the effect of cutting speed and the variability in composite wood material density on the linear wear of cutter teeth. The magnitude of linear wear on the milling cutter teeth directly determines the grinding allowance removed during sharpening and the number of required regrinds for the disk-type cutters.

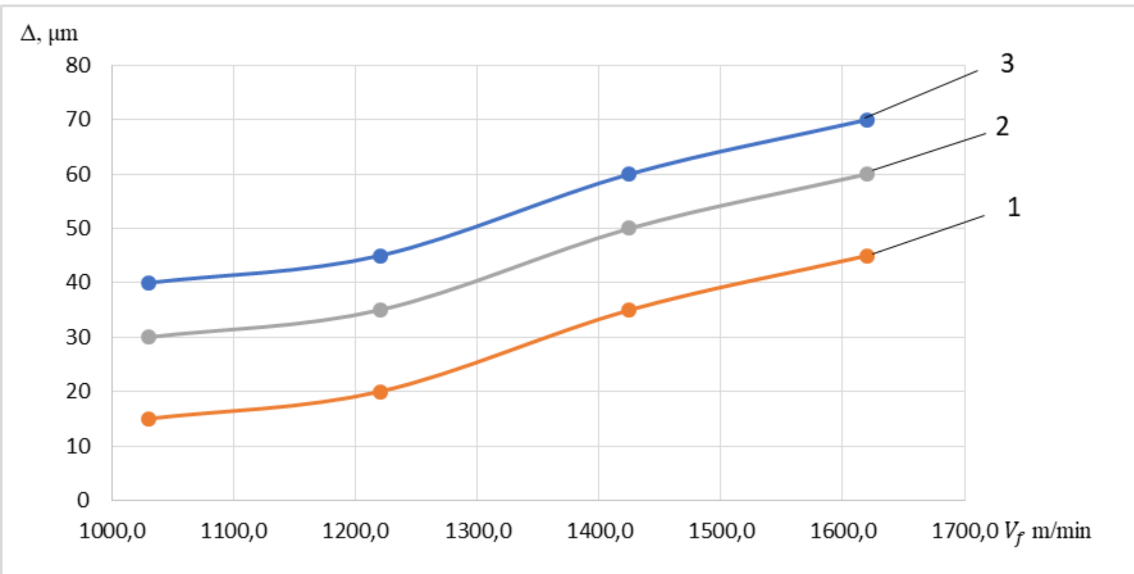

Fig. 5. Wear on the clearance face of the cutter tooth depending on the density of the composite wood material and cutting speed.

To address this, the linear wear of cutter teeth during the cutting of composite wood materials with varying densities has been analyzed, and the results are illustrated in the graphs provided in Fig. 5. Here, Curve 1 represents composite wood materials with a density of $550\,kg/m^3$, Curve 2 corresponds to $650\,kg/m^3$ and Curve 3 reflects the outcomes for materials with a density of $750\,kg/m^3$.

$$\left.\begin{array}{l} \textit{Equation}\text{ of Curve 1 } y=0{,}000003x^2-0{,}0278x+35{,}421 \\ \textit{Equation}\text{ of Curve 2 } y=0{,}000003x^2-0{,}0278x+25{,}421 \\ \textit{Equation}\text{ of Curve 3 } y=0{,}000003x^2-0{,}0278x+10{,}421 \end{array}\right\} \quad (2)$$

Figure 5 presents the graphs processed using Excel software as a function of cutting speed, while the mathematical equations of the corresponding curves, derived using IT tools, are given in Equation (2).

As seen in Fig. 5, the linear flank wear of milling cutter teeth increases with the density of composite wood materials and cutting speed (evident from the curve trends). This is attributed to the rise in forces, temperature, and frictional velocity acting on the cutting teeth within the contact zone during chip formation.

Conclusion.

1.It has been established that during the machining of rectangular cutter bodies with disk-type milling cutters in composite wood materials, the wear characteristics and deformation of each tooth vary depending on the density and anisotropy of the machined material, as well as other technological factors of the cutting process.

2.It has been determined that increasing the density of composite wood materials leads to greater bending and bulging deformation in the teeth of disk-type milling cutters. This is explained by changes in chip formation conditions, elevated cutting forces, and intensified vibrations caused by the higher material density.

3.The conducted research has revealed that increasing the cutting speed during the milling of rectangular cutter bodies in composite wood materials leads to a rise in linear wear of disk-type milling cutter teeth. This necessitates a larger grinding allowance during tool sharpening. Furthermore, higher cutting speeds exacerbate uneven wear and deformation of the teeth, intensifying tool chatter. Consequently, this increases geometric dimensional errors in the machined cutter bodies.

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