Tribological Behavior of Microtextured Cemented Carbide in Contact with Wood

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Abstract

We used microtextures to develop a novel antifriction technology for wood cutting tools. Northeast China ash (*Fraxinus* spp.) was selected as the research species, and the influence of the microtexture on the friction coefficient of cemented carbide samples with and without the texture was studied using various loads and wood moisture content. The results showed that a reasonable microtexture form ($d = 40$ μm) can effectively reduce the friction coefficient between wood and cemented carbide regardless of the moisture content. The moisture in the wood is conducive to reducing the friction coefficient between the cemented carbide and the wood surface. Its mechanism of action is affected by the wood moisture content, the load used, and other factors. The friction coefficient significantly decreased when the wood moisture content was above the fiber saturation point.

One of the significant energy inputs in woodcutting processes is the amount of energy necessary to overcome the frictional forces between the workpiece and the cutting tool. During woodcutting, the frictional forces acting on the rake face have a direct effect on the tool wear and on the nature of the surface produced, whether it is the surface of a finished product or the chips that are used in a subsequent process (McKenzie 1961). Tool wear is still a key factor restricting the further improvement of the service life and cutting efficiency of tools (McKenzie and Karpovich 1968). The reduction of the friction coefficient between the tool and the wood surface, the improvement of the wear resistance of the tool, and the extension of the service life of the tool are core research topics of woodcutting.

Currently, cemented carbide is the most widely used material in woodworking tools. Superhard ceramics (Beer 2005), coating technologies (Beer et al. 2007, Guo et al. 2017), and the optimization of the cutting tool structure (McKenzie 1991) are commonly used to reduce the coefficient of friction.

The frictional process in the cutting operation under the condition of a cutting tool edge radius of 0 μm is shown schematically in Figure 1. It was assumed that both the chip and the tool surfaces are not perfectly smooth and that frictional forces arise due to the interaction of the surface asperities (unevenness) as the chip moves over the rake surface of the tool (Klamecki 1976). The forces acting on the tool are the tangential friction force, T, and the force normal to it, N. The formation of an excellent working face between the tool surface and wood is a focal point of antifriction technology.

Microtextures can improve material friction performance (Kawasegi et al. 2009, Duan et al. 2018) and have been applied in the metal cutting process. We applied a surface microtexture to woodcutting tools to reduce the attrition and friction on a knife or workpiece contact zone. The controlled surface texture on the surface of the cemented carbide was produced using a laser processing technology. The friction performance test compared the influence of the wood moisture content and load on the friction coefficient with different microstructure. This study revealed a new antiattrition technology that can extend the service life of cutting tools, improve the cutting efficiency and machining quality, and reduce the loss of wood and energy. This study also has reference value for developing new cutting tools that can be used for veneer peeling, slicing, or greenwood cutting.

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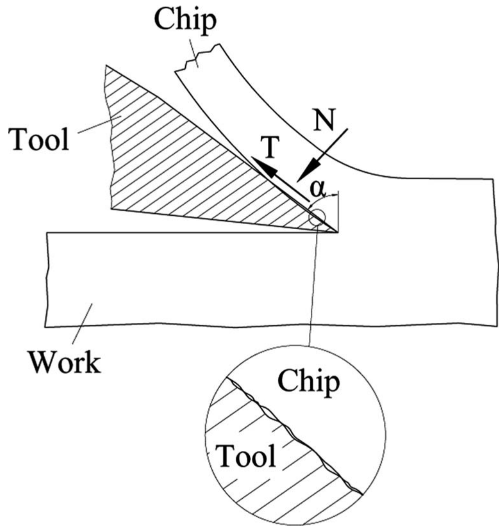

Figure 1.—Schematic diagram of the tool-chip surface interaction during orthogonal cutting showing the action of the force system. An enlarged section of the tool and chip contact area is shown (Klamecki 1976).

Materials and Methods

Materials

Cemented carbide (YG8) was the sample material used in the tool. It is a cylinder with a density of 14.7 g/cm^3, a diameter of 6 mm, and a height of 6 mm. A nanoscale pulsed laser was used for micropit processing the microtextured upper samples: the diameters were 0, 40, 80, and 120 μm on the surface and had a depth of 20 μm and a center hole interval of 150 μm with a processing accuracy of ±10 μm. Figure 2 shows the configuration of the micropits with a diameter of 40 μm on the surface of the cemented carbide under the microscope. Figure 2a shows the three-dimensional topography of the microtexture using laser confocal scanning microscopy at a magnification of ×20. Figure 2b shows the surface shape of the texture (×20 magnification). During the laser micromolding on the surface of the test piece, molten residue caused burrs that needed to be cleaned from around the micropit. The burrs were cleared with W7 (05) metallographic sandpaper. After removing the burrs, the samples were cleaned with an ultrasonic cleaner. The cleaning solution was acetone, and the surface roughness was Ra 0.4 μm.

Wood samples from Northeast China ash (*Fraxinus* spp.) were purchased and used in the experiments. The samples had an air-dry density of 0.67 g/cm^3 and 16 percent initial moisture content and were 70 by 70 by 5 mm (length by width by thickness). The specimen wood was divided into four parts so that varying levels of specimen moisture content could be evaluated. The moisture content of one part was close to 5 percent. The remaining parts were soaked in water at 20°C. After the pieces reached a moisture content greater than 60 percent, they were dried to 20, 40, and 60 percent. The moisture content of the test pieces was adjusted to 5, 20, 40, and 60 percent. The moisture content is the absolute moisture content compared with the dry wood with the same conditions.

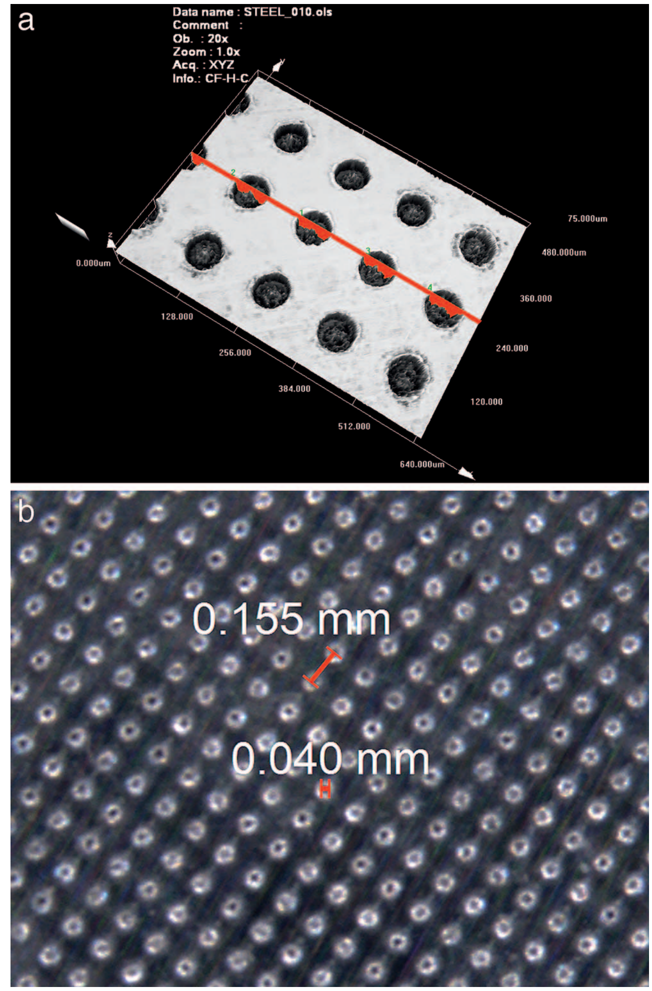

Figure 2.—Configuration of the micropits on the cemented carbide surface observed under a microscope: (a) three-dimensional shape figure and (b) two-dimensional surface figure. (Color version is available online.)

Methods

The tool with the cemented carbide was the upper sample, and the ash was the lower sample. The reciprocating friction and wear tester was used for the friction characteristics test. As shown in Figure 3, the upper sample was fixed on the clamp, and the lower sample was fixed on the tray. The contact form of the friction pair was surface to surface, and the wood section that made contact with the microtexture part of the tool was the radial section. The clamp drove the upper sample to perform a reciprocating movement that helped to avoid the impact of wood knots and other defects. The friction force was produced between the upper sample and lower sample under the action of the positive pressure, Fn. The friction coefficient was calculated using the law of Coulomb friction, $F = \mu Fn$. In the equation, F is the friction force, μ is the friction coefficient, and Fn is the positive pressure. The experimental principle is shown in Figure 4a.

The frequency of movement was 2 Hz, and the reciprocating movement displacement was 10 mm. The angle between the movement and fiber was 0°. Wood samples with varying moisture contents were tested at different normal loads (10, 20, and 40 N) to reduce the test error, and friction pairs were formed between the different

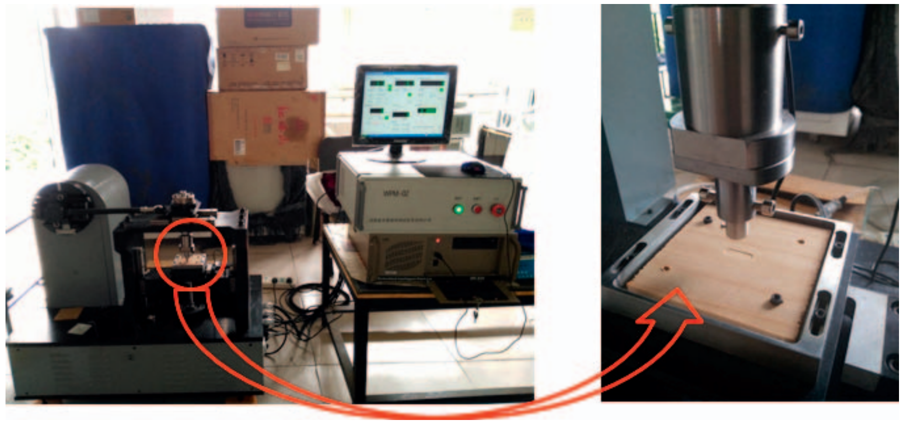

Figure 3.—Reciprocating friction and wear tester. (Color version is available online.)

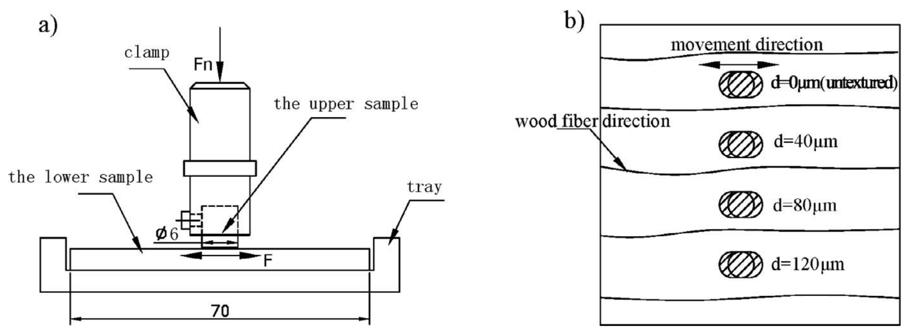

Figure 4.—Schematic diagram of the friction coefficient test: (a) the principle of test and (b) the test position. Fn = test load (positive pressure); F = friction force.

microtexture specimens and wood at different locations on the same piece of wood, as shown Figure 4b. Because the contact time between the surface of the tool and the wood was relatively short and new wood layers were continuously making contact with the tool during woodcutting, this test took into account only the average friction coefficient within 30 seconds at the *a* stage. We used the mean value of 30 seconds for the test values. Every test was repeated three times, and the final measurement result was the average of the three groups' testing values. All tests were done using a new cement carbide sample and a new wood specimen. A total of 36 wood specimens were used.

Results and Discussion

Influence of the different loads on the friction coefficient

Figures 5a and 5b show the influence of the applied load on the friction coefficient of different friction pairs with a wood moisture content of 40 percent with no texture samples and with a wood moisture content of 40 percent and textured samples (d = 40 μm), respectively. Figure 5 shows that the friction coefficient changed slightly with time regardless of whether the surface of the cemented carbide was planar or textural. However, the general trend was that the augmentation of the interfacial friction coefficients occurred with the increase in the load used. Figure 5a indicates that the average friction coefficient between the nontextured sample and the wood at 30 seconds was 0.121, 0.153, and 0.233 at loads of 10, 20, and 40 N, respectively. The average friction coefficient between the textured sample and the wood at 30 seconds was 0.043, 0.086, and 0.140 at loads of 10, 20, and 40 N, respectively (Fig. 5b). These results may be due to the increase in the positive pressure with the elevation of the load used, which led to defects (such as fractures and wrinkles) in the fiber on the wood surface in the process of the reciprocating movement. The damage increased the surface roughness, resulting in the augmentation of the values of the friction coefficient between the surfaces.

Influence of the wood moisture content on the friction coefficient

Figure 6 shows the influence of the wood moisture content on the friction coefficient of the different friction pairs under various load conditions, samples without texture (Fig. 6a), and when d = 40 μm (Fig. 6b). Figure 6a shows that the average friction coefficient between the nontextured species and wood surface decreased with the increase of the water content under different loads. At a load of 10 N, the average friction coefficient decreased from 0.162 to 0.101, whereas at a load of 40 N, the average coefficient of friction was reduced from 0.274 to 0.194. The decline was greater when the load was relatively low. This phenomenon is due mainly to the fact that the moisture can be used as excellent lubrication and cooling medium during the friction between the cemented carbide and the wood. It is conducive to improving the carbide–wood contact during friction, which is consistent with the results obtained earlier by McKenzie and Karpovich (1968). Figure 6b shows that the average

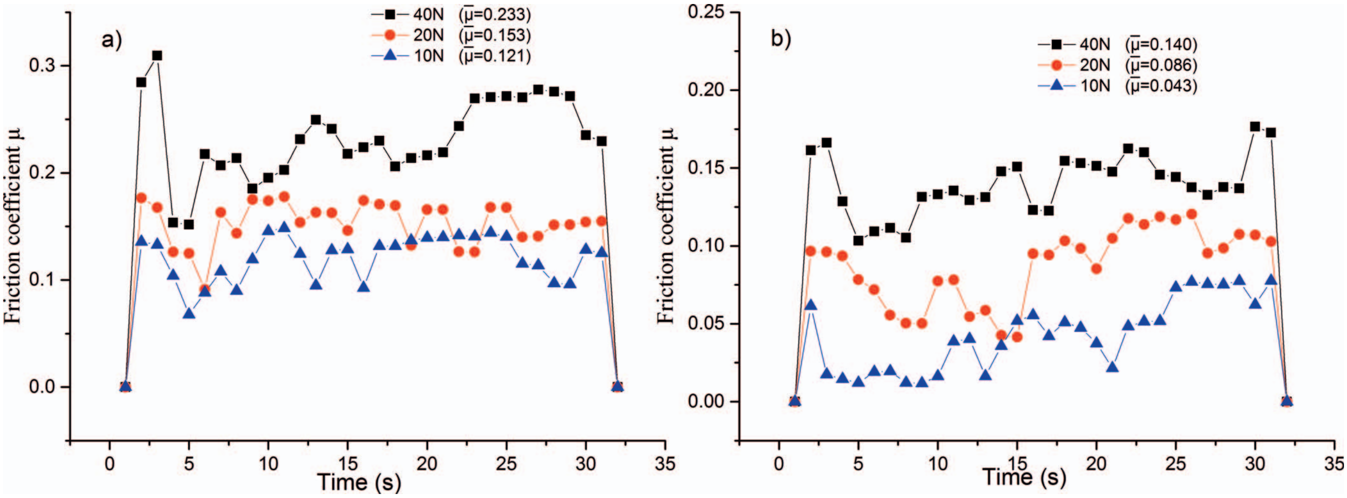

Figure 5.—Influence of the load on the friction coefficient: (a) d = 0 and (b) d = 40 m. (Color version is available online.)

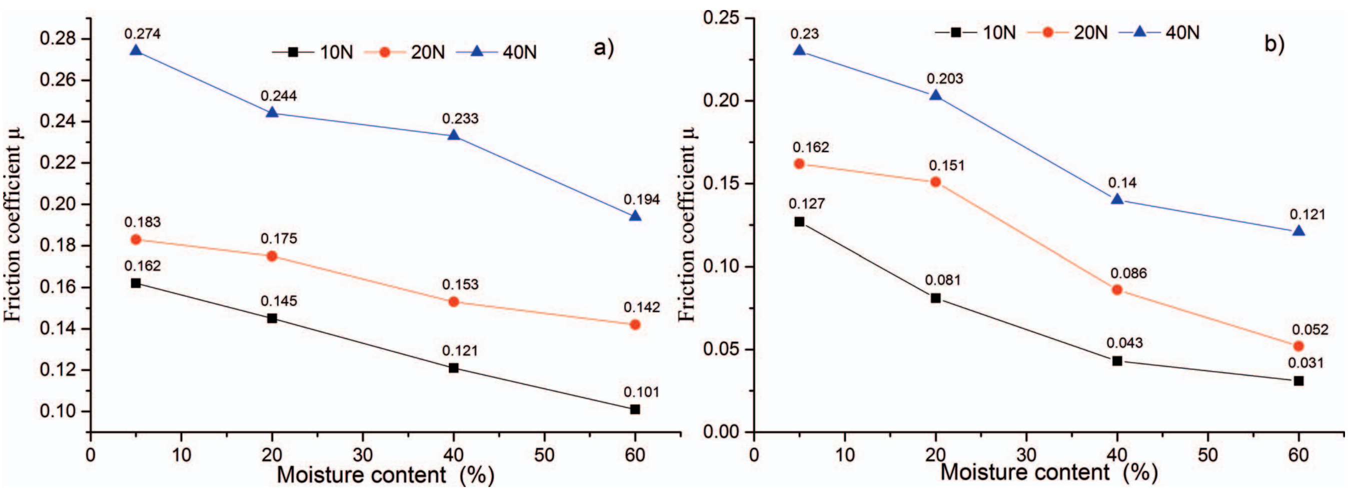

Figure 6.—Influence of the wood moisture content on the friction coefficient: (a) d = 0 and (b) d = 40 m. (Color version is available online.)

coefficient of friction between the textured sample (d = 40 μm) and the wood surface decreased with the increase of the moisture content under different loads. An especially obvious decrease was observed when the moisture content increased from 20 to 40 percent. At a water content of more than 30 percent, the free water levels in the wood gradually increased. Under this condition and the application of a load, a lubrication interface is easier to form, which helps to reduce the friction coefficient.

Influence of the microtexture surface on the friction coefficient

Figure 7 shows a comparison between the friction coefficients of the nontextured and textured samples (d = 40 μm) under different loads and surface parameters. The friction coefficient of all textured samples (d = 80 μm) decreased under different loads used. The textured sample with d = 120 μm had a slightly higher friction coefficient. However, there was no significant gap between the friction coefficient of the textured sample (d = 80 μm) and the friction coefficient of the nontextured sample. Figure 7a shows that when a load of 10 N was applied, the minimum and maximum decreases of the friction coefficient of the textured specimen (d = 40 μm) were 23.9 percent (moisture content [MC] = 5%) and 69.3 percent (MC = 60%), respectively. Figure 7b shows that when the load was 20 N, the minimum and maximum decreases of the friction coefficient of the textured specimen (d = 40 μm) were 11.5 percent (MC = 5%) and 63.3 percent (MC = 60%), respectively.

Figure 7c shows that when a load of 20 N was utilized, the minimum and maximum decreases of the friction coefficient of the textured specimen (d = 40 μm) were 16.1 percent (MC = 5%) and 39.9 percent (MC = 40%), respectively. Thus, the texture exerted more obvious friction reduction effects with an elevated moisture content. More specifically, the friction coefficient curve declined with the increase of the moisture content from 20 to 40 percent. At room temperature, the fiber saturation point of wood is usually around 30 percent. However, at a wood moisture content higher than 30 percent, the levels of free water in the wood gradually increase. Thus, it becomes easier for the free water in the cell cavities and cell gaps to penetrate into

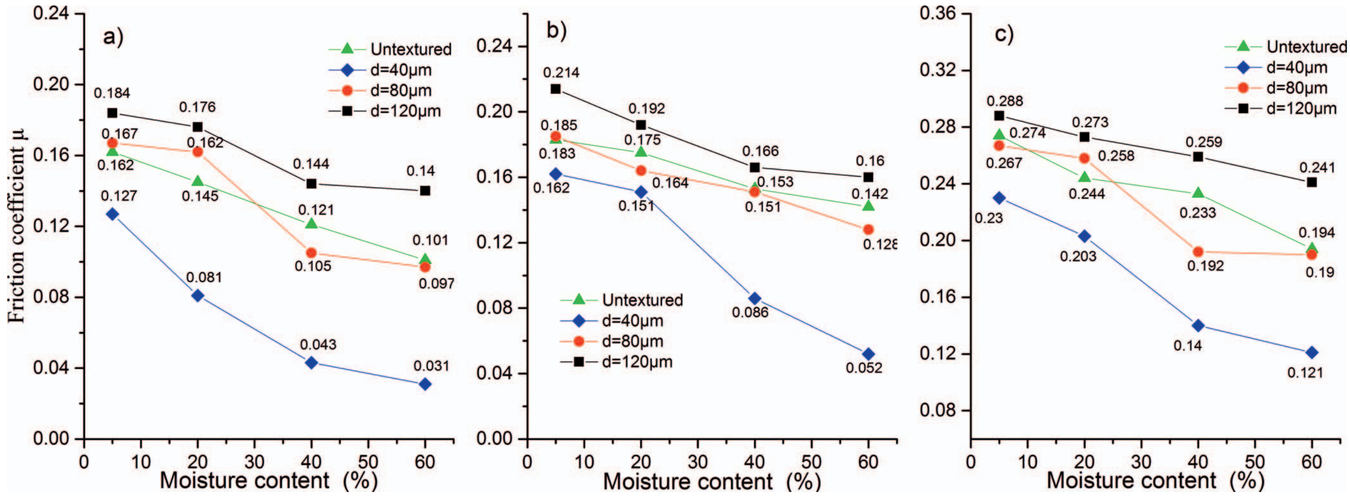

Figure 7.—Influence of the wood moisture content on the friction coefficient: (a) 10 N, (b) 20 N, and (c) 40 N. (Color version is available online.)

the material surface, forming a lubrication interface under a certain pressure. The increase of the free water content contributes to the water extrusion by the pressure from loading. However, the hardness of the wood is also reduced, and damage is caused during friction, affecting the friction coefficient. With the increase of the pore diameter of the microtexture, the surface roughness increases, which influences the friction coefficient. This is the main reason for the increase of the friction coefficient of the texture sample with a diameter d = 120 μm.

When the moisture content of wood is close to that of a wet material, under a certain pressure, the water flows out of the wood surface. Each pit on the microtexture is equivalent to a fluid dynamic lubrication bearing. The mutual movement of the friction pair enhances the fluid dynamic pressure; this promotes the formation of the lubrication film created by the fluid dynamic pressure on the surface of the friction pair. This film contributes to a reduction in the friction and wear resistance (Fig. 8).

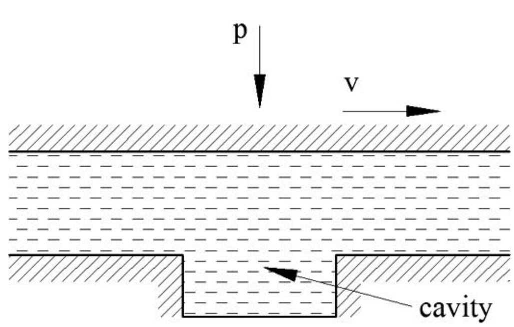

Figure 8.—Mechanism of action at a high moisture content.

We found that a decrease in the moisture content of the wood resulted in lower free water levels in the wood. Furthermore, the surface texture of the pits can reduce the actual contact area between the friction pair. The surface texture can hold and retain wood chips or hard particles, such as quartz, that reduce the surface roughness caused by the wood chips or hard particles, leading to a reduction of the friction coefficient (Fig. 9).

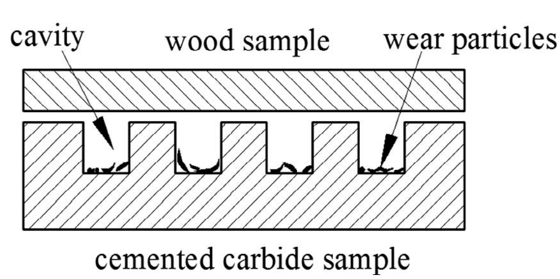

Figure 9.—Mechanism of action at low moisture content.

Conclusions

The moisture in the wood is conducive to reducing the friction coefficient between the cemented carbide and the wood surface. The increase of free water content can lead to a more obvious decrease in the friction coefficient. The rise in the free water content contributes to water being squeezed out under the pressure from the loading. With the increase in moisture content, the hardness of wood is reduced. When the positive pressure increases, the friction coefficient increases. This is because wood surface roughness increases as the pressure increases with the friction movement.

Regardless of whether there is a low or high moisture content, a reasonable microtexture form (d = 40 μm) can effectively reduce the friction coefficient between wood and cemented carbide. When the moisture content of wood is above FSP (30%) under a certain pressure, the water flows out of the wood surface, and a lubricating film forms gradually on the surfaces with the friction process. The increase in pressure contributes to the formation of lubricating film, but it can damage the wood.

It is important to continue with research on this topic. The texturing process on the surface of cemented carbide resulted in a decrease in the coefficient of friction and might be influential in designing new woodcutting tools, especially since wood is a porous material and contains water. The excellent properties of microtextured cemented carbide show great potential of application in cutting wood with high moisture content, such as in veneer peeling and slicing, or when applied to the circular saw blade.

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