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RAPID COMMUNICATION

Smoothness of a spruce surface rubbed with a metal tool under high-speed friction

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Introduction

Wood is widely used in architecture and furniture, and is often painted for esthetic reasons, as well as to protect its surface. The performance of the paint on wood is affected by the asperity of the wood surface; therefore, the wood is sanded before painting to eliminate the heterogeneity of the surface tissue and to produce a smoother surface.

Therefore, if a new processing technology for smoother wood is developed, it may be possible to improve the paint performance. Furthermore, controlling the surface of wood to produce a shape with more regular asperity could also yield superhydrophobic and hydrophilic properties, extending the conventional functionality of wood, as has been reported in previous biomimetics surface studies [1].

We have previously developed a wood surface treatment technology that modifies wood by rubbing with smooth metal tools at high speed to obtain new functionalities [2]. The temperature changes and asperity transcription are affected by thermal and mechanical action under high-speed friction.

Furthermore, another of our previous studies showed that contact between the surface asperities of the metal tools and the rubbed wood is important to the mechanical action. The transcription of the asperity shape to the wood surface was improved, as the curvature radius of the surface asperities of the wood and metal tools became closer [3].

The other studies of contact between wood and metal have examined conditions, such as the friction of wood and metal [4], the effect of wood flowability when forming wood with a metal die [5], and pressing wood veneer with heated plates [6]. However, a processing technology for controlling the asperity shape of the wood surface has not been reported.

In this study, we investigate the production of a smooth wood surface to find the limits of the existing fine asperity-processing technology as the first step in various controlling the asperity shape.

Materials and methods

Materials

The material was air-dried spruce with a moisture content of 10.3 % and a density of 0.46 g/cm^3. Specimens with

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dimensions of 3(T) × 50(L) × 11(R) mm were cut from the square timber with a circular saw, and the rubbed surface was produced in T × L. Pretreatment of the test specimen surface was completed by router cutting.

The wood specimen surface was rubbed with a round metal bar tool with a smooth surface. Table 1 shows the tool surface properties of the sanding tool (S-tool) and the mirror-polished tool (MP-tool), and Fig. 1 shows the surface profiles of the tools. Each tool was fabricated from SK3 carbon tool steel rod with a diameter of 12 mm. The S-tool was finished with #320 sandpaper, and the MP-tool was specially polished by Nanotech Inc., Japan. The surface roughness of each tool was measured using a surface roughness meter with stylus (SJ-210, Mitutoyo, Japan).

Rubbing treatment method

A spruce specimen was rubbed with the metal round bar tool under pressure using our previously reported method [2]. The wood specimen was clamped on a unidirectional movable stage in contact with the tool and moved in the feed direction under pressure. The pressure of the round bar tool with a diameter of 12 mm on the wood specimen was controlled by the reduction rate, t. The wood specimen was rubbed at a rotation speed of $R = 13{,}000$ rpm at a constant feeding speed of $f = 0.2$ mm/s. The tool rotated and the feeding direction was set in parallel to L direction. The temperature was measured with an infrared thermal imaging camera as previously reported [2]. The specimen was either rubbed at $t = 0.3$ mm with the S-tool, or it was first rubbed at $t = 0.3$ mm and then seven times at $t = 0.1$ mm. The specimen was finished by rubbing with the MP-tool twice at $t = 0.1$ mm. To prevent from adhering to the tool surface, linseed oil in the marketplace(Simamoto Inc, Fukuoka, Japan)was applied to each specimen.

Table 1 Metal tool properties

Tool	Preprocessing	R_a (μm)	R_z (μm)	R_{sk}	R_{ku}
S-tool[a]	Sanded by #320	0.10	1.27	−0.59	5.40
MP-tool[b]	Mirror polished	0.05	0.58	1.08	11.39

[a] Sanded tool

[b] Mirror-polished tool

Evaluation after rubbing treatment

The wood surfaces were observed by scanning electron microscopy (SEM) for the control specimen and by field-emission SEM for the rubbed specimens because of considering the effect of electron beam. The asperity shape of the surface profile was evaluated with a surface roughness meter by tracing a stylus with a tip radius of 2 μm parallel and perpendicular to the rubbing direction. The measurements were taken over a length of 2.5 mm with a cut-off value of 0.25 for evaluating surface roughness, and the surface profile was treated with a Gaussian filter according to ISO 4287-1997 [7]. The asperity shape was also evaluated by a confocal laser scanning microscope (VK-X150/160, KEYENCE) in a 1.5 × 1.5 mm area according to ISO 25178 [8].

Results and discussion

Effect of rubbing treatment on the spruce specimen surface

The surface of the spruce test specimen was observed after high-speed rubbing with the S-tool and MP-tool. Figure 2a–c shows the rubbed surfaces of the spruce test specimens and the control surface cut with a microtome in the air-dry condition. On the rubbed surfaces, the tracheid tissue disappeared, and it was found to be densified by the pressure and smoothed by the thermal and mechanical action of high-speed rubbing. The specimen temperature in Fig. 2b, c exceeded 100 °C because of friction as reported in the previous research [2]. In contrast, on the control surface, the tracheid tissue had a clear structure in the tangential section.

Figure 3a–c shows the 3D images observed by a confocal laser microscope. The depth direction for the control surface (Fig. 3a) ranged from −95 (blue) to 35 μm (red).

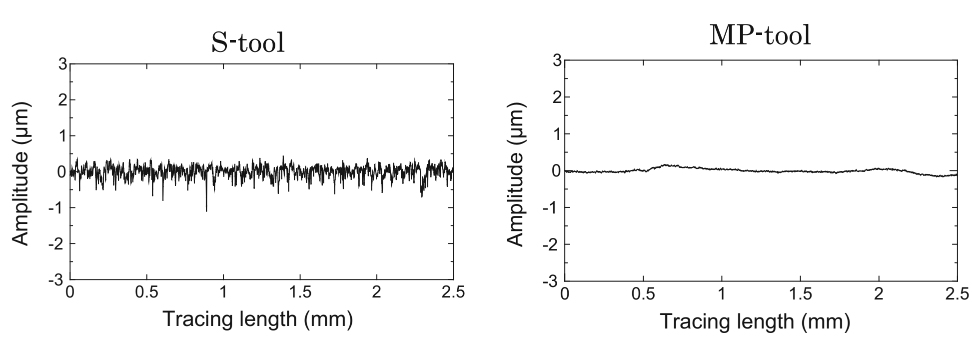

Fig. 1 Surface profiles of the S-tool and MP-tool

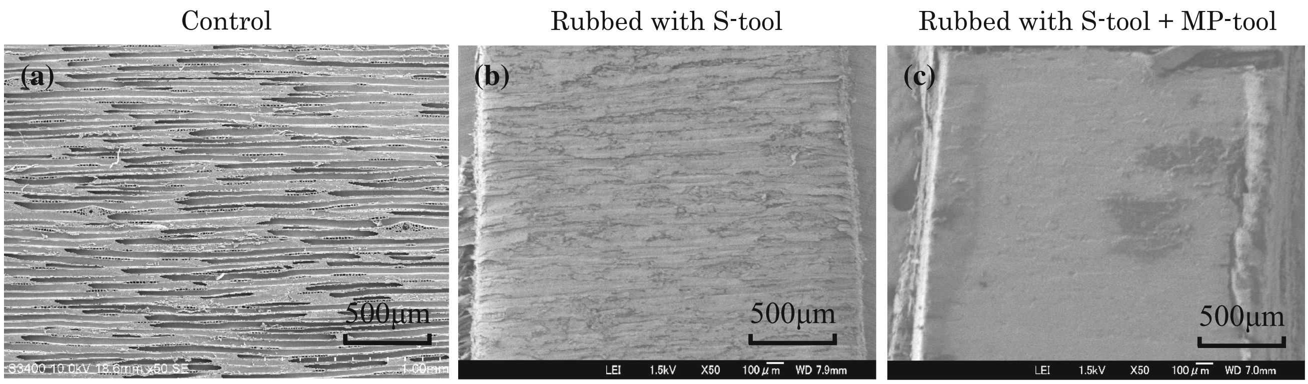

Fig. 2 SEM images of spruce specimen surfaces

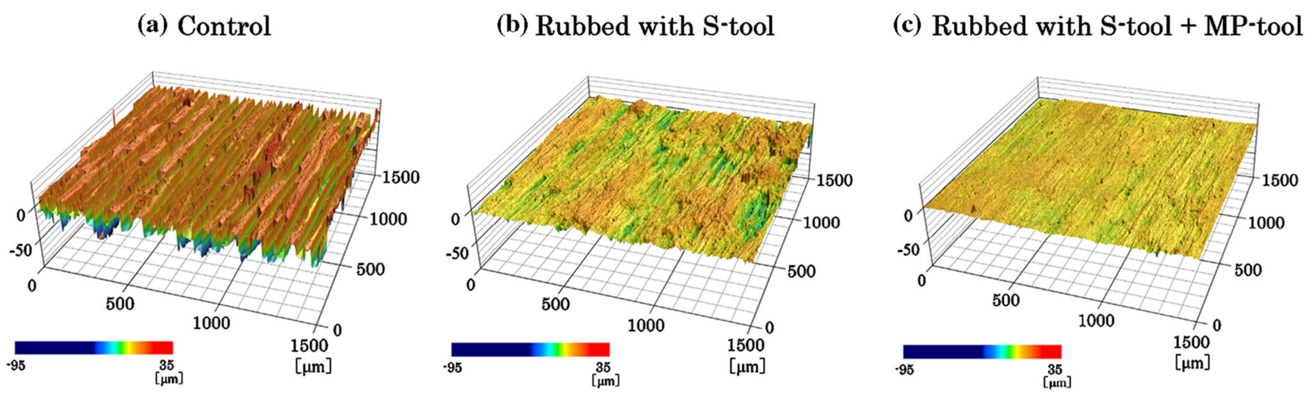

Fig. 3 3D images of spruce specimen surfaces observed by a confocal laser microscope

However, the rubbed surfaces (Fig. 3b) had a narrow range from −33 to 19 µm, and the range of the surface rubbed with the S-tool and MP-tool (Fig. 3c) was particularly narrow in range from −15 to 13 µm.

The SEM and 3D images showed that greater smoothness was obtained by rubbing with the S-tool and MP-tool (Figs. 2, 3c) than with the S-tool alone (Figs. 2, 3b). Figures 2 and 3 also indicate that a smoother surface can be formed by the proposed method through rubbing with metal tools that have finer asperity shapes.

Effect of rubbing treatment on surface roughness

The surface roughness was measured to investigate the asperity shapes of the rubbed spruce surfaces. Table 2 shows the average value of the surface roughness parameter in 3D and 2D for spruce specimens treated with various methods. The 3D parameters of arithmetical mean height (S_a) and maximum height (S_z) were smaller for the specimen rubbed with the S-tool + MP-tool than for the control and the specimen rubbed with the S-tool alone.

Table 2 Average value of surface roughness parameter for each rubbing condition

Specimen	3D (laser)				2D (stylus)				
	S_a	S_z	S_{sk}	S_{ku}	Tracing direction	R_a	R_z	R_{sk}	R_{ku}
Control	11.76	128.44	−0.69	2.84	⊥	5.33	37.81	−0.70	3.42
					//	1.47	16.21	0.17	5.87
S-tool[a]	3.08	58.08	−0.50	4.96	⊥	1.28	14.13	−0.81	4.80
					//	0.76	11.36	−0.25	5.59
S-tool[a] + MP-tool[b]	1.55	33.46	−1.08	7.89	⊥	0.46	5.51	−1.53	7.80
					//	0.33	4.00	−0.60	8.59

[a] Sanded tool

[b] Mirror-polished tool

The 2D arithmetical mean deviation (R_a) and maximum height (R_z) perpendicular and parallel to the fiber direction show the same trend as the 3D values, and the value of the specimen rubbed with the S-tool + MP-tool in the perpendicular direction became closer to that of the specimen rubbed in the parallel direction. The skewness (S_{sk}, R_{sk}) and kurtosis (S_{ku}, R_{ku}) values in 3D and 2D for the specimen rubbed with the S-tool + MP-tool are S_{sk}, $R_{sk} \ll 0$ (normal distribution) and S_{ku}, $R_{ku} \gg 3$ (normal distribution), respectively. These results indicate that the surface smoothing effect from rubbing with the S-tool + MP-tool is represented by the geometry values of the surface asperities. Here, S_a, S_z, R_a, and R_z differed at the 1 % significance level between rubbing with the S-tool + MP-tool and rubbing with the S-tool alone.

It has been reported that a smoother wood surface is obtained by contact with metal and the thermomechanical densification of wood veneer changes the surface morphology and decreases the surface roughness [6]. The effect of thermomechanical densification was similar to the results of friction, and the smoothness obtained in this study was superior to that of wood veneer.

Conclusion

Spruce wood surfaces were rubbed with smooth hardened metal tools, and the rubbed surfaces were analyzed. The SEM and 3D images showed that the cellular structure of the wood in the specimens that were treated with our method was much smoother than that in the control. Future work will investigate problems with the wood surface after rubbing, such as elastic deformations, shape memory, chemical reactions between polymers, hygroscopicity, and hardness.

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