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Research on neural network model of surface roughness in belt sanding process for *Pinus koraiensis*

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ABSTRACT

At present, researches about surface roughness mainly focus on the measurement methods and the relation between wood surface roughness and adhesion strength as well. It is well known that some sanding parameters are considerably key factors for analyzing the cause of surface roughness. However, only a few research studied the relations among surface roughness, sanding parameters, sanding pressure and wood texture direction. Back-propagation network (*BP* network) system was applied to simulate and predict the surface roughness value during the sanding process. The aim of this study was to determine the effects of sanding parameters on surface roughness of *pinus koraiensis* and the relation between sanding pressure and surface roughness, and finally establish the model of surface roughness combined with wood texture characteristic of *pinus koraiensis* through neural network system. The results showed that All values of surface roughness had a "vacuum belt" when $\lambda = 0^\circ$ and $\lambda = 45^\circ$, but it did not appear when $\lambda = 90^\circ$ (λ refers to the angle between the feeding direction and the wood grain). The confidence of the fitting surface roughness results was 97% by *BP* network model and the average error was 5.8%, which can simply and successfully predict surface roughness during sanding process.

1. Introduction

Abrasive sanding is one of the most significant processes in wood processing industry as it determines the dimensional precision, adhesion strength and painting quality of wood products. Abrasive sanding has been proven to have great potential for the reduction of substantial waste in wood products manufacturing. There are two distinct advantages associated with the removal characteristic of sanding. Firstly, a large removal quantity must be set to do an acceptable job during conventional knife planing process, whereas in sanding process there is a small removal quantity due to the very small cutting edges. Secondly, almost all of the rake angles of grits are negative in wood cutting process and the advance splitting is inexistence, which inflicts that there is none of the wood damage during abrasive sanding compared to planing [1]. Such damage can account for a reject rate of 8% in the solid wood products manufacturing industry [2]

Sanding is a kind of multi-tooth cutting method, and wood sanding surface roughness involves numerous tiny cutting traces and grain characteristics. Increasing the surface roughness value of veneers reduces the glue strength between veneers and substrates. Veneers with smooth surface have higher adhesive strength. And also improving the surface roughness of veneers can enhance glue bonding during the press [3].

There are several factors that influence surface roughness in sanding wood materials. One group of features is related to the wood characteristics, such as texture, density, surface hardness and others. Important are also the sanding parameters, such as sanding speed, feed speed, granularity, sanding thickness [4]. Surface roughness decreased slightly with increased sanding speed when sanding medium density fiberboard (MDF) [5], and the same result was also verified in sanding *Eucalyptus grandis* [6]. Unlike metal sanding, wood surface roughness does not decrease as the granularity increases. For example, lower arithmetic mean deviation of profile (*Ra*) was obtained when 100 grit abrasive belt was used rather than 120 grit abrasive belt, which due to the anatomy and density of wood materials. Besides, the relation between pressure and surface roughness is indefinable in wood sanding process. In the studies of metal grinding, Singh [7] found that the pressure would directly affect the surface roughness of steel. In general, a greater pressure produces a better surface roughness. It was found that tribological factors (ratio of friction) controlled the efficiency and quality of the grinding [8]. However, Luo [9] found normal pressure (*nP*) and Ra did not have a specific relation when sanding MDF and particleboard (PB).

Nowadays there are many studies about the relation between wood surface roughness and adhesion strength. However, few studies focused on the effects of sanding parameters on the wood surface roughness,

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and relations among surface roughness, sanding parameters, sanding pressure and texture direction were indefinable. The aim of this study is to analyze the effects of sanding parameters on surface roughness and the relation between sanding pressure and surface roughness, and finally establish the model for wood surface roughness combined with wood texture characteristic through neural network system. The results are of significant value for improving the wood sanding quality and optimizing the grinding theory.

2. Materials and methods

2.1. Experimental facilities and materials

A single contact-roller experimental sander was adopted in this study. Work-piece and force sensor was solid fixed with fixture. The sanding pressure (*sP*) could be real-time measured during sanding process. Once sanding the sander was shut down and the dust was blown off from the work-piece, then the surface roughness (*R*) was tested three times by a surface roughness measuring instrument. The testing traces were vertical to feed direction. One of the testing traces was on the middle of the work piece and the other two traces were on the two sides of the work piece. The values of *R* were average values of the three testing results. The experimental system was shown in Fig. 1.

Pinus koraiensis Sieb.et Zucc as the work-piece was cut from a single timber obtained from Changbai Mountain District in Northeast of China. The size of the work-piece was 150 mm (length) × 100 mm (wide) × 30 mm (thickness), the air-dry density and the surface hardness were 0.33 g/cm^3 and 49 HD, respectively. The abrasive belts were made by Tianjin Deerfos Co., Ltd. (base material: twill, grit: white fused alumina, electro coated abrasive and adhesive: phenol formaldehyde resin). The contact roller was made by rubber with a spiral pattern, the hardness was 75 HD. The measuring equipment included a 3D force sensor (KISTLER 3257A; Switzerland), a change-amplifier (KISTLER 5806; Switzerland), a signal analyzer (NEC Omniace II RA2300; Japan), and a surface roughness measuring instrument (Surtronic3 +, UK; range is ± 150 μm, accuracy is 10.0 nm, diamond stylus tip is in 90° cone shape, vertex is 5 μm in radius, and tracing speed is 1 mm/s).

3. Experimental methods

Orthogonal experiment was adopted in this research. The major factors considered in this study were granularity (*G*), feed speed (*U*), sanding speed (*V*) and sanding thickness (*Ts*). Each factor had five levels (as shown in Table 1), resulting in a [$L_{25}(5^6)$] orthogonal table. The values of *U* were low because the workbench moved through a rail system instead of the conveyer belt. Additionally, *V* cannot be very fast as well in order to prevent errors due to the vibrations.

Average roughness (*Ra*), mean peak-to-valley height (*Rz*), mean width of the profile (*RSm*) and maximum height (*Ry*) were used to determine surface quality in this study. Wood was anisotropic, and the texture direction could influence the values of *R*. Three feed-texture angles λ (λ refers to the angle between feed speed and texture direction, they were λ = 0°, λ = 45° and λ = 90°) were considered in this study. The values of *nP* were average real-time measured values. Each experiment was repeated three times under the same condition to reduce error, and the final values were selected as the average values of the three tests.

Table 1
Orthogonal factors and levels.

Levels	*G*	*U* (m min^{-1})	*V* (m s^{-1})	*Ts* (mm)
1	40	2.52	5.35	0.1
2	60	3.00	6.69	0.2
3	80	3.72	8.04	0.3
4	100	4.44	9.38	0.4
5	120	5.16	10.74	0.5

4. Results and discussions

4.1. Effects of sanding parameters on wood surface roughness

Except *RSm*, *R* and *nP* shared a same rule that the maximum values appeared when λ = 0° and the minimum values appeared when λ = 90° (Fig. 2) [10]. It mainly resulted from different damage forms of wood fibers. Fibers were more likely to be pulled off when λ = 0° instead of being cut off when λ = 90°. During the process of pulling the fibers away from the wood surface, some fibers were removed whereas the rest portion was remained on the surface forming burrs. In contrast, shearing the fibers could result in micro-crook rather than burrs (Fig. 3).

The tendency of *nP* corresponded to the sanding force [11]. The pulling strength was greater than cutting strength since the tensile strength was higher than the shear resistance. As a result, *nP* was greater than the sanding force.

When λ = 45° (λ means the angle between feed direction and measurement direction), the distance between fibers along the measurement direction was the largest. This distance accounted for calculating *RSm* at the same time resulting the largest *RSm* (Fig. 4).

As can be seen from Table 2 and Fig. 5, *G* had the most significant influence on the surface roughness, and the surface roughness was affected slightly by *U*, *V* and *Ts* [12,13]. The average grit size decreased and the cutting edge became shorter with *G* increased, thus resulting that the cutting marks became less noticeable on the wood surface. It can be seen from the results that the overall trend of roughness went down, and this was consistent with grinding homogeneous material such as steel which has already been proven before [14]. Assuming that the wood surface is flat and there is no trace of processing, the

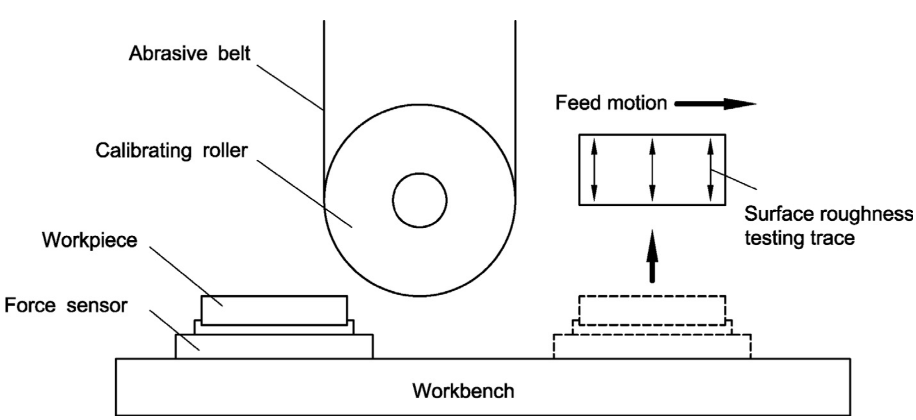

Fig. 1. Experimental system.