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The effect of anisotropicity of Norway spruce (*Picea abies*) during two-body abrasion

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ABSTRACT

The effect of anisotropicity of Norway spruce (*Picea abies*) during two-body abrasive wear was investigated by rubbing the wood with five different orientations while using constant surface pressure and a sanding belt with very fine abrasive grits. The anisotropic nature was found to affect the microstructure of the worn surface and the breakage mechanism of the surface. The properties of the particles that were released from the surface during abrasion were dependent on the grinding orientation and if the particle originated from early- or latewood. The wear process was influenced by the anisotropic nature of wood.

1. Introduction

Norway spruce (*Picea abies*) is the most common wood species used by the northern European woodworking industry. In this industrial domain, two-body abrasion is typically found in the surface finishing stage. Due the anisotropic and inhomogeneous nature of wood, the resulting surface and released wood particles are influenced by the orientation of the wood when it is imposed on the abrasive wear.

Ohtani with co-workers has studied the wear process and worn surfaces of different wood species during two-body [1,2] and three-body abrasion [2–4] considering the anisotropic nature. They have found out that during the two-body abrasion of katsura wood, the wear rate increases when higher load is applied and that the two-body wear is affected by the anisotropicity of the wood. In the case of Norway spruce, the effect of anisotropicity under the abrasive wearing process has not been studied. This study aimed to gain thorough understanding about the effect of anisotropicity of Norway spruce under the two-body abrasion considering the surface under wear, particles generated during wearing and the wear process.

The effect of anisotropy of Norway spruce under abrasive wear was studied by carrying out the sanding of cubic wood pieces that were cut from the same tree. These pieces were ground so that physically three different surfaces were imposed on the abrasion. The effect of the abrasion on the wood was inspected from two points of view: by considering the properties of the surface of the worn wood and the properties of the wood particles released during wearing. The wear process was investigated by studying the wear rate and energy consumption. The results indicated that the anisotropicity of wood affects the resulting surface, released particle properties and wear rate as well as capability to resist wear when it is imposed on the abrasion.

2. Materials and methods

2.1. Wood samples

The raw material used in the experiments was dried Norwegian spruce (*Picea abies*) with dry matter content approximately 94%. Cubic wood pieces with an average length of 34 mm (whose exact dimensions were measured) were prepared as far away as possible from the pith to neglect the effect of curvature of the growth rings making it possible to consider the wood as an orthotropic material instead of anisotropic.

The prepared wood pieces contained six faces where opposing faces could be considered identical by the material behaviour due to the orthotropic nature. In this study three surfaces perpendicular to the axes L, R and T (see Fig. 1) were investigated. These three faces of the cubic sample can be stressed in two main directions which contain the largest differences between mechanical properties when considering abrasive wear. These form six totally different com-

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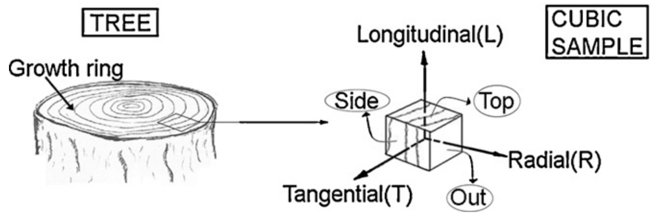

Fig. 1. Schematic illustration of a cubic sample with the grinding directions and three different surfaces: Top, Side and Out.

binations to impose shear stresses on orthotropic wood sample: Out-L, Out-T, Side-L, Side-R, Top-R and Top-T. Out, Side and Top identify the sample's face perpendicular to the axis R, T or L (see Fig. 1) towards the abrasive belt while the second letter refers to the moving direction of the abrasive belt. In this investigation the orientations Out-L, Out-T, Side-L, Side-R and Top-R were studied. Replicate runs were done for investigated orientations in order to estimate the confidence interval.

2.2. Grinding experiments

Experimental setup for the abrasive grinding is illustrated in Fig. 2. A piece of wood cut from the Norway spruce i.e. a cubic wood sample was placed on the top of a belt sander. An obstacle was positioned alongside the abrasive belt of the grinding machine to prevent any movement of the wood sample while in addition to acting as a device to secure a weight, positioned on top of the wood sample, to prevent any horizontal movement. The weight was used to adjust the compressive load on the sample while the centre of the gravity of the weight was balanced with the wood sample to prevent the uneven abrasion of the wood. Before experiments took place, the wood samples were pre-ground using an abrasive belt with a grit size below 125 μm (P120) to ensure an identical initial stage for every sample. The experiments were carried out with an abrasive belt containing corundum abrasives with a grit size below 68 μm (P220). The wood powders produced during wearing were collected after the obstacle from the surface of the belt with an efficient hoover and gathered into small dust bags where they were later removed for analysis. The abrasive belt was replaced between samples.

Grinding experiments were performed using a compressive loading of 36 N. The dry mass of the cubic samples was lower than 20 g before grinding, which means that their contribution to the surface pressure was negligible. The speed of the abrasive belt varied between 47 and 51 rpm during the trials. It was decided that the grinding process would be kept running as long as the weight

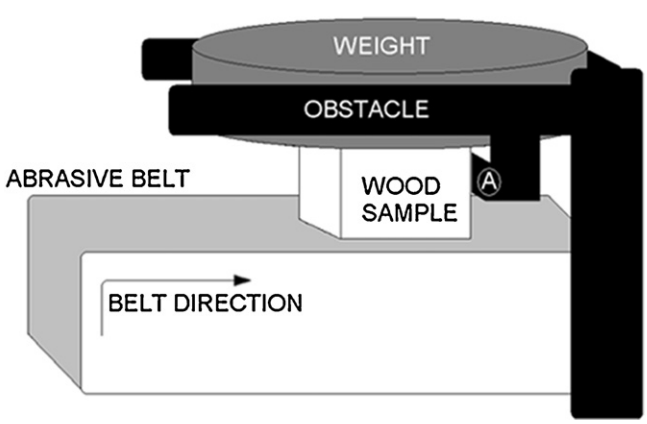

Fig. 2. Schematic illustration of a used experimental setup for surface grinding. The black arrow indicates the direction of the abrasive belt.

Table 1
The averaged wear rate and energy usage for different orientations.

Orientation	Pressure [kPa][a]	Average wear rate [mg[b]/s]	Average energy usage [J/g[b]]
Side-L	30.3	81	896
Out-L	30.7	81	894
Side-R	30.1	86	548
Out-T	30.9	70	934
Top-R	31.2	6	10,050

[a] Pressure was calculated from the force imposed by the weight to the surface area of the cubic sample assuming that the whole area is in contact with the belt.
[b] Oven dry mass.

was not touching the obstacle below (A in Fig. 2). However, due to an inefficient grinding process of the specimens in the Top-R orientation, the process was stopped even though weight remained far away from the obstacle.

The mass of the wood samples was measured before and after grinding to obtain an idea of how much wood powder was produced by wearing. In addition, the grinding time and average power consumption of the grinding machine were recorded. The average wear rate and energy consumption during the grinding process were calculated using Eqs. (1) and (2), respectively.

$$\dot{m} = \frac{(m_0 - m_g)}{t_g}, \quad (1)$$

where $\dot{m}$ is the wear rate, m_0 is the mass of the wood sample before grinding, m_g is the mass of the wood sample after grinding and t_g is the time used in the grinding process.

$$E = \frac{(P_a - P_i)}{\dot{m}}, \quad (2)$$

where E is the average energy consumption per gram, P_a is the average power consumption during the grinding process and P_i is the average power consumption during idle running.

2.3. Analysis of the worn surfaces

Images of the worn surfaces were obtained with a Field Emission Scanning Electron Microscope (FESEM, Zeiss Ultra plus). Confocal Laser Scanning Microscope (CLSM, Zeiss LSM 5 Pascal) was used to measure the maximum and average peak to the valley values of the worn surfaces.

2.4. Analysis of the released wood particles

Particle size distributions of the wood powders were measured with a laser diffraction instrument (Beckman Coulter LS 13320) using the Fraunhofer optical model. Particle size measurements were carried out in dilute water-wood suspension. Particle shape was investigated by analysing the optical images of the powders that were gathered with CCD-camera from a tube flow of the samples in very dilute water-wood suspension. In the imaging section the flow was introduced into cuvette. Images were used to gain information about the aspect ratio from the particles larger than 2 μm. Over 30,000 particles were analysed per sample to obtain projected area based aspect ratio distribution.

3. Results

3.1. Average wear rate and energy usage

The average wear rate and energy consumption of the studied wear processes are presented in Table 1. The wear rate was the lowest, with less than ten percent of the other orientations, in the case of the Top-R orientation. In the case of orientation Out-T the