EFFECT OF PLANING ON PHYSICAL AND MECHANICAL PROPERTIES OF SUGAR MAPLE WOOD

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ABSTRACT

Matched specimens of sugar maple wood were prepared using two types of planing machines, a conventional planer, and a fixed-knife pressure-bar planer. The equilibrium moisture content (EMC), swelling in all principal directions, and the compliance coefficient in radial compression were measured after adsorption and desorption experiments. Two specimen sizes were used for these experiments. The results showed that conventional planing affected the superficial layer, and a significant negative effect on the EMC and swelling behavior of sugar maple after a cycle of moisture adsorption-desorption existed. No differences were found between planing methods for the radial compliance coefficient. These findings are in agreement with earlier results showing a negative effect of conventional planers on the superficial layer of wood. We confirmed that less affected properties could be obtained using the fixed-knife pressure-bar method. Finally, the EMC and the radial compliance coefficient, but not the swelling, were slightly affected by the specimen size.

Keywords: Wood planing, moisture sorption, adsorption, desorption, mechanical properties, compliance coefficient, swelling, sugar maple.

INTRODUCTION AND BACKGROUND

During wood machining, surfaces are usually prepared with a conventional knife planer, which works with a peripheral cutting action. This machine and circular saws currently used appear to produce a good quality surface, without noticeable defects.

Although the conventional planing technique appears to give good quality surfaces, some previous studies indicate that this assumption is not always true. Stewart (1989) observed crushed and damaged cells at the surface and subsurface of the wood machined by this technique. The severity of damage depends on specific machining conditions. River and Miniutti (1975) noted that previous machining could cause a decrease in the shear strength of glued joints in wood. These researchers tested wood surfaces machined by a circular saw, a conventional planer, and a jointer. Although there were differences between species, the glue joint performance generally decreased from jointed surfaces to planed surfaces and with the poorest performance for sawn surfaces.

Other workers have shown that abrasive-planed surfaces perform more poorly than knife-planed surfaces when glue joint shear strength is tested (Jokerst and Stewart 1976; Caster et al. 1985). These researchers pointed out that the perpendicular-to-surface component of cutting forces is greater during abrasive planing than during conventional planing. This vertical force exceeds the stress at the

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proportional limit, which causes permanent crushing of cells at or near the surface of the wood. The abrasive particles generally have negative rake angles, causing normal forces to become greater (Stewart 1971).

Microscopic surface analysis has shown that crushed or damaged cells occur more frequently in abrasive-planed material than in knife-planed material (Jokerst and Stewart 1976; Stewart and Crist 1982). However, an accelerated aging exposure test was required, in order to detect differences in gluing strength and delamination between abrasive-planed and knife-planed surfaces (Jokerst and Stewart 1976; Caster et al. 1985). Detailed microscopic analysis has also shown damaged cells on the surface of knife-planed wood. Murmanis et al. (1983) indicated that after one cycle of soak-dry exposure, knife-planed Douglas-fir specimens had some microruptures between the S_1 and S_2 cell-wall layers as well as within the S_2 layer. These microruptures could explain the decrease in glueline shear strength after the aging exposure treatment previously mentioned.

Stewart (1986, 1989) proposed the fixed-knife pressure-bar system, as an alternative planing method, to reduce or eliminate subsurface damage induced in wood. The method works in a manner similar to a veneer cutter, using a high rake angle, but applied to planed surfaces. In addition, the wood feed is nearly along the grain rather than perpendicular to the grain. Micrographs from these studies show that the fixed-knife pressure-bar planed wood surfaces remained virtually intact. Recently, we have demonstrated that this new method produces wood surfaces with improved gluing behavior compared to conventional planing (Hernández 1994).

Apart from the effect of machining on gluing behavior of wood, little information is available on the effect of this process on other wood properties. Some earlier data from the literature might be reconsidered in light of the above findings. For example, many basic studies use small dimension (about 1-mm-thick) wood specimens to reduce experimental time or to facilitate matching techniques. Such experiments have been conducted with material already possibly affected by wood machining itself.

The purpose of this investigation was to compare the effect of two surfacing methods on wood properties of sugar maple. The conventional knife planing method and the fixed-knife pressure-bar planing method were applied to two sizes of specimens. The properties evaluated and reported here are: swelling in all principal directions, compliance coefficient in radial compression, and equilibrium moisture content obtained during the first adsorption-second desorption cycle at 21°C. Normal cutting forces produced during peripheral planing act in the transverse direction of wood. Knowing that the tangential direction is the least resistant in wood, we expected that the effect of planing on the superficial layers formed in the radial-longitudinal plane of wood would be detected by the changes in radial compliance coefficient. A better knowledge of these effects may lead to better wood machining techniques, which have fewer negative effects on the quality of this material.

MATERIALS AND METHODS

Experiments were carried out with sugar maple (*Acer saccharum* Marsh) sapwood. Six logs with minimum visual defects were selected in the green state. Groups of boards matched tangentially were prepared from these logs; each group included four adjacent radial sawn boards with two different cross sections. The final cross section of the two middle boards used for preparing the small specimens was 15 (t) by 45 (r) mm. The final cross section of the two outside boards used for preparing the large specimens was 25 (t) by 75 (r) mm. These green boards were slowly dried to 14% MC, by dehumidification at room temperature. Final surfacing took place at this MC with two different methods.

Surfacing treatment

The final surfacing on the radial and tangential faces of the boards was done either by the rotating knife-planing method (peripheral planing) or by the fixed-knife pressure-bar planing method (oblique planing). In each matched group, one large and one adjacent small board were surfaced by peripheral planing and two other large and small adjacent boards were surfaced by oblique planing.

The peripheral planing was done separately on each side of the boards. The feed rate was set to give 34 knife marks per 25 mm of length, and the cutting depth was adjusted to remove 1 mm of wood in one pass. The knife and clearance angles were 40 and 15 degrees, respectively.

The oblique planing was done by removing 1 mm from each side of the boards using four passes of 0.25 mm each. The vertical gap between the pressure-bar edge and the knife edge was adjusted to 0.20 mm, while the horizontal gap was set at 0.38 mm. The planing was performed by oblique cutting 20-0 using a universal milling machine at a feed rate of 200 mm/min. The knife and clearance angles were 30 and 8 degrees, respectively. A detailed description of this method is given by Stewart (1986, 1989).

The knives for both types of planing had been freshly sharpened and ground with a 150-grit borax stone (Borazon grinding wheel). A final pass was ground manually with an emulsion of abrasive powder on a very fine surface. After planing, each board was cross-cut to yield either 15-mm-long small specimens or 25-mm-long large specimens.

Sorption tests

As mentioned previously, boards were matched to evaluate the effect of planing on physical and mechanical properties of wood. Matched specimens were prepared from four adjacent radial boards, one each for a specific type of planing treatment and sample size. The effect of planing was evaluated under six moisture sorption conditions. Each moisture condition required twenty specimens, which were taken in longitudinal series of six within each board.

Prior to the sorption experiments, all specimens were oven-dried. This first drying was done slowly to reduce drying stresses in the material and was the first desorption. This step lasted 16 days, with the temperature gradually increased from 20°C up to 100°C. After oven-drying, residual moisture was reduced by keeping the specimens over phosphorus pentoxide for one week. Specimens for the adsorption experiments were kept over phosphorus pentoxide until the start of sorption. Specimens for the desorption tests were re-wetted until their nearly full saturated MC was reached. Naderi and Hernández (1997) previously investigated the effect of this saturation treatment on physical properties of wood. Their results indicated that the following protocol was appropriate. Specimens were saturated at room temperature in four steps: exposure to 58%, 86%, 100% relative humidity (RH), and final immersion under distilled water. The final MC was slightly greater than 100%. The saturation treatment for small samples took 60 days, and for large samples the treatment took 90 days, with a vacuum (approximately 72 cm Hg) for 30 min required.

The first adsorption and second desorption tests were carried out simultaneously on all specimens using sorption vats described elsewhere (Goulet 1968). These vats provide temperature control of ±0.01°C over extended periods, allowing RH control in glass desiccators serving as small sorption chambers. Saturated salt solutions of $MgCl_2$, NaBr, NaCl, and KCl were used at 21°C to obtain RHs of 33%, 58%, 76%, and 86%, respectively. The sorption tests were carried out in one step under atmospheric pressure. Three adsorption conditions (58%, 76%, and 86% RH) and three desorption conditions (33%, 58%, and 76% RH) were used. Each desiccator held 20 specimens, which were placed in two levels at a constant distance from the salt solution surface for each level. Half of the specimens planed by peripheral cutting and half of those prepared by oblique cutting for each sorption condition were placed in each desiccator. These samples were equally distributed on both levels. The four desiccators required for holding the two small and two large samples for each sorption condition were placed next to each other in one vat, to reduce any variability associated to the sorption test itself.

To evaluate the state of equilibrium, control specimens for each sorption condition and dimension were periodically weighed, without removal from the desiccator. These experiments required between 140 and 435 days of sorption, depending on the RH and specimen size considered.

Physical and mechanical tests

As soon as each sorption test was completed, the sample mass was measured to the nearest 0.001 g. Dimensions in all principal directions were taken to the nearest 0.001 mm with a micrometer. Radial compression tests were immediately carried out on a Riehle machine. Deformation in the radial direction was measured in the central part of the specimen, using a two-side clip gauge provided with a linear variable differential transformer (LVDT). The span was 35 mm for small specimens and 65 mm for large specimens. Complete deformation of the specimen was also measured by the displacement of the cross-head, using another LVDT. In all cases, hygrothermal changes during the mechanical test were controlled by wrapping the specimen in cotton, which had been conditioned previously above the same humidity conditions as the wood. As per Sliker (1978), the cross-head speed was set to ensure a similar strain rate for all moisture conditions. In the elastic range this strain rate on the total radial dimensions of specimens was 1 percent per minute for both types of specimens.

These tests enabled us to establish the compliance coefficient in the radial direction s_{22} of the wood; the reciprocal of this parameter is Young's modulus. We used the cross-sectional area measured during mechanical test conditions for the calculations. The difference in specimen dimensions after oven-drying and just before the mechanical test was used to estimate the partial percent swelling in the tangential (α_{TH}), radial (α_{RH}), and longitudinal (α_{LH}) directions of wood. Volumetric swelling was estimated as the summation of these three directional swellings ($\alpha_{TH} + \alpha_{RH} + \alpha_{LH} + \alpha_{TH} \cdot \alpha_{RH}$). Finally, the mass of the specimens just before the mechanical test and their oven-dry mass measured after oven-drying were used to calculate the EMC, expressed as a percentage of oven-dry mass.

RESULTS AND DISCUSSION

Results of EMC, partial swelling, and compliance coefficient s_{22} measured over the central part of the specimen for sugar maple wood after adsorption are shown in Table 1. These values are presented as a function of relative humidity, type of planing treatment, and specimen size. Table 2 shows these same properties after the second desorption.

Effect of the planing on wood properties

The EMC at 58% RH after adsorption was not affected by the type of planing (Table 1). However, the effect of wood planing was seen as RH increased. EMCs at 76% and 86% RH were significantly higher for the oblique method compared to the peripheral method at 95% and 99% probability levels, respectively. Irrespective of specimen size, EMCs at 76% and 86% RH for obliquely planed specimens were respectively, 13.20% and 16.61%, compared to 13.15% and 16.52% EMCs for specimens prepared by peripheral cutting.

The effect of wood planing on EMC after adsorption followed by a desorption were more pronounced (Table 2). Oblique planing yielded higher EMCs than peripheral planing, with differences ranging from 0.10% to 0.25% EMC, depending on the RH and size of specimen. EMCs were not obtained at 33% RH from desiccators containing the small samples since at the end of the desorption period it was found that the $MgCl_2$ solution was not saturated.

In general, the effect of wood planing on the radial, tangential, or volumetric swelling