Fundamental Properties of Masson Pine (*Pinus massoniana* Lamb.) Wood from Plantation

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Abstract

Pine is one of the world’s three largest fast-growing wood species, among which Masson pine (*Pinus massoniana* Lamb.) is native to a wide area of central and southern China and is a common trees in plantation forestry for replacing or compensating of the loss of the natural forest in southern China. To efficiently utilize the Masson pine plantation wood, it is important to understand its wood properties. In this report, experiments were carried out on the same thin clear wood specimen to determine its basic density, microfibril angle (MFA) and tensile modulus of elasticity parallel to grain (*E*<sub>L</sub>). 1020 Specimens, 1.5 (R)×10 (T)×80 (L) mm, were cut from 19 disks at breast height of Masson pine plantation trees grown in Huangshan public welfare forest field, Anhui province. MFA was measured by X-ray diffraction. Results indicate that MFA ranges from 9.8° to 45.6° and is large in the juvenile wood and small in the mature wood. There is much less variation and smaller MFA in the mature wood than in the juvenile wood. The average basic density and *E*<sub>L</sub> at about 14% moisture content are 0.428 g/cm<sup>3</sup> and 11.2 GPa, respectively. Coefficient of variation (COV) for basic density and *E*<sub>L</sub> averaged 21% and 48%. It is concluded that MFA, combined with basic density, has a strong relationship to *E*<sub>L</sub>. Nevertheless variations of both MFA and basic density are generally insufficient to explain variations in *E*<sub>L</sub> of wood because variations in the composition of wood can contribute strongly to variations in *E*<sub>L</sub>.

**Keywords:** Masson pine, Basic density, Microfibril angle, Tensile modulus of elasticity parallel to grain
Introduction

Masson pine (*Pinus massoniana* Lamb.) is a species of pine, native to a wide area of central and southern China, and is considered the most important commercial species for fiber and solid wood products. The species is also a common tree in fast-growing plantation forestry in southern China. According to 7th national forest resources inventory results, the area of Masson pine plantation was 3.36 million hm$^2$ and its accumulation was 157.93 million m$^3$ in China. To better and efficiently utilize the Masson pine wood from plantation, it is essential to study the basic wood properties important to manufacturing processes and uses, including density $\rho$, microfibril angle (MFA), modulus of elasticity (MOE), and so on.

The density of a substance is defined as the ratio of its mass to its volume. For wood, both mass and volume depend on moisture content (MC), so its density is related to MC and is not constant. To make comparisons between species, a standard reference is the combination of oven-dry mass and green volume, referred to as basic density. Bunn (1981) stated “Basic density is probably the single most important intrinsic wood property for most wood products, particularly if we are contemplating adopting short rotations.” After Bunn, Bamber & Burley (1983) pointed out “Of all the wood properties density is the most significant in determining end use. It has considerable influence on strength, machinability, conversion, acoustic properties, wearability, paper yield and properties and probably many others.” Therefore density can be used as a general measure of wood quality.

MFA refers to the mean helical angle between the cellulose fibrils and the longitudinal cell axis. MFA is perhaps the easiest ultrastructural variable to be measured by X-ray diffraction (XRD) for wood cell walls. MFA is known to have significant influences on longitudinal shrinkage (Harris & Meylan 1965, Meylan 1972) and stiffness (Cave & Walker 1994). Donaldson (2008) comprehensively reviewed MFA’s measurement methods, variability and relations to wood properties. So MFA has become an important indicator of wood quality to the forest products industry.

The mechanical properties of wood are usually the most essential characteristics for its application. MOE, especially along the longitudinal axis of wood $E_L$, is the most representative parameter to describe the wood mechanical property. $E_L$ is usually determined from bending rather than from longitudinal tensile test. $E_L$ values obtained from bending test include an effect of shear deflection, which results in lower $E_L$ values (FPL 2010). This study addressed $E_L$ determined by tensile test parallel to grain of wood.

Materials and Methods

19 Masson pine (*Pinus massoniana* Lamb.) trees were selected and felled from the Huangshan plantation stand aged 40 years in Anhui province. The 19 trees were all straight in form and had an average diameter at breast height (DBH) of 31.2 cm. The details of these sample trees were presented in table 1. A disk approximately 20 cm thick was removed at breast height from each tree. After air-seasoning, these discs were processed to be central
strips (1 cm×8 cm in T×L directions) from north through the pith to south. Then 1.5-mm-thick tangential slices were cut along the growth rings. The nominal dimensions of the thin clear specimen is 1.5 mm (R)×10 mm (T)×80 mm (L).

The experimental procedure was first to measure MFA, then to determine $E_L$ and last to determine basic density of the specimen. The average MFA of specimen was measured by an X-ray powder diffractometer (PHILIPS X’Pert PRO PW3050/60). A line-focused X-ray beam (Cu-Kα X-ray) was applied to the wood specimen which was mounted in a holder that can be rotated about a horizontal axis (X axis of a right handed cartesian set X, Y, Z). The specimen is mounted at the centre of rotation, with its longitudinal (L) axis set initially in the vertical direction, Z, and usually with its L-T face normal to the X axis. The measurements were made a circle rotation at 0.5 sec/step and scan step size 1°, at a Bragg’s angle $2\theta=22.4^\circ$, using the 2 mm diverging slit and 1 mm receiving slit. A diffractogram (Fig. 1) is produced

### Table 1. Specification of Masson pine plantation sample trees

<table>
<thead>
<tr>
<th>Tree No.</th>
<th>DBH (cm)</th>
<th>Tree height (m)</th>
<th>Clear length (m)</th>
<th>Growth ring (a)</th>
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<td>1</td>
<td>23.8</td>
<td>14.0</td>
<td>7.3</td>
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<td>2</td>
<td>31.9</td>
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<td>11.0</td>
<td>44</td>
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<tr>
<td>3</td>
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<td>14.0</td>
<td>5.3</td>
<td>33</td>
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<tr>
<td>5</td>
<td>28.9</td>
<td>19.0</td>
<td>13.8</td>
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</tr>
<tr>
<td>7</td>
<td>22.0</td>
<td>17.0</td>
<td>11.8</td>
<td>41</td>
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<td>9.7</td>
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<td>11</td>
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<td>44</td>
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<tr>
<td>Mean</td>
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<td>18.0</td>
<td>10.4</td>
<td>40</td>
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</tbody>
</table>
Figure 1. X-ray diffraction profile for specimens from different rings of the wood strip

by the crystalline structure and recorded by a X’Celerator detector. According to the
calculation of MFA presented by Cave (1966, 1997), the value of MFA was equal to 0.6 by
parameter T obtained from the diffraction intensity around (002) arc. After the MFA of each
specimen had been measured, an INSTRON 5848 Micro-Tester was used to perform the axial
tensile test on the same specimen to obtain its tensile $E_L$ when the specimen reached the
equilibrium moisture content (EMC) in a temperature & humidity chamber with $(20\pm2)\,^\circ C$
and $(65\pm3)\%$ RH. The grip air of 250 N and the static load cell of 2 kN were chosen. The strain of
longitudinal deformation was detected by a 25 mm dynamic extensometer. The loading rate
was 1.5 mm/min and the max. load was 350 N. The calculation of $E_L$ was as follows

$$E_L = \frac{\sigma_{150} - \sigma_{300}}{\epsilon_{150} - \epsilon_{300}} \quad (1)$$

where $\sigma_x$ and $\epsilon_x$ respectively indicated the stress and strain corresponding to the load of x N.
The wood basic density was determined using the conventional gravimetric method with
water-saturated volume and oven-dry mass.

Results and Discussion

Wood density and within-tree variation

Figure 2 showed the basic density of 713 Masson pine wood specimens in this study. The
average basic density and corresponding coefficient of variation (COV) were $0.428 \,g/cm^3$ and
21\%, respectively. Because of the specimen from the same growth ring, in fact, the density
was the growth ring density, which was affected by the cell wall thickness, cell diameter, the
ratio of earlywood to latewood, chemical content and the age.
The predictable pattern for basic density is that it is lowest near the pith, increasing outwards to about 25th growth ring, thereafter remaining relatively constant (Bunn 1981). For Masson pine, wood density adjacent to the pith averages about 0.378 g/cm³ whereas the outer wood after 25th ring averages about 0.460 g/cm³. The figure 3 shows that the basic densities of two sample trees vary with the growth rings. Different trees can have markedly different density gradients across those 25 rings.
MFA and within-tree variation

The MFA was systematically studied over a wide range of growth rings in each tree. The distribution of measured MFA summarized in figure 4 shows most of the MFA range from 10° to 15°. The average MFA for all 1020 specimens was 17.5°. The MFA were correlated with the distance from the pith and the results were compared (figure 5). The MFA was found to decrease from pith to about 20th ring and then to remain stable in all trees.

Figure 4. MFA of Masson pine wood from plantation

Figure 5. Variation of MFA of Masson pine along the radial direction
The tensile modulus of elasticity parallel to grain $E_L$

The average tensile $E_L$ for 182 clear specimens at 14% MC was 11.2 GPa. The corresponding COV was approximately 48%. Stress-strain curves for specimens with different MFA are shown in figure 6. It is obvious that specimens with larger MFA show increased extensibility. Longitudinal strain increases from 0.08% to 0.4% as MFA increases from 10.3° to 41.1° when the stress is 17 MPa.

![Stress-strain curves for Masson pine wood with different MFA](image)

*Figure 6. Longitudinal tensile stress-strain curve of Masson pine wood with different MFA (within elastic limit)*

**Conclusion**

It is the first time to experimentally determine the longitudinal tensile modulus of elasticity $E_L$ of Masson pine wood from plantation in China. The average wood basic density, MFA and tensile $E_L$ at 14% MC are 0.428 g/cm³, 17.5° and 11.2 GPa, respectively. These data may serve as a basis for the efficient utilization of Masson pine. This study has important basic and practical meanings.

**References**


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