Mechanical Properties of Small Clear Wood Specimens of *Pinus patula* Planted in Malawi

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*Pinus patula* is one of the major exotic species grown in Malawi mainly for saw-timber production. It is native to Mexico. Little has been reported about the mechanical properties of the wood. The objective of this study was to investigate the mechanical properties of *Pinus patula* in more detail, in order to provide a basis for utilizing this resource. The mechanical properties of small clear wood specimens of *Pinus patula* were evaluated using 40 cm logs from 1, 3, 5, 7 and 9 m above the ground. Small clear wood specimens were selected and subjected to a bending test in accordance with Japan Industrial Standards (JIS) air-dry conditions. The growth rate did not affect the mechanical properties measured. There were significant correlations at 1% level between air-dry density and Modulus Of Rupture (MOR) \((R = 0.85)\) and between air-dry density and Modulus Of Rupture (MOR) \((R = 0.83)\). There was also a significant correlation between MOE and MOR at 1% level \((R = 0.90)\). At about 12% moisture content, the tested five *Pinus patula* families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively.

**Keywords:** *Pinus patula*; Modulus of Elasticity; Modulus of Rupture; Malawi; Air-Dry Density; Wood

**Introduction**

In Malawi, high demand for wood coupled with high deforestation rates has led to the increase in the adoption of exotic trees and introduction of plantation forestry. Although wood is naturally variable, fast grown trees produce wood, which may be significantly different in properties, compared with wood from slow grown trees. Furthermore, for trees grown as exotic, the wood produced may have different properties from wood of the same species in the original environment.

*Pinus patula* is one of the major exotic species grown in Malawi. It is planted about 80% of Malawi’s 74,000 ha of softwood plantation. It is native to Mexico. Tree height of *Pinus patula* ranges from 30 m to 35 m and the diameter at breast height ranges from 50 cm to 90 cm (Stanger, 2003). Under favorable conditions, it may attain a height of 15 m after 8 years. Among these properties are species specific, stronger in others but weaker in other species. These relationships allow prediction of effect of selecting one property to breed on the other properties. The relationships are also important in machine stress grading.
The main objective of this research was to look at the mechanical properties of *Pinus patula* in more detail, in order to provide a basis for utilizing this resource in Malawi. In general, this research seeks to provide reliable data for comparing the mechanical properties of *Pinus patula* grown in Malawi with various species. It also provides data, which may be used to analyze the influence on the mechanical properties of such factors as: distance of timber from the pith of the tree, height of timber in the tree, etc. The study further seeks to provide data, which can be used to classify the strength of *Pinus patula* grown in Malawi for grading purposes.

### Materials and Methods

#### Sampling

The samples used in this research were collected from Dedza in Central Malawi (altitude 1737 meters above sea level). The orchard used in this study was planted with forty-two families without routine silvicultural treatments. Families were randomized within each block. The total number of treatments (families) was 42 in 4 replications. Plot size was $7 \times 7$ trees at a spacing of $9 \times 9$ feet ($2.74 \times 2.74$ m). The plantation was 30 years old, but for unknown reasons, some of the trees studied were less than 30 years old.

This study looked at five of the 42 families. One tree per family was used representing a total of five trees with representative growth rates. **Table 1** shows the growth information of the five trees in terms of height, Diameter at Breast Height (DBH) and height at 15 cm diameter. The 15 cm diameter is the minimum merchantable diameter in Malawi. The mechanical properties of *Pinus patula* were evaluated using 40 cm logs from 1, 3, 5, 7 and 9 m above the ground. The logs were further cut into 20 mm × 20 mm × 32 cm specimens. The total number of small clear wood specimens was 86. A lot of care was taken to avoid any defect on the specimens. The specimens were selected and subjected to a bending test in accordance with Japanese Industrial Standards (JIS) air-dry conditions. The moisture content for the specimens was about 12%.

#### Data Analysis

In order to find out the relationship between the mechanical properties, scatter plots with regression line were produced using Minitab statistical software. The relationship was compared at individual tree and family levels. Analysis of variance was run at family and height above the ground levels for Modulus Of Elasticity (MOE), Modulus Of Rupture (MOR) and air-dry density. This was done in order to find out the extent of variation of the properties among the families.

**Table 1.** Volume growth information of five trees (five families) of *Pinus patula* at 30 years old.

<table>
<thead>
<tr>
<th>Family</th>
<th>DBH (cm)</th>
<th>Height (m)</th>
<th>Height at 15 cm diameter (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30.0</td>
<td>26.0</td>
<td>18.9</td>
</tr>
<tr>
<td>2</td>
<td>34.0</td>
<td>27.7</td>
<td>20.2</td>
</tr>
<tr>
<td>3</td>
<td>28.0</td>
<td>23.2</td>
<td>16.7</td>
</tr>
<tr>
<td>4</td>
<td>31.0</td>
<td>23.5</td>
<td>19.3</td>
</tr>
<tr>
<td>5</td>
<td>27.0</td>
<td>23</td>
<td>15.1</td>
</tr>
</tbody>
</table>

### Mechanical Properties of Juvenile Wood versus Mature Wood

Data from a previous research (Kamala et al., unpubl. data) on tracheid length for the same sample trees was used to determine juvenile and mature wood boundary. The study of the tracheid length of the five families showed that there was a rapid increase of tracheid length up to ring number 10 and then a stable pattern towards the bark. Therefore, ring number 10 was assumed to be the boundary between the juvenile wood and mature wood for *Pinus patula* grown in Malawi. The data for the juvenile wood and mature wood mechanical properties was subjected to an analysis of variance to find out if the variation of the mechanical properties was significant or not.

#### Grade Yield

Grading standard of physical and mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute (FFPRI) in Japan and the South African national standards were used to check the grade yield using MOE and MOR separately. **Tables 2 and 3** show the grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute and the grades according to the characteristic stress for South African Pine respectively.

**Table 2.** Grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions by Forestry and Forest Products Research Institute (FFPRI) (1975).

<table>
<thead>
<tr>
<th>Grade</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>- 7.35</td>
<td>- 58.8</td>
</tr>
<tr>
<td>II</td>
<td>7.45 - 10.3</td>
<td>58.9 - 82.4</td>
</tr>
<tr>
<td>III</td>
<td>10.4 - 13.2</td>
<td>82.5 - 107</td>
</tr>
<tr>
<td>IV</td>
<td>13.3 - 16.2</td>
<td>107 - 130.4</td>
</tr>
<tr>
<td>V</td>
<td>16.3</td>
<td>131</td>
</tr>
</tbody>
</table>

**Table 3.** Mechanical grades according to the characteristic stress for South African Pine (SANS 10163, 2003).

<table>
<thead>
<tr>
<th>Grade</th>
<th>MOE (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>xxx</td>
<td>7.79</td>
</tr>
<tr>
<td>Five</td>
<td>9.59</td>
</tr>
<tr>
<td>Seven</td>
<td>11.99</td>
</tr>
<tr>
<td>Ten</td>
<td>18</td>
</tr>
</tbody>
</table>
Average mechanical properties for the five families (Total five trees).

<table>
<thead>
<tr>
<th>Family</th>
<th>Air dry density (g cm$^{-3}$)</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.50 (0.11)$^*$</td>
<td>11 (3.42)$^*$</td>
<td>101.34 (35.83)$^*$</td>
</tr>
<tr>
<td>2</td>
<td>0.50 (0.07)$^*$</td>
<td>11.54 (3.28)$^*$</td>
<td>107.92 (28.25)$^*$</td>
</tr>
<tr>
<td>3</td>
<td>0.50 (0.12)$^*$</td>
<td>10.84 (3.23)$^*$</td>
<td>110.77 (34.15)$^*$</td>
</tr>
<tr>
<td>4</td>
<td>0.51 (0.11)$^*$</td>
<td>10.47 (3.51)$^*$</td>
<td>105.97 (32.95)$^*$</td>
</tr>
<tr>
<td>5</td>
<td>0.54 (0.09)$^*$</td>
<td>11.90 (3.59)$^*$</td>
<td>111.47 (39.91)$^*$</td>
</tr>
</tbody>
</table>

Note: $^*$ Standard deviation.

Table 5 shows the summarized mechanical properties among the five trees from five families. The maximum MOE and MOR were 16.72 GPa and 185.19 MPa respectively. The maximum air-dry density was 0.69 g cm$^{-3}$. At about 12% moisture content, the tested five 

Pinus patula families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively.

Tables 6 and 7 show the analysis of variance (Anova) results for MOE and MOR respectively. The Anova results show that stem height had no significant effect on the mechanical properties. The results also show that despite the differences in growth rate among the five trees from the five families, the mechanical properties were not significantly different among them. This shows that growth rate had no effect on the mechanical properties of the species.

This result is comparable to the results by Anon (1947) for South African 

Pinus patula. He also reported no correlation between timber strength and rate of growth. Craib (1939) also concluded that the rate of growth did not affect lumber strength in 

Pinus patula. The absence of influence of growth rate on mechanical properties is an advantage to forest managers who prefer higher growth rate to increase the volume yield of plan-

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This study.
Relationships among Wood Properties

Research has shown increased density to be strongly linked to favorable strength, stiffness, hardness and working properties of sawn timber, as well as wood pulp yield and paper-making quality. The relationships among the mechanical properties in this study were linear and positive.

Figures 1-3 show the relationships among air-dry density, MOR and MOE. There were significant correlations at 1% level between air-dry density and MOE ($R = 0.85$) and between air-dry density and MOR ($R = 0.83$). There was also a significant correlation between MOE and MOR at 1% level ($R = 0.90$). These results are also comparable with results for East African grown *Pinus patula* where wood density correlated significantly with all green and dry lumber strengths (FFPRI, 1975).

The correlation of MOR and MOE with specific gravity is typically very strong, as reported by Shottafer et al. (1972) and Shepard & Shottafer (1992) for red pine, Wolcott (1985) for red spruce, and Han (1995) for red maple. However, in some coniferous species, such as *Abies fabri*, *Picea asperata*, and *Pinus massoniana*, the relationship of MOE to specific gravity is weaker than the relationship between MOR and specific gravity (Zhang, 1997), and this was also found to be true in fast-growing red pine (Deresse, 1998). It has been reported that wood samples having similar specific gravity can also exhibit significantly different strength values due to factors that may be associated to other factors to which specific gravity is less sensitive (Perem, 1958; Zhang, 1995; Deresse, 1998). Correlations in this study indicate that controlling density would have a positive effect on some mechanical properties.

Mechanical Properties and Grade Yield of Juvenile Wood versus Mature Wood

Tables 9 and 10 show the analysis of variance results for juvenile and mature woods among the five trees for MOE and MOR respectively. Significant variation was noted between juvenile wood and mature wood in terms of mechanical properties.

Figures 4-7 show the grade yield for both juvenile and mature wood according to MOE and MOR using grading standard of mechanical properties of timbers from Southeast Asia and Pacific regions (FFPRI, 1995). The grade yield for MOE in juvenile wood was highest for Grade II followed by Grade I. Grade III and Grade IV was lower. There was no grade yield for Grade V according to MOE in juvenile wood (Figure 4). The grade yield for MOE in juvenile wood was highest for Grade III followed by Grade II and Grade I. Grade IV was lower and the grade yield for Grade V was the lowest (Figure 5).

Table 9.
MOE Analysis of variance summary for juvenile and mature wood (86 specimens).

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOE Juv/MAT</td>
<td>1</td>
<td>565.99</td>
<td>565.99**</td>
</tr>
<tr>
<td>Error</td>
<td>86</td>
<td>314.25</td>
<td>3.65</td>
</tr>
</tbody>
</table>

Note: **Significant at 1 % level.

Table 10.
MOR Analysis of variance summary for juvenile and mature wood (86 specimens).

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Type III SS</th>
<th>Mean Square</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOR Juv/MAT</td>
<td>1</td>
<td>40618.47</td>
<td>40618.47**</td>
</tr>
<tr>
<td>Error</td>
<td>86</td>
<td>44476.93</td>
<td>517.17</td>
</tr>
</tbody>
</table>

Note: **Significant at 1 % level.
The grade yield for MOR in mature wood was highest for Grade V followed by Grade IV and Grade III. Grade II was lower and there was no grade yield for Grade I according to MOR in mature wood (Figure 7).

Figures 8 and 9 show grade yield for both juvenile and mature wood according to the South African national standards. The grade yield for MOE in juvenile wood was highest for Grade five at followed closely by Grade XXX. Grade Seven was lower and the lowest grade yield according to MOE in juvenile wood was in Grade Ten (Figure 8).

The grade yield for MOE in mature wood was highest for Grade IV followed by Grade III. Grade V and Grade II was lower. There was no grade yield for Grade I according to MOE in mature wood (Figure 6).
The grade yield for MOE in mature wood was highest for Grade Ten at followed by Grade Seven. Grade II was lower and there was no grade yield for Grade Five and XXX with both grades yielding according to MOE in mature wood (Figure 9).

The grade yield according to MOE and MOR was different for juvenile wood and mature wood. Some grades had high yields in juvenile wood but low yields in mature wood. In other cases, grades with high yield in juvenile wood were non-existent in mature wood. The results show that mature wood yielded more grades with high values of MOE and MOR. This clearly shows that mature wood for *Pinus patula* is superior in strength and grade than juvenile wood. The implication for this is that mature wood and juvenile wood should be used for different purposes to avoid underutilization. Uniform use of juvenile wood and mature wood for structural purposes would be potentially dangerous because juvenile wood has inferior mechanical performance. To improve lumber strength, one can process logs of older trees and minimize the use of the interior portion of the log. Correct drying of the boards will increase the most important lumber strength traits of modulus of rupture and modulus of elasticity. Export of dried lumber of *P. patula* occurs and should increase if uniformity can be maintained.

The common steps in establishing grades for lumber are: testing of small clear specimens according to guidelines, establishing strength values and allowable properties, establishing visual grading rules and lastly verifying grades using in-grade testing. The contribution of this research towards creating an acceptable grading system is that it has clarified the variation of mechanical properties. More mechanical properties data, through testing of small clear wood specimens, from other areas in Malawi need to be accumulated.

This research has established first steps in assigning allowable mechanical properties for *Pinus patula* grown in Malawi. After accumulating more small clear wood specimen data, testing using the “in grade” approach, in which large representatives samples of full size lumber can be tested to destruction is recommended to compare the results. This will help in the assignment of standard grades that will ensure the efficient utilization of *Pinus patula* structural lumber in Malawi.

**Conclusion**

At about 12% moisture content, the tested five *Pinus patula* families have average MOR and MOE of 105.17 MPa and 10.93 GPa, respectively. There were significant correlations at 1% level between air-dry density and MOE (R = 0.85) and between air-dry density and MOR (R = 0.83). There was also a significant correlation between MOE and MOR at 1% level (R = 0.90). There was no significant variation in MOE and MOR among the five families. Stem level variation in MOE and MOR is not significant. Mature wood of *Pinus patula* has more superior mechanical performance than juvenile wood. The growth rate did not affect the mechanical properties of the species. This study suggests that it is potential to simultaneously improve tree growth, density, and some mechanical properties of the wood of this species. The results of this study are a foundation that will provide a technical basis for the machine grading of *Pinus patula* structural lumber in Malawi.

**REFERENCES**