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Study of the Modulus of Rupture and Modulus of Elasticity of Green Wood of Local Tree Species

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Abstract – Singapore is well-known for its vision of “City in the Garden”, which it achieves by co-existing building and infrastructure development with extensive urban greenery. A large component of this urban greenery comprises of thousands of urban trees. Mature trees are large living structures that can cause harm and inconvenience to the residents of Singapore upon tree failure. Thus, further research about tree failure is needed. This study focuses on measuring the material properties of greenwood. The modulus of elasticity (MOE) and modulus of rupture (MOR) of four common local tree species in Singapore; Saman samanea (Rain tree), Tabebuia rosea (Trumpet tree), Khaya senegalensis (Khaya), and Peltophorum pterocarpum (Yellow Flame) were measured with comparisons made. Three-point bending test was determined to be the most suitable test to measure the properties. In addition, the samples were taken from the site directly and tested immediately to minimize the loss of moisture content. It was found that among them, Tabebuia rosea was the most brittle and Samanea saman was the most ductile. In terms of highest MOE and MOR, the best performing species was held by Peltophorum pterocarpum as it had the highest MOE and MOR. The worst was held by Samanea saman.

Future recommendations are to test more species of trees and increase the sample size to improve the database.

Keywords – MOE; MOR; greenwood; boxplot; three-point bending test; stress strain curve

1 INTRODUCTION

1.1 BACKGROUND

Singapore aims to be a “City in the Garden” by 2016 [7]. The urban trees play a vital role in realization of this vision. Extensive care for urban trees is required as Singapore is a densely populated city with 5.3 million people sharing space with more than 2000 native plant species [6]. Thus, potential occurrences of tree failures must be quickly identified along with the steps taken to reduce the risk of human injuries and lives.

Previous research have been conducted to investigate the tree failure mechanisms. The most important external cause for tree failure are drag forces produced by high wind pressures [5]. Consequently, tree architecture and shape become important as they determine the drag forces acting on the tree when wind passes through it. To further understand the response of the tree to external loads, greenwood properties of trees such as modulus of elasticity and modulus of rupture must be determined.

1.2 OBJECTIVES

The primary objective of this project was to study the modulus of elasticity and the modulus of rupture of four common roadside tree species. The species tested were Saman samanea (Rain tree), Tabebuia rosea (Trumpet tree), Khaya senegalensis (Khaya), and Peltophorum pterocarpum (Yellow Flame). Those four local tree species were chosen as they are the most common local urban trees found in Singapore. In addition, this project also compared the performance of those species in terms of their greenwood properties, as the comparison would be useful for practitioners in selecting the suitable tree species for planting in urban areas.

2 LITERATURE REVIEW

2.1 GREENWOOD PROPERTIES

Wood is a composite material that is made up of several distinct layers. At the periphery of the log surface, a layer called bark exists. Below the bark, there is the sapwood layer and then the heartwood. Although most greenwoods have the same structural composition, different species have different mechanical properties. Even within a single tree, one branch’s properties may vary slightly from others’. Differences in wood properties can be caused by several factors, i.e. age, supply of nutrition available, condition of the tree’s surroundings [3].

Wood possesses anisotropic properties [3]. Different directions of applied loads or stresses result in different responses from the wood. Research has shown that this anisotropic behavior is due to the natural growth of the tree itself. This leads to fiber arrangements in trees to be different directionally. The type of the load (compression, tension, shear, bending, or torsion) also leads to different mechanical responses shown by wood in different directions.

Drywood has higher strength and elastic modulus than greenwood [8]. The condition of having much less water in the wood makes bonding between fibres stronger. Water reduces the bonding between the fibres through a complex chemical reaction [2].
3 METHODOLOGY

3.1 THREE-POINT BENDING TEST

Three-point bending tests were conducted by using the three-point bending test apparatus as shown in Fig. 1. It consisted of a four-leg platform, a dial gauge, and a hydraulic hand-pump with a pressure reading attached onto it. The platform was able to make contact with the branch over three points; two at the end of the branch, and one in the middle of the branch. The dial gauge functions as a mid-span deflection measurement, where a full 360 degree rotation represented 1 mm displacement at the midpoint of the branch. The hydraulic pump operated a piston which acted as the source of the load, pushing the branch at the midpoint until it failed.

At least forty samples were tested from each species. They were obtained fresh from the tree pruning or trimming site and tested immediately so as to minimize change of moisture content. The tested samples’ length was approximately 500 mm but varied in diameter and weight.

3.2 BOXPLOT

Boxplots are a useful charting method for depicting experimental data statistically. Boxplots describe the statistical features of a data set such as: center (median), spread (whiskers), also the extent and nature of any departure from symmetry (quartiles). A useful part of this charting method is the usage of median and a measure of variability called the fourth spread instead of mean and standard deviation. The reason they are used is because of their resistance toward the presence of outliers, which are observations that lie unusually far from the main body of data [1].

Fig 2. displays an example of a simple boxplot. The lowest whisker shows the minimum value of a data set. The lowest part of the green box shows the 25th percentile, while the border between the green and purple box depicts the median value. The upper part of the purple box gives the 75th percentile value. Finally, the highest whisker shows the maximum value of a data set.

4 RESULTS AND DISCUSSION

4.1 STRESS STRAIN CURVE

Fig. 3 shows the stress-strain curve presented in boxplot chart for each of the tree species. Rain tree (Saman saman) reached 3.5-4.0 percent mean failure strain however, it was able to maintain close to peak stress up to 10 percent strain, and the mean peak stress was about 35 MPa, the smallest among those four. Trumpet tree (Tabebuia rosea) had the smallest peak strain, 3.0-3.5 percent and the peak stress was about 37 MPa. Khaya (Khaya senegalensis) reached 4-4.5 percent peak strain, and the median peak stress was about 43 MPa. The largest peak stress was had by Yellow Flame (Peltophorum pterocarpum), around 47 MPa, and its mean peak strain reached 3.5-4.0 percent. Based on the results, it could be concluded that among the four species tested, Rain tree (Saman saman) was the most ductile and Trumpet tree (Tabebuia rosea) was the most brittle. The toughness of each species was obtained based on the area under the curve. Rain tree (Saman saman) had toughness of 2.84 x10⁴ J.m⁻³. Trumpet tree (Tabebuia rosea) had the smallest value of toughness, which is 2.23 x10⁴ J.m⁻³. The highest value of toughness was held by Khaya (Khaya senegalensis) with a value of 3.74 x10⁴ J.m⁻³. Last but not least, Yellow Flame (Peltophorum pterocarpum) had toughness of 3.62 x10⁴ J.m⁻³.
Figure 3 Stress-strain curve of *Saman samanea*, *Tabebuia rosea*, *Khaya senegalensis*, and *Peltophorum pterocarpum*

### 4.2 GREENWOOD PROPERTIES

Table 1 shows the average greenwood properties of each local tree species. The highest moisture content was held by Trumpet tree (*Tabebuia rosea*) with a value of 46.94%. In contrast, Khaya (*Khaya senegalensis*) had the lowest mean moisture content of only 41.31%.

However, the lowest MOR was not held by the species that had highest moisture content. The lowest mean MOR was held by Rain tree (*Saman saman*) with a value of only 31.58 MPa. In addition, the highest MOR was held by Yellow Flame (*Peltophorum pterocarpum*), not Khaya (*Khaya senegalensis*), the one that had the lowest moisture content. The same phenomenon also observed in the relationship between MOE and moisture content.

Yellow Flame (*Peltophorum pterocarpum*) had the highest MOE, which made it the stiffest tree species among the tested species. As it also possessed the highest MOR with an adequate value of strain at failure, it can be concluded that Yellow Flame (*Peltophorum pterocarpum*) performed the best among the other three species. When it comes to the worst in performance, Rain tree (*Saman saman*) had the lowest MOR and MOE.

Table 1 Greenwood properties of *Saman samanea*, *Tabebuia rosea*, *Khaya senegalensis*, and *Peltophorum pterocarpum*

<table>
<thead>
<tr>
<th>Species</th>
<th>Saman samanea</th>
<th>Tabebuia rosea</th>
<th>Khaya senegalensis</th>
<th>Peltophorum pterocarpum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet Density (g/cm³)</td>
<td>0.836</td>
<td>0.830</td>
<td>0.983</td>
<td>0.793</td>
</tr>
<tr>
<td>Dry Density (g/cm³)</td>
<td>0.454</td>
<td>0.432</td>
<td>0.579</td>
<td>0.440</td>
</tr>
<tr>
<td>Greenwood Moisture Content (%)</td>
<td>45.06</td>
<td>46.94</td>
<td>41.31</td>
<td>44.12</td>
</tr>
<tr>
<td>Strain at Failure (%)</td>
<td>4.59</td>
<td>3.54</td>
<td>5.29</td>
<td>4.41</td>
</tr>
<tr>
<td>MOR (MPa)</td>
<td>31.58</td>
<td>37.40</td>
<td>40.06</td>
<td>50.35</td>
</tr>
<tr>
<td>MOE (MPa)</td>
<td>745</td>
<td>1104</td>
<td>893</td>
<td>1273</td>
</tr>
<tr>
<td>Toughness (×10⁶ J/m²)</td>
<td>2.84</td>
<td>2.23</td>
<td>3.74</td>
<td>3.62</td>
</tr>
</tbody>
</table>

**5 CONCLUSIONS**

From the project, several conclusions can be drawn as follows:

- From the stress-strain curve of each local tree species, Rain tree (*Saman saman*) had the most ductile properties while Trumpet tree (*Tabebuia rosea*) had the most brittle performance.
- There was no clear relationship between greenwood moisture content with modulus of rupture, as well as with modulus of elasticity of local tree species.
Yellow Flame (*Peltophorum pterocarpum*) had the best performance among those four trees regarding its green wood stiffness and strength, while Rain tree performed the worst.

Further research can be carried out to improve the assessment of greenwood properties of local tree species in Singapore such as broadening the number of species being observed and assessing other greenwood properties that can affect the MOE and MOR.

**ACKNOWLEDGMENT**

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**REFERENCES**


