STUDIES ON REPRODUCIBILITY AND ACCURATE MEASUREMENT OF MOISTURE CONTENT OF WOOD SAMPLES USING AN ELECTRIC MOISTURE METER

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ABSTRACT
Studies were conducted on reproducibility, and accurate measurement of moisture content of four wood samples using an electric moisture meter. Experimental results indicated that there was no clear relationship between moisture content and grain angle within a radius of 30mm. Repeated measurements of moisture content at different locations or points on the wood surface showed similar patterns of variation. Within-point standard deviation of the moisture content was bigger than between-point standard deviation. A non-destructive method of measuring moisture content at the same location or point on the wood surfaces could not be proposed because of the high variation of moisture content when repeated measurements were taken at the same point. Instead, accurate measurements of moisture content could be obtained at random positions with a radius of 30mm.

INTRODUCTION
Lumber drying is an important phenomenon in the timber industry. Lumber that is not properly dried will result in loss in strength, susceptibility of the lumber to decay and insects attack and more importantly deformation by warping. The essence of drying is to remove the moisture in the wood to a preferred level. In the timber industry, a non-destructive method of measuring the moisture content of wood samples at different locations is normally employed using an electric moisture meter. However, because of the variation of moisture in wood, in both the radial and tangential directions, readings from the electric moisture meter at different locations on the wood surface may not show similar patterns of variation. Therefore reproducibility which refers to the consistency of the moisture meter to show repeatedly similar patterns of variation may be missing. The purpose of this study is to determine an accurate method of measuring the moisture content of wood samples within a radius of 30mm from the pins of the moisture meter, and also determine if at particular locations or points, there is reproducibility, that is, repeatedly similar patterns of variation when multiple readings are taken.

THEORETICAL CONSIDERATIONS
The standard deviation of a set of measurement is a useful parameter in precision engineering to determine accuracy and reproducibility. In wood processing, standard deviation of a board thickness is a useful parameter to determine lumber thickness variation [1]. The standard deviation of repeated readings at points on the surface of lumber using a moisture meter can be described as within-point standard deviation, \( S_w \), which is the average of the standard deviation of moisture content repeatedly measured at individual points. The between-point standard deviation, \( S_b \), is the standard deviation of the average moisture content repeatedly measured at individual points. Equations 1, 2, and 3 can be used to determine the standard deviation, \( S_j \), of repeated measured moisture content at a point on the wood surface, within-point standard deviation, \( S_w \), and between-point standard deviation, \( S_b \), respectively [2].

\[
S_j = \sqrt{\frac{\sum_{j=0}^{N_j} x_j^2 - \left( \frac{1}{N_j} \left( \sum_{j=0}^{N_j} x_j \right) \right)^2}{N_j - 1}}
\]

\[
S_w = \sqrt{\frac{\sum_{j=0}^{k} S_j^2}{k}}
\]

\[
S_b = \sqrt{\frac{\sum_{j=0}^{k} A_j^2 - \left( \frac{1}{k} \left( \sum_{j=0}^{k} A_j \right) \right)^2}{k - 1}}
\]
The variables used in describing Equations 1 to 3 above are defined as follows:

\[ A_j: \text{ average moisture content at point } j \]
\[ K: \text{ number of points} \]
\[ N_j: \text{ number of measurements at point } j \]
\[ S_j: \text{ standard deviation for point } j \]
\[ X_j: \text{ measurement from individual points} \]

**MATERIALS AND METHODS**

Four wood samples, *Elais guineensis*, *Milicia excelsa*, *Khaya ivorensis*, and *Triplochiton scleroxylon*, of tropical origin were selected for the study. The moisture content was measured at grain angle of 0 degree to 150 degrees in step of 30 degrees using an electric moisture meter, that is, measurements were in the order of 0, 30, 60, 90, 120, and 150 degrees. Measurements in the direction of the grain orientation corresponded to 0 degree whilst measurement perpendicular to the grain orientation corresponded to 90 degrees. The wood samples were partitioned into four quadrants and measurements of moisture content were taken at a radius of 30mm from the center axis of the quadrant at six points.

**RESULTS AND DISCUSSION**

**MOISTURE CONTENT DISTRIBUTION**

Figure 2 shows the relationship between mean moisture content and grain angle of wood samples, *Elais guineensis*, *Milicia excelsa*, *Khaya ivorensis* and *Triplochiton scleroxylon* measured at six locations. It can be seen from figure 2 that with the exception of *Triplochiton scleroxylon* which showed a continuous decrease of moisture content with increase in grain angle from 0 to 120 degrees, no clear relationship could be established between moisture content and grain angle. In the case of wood samples, *Elais guineensis*, *Milicia excelsa* and *Khaya ivorensis*, there were fluctuations in moisture content with increasing grain angle.
established that cutting force is influenced by grain angle [3]. This study sought to establish the relationship between moisture content and grain angle and to clarify if moisture content has an effect on the relationship between cutting force and grain angle. Experimental results shown in figure 2 indicated that moisture content distribution in wood was not influenced by grain angle due to the fluctuating effect of moisture content with increasing grain angle.

WITHIN-POINT AND BETWEEN-POINT STANDARD DEVIATION OF MOISTURE CONTENT

Table 1 shows within-point and between-point standard deviation of moisture content of the four wood samples selected for the study. It can be seen that regardless of the wood species, within-point standard deviation is always greater than between-point standard deviation. Thus the ratio of within-point standard deviation to between-point standard deviation is greater than unity. A close observation of table 1 shows a high value of within-point standard deviation for all species. The high value of within-point standard deviation is due to the high variation of moisture content for repeated readings. When repeated readings are taken at the same point, the wood cells are broken and the water in the cells is absorbed into the atmosphere thus accounting for variation of moisture content.

REPRODUCIBILITY

This section is solely devoted to reproducibility which refers to the consistency of the moisture meter to show repeatedly similar patterns of variation. Note that reproducibility forms the basis of this study and therefore attempts have been made to treat this topic in a holistic manner. As shown in table 1, similar patterns of variation are recorded, that is, within-point standard deviation is always greater than between-point standard deviation for all the species selected for the study. To address the issue of reproducibility of moisture content measurement, one needs to have a critical look at non-destructive method of moisture content measurement. Ordinarily, the best approach is to measure the moisture content of wood samples at the same location for consistent readings due to the variation of moisture content along the radial or tangential direction of wood. Table 1 clearly suggests that there will be high variation of moisture content if measurements are taken at the same location or points as indicated by higher values of within-point standard deviation. However, consistent readings can be recorded if measurements of moisture content are taken at different locations or points on the wood surface as indicated by lower values of between-point standard deviation.

**TABLE 1.** Within-point and between-point standard deviation of moisture content of wood samples, *Elais guineensis*, *Milicia excelsa*, *Khaya ivorensis* and *Triplochiton scleroxylon* measured at six locations.

<table>
<thead>
<tr>
<th>Species</th>
<th>MC(%)</th>
<th>$S_b$</th>
<th>$S_w$</th>
<th>$S_w/S_b$</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>M. excelsa</em></td>
<td>12.26</td>
<td>0.20</td>
<td>1.07</td>
<td>5.35</td>
</tr>
<tr>
<td><em>T. scleroxylon</em></td>
<td>16.54</td>
<td>0.65</td>
<td>0.94</td>
<td>1.45</td>
</tr>
<tr>
<td><em>K. ivorensis</em></td>
<td>13.17</td>
<td>0.17</td>
<td>0.38</td>
<td>2.24</td>
</tr>
<tr>
<td><em>E. guineensis</em></td>
<td>20.33</td>
<td>1.03</td>
<td>1.56</td>
<td>1.51</td>
</tr>
</tbody>
</table>

CONCLUSION

Cutting force in wood machining is influenced by moisture content and grain angle. However, no clear relationship has been established between moisture content and grain angle. This study sought to determine an accurate and non-destructive method of measuring moisture content at the same point or location. Experimental results indicated that there is no clear relationship between moisture content and grain angle, that is, the moisture content in wood is not influenced by the grain angle. Repeated measurements of the moisture content at different locations or points on the wood surface showed similar patterns of variation. Within-point standard deviation of the moisture content was bigger than between-point standard deviation. Thus, a non-destructive method of measuring moisture content at the same location or point on the wood surfaces could not be proposed because of the high variation of moisture content when repeated measurements were taken at the same point. Instead, accurate measurements of moisture content could be obtained at random positions with a radius of 30mm.

REFERENCES
