IS RESISTOGRAPH AN APPROPRIATE TOOL FOR THE ANNUAL RING MEASUREMENT OF PINUS BRUTIA?

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Abstract
The study reports on the applicability of the IML RESI F500-S Resistograph for efficient and practical determination of some ring properties (mainly annual ring) of Pinus brutia depending on preliminary results of an ongoing project. For this purpose increment core samples and resistograph data were collected from Mediterranean Region of Turkey. The preliminary results reveal that resistograph is very promising for annual ring measurement of P. brutia.

Keywords: NDE, Pinus brutia, Resistograph, annual ring.

1. Introduction

Pinus brutia is naturally distributed mainly in the eastern Mediterranean Basin encompassing Turkey, Greece, Cyprus, Syria, Palestine, Jordan and Iraq (Boydak, 2004). The species has been given a high priority in plantations in various countries with Mediterranean climate due to its relatively fast growth rate and wide ecological adaptability (Arbez 1974). The species has a wide geographic distribution (5,420,524 ha forest land) in Turkey, and is an important source of forest products in the country (Guller 2007; http://amenajman.ogm.gov.tr/).

Determination of ring width is crucial for many areas in forestry. Generally increment coring is used for annual ring measurement all around the world. Although this is accepted as semi destructive sampling method, depending on the core diameter (increasing core diameter) this may be considerably destructive for living trees. Additionally it is time consuming. The Resistograph is an instrument that penetration resistance of a fine drill needle is measured and recorded. In recent years the use of Resistograph is widening for the purpose of non-destructive evaluation of some properties of standing trees (Rinn et al.1996; Chantre and Rozenberg 1997; Isik and Li 2003; Bouffier et al.2008; Saez et al. 2008; Ukrainetz and O’Neill 2010). In fact this method is quasi non-destructive, since the diameter of the needle is so small, that the weakening effect caused by the whole is negligible. Because of this negligible destruction many researchers mention it as a non-destructive instrument.

The resistograph provides a graphic representation (resistogram) of the energy which is consumed by the electric engine in penetrating the sample. Thus, given the internal constitution of the wood, a series of variables can be determined relating the characteristics of the material (Rinn et al. 1996). The total energy consumed in penetrating the sample is closely related to the material density. Due to anatomical nature of Pinus brutia, early wood and late wood visually separable and denser wood (late wood) formed at the end of the growth ring. Thus, the resistogram appears as a succession of peaks and valleys, corresponding to the varying difficulty in penetrating early and latewood part of annual rings.
The purpose of our project (TUBİTAK 110-O-560, started in 2011 and will be ended in 2013) is the determination of P. brutia wood properties using NDE techniques. The study reports our preliminary results on the applicability of the IML RESI F500-S Resistograph for efficient and practical determination of some ring properties (mainly annual rings).

2. Material and Method
Wood samples examined in the study were collected from 35-40-year-old trees planted at a provenance test trial (36° 55’ 18” N, 30° 37’ 00” E) within the optimal distribution range of the species near Antalya in South-western Turkey.

One increment core (5 mm thick) per tree was taken at breast height (1.3 m) in the north-south direction from bark to bark, intersecting the pith.

IML RESI F500-S and its software (F-Tools) used for resistograph measurements. Resistograph measurements were obtained from the closest place and same direction of coring.
Ring width was measured on increment cores via image analysis method (Data set RW1, Image analysis system of the Faculty of Forestry, Suleyman Demirel University was used for the measurements). Normally an additional software module (including export option) must be purchased to obtain each amplitude values. But, in the study a free and easy way (free software, Image J, used for exporting resistograph data proposed by Guller, 2012) which allows exporting data without any additional purchased module was preferred. Because of moisture differences between standing trees and increment cores, all the cores were acclimatized (12% equilibrium) before the measurements and the moisture of each sample was determined after the measurements. Radial shrinkage of samples was calculated as 4.1% following the Formula 1 below (Haygreen and Bowyer, 1996) and then, considering moisture differences, resistograph ring measurements were converted to the new data set which had the same moisture content of increment cores according to the Formulas 2 and 3 below. Statistical comparisons were applied for converted data, moisture corrected (RW2), and unconverted (raw measurements from standing trees) data set (RW3). Ring measurements obtained from two populations (98 measurements for population 1; 37 measurements for population two, hence 135 in total) using two different ways (resistograph and increment cores) were compared for each individual ring and mean values by using statistical analysis (paired sample t test and ANOVA).

\[ \beta_r = \frac{\Delta dr}{dr} \times 100 \]  

(1)

where;
\( \beta_r \): Radial shrinkage (%)
\( \Delta dr \): Decrease in radial dimension
\( dr \): original radial dimension of sample (mm)

\[ \Sigma \beta r = k \beta r \times \Delta m \times dr \]  

(2)

\[ RW2 = RW3 - \Sigma \beta r \]  

(3)

where;
\( \Sigma \beta r \): Total radial shrinkage (mm)
\( \Delta m \): Moisture difference (from fiber saturation point (28%) to sample moisture; ie:28-12=16)
\( dr \): Original radial dimension of sample (mm)
\( k \beta r \): Radial shrinkage value for 1% moisture change from FSP to 0% moisture;0.001464 for our samples)

3. Findings
Correlation is significant (Pearson correlation coefficient found as 0.97) at the 0.01 level for ring widths between resistograph and core measurements. Descriptive statistics for all data (Table 1) and separate for two populations are given (Table 2) below.
Table 1. Descriptive statistics for all data

<table>
<thead>
<tr>
<th>Measured properties</th>
<th>N</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>RW1 (Increment core)</td>
<td>135</td>
<td>2.613</td>
<td>0.125</td>
<td>1.452</td>
</tr>
<tr>
<td>RW2 (resistograph-moisture corrected)</td>
<td>135</td>
<td>2.784</td>
<td>0.139</td>
<td>1.612</td>
</tr>
<tr>
<td>RW3 (resistograph-raw)</td>
<td>135</td>
<td>2.851</td>
<td>0.142</td>
<td>1.651</td>
</tr>
</tbody>
</table>

RW: Ring width (mm)

Table 2. Descriptive statistics for two populations

<table>
<thead>
<tr>
<th>Population</th>
<th>Measured properties</th>
<th>N</th>
<th>Mean</th>
<th>Std. Error</th>
<th>Std. Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RW1</td>
<td>98</td>
<td>2.618</td>
<td>0.148</td>
<td>1.460</td>
</tr>
<tr>
<td></td>
<td>RW2</td>
<td>98</td>
<td>2.842</td>
<td>0.169</td>
<td>1.676</td>
</tr>
<tr>
<td></td>
<td>RW3</td>
<td>98</td>
<td>2.910</td>
<td>0.173</td>
<td>1.716</td>
</tr>
<tr>
<td>2</td>
<td>RW1</td>
<td>37</td>
<td>2.599</td>
<td>0.238</td>
<td>1.448</td>
</tr>
<tr>
<td></td>
<td>RW2</td>
<td>37</td>
<td>2.631</td>
<td>0.237</td>
<td>1.439</td>
</tr>
<tr>
<td></td>
<td>RW3</td>
<td>37</td>
<td>2.695</td>
<td>0.242</td>
<td>1.474</td>
</tr>
</tbody>
</table>

Although there is high correlation (r=0.97) between resistograph and increment core measurements and good match for many of the ring boundaries (Figure 3), paired sample t-test results show that the difference between two ways is statistically significant at 95% confidence level (Table 3). This finding shows that the ring widths measured by resistograph are different from core measurements at ring basis. However, if the mean values of the populations are compared (Table 4), there are no significant differences indicating that the resistograph can be used to determine population mean ring width.

Table 3. Paired sample t-test for all data (ring basis)

<table>
<thead>
<tr>
<th>Pair</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
<th>t</th>
<th>df</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>RW1-RW2</td>
<td>-0.172</td>
<td>0.394</td>
<td>-5.055</td>
<td>134</td>
<td>0.000</td>
</tr>
<tr>
<td>2</td>
<td>RW1-RW3</td>
<td>-0.238</td>
<td>0.415</td>
<td>-6.668</td>
<td>134</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Table 4. Comparison of means for two populations and three grouping data set

<table>
<thead>
<tr>
<th>Population</th>
<th>Groups (RW1, RW2 and RW3)</th>
<th>Sum of Squares</th>
<th>df</th>
<th>Mean Square</th>
<th>F</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Between Groups</td>
<td>4.582</td>
<td>2</td>
<td>2.291</td>
<td>0.871</td>
<td>0.419</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>765.016</td>
<td>291</td>
<td>2.629</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>769.597</td>
<td>293</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Between Groups</td>
<td>0.174</td>
<td>2</td>
<td>0.087</td>
<td>0.041</td>
<td>0.96</td>
</tr>
<tr>
<td></td>
<td>Within Groups</td>
<td>228.267</td>
<td>108</td>
<td>2.114</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>228.442</td>
<td>110</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Images obtained from increment cores and resistograph chart for each sample are overlaid and all failures were determined (Figure 3); also the possible causes of the failures were examined.

4. Results

- The preliminary results for the project show that resistograph is very promising for annual ring measurement of *P. brutia* as a practical hand tool in the field, particularly for the determination of population mean value.
- Resistograph measurement should be a straight direction intersecting pith. Any slope causes a failure for matching ring boundaries.
- Viscosity of resin in the summer period affects the efficiency of the work with the tool (Resistograph needle should be changed more frequently).
- The first part of resistograph charts (from starting point to pith) shows better synchronization with the ring boundaries than continuing part of chart (generally shows gradual increasing slope from pith to the end point, possible cause of increasing resistance).
- All defects such as cracks, decay, resin pockets affect reliability of resistograph ring measurements. The instant paper graph should be followed carefully for each measurement.

References

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