African mahogany wood defects detected by ultrasound waves

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Abstract

This study aims to investigate the potential of ultrasound wave to detect defects in 19 years old of two species of African mahogany planted in Brazil. Were used five 76 x 5 x 5 cm samples from each species with different types of defects, and were conditioned to 12% moisture content. The samples were scanned with ultrasound wave in longitudinal direction and every 2,54 cm in radial and tangential directions along the samples. It was possible to identify end split and pin knots in *Khaya ivorensis* and reaction wood in *Khaya senegalensis* wood. Beetle galleries did not affect wave velocities in *Khaya senegalensis* wood. Grain angle had a large effect in ultrasound velocities in radial and tangential directions. *Khaya senegalensis* exhibit lower longitudinal velocities related to larger amount of interlocked grain in this species. The ultrasound waves can be useful in lumber classification process in wood industry.

Keywords: *Khaya ivorensis*. *Khaya senegalensis*. Nondestructive test

Introduction

African mahogany has been an important multipurpose species in its natural range in Africa. It is valued for a range of non-timber traditional use products. *Khaya* is a genus of seven species of trees in the family Meliaceae, native from this continent and called African mahogany, the only timber widely accepted as mahogany besides the South American mahogany from genus *Swietenia* (Arnold, 2004; Robertson and Reilly, 2012).
The use of ultrasonic wave propagation as a nondestructive testing method has proved to be a viable method to characterizing wood. Research on ultrasound method has evidence the efficacy of the method to determine the mechanical properties of wood. The method was tested and significant correlations were found between nondestructive and destructive results (Karlinasari, 2006).

Detection of defects in wood by nondestructive ultrasonic methods have been investigated by many researchers with a variety of ultrasonic parameters (McDonald, 1980; Patton-Mallory and Degroot, 1990; Ross et al., 1992) showing that ultrasound method can detect defects in wood, like knots, interlocked grain, bark pockets, insect holes, splits, decay, and reaction wood.

Based on studies that showed the effects of defects change ultrasonic signal propagation in wood, this study aims to scan African mahogany (Khaya ivorensis and Khaya senegalensis) wood samples searching for variations in wood (sapwood/heartwood, grain angle, knots, and end checks reaction wood) using ultrasound waves.

**Material and Methods**

The species studied were two 19-year-old African mahogany species (Khaya ivorensis and Khaya senegalensis) from Vale Nature Reserve located in Sooretama, ES, Brazil. Five trees from each species were cut and sawed into boards. After air dry (9 month), 5x5x76 cm static bending test specimens (ASTM D143, 2005) were cut and conditioned into 12% moisture content. Six samples of Khaya ivorensis and seven samples of Khaya senegalensis showed different characteristics and defects were selected for this study.

Nondestructive testing was conducted by ultrasonic wave velocity measurements. The wave propagation was measured by Sylvatest Duo® (f=22kHz) ultrasonic device. The equipment consists in two accelerometer transducers located in opposite sides of the material that was being evaluated. The wave flows through the wood from one transducer (transmitter) to other one (receiver) and the time in microseconds is recorded by the equipment.

Twenty-eight readings of propagation times were taken at intervals of 2.54 cm along the specimen in radial and tangential directions and two readings in longitudinal direction were collected while the velocities of wave propagation in all three directions were calculated.

**Results and Discussion**

Average velocities and coefficient of variation for longitudinal, radial, and tangential directions, specific gravity and wood characteristics of the two species of African mahogany specimens are shown in Table 1.

<table>
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<th>SPECIES</th>
<th>VELOCITY (m/s)</th>
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<td>Tangential</td>
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<tr>
<td></td>
<td>4 4935</td>
<td>2351</td>
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</tr>
<tr>
<td></td>
<td>(1.96)</td>
<td>(3.09)</td>
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### Khaya senegalensis

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**Khaya ivorensis**

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<td>2237</td>
<td>1813</td>
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**Parentheses: coefficient of variance (%).**

For *Khaya ivorensis* wood samples, the average longitudinal velocities ranged from 4780 to 5170 m/s. Radial velocities ranged from 1724 to 2630 m/s and in tangential direction from 1087 to 1923 m/s. In *Khaya senegalensis* wood specimens, the longitudinal velocities ranged from 4294 to 5171 m/s. In radial direction velocities ranged from 1515 to 2940 m/s. Tangential velocities ranged from 1390 to 2380 m/s. Higher specific gravity were found in *Khaya senegalensis* wood, ranging from 567 to 795 kgm⁻³. In *Khaya ivorensis* it ranged from 486 to 566 kgm⁻³.

*K. ivorensis* sample no. 1 with a 45° grain orientation showed high tangential and reduced radial velocities (Fig. 1-a). A tangential end check was easily detected by the ultrasound techniques (higher coefficient of variation in radial velocities). Sample no. 2 with no defects showed radial velocity 47% higher than tangential velocity (Fig. 1-b). Pin knots changed tangential velocities in sample no. 3 (Fig. 1-c), but were not detected in sample no. 4 (Fig. 1-d) because there were reduced amount of defects. Sample no. 5 (Fig. 1-e) made with sapwood and heartwood had greater longitudinal velocity if compared with sapwood sample no. 6 (Fig. 1-f).

*K. senegalensis* sample no. 1 (Fig 2-a) made with sapwood had greater longitudinal velocity if compared with sapwood/heartwood sample no. 2 (Fig. 2-b) and heartwood sample no. 3 (Fig. 2-c). Reaction wood in sample no. 4 (Fig. 2-d) and no. 5 (Fig. 2-e) increased in longitudinal velocities. Beetle galleries in the same samples did not affect radial and tangential ultrasound velocities. Sample no. 6 (Fig. 2-f) showed low longitudinal velocity (interlocked grain). No defects in sample no. 7 (Fig. 2-g) showed radial velocity 28% higher than tangential velocities. Samples with 45° grain had low difference between radial and tangential velocities.
The velocities in sapwood, heartwood, reaction wood, grain angle, pin knots, and beetle galleries on ultrasound velocities for *Khaya ivorensis* wood are shown in Figure 2 and *Khaya senegalensis* wood are shown in Figure 3.

**Figure 2.** Ultrasonic measurements in *Khaya ivorensis* wood specimen: a) 45° grain + end check; b) no defects; c and, d) pin knots; e) sapwood/heartwood; f) sapwood
Figure 3. Ultrasonic measurements in *Khaya senegalensis* wood specimen: a) sapwood/heartwood; b) heartwood; c) sapwood; d) reaction wood and beetle galleries; e) 45° grain + reaction wood; f and g) no defects.

Longitudinal velocities in *K. senegalensis* wood were lower if compared to *K. ivorensis*. Interlocked grain present in *K. senegalensis* wood is the reason for reduced velocities. No correlations were found between specific gravity and longitudinal velocities for *Khaya ivorensis* ($r^2=0.02$) and a low correlation were found for *Khaya senegalensis* ($r^2=0.20$). Oliveira and Sales (2005) reported that the ultrasonic velocity tends to increase with increasing wood density. Vun et al. (2002) studying ultrasonic transmission systems for measuring OSB properties as panel density, flake alignment level, and layering structures reported high correlation between wave transmission velocity and density.

Higher longitudinal velocities were found in sapwood/heartwood in *Khaya ivorensis* and in sapwood for *Khaya senegalensis*. This may occur because adult wood has better wood properties in the sapwood/heartwood transition areas. Sapwood may be heavier than heartwood at the time of cutting the tree due to higher moisture content. However, the basic density may be less than that of heartwood because of the absence of materials that may have been infiltrated into heartwood (Panshin and De Zeeuw, 1980; Wellwood and Jurazs, 1968).
A large end split and pin knots in *Kaya ivorensis* were detected by the increasing the ultrasound time of flight. Fuller et al., (1995) concluded that defect, such as a knot, checks, and honeycomb, in a small increase in transit time tended to result in a localized increase in transit time. Sound transmission time perpendicular to the grain was significantly increased by the presence of honeycomb and surface checks in red oak lumber.

Reaction wood in *Khaya senegalensis* increased the ultrasound velocities in all three directions. The higher group velocity values in tension wood could be related to the longer fibers and to the existence of the G-layer. Bucur and Feeney (1991) reported higher sound velocity values in beech tension wood. In reaction wood and normal wood of two species, wave velocity variations were greater in the longitudinal direction than in the transverse direction.

Nondestructive tests such as those involving ultrasound have been developed to detect reaction wood (Bucur, 2003). Ultrasonic waves are affected by the anatomical structure of wood. Thus the main descriptors of ultrasonic waves (velocity, rate of energy flow, and attenuation) change during propagation. As the anatomical structure of reaction wood differs from that of normal wood, some differences may be observed in the wave descriptors (Saadat-Nia et al., 2011). The main problem associated with the quality and use of wood and timber containing reaction tissue is that their shrinkage characteristics differ from those of adjacent normal wood (Barnett and Jeronimidis, 2003).

**Conclusion**

Adult wood had greater velocities if compared to juvenile wood. It was possible to detect an end crack and pin knots in *Kaya ivorensis* wood and reaction wood in *Khaya senegalensis*. However, it was not possible to detect beetle galleries in *Khaya senegalensis* wood. Grain angle had a large effect in ultrasound velocities in radial and tangential directions for both species.

**Acknowledgments**

The authors would like to thank the USDA Forest Product Laboratory (USA), Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (Brazil), VALE S.A. (Brazil), and Universidade Federal do Espírito Santo (Brazil).

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African Mahogany (aka 'Khaya') is perhaps the most common substitute, and unlike some of the other pretenders, it is in the same botanical family as American Mahogany. But, it is not a matter of simple substitution, as African Mahogany is a group of seven related species. Four of these species are commonly found in the workshops of woodworkers—the species that tends to predominate is 'Khaya ivorensis'. All seven of the African Mahoganies are common to West Africa, particularly the Ivory Coast, Ghana, and Nigeria. This is a group that can tolerate a wide range of climactic African Mahogany is a wood that continues to grow in popularity so much so that this new millennium has seen its various species be replanted into tropical regions in Central America, as well as becoming a contemporary plantation roster addition. Depending on its origin, growth conditions and specific strain (African Mahogany encompasses four different Khaya species), its color can range from a pale pink or muted orange, to a somewhat darker reddish- or golden-brown. It can also have darker striping, and, aesthetically, it can be further enhanced through figuring (ribbon; wavy diagonal; mot Mahogany, African. 500 - 850. Mahogany, Cuban. 660. Mahogany, Honduras. 650. Mahogany, Spanish. 850. Maple. Wood Screws - Withdrawal Forces - Allowable withdrawal load force. Wood Species - Moisture Content and Weight - Weight of green and air-dried fire wood.