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Dispersion of ultrasonic waves in *Eucalyptus* lumber as a function of the geometry of boards

Dispersão de ondas de ultra-som em peças de madeira serrada de *Eucalyptus* em função da geometria

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ABSTRACT: The aim of this article is to study the ultrasonic propagation phenomena in *Eucalyptus* lumber taking into consideration the dispersion of ultrasonic waves induced by the size of boards. Two types of waves were selected: surface waves and longitudinal waves of 45kHz frequency. The boards of 2m length in air dry condition were selected to have well defined transversal sections, related to three axes of wood, longitudinal (L), radial (R) and tangential (T). The velocity of propagation of surface waves in L direction decreased as a function of propagation distance (d), wavelength λ and the ratio $d/\lambda < 5$. For higher values the velocity was constant. The polarization plane of surface waves LR or LT induced differences from 3% to 20% on the measured value of surface velocity in L direction, in tangential boards. The velocity of propagation of bulk longitudinal waves was studied on the same boards, on which by successive cuttings the section was modified. If the length of the board is variable and the section is constant, then the velocity of propagation in longitudinal direction is very much influenced by the mode conversion of pure bulk waves into surface waves. Both surface waves and bulk waves can be used for the nondestructive testing of lumber.

KEYWORDS: Ultrasonic waves, Lumber, Surface waves, Bulk waves, *Eucalyptus* spp

RESUMO: O objetivo deste artigo foi estudar o fenômeno de propagação de ondas de ultra-som em peças estruturais de madeira de *Eucalyptus*, levando em consideração a dispersão das ondas induzida pelo tamanho das peças. Dois tipos de ondas foram selecionadas: ondas de superfície e ondas de volume, ambas com frequência de 45kHz. Peças de 2m de comprimento, secas ao ar, foram selecionadas em uma serraria de maneira a apresentarem melhores condições de posicionamento dos anéis de crescimento na seção transversal, em relação aos três eixos principais da madeira, longitudinal (L), radial (R) e tangencial (T). Os resultados mostram que a velocidade de propagação das ondas de superfície na direção L varia em função da distância de propagação (d), do comprimento de onda (λ) e da relação d/λ . Para $d/\lambda > 5$ a velocidade permanece praticamente constante, no entanto, para $d/\lambda < 5$ a velocidade diminui. A polarização das ondas de superfície nos planos LR ou LT induziu a diferenças de 3% a 20% nas medidas dos valores de velocidade na direção L em pranchas tangenciais. As velocidades de propagação das ondas longitudinais de volume foram estudadas nas mesmas peças enquanto cortes sucessivos eram realizados para modificar a seção transversal. Se o comprimento das peças é variável e a seção é constante, a velocidade de propagação na

direção longitudinal é bastante influenciada. Este fenômeno pode ser explicado pela conversão da onda de volume pura em onda de superfície. Tanto as ondas de superfície quanto as ondas de volume podem ser utilizadas para avaliar peças estruturais de madeira pelo método não destrutivo.

PALAVRAS-CHAVE: Ondas de ultra-som, Madeira serrada, Ondas de superfície, Ondas de volume, *Eucalyptus* spp

INTRODUCTION

Lumber grading by nondestructive tests is of major interest for timber industry. These methods were initiated by Bell et al. (1950), Galiginaitis et al. (1954), Jayne (1955, 1959), James (1959), Hoyle (1961).

Probably the most important improvement to consolidate the nondestructive tests was made by Jayne (1959), who established the relationship among nondestructive parameters and mechanical properties of materials.

More recently works of Waubke (1988), Sandoz (1993 and 1998) and Steiger (1996) demonstrated the validity of ultrasonic methods for the classification of wood lumber. Waubke (1988) and Sandoz (1998) tested several beams of fichte and spruce, respectively, with static destructive method (static bending) and with dynamic non-destructive method (ultrasonic). Starting from the results, they proposed correlation between the destructive and non-destructive methods. These correlations were used for their proposition of a new manner of lumber classification using ultrasonic waves velocity.

Data related to the evaluation of tropical lumber by ultrasonic velocity method were published by Bartholomeu et al. (1998) and Gonçalves and Bartholomeu (1999). Strong correlations were deduced between the velocities of propagation of ultrasonic waves in L direction with the mechanical parameters deduced on standard specimens, as prescribed by the procedure described by the Brazilian standard NBR 7190/97 (ABNT, 1997).

Ultrasonic waves propagation in lumber of different size (length, width and thickness) are influenced by the dispersion phenomena. The dispersion phenomena can be studied with bulk waves and with surface waves. Bucur (1995) discussed the influence of specimen length and specimen cross-section on longitudinal wave velocities measured for spruce. For her experiment, the longitudinal wave velocity was strongly and continuously affected by the ratio width versus thickness with constant length. For the experiment with constant width and thickness the wave velocity was nearly constant when the ratio length versus width was varied from 20 to 40. Below this limit the longitudinal velocity diminishes.

It is very important for the improvement of ultrasonic researches the knowledge of how the velocity is affected by geometric parameters of wood – length, width and thickness.

The aim of this paper is to study the dispersion phenomena of ultrasonic waves in *Eucalyptus* boards of commercial size using surface and bulk waves.

MATERIAL AND METHOD

Four *Eucalyptus* boards of commercial size at approximately 12% moisture content were selected from the normal production of a sawmill at Itatiba, São Paulo State, in Brazil. The boards were 2 m long with well-defined transversal section, two in radial plane and two in tangential plane (Figure 1). The sections were between (0.05 m x 0.07 m) to (0.05 m x 0.14 m).

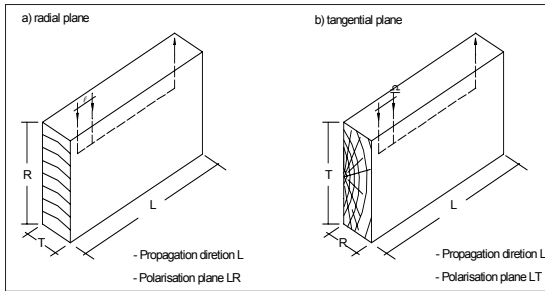


Figure 1

Propagation mode of surface waves in L direction, on a radial and on a tangential board.

(Modos de propagação das ondas de superfície na direção L, em tábuas radial e tangencial)

Two types of waves were studied: surface waves and bulk waves, both propagating in L direction. The polarization directions of surface waves were in LR and LT planes, depending on the transversal section of the board.

Ultrasonic portable apparatus BP7, produced by Steinkamp Ltd. was used. The apparatus was equipped with 45 kHz transducers for bulk longitudinal waves. The surface waves were produced by mode conversion of longitudinal waves at the surface of the sample (Bucur, 1995). Figure 1 shows the propagation mode of surface waves in L direction, on a radial and on a tangential board. The surface velocity was measured for different distances (d) between the two transducers, variable from 0.2 m to 2 m with constant cross section. In the next step the surface velocity was measured for constant length and variable cross section, produced by successive planing of the boards (Figure 2).

The same methodology was used for bulk waves. The velocity of propagation of bulk waves V_{LL} was measured in a board of variable length and constant section, obtained by successive cross cuttings of 0.2 m (Figure 3).

Initially the board can be considered an infinite solid. At the end of the experiment the board was transformed into a plate, favoring the propagation of surface waves.

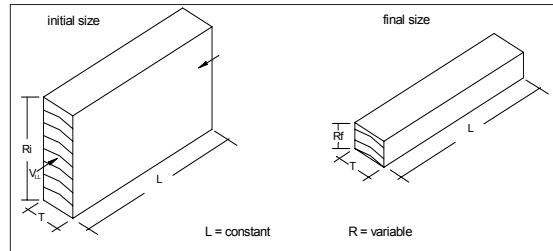


Figure 2

Representation of board with constant length and variable cross section, produced by successive planing of the boards

(Representação da tábua com comprimento constante e seção variável, produzida por cortes sucessivos).

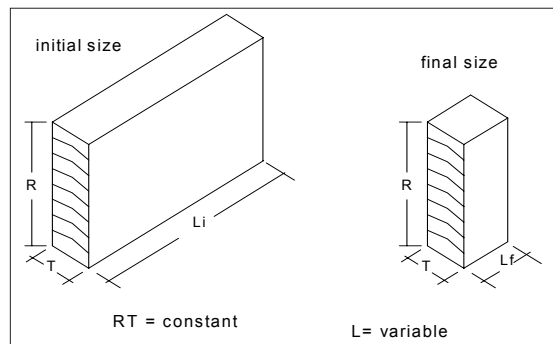


Figure 3

Representation of board with variable length and constant section, obtained by successive cross cuttings of 0.2 m it one.

(Representação da tábua com comprimento variável e seção transversal constante, obtida por cortes sucessivos de 0,2m cada).

RESULTS AND DISCUSSIONS

The propagation of surface waves is shown in Figure 4a and b. To assist the understanding of dispersion phenomena, the variation of the velocity was expressed as a function of the ratio: distance of propagation versus the wavelength. The wavelength (λ) was deduced from the velocity of propagation of a bulk wave V_{LL} on a 2 m board long, of (0.05 m x 0.14 m) cross section and it was considered that this board satisfies the conditions of an infinite solid.

The velocity of surface wave depends of the polarization plane. Generally, the polarization

plane LR produced velocities higher than the velocities polarized in LT plane (Table 1). The difference is between 3% and 20% and depends on the ratio d/λ . A possible explanation of higher values of velocity is related to the presence of medulary rays, well oriented and well organized in LR plane.

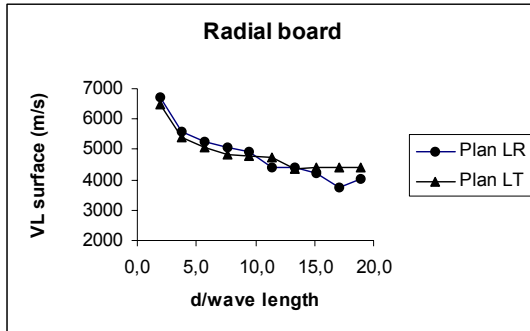


Figure 4a
Surface wave velocity as a function of the ratio distance of measurement, wave length, d/λ . Radial board (Velocidade de ondas de superfície em função da relação entre a distância da medição e o comprimento de onda, d/λ . Tábua radial).

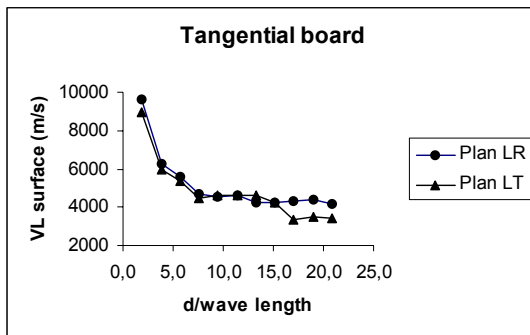


Figure 4b
Surface wave velocity as a function of the ratio distance of measurement wave length, d/λ . Tangential board (Velocidade de ondas de superfície em função da relação entre a distância da medição e o comprimento de onda, d/λ . Tábua tangencial).

Figure 5 shows the variation of the reduced velocities V_{LL}/V_{LLi} and V_{TT}/V_{TTi} in a board of

constant length of 2 m length and of variable cross section from 0,07 m to 0,0075 m, where the velocity V_{LL} or V_{TT} are the velocities for the highest ratio of the size of transversal section R/T. The reduced values of velocities in L direction is constant if the size ratio $R/T > 0.3$ and in T direction if $R/T > 0.75$. It can be noticed that these velocities are also influenced by the modification of the geometry of the specimen, induced by successive planing of boards.

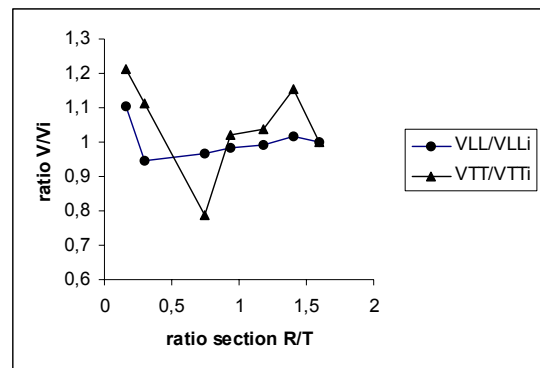


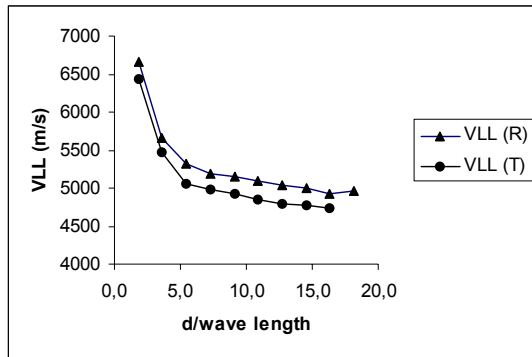
Figure 5
Reduced bulk waves velocity V_{LL}/V_{LLi} and V_{TT}/V_{TTi} on boards of constant length and variable section (Relação de ondas de volume V_{LL}/V_{LLi} e V_{TT}/V_{TTi} nas tábuas com comprimento constante e seção variável)

Figure 6 shows the variation of V_{LL} on a specimen of variable length and constant section. The mode conversion from bulk wave to surface wave can be observed for $d/\lambda > 5$. In this range, the distance of measurement has a minor influence in the velocity propagation of surface waves than that of bulk waves. It can be accepted that the surface waves were converted in bulk waves of the same velocity. The statistical analysis of the results (Figure 7) shows a high correlation coefficient ($r=0.89$) between the velocities of surface waves and of bulk longitudinal waves propagating in L direction.

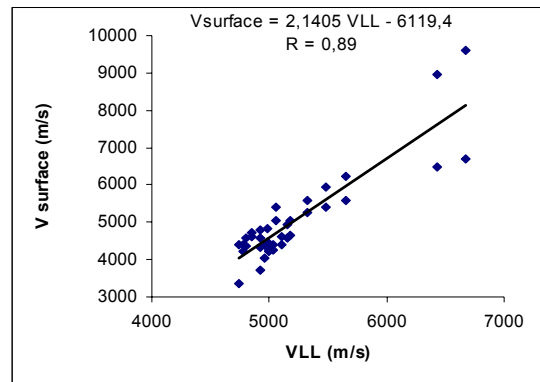
Table 1

Ultrasonic surface wave propagating in L direction and polarizing in LR and LT planes
 (Ondas superficiais de ultra-som com propagação na direção L e polarização nos planos LR e LT)

Distance Of Measurement (d) (10 ⁻² m)	d/λ	Radial board L=2,08 m; R=7,1 10 ⁻² m; T=4,7 10 ⁻² m		Tangential board L=2,20 m; R=5,5.10 ⁻² m; T=13,8 10 ⁻² m	
		Polarization		Polarization	
		Plane LR	Plane LT	Plane LR	Plane LT
200	20.9	4137	3449	4028	4395
180	19.0	4399	3527	3727	4406
160	17.1	4334	3358	4211	4385
140	15.2	4249	4232	4399	4361
120	13.3	4264	4593	4387	4737
100	11.4	4599	4612	4921	4796
80	9.5	4568	4587	5057	4842
60	7.6	4659	4489	5244	5059
40	5.7	5576	5390	5586	5398
20	3.8	6240	5961	6711	6493


Figure 6

Bulk wave velocity V_{LL} on boards of variable length and constant transversal section, as a function of d/λ .
 (Velocidade das ondas de volume VLL nas tábuas de comprimento variável e seção transversal constante, em função de d/λ).


Figure 7

Correlation between the velocities of surface waves and of bulk longitudinal waves propagating in L direction.
 (Correlação entre as velocidades das ondas de superfície e de volume na direção Longitudinal)

CONCLUDING REMARKS

The study of dispersion phenomena induced by the geometry of the specimen underlined the limiting conditions for the velocities measured on *Eucalyptus* boards. The measurement of velocity in L direction can be performed with bulk waves as well as with surface waves, if the ratio $d/\lambda > 5$. Also, the ratio of the cross section R/T is recommended to be higher than 0.3 for V_{LL} and than 0.75 for V_{TT} . The ultrasonic velocities

of bulk and surface waves can be used for the grading of boards and also for the nondestructive evaluation of the corresponding mechanical parameters. It is very important the observance of the measurement distance (L) related with wavelength (λ) because this ratio affect the velocity of propagation on both bulk and surface waves. If this ratio is not observed we can obtain values of velocity that are affected and we can loss the accuracy of the method.

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