STIFFNESS VARIATION OF PEELED VENEER FROM *Acacia mangium*, Acacia hybrid *(A. mangium* x *A. auriculiformis)* AND *Eucalyptus urophylla*

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SUMMARY

In this study, three Vietnamese common plantation species *Acacia mangium,* Acacia hybrid (*A. mangium x A. auriculiformis*) and *Eucalyptus urophylla* in total nine sites (three sites per species) were selected. Each site had a different silvicultural or age regime including trees of the appropriate age/size class to meet the requirements for veneer production. The largest trees were used for peeling veneer with dimensions were 2.8 mm thick × 1.3 m (same as log length) × 0.95 m. Acoustic stiffness determination was performed on the 2.8 mm thick × 1.15 m (same as log length) × 15 cm strips after they were air-dried to approximately 15% MC. The mathematical processing of selected frequencies is made from the geometrical characteristics and the weight of the strips. Dynamic MOE of Acacia hybrid veneer increased steadily with the radius before stabilising to an approximate average value of 14,100 MPa; MOE stabilisation begins at a radial distance of approximately 85 mm from the pith indicating that the mature state of wood starts from this point. Dynamic MOE of *Acacia mangium* veneer increased steadily with radius with no apparent trend of stabilisation detected in the outer part of the logs; this indicates that the mature state is not yet reached. Similarly, for *Eucalyptus urophylla*, the MOE values indicates that the mature state had not yet been reached due to the appearance of no stabilisation trend. The most apparent observation was *Eucalyptus urophylla* superiority in terms of veneer MOE (maximum 15,200 MPa). Both acacia species have similar maximum veneer MOE values around 13,500 MPa. *Acacia mangium* was shown to have a relatively long or late transition from juvenile to mature wood compared with the other two species, thus producing a relatively higher proportion of low stiffness material. Characterising veneer stiffness with square of radius position is also discussed in the paper.

Keywords: Acacia, acoustic, eucalyptus, MOE, veneer.

1. INTRODUCTION

The Vietnam furniture industry now constitutes one of the key export staples in the national economy. Vietnam exported wooden furniture and other wood products up from US$ 2.4 billion in 2007 to US$ 9.4 billion in 2018 (MARD, 2019). This phenomenal growth, coupled with domestic supply restrictions, has driven an equally rapid rise in Vietnam's timber imports. A significant constraint to continued expansion is wood supply, and Vietnam imports more than 80% of its wood requirements. Moreover, changes in these markets in response to growing demand for legal wood products from governments, retailers, and consumers puts pressure on Vietnamese exporters and creates uncertainty around future market access. Thus a major challenge facing Vietnamese wooden furniture export companies is obtaining from sources that are both legal and sustainable. The expanding plantation estate now includes over 1 million ha of acacias, and some 500,000 ha of eucalypts. Although Vietnam's acacia and eucalypt plantations have been established primarily for the production of pulpwood, there is increasing use of this resource for the production of sawn timber. For this base product, production plantations require a minimum rotation of 10 years compared with 4 years for pulp and paper, which offer a quicker and more attractive cash flow. Meanwhile, plantation timber quality is declining because of excessive demand and early harvesting of juvenile trees. Whereas trees of 25 cm diameter were once common, only trees with 20 cm diameter and less are now available; the smallest diameter that can be used to make solid wood based furniture is approximately 18 cm. New technologies to produce veneer (traditionally produced from natural forest and imported timbers) don't require logs as big as those for sawn timber giving rise to an emerging interest in the production of veneer from the plantation resource. Both acacias and eucalypts have demonstrated applicability to the production of veneer, log and wood quality permitting (Redman et al., 2016).

In the study of McGavin *et al*. (2015), peeled veneers resulting from processing trials of six commercially important Australian hardwood species were used to determine key wood properties (i.e., density, dynamic modulus of elasticity (MOE); the results revealed that a wide variation of properties existed between species and also within species; simple mathematical modelling, using sigmoidal curves, was demonstrated to be an effective method to model the evolution of key wood properties across the billet radius and along the veneer ribbon with benefits for tree breeders and processors. According to Brancheriau and Bailleres (2003), acoustic measurements could be performed for non-destructive evaluation of strength properties of structural timber beams. Direct use of spectra as predictive variables to estimate MOR (modulus of rupture) and MOE in both edgewise and longitudinal vibration was the main feature of the method. Predicting the material characteristics of wood through non-destructive timber (NDT) techniques is vital for the timber industry and has a long history of application (Halabe *et al*., 1995). Moreover, the use of structural components is generally under standard applications which define the performance of the product with regard to its purpose (Bailleres *et al*., 2009).

The objective of this study was to describe dynamic modulus of elasticity (MOE) of veneer recovered from three Vietnam common plantation wood *A. mangium*, *Acacia* hybrid *(A. mangium × A. auriculiformis)* and *E. urophylla* based on variation from pith to bark (across the log radius). Sigmoidal curves were used to describe these characteristics. Dynamic MOE of veneer is a main factor in determining the suitability of veneer for structural veneer-based engineered wood products. The study results provide guidance on the quality of current plantation resources for structural product end-uses and plantation management.

2. RESEARCH METHODOLOGY

Plantation resource and veneer processing

Three Vietnamese plantation species selected for this work were: *Acacia mangium* (6-14 years), Acacia hybrid (*A. mangium* x *A. auriculiformis*) (7-11 years) and *Eucalyptus urophylla (11-19 years),* harvested in Cau Hai, Phu Tho and Ba Vi, Ha Noi. In total nine sites, three per species were chosen for the study. Each site had a different silvicultural or age regime including trees of the appropriate age/size class to meet the requirements for veneer production. Details of each trial site including species, age, location, stocking rate, silvicultural history, soil type, elevation and slope were described in a previous work (Trinh and Redman, 2018).

In each site, the number of trees chosen was sufficient to produce 20-30 billets 1.3 m long with small-end diameters over 130 mm. Merchantable 1.3 m long billets met the minimum form requirements such as: straightness, small end over-bark diameter no less than 130 mm, along with an absence of ramicorns, double leaders, major branches and visible external injuries. Billets were peeled using a Ming Feng brand lathe to produce veneers with a target green thickness of approx. 2.8 mm until a core diameter of approximately 40 mm was attained. During peeling a guillotine was used to clip 1,300 mm (length) x 950 mm (width) veneer sheets. Veneer sheets were divided into two sections such that 150 mm wide strips were removed from the veneer edge closest to the outside of the billet, leaving veneer sheets with width 800 mm. These strips were labelled the same as the original veneer sheet, wrapped in impermeable plastic and transported to the Vietnam National University of Forestry (VNUF) laboratory for stiffness (BING), moisture content, basic density and shrinkage measurements. A 150 mm x 150 mm section was removed from veneer strips for moisture content, basic density and shrinkage measurements. The remaining 150 mm x 1,150 mm strips were used for stiffness (BING) assessment (Figure 1). Quantity of BING samples for each species per site range from 100-300 strips.

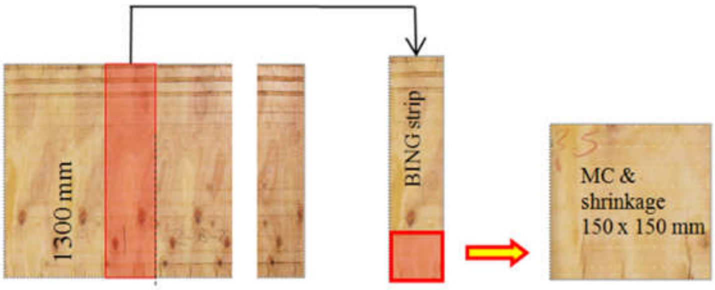

Figure 1. BING strip samples for stiffness (dynamic MOE) assessment

Veneer stiffness (dynamic MOE) assessment

Acoustic stiffness grading was performed on the 1,150 mm x 150 mm strips after they were air-dried to approximately 15% MC. Dimensions (length, width, thickness) and mass (grams) of samples were measured before being positioned on two elastic supports so that the longitudinal propagation of vibration is as free as possible and can be induced by a simple percussion on one end in the grain direction. At the other end, a Lavalier type microphone recorded the vibrations and transmitted them via an anti-aliasing filter (low-pass) to an acquisition card including an analogue-to-digital converter which sends a digitised signal to a computer (Figure 2). A Fast Fourier Transform processed the signal to convert the information from the time to the frequency domain. The mathematical processing of selected frequencies was undertaken using BING (Beam Identification using Non-destructive Grading) software in combination with the geometrical characteristics and the weight of the specimen, to provide the dynamic MOE, among other specific mechanical characteristics. Previous studies have shown, through comparative tests, a very good stiffness correlation between this type of acoustic testing and conventional quasi-static transversal tests (3 and 4 point-bending) on wood samples of all sizes, with and without defect (Brancheriau and Bailleres, 2002).

(a)

(b)

(c)

(d)

Figure 2. Veneer stiffness testing: dimension (a) and weight measurements (b), BING set-up (c), BING test (d)

3. RESULTS AND DISCUSSION

3.1. Veneer stiffness variation across the log radius

The way to model the variation of wood properties from pith to bark has been extensively studied (Downes et al., 1997). Different approaches based on mathematical parametric or non-parametric fitting, have been explored.

The relatively simple approach adopted is to model the variation of MOE from pith to bark due to the transition from juvenile to mature wood based on a sigmoidal function fitting.

A sigmoid function is a mathematical function having an "S" shape (sigmoid curve). Often, sigmoid function refers to the special case of the logistic function defined by the formula:

$$S(t) = \frac{1}{1+e^{-t}} \qquad (1)$$

A sigmoid function is a bounded differentiable real function that is defined for all real input values and that has a positive derivative everywhere (http://en.wikipedia.org/wiki/Sigmoid_function).

It is used in modelling systems that saturate at large values of ‘t’. A wide variety of sigmoid functions have been used as the activation function of artificial neurons, including the logistic and hyperbolic tangent functions. Many natural processes, including those of complex system learning curves, exhibit a progression from small beginnings that accelerates and approaches a climax over time. When a detailed description is lacking, a sigmoid function is often used.

In general, a sigmoid function is real-valued and differentiable; having either a non-negative or non-positive first derivative which is bell shaped. There is also a pair of horizontal asymptotes which provide the lowest and the highest Y values when X tends to infinity. In our case this is a convenient way to model MOE variation from pith to bark since it tends to increase with increase in diameter due to cambial activity.

The sigmoid fitting is:

$$y = a + \frac{b}{\left(1+e^{\frac{-(x-c)}{d}}\right)} \qquad (2)$$

With:

Transition height: b;

Transition centre: c;

Transition width: 2.197224578*d;

Constraints: d<>0;

Asymptote: a.

Figure 3 to 5 show the veneer MOE versus the radial distance, for each species, from the log centre calculated from the actual position of the veneer in the ribbon and its average thickness. The plots use combined data from the three plantations observed for each species. This representation provides a standard variation of veneer MOE at a given age of the plantation. The red curve in the plots shows the sigmoid curve fitting.

The noticeable observation from the plots is the wide spread of the individual veneer MOE along the radius that can be explained by the impact of knots, the local and global grain angle as well by the deviation between the position of the pith and the rotational axis of peeling. Depending on the extent of this deviation, the veneer at the same distance from the rotational axis can be more or less close to the pith, in other words more or less in juvenile wood.

Acacia hybrid veneer MOE increased steadily with the radius before stabilising to an approximate average MOE of 14,100 MPa. MOE stabilisation begins at a radial distance of approximately 85 mm from the pith indicating that the mature state of wood starts from this point.

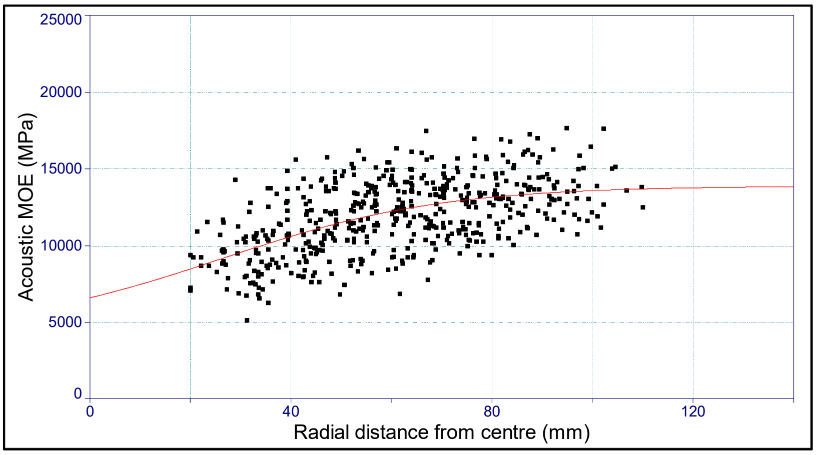

Figure 3. Variation of *Acacia* hybrid veneer MOE with radius position

(The curve in the plot shows the sigmoid curve fitting)

Acacia mangium veneer MOE increased steadily with radius with no apparent trend of stabilisation (asymptote) detected in the outer part of the logs. This indicates that the mature state is not yet reached.

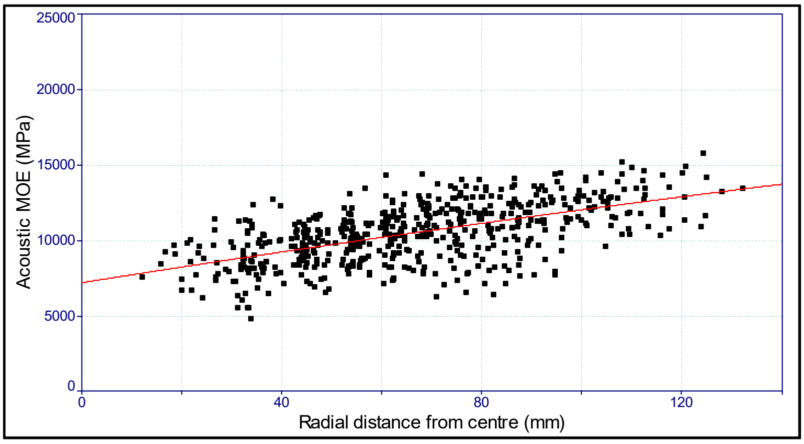

Figure 4. Variation of *Acacia mangium* veneer MOE with radius position

(The curve in the plot shows the sigmoid curve fitting)

Similarly, for *Eucalyptus urophylla*, the fitted sigmoid function indicates that the mature state had not yet been reached due to the appearance of no stabilisation trend. However, closer inspection of the data shows a somewhat tapering off at the outer part of the logs which seems to be overridden by the strength of the scattered veneer MOE data at lower radial distances.

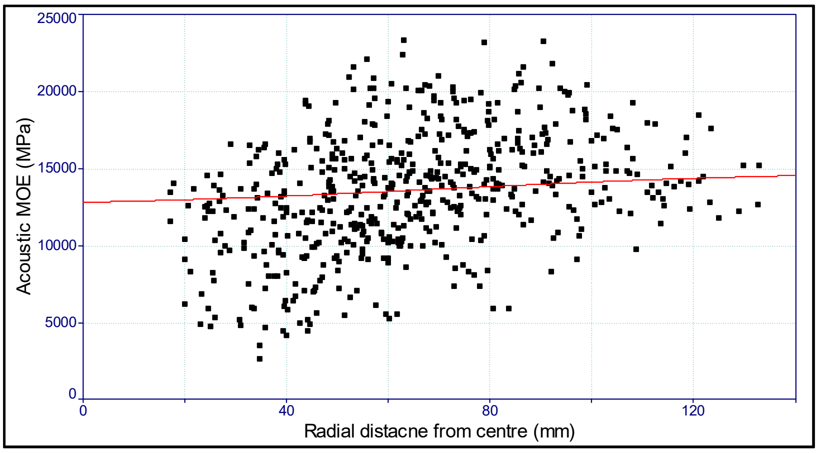

Figure 5. Variation of *Eucalyptus urophylla* veneer MOE with radius position

(The curve in the plot shows the sigmoid curve fitting)

3.2. Veneer stiffness variation across the square of the log radius (R^2)

Characterising wood properties in logs against their radial distance from the pith is a commonly used method for providing industry with typical wood quality information in regards to growth trends. However, the use of radial distance does not accurately represent the 'volume' of material possessing a particular property or quality observed in the veneer processing industry. This is because the volume of a log is directly correlated to the square of the radial distance from the pith (R^2). Another way to express this is if you double the radius of a log the volume is quadrupled.

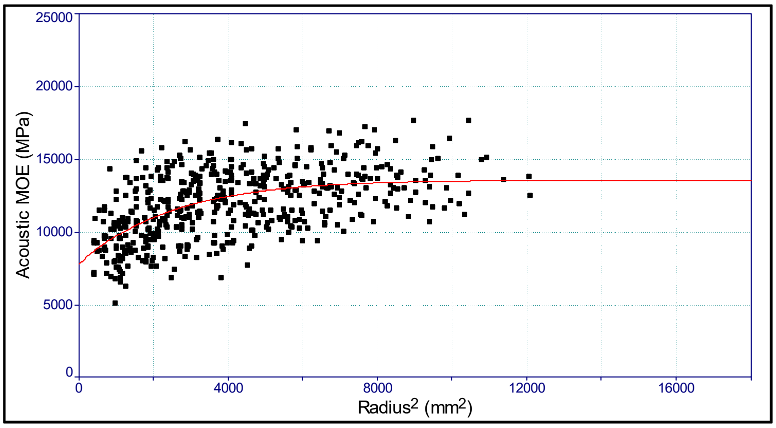

Figure 6. Variation of *Acacia* hybrid veneer MOE with square of radius position (R^2)

(The curve in the plot shows the sigmoid curve fitting)

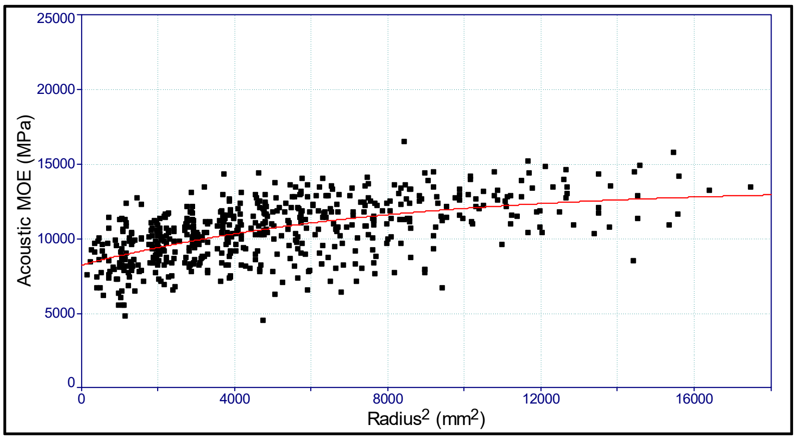

Figure 7. Variation of *Acacia mangium* veneer MOE with square of radius position (R^2)

(The curve in the plot shows the sigmoid curve fitting)

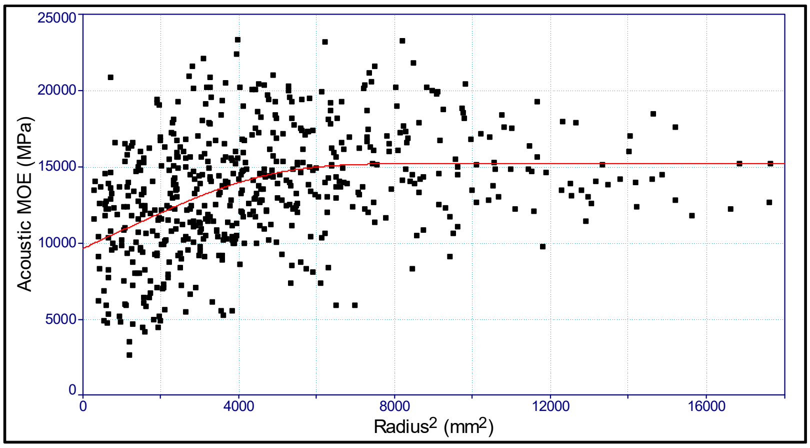

Figure 8. Variation of *Eucalyptus urophylla* veneer MOE with square of radius position (R^2)

(The curve in the plot shows the sigmoid curve fitting)

Figure 6 to 8 show the same veneer MOE data against the square of the radial distance (R^2) for each species. These figures provide good indication of the stiffness trend in terms of volume of material produced in industry. Sigmoid curves for each species are all asymptotic, stabilising to a maximum MOE, the expected nature of all wood species.

Figure 9 shows the sigmoid curve fitting for all species and age classes. The convenient representation gives at a glance, the pattern of MOE variation along the radius. Table 1 provides the sigmoid curve fitting parameters for all species.

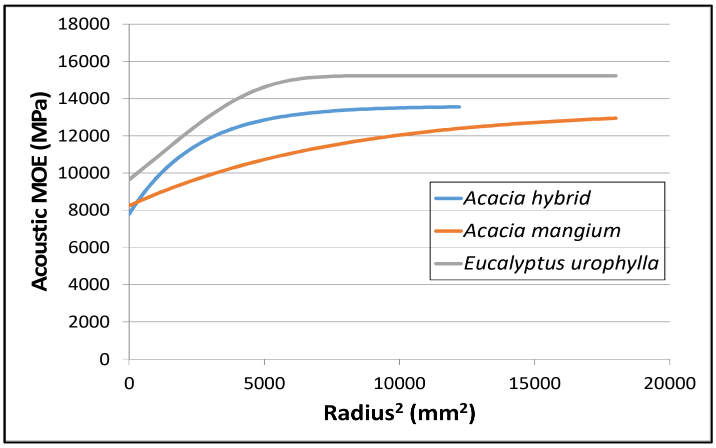

Figure 9. Variation of veneer MOE along the square of radius position between species from sigmoid curve fitting

Table 1. Sigmoid parameters from acoustic MOE curve fitting versus R^2 and radius for each species

Species	Age (years)	MOE pith (MPa)	Max MOE (MPa)	Asymptote	MOE (MPa) Transition height	Radius²/radius (mm²/mm) Transition centre
A. hybrid	7 - 11	7,800	13,600	Yes	5,800	2,400/50
A. mangium	6 - 14	8,200	13,400	Yes	5,200	7,000/84
E. urophylla	11 - 19	9,600	15,200	Yes	5,600	3,600/60

The most apparent observation is the *Eucalyptus urophylla* superiority in terms of veneer MOE (maximum 15,200 MPa). Both acacia species have similar maximum veneer MOE values around 13,500 MPa. *Acacia mangium* has a relatively long or late transition from juvenile to mature wood compared with the other two species, thus producing a relatively higher proportion of low stiffness material.

These curves provide the potential MOE recovery for each species and the proportion of juvenile to mature wood in relation to log radius. The results highlight that improved MOE recovery, in terms of material volume, occurs for larger diameter logs with low radius juvenile cores.

4. CONCLUSIONS

Acacia mangium has a relatively long or late transition from juvenile to mature wood compared with the other two species, thus producing a relatively higher proportion of low stiffness material.

Average veneer stiffness tends to increase with increasing age for each species before plateauing around 14 years of age. *Eucalyptus urophylla* was significantly stiffer than the acacia species at 11 and 14 years of age indicating its greater potential to be used for structural purposes.

The generation of veneer stiffness in relation to the square of the log radius curves provided the potential MOE recovery for each species and the proportion of juvenile to mature wood in relation to log volume. The most apparent observation was *Eucalyptus urophylla* superiority in terms of veneer MOE with maximum 15,200 MPa. Both acacia species have similar maximum veneer MOE values around 13,500 MPa. *Acacia mangium* was shown to have a relatively long or late transition from juvenile to mature wood compared with the other two species, thus producing a relatively higher proportion of low stiffness material. The results highlighted that improved MOE recovery, in terms of material volume, occurs for larger diameter logs with small radius juvenile cores.

Acknowledgements

The authors acknowledge in-kind support of all collaborators involved in the project and funding provided by the Australian Centre for International Agricultural Research (ACIAR), Canberra, Australia.

REFERENCES

1. Adam Redman, Henri Bailleres, Gary Hopewell, (2016). *Final report - Enhancement of veneer products from acacia and eucalyptus plantations in Vietnam and Australia*, the ACIAR project FST/2008/039.

2. Brancheriau, L. and Bailleres, H. (2002). Natural vibration analysis of clear wooden beams: a theoretical review. Wood-science-and-technology. Volume 36(5): 367-383.

3. Downs, G.M.,Hudson, I.L., Raymond, C.A., Dean, G.H., Mitchell, A.J., Schimleck, L.R., Evans, R. and Muneri, A. (1997). *Sampling Plantation Eucalypts for Wood and Fibre Properties*, CSIRO Publishing, Collingwood, Victoria, Australia.132 pp.

4. Loic Brancheriau and Henri Bailleres (2003). *Use of the partial least squares method with acoustic vibration spectra as a new grading technique for structural timber,* Holzforschung, Volume 57(6): 644-652.

5. Ministry of Agriculture and Rural Development (2019). *Wood product processing industry, wood and forest product export in 2018 – success, exprerient lesson, breakthrough solution for 2019*.

6. Halabe, U.B., Bidigalu G.M., Ganga Rao H.V.S and Ross R.J. (1995). *Nondestructive evaluation of green wood using stress wave and transverse vibration techniques,* Volume 55 (9).

7. H. Bailleres, G. Hopewell and G. Boughton (2009). *MOE and MOR assessment technologies for improving graded recovery of exotic pines in Australia,* Forest and Wood products Australia.

8. Robert L. McGavin, Henri Bailleres, Joh Fehrmann and Barbara Ozarska, (2015). *Stiffness and density analysis of rotary veneer recovered from six species of Australian plantation hardwoods*, Bioresources, Volume 10 (4): 6395-6416.

9. Trinh Hien Mai, Adam Redman (2018). *Characterisation of plantation acacias and eucalypts for veneer production in Vietnam,* Journal of Forest Science and Technology, Vietnam National University of Forestry, ISSN 1859-3828, Volume 5:127-135.

BIẾN ĐỘNG VỀ MODUL ĐÀN HỒI CỦA VÁN BÓC GỖ KEO TAI TƯỢNG, KEO LAI VÀ BẠCH ĐÀN UROPHYLLA

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TÓM TẮT

Trong nghiên cứu này, 3 loại gỗ rừng trồng phổ biến ở Việt Nam gồm: Keo tai tượng (*Acacia mangium),* Keo lai (*A. mangium x A. auriculiformis*) và Bạch đàn Uro (*Eucalyptus urophylla)* trong 9 ô tiêu chuẩn (3 ô tiêu chuẩn/loài) đã được lựa chọn. Mỗi ô tiêu chuẩn có các điều kiện lâm sinh hoặc độ tuổi khác nhau, gồm các cây gỗ có độ tuổi/kích thước phù hợp cho sản xuất ván bóc. Các cây gỗ lớn được sử dụng để bóc ván với kích thước ván: dày 2,8 mm, dài 1,3 m (cùng chiều thớ gỗ), rộng 0,95 m. Việc xác định modul đàn hồi của ván (dynamic MOE) bằng phương pháp âm thanh đã được thực hiện trên thanh ván có kích thước: dày 2,8 mm, dài 1,15 m (cùng chiều thớ gỗ), rộng 15 cm sau khi hong phơi tự nhiên tới độ ẩm trung bình 15%. Quá trình xử lý toán học của các tần số âm thanh để nhận được trị số MOE của ván được thực hiện dựa vào đặc điểm hình học và khối lượng ván. MOE của ván bóc từ gỗ Keo lai tăng dần theo phương bán kính trước khi ổn định ở giá trị xấp xỉ 14.100 MPa; trị số MOE ổn định ở khoảng bán kính xấp xỉ 85 mm từ tủy cho thấy trạng thái “trưởng thành” của gỗ bắt đầu từ điểm này. MOE của ván bóc từ gỗ Keo tai tượng tăng dần theo phương bán kính và không có xu hướng “ổn định” ở phần ngoài của khúc gỗ; điều này cho thấy trạng thái “trưởng thành” chưa đạt tới. Tương tự như vậy, gỗ Bạch đàn Uro cho thấy trạng thái “trưởng thành” chưa đạt tới do không có xu hướng ổn định của trị số MOE. Kết quả nghiên cứu cho thấy ván bóc gỗ Bạch đàn Uro có giá trị MOE đạt cao nhất (tối đa 15.200 MPa); cả hai loài gỗ keo có trị số tối đa của MOE tương đương nhau, khoảng 13.500 MPa. Gỗ Keo tai tượng cho thấy sự chuyển dịch từ trạng thái “non” sang “trưởng thành” khá chậm so với 2 loại gỗ còn lại, do đó tạo ra tỷ lệ cao hơn của vật liệu có độ cứng thấp. Trị số MOE theo bình phương của bán kính cũng được thảo luận chi tiết trong bài báo này.

Từ khóa: Âm thanh, bạch đàn, keo, MOE, ván bóc.

Received	**: 11/3/2019**
Revised	**: 26/4/2019**
Accepted	**: 03/5/2019**