Characteristics of lathe check and surface roughness of fast growing wood veneers and their performance on laminated veneer lumber

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CHARACTERISTICS OF LATHE CHECK AND SURFACE ROUGHNESS OF FAST GROWING WOOD VENEERS AND THEIR PERFORMANCE ON LAMINATED VENEER LUMBER

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Bogor, August 2016

Istie Sekartining Rahayu

RINGKASAN

ISTIE SEKARTINING RAHAYU. Karakteristik Retak Kupas and Kekasaran Permukaan Finir Kayu Cepat Tumbuh dan Pengaruhnya terhadap Laminated Veneer Lumber. Di bawah bimbingan I WAYAN DARMAWAN, NARESWORO NUGROHO dan REMY MARCHAL

Penanaman hutan tanaman untuk memenuhi kebutuhan kayu masyarakat, telah menghasilkan kayu cepat tumbuh. Kayu tersebut mengandung porsi kayu *juvenile* yang memiliki sifat-sifat yang inferior. Pada saat yang bersamaan perkembangan produk komposit kayu berupa *laminated veneer lumber* (LVL) juga berkembang dengan pesat. Oleh karena itu, dalam rangka meningkatkan nilai tambah penggunaan kayu-kayu cepat tumbuh, penelitian tentang pengaruh kayu *juvenile* terhadap kekuatan lentur dan keteguhan rekat LVL sangat diperlukan. Tujuan penelitian ini adalah 1) menentukan titik demarkasi/umur transisi antara kayu *juvenile* dan kayu dewasa pada sengon (*Falcataria moluccana*), jabon (*Anthocephalus cadamba* Miq.), poplar (*Populus* sp) dan douglas fir (*Psedotsuga menzii*); 2) menganalisa pengaruh kayu *juvenile* terhadap retak kupas, kekasaran permukaan dan keterbasahan; 3) menganalisa pengaruh retak kupas dan kayu *juvenile* terhadap keteguhan rekat dan lentur *laminated vener lumber* (LVL); dan 4) menggunakan model analitik baru untuk menentukan variasi nilai MOE (*Modulus of Elasticity*) spesifik LVL dari arah empulur ke kulit.

Berdasarkan panjang serat, titik demarkasi antara *juvenile* dan dewasa kayu sengon adalah pada *segmented ring* 17 (diameter 34 cm) dan untuk jabon pada *segmented ring* 24 (diameter 48 cm). Berdasarkan panjang serat, umur transisi kultivar poplar dan douglas-fir, masing-masing terjadi antara umur 12 tahun dan antara umur 18 tahun.

Hasil penelitian menunjukkan bahwa bagian kayu dekat empulur baik pada kayu sengon dan jabon menghasilkan finir dengan frekuensi retak kupas tinggi, permukaan finir kasar dan keterbasahan tinggi, sedangkan pada bagian kayu dekat kulit menghasilkan finir dengan frekuensi retak kupas yang rendah, permukaan lebih halus dan keterbasahan rendah. Perlakuan perebusan sebelum pengupasan terbukti dapat meningkatkan kualitas finir sengon dan jabon baik pada bagian kayu dekat empulur maupun dekat kulit. Perebusan pada temperatur 75°C selama 4 jam, menghasilkan finir dengan frekuensi retak kupas terendah, permukaan finir halus namun keterbasahan tinggi.

Keteguhan rekat, MOE spesifik (SMOE) dan modulus patah (MOR) spesifik LVL sengon dan jabon menurun seiring dengan meningkatkan frekuensi retak kupas atau nilai-nilai kekuatan tersebut meningkat dari arah empulur ke kulit. Finir hasil perebusan pada temperatur 75°C selama 4 jam yang direkat menggunakan *layout* tipe II (pada permukaan *loose* dengan *loose*) dapat meningkatkan nilai keteguhan rekat, SMOE dan SMOR LVL sengon dan jabon. Penggunaan finir yang berasal dari poplar dewasa terbukti dapat meningkatkan keteguhan lentur LVL sebesar 15-20%, sedangkan pada LVL douglas-fir dapat meningkatkan keteguhan lentur sebesar 7-22%.

Model analitik dapat menentukan nilai variasi spesifik MOE LVL dari arah empulur ke kulit. Model ini mengggunakan parameter kerapatan dan MOE kayu solid sengon and jabon. Secara umum, koefisien variasi LVL sengon dan jabon pada ketebalan veneer 3 dan 5.25 mm tergolong rendah (kurang dari 10%). Variasi MOE spesifik kayu dekat empulur dengan dekat kulit rendah. Pemisahan finir *juvenile* dari finir dewasa pada kayu sengon dan jabon berumur 5 tahun tidak direkomendasikan.

Kata kunci: jenis cepat tumbuh, kayu *juvenile*, retak kupas, kekasaran permukaan, *laminated veneer lumber*

SUMMARY

ISTIE SEKARTINING RAHAYU. Characteristics of Lathe Check and Surface Roughness of Fast Growing Wood Veneers and Their Performance on Laminated Veneer Lumber. Supervised by I WAYAN DARMAWAN, LOUIS DENAUD, NARESWORO NUGROHO and REMY MARCHAL.

The development of plantation and community forest to meet wood demand in society has produced fast growing wood species. They contain juvenile wood portion which had inferior characteristics. At the same time various engineered wood product (EWP) have been developed and manufactured all around the world. Therefore, the research concerning the effect of juvenility on LVL bending and glue bond strength is needed. The research objectives were 1) to determine demarcation point/transition age between juvenile and mature wood on Sengon (*Falcataria moluccana*), Jabon (*Anthocephalus cadamba* Miq.), poplar (*Populus* sp) and douglas fir (*Psedotsuga menzii*); 2) to analyze the effect of juvenility on lathe check, surface roughness and wettability; 3) to analyze the effect of lathe check and juvenility on glue bond strength and laminated veneer lumber (LVL) bending properties; and 4) to apply a new analytical model to determine the variation of specific MOE LVL values of Sengon and Jabon from pith to bark.

Based on fiber length trait, the demarcation point between juvenile and mature wood for Sengon, it was approximately at segmented rings 17th (diameter 34 cm) and for Jabon, at segmented ring 24th (diameter 48 cm). Further, according to fiber length, transition age of poplar cultivars and Douglas-fir, transition age happened approximately at 12 years old and 18 years old, respectively.

The results showed that wood near pith on Sengon and Jabon resulted veneers with higher lathe check, rougher surface and high wettability, while wood near bark resulted veneers with lower lathe check, smoother surface and low wettability. Boiling in 75°C water for 4h resulted veneers with less lathe check, smooth surface but high wettability.

Glue bond strength, Specific MOE (SMOE) and Specific MOR (Modulus of Rupture) of Sengon and Jabon LVL were decreased as the frequency of lathe check increased or those strength values increased from pith to bark. Veneer resulted from boiling in 75°C water for 4h which were glued on loose and loose side, had successfully increased glue bond, SMOE and SMOR of Sengon and Jabon LVL. The advantage of using poplar veneers from mature wood was proved with an improvement of 15 to 20% on average for mechanical properties, with almost the same panel weight. While for Douglas-fir, utilization of mature veneers in producing LVL appears to improve bending strength from 7 to 22%.

Analytical model could determine the variation of SMOE LVL values from pith to bark. The model used density and MOE Sengon and Jabon solid wood as parameters. Concerning in general, the coefficient variation of Sengon and Jabon were considered low (less than 10%). The variation of specific MOE between wood near pith and wood near bark were low or uniform. Therefore, sorting the veneers to separate juvenile from mature veneers for 5 years old Sengon and Jabon was not recommended.

Keywords: fast growing species, juvenile, lathe check, surface roughness, laminated veneer lumber

RÉSUMÉ

ISTIE SEKARTINING RAHAYU. Influence des fissures de déroulage, de l'état de surface et du caractère juvénile des placages sur les performances mécaniques de panneaux de LVL constitués à partir d'essences de bois à croissance rapide. Supervisé par I WAYAN DARMAWAN, LOUIS DENAUD, NARESWORO NUGROHO and REMY MARCHAL.

Pour répondre à la demande croissante de bois et pour préserver les forêts primaires, les méthodes de sylviculture les plus dynamiques ont été privilégiées de manière générale dans les pays du monde entier. La contrepartie est un bois dont les caractéristiques sont réputées mécaniquement plus faibles puisqu'il comprend une proportion importante de bois juvénile. En parallèle, des solutions constructives de produits d'ingénierie bois (*engineered wood products*, EWP) ont également été développées dans le monde entier sans nécessairement s'attacher à quantifier l'impact du caractère juvénile du bois de plantation. Ce travail se propose d'aborder le cas du LVL (Laminated Veneer Lumber ou lamibois). Les objectifs de la recherche étaient :1) déterminer le point de démarcation (âge de transition) entre le bois juvénile et le bois mature dans les cas du sengon (*Falcataria moluccana*), jabon(*Anthocephalus cadamba* Miq.), peuplier (*Populus* sp) et douglas (*Psedotsuga menziesii*); 2) analyser l'effet de la juvénilité sur un fissuration cyclique, la rugosité et la mouillabilité; 3) analyser l'effet de la fissuration cyclique et juvénilité sur la résistance à l'adhérence de la colle et les propriétés mécaniques du LVL en flexion; et 4) appliquer un nouveau modèle analytique pour estimer la variation du module d'élasticité du lamibois (sengon et jabon) depuis la moelle jusqu'à l'écorce.

A partir de la longueur des fibres, le point de démarcation entre le bois juvénile et le bois mature ont été estimés. Pour le sengon, il était environ au 17^{ième} cerne annuel (diamètre 34 cm) et pour jabon, au 24^{ième} cerne (diamètre 48 cm). Toujours à partir de la longueur des fibres, l'âge de transition des cultivars de peupliers et de sapin de Douglas, était environ de 12 ans et 18 ans, respectivement.

Pour les essences sengon and jabon, les placages obtenus à partir du cœur des arbres, réputés juvéniles, sont plus fissurés plus rugueux et avec une haute mouillabilité comparativement à ceux obtenus à partir du bois près de l'écorce (plus mature). Une phase d'étuvage préliminaire des bois dans un bain d'eau chaude à 75°C pendant 4 heures a permis d'améliorer sensiblement la qualité des placages en diminuant la fissuration, la rugosité et s'accompagne d'une augmentation de la mouillabilité.

La résistance à l'adhérence de la colle, et, les modules élastiques et de rupture spécifiques (SMOE et SMOR) du LVL (jabon et sengon) diminuent à mesure que la fréquence de fissure augmente mais également en partant de l'écorce vers la moelle. L'influence de l'étuvage et le positionnement des placages est aussi très sensible sur les propriétés mécaniques des LVL. L'avantage de l'utilisation de placages en peuplier de bois mature a été prouvé avec une amélioration de 15 à 20% en moyenne pour les propriétés mécaniques, pour un poids de panneau comparable. Pour le douglas, l'utilisation de placages de bois mature dans la constitution des panneaux de LVL permet également d'améliorer les performances en flexion (de 7 à 22 % sur le MOR).

Le modèle analytique développé par Girardon et présenté dans le présent mémoire a été utilisé afin de prédire les variations du module élastique allant de la moelle à l'écorce. Pour le sengon et le jabon, le modèle utilise la densité du bois et le module élastique en fonction du rayon pour simuler un déroulage virtuelle et la fabrication de panneaux de LVL testés à plat ou sur chant. Il permet à partir d'un grand nombre de combinaisons d'estimer le potentiel issu d'une ressource donnée. Pour le contexte de l'étude qui représente bien le potentiel sylvicole de l'Indonésie, la proportion de bois juvénile étant quasi-totale (proche de 100%), l'action de trier les placages n'est pas apparue comme pertinente dans ces cas précis. En revanche, le même type de simulation pourrait être reconduit en prenant en compte du bois plus matures.

Mots-clés: espèces à croissance rapide, bois juvénile, fissuration cyclique, rugosité, LVL

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PREFACE

Syukur Alhamdulillahirabbilalamin, grateful to Allah Subhanahu Wa Ta'ala for His blessing so that this manuscript could be completed. Research topic choosen is a promising subject in wood science. The increasing wood demand throughout the world has made the community and industries sectors need to find another source of wood materials. Fast growing species is the answer. However the characteristics of juvenile wood consider low qualities, therefor, treatments to improve their qualities and added values are essential.

This work could not be accomplished without support from the supervisors, research team, colleagues, friends and family members. The author would like to express my highly gratitude to:

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Hopefully, this PhD work would benefit the science particularly in wood science.

Bogor, August 2016

Istie Sekartining Rahayu

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1 INTRODUCTION

French summary

Depuis plusieurs décennies, la France et l'Indonésie ont fait le choix de sélectionner des essences à croissance rapide pour l'exploitation et la régénération de leurs forêts. Les principales débouchées sont la pâte à papier, l'emballage léger, les panneaux de particules, les panneaux de fibres, le contreplaqué, le bois massif ou la production énergétique. Parallèlement, divers produits bois d'ingénierie (EWP) ont été développés et sont actuellement fabriqués afin d'offrir des produits industriels (homogènes et hygroscopiquement stables comparativement au bois massif) au marché de la construction. Dans certains pays tropicaux, les forêts naturelles ne peuvent subvenir à la demande énergétique et en matériau. Cette situation s'accentue puisque la forêt laisse place à d'autres espaces fonctionnels : l'agriculture, la plantation, le logement et d'autres. La demande en solutions constructives bois est en forte croissance depuis une quinzaine d'année et plus particulièrement en Europe, en raison non seulement de la séquestration de carbone atmosphérique réalisée dans les produits en bois (présentant aussi un cycle de vie LCA intéressant) mais également grâce aux propriétés thermiques et mécaniques remarquables du bois.

Selon le ministère de l'environnement et de forêt indonésien (2014), la consommation de bois dans l'industrie a atteint plus de 64 millions m^3 alors que la production nationale de grume de 2013 est inférieure à 24 million m^3. La forêt naturelle est l'une des sources d'approvisionnement potentiel mais sa part diminue chaque année. La production de bois issus de forêts naturelles qui était de 8 millions m^3 en 2008 s'est effondrée en deçà de 5,3 millions m^3 en 2012 (BPS 2013). Ce contexte impose de nouvelles stratégies d'approvisionnement pour les industriels de la filière. Les forêts privées gérées constituent une solution potentielle importante. Elles sont contrôlées par un organisme communautaire et principalement plantées avec des essences de bois à croissance rapide comme par exemple le jabon (*Anthocephalus cadamba* Miq.), le sengon (*Falcataria moluccana*), et d'autres espèces, sur des terres elles-mêmes privées (Darusman et Hardjanto 2006). Selon Ditjen RLPS du ministère de l'environnement et de la sylviculture (2006), la surface totale de la forêt privée en Indonésie est 1,3 millions d'hectare et devenu 3,6 millions d'hectare le 2009.

Selon FCBA (2015), en 2013, le volume total de bois récolté en France était de 35,8 millions m^3. La forêt de plantation Française représente une grande partie de cette ressource. Parmi les essences privilégiées pour les plantations, le peuplier (*Populus* sp) et le douglas (*Pseudotsuga menziesii*) ont des atouts certains qui expliquent leur importance commerciale. La France est le plus grand cultivateur du peuplier d'Europe. La récolte annuelle de peuplier avoisinne 1,3 millions m^3 pour une production biologique entre 2009 et 2013 de 2,4 millions m^3/an, alors que la récolte annuelle de bois de résineux n'a atteint que 19,4 millions m^3 (FCBA 2015). Selon la FAO (2011), le contreplaqué et le placage représentent toujours la plus grande part des produits de peuplier avec 59.9 % de la production totale.

Dans ce contexte, la plantation d'essence à croissance rapide permet d'aider à protéger les forêts naturelles et, dans un même temps, de subvenir aux besoins de la filière en matériau bois. Actuellement, l'un des produits d'ingénierie bois les plus prometteurs par ses propriétés et pour valoriser une ressource issue de plantations est le LVL (lamibois) qui connaît un développement très fort dans le monde entier (Tenorio *et al.* 2011). Le lamibois est différent du bois de charpente. Il est constitué de placages collés principalement dans le sens longitudinal du bois. Les placages de résineux ou de feuillus sont premièrement déroulés à partir de grumes (étuvées ou non) puis séchés. Comparé au bois massif, les lamibois a de nombreux atouts : 1) moins de défauts (nœuds non adhérents, fissures) parce que ces défauts ont été dispersés pendant la production (Ranta-Maunus 1995 ; Daoui *et al.* 2011) on parle d'un effet « lamellation »; 2) plus stable dimensionnellement et plus résistant à la flexion, à la torsion et à la rupture avec un haut module élastique (Harding et Orange 1998; Kamala *et al.* 1999; Erdil *et al.* 2009); 3) disponible dans de grandes dimensions

Néanmoins, la production de LVL de haute qualité à partir de bois à croissance rapide présente des contraintes fortes : 1) la présence d'une proportion importante de bois juvénile ou de transition (Kretschmann *et al.* 1993) ; 2) une qualité extérieure des placages réputée moindre (rugosité, variations d'épaisseur et fissuration cyclique) (Rohuma *et al.* 2013; Darmawan *et al.* 2015); 3) la consommation importante de colle qui peut représenter jusqu' à 20% en masse du produit final (Daoui *et al.* 2011). D'ailleurs, la présence du formaldéhyde doit être prise en compte pour des questions de risques sur la santé. Certains de ces critères pourraient être réduits en appliquant un traitement d'étuvage préliminairement au déroulage.

Par nature, une sylviculture dynamique favorise la production de grumes rectilignes, cylindriques et donc bien adaptées au procédé de déroulage. En revanche, étant beaucoup plus riches en bois juvénile, certains défauts majeurs sont susceptibles d'être favorisés comme la fissuration cyclique des placages (Darmawan *et al.* 2015). Il est donc essentiel d'étudier l'impact de la juvénilité du bois sur la fissuration cyclique des placages et sur les propriétés mécaniques des LVL. Ce type de défaut peut être contrôlé en utilisant une barre de pression bien réglée ou un traitement hygrothermique adapté préalable (Kollmann *et al.* 1975). Cependant, les technologies privilégiées actuellement s'orientent vers les dérouleuses à entrainement périphérique qui sont bien adaptées pour dérouler le petit bois, mais qui ne permettent pas un réglage optimal de la barre de pression. Un étuvage des billons, non généralisé dans les cas des essences à croissance rapide, reste une bonne option pour limiter le phénomène de fissuration (Kabe *et al.* 2013; Dupleix et al. 2013, Darmawan *et al.* 2015).

Basé sur la recherche présentée par Pugel *et al.* (1990), le bois juvénile peut être utilisé pour fabriquer les produits bois recomposés (OSB, panneau de particules, panneau de fibres). Kretschmann *et al.* (1993) a également montré qu'il est possible de fabriquer du LVL à partir du placage de bois juvénile. Un des avantages techniques les plus significatifs du LVL est que ses caractéristiques mécaniques spécifiques peuvent être maitrisées dès sa conception (Wang *et al.* 2003). En plaçant stratégiquement les placages sélectionnés dans le composite, il est possible de fabriquer un produit à base de bois qui a des propriétés physiques et mécaniques bien contrôlées et maitrisées.

L'effet de qualité de placage et particulièrement des fissures sur les propriétés fondamentales du LVL sera étudié. En particulier, l'effet de la fissuration sur les performances mécaniques du joint de colle, le module d'élasticité (MOE) et le module de rupture (MOR) des LVL sera mesuré. DeVallance *et al*. (2007), a relevé qu'une haute fréquence de fissuration s'accompagne de caractéristiques mécaniques moindres. D'après lui, l'augmentation du nombre de fissures sur le placage conduirait à abaisser la qualité de collage de l'interface et donc les résistances à la flexion (MOE et MOR).

Un essai de flexion 4 point permet de mesure le module élastique quasi statique et la contrainte à la rupture du matériau tandis qu'une approche vibratoire permet d'estimer le module d'élasticité dynamique. A partir d'essences diverses, pour différents types de sylviculture et des géométries d'éprouvettes variables, plusieurs études ont montré une corrélation linéaire forte entre les modules d'élasticité dynamique et statique (Biblis *et al*. 2004; El-Haouzali 2009). Cependant, l'utilisation de telles méthodes pour estimer le MOE des produits bois reconstitués, en particulier le LVL, n'a été que très peu mis en œuvre (Daoui *et al*. 2011) et avec un succès limité.

À partir du contexte et des observations précédentes, les objectifs de l'étude proposée sont : 1) la détermination de point de délimitation(âge de transition) entre le bois juvénile et bois mature; 2) l'effet de la juvénilité sur la fissuration cyclique des placages et leur rugosité; 3) l'effet de la juvénilité sur les caractéristiques mécaniques des LVL (Résistance du joint de colle, MOE, MOR) 4) détermination de module d'élasticité de LVL du sengon et du jabon par la modélisation du déroulage et de l'évolution des propriétés mécaniques depuis le cœur jusqu'à l'écorce.

Les hypothèses qui ont été proposés dans cette étude sont les suivantes :

1. Certains caractères peuvent être employés pour déterminer le point de démarcation (âge de transition) entre le bois juvénile et bois mature sur des espèces à croissance rapide
2. La juvénilité influence la fissuration et la rugosité mais l'étuvage permet de limiter cet impact.
3. La fissuration cyclique et le caractère juvénile du bois dégradent fortement les propriétés mécaniques du LVL.
4. Un modèle analytique pourrait être utilisé pour prédire la variation des valeurs spécifiques de MOE du LVL en intégrant les variations des propriétés depuis la moelle jusqu'à l'écorce.

1.1 Background

Since few decades, both France and Indonesia have planted fast growing forests mainly for paper, particle board, fiberboard, plywood, light packaging, solid wood or energy production. At the same time : 1) various Engineered Wood Products (EWP) have been developed and manufactured all around the world, showing much lower mechanical and physical variability than solid lumber; 2) environmental concerns have dramatically grown, especially in some tropical countries where natural forests reach more and more difficulties to resist to the demand both of energy and of wood material. Moreover, the area of natural forests in Indonesia has been declining, and this happens because the activities carried out have changed the functions of forest to other functions such as for plantation, mining, agriculture, housing and others; and 3) the demand for wood products for building has increased quite everyway and especially in Europe, because of not only the atmospheric carbon sequestration into wood products, the attractive Life Cycle Analysis (LCA) of these products but also because of the intrinsic technical performances of these products (thermal and mechanical specific properties).

According to Ministry of Environment and Forestry (2014), utilization wood raw material in forest product industries in Indonesia reach over 64 million m^3. On the other hand, the national log production on 2013 is less than 24 million m^3. Therefore, there is gap between the ability to supply wood and the wood demand. The natural forest is one of the sources of log material however its area is decreasing every year. The log production of natural forest on 2008 is 8 million m^3, while on 2012 is 5.3 million m^3 (BPS 2013). These conditions make wood industries have to find other sources of raw material to fulfill their demand. One of them is woods from community forest. Community forests are forests that are managed by community, planted usually by fast growing wood species on land owned by community themselves (Darusman and Hardjanto 2006). According to Ditjen RLPS of Ministry of Environment and Forestry (2006), the total area of community forest in Indonesia is 1.3 million ha and become 3.6 million ha on 2009. Community forest are dominantly planted by fast growing tree species, e.g. jabon (*Anthocephalus cadamba* Miq.), sengon (*Falcataria moluccana*), and other species. According to FCBA (2015), in 2013, total harvested wood in France was 35.8 million m^3. France plantation forest represent large portion of the resources are planted by Poplar (*Populus* sp) and Douglas fir (*Psedotsuga menzii*). France is the largest grower of poplar in Europe. Average annual poplar harvesting reach 1.3 million m^3 for a biologic production around 2.4 million m^3 / year between 2009 and 2013, while annual softwood harvesting reached 19.4 million m^3 (FCBA 2015). According to FAO (2011), plywood and veneer still account for the largest share of poplar products with 59.9 % of total production.

In this context, it is more and more considered than fast growing plantation could help to protect natural forest offering raw material for wood industry and in a same movement to increase wood material diffusion, manufacturing EWP. Currently, one of the most promising EWP is Laminated Veneer Lumber (LVL) which knows a very strong development worldwide (Tenorio *et al*. 2011). LVL is different from solid lumbers. It is made of natural veneers which are bonded together by adhesives. The veneers are firstly peeled from hardwood or softwood logs and then dried. Compared with solid lumber, LVL have more advantages: 1) less lumber defect (rotted knots, cracks and other defects) because the common lumber defects have been dispersed during production (Ranta-Maunus 1995; Daoui *et al*. 2011); 2) stable in dimension and more resistant to warp, twist, bow, and cup (Harding and Orange 1998; Kamala *et al*. 1999; Erdil *et al*. 2009); 3) available in large dimensions (LVL can be as long as 8000 mm, as thick as 300 mm, as wide as 1200 mm) (Erdil *et al*. 2009); 4) high elastic modulus and bending stress (Erdil *et al*. 2009).

However, the production of high quality LVL using fast growing wood species would be faced against two main problems: 1) presence of important rate of juvenile wood, transition age between juvenile and mature wood being often close to harvesting age (Kretschmann *et al*. 1993); 2) veneer surface quality (surface roughness, thickness variations and lathe checking) (Rohuma *et al*. 2013; Darmawan *et al*. 2015); 3) the drawback of LVL is that the part of the glue inside can reach important ratio until 20% (Daoui *et al*. 2011). Moreover, the presence of formaldehyde still has to be taken under consideration. These criteria might be able to be minimized by careful application of boiling treatment on fast growing wood species having high portion of juvenile wood.

Due to the shape of fast growing species logs are round, straight and cylindrical, recently, fast growing species in Indonesia and France, have been rotary cut for laminated-wood products. However, as fast growing species are being peeled and much more juvenile woods are being utilized, severe lathe check veneer would be produced and manufactured ; according to Darmawan *et al.* (2015). Therefore, it considerably needs to study lathe checks of veneer peeled from those fast growing species. The risk of this checking can be reduced by using a nosebar (Kollmann *et al*. 1975). However, recent spindle less rotary lathes, which are widely used to peel small log diameter of fast growing wood species, have not been completed with an adjustable nosebar. A boiling treatment of bolts would be considered to reduce the lathe check (Kabe *et al*. 2013; Dupleix *et al.* 2013, Darmawan *et al*. 2015).

Based on the research conducted by Pugel *et al.* (1990), juvenile wood can be utilized to produce composite products (flakeboard, particleboard, and fiberboard). Kretschmann *et al.* (1993) also reported that it is possible to make LVL from juvenile wood veneer. One of the most significant technical advantages of laminated veneer lumber (LVL) is that specific performance characteristics can be considered in its design (Wang *et al*. 2003). By strategically placing selected veneer sheets within the composite, it is possible to manufacture a wood-based product that has well-controlled physical and mechanical properties.

DeVallance *et al.* (2007), reported that a high frequency of lathe checks results in lower strength. It is due to the increasing of lathe check on the veneer would lead to lower glue-bond quality and bending strength (MOE and MOR). Moreover, Pot *et al.* (2015) underlined the impact of lathe check depth on shearing modulus of LVL. The effect of veneer quality especially lathe checks on glue-bond quality, modulus of elasticity (MOE) and modulus of rupture (MOR) during laminated veneer lumber (LVL) production should be also important to be studied.

A static bending test allows measuring static MOE and MOR while dynamic MOE could be measured by using vibration technics. Using various species of wood, sample dimensions and growth conditions, several studies have shown a strong linear correlation between the dynamic and static modulus of elasticity (Biblis *et al*. 2004; El-Haouzali 2009). However, the use of such methods for estimating the MOE of engineered wood products, particularly LVL, has not been widely applied. To the best of our knowledge, only Daoui *et al*. (2011) used a vibrating method with limited success.

By considering the above issues and references, the research topics proposed were 1) determination of demarcation point/transition age between juvenile and mature wood; 2) the effect of juvenility on veneer lathe check and surface roughness of fast growing wood species; 3) the effect of lathe check and juvenility on fast growing wood species LVL glue bond and bending strength; and 4) determination of sengon and jabon LVL specific modulus of elasticity by modelling peeling an evolution of raw material properties on radial segment basis.

Hypothesis that were proposed in this study were as follow:

1. Some traits could be used to determine the demarcation point/transition age between juvenile and mature wood on fast growing species
2. Juvenility would affect lathe check and surface roughness, and boiling treatment would decrease lathe check and surface roughness
3. Lathe check and juvenility would influence glue bond strength and LVL bending properties
4. An analytical model should be used to determine the variation of specific MOE LVL values from pith to bark

1.2 Research Objectives

The research objectives in this study were:

1. To determine demarcation point/transition age between juvenile and mature wood on sengon (*F. moluccana*), jabon (*A. cadamba*), poplar (*Populus* sp) and Douglas fir (*P. menzii*)
2. To analyze the effect of juvenility on lathe check, surface roughness and wettability
3. To analyze the effect of lathe check and juvenility on glue bond strength and LVL bending properties
4. To apply a new analytical model to determine the variation of specific MOE LVL values of sengon and jabon from pith to bark

1.3 Novelty

The novelties in this study were:

1. Characteristics of juvenile wood of sengon and jabon and determination of their demarcation point by segmented regression model
2. The importance of veneer qualities on LVL glue bond and bending strength
3. The importance of juvenility in Douglas-fir on LVL bending properties and the recommendation of poplar cultivars for LVL construction purposes
4. The use of a new analytical model to determine the variation of specific MOE LVL values from pith to bark

1.4 Research Benefits

Utilization of fast growing species especially, sengon, jabon, poplar and Douglas-fir for LVL production can help to solve the problems linked to the shortage of raw material and to the protection of natural forest. This study would increase fast growing species added values. In details, research advantages were as follow:

1. In term of wood science development, segmented regression model can be used to determine demarcation point/transition age between juvenile and mature wood in fast growing wood species (hardwood and softwood).
2. Boiling treatment prior to sengon and jabon peeling can be applied to increase veneer qualities in wood industries.
3. LVL made of fast growing wood species can be used for light construction in society.
4. An analytical model was used to determine the variation of specific MOE LVL values from pith to bark in wood science.

1.5 Research Stages

In order to accomplish the objectives of the research, this study was divided into four stages. The stages of the research are shown in Table 1.

Table 1 Research stages

No.	Research Stages	Parameters
1.	Determination of demarcation point / transition age between juvenile and mature wood	Parameters that were measured on solid wood : density, fiber length, MOE and MOR
2.	The effect of juvenility on lathe check, surface roughness and wettability	Parameters that were measured on veneer : lathe check (frequency, depth and length), surface roughness and contact angle
3.	The effect of lathe check and juvenility on glue bond strength and LVL bending properties	Parameters that were measured on LVL : glue bond strength, MOE by non destructive and destructive test and MOR
4.	Utilization of the new analytical model to determine pith to bark specific MOE values of LVL	Parameters that were measured : specific MOE of experimental data and model

2 DETERMINATION OF DEMARCATION POINT / TRANSITION AGE BETWEEN JUVENILE AND MATURE WOOD

French summary

L'Indonésie et la France ont une politique de gestion de leurs plantations basée sur les essences à croissance rapide, destinées à des applications de pâte à papier, d’emballage léger, de panneaux de particules, de panneaux de fibres ou de production énergétique. D'ailleurs, en Indonésie, il est difficile de trouver sur le marché des bois de construction de grands diamètres pouvant être utilisés pour des charpentes. Afin de satisfaire la demande et de préserver les forêts naturelles, le bois issu de plantations a donc été privilégié. Ces arbres contiennent une grande proportion de bois juvénile du fait de la rotation rapide des parcelles. Le bois juvénile est un xylème qui est créé par un cambium jeune pendant les premières années de la croissance pour une unité donnée de croissance (Bowyer *et al*. 2007).

Au niveau du diamètre à 1,30 m de hauteur (dhp), on distingue le bois près de la moelle d'un arbre, le bois juvénile, et le bois près de l'écorce, le bois mature. Le bois juvénile est réputé pour présenter des propriétés mécaniques amoindries aussi bien que de poser des problèmes de déformations, de retrait et de gonflement excessif, de surfaces pelucheuses, être à l’origine de l'instabilité générale dans la fabrication et de l'utilisation du bois. Ces problèmes peuvent apparaître dans le bois lors du déroulage, du sciage du séchage ou de l’usinage (Maeglin 1987). Le bois juvénile est caractérisé par une plus faible densité, des trachéides ou des fibres plus courtes, un pourcentage inférieur de bois final, des parois cellulaires plus minces, de plus petites dimensions cellulaires tangentielles, une teneur inférieure en cellulose, une résistance inférieure, un retrait longitudinal plus élevé, un angle de microfibrilles de cellulose plus élevé, un lumen plus large de cellules, plus de grain tors et un degré plus élevé de nodosité comparés au bois mature (Panshin et de Zeeuw 1980). Dans le cas des résineux, le bois mature est caractérisé par une longueur relativement constante des trachéides tandis que pour le bois juvénile, leur longueur est d’autant plus courte que le bois est jeune (Yang et Hazenberg 1994). En raison de la sylviculture intensive, la proportion de bois juvénile est importante. Cette proportion influence directement, par exemple, le rendement de la pâte ou les propriétés mécaniques des produits. Par conséquent, la détermination du point de démarcation entre le bois juvénile et bois mature est pertinente.

Le point de démarcation entre le bois juvénile et bois mature peut être déterminé à partir des mesures de densité, de longueur des fibres, du module de rupture (MOR) et de l'angle de microfibrilles de cellulose de chaque cerne de croissance. Dans la zone de bois juvénile la densité et la longueur de fibre augmentent depuis la moelle vers l'écorce. La zone de bois présentant des valeurs de densité et une longueur de fibres constante est considérée comme celle du bois mature. La limite entre ces deux secteurs est la zone de transition (Tsoumis 1991, Bowyer *et al*. 2007).

Selon Alteyrac *et al.* (2006), le point de démarcation (limite bois juvénile/bois mature) a été évalué a partir de quatre indicateurs : surface radiales de cernes annuels, densité maximale des cernes, de la largeur et de l'infradensité de cerne. Cette détermination quantitative a été obtenue par régression à partir d'interprétation visuelle, de régression polynômiale (Koubaa *et al.* 2005), régression linéaire segmentée (Bustos *et al.* 2003, Sauter *et al.* 1999, Abdel-Gadir et Krahmer 1993), fonction dérivée, étude d'image (Yang et Hazenberg 1994; Sauter et al, 1999), hauteur de l'échantillonnage et la densité du peuplement, et l'estimation du bois proportion juvénile. Dans cette étude, la détermination du point de démarcation a été basée sur la longueur de fibre en utilisant l'analyse par régression segmentée. Ce modèle utilisé par certains chercheurs a montré son efficacité pour évaluer la zone de transition entre le bois juvénile et le bois mature (Abdel-Gadir et Krahmer 1993; Sauter *et al.* 1999; Bustos *et al.* 2003; Darmawan *et al.* 2013; Rahayu *et al.* 2014)

Sengon (*Falcataria moluccana*) et jabon (*Anthocephalus cadamba*) sont des espèces de bois à croissance rapide largement plantées en Indonésie. Leur cycle de rotation étant court (5 à 7 ans), les troncs présentent de fortes proportions de bois juvénile. Selon Sumarna (1961), l'accroissement annuel moyen pour le sengon varie entre 4 et 5 cm jusqu'à l'âge de 6 ans. Pour un âge de 8 à 9 années, l'accroissement annuelle reste conséquent, environ 3-4 cm; pour diminuer graduellement ensuite. Young *A (20XX)* pour le Jabon observe qu'après 5 ans, la croissance en diamètre peut s'échelonner de 1.2 à 11.6 cm par an. En géneral, le taux de croissance du diamètre est d'environ 2 cm par an (Sudarmo 1957; Suharlan *et al.* 1975). La microstructure de sengon et jabon est présentée sur la Figure 1a et 1b.

La France est le plus grand producteur de peuplier (*Populus* sp) en Europe. La récolte moyenne de peuplier annuelle entre 2009 et 2013 a atteint 2.4 m3 (FCBA 2015). Selon la FAO (2011), le contre-plaqué et le placage représentent toujours la plus grande part de produits issus du peuplier avec 59.9 % de production totale. Le douglas (*Pseudotsuga menziesii*) est connu pour sa capacité à produire un volume de bois élevé dans les pays Européens (Podrazsky *et al.* 2013) avec des propriétés mécaniques intéressantes. Il a été classé comme espèce à croissance rapide (Rowell *et al.* 2005), il est donc susceptible de présenter une grande part de bois juvénile (Zobel and Sprague 1998). En outre, Langum *et al.* (2009) ont montré que la rigidité et la résistance en flexion du douglas augmente avec la distance à la moelle. Par conséquent, il est très important de déterminer la zone de transition entre bois juvénile et bois mature. La microstructure des cultivars de peuplier et de douglas sont présentées sur la Figure 2a et 2b.

L'objectif de cette partie est d'estimer et d'analyser le point de démarcation (âge de transition) entre le bois juvénile et bois mature pour les 4 essences par une analyse de régression segmentée. Les échantillons ont été préparés selon un protocole légèrement différent entre les essences françaises et indonésiennes. La longueur des fibres et la densité des échantillons de sengon et de jabon ont étés mesurées sur des segments artificiellement créées puisque la limite de cerne qui caractérise la croissance annuelle est très difficile à identifier dans la pratique.

Selon l'indicateur de longueur de fibre, l'âge de transition des bois de sengon et de jabon âgés de 5, 6 et 7 ans s'étendent respectivement du 16ème au 17ème segment radial et du 21ème au 24ème segment radial. L'âge de transition des cultivars de peuplier est proche de la 16ème année pour les cultivars caractérisés. Enfin, cet âge de transition a été la 20ème année pour le douglas.

Ainsi, on peut estimer la proportion de bois juvénile pour les différentes espèces en moyenne. Les proportions de bois juvénile aussi bien pour le sengon que le jabon au diamètre hauteur poitrine (dhp) à l'âge de 5 ans, 6 et 7 ans étaient de 100 %. Les variétés cultivées de peuplier et le Douglas ont contenu 52 % et 77 % de part de bois juvénile, respectivement en moyenne. Il s'agit d'estimations moyenne non révélatrice des tous les arbres et de tous les cultivars.

La longueur de fibre a semblé être un bon indicateur anatomique du point de démarcation entre le bois juvénile et le bois mature comparativement à la densité dans cette étude. L'analyse de régression segmentée s'est avérée être une méthode pratique et objective d'évaluer le point de démarcation (l'âge de transition) pour le sengon, jabon, les cultivars de peuplier étudiés et le pin de douglas.

Le point de démarcation (âge de transition) entre bois juvénile et bois adulte a été estimé dans cette étude pour le sengon, le jabon, des cultivars de peuplier de peuplier et le douglas ce qui constitue un élément utiles pour gérer les stocks de bois ou orienter leur approvisionnements. En particulier, la connaissance de l'étendue de la zone de transition peu permettre d'adapter leur utilisation de ces bois. En particulier, les résultats obtenus pour les bois indonésiens suggèrent de véritablement allonger les durées de rotation afin de disposer d'un minimum de bois adulte pour optimiser son positionnement dans les LVL. Dans le cas contraire, le LVL contient exclusivement du bois juvénile qui le rend difficilement valorisable.

2.1 Introduction

Since few decades, both Indonesia and France have planted fast growing forests mainly for light packaging pulp and paper, particle board, fiberboard or energy production. Moreover, in Indonesia, it is difficult to get large diameter timber for lumber purposes in the market. In order to meet the demand and maintain natural forests, wood will have to be taken from fast-growing trees grown in plantation forests. These trees with short cutting cycle contain large proportion of juvenile wood. Juvenile wood is xylem which is created during the first few years of the cambium.

At diameter at breast height, wood near the pith of a tree, i.e. juvenile wood is different from wood near the bark, i.e. mature wood. The presence of juvenile wood can reduce mechanical properties as well as cause problems of warping, excessive shrinking and swelling, fuzzy grain, and general instability in the manufacture and use of the wood. These problems may show up in the wood when sawing, veneering, drying and machining (Maeglin 1987). Juvenile wood is characterized by lower density, shorter tracheid or fibers, lower percentage of latewood, thinner cell walls, smaller tangential cell dimensions, lower cellulose content, lower strength, higher longitudinal shrinkage, higher microfibril angle, larger cell lumen, more reaction wood, more spiral grain and higher degree of knottiness compared with mature wood (Panshin and de Zeeuw 1980). Mature wood in softwood is defined by relatively constant tracheid length whereas juvenile wood, by increasing tracheid length (Yang and Hazenberg 1994). Due to intensive forestry, proportion of juvenile wood relative to mature wood has increased, resulting in warping problems during drying. This higher proportion of juvenile wood can have significant impact on wood quality, e.g. reduced lumber strength and reduced yields in pulp production.

Therefore, determination of demarcation point between juvenile and mature wood is very important. Demarcation point between juvenile and mature wood could be determined based on density value, fiber length, modulus of rupture (MOR) and microfibril angle from each growth ring. Juvenile area has increasing density and fiber length from pith to bark. Area with constant density value and fiber length is considered as mature wood. Turn point between these two areas is the transition area between juvenile and mature wood (Tsoumis 1991, Bowyer *et al*. 2007).

According to Alteyrac *et al*. (2006), demarcation point (transition age) was estimated from radial pattern of the average ring area, ring maximum density, ring width and ring basic density by a quantitative determination based on regression analyses by : visual interpretation, polynomial regression (Koubaa *et al*. 2005), segmented linear regression (Bustos *et al*. 2003, Sauter *et al*. 1999, Abdel-Gadir and Krahmer 1993), derivative function, studied features (Yang and Hazenberg 1994; Sauter *et al*. 1999), sampling height and stand density, and estimation of wood juvenile proportion. Methods used include visual interpretation, polynomial regression and segmented linear regression. In this study, determination of demarcation point was based on fiber length by using segmented regression analysis. This model has been used by some researcher and proved to be a practical and objective method to estimate transition ring between juvenile and mature wood (Abdel-Gadir and Krahmer 1993; Sauter *et al*. 1999; Bustos *et al*. 2003; Darmawan *et al*. 2013; Rahayu *et al*. 2014)

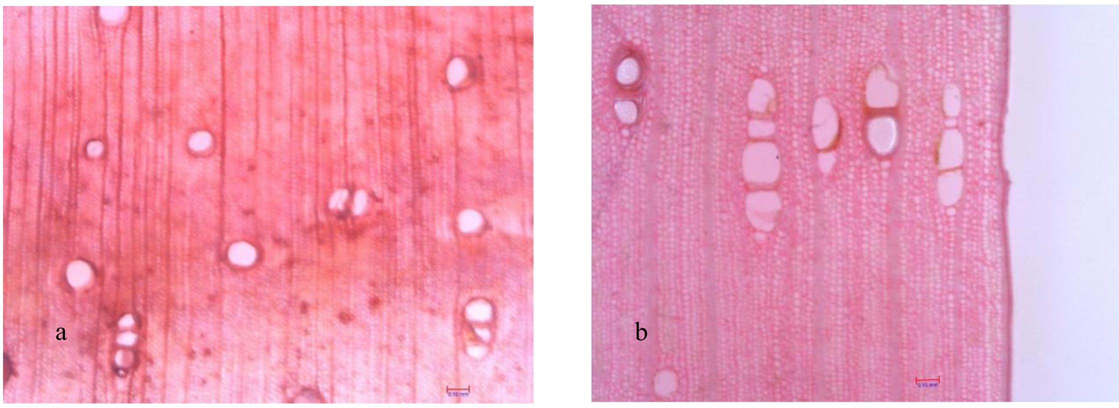

Figure 1 Microstructure of 5 years old sengon (a) and jabon (b) near bark with magnitude 300x

Sengon (*Falcataria moluccana*) and jabon (*Anthocephalus cadamba*) are a fast growing wood species widely planted by community in Indonesia. They have short cutting cycle (5 to 7 years) consequently there would be high percentage of juvenile portions in the tree stems. According to Sumarna (1961) mean annual increment (MAI) for sengon wood in diameter fluctuates around 4–5 cm until the age of 6 years. At the age of 8–9 years, the diameter increment is still high, about 3–4 cm; it then decreases slowly thereafter. Young *A. cadamba* trees up to 5 years old can grow 1.2–11.6 cm per year in diameter. In general, growth rates are about

2 cm per year in diameter (Sudarmo 1957; Suharlan *et al*. 1975). The microstructure (RT plan) of sengon and jabon were presented on Figure 1a and 1b.

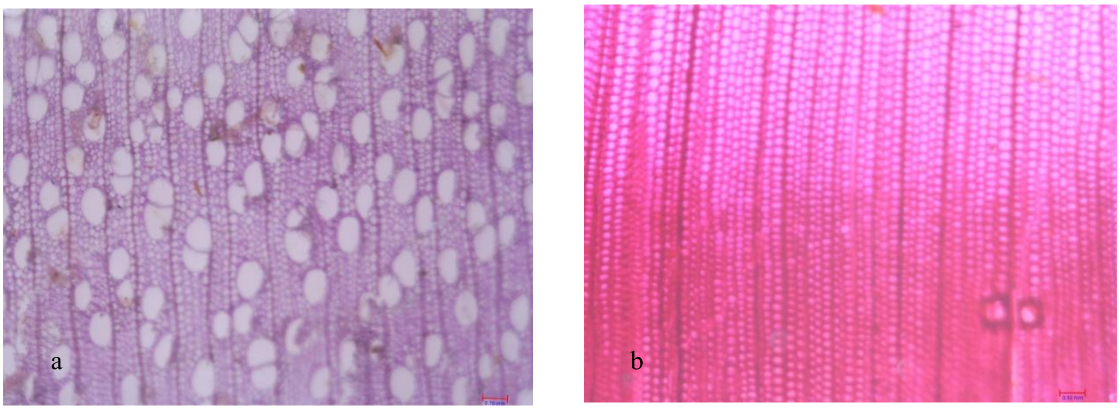

Figure 2 Microstructure of 18 years old poplar cultivar 'I214' (a) and 26 years old Douglas-fir (b) near bark with magnitude 300x

France is the largest grower of poplar (*Populus* sp) in Europe. Average annual poplar harvesting between 2007 and 2011 reached 2.4 million m^3 (FCBA 2013). According to FAO (2011), plywood and veneer still account for the largest share of poplar products with 59.9 % of total production. Douglas-fir (*Pseudotsuga menzii*) is known by its ability to produce high wood volume in European countries (Podrazsky *et al*. 2013). It was categorized as fast growing species (Rowell *et al*. 2005) which is capable of rapid early growth rate resulting in a large portion of juvenile wood (Zobel and Sprague 1998). The microstructure of one poplar cultivar and Douglas-fir were presented on Figure 2a and 2b. In addition, Langum *et al*. (2009) reported that flexural stiffness and strength in solid Douglas-fir increase with increasing distance from pith to bark. Therefore, determination of transition area between juvenile and mature wood is very important.

The objective of this research was to analyze demarcation point/transition age between juvenile and mature wood of sengon, jabon, poplar and Douglas-fir by segmented regression analysis.

2.2 Materials

The details information of the tree samples that were used in this study are shown in Table 2. After cutting, we took 2.5 m section in length from the bottom part of each tree stem. Sample logs were wrapped in plastic and maintained in green condition before they were transported to the workshop for testing.

Table 2 Trees information for determination of demarcation point/transition age between juvenile and mature wood

Wood Species	Growth Site	Age (years old)	Diameter at breast high (dbh) (cm)
Sengon (*F. moluccana*)	Sukabumi, Indonesia	5, 6 and 7	32-36
Jabon (*A. cadamba*)	Sukabumi, Indonesia	5, 6 and 7	34-38
Douglas fir (*P. menziesii*)	Cluny, France	26	34
Poplar cutivar I-214 (*P. deltoids* Bartr. x *P. nigra* L.)	Saint Nicholas la Chapelle and La Rèole, France	18	47-50
Poplar cutivar Koster (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and La Rèole, France	18	50-52
Poplar cutivar Lambro (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and La Rèole, France	18	47-53
Poplar cutivar Soligo (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and Saint Nicholas la Chapelle, France	18	48-54

2.3 Method

The measurements of juvenility parameters were performed in three research facilities, Laboratory of Wood Anatomy and Physical Properties of Faculty of Forestry, Bogor Agricultural University, Indonesia, LaBoMaP (Laboratoire Bourguignon des Matériaux et des Procédés), Ecole National Superieure d'Arts et Métiers (ENSAM) Cluny, Bourgogne, France and Laboratory INRA- Centre de Nancy, France.

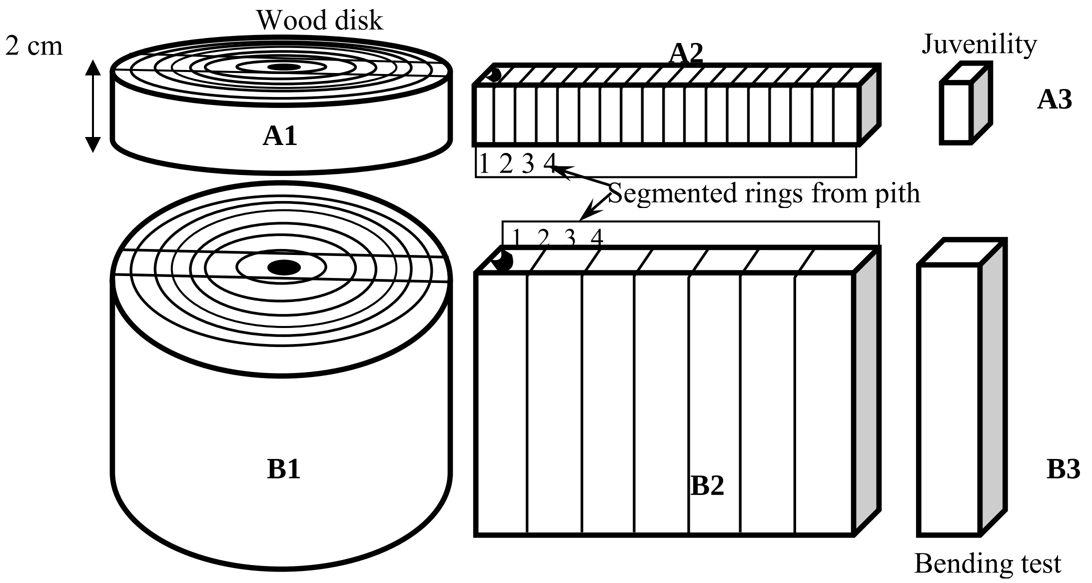

Figure 3 Schematic drawing of the preparation of juvenility and bending test specimen for sengon and jabon

2.3.1 Sample preparation for sengon and jabon

Discs of 2 cm thick (Figure 3-A1) were cross-cut from the middle part of the log (1.3 m sampling height = diameter breast height (dbh)) using band saw. The rest of the cut logs (Figure 3-B1) were kept as bending sample discs. From the A1 discs, flitches of 2 cm width were prepared from bark to bark through the pith using a band saw for measurements of density and fiber length (Figure 3-A2). The flitches were cut in segments of 1 cm thick from pith to bark and numbered consecutively. Segments for determination of fiber length were kept in green condition (Figure 3-A3). From the B1 discs, boards of 2.5 cm width were band sawn bark to bark through the pith for specimens of bending strength (MOE and MOR) tests (Figure 3-B2). The boards were also re-sawed in segments of 2 cm thick from pith to bark and numbered consecutively. Individual test specimens (Figure 3-B3) were carefully air dried to prevent warping.

2.3.2 Sample Preparation for Douglas-fir

The disks of 2 cm thick (Figure 4-A1) were cross cut from the middle part (2 m above the ground) of the sample log. From the A1 disks, flitches of 2.0 cm width were prepared from pith to bark for specimens of fiber length (Figure 4-A2). Douglas fir wood samples were cut according to its annual ring segments from pith to bark (they were numbered consecutively) (Figure 4-A3). The dimension of each Douglas fir sample was 2 cm (length) x 2 cm (width) x 1 cm (thickness).

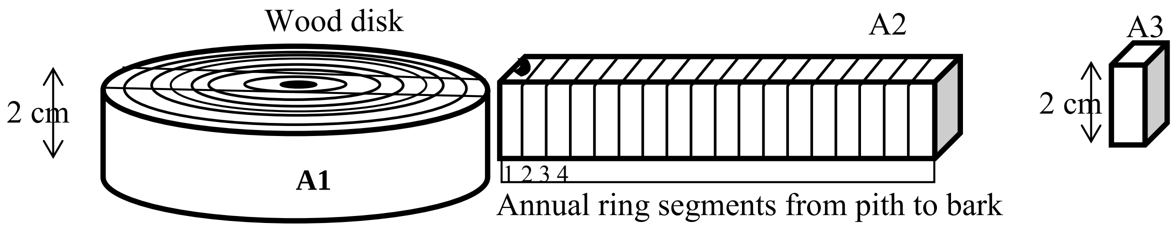

Figure 4 Schematic drawing of the preparation of the tracheid length measurement test for Douglas-fir

2.3.3 Sample Preparation for poplar

Logs were peeled by using “SEM Automation S500” at LaBoMaP (Laboratoire Bourguignon des Matériaux et des Procédés), Ecole National Superieure d’Arts et Métiers (ENSAM) Cluny, Bourgogne, France. It could peel logs from 450 to 850 mm in length and 180 to 500 mm in diameter. Logs were peeled by using a 1° clearance angle, 1 m s^{-1} cutting speed and with a moderate pressure rate of the pressure bar 10% to limit lathe check growth and thickness variation (Lutz 1974; Feihl 1986; Marchal *et al*. 2009).

Before peeling, each log was holed by 1 cm diameter drill bit from bark to pith, to mark the radial segment of veneers sample. Each cultivar of poplar logs were peeled with 3 mm thickness. The logs were peeled until the core diameter of 7 cm. Veneers were dried with a vacuum dryer to ensure a flat veneer surface (dried until they reached 8 - 10% moisture content). In each radial segment veneer samples in the size of 10x60 cm and kept in plastic for analyzing fiber length of poplar.

2.3.4 Density measurements for sengon and jabon

The density profiles from pith to bark were measured using X-ray densitometer at the Institut National de la Recherche Agronomique (INRA) in Champenoux, Nancy, France. The A2 filches were air dried before being sawn into 2-mm thick (longitudinal) strips with a specially designed pneumatic-carriage twin-bladed circular saw. The strips were scanned to estimate the air-dried wood density for each radial segment from pith to bark. Density of each 1-cm ring width (each radial segment) was determined based on the intra-ring microdensitometric profiles. Density value (kgm^{-3}) from each radial segment was obtained and the density profiles were recorded.

2.3.5 Density of solid Douglas-fir and poplar

The samples in Figure 2-A3 were weighted (air dried weight), then measured theirs length, width and thickness by using caliper. Wood densities from pith to bark were calculated by using formula Equation 1:

$$\rho = \frac{\text{air dried weight (kg)}}{\text{air dried volume (m3)}} \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

2.3.6 Static bending test measurement

Sengon and jabon air dried bending test specimens which are straight-grained and free from any visible defects, 2 × 2 cm in cross section, with true radial and tangential surfaces were prepared for the measurement of bending strength. The bending test specimens were numbered consecutively from the pith to bark. Static bending tests were conducted on the Instron universal testing machine based on the ASTM D-145 testing procedure.

2.3.7 Fiber length

Specimens for juvenility test (Figure 3-A3) were used to determine fiber length from the pith to bark. The specimens were macerated using a cutter based on Schulze's method of TAPPI T 401 om-88 (TAPPI 1991). The small pieces were treated with nitric acid and 0.03 g of potassium chlorate to dissolve the middle lamella and allow the fibers to become separated from one another. Using a needle dropper, the macerated fiber suspension was placed on a standard slide of 7.5 cm × 2.5 cm based on TAPPI T401 om-88 procedure (TAPPI 1991). Thirty slides of macerated fibers were prepared from each segmented ring (segment of 1 cm width). The slides were then dried and a cover glass of 22 mm × 30 mm was placed over the fibers. Fiber length was measured under an optical video microscope. Undamaged single fiber was selected from each slide and its image was taken. The captured images were analyzed using Motic image software for measurement of the fiber length. The number of measured fibers were 30 fibers in each segmented ring.

2.3.8 Transition age

A segmented regression analysis was used to determine the ring of transition from juvenile to mature wood. It was assumed that development of density and fiber length from pith to bark can be described by two functions in a curve. The first function was a steep slope of the curve over the first few years beginning at the pith (juvenile wood) and the second function was a constant slope for the later part of the curve (mature wood). The fitted regression model for the functions took the form of quadratic model with plateau (Figure 5). The change of slope in the radial fiber length and density trends as a function of segmented ring number was modelled as follows (Equation 2):

$$Yi = A + BXi + CXi^2 + Ei \ldots\ldots\ldots (2)$$

where Yi = dependent variable (fiber length, density), Xi = segmented ring number, A = intercept of the line of the juvenile wood, B and C = regression coefficients and Ei = error.

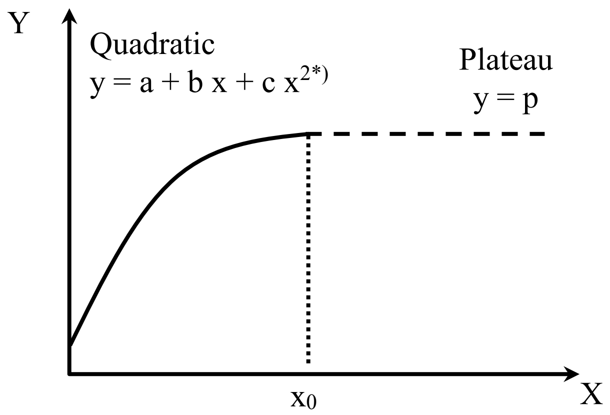

Figure 5 Fitting a segmented model using NLIN (non linear)
*)Where, y = independent variable, a = intercept, b and c = regression coefficients for the equation, x = experimental data

From theoretical considerations, it can be hypothesized that:

$y = a + bx + cx^2$ if $x < x_0$, the equation relating y and x is quadratic and

$y = p$ if $x \geq x_0$, the equation is constant (horizontal line)

where x_0 = ring number at which wood changes from juvenile to mature wood, p = fiber length or density at which wood changes from juvenile to mature wood, a = intercept, b and c = regression coefficients for the equation.

With segmented regression, the model (Equation 2) can simultaneously estimate parameters of the model and a demarcation point between juvenile and mature wood. The demarcation point can be directly obtained using non-linear least squares procedures (PROC NLIN) in SAS (1990, Version 6), which minimizes the mean squared error. The PROC NLIN in SAS was used to obtain estimates of regression parameters and the demarcation point. PROC NLIN could fit segmented model as in Figure 5. The curve in Figure 5 must be C0 and C1 from mathematical point of view (the two sections must meet at x_0 and the first derivate with respect to x are the same at x_0). These conditions implied that $x_0 = -b/(2c)$, and $p = a - 2b/(4c)$ where b and c = regression coefficients, p = fiber length or microfibril angle or density, at which wood changes from juvenile to mature wood.

2.4 Results and Discussion

2.4.1 Density

Average density of 5, 6 and 7 years old sengon and jabon wood, 26 years old Douglas-fir and 18 years old poplar cultivars are shown in Figure 6a-d. Generally, densities of sengon, jabon and Douglas-fir tended to increase from pith to bark. Poplar cultivars (‘lambro’, ‘soligo’, ‘koster’ and ‘I214’) showed different trend. It was due to the samples were taken from veneer samples not solid wood samples. Therefore, the wood very close to the pith was not represented enough in poplar samples. Douglas-fir had the highest density in average of 726 kg m^{-3}, followed by jabon’s density (437 kg m^{-3}), poplar cultivars’ density (401 kg m^{-3}) and sengon was the lowest (331 kg m^{-3}).

Density of 5 years old, 6 years old and 7 years old sengon wood near the pith were 237 kg m^{-3}, 259 kg m^{-3} and 248 kg m^{-3}, respectively (Figure 6a).

Densities of sengon wood near the bark were 393 kg m^{-3} (5 years old), 456 kg m^{-3}(6 years old) and 442 kg m^{-3} (7 years old). Martawijaya *et al*. (2005) stated that the density of sengon wood ranged from 240 to 490 kg m^{-3} (average 330 kg m^{-3}).

Wood density near the pith for the 5 years old, 6 years old and 7 years old jabon wood were 234 kg m^{-3}, 297 kg m^{-3} and 284 kg m^{-3}, subsequently (Figure 6b). While the densities of jabon wood near the bark were 573 kg m^{-3} (5 years old), 606 kg m^{-3} (6 years old) and 615 kg m^{-3} (7 years old). Martawijaya *et al.* (2005) reported that the density of jabon wood, 290 to 560 kg m^{-3} (average 420 kg m^{-3}), although no information was given on whether the samples were near the bark or pith.

For 26 years old Douglas-fir, wood density near the pith was 405 kg m^{-3}, and wood density near bark was 570 kg m^{-3} (Figure 6c). Martin *et al.* (2006) reported that the density of 31 years old Douglas-fir is 447 kg m^{-3}, while CIRAD (2011) found solid Douglas-fir density is 540 kg m^{-3} although no information was available whether the samples were taken from wood near the bark or pith.

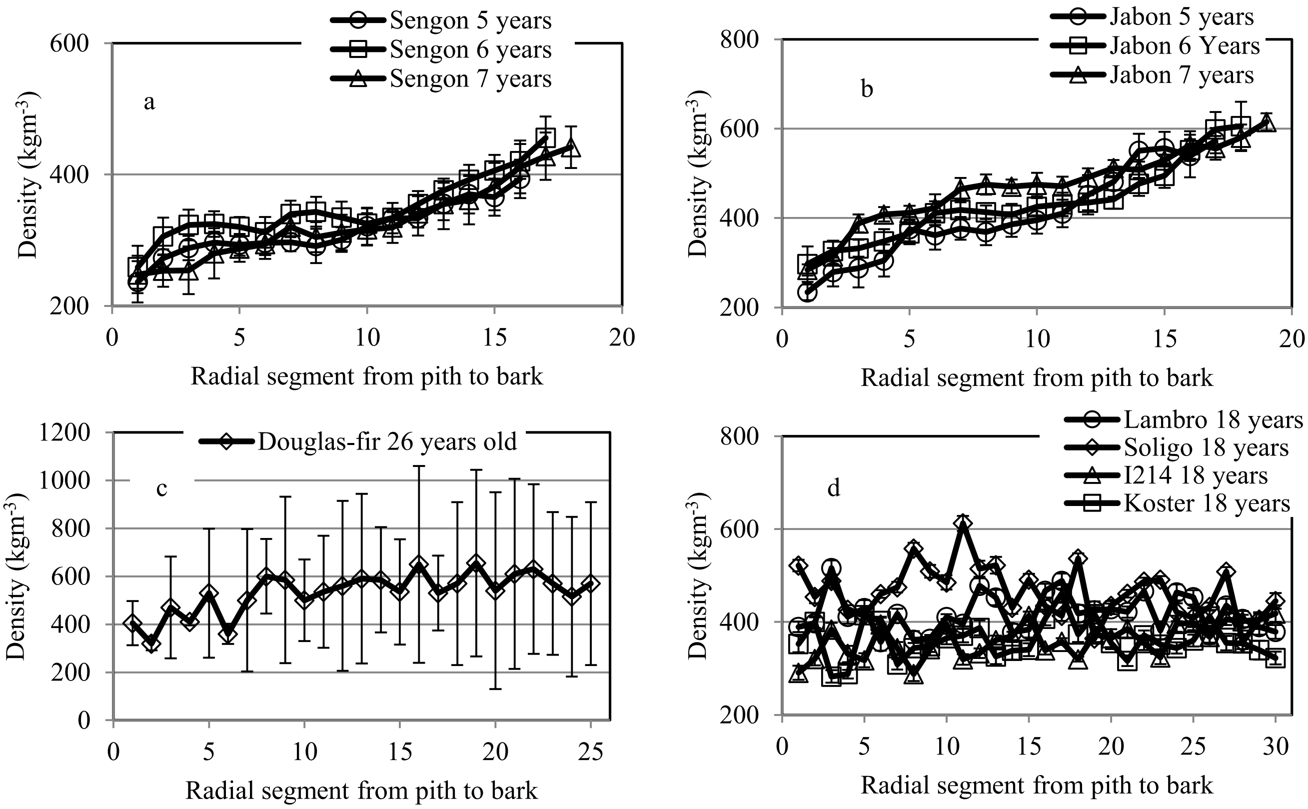

Figure 6 Average density values from pith to bark of sengon (a), jabon (b), Douglas-fir (c) and poplar cultivars (d)

The result in Figure 6d show that the average densities of poplar cultivars tend to slightly fluctuated from pith to bark. It was due to veneers samples were collected up to core diameter of 7 cm and to the presence of tension wood for most of the cultivars. Nurbaiti (2012) declared that the average density of ‘lambro’, ‘soligo’, ‘I214’ and ‘koster’ are 380 kg m^{-3}, 370 kg m^{-3},300 kg m^{-3} and 370 kg m^{-3}, respectively.

In the current study, since density near the pith was lower than that near the bark for sengon, jabon and Douglas-fir, attention should be given for the utilization of these woods in certain wood-processing technologies, e.g. production of sawn timber, drying, plywood and laminated veneer lumber. These results correspond with results of Bendtsen (1978) who reports that specific gravity or density, cell length, strength, cell wall thickness, transverse shrinkage and per cent latewood increase towards the bark, while microfibril angle, longitudinal shrinkage and moisture content decrease. It could be considered that the density behavior from pith to bark of fast growing species not only happened on intensively-managed stands but also unmanaged community forest in Indonesia and in France.

When segmented regression models were applied, it was deduced that the use of density was not appropriate because of low coefficients of determination and large range of ages for transition from juvenile to mature wood. Thus, density could not be considered as a suitable parameter for determining demarcation point of sengon, jabon, douglas-fir and poplar cultivars. The same result was observed by Darmawan *et al*. (2013) who find density trend from pith to bark was also not suitable for determination of transition age between juvenile and mature wood of 7 years old sengon and jabon. On the contrary, the value of ring density and ring area can be used to determine the transition age on black spruce (*Picea mariana*) (Alteyrac *et al*. 2006).

2.4.2 Fiber length

Average fiber length at dbh from pith to bark is presented in Figure 7a-d. The coefficient variations of fiber length values in each segmented rings were observed to be less than 10% for all wood species. The highest value of fiber length was at near the bark. In sengon (5, 6 and 7 years old), average fiber lengths of the first to third segmented rings began from less than 1 mm while in the fourth ring onwards, they exceeded 1000 µm (Figure 7a). In jabon (5, 6 and 7 years old), the average fiber lengths of the first to second segmented ring began from less than 1000 µm, while, starting from the third ring, the lengths exceeded 1000 µm (Figure 7b).

Sengon and jabon of 5, 6 and 7 years old still showed gradual increase in fiber length until near bark. Shorter fiber length near pith is caused by accelerated rate of anticlinal division in fusiform initial cell while longer fiber length near the bark is due to this rate slowing down (Panshin and de Zeuw 1980). Further, average fiber lengths at the dbh from pith to bark for sengon at the age of 5, 6 and 7 years were 1131, 1170 and 1147 µm, respectively, for jabon 5, 6 and 7 years were 1190, 1245 and 1224 µm, respectively. These results also corresponded with results from Kiaei *et al*. (2012) who find that fiber length of *Acer velutinum* increase along the radial direction from pith to bark. The proportional increase of fiber length from pith to bark proved fiber length as a reliable indicator of the juvenile wood presence.

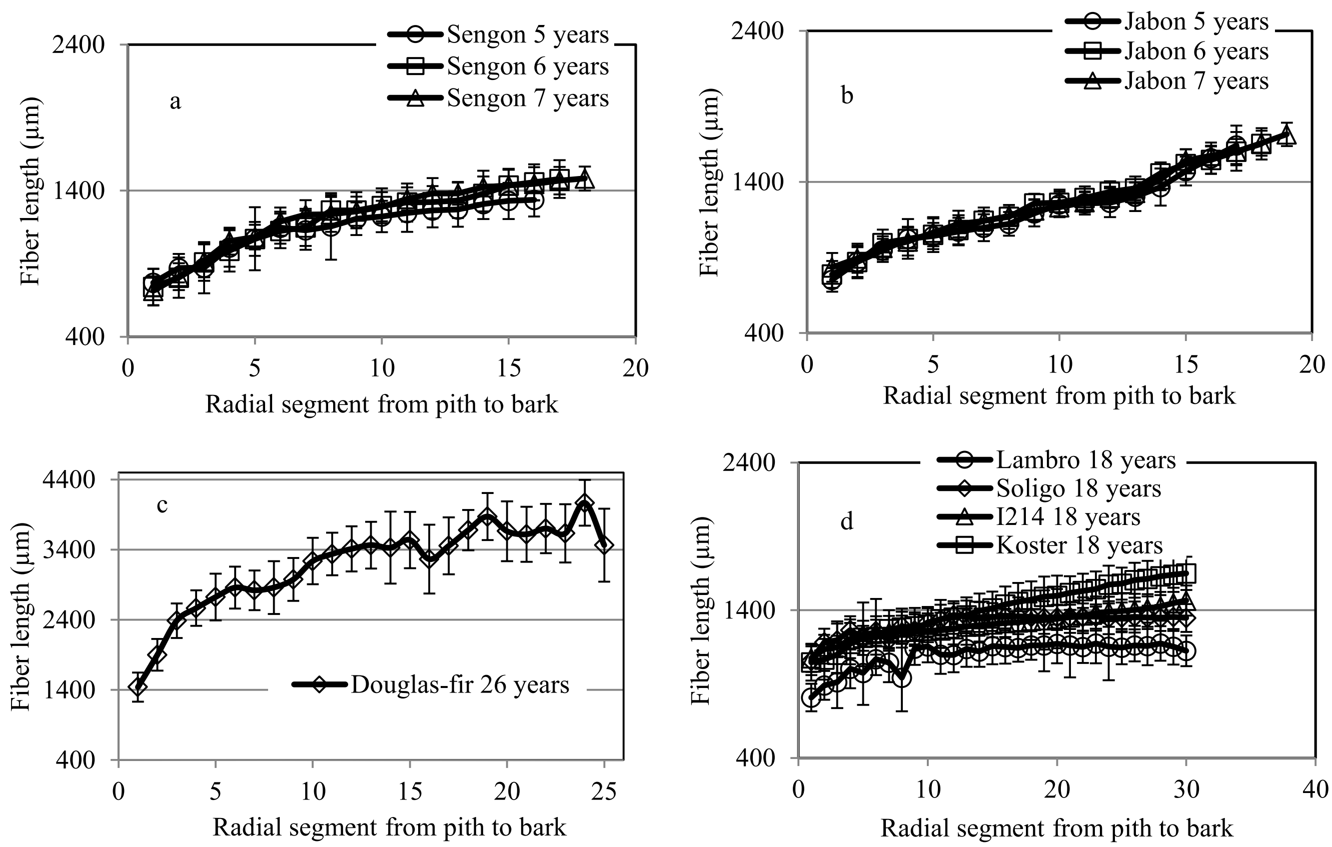

Figure 7 Average fiber/tracheid length values from pith to bark of sengon (a), jabon (b), Douglas-fir (c) and poplar cultivars (d)

Douglas-fir produced longer average fiber length from pith to bark compare to other species in this study. The average fiber length value for 26-years old Douglas fir was 3177 µm (Figure 7c). It correspond to the results presented by Martin *et al*. (2006), who discovered that the average fiber length of 31 years old Douglas fir is 3360 µm.

Figure 7d also shows that 'koster' had fiber length less than 1000 µm from the first to third radial segments. The other cultivars had more than 1000 µm of fiber length starting from the first radial segments. Poplar cultivars did not show gradual increase in fiber length from pith to bark. The average fiber length for 'lambro', 'soligo', 'I-214' and 'koster' were 1097, 1311, 1306 and 1403 µm, respectively. These results corresponded to Panshin and de Zeuw (1980) who reported that the poplar fiber length are in range from 1320 and 1380 µm. However, these results did not correspond to Berthelot *et al*. (2013) who find the average of fiber length for 'lambro', 'soligo', 'I-214' and 'koster' were 853, 867, 868 and 979 µm, respectively. The higher values of fiber length from these results were due to the samples were taken after log diameter of 14 cm, otherwise Berthelot *et al*. (2013) use the samples from pith to bark.

Douglas-fir (softwood) had the longest fiber length, then followed by jabon, poplar cultivars and sengon (belongs to hardwood). This is in line with Bowyer *et al*. (2005) who state that hardwood fibers are shorter than softwood tracheids. These differences gave an indication that the tree species in this study would have different impacts on their utilization.

Segmented regression analysis suggested that fiber length was an appropriate trait to determine the demarcation point from juvenile to mature wood in sengon, jabon, poplar cultivars and Douglas-fir. The demarcation point according to the fiber length values are presented in Table 3. Using segmented regression analysis, we concluded that juvenility of 5, 6 and 7 years old sengon occurred until the 17^{th}, 17^{th} and 16^{th} ring while that of jabon occurred until the 24^{th}, 23^{rd} and 21^{st} rings. Therefore, based on fiber length trait, we concluded that 5, 6 and 7 years old jabon and sengon were all juvenile. These results suggested that the mature wood for sengon would be occurred after dbh 34 cm and for jabon would be occurred after dbh 48 cm. Unfortunately, sengon and jabon in Indonesia are felled at the ages between 5 and 7 years because the dbh of about 35 cm is large enough for wood industry and selling at shorter cycle will mean more income for the communities.

Table 3 Estimated demarcation point (transition age) from juvenile to mature wood for sengon, jabon, Douglas-fir and poplar cultivars based on fiber length using segmented regression analysis

Species	Age (years)	Number of radial segments based on fiber length
Sengon	5	17^{th}
	6	17^{th}
	7	16^{th}
Jabon	5	24^{th}
	6	23^{rd}
	7	21^{st}
Douglas-fir	26	20^{th}
Poplar – 'soligo'	18	16^{th}
Poplar – 'koster'	18	16^{th}
Poplar – 'I214'	18	15^{th}
Poplar – 'lambro'	18	16^{th}

Transition age for the 26 years old Douglas-fir occurred at 20^{th} radial segments (20 years old). We concluded that the 26-years old Douglas fir contained 77% of juvenile wood portion. Di Lucca (1989) used segmented regression modelling in an effort to identify the transition age for Douglas-fir. He found that the transition age is about 20 rings from the pith at breast height.

Using segmented regression approach, we concluded that juvenility of 'lambro', 'soligo' and 'koster' occurred until 16^{th} radial segments, while for 'I-214' occurred until 15^{th} radial segments. These results suggested that poplar cultivars contained approximately 52% of juvenile portion (at the age around 12-13 years old). This result is in line with Pezlen (1994), who found that the transition age of Euramerican hybrid poplar [*Populus* x *euramericana* (Dode) Guinier] clones occur on 10-13 years old.

2.4.3 Variation of transition age with traits

The transition age (demarcation point) for wood species was calculated based on fiber length, using segmented regression analysis, as described above. The segmented regression analysis applied to fiber length (Table 3).

The variations in fiber length in temperate woods have been extensively characterized in many species, especially in pine. The commercial importance of fiber length, as it relates to wood quality, is well established for temperate woods, but is less clear for tropical woods. Relatively few tropical woods have been characterized, so there is a need to extend the range of species and ecotypes that have been investigated. Additionally, more well-designed studies relating fiber length and its interaction with other wood properties to timber quality are needed. Finally, the means through which trees control changes in fiber length in response to developmental and environmental influences are poorly understood.

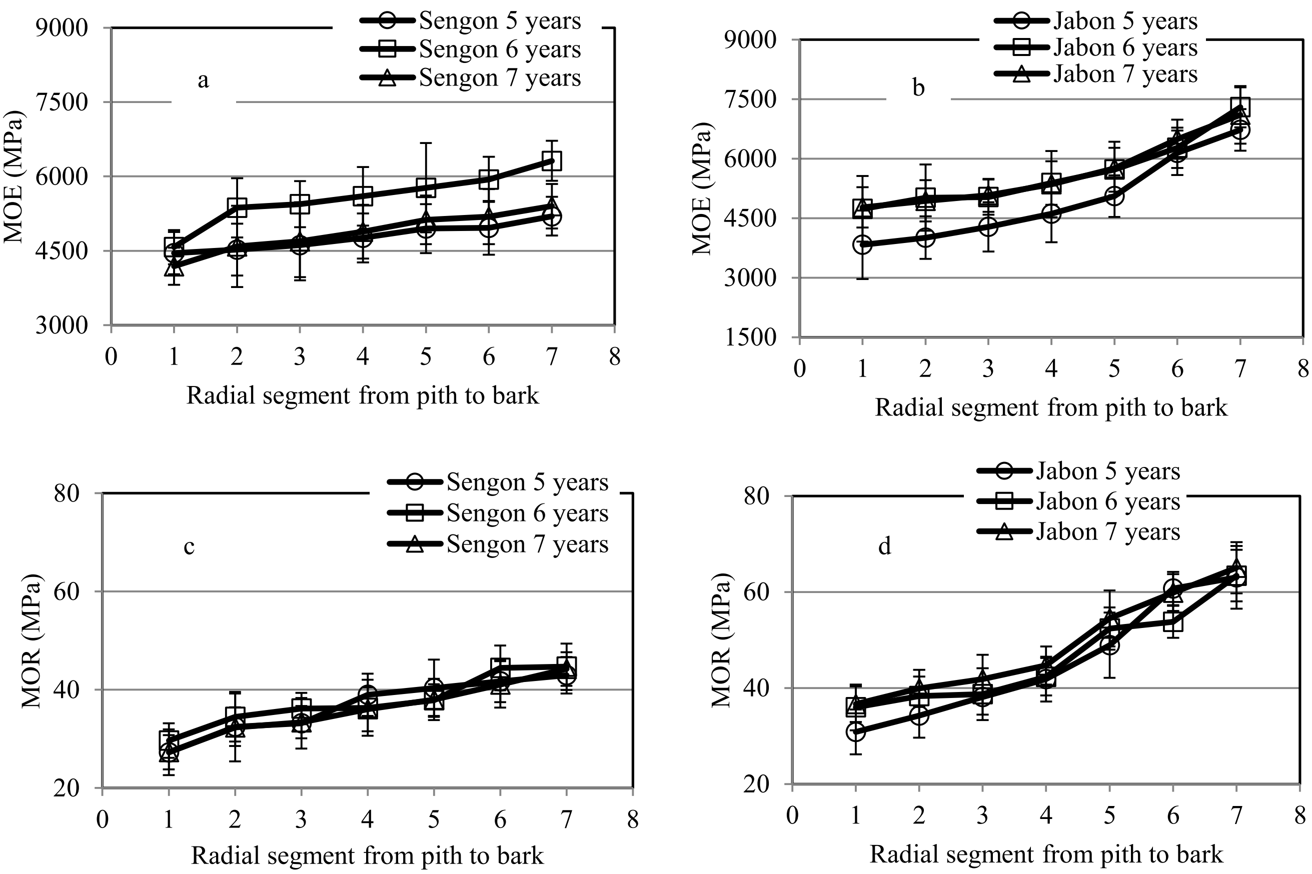

Figure 8 Average values from pith to bark of sengon MOE (a), jabon MOE (b), sengon MOR (c) and jabon MOR (d)

The behaviors of MOE and MOR from pith to bark for sengon and jabon are presented in Figure 8a-d. The results indicated that wood near pith of sengon and jabon had lower MOE and MOR values than wood near the bark. The lower MOE and MOR of wood near pith were due to larger microfibril angle and lower density. However, the proportional increase of the MOE and MOR from pith to bark precludes the use of MOE and MOR as a reliable juvenile wood presence indicator.

Mean MOE values from pith to bark for 5, 6 and 7 years old sengon wood were 4780, 5573, and 4867 MPa, respectively. The mean MOR values from pith to bark were 37 MPa (5 years old), 38 MPa (6 years old) and 36 MPa (7 years old).

Mean MOE values from pith to bark for 5, 6 and 7 years old jabon wood were 4951, 5638, and 5642 MPa, respectively. The mean MOR values from pith to bark were 45 MPa (5 years old), 46 MPa (6 years old) and 49 MPa (7 years old). Martawijya *et al.* (2005) found out that the MOE and MOR of sengon are 4450 MPa and 32 MPa, respectively, and that of jabon are 5545 and 39 MPa, respectively. However, the average strength values in this reference was without any information whether the samples from juvenile or mature wood. Fortunately, the MOE and MOR results in this work are within the range reported in that literature.

The behaviors of density and fiber length and strength values of sengon and jabon wood obtained in this study were expected to provide practical information for processors and silviculturists of sengon and jabon, leading to a more appropriate usage of these species. The presence of juvenile wood has to be taken into consideration with respect to the use of sengon, jabon, Douglas-fir and poplar cultivars for construction purposes particularly when bending and dynamic strength properties are critically important factors. Lower strength properties of juvenile wood imply that strength properties of sengon, jabon, Douglas-fir and poplar cultivars trees depend on their juvenile wood contents. Thus, timber with large percentages of juvenile wood, especially from fast growing trees, will be less desirable for solid wood products. Several studies completed on solid-sawn lumber have provided a good understanding of how juvenile wood affects the mechanical properties of solid-sawn lumber (Biblis 1990; Kretschmann and Bendtsen 1992; MacPeak *et al.* 1990).

Considering efficiency in utilizing fast growing timber, reducing the volume of juvenile wood would be beneficial. There are long- and short-term alternative solutions for reduction of juvenile wood proportion. The former would include genetic and sylvicultural treatments while the latter, improvement in wood utilization methods, e.g. producing laminated veneer lumber from fast growing species which will help solve problems linked to shrinkage of raw material for construction and protection of natural forest. Moreover, the shapes of fast growing species logs (round, straight and cylindrical) also become supporting factor in peeling process. However, a major problem in the production of laminated veneer lumber is ensuring veneer surface quality whereby advanced research is needed to optimize peeling process of logs containing large amounts of juvenile wood.

2.5 Conclusion

The demarcation point (transition age) between juvenile and mature wood was dependent on the traits or parameter used. According to fiber length traits, transition age of 5, 6 and 7 years old of sengon and jabon were occurred ranging from 17 to 18 radial segment. Based on fiber length, the transition age of poplar cultivars and Douglas-fir, occurred from 12 and occurred from 18 respectively. The portions of juvenile wood both in sengon and jabon at dbh at the age of 5, 6 and 7 years old were 100 %. Poplar cultivars and Douglas-fir contained 52% and 77 % of juvenile wood portion, respectively.

Fiber length appeared to a good anatomical indicators of demarcation point between juvenile and mature wood compare with density in this study. Segmented regression analysis proved to be a practical and objective method to estimate demarcation point (transition age) between juvenile and mature wood in sengon, jabon, poplar cultivars and Douglas-fir.

The demarcation point (transition age) of sengon, jabon, poplar cultivars and Douglas-fir wood obtained in this study were expected to provide practical information for industries and silviculturists of these species. This would eventually provide more appropriate utilization of these species especially for construction purposes. Lower density and static bending strength (MOE/MOR) of the juvenile wood at the age of 5, 6 and 7 years suggested that both sengon and jabon plantation forest can be manipulated effectively through appropriate management practices (e.g. longer rotation age) to reduce juvenile wood content. Because timber with large percentage of juvenile wood, especially from fast-growing trees, will be less desirable for solid wood products.

3 THE EFFECT OF JUVENILITY ON VENEER LATHE CHECK AND SURFACE ROUGHNESS OF FAST GROWING WOOD SPECIES

French summary

La qualité des surfaces des placages est un critère essentiel dans la fabrication de panneaux LVL. Cette étape de déroulage est d'autant plus critique pour les bois à croissance rapide qui contiennent une forte proportion de bois juvénile réputé plus sensible aux principaux défauts susceptibles d'apparaitre pendant le déroulage. Pour les cas du sengon (*Falcataria moluccana*) et du jabon (*Anthocephalus cadamba*) traitées dans cette étude et révélateurs de la ressource actuelle indonésienne, on peut même considérer que la proportion de bois juvénile atteint 100% (Chapitre 3). L'objectif de cette partie sera donc de caractériser l'impact du caractère juvénile du bois sur la qualité des placages et en particulier l'état de surface et la fissuration.

Dans la fabrication de placage, en particulier lors du déroulage, le bois a tendance à fissurer de manière plus ou moins périodique sur la face dite « ouverte » le long du fil du bois (Figure 9). Ces fissures s'ouvrent sur la face ouverte suite à un champ de contrainte en traction perpendiculaire aux fibres généré par la géométrie de coupe (Thibaut 1988, DeVallance *et al*. 2007, Leney 1960; Lutz 1974). En fonction de plusieurs paramètres dont les principaux sont l'épaisseur du placage déroulé, la densité du bois et sa température, l'énergie nécessaire pour créer le placage par cisaillement peut excéder celle d'ouverture de fissure. Le mécanisme de coupe change et le copeau n'est donc plus obtenu par cisaillement mais par fendage d'après fissure (Thibaut et Beauchêne 2004). La profondeur, la longueur et la fréquence de fissuration ont une part majeur dans l'évaluation de qualité des surfaces des placages. Plusieurs propriétés du bois lui-même ont une influence importante sur la fissuration. On peut citer en particulier et sans ordre d'importance : la vitesse de croissance des bois, la densité, la variation des propriétés du bois de la moelle à l'écorce comme la densité, la longueur des fibres, le retrait longitudinal, la microstructure (porosité), la largeur des cernes, la proportion de bois final, la composition lignocellulosique, les conditions de stockage des grumes (Leney 1960; Cumming *et al*. 1969, Lutz 1974; Thibaut 1988, Dupleix *et al*. 2013, Darmawan *et al*. 2015).

Le phénomène de fissuration peut être limité en utilisant un outil complémentaire appelé barre de pression dont le rôle est de générer un champ de contraintes antagoniste en compression (Kollmann *et al*. 1975). Cependant, la tendance actuelle du déroulage va vers des machines « légères » à entrainement périphérique, surtout en Asie, qui ne permet pas un régalage optimal de la barre de pression comme sur les machines plus massives communément utilisées pour les feuillus en Europe. Une autre possibilité de limiter la fissuration est de procéder à un étuvage préalable (Dupleix *et al* 2013). En résumé, les conditions de déroulage ont elles aussi une influence capitale sur la fissuration : angle de coupe, angle de dépouille, épaisseur, pression, température d'étuvage, vitesse de déroulage (Leney 1960; Lutz 1974; Thibaut 1988, Thibaut Beauchêne 2004, Dupleix *et al*. 2013). Tous ces paramètres ont une influence directe sur le ratio entre la contrainte d’écoulement par cisaillement et la limite à l’ouverture de fissures de mode I. En conséquence, la température du bois a un impact fondamental sur cet équilibre. Ainsi, Palka 1974 observe une nette réduction de la sévérité des fissures suite à l’étuvage. D’après Dundar *et al.* (2008), en fonction des essences ces températures peuvent s’échelonner de 38 à 71°C. Resch and Parker (1979) ont déclaré que la température optima de déroulage des rondins de douglas s'étendent de 49°C à 60°C pour avoir le placage avec une meilleure qualité. En général les bois de résineux sont étuvés à des températures moindres que les feuillus essentiellement du fait de leur différence de densité. De plus, l’étuvage qu’il soit réalisé par eau chaude liquide ou à l’état de vapeur permet aussi d’améliorer l’état de surface des placages, l’uniformité de leur épaisseur et par conséquence la qualité du joint de colle (Berkel *et al.* 1969; Bozkurt and Goker 1986; Goker and Akbulut 1992; Lutz 1978; Ozen 1981).

Le taux de compression appliqué lors du déroulage est également essentiel. Il a été précisément décrit dans Thibaut 1988. Pour l’Eucalyptus, un taux de compression supérieur à 5% a sensiblement réduit la fissuration (rapport entre la profondeur de passe soit l’épaisseur théorique du placage et la passage soit la distance entre la face de coupe et la barre de pression). Entre les pressions de 0,5 à de 5%, la déformation est dans la zone élastique de l'eucalyptus (Acevedo *et al.* 2012). Une autre étude (Cumming and Collett 1970) a montré qu’un taux de compression entre 5 et 20% permettait de réduire sensiblement la profondeur des fissures de déroulage pour le sequoia.

Pot *et al.* (2015) ont observé une variation inversement proportionnelle entre la profondeur des fissures et leur fréquence pour du hêtre. Plus le taux de compression appliqué est fort et plus les fissures sont nombreuses mai peu profondes.

Les méthodes et les dispositifs pour évaluer la fissuration sont peu nombreux. Palubicki *et al.* (2010) a proposé un prototype qui mesure les fissures à l'aide d’une poulie pour fléchir le placage et d’une caméra. L’avantage de cet outil est qu’il permet de mesurer des grandes longueurs de placages (milliers de fissures) mais en revanche, le choix du diamètre de la poulie peut influencer les mesures de profondeur. La méthode la plus simple reste un marquage couleur et une observation au microscope (Palka 1961; Jung and Day 1981). En revanche elle est très fastidieuse et ne peut raisonnablement concerner que quelques dizaines voire une centaine de fissures.

L’état de surface de placages déroulés est l’un des paramètres essentiels dans le procédé de fabrication des LVL puisqu’il influence fortement ses propriétés (Tiryaki *et al.* 2014). Selon la Tabarsa et al. (2011), l'un des paramètres majeurs de l'adhérence des placages est la rugosité, une mesure des fines irrégularités sur la surface de placage. Le fait d’utiliser des bois de petits diamètre à croissance rapide et de dérouler pratiquement jusqu’à la moelle favorise la production de placages rugueux. (Faust et Rice, 1986) ont observé une tenue moindre des joint de colle pour des placages rugueux.

La rugosité est un paramètre délicat à mesurer qui peut être largement influencé par la microstructure du bois et le procédé de mesure. La rugosité de surface peut être mesurée au moyen de méthodes avec et sans. Selon JIS 0601-2001, les paramètres exprimant l'aspérité de la surface d'un objet sont rugosité moyenne arithmétique (Ra), rugosité moyenne en dix points (Rz), et taille maximum (Rmax). Beaucoup d'études dans ce domaine utilisant le Ra en tant que paramètre de rugosité parce qu'il est facile à calculer (Vorberger and Teague 1981; McColl 1987; Sherrington and Smith 1987; Mummery 1993; Richter *et al*. 1995; Sofuoglu 2015). Il n'est cependant pas le toujours le meilleur critère pour le cas du bois.

La mouillabilité d'une surface caractérise sa capacité à absorber et diffuser un liquide (Baldan 2012). La mouillabilité du bois est paramètre important qui caractérise l'interaction entre une surface de bois et un liquide (tels que l'eau, le revêtement et l'adhésif) (Gray 1962; Elbez 1978; Gardner *et al*. 1991; Gindl *et al*. 2004; Rathke et Sinn 2013) et qui est également un indicateur de la résistance des interfaces dans les produits multiplies.

Quand un liquide est déposé sur une surface en bois, on peut observer trois effets (Shi et Gardner 2001) : (1) la formation d'un angle de contact à l'interface solide/adhésif, (2) la propagation du liquide sur le bois, et (3) la pénétration du liquide dans le bois. La mouillabilité d'un liquide sur la surface en bois est habituellement évaluée par la mesure d'angle de contact. Shi et Gardner (2001) a déclaré que l'angle de contact change en fonction du temps en raison de la diffusion et la pénétration du liquide.

L'objectif de cette partie était de determiner les effets du caractère juvénile du bois et de l'étuvage sur la fissuration, la rugosité et la mouillabilité des placages déroulés de 3 millimètres de sengon et de jabon. De bandes de placages ont été découpées pour effectuer des mesures d'état de surface et d'angle de contact puis d'autres échantillons ont été sélectionnés pour caractériser la fissuration en respectant le séquençage proposée depuis la moelle jusqu'à l'écorce. La fréquence de fissuration, la rugosité et l'angle de contact diminuent depuis le cœur jusqu'à la moelle. Concernant la profondeur des fissures et leur longueur, bien que la variabilité soit importent, les tendances observées dans la littérature se confirment : plus le fissurent sont nombreuses et moins elles sont profondes.

D'une manière générale, le fait d'étuver les bois semble favorable puisque tous les indicateurs diminuent concernant la fissuration ou l'état de surface et la mouillabilité est améliorée.

3.1 Introduction

Veneer surface quality becomes important factors to be studied thoroughly to optimize peeling process of logs containing large amounts of juvenile wood. Fast growing species such as sengon (*Falcataria moluccana*) and jabon (*Anthocephalus cadamba*) contained 100 % of juvenile wood at the age of 5, 6 and 7 years old (see Chapter 2). Since the sengon and jabon wood is being used in the laminated and plywood industry, high bonding properties are expected. However, as the sengon and jabon logs are being peeled and much more juvenile woods are being utilized, lathe check veneer and the level of veneer surface roughness would be important to be measured. Therefore, it considerably needs to study lathe checks and surface roughness of veneer peeled from the sengon and jabon logs.

Most new cultivars display a very interesting growth rate, which implies a large proportion of juvenile wood (Rowell *et al*. 2005). Considering the results on

Chapter 2, poplar cultivars contained 52 % of juvenile wood at the age of 12 years old. A high growth rate induces lower density, lower strength, numerous knots and possibly a large proportion of juvenile wood and these factors appear to contribute to low veneer stress grading (Zhang *et al*. 2004). Several studies reported that poplar wood is excellent for veneer-making without requiring treatment prior to peeling (Pourtet 1951; El-Houzali 2009; Nurbaity 2012). Therefore, in this study, we did not apply any treatment prior to peeling on poplar logs.

In rotary-cut veneer manufacturing, when peeling starts, the wood tends to split along the grain. Lathe checks are formed at the veneer's loose side (Figure 9) as tension force of the lathe's knife pulls the veneer away from the peeler block and flattens the veneer from its natural curvature (DeVallance *et al*. 2007). With respect to the cross section of the veneer, this advance splitting causes the formation of vertical cracks (known as lathe checks). Lathe checks are created by the cutting geometry during peeling process (Leney 1960; Lutz 1974; Thibaut 1988). Depending on several parameters as veneer thickness, wood density and wood temperature, the energy required to produce the veneer during cutting can be lower by splitting than by shearing. Indeed, the cutting geometry generates a traction stress field which favors check opening (Thibaut and Beauchene 2004). The depth, length and frequency of lathe checks have been widely taken into account during veneer surface quality evaluation. The risk of this checking can be reduced by using a nosebar (Kollmann *et al*. 1975). However, recent spindle less rotary lathes, which are widely used to peel small log diameter of fast growing wood species, have not been completed with an adjustable nosebar. A boiling treatment of bolts would be considered to reduce the lathe check.

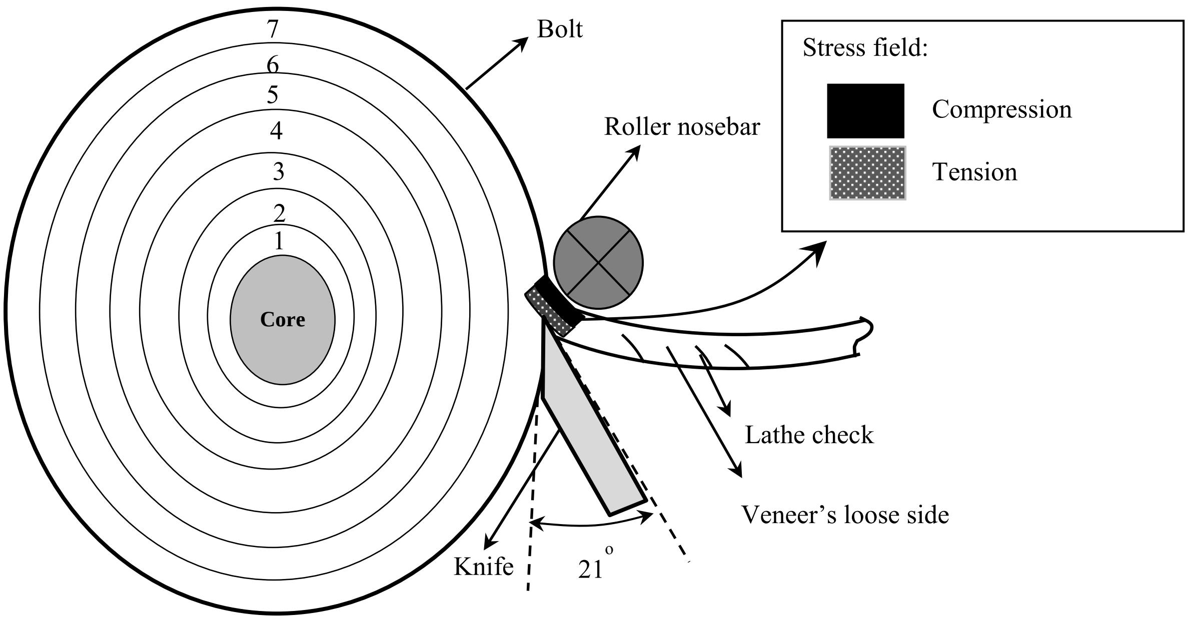

Figure 9 Peeling diagram on the cross section of logs to produce veneers from segmented rings number 1 to 7, and stress (tension and compression) occurring during the peeling (Darmawan *et al*. 2015)

There are many factors which contribute to the formation and severity of veneer lathe checks. It is usually very difficult to determine the exact cause of checking for any given incident. However, experience and research have taught us some of the most common and severe influences of veneer lathe checking. Veneer lathe check can be affected by wood log's characteristic (specific gravity and wood pores). In addition, pretreatment and manufacturing conditions such as steaming or boiling, knife bevel and nose bar pressure, peeling temperature, peeling thickness and peeling speed, may also affect lathe checks (Darmawan *et al*. 2015).

Differences in log's wood properties have shown significant relationships to lathe check formation when peeled into veneer. In particular, tree growth rate, specific gravity, the pith-to-bark variation in wood traits such as density, fiber length, longitudinal shrinkage, ring width, latewood proportion, and lignin-cellulose composition, and log conditioning have shown to affect veneer quality (Leney 1960; Lutz 1974; Thibaut 1988, Dupleix *et al*. 2013, Darmawan *et al*. 2015). A spindle-less rotary lathe allows manufacturers to peel smaller log's diameter and to produce more veneer sheet up to the log's core. When fast-grown logs were peeled, deeper lathe checking resulted (Darmawan *et al*. 2015). In general, it has been found that peeled quality is reduced as peeling from the log's sapwood to core material, due to factors such as lower specific gravity, highest growth rate, cutting speed, and highest angle of attack at the core material (Palka and Holmes 1973). It has been noted that the best veneer was produced when peeling logs with growth rings orientated at 0^o to the knife, while veneer quality decreased progressively as growth ring angle varied in either the plus or minus directions (Cumming and Collett 1970). Past research indicated that coarse grain, higher specific gravity veneer tends to check more significantly than does fine grain, lower specific gravity veneer. Lathe check depth was significantly less for fast growing trees (Cumming *et al*. 1969) which is in contradiction. Species of wood with fine pores check less than wood with large pores. This is because deep lathe checks and large pores create weak spots on the face veneer which provide less resistance to failure when the face veneer is under stress (Forbes 1997).

The pretreatment and manufacturing factors affecting lathe check can be controlled to achieve better veneer surface. Log temperature at the time of peeling veneer significantly affects the quality of veneer. Low temperatures produce veneers with deeper and more spaced checks than high temperatures log (Suh and Kim 1988; Dupleix *et al*. 2013). Heating of logs with steam is one of the most important processes during the veneer manufacturing. The main function of steam heating is to soften veneer log temporary and making it more plastic, pliable, more readily peeled, and improving the quality and quantity of material recovered from the log. Steam heating is more efficient than water heating in terms of its safety aspects and shorter heating time (Baldwin 1995). The other advantages of steam log heating include decrease in energy use during the peeling, reducing cracks on the veneer due to knife checks, improve tensile strength, and produce veneers having small color variations. Surface characteristics, uniform thickness of veneer, and bonding quality for plywood manufacture are influenced by steaming temperature and duration between steaming and peeling processes (Berkel *et al*. 1969; Bozkurt and Goker 1986; Goker and Akbulut 1992; Lutz 1978; Ozen 1981). Above benefits can also be reached by determining the optimum steaming temperature, steaming time as function of wood density and log diameter. Gupta and Bist (1981) found that the optimum heating temperatures of logs for obtaining higher shear strength of plywood are varied by wood species.

Higher peeling temperatures reduce the severity of lathe check depth (Palka 1974). Most wood species are said to produce the best veneer quality when log temperatures are between 38°C to 71°C. Dundar *et al*. (2008) found that when beech logs boil in water at 60–70°C for 20 h, 40 h, and 60 h, the veneers obtain from a 40 h boiling period could minimize the mean surface roughness values for all veneers obtain from inner (heartwood), center or outer (sapwood) portion of the logs. Quality of veneer obtain from Canadian pine and Norway spruce logs is also influenced by the temperature of the logs during the peeling (Anonymous 1998). Another study shows that surface roughness and the quality of the veneer obtained from Douglas-fir logs felled following heavy rainy days are better than those of felled during dry times in summer (Hecker 1995). In the same study, it was also reported that Douglas-fir logs leave in the rain for 13 days after harvesting produce veneer with smoother surface. Resch and Parker (1979) stated that optimum peeling temperature of Douglas-fir logs range from 49°C to 60°C to have veneer with better quality. In general peeling temperature of the softwood logs are lower than that of hardwood logs due to their higher density. Another studies concluded that by boiling jabon (Kabe *et al*. 2013) and sengon (Darmawan *et al*. 2015) logs in water at 75°C for 4 h, could reduce the lathe check frequency.

The magnitude of compression applied to veneer surface was considered as important factor that affects peeled veneer quality. Pressure can be applied ahead of the knife by use of nose bar pressure. In eucalyptus veneer, the lathe check was found to decrease when the veneer was peeled with nose bar pressure up to 5% (ratio of lead gap opening to thickness). Between 0.5 to 5% pressures, deformation is within the elastic zone of the eucalyptus (Acevedo *et al*. 2012). Another study indicated that settings the nose bar pressure up to a certain point by adjusting the lead and exit gap lathe (5% to 20%) reduced lathe check depth in redwood veneer (Cumming and Collett 1970) and also showed a tendency to produce more frequent shallow lathe checks. In many instances, higher horizontal pressures are needed for thicker veneers and lower pressure for thinner veneers, and in general, the thinner the veneer, the better the resulting peeled veneer quality. Rotary cutting speed (meter of veneer produced per minute) is another variable that affects veneer lathe check. An increase in cutting speed results in weaker veneer with deeper lathe checks (Lutz 1974).

The measurement of lathe check methods and devices for lathe check detection are not so common. Palubicki *et al*. (2010) found the lathe check method by using pulley to arch the veneer. The success of measurement is strongly influenced by the choice of pulley diameter. He investigated that when diameter of the pulley is too small, the measurement process will lead to cracking and increase the depth of lathe check thus the measure is not reliable. Otherwise, if diameter of pulley is too large, veneer cracks would not open so it is difficult to be detected by the camera. It was reported in other studies that a color marking is proposed for the lathe check measurement, without increasing the depth and length of lathe check (Palka 1961; Jung and Day 1981).

The quality of wood surface roughness is one of the most important properties influencing further manufacturing process such as joining application, bonding quality and strength characteristics (Tiryaki *et al*. 2014). According to Tabarsa *et al*. (2011), one of the parameters that affecting interfacial adhesion is the veneer roughness, a measure of the fine irregularities on the veneer surface. Factors such as the utilization of smaller diameter logs and high speed lathe technology that allows for peeling veneer near then center of logs contribute rougher veneers being used for engineered wood product. High veneer roughness leads to lower glue bond quality (Faust and Rice 1986). The surface roughness of veneer depend on structural features such as annual ring variation, wood density, cell structure and latewood/earlywood ratio (Magoss 2008; Kilic *et al*. 2009). In order to accurately characterize the surface roughness of veneer, it is important to select suitable roughness measurement devices and methodology (Hendarto *et al*. 2006). Veneer surface roughness can be measured by means of contact and non-contact method. The first type includes contact stylus tip, tactile sensation and pneumatic method. The stylus trace method has emerged as applicable method for measuring surface roughness (Peters and Mergen 1971; Faust 1987; Richter *et al*. 1995; Sofuoglu 2015) even if it non-contact methods could be more efficient for wood.

According to JIS 0601-2001, parameters expressing the surface roughness from the surface of an object are arithmetical mean roughness (Ra), ten point mean roughness (Rz), and maximum height (Rmax). Many studies in this field using Ra as their roughness parameters because it is easy to calculate (Vorberger and Teague 1981; McColl 1987; Sherrington and Smith 1987; Mummery 1993; Richter *et al*. 1995; Sofuoglu 2015). According to Dundar *et al*. (2008), Ra is the average distance from the profile to the mean line over the length of assessment.

Wetting refers to how easily and efficiently a liquid spreads over a solid surface (Baldan 2012). The wettability of wood is an important parameters that provides a series information on the interaction between wood surface and liquids (such as water, coating and adhesive) (Gray 1962; Elbez 1978; Gardner *et al*. 1991; Gindl *et al*. 2004; Rathke and Sinn 2013), which also had a significant influence on the bonding strength of wood composites. To obtain proper interfacial bonding and a strong adhesive joint, good adhesive wetting, proper solidification (curing) of the adhesive and sufficient deformability of the cured adhesive (to reduce stresses that occur in the formation of the join) are important. When a liquid wets wood surface, three effects can be observed (Shi and Gardner 2001): (1) the formation of a contact angle at the solid and adhesive interface, (2) the spreading the liquid on the wood, and (3) the penetration of the liquid into the wood. Wettability of a liquid on wood surface is usually evaluated by contact angle measurement. Dropping some fluids (water or adhesive) on to the loose side or tight side of veneers are common method to measure contact angle (Shi and Gardner 2001; Sulaeman *et al*. 2009).

The objective of this research was to determine the effects of wood juvenility and boiling treatment on lathe checks, surface roughness and wettability of the 3 mm rotary-cut sengon and jabon veneer.

3.2 Materials

Wood sample used in this study were sengon and jabon as described in Table 4. The sample trees having straight stems and free external defects were chosen with the intent of minimizing tree-to-tree variation.

Table 4 Trees information for the peeling process

Wood Species	Growth Site	Age (years old)	Dbh (cm)
Sengon (*F. moluccana*)	Sukabumi, Indonesia	5	28
Jabon (*A. cadamba*)	Sukabumi, Indonesia	5	28

The sengon and jabon samples trees had a height of branch-free stem range from 6-8 m. The length of sengon and jabon logs samples was 60 cm, which were cut from 125 cm log of the bottom part of each tree. The sample logs were wrapped in plastics, kept cold, and maintained the green condition before they were transported to the wood workshop for the rotary cutting.

3.3 Method

The peeling process of sengon and jabon were taken place at Workshop of Wood Quality Improvement Division of Forest Product Department of Faculty of Forestry, Bogor Agricultural University, Indonesia. All veneer qualities measurements were performed at Wood Quality Improvement Division of Forest Product Department of Faculty of Forestry, Bogor Agricultural University, Indonesia

3.3.1 Peeling process

Tree rings have been used for a long time in areas outside the tropics to characterize the presence of juvenile and mature wood. Considering distinct growth rings are absence in sengon and jabon trees, segmented ring was considered to be practically useful for characterizing their juvenility. A specified 1 cm width of segmented rings was made from pith to bark on the cross section of logs and numbered consecutively (No. 1-7) as shown in Figure 9**.**

Four logs section (bolts) in diameter of 28 cm for sengon and jabon in length of 60 cm were selected. The first two bolts were soaked in water at room temperature (called unboiled), and the other two bolts were subjected to boiling process in hot water at 75°C for 4 h (called boiled). Subsequently, the bolts were peeled off to obtain veneers in the thickness of 3mm. For each peeling, a sharp knife was used. The other factors such as knife angle, peeling angle, log temperature, peeling speed were kept constant in the study. The knife angle was 20°, and peeling angle was 21° (clearance angle and knife angle). The veneers were peeled using a spindle less rotary lathe. The bolts were peeled up to core diameter of 6 to 8 cm in order to produce veneers from the 7 different radial segments (Figure 9). The veneers were collected and grouped for each radial segments and numbered consecutively from near the pith (number 1) to near the bark (number 7). Veneer in each radial segments was measured for characterizing the thickness variation, lathe checks, surface roughness and contact angle

3.3.2 Veneer quality

3.3.2.1 Measurements of thickness variation

Veneer sheets produced from each radial segments were collected and clipped to 10 cm x 60 cm veneer specimens. Three test specimens were used for the measurements of thickness variation. Six points of thickness measurements were marked on the side of each test specimen. (see Figure 10)

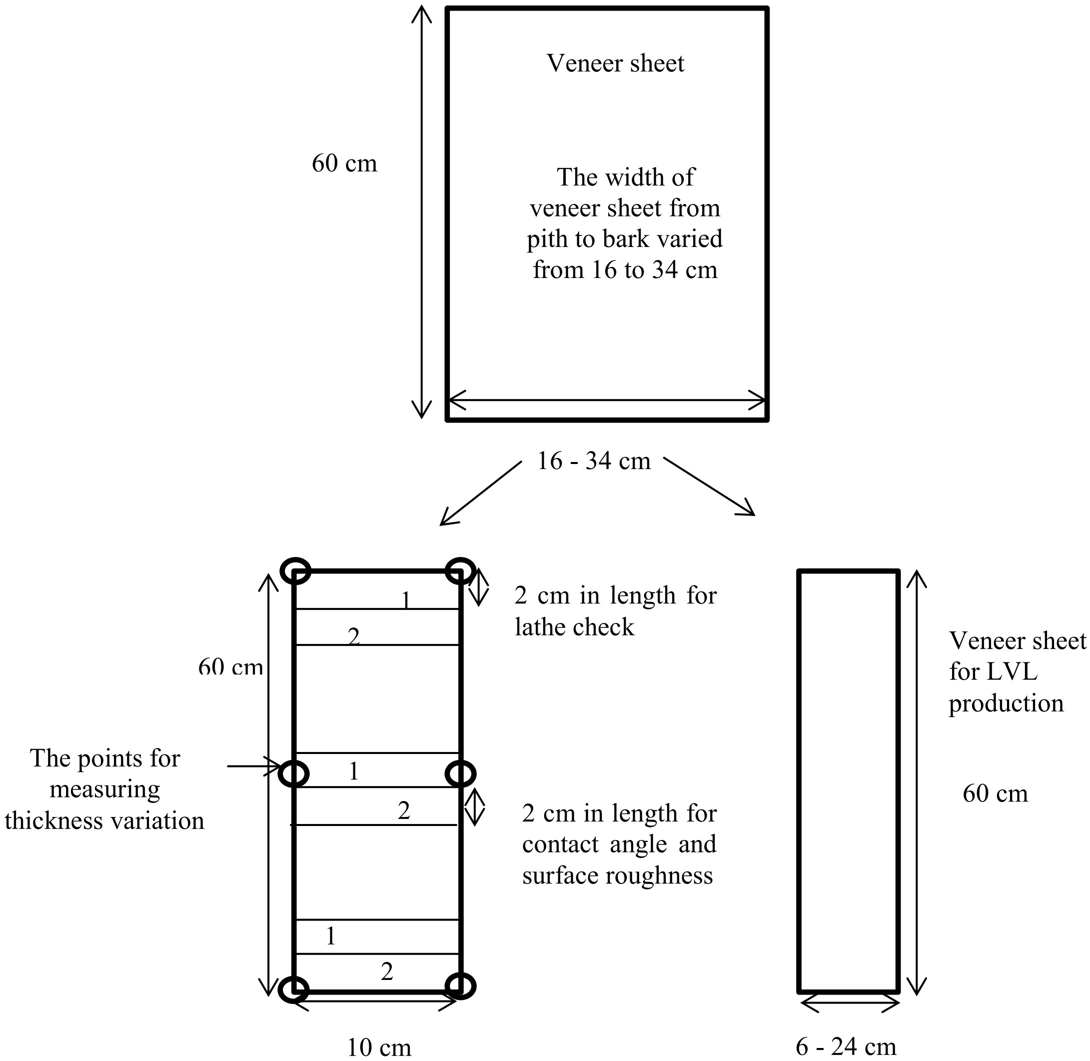

Figure 10 Schematic diagrams of samples for veneer thickness variation, contact angle, surface roughness and LVL production

3.3.2.2 Measurements of lathe check frequency

Sengon and jabon test specimens were kept in the green condition. In order to be able to observe lathe checks clearly (improve contrast), red ink was stained on loose side of veneer samples.

The loose side by the dimension of 20x100x3 mm (Figure 11) was set up on the table of digital video microscope under 30X magnification. Then a digital video microscope was used to capture images from the surface of veneer's loose side. The images then were analyzed using motic image 2.0 version software to count the lathe checks frequency, length and depth (Figure 11). Frequency of lathe check was presented as the number of lathe check per cm length of veneer.

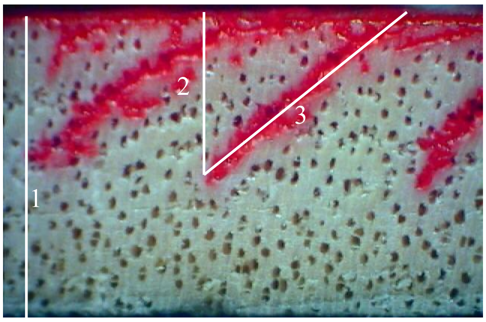

Figure 11 Veneer thickness (1), depth of lathe check (2) and length of lathe check (3) of poplar veneers' loose side

3.3.2.3 Surface roughness measurement

A portable surface roughness tester TR200 was used for roughness evaluation of the samples. A total of 10 roughness measurements were conducted according to JIS standard 2001 by using the roughness tester. Measurements were performed on each surface roughness test specimen across the grain orientation of the veneer. Tracing speed, diamond tip radius, and tip angle were 0.5 mm/s, 5 µm and 90^{o}, respectively. The length of tracing line was 15 mm and cut-off was 2.5 mm. The measuring force of the scanning arm on the surfaces was 4mN (0.4 g), which did not put any significant damage on the surface. Measurements were repeated whenever the stylus tip fell into the pores. The calibration of the instruments was checked in every 100 measurements by using a standard reference plate with Ra values of 7 µm. Average roughness (Ra) values were recorded to evaluate surface roughness.

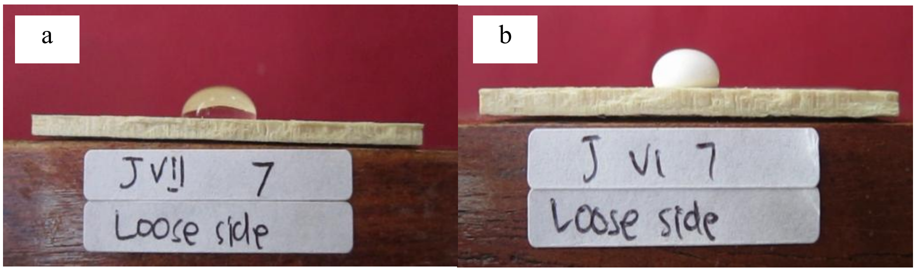

Figure 12 Contact angle of water (a) and PVAc as adhesive (b) on jabon veneers' loose side

3.3.2.4 Measurements of contact angle

Water and PVAc were dropped by using pipette on loose side of veneer (Figure 12). Video images were taken starting from initial drop up to 180 seconds wetting. Then pictures were consecutively collected at every 10 seconds from the video images. Those single pictures were analyzed by motic image software to measure their contact angles. Then, equilibrium contact angle was determined by segmented regression analysis using PROC NLIN on SAS software.

3.3.3 Data Analysis

In this study, we analyzed the correlation between dependent variable (equilibrium contact angle) and independent variables (frequency of lathe check and Ra values) by using multiple linear regressions. The model was as follow

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2$$

where,

Y = equilibrium contact angle value

α = constant

β_1, β_2 = regressions coefficient

X_1 = frequency of lathe check

X_2 = Ra values

Analysis of variance/ANOVA of multiple linear regression were calculated by minitab16 in order to obtain the effect of frequency of lathe check and surface roughness to equilibrium contact angle at 95% confidence level ($p \leq 0.05$).

3.4 Results and Discussion

3.4.1 Variation of veneer thickness

Uniformity of veneer thickness is a very important factor affecting the quality of glue bond strength in LVL or plywood. The results presented in Figure 13a-b show that a slight thickness variations of rotary cut sengon and jabon veneers are observed.

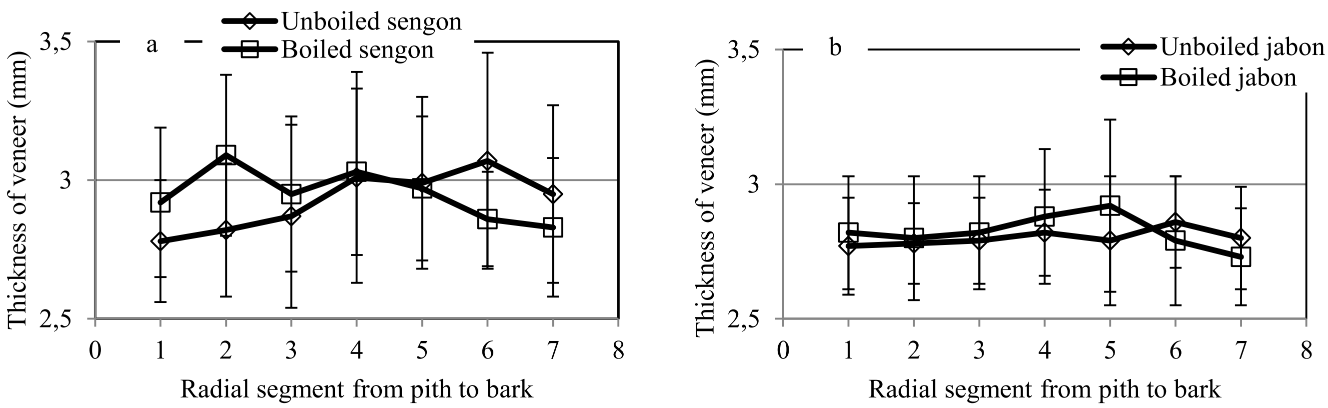

Figure 13 Variation of veneer thickness from pith to bark of sengon (a) and jabon (b)

The thickness of jabon veneer peeled from some bolts, which was intended to be 3.0 mm, varied from the lowest 2.50 mm to the highest 3.38 mm. The veneer thickness of sengon varied from the lowest 2.50 mm to the highest 3.80 mm. Since our spindle less rotary lathe was not able to peel 3 mm veneer, so that the targeted 3 mm veneer thickness was not accomplished. However, the uniformity of veneer thickness variation from pith to bark was reached with coefficient variation less than 6%. Coefficient of variations of the veneer thickness from pith to bark calculated was 1.02% for the jabon veneers from unboiled log and 2.17% for the jabon veneers from boiled veneers. The coefficients of variation of veneer thickness from pith to bark of unboiled and boiled sengon were 3.65% and 3.05%, respectively. By considering all the coefficient of variations was less than 6%, the bolts of sengon and jabon were correctly peeled to maintain the thickness regularity.

3.4.2 Lathe check frequency, depth and length

The average values of lathe check frequency per cm of veneer length taken from the loose side of the veneer of sengon and jabon were presented in Figure 14a-b.

The average frequency of lathe check tended to decrease from pith to bark of the veneers. The veneers near the pits showed larger frequency of lathe check. The average value of frequency of lathe check per cm veneer length of unboiled and boiled sengon were 2.5 and 1.8, respectively (Figure 14a). Frequency lathe check of jabon per cm veneer length were 4.1 (unboiled) and 3.5 (boiled) (Figure 14b). Several researchers also observed the same trend on 2 mm jabon veneers (Kabe *et al*. 2013) and sengon veneers (Darmawan *et al*. 2015). Higher lignin content of the wood near the pith could be responsible for high frequency of lathe check of the veneers taken from the inner parts of the sengon and jabon logs. Bao *et al.* (2001) noted that juvenile wood is an important wood quality attribute because it can have lower density, larger fibril angle, and high (more than 10%) lignin content and slightly lower cellulose content than mature wood. Higher frequency of lathe check near the pith could be also caused by smaller radius of its natural curvature in the bolt, which imposed greater tension during the flattening.

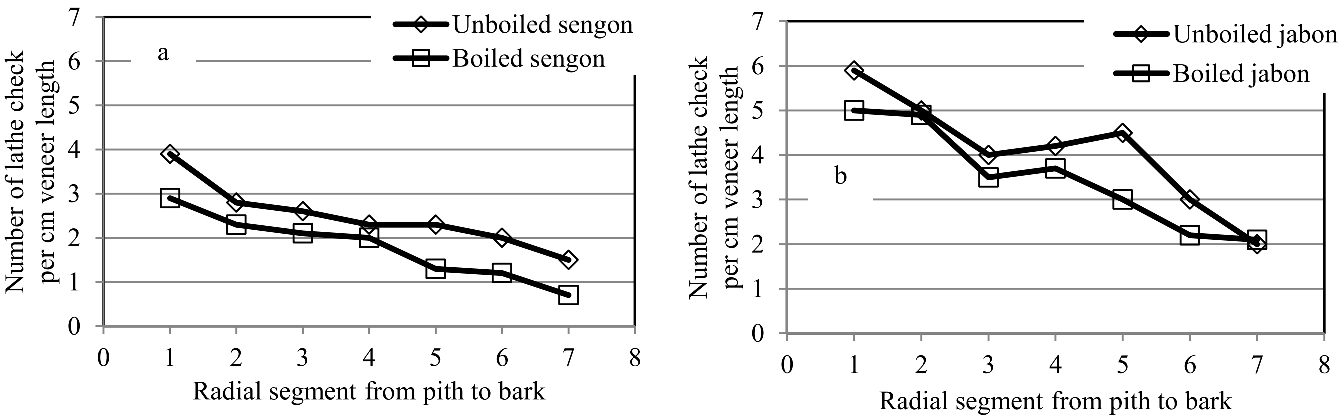

Figure 14 The progress of lathe check frequency from pith to bark of sengon (a) and jabon (b) veneers

The results in Figure 14a-b also reveal that veneers with lower average frequency of lathe checks are produced by boiled sengon and jabon bolts for 4h at temperature of 75°C, compared to unboiled bolts. It is in agreement with temperature effect on average lath check distance observed in Dupleix *et al* (2012) for beech, spruce and birch. This result gave an indication that boiling at 75°C resulted in better surface properties of the veneers. It could be announced that sengon and jabon bolts boiled for 4h at 75°C could be proposed before manufacturing veneers. The boiling of sengon and jabon bolts at the temperatures and periods is considered to soften their bolts during the peeling process. A softening process does temporarily alter the microstructure of the wood, making it more plastic due to thermal expansion of cellulose, and softening of lignin in the cell wall (Jorgensen 1968). The softening by heat has produced a degree of plasticity roughly 10 times than that of wood at normal temperature (Peck 1957). Therefore the flattening of the veneer from its natural curvature is more easily accommodated with less formation of lathe check.

The frequencies of lathe check per cm veneer length near pith were 5.9 and 5.0 for unboiled and boiled jabon, respectively. The lathe check frequencies near bark were 2.0 (for unboiled jabon) and 2.1 (for boiled jabon). According to literature (Thibaut 1988, Denaud *et al* 2007, Pałubicki *et al* 2010, Darmawan *et al*. 2015), the thicker the veneer peeled from the logs tend to produce larger frequency of lathe check compere to thinner veneer. Kabe *et al*. (2013) found that the frequencies of lathe check for 2 mm jabon veneers are 2.6 (for unboiled) and 1.4 (for boiled). The frequencies of lathe check per cm veneer length near pith were 3.9 and 2.9 for unboiled and boiled sengon, respectively. The lathe check frequency near bark were 1.5 (unboiled sengon) and 0.7 (boiled sengon). In Darmawan *et al*. (2015), the frequency of lathe check for 2 mm sengon veneers are 2.03 (for unboiled logs). Sengon veneers checked less than jabon veneers (Figure 14a-b) probably since its density is lower. Moreover, This results was correspond to Forbes (1997) who stated that fine pores wood tend to check less than larger pores wood. The average pores diameter of sengon is 170 µm, while jabon is 175 µm (Martawijaya *et al*. 2005) (see Figure 1a-b)

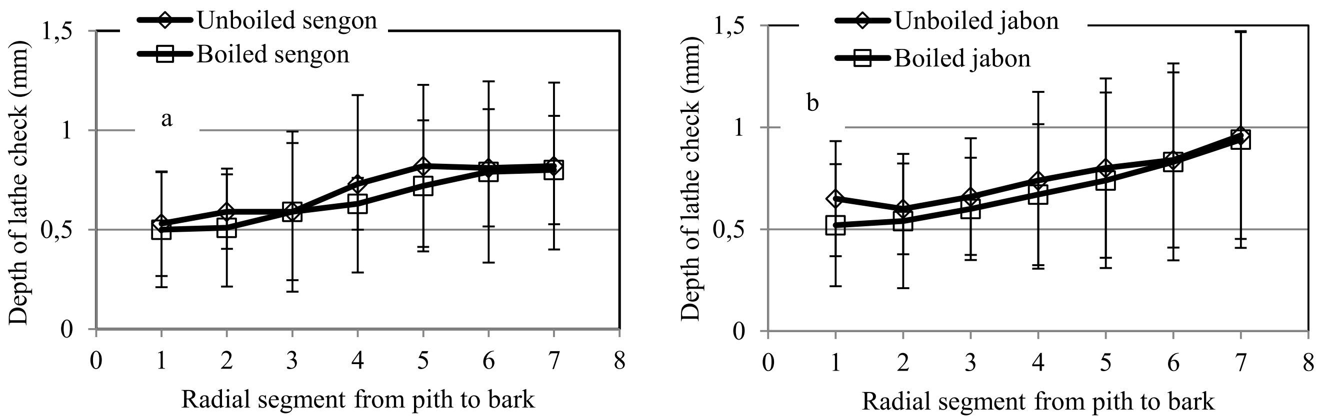

Figure 15 The progress of depth of lathe check from pith to bark of sengon (a) and jabon (b) veneers

The second variable that is important in determining the veneer quality is deep or shallow lathe check. The depth of lathe check tended to slightly fluctuate from pith to bark (Figure 15a-b). . The lathe check frequency of veneers near pith was approximately twice larger than near the bark. It can be considered that lathe checks on the loose side of veneer were generated due to tensile stress in bending at the rake face of the knife (Figure 9). Then, further unbending process during flattening the veneer from its natural curvature caused the increase of lathe check. Surface tension generated by unbending process would increase with veneer thickness, and much more cutting splits occurred during peeling and so it would generate deeper and longer lathe check (Figure 15 and 16).(Darmawan *et al*. 2015)

The thicker the veneer peeled, the deeper the lathe check will be. The depth of lathe check near pith were 0.65 mm (unboiled jabon) and 0.52 mm (boiled jabon), while near bark were 0.96 mm (unboiled jabon) and 0.94 mm (boiled jabon). Kabe *et al*. (2013) stated that the depth of 2 mm jabon veneer is 0.58 mm. Lathe check depths of sengon near pith for unboiled and boiled logs were 0.53 mm and 0.50 mm, respectively. The depths of lathe check of sengon were 0.82 mm (unboiled) and 0.80 mm (boiled). Similar results noted by Darmawan *et al*. (2015) that the depth of 2 mm sengon veneers is 0.57 mm.

The other lathe check measured in determining veneer quality was length of lathe check. The length of lathe check followed the behavior of depth of lathe check (Figure 16a-b). The thicker the veneer peeled, the longer the lathe check would be. The lathe check lengths for unboiled and boiled jabon veneers near pith were 1.07 mm and 0.97 mm, respectively. Lengths of lathe check near bark were 1.49 mm (unboiled jabon) and 1.48 mm (boiled jabon). The lengths of lathe check near pith were 1.06 mm (unboiled sengon) and 0.91 mm (boiled sengon). The lengths of lathe check of unboiled and boiled sengon near bark were 1.40 mm and 1.45 mm, respectively. Those results were longer than 2 mm veneer of sengon (0.88 mm) and jabon (0.99 mm) obtained from previous studies (Kabe *et al*. 2013; Darmawan *et al*. 2015).

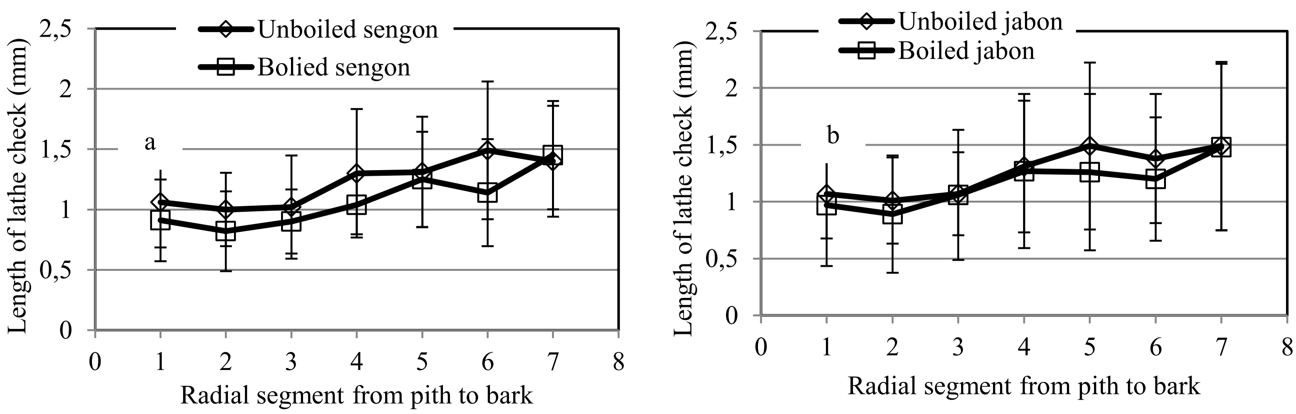

Figure 16 The progress of length of lathe check from pith to bark of sengon (a) and jabon (b) veneers

In this study the lathe checks were propagated in the same radial direction at a roughly 45° angle to the annual ring for all veneer thickness, as shown in Figure 9. For most of industrial application as LVL, during the rotary peeling of veneer, lathe checks are formed in the veneer with the depth between 20 – 30 % of the veneer thickness (Rohumaa *et al* 2013). In this study the average jabon lathe check depth were 25.0% (unboiled) and 23.0% (boiled) of the veneer thickness. The average lathe checks depth of unboiled and boiled sengon were 23.3% and 21.7%, respectively. The ratios between depth and length of the lathe check for sengon and jabon was 59%.

3.4.3 Surface Roughness

The average Ra values tended to decrease from pith to bark of the jabon veneers (Figure 17).

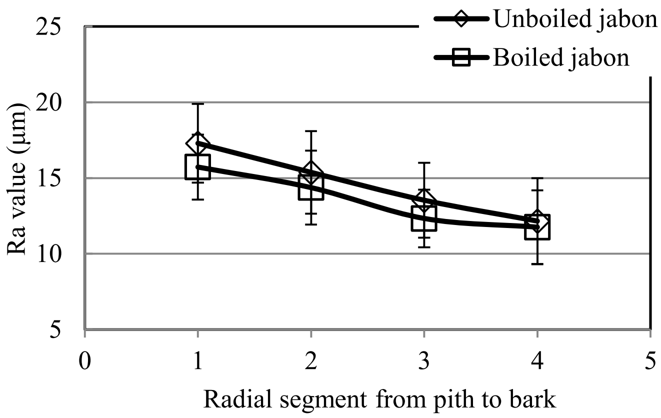

Figure 17 The progress of surface roughness from pith to bark of jabon (a) veneers

The veneers near the pith showed larger Ra values. The values of surface roughness of unboiled and boiled jabon near pith were 17.3µm and 15.7µm, respectively. Surface roughness values at near bark were 12.2 µm (unboiled jabon) and 11.8 µm (boiled jabon) (Figure 17). It was due to veneers near pith had lower density than veneers near bark that could lead to the formation of grain-raised during tension stress on peeling process. This condition could cause rougher surfaces of veneer. Moreover, veneers near pith usually consisted of larger fiber diameter. Veneers near pith on jabon had fiber diameter of 34.0 µm compared to 27.5 µm (veneers near bark). This condition could cause the rougher surface on veneer near pith. Also higher frequency of lathe check near the pith could also contribute to rough surface of juvenile veneers.

Further Tanritanir *et al.* (2006) investigated the effect of steaming time on surface roughness of beech veneer and they also found that the roughness of veneer sheets taken from heartwood (near pith) had higher values than those of sapwood (near bark). Average Ra values of the samples manufactured from the jabon logs with a temperature of 75°C from pith to bark was 13.8 µm, while for control was 14.8 µm. Findings in this study suggest that surface roughness of the veneer improved with boiling the log at that temperature. This result corresponded with Aydin *et al.* (2005), who discovered the same phenomena on spruce veneer. It seems that boiling temperature resulted in better surface properties of the samples based on the results of the tests. This finding would also contribute to reduced resin consumption during the gluing.

Faust and Rice (1986) found that the use of rough veneers in LVL decreased bonding quality compared to LVL made of smooth surface veneers. Rough veneers reduce contact between the layers resulting in a weak glue line and low strength properties of the plywood (Kantay *et al.* 2003). Veneer with a rough surface can also cause excessive resin use and may result in resin bleeding through the face veneer. Roughness of face veneer can be improved to a certain extent by sanding; however, this increases overall production costs (Lebow and Winandy 1998, Taylor *et al*. 1999).

3.4.4 Wettability – contact angle

In general, contact angle values decreased as a function of time in sengon, jabon (Figure 18 and 19). This result was in line with Shi and Gardner (2001). The average initial contact angle of unboiled jabon when we dropped water onto the veneers was 89°, while for boiled jabon was 53° (Figure 18a-b). The average initial contact angle of sengon was 84° (unboiled) and 63° (boiled) (Figure 19a-b).

Further, when we dropped PVAc, the initial contact angle were more than 90° for both sengon and jabon (Figure 18c-d and 19c-d). We could conclude that PVAc on surface of sengon and jabon wood had lower wettability compared to water. It was due to PVAc had higher viscosity than water so that adhesive was slower and more difficult penetrating jabon veneers. Viscosity value of water was 0.008poise, while PVAc was 90-110poise. Surface wettability would decrease as viscosity value increase (Gavrilovic-Grmusa *et al.* 2012).

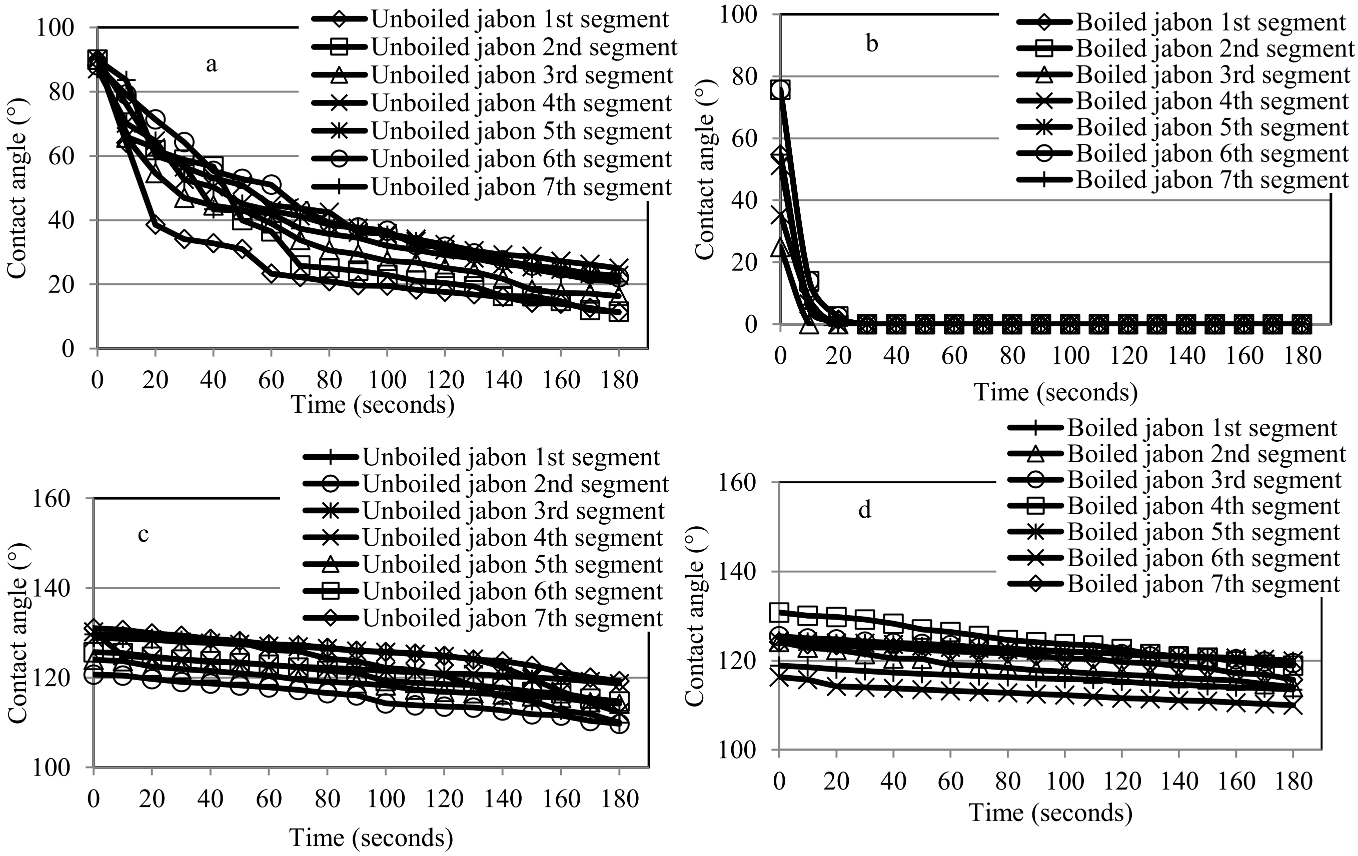

Figure 18 Contact angle on veneer loose side from pith to bark of unboiled jabon by using water (a), boiled jabon by using water (b), unboiled jabon by using PVAc (c) and boiled jabon by using PVAc (d)

According to Yuan and Lee (2013), contact angle less than 90° indicates that wetting of the surface is favorable, and the fluid will spread over a large area on the surface, while contact angles greater than 90° generally means that wetting of the surface is unfavorable so the fluid will minimize its contact with the surface and form a compact liquid droplet. For example, complete wetting occurs when the contact angle is 0°, as the droplet turns into a flat puddle. For superhydrophobic surfaces, water contact angles are usually greater than 150°, showing almost no contact between the liquid drop and the surface.

Jabon produced higher contact angle than sengon both for water and PVAc. It was due to sengon had lower density than jabon. According to Shi and Gardner (2001), liquid penetration in the phase of wetting is mainly related to the wood structure. Sengon was more porous than jabon.

The contact angle values of sengon and jabon veneers near bark were larger than that of veneers near pith (Figure 18 and 19). Veneers near pith had rougher veneer surface and more numerous checks than near bark. Surface roughness affected contact angle. These results were correspond to Airylmis *et al.* (2010), who concluded that rough surface roughness had higher wettability compare to smoother surfaces

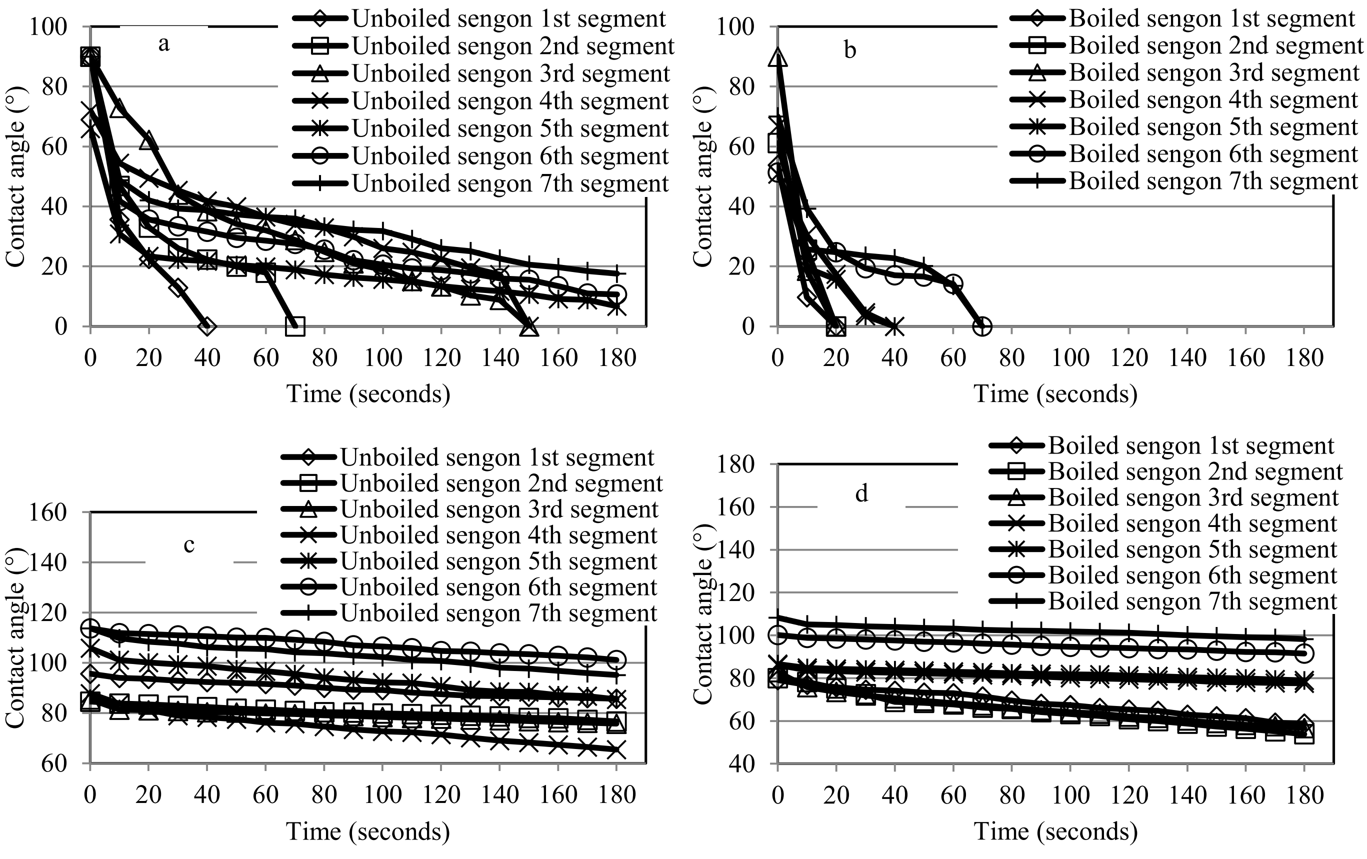

Figure 19 Average contact angle on veneer loose side from pith to bark of unboiled sengon by using water (a), boiled sengon by using water (b), unboiled sengon by using PVAc (c) and boiled sengon by using PVAc (d)

Though, the surface roughness of boiled sengon and jabon were slightly lower than unboiled sengon and jabon, however the contact angle value of boiled sengon and jabon was smaller than unboiled (Figure 18 and 19). It was due to the boiled veneers become more porous compared to unboiled veneers. This condition made liquids (water and PVAc) were easy to spread and penetrate into sengon and jabon boiled veneer surfaces. Trung (2014) found that large holes are created at radiata pine array areas at softening condition of wood moisture content of 30% and temperature 100°C.

Wetting is directly related to the oxygen: carbon (O/C) ratio and inversely related to the C1/C2 ratio (Sernek 2002). The C1 component is related to C-C or C-H bond and C2 component represent single C-O-bond. A high O/C ratio and low C1/C2 ratio reflect a high concentration of polar wood component on the wood surface, which made the wood surface hydrophilic. When wood is heated, hemicellulose begins to degrade, results the production of methanol, acetic acid and various volatile heterocyclic compounds (Hill 2006). This condition could lead to prevention veneer surfaces inactivation. According to Aydin (2004) surface inactivation could lead to the interference wetting, flow and penetration of the adhesive. Ideally, the shape of a liquid droplet is determined by the surface tension of the liquid. In a pure liquid, each molecule in a bulk is pulled equally in every direction by neighboring liquid molecule, resulting in a net force of zero (Yuan and Lee 2013). However, the liquid exposed at the surfaces of boiled sengon and jabon veneer have neighboring molecules in all direction caused by high O/C ratio. As a results, the liquid voluntarily spread its surface area which lead to low contact angle. Lower values of contact angle are caused by the difference between wood and adhesive surface tension. In order to have high bonding quality, surface tension of wood must be lower than surface tension of adhesive (Yuan and Lee 2013).

3.4.5 Correlation between equilibrium contact angle and frequency of lathe check and surface roughness

The correlation between dependent variable (equilibrium contact angle) and independent variables (frequency of lathe check and Ra values) could observe from multiple linear regressions (Table 5). Generally, frequency of lathe check and surface roughness were correlated negatively with contact angle. The more frequency of lathe check, the contact angle would be lower. The same with surface roughness, the rougher the surface, the contact angle would be lower.

Table 5 Correlation between dependent variable (equilibrium contact angle) and independent variables (frequency of lathe check and Ra values) at a 95% confidence level ($p \leq 0.05$)

Wood Species	Equation	R^2	P
Unboiled jabon	$Y= 114.195 - 0.0877544X_1 - 0.191574 X_2$	98.19%	0.013
Boiled jabon	$Y= 25.3831 - 1.65247 X_1 + 10.2127 X_2$	89.5%	0.032

where,
Y = equilibrium contact angle
X_1 = frequency of lathe check
X_2 = Ra values (surface roughness)
R^2 = coefficient determination

The results in Table 5 indicate that the surface roughness did not show the negative effect on equilibrium contact angle in boiled jabon. We suspected that boiled jabon veneer surfaces were more porous compared to unboiled veneers and

75°C boiling treatment prevented surface inactivation. The boiled veneer contained high O/C ratio and low C1/C2 ratio that could lead to low values of contact angle. We could conclude that veneers from boiled logs had higher wettability than veneers from unboiled logs. This characteristic would contribute to better LVL glue bond and bending strength.

3.5 Conclusion

The frequency, depth and length of lathe check, surface roughness and contact angle were influenced by juvenility. The frequency of lathe check and surface roughness decreased from pith to bark, while the value of length and depth of lathe check and contact angle tended to increase from pith to bark. These results were occurred in all wood species that were used in this study.

In general, 3 mm sengon and jabon veneers from 5 years old boiled sengon and jabon logs had better veneer quality (lower lathe check frequency, better surface roughness however better wettability) than unboiled logs.

4 THE EFFECT OF LATHE CHECK AND JUVENILITY ON FAST GROWING SPECIES LVL GLUE BOND AND BENDING STRENGTH

French summary

Avec l'émergence d'une ressource de bois à croissance rapide, une plus grande proportion de bois destiné à la construction sera sous forme de bois juvénile. La première étape consiste à caractériser la ressource et son potentiel. Cette connaissance permettra alors à l'industrie d'adapter les méthodes et les techniques existantes à cette matière première afin de conserver des produits LVL à haute performance.

Sengon (*Falcataria molluccana*) et Jabon (*Anthocephalus cadamba*) en tant qu'espèces à croissance rapide ont été largement plantés en Indonésie, ont cycle de coupe court (5 à 7 ans). D'après notre échantillonnage (voir le chapitre 2), près de 100% du bois reste juvénile même à l'âge de 7 années. Nous avons également vu dans le chapitre 3 que l'étuvage avant le déroulage pourrait diminuer la fréquence de fissuration des placages, diminuer les valeurs de rugosité (Ra), tout en augmentant leur mouillabilité. Pour les cultivars de peuplier et le douglas, les proportions de bois adulte sont un peu plus importantes puisque les arbres ont été coupés beaucoup plus tard. Dans cette partie, les résultats de très nombreux essais mécaniques réalisés soit sur les joints de collage soit sur des éprouvettes de LVL intégrant plusieurs critères liés au déroulage ou au matériau (essence et juvénilité en particulier) sont présentés. L'objectif principal est d'analyser l'impact de la juvénilité du bois sur les propriétés mécaniques des LVL. L'étude de la fissuration cyclique du placage est également intégrée puisque son impact sur les propriétés mécaniques est fondamental.

La qualité du placage, tel que la teneur en eau, densité, fissure, et rugosité influencerait la résistance du joint de colle (Dundar *et al.* 2008). Parmi ces facteurs, la fissure est l'un des facteurs importants. En outre, les placages avec des fissures importantes exigent beaucoup plus de colle en raison de la dégradation de la topographie des surfaces (Daoui *et al*. 2011).

(Ranta-Maunus 1995, Shukla et Kamdem 2007) ont publié des mesures de propriétés mécaniques de LVL pour des résineux et des feuillus. Ces valeurs sont normalement plus hautes que celles obtenues pour du bois massif avec défaut puisque les gros défauts peuvent être purgées ou distribués (effet lamellation). De plus, ses propriétés sont plus facilement contrôlables, et homogènes ce qui rend son usage plus simple.

L'impact du bois juvénile sur le lamibois utilisant le pin jaune du sud et le douglas a été proposé dans une étude de Kretschmann *et al*. (1993). Cette étude a constaté que le bois juvénile pouvait réduire l'intégrité structurelle d'un produit de lamibois quand des quantités significatives de bois jeune sont employées. Le LVL de douglas a semblé être influencé davantage par l'inclusion du bois juvénile que le pin jaune du sud. Kretschmann *et al*. (1993) a également montré qu'un ratio placages juvéniles/ placages de bois mature de 0,8 permettait de conserver une bonne rigidité et une bonne limite à la rupture. Langum *et al*. (2009) a lui aussi observé une 'augmentation de la rigidité et de la limite à la rupture en flexion pour du douglas massif avec la distance de la moelle à l'écorce. En sélectionnant et en positionnant judicieusement les placages, il est possible d'optimiser les performances d'un panneau LVL. Ainsi, en service à plat, les couches extérieurs sont les plus sollicités et doivent donc présenter les meilleures propriétés tandis que les plis internes ont plutôt intérêt à être légers.

Un des inconvénients du LVL est qu'il utilise un adhésif qui peut représenter une part importante de sa masse (jusqu'à 20% d'après Daoui *et al.* 2011). Pour limiter cet effet, une solution simple consiste à limiter le nombre d'interfaces et donc à dérouler les placages plus épais. Mais cette logique fait face à deux écueils : la limitation de l'effet lamellation et l'apparition de fissurations importantes de déroulage.

Le MOE du LVL peut être mesuré par le module d'élasticité dynamique et statique. L'analyse dynamique est un moyen simple et efficace de caractériser le Module de l'élasticité (MOE) d'un matériau, y compris le bois (Brancheriau et Bailleres 2002; Bucur 2006). Utilisant diverses espèces de bois, les dimensions d'échantillon et les états de croissance, plusieurs études ont montré une corrélation linéaire forte entre le module d'élasticité dynamique et statique (Biblis *et al.* 2004; El-Haouzali 2009). Cependant, l'utilisation de telles méthodes pour estimer le MOE des produits en bois reconstitués, en particulier le LVL est encore confidentielle (Daoui *et al.* (2011). Dans cette étude, la méthode de BING a été employée pour évaluer son efficacité en prévoyant le MOE du lamibois de peuplier et de sapin de douglas. Des essais de flexion 4 points ont été réalisés pour les différentes essences afin de mesurer le MOE et le MOR des LVL en fonction du caractère juvénile et du protocole de déroulage et d'assemblage (épaisseur, étuvage, fissuration, type d'empilage de placages).

La résistance du joint de colle, le SMOE et le SMOR du LVL de sengon et de jabon ont augmenté de la moelle jusqu'à l'écorce bénéficiant à la fois d'une diminution de la proportion de bois hautement juvénile et de la réduction de la fréquence de fissuration cyclique. Il serait intéressant d'intégrer également l'impact de la profondeur des fissures qui est plus complexe à appréhender.

L'avantage d'employer des placages de peuplier mature a été démontré avec une amélioration de 15 à 20% en moyenne pour les propriétés mécaniques, pour un poids comparable des panneaux. Le même effet est observé pour les placages de douglas. L'utilisation des placages mature dans la production du lamibois de douglas semble améliorer la résistance à la flexion de 7 à 22%. Concernant les bois indonésien, cette tendance est confirmée mais dans des proportions plus faible du fait de la grande proportion de bois hautement juvénile dans tour l'échantillonnage.

L'utilisation des placages plus épais dans le lamibois de peuplier et de Douglas, réduit l'utilisation de l'adhésif, simplifie la production des panneaux sans altérer leurs propriétés mécaniques du LVL. La direction de sollicitation des éprouvettes (à plat ou sur chant) n'a pas donné d''effet significatif sur le MOE statique, le SMOE ou la densité du lamibois de peuplier. Le MOE, le MOR et le SMOR dynamiques du lamibois de peuplier pour les essais à plat étaient toujours un peu plus haut.

Quelques cultivars ont un vrai potentiel pour des applications structurelles (Lambro, Soligo, Alcinde, Brenta, et taro), certains devraient être employés avec la sélection rigoureuse d'échantillon (Lena, Trichobel, Mella, Koster, et Dvina), tandis que Polargo, A4A, I-214 et Triplo devrait être exclus de cette application.

La technique vibratoire (BING) est un outil fiable pour estimer MOE de LVL et éviter l'essai destructif. Il est particulièrement utile pour le peuplier et le douglas.

4.1 Introduction

With the emergence of a rapidly grown plantation timber resource throughout the world, a larger proportion of available timber will be found in the form of juvenile wood. To be able to use juvenile wood, it is first required that a working knowledge of the juvenile wood component be gained. This knowledge will then allow the manufacturing sector to modify existing procedures and techniques to more fully utilize this juvenile material for the production of high performance LVL.

Sengon (*Falcataria molluccana*) and Jabon (*Anthocephalus cadamba*) as fast growing wood species widely planted in Indonesia, have short cutting cycle (5 to 7 years). Based on this research (see Chapter 2), they contained 100% of juvenile wood by the age of 7 years old. The boiling treatment prior to peeling could decrease lathe check frequency of 3 mm veneer, decrease Ra values (the veneer surface become smoother). Moreover their wettability was higher compared to unboiled veneers (see Chapter 3).

Poplar (*Populus* spp) and douglas-fir (*Pseudotsuga menzii*), contained in average 52 % and 77 % of juvenile wood portion (see Chapter 2). Poplar logs did not need any treatment prior to peeling. Juvenile veneers were higher than mature veneers, in terms of lathe check frequency and surface roughness. Moreover in terms of contact angle, the juvenile veneers were lower than that of mature veneers (see Chapter 3). Douglas-fir is easily machined and dried and also its peeling and gluing properties are good (CIRAD 2011). It is known as one of the wood species widely utilize as laminated veneer lumber. Since they are being used in the laminated veneer lumber industry, their bonding quality became important to be analyzed

The quality of veneer, such as moisture content, density, lathe checks, and surface roughness would influence the bonding strength of the veneers (Dundar *et al.* 2008). Among these factors, lathe check is one of the important factors on the bonding strength. The bonding strength decreases, probably because of the presence of important lathe checks. Also, the veneers with lathe checks require much more glue spread because of the degradation of veneer surface topography (Daoui *et al*. 2011). Veneers with lathe checks can also cause excessive resin use and may result in resin-bleed through the inside of veneer.

Some researchers have published physical and mechanical properties of LVL manufactured from softwood as well as hardwood of different species (Ranta-Maunus 1995, Shukla and Kamdem 2007). The reported values for LVL are normally higher than those obtained for other traditional wooden products, which may be explained by the fact that large defects can be avoided when logs are cut into thin veneers and these are laid and glued parallel to the grain (Ranta-Maunus 1995). In addition to its very good mechanical behavior, LVL exhibits other advantages common to all wooden materials such as those related to environmental aspects (Shukla and Kamdem 2007). Using fast growing wood species for LVL production can help to solve the problems linked to the shrinkage of raw materials for construction and to the protection of natural forests. The impact of juvenile wood on LVL using southern yellow pine and Douglas-fir was discussed in depth in a study by Kretschmann *et al*. (1993). This study found that juvenile wood could reduce the structural integrity of an LVL product when significant quantities of juvenile wood were used. Douglas-fir LVL seemed to be more influenced by the inclusion of juvenile wood compared to the southern yellow pine. Finally, it was also found that the inclusion of juvenile wood did not significantly influence the amount of warp found in the LVL studs. Kretschmann *et al*. (1993) also showed that the ratio between Douglas fir LVL from juvenile and mature veneers is 0.8 for strength and stiffness. Langum *et al*. (2009) reported that flexural stiffness and strength in solid Douglas-fir increase with increasing distance from pith to bark. Therefore the juvenility effect on LVL bending strength was important to be analyzed.

Wang *et al*. (2003) indicated that veneer peeled from low value red maple logs may be used to manufacture high quality LVL products. This could be done with the incorporation of low density wood species as core layer and high density wood species as surface layer, where a superior end product can be produced without compromising the strength and quality of high commercial value wood species. Low strength and stiffness values of juvenile wood are well known in wood science. LVL was produced as a possible means to reduce the overall structural problems inherent in poorer quality timber (Koch 1966). This potential reduction is made possible by laminating veneers of high stiffness in the outer layers, due to the transformed section modulus, lower stiffness veneers may be used in the central core of the LVL product for a use on flatwise. Since the core does not require the same stiffness as the outer layers (Bodig and Jayne 1993). Harding and Orange (1998) stated that on radiata pine, the lay-up pattern of the loose side with tight side produces a LVL with a significantly lower stiffness than for a pattern that matches the loose side with the loose side. By strategically placing selected veneer sheets within the composite, it is possible to manufacture a wood-base product that has well-controlled physical and mechanical properties (Wang *et al*. 2003). The effect of different layout on glue bond and bending propertied in sengon and jabon LVL was analyzed in this study.

LVL presents the inconvenience of using a large amount of adhesive during its manufacturing, which can be up to 20% of its total mass (Daoui *et al*. 2011). According to De Melo and Del Menezzi (2014), the adhesive is a component with significant technical and economic implications with regard to the utilization of wood products and its cost can be half the product price. Echols and Currier (1973) found better results on bending strength of solid wood than on 5-ply, and better results on 5-ply than on 7-ply Douglas-fir LVL. Therefore, increasing veneer thickness on poplar and douglas-fir LVL can enable a decrease in adhesive use for these panels.

MOE LVL could be measured by dynamic and static modulus of elasticity. Dynamic analysis is a simple and efficient way of characterizing the BING Module of Elasticity (MOE) of many materials, including wood (Brancheriau and Bailleres 2002; Bucur 2006). Using various species of wood, sample dimensions and growth conditions, several studies have shown a strong linear correlation between the dynamic and static modulus of elasticity (Biblis *et al*. 2004; El-Haouzali 2009). Dynamic tests based on vibration frequency measurements have been applied successfully to analyze the dynamic MOE of structural timber (Haines *et al*. 1996; Ouis 1999). However, the use of such methods for estimating the MOE of engineered wood products, particularly LVL, has not been widely applied. To the best of our knowledge, only Daoui *et al*. (2011) used a vibrating method with limited success, probably because of the existence of important lathe checks. In this study, the BING method was used to evaluate its efficiency in predicting the MOE of poplar and douglas-fir LVL.

The objectives in this study were: 1) to determine the juvenility effect on LVL glue bond and bending strength from fast growing species; 2) to determine the effect of boiling treatment and LVL layout on glue bond and bending strength of sengon and jabon LVL; 3) to analyze the impact of lathe checks frequency on the LVL glue-bond and bending strength of sengon and jabon LVL; 4) to analyze the effect of veneer thickness on poplar and Douglas-fir LVL mechanical properties; 5) to determine poplar cultivars that could be suitable for structural applications of LVL; and 6) to analyze whether the vibrating method (BING) could be applied to predict LVL MOE of poplar and Douglas-fir.

4.2 Materials for sengon and jabon LVL

Trees information details are presented in Tables 6. The sample trees having straight stems and free external defects were chosen with the intent of minimizing tree-to-tree variation. The samples trees had a height of branch-free stem range from 6-8 m. After felling trees, log sections (bolts) in length of 60 cm were taken from each tree, from the bottom part up to the end of the free-branches tree stem. The sample logs were wrapped in plastics, kept cold, and maintained in the green condition before they were transported to the wood workshop for the rotary cutting.

Table 6 Trees information for sengon and jabon LVL

Wood Species	Growth Site	Age (years old)	dbh (cm)
Sengon (*F. moluccana*)	Sukabumi, Indonesia	5	28
Jabon (*A. cadamba*)	Sukabumi, Indonesia	5	28

4.3 Materials for Poplar cultivars and Douglas-fir LVL

Trees information details are presented in Tables 7. Poplar cultivars that were used in this research were as follow: 1) *P. deltoides* Bartr. was crossed by *P. nigra* L, produced poplar cultivars : 'A4A', 'Brenta', 'I-214', 'Koster', 'Lambro', 'Mella', 'Polargo', 'Soligo', 'Triplo'; 2) *Popolus sp.* was crossed by *Populus sp.* produced poplar cultivar : 'Taro'; 3) *P. deltoides* Bartr. produced poplar cultivar : 'Dvina', 'Lena', 'Alcinde'; and 4) *P. trichocarpa* was crossed by *P. trichocarpa* produced poplar cultivar : 'Trichobel'

After felling trees, the poplar and Douglas-fir logs were debarked and cut in length of 60 cm for peeling process. The total logs were 38 pieces (33 poplar logs and 5 Douglas-fir logs). The sample logs were kept cold (winter), and maintained in the green condition before they were transported to the wood workshop for the rotary cutting.

Table 7 Trees information for poplar cultivars and Douglas-fir LVL

Wood Species	Growth Site	Age (years old)	dbh (cm)
Poplar cultivar A4A (*P. deltoids* Bartr. x *P. nigra* L.)	Bussy les Daours, Clarques and Argenton, France	12-13	41-49
Poplar cultivar Brenta (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and Saint Nicholas la Chapelle, France	18	43-50
Poplar cultivar I-214 (*P. deltoids* Bartr. x *P. nigra* L.)	Saint Nicholas la Chapelle and La Rèole, France	18	47-50
Poplar cultivar Koster (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and La Rèole, France	18	50-52
Poplar cultivar Lambro (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and La Rèole, France	17	47-53
Poplar cultivar Mella (*P. deltoids* Bartr. x *P. nigra* L.)	Saint Nicholas la Chapelle and La Rèole, France	17-18	39
Poplar cultivar Polargo (*P. deltoids* Bartr. x *P. nigra* L.)	Bussy les Daours, Epieds, and Saint Jean d'Angely, France	13	44
Poplar cultivar Soligo (*P. deltoids* Bartr. x *P. nigra* L.)	Sainte Hermine and Saint Nicholas la Chapelle, France	18	48-54
Poplar cultivar Taro (*Populus sp.* x *Populus sp.*)	Saint Nicholas la Chapelle and La Rèole and Blanzay sur Boutonne, France	17-18	41-63
Poplar cultivar Triplo (*P. deltoids* Bartr. x *P. nigra* L.)	Vervant, Saint Jean d'Angely and Bussy les Daours, France	13-14	38-47
Poplar cutivar Alcinde (*P. deltoids*)	Le Busseau, Vervant and Saint Jean d'Angely, France	13-19	46
Poplar cutivar Dvina (*P. deltoids*)	Sainte Hermine, Blanzay sur Boutonne and La Rèole, France	17-18	42-52
Poplar cutivar Lena (*P. deltoids*)	Sainte Hermine and La Rèole, France	17-18	52-58
Poplar cutivar Trichobel (*P. trichocarpa x P. trichocarpa*)	Le Busseau, Long and Vauchelle le Authis, France	14-22	43-47
Douglas-fir (*Pseudotsuga menzii*)	Cluny, France	26	34-35

4.4 Method for production of sengon and jabon LVL

The peeling process and LVL production of sengon and jabon were performed at Division of Wood Quality Improvement, Forest Product Department Faculty of Forestry Bogor Agricultural University, Indonesia.

4.4.1 Peeling process

All peeling process procedures of sengon and jabon were the exactly the same with sengon and jabon peeling process on Chapter 3 (see 3.3.1.1). The veneers were collected and grouped for each 7 segmented rings and numbered consecutively from near the pith (number 1) to near the bark (number 7). LVL with the dimension of 20mm x 20mm x 500mm from each segmented rings was produced.

4.4.2 LVL production, glue bond and bending strength tests

4.4.2.1 LVL production

The veneer specimens were conditioned at relative humidity (RH) of 85% and temperature of 25°C to an air-dry moisture content of 12%. LVL panels with dimension of 20 mm x 20 mm x 500 mm were manufactured by 3 mm veneer thick (7-ply) at each segmented rings. Veneers were selected randomly in each radial segments. LVLs of 7 layers of 3 mm veneer were made, so that the target LVL thickness of 20 mm was achieved.

There were two different lay out that were used in this study. First lay out, LVL with loose side veneers glued with theirs tight side called type I. Second lay out, LVL with loose side veneer glued with its loose side called type II (see Figure 20)

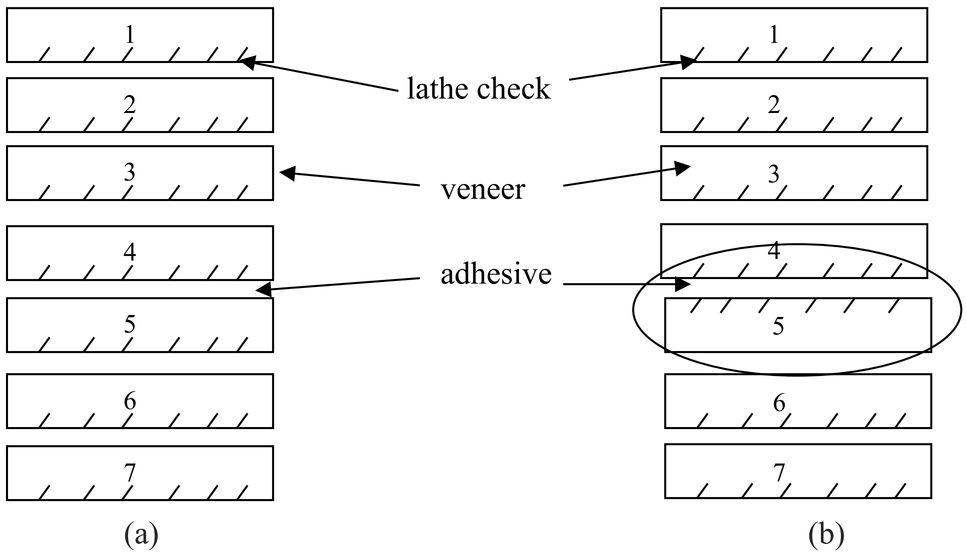

Figure 20 Type I layout: loose-tight side lay out (a) and type II layout: loose-loose side lay out (b)

4.4.2.2 Gluing process

PVAc (Poly Vinyl Acetate) was used as the adhesive. The vinyl adhesive used was marketed under the name INWOOD P 900 A®. It is in the form of an emulsion and ready for application. The PVAC resin had a viscosity of 90-110 poise at 23°C, pH 4-5, solid material 50±1% and a density of 1.23 g cm^{-3}. Table 8 summarizes the conditions of the gluing process.

Table 8 Condition of gluing process of sengon and jabon laminated veneer lumber made of 3 mm veneers

Gluing parameters	LVL (from 3mm veneer)
Veneer moisture content	11 – 13%
Room temperature during gluing process	25 - 27°C
Average adhesive spreading rate (g m^{-2})	260
Application instrument	Hand brushing
Open assembly time	8 minutes
Cold press pressure	2.5 kg cm^{-2}
Cold press pressure time	45 minutes

4.4.2.3 Glue-bond and bending strength test

Tests for the glue bond and bending strength properties were conducted on test specimens prepared from the LVL panels. Prior to the testing, the specimens were conditioned for 2 weeks at 25 °C and 85% relative humidity (RH) to air dry moisture content (around 12%). Total samples tested were 122 Samples. The glue bond and bending tests were carried out on an INSTRON universal testing machine. Perpendicular to the fiber and glue line (flatwise) and four point bending test for modulus of rupture (MOR) and modulus of elasticity (MOE) tests were carried out according to EN standard (EN 789). Specimen size for the bending tests was 400 mm long by 20 mm wide by 20 mm thick of LVL. Glue-bond tests were also carried out according to JAS SE 11 and modification of SNI 01-5008.2-2000. The dimension of test samples was 100 mm length by 20 mm width by 20 mm thick. A loading rate of 10 mm/min was used in all tests according to the JAS SE 11. Loading on the glue bond test was continued until separation between the surfaces of the specimens occurred.

4.5 Method for production of poplar cultivars and Douglas-fir LVL

The peeling process and LVL production of poplar cultivars and Douglas-fir were performed in LaBoMaP (Laboratoire Bourguignon des Matériaux et des Procédés), Ecole Nationale Superieure d'Arts et Métiers (ENSAM) Cluny, Bourgogne, France and Laboratory INRA- Centre de Nancy, France.

4.5.1 Poplar cultivars and Douglas-fir logs preparation for rotary cutting

Logs were peeled by using "SEM Automation S500" at LaBoMaP (Laboratoire Bourguignon des Matériaux et des Procédés), Ecole National Superieure d'Arts et Métiers (ENSAM) Cluny, Bourgogne, France. Logs were peeled by using a 1° clearance angle, 1 m/s speed and with a moderate pressure rate of 10% to limit lathe check growth and thickness variation (Lutz 1974; Feihl 1986; Marchal *et al*. 2009). Those veneers were used to produce 50x50 cm^2 LVL.

4.5.2 LVL production of poplar and Douglas-fir LVL

4.5.2.1 Veneer selection and panel composition of poplar cultivars

Before peeling, each log was holed by 1 cm diameter drill bit from bark to pith, to mark the radial segment of veneers sample. Each cultivar of poplar logs were peeled with 3 mm thickness. The logs were peeled until the core diameter of 7 cm. According to transition age resulted from fiber length trait (see Chapter 2), we divided poplar veneers into two types. First, veneers from mature wood (taken from bark to false heartwood). Second, veneers from juvenile wood (beginning false heartwood to core diameter). For each tree, logs were peeled with 3 mm and 5.25 mm thickness. Veneers were dried with a vacuum dryer to ensure a flat veneer surface (dried until they reached 8 - 10% moisture content).Veneers were selected randomly in each category (juvenile or mature). LVLs of 7 layers of 3 mm veneer and 4 layers of 5.25 mm veneer were made, so that the target LVL thickness of 20 mm was achieved. We made 188 LVL panels.

4.5.2.2 Veneer selection and panel composition of Douglas-fir

The same with poplar, to separate juvenile veneers from mature veneers, a group of veneers was selected from sapwood (close to the bark, adult wood) and a group of veneers was taken from heartwood (close to the pith, juvenile wood). LVL with 20 mm in thickness were produced. Those LVL consisted of 7-plies of 3 mm veneer and 4-plies of 5.25 mm veneers. Veneers were selected randomly in each category. Each board was cut into standardized test samples (EN 789), parallel to grain with total of 140 samples (LVL of 3 mm veneer = 63 samples and LVL 5.25 mm veneer = 77 samples).

4.5.3 Gluing Process

PVAc (Poly Vinyl Acetate) was used as the adhesive. The vinyl adhesive that we used was marketed under the name "Rakoll®" _GXL 4. It is in the form of an emulsion and ready for application. Table 9 summarizes the conditions of the gluing process for poplar cultivars and Douglas-fir LVL.

Table 9 Condition of gluing process of poplar cultivars and Douglas-fir laminated veneer lumber from 3 mm and 5.25 mm veneers

Gluing parameters	Poplar and Douglas-fir LVL (from 3 mm and 5.25 mm veneer)
Veneer moisture content	10 – 15%
Room temperature during gluing process	18 - 20°C
Relative humidity (RH)	60 – 65%
Average adhesive spreading rate (g m^{-2})	260
Application instrument	Glue machine (Figure 21a)
Open assembly time	10 minutes
Cold press (Figure 21b) pressure	2.5 kg cm^{-2}
Cold press pressure time	45 minutes

4.5.4 Sample Preparation for Mechanical Properties

Each board was cut into standardized test samples (EN 789), parallel to grain with total of 1808 samples for poplar and 140 samples for Douglas-fir (Figure 22).

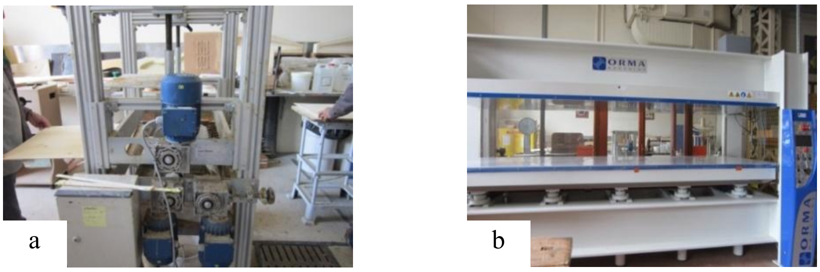

Figure 21 Glue machine and gluing process (a) and cold press (b)

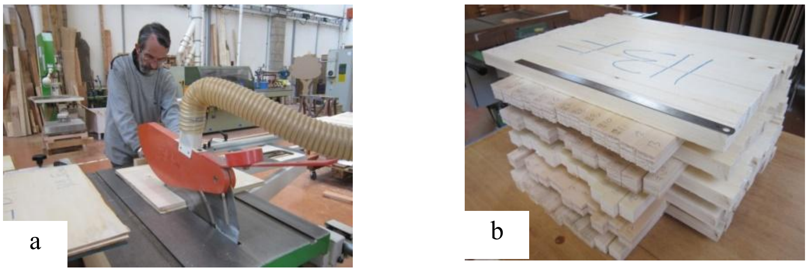

Figure 22 Preparation samples for nondestructive and destructive test (a); and samples for bending properties (b)

The parameters for mechanical properties were Modulus of Elasticity (MOE) and Modulus of Rupture (MOR). First, dynamic tests (BING) were performed then a static 4-point bending test were performed for each sample.

4.5.4.1 Non Destructive Test

Dynamic analysis is a simple and efficient way of characterizing the Module of Elasticity (MOE) of many materials, including wood (Brancheriau and Bailleres 2002; Bucur 2006). In order to estimate the dynamic MOE from non-destructive test method, bending vibration method BING was used for the 1808 samples (poplar cultivars) and 140 samples (douglas-fir). This is a fully automated system designed by CIRAD-Forêt following work of Bordonné (1989) and Hein *et al.* (2010). It is based on measurement and interpretation of the natural frequencies of vibration from a wood piece subjected to impulse loading. This method was easy to apply, very quick and practical. The dynamic MOE were obtained through percussion bending perpendicular to the glue joints in two loading position (flatwise (FW) and edgewise (EW)). The interpretation of the spectrum of the natural frequencies was based on the fact that the ratio of elastic modulus to density (specific modulus) of a material was proportional to the speed of signal propagation in the material.

BING method could be divided into three interrelated steps: 1) begins with a general initialization of the equipment and preparation the samples; 2) the acquisition and analysis of the digitized signal; and 3) the mathematical and mechanical processing of the signal.

After setting the acquisition device, the tested samples were first weighted and measured in length, width and height. Then the samples were positioned on the two elastic bearings (like shown in the Figure 23) and made sure that the supports were located at a distance of ¼ of the total length of each specimen.

Afterwards the microphone was set up in perpendicular with the length of the samples (see Figure 23) with the distance of 1 or 2 cm from the sample. The samples were hit by percussion bar at one end of the sample and the sound emitted was recorded in another end of the samples by microphone. The emitted sound from the end of the samples was converted into electrical signal by the microphone. This signal was then amplified and filtered by means of the acquisition card acting as an analog-digital converter and which delivered to the computer to digitize the signal.

Figure 23 Samples placement on BING bending vibration method

After digitizing the signal, then it was recorded and transferred to a user's computer memory. The spectral composition of the recording was given by fast Fourier transform, the spectral width of the acquisition depends on fixed parameters (point number and acquisition time). The mathematical calculation of the selected frequency was performed via software from the geometric characteristics and mass of the sample. It was used to determine the elastic moduli by Bernoulli and Timoshenko models. Timoshenko model was used in several studies (Bordonné 1989; El-Houzali 2009) including this research. Timoshenko had an equation of motion that took into account the bending moment, shear, and rotational inertia. Bernoulli's model did not take into account either the shear or rotation inertia. This model was a simplified model of Timoshenko where we considered the strain energy due to the negligible shear during bending.

4.5.4.2 Destructive test

Four-point bending tests were performed on an INSTRON universal testing machine (Figure 24) to measure MOE (static) and Modulus of Rupture (MOR). Moisture content values of poplar cultivars and Douglas-fir samples were (8.5% ± 0.5) and (13.3 ± 1.6%), respectively. The moisture content values were uniform when the destructive tests were performed. Specific MOE and specific MOR were obtained by dividing static MOE and MOR by the LVL density at those moisture content values.

4.5.5 Statistical Analysis

4.5.5.1 Statistical Analysis of poplar LVL

Density, MOE, MOR, Specific MOE (SMOE) and specific MOR (SMOR) were the observed parameters. The experimental results were statistically analyzed using an analysis of variance (ANOVA) to analyze the effects of veneer thickness (3 mm and 5.25 mm), poplar cultivars, juvenility (juvenile and mature) and loading direction (edgewise and flatwise). Mean differences between levels of factors were determined using Duncan's Multiple Range Test.

4.5.5.2 Statistical Analysis of Douglas-fir LVL

Density, MOE and MOR were the observed parameters. The experimental results were statistically analyzed using an analysis of variance (ANOVA) to analyze the effects of veneer thickness (3 mm and 5.25 mm), juvenility (juvenile and mature) and loading direction (edgewise and flatwise). Mean differences between levels of factors were determined using Duncan's Multiple Range Test

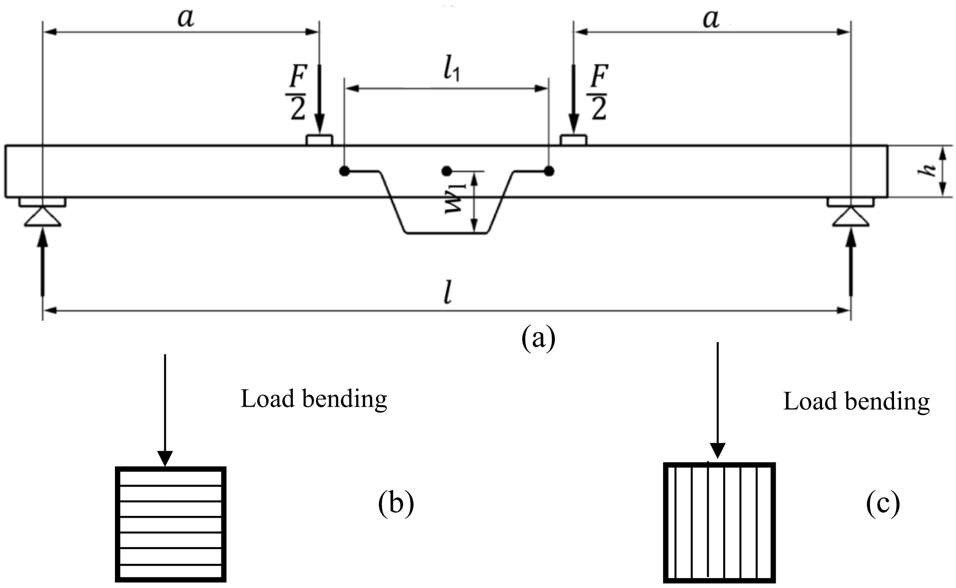

Figure 24 Schematic diagram of destructive test for LVL from 14 poplar cultivars and douglas-fir: four point bending test (a); flatwise direction (b); and edgewise direction (c)

4.6 Results and Discussion for sengon and jabon LVL

4.6.1 LVL density

LVL density increased from pith to bark for LVL made of unboiled and boiled veneers of sengon and jabon (Figure 25a-b). The average sengon LVL density of unboiled and boiled type I were 370.1, 401.1, kgm^{-3} respectively. Otherwise, the average sengon LVL unboiled and boiled type II were 391.4 and 408.1 kgm^{-3}, respectively (Figure 25a). The average jabon LVL densities were 473.7 kgm^{-3} (unboiled type I), 494.4 kgm^{-3} (boiled type I), 497.6 kgm^{-3} (unboiled type II), and 520.3 kgm^{-3} (boiled type II) (Figure 25b).

A strong relationship between density of solid wood and of LVLs with bending properties was observed by numerous authors (Kilic *et al*. 2006; Shukla and Kamdem 2007; H'ng *et al*. 2010). In general, LVL density of jabon had higher values than sengon. This fact was caused by the higher density of jabon veneer compared to sengon veneers. The average veneer densities of sengon were 287.0 kgm^{-3} (unboiled sengon) and 318.4 kgm^{-3} (boiled sengon). The average veneer densities of unboiled and boiled jabon were 395.3 and 406.9 kgm^{-3}, respectively.

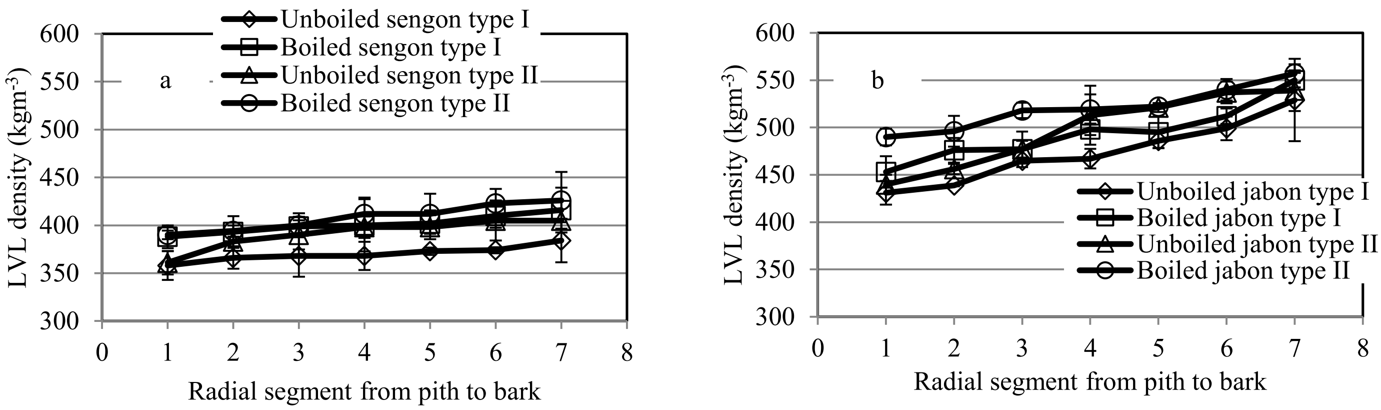

Figure 25 LVL density from pith to bark made of unboiled and boiled sengon (a) and jabon (b) veneers

4.6.2 Effect of lathe check on glue bond strength of LVL

The average glue bond strengths of the LVL increased from pith to bark for unboiled and boiled of sengon and jabon (Figure 26a-b). The average glue bond strength of unboiled and boiled sengon type I were 35.8 and 38.2 $kgcm^{-2}$, respectively. Otherwise the average glue bond strengths of unboiled and boiled sengon type II were 39.8 and 43.1 $kgcm^{-2}$, respectively (Figure 26a). The average glue bond strengths of jabon LVL were 39.8 $kgcm^{-2}$ (unboiled type I), 45.5 $kgcm^{-2}$ (boiled type I), 43.2 kg cm^{-2} (unboiled type II) and 50.7 kg cm^{-2} (boiled type II) (Figure 26b).

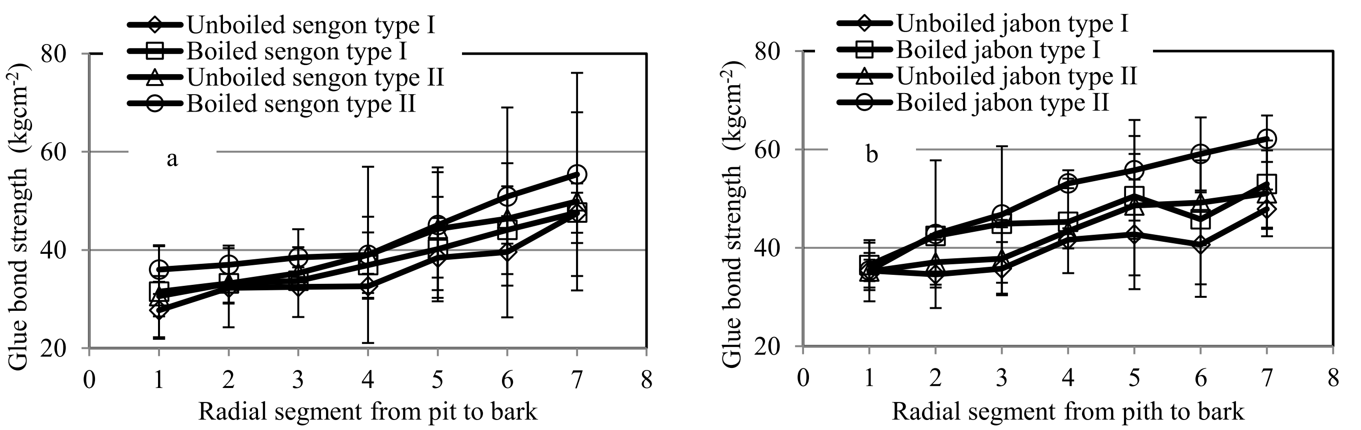

Figure 26 Glue bond strength of LVL from pith to bark made of unboiled and boiled sengon (a) and jabon (b)

The results suggest that increasing proportion of veneer near the pith would decrease the glue-line's capacity to withstand concentrated shear stresses, thus resulting in higher amounts of glue-line failure and a reduction in percent wood failure. However, as the proportion of veneer near bark increased, percent glueline failure decreased. These results are in line with Darmawan *et al*. (2015) who found the same phenomena on 2 mm LVL made of sengon veneers.

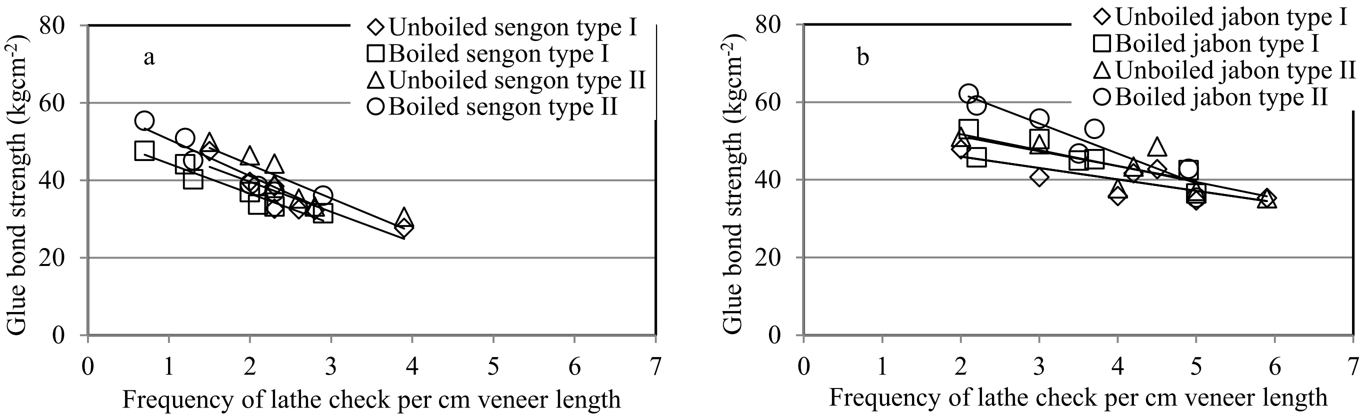

Figure 27 The correlation between frequency of lathe check and the LVL glue bond strength of unboiled and boiled sengon LVL (a) and jabon LVL (b)

These phenomena were not caused only by veneer density, but also the frequency of lathe check (Figure 27a-b). The glue bond strength had a statistically significant, negative correlation to lathe check frequency. Its correlation coefficients according to the lines in Figure 27a-b are summarized in Table 10. The results show that the regression coefficients for the glue bond strength linear equation depicted by boiling treatment and layout. The more lathe check frequency in veneers, would result in the lower glue bond strength of the LVL for unboiled and boiled.

Table 10 Linear regression equation and determination coefficients according to Figure 27 (Y = glue bond strength, X = frequency of lathe check, R^2 = determination coefficient)

	Linear regression	R^2
Unboiled sengon type I	Y = 55.02 – 7.72X	0.79
Boiled sengon type I	Y = 51.98 – 7.73X	0.93
Unboiled sengon type II	Y = 61.42 – 8.69X	0.81
Boiled sengon type II	Y = 60.03 – 9.47X	0.89
Unboiled jabon type I	Y = 51.77 – 0.29 X	0.60
Boiled jabon type I	Y = 58.85 – 0.38 X	0.70
Unboiled jabon type II	Y = 59.94 – 4.10X	0.64
Boiled jabon type II	Y = 77.73 – 7.74X	0.89

Lathe check frequency was the first variable analyzed to explain the glue bond strength. As lathe check frequency of veneers in between the glue line increased, the amount of bridging wood material between each lathe check decreases. This decrease would reduce contact between the layers resulting in a weak glue line and low glue bond strength of the LVL. This result is in agreement with DeVallance *et al*. (2007), who reported that a high frequency of lathe checks results in lower strength. The LVL failures after glue bond test were observed and evaluated visually. The specimens failed mainly along a line delineated by the propagation of fracture of lathe checks within the veneer itself. This failure confirmed to the observation results of Rohumaa *et al.* (2013).

The approach that underlined the formation of the loose-loose side layout in this study was bending and shearing stress. They were varied linearly inside wood beam when bending test occurred. According to Bodig and Jayne (1993), when wood beam sufferer from flexural loading, normal stress, horizontal shear stress and deflection would occur. Wood fiber above neutral axis would receive tension stress, at neutral axis would have zero value and below neutral axis would attain tensile stress. Shearing stress maximum happen on wood fiber at neutral axis. Therefore, we put loose-loose side formation below neutral axis in order to resist tensile and shear stress (see Figure 20).

Moreover, the glue bond strengths of LVL type I were lower compared to LVL type II on both wood species, because the veneers on type II were glued loose side to loose side on glue line below neutral axis. The adhesive would spread and penetrate into lathe checks on both veneers that lead to mechanical bonding between adhesive and veneer. That bonding could resist the shearing and tensile stress during bending test. Lathe checks on both veneers contributed to the increase of glue bond strength. Surface roughness affects adhesion on two surfaces because it increases the total contact are between adhesive and wood surface. It could also provide mechanical interlocking effect that could trap the adhesive in the lathe check and act like anchor to each other (Petri 1987). Correspond with Vick (1999) who declared that in order to have the most effective bonding we need to obtain interfacial forces, which may be valence force, mechanical bonding, or both. Valence forces are forces of attraction produced by the interaction of atoms, ions, and molecules that exist within and at the surface of both adhesive and wood surface. Mechanical bonding, means surface are held together by an adhesive that has penetrated the porous surface while it is liquid, then anchored itself during solidification.

4.6.3 Effect of lathe check on bending strength of LVL

4.6.3.1 Modulus of elasticity (MOE) of LVL

The MOE LVL made of unboiled and boiled veneers of sengon and jabon increased from pith to bark (Figure 28a-b). The average MOE of unboiled and boiled sengon type I and type II were 6107.6, 6203.5, 6788.5 and 7121.4 MPa, respectively (Figure 28a). The average MOE of jabon were 7444.5 MPa (unboiled type I), 8387.4 MPa (boiled type I), 8343.2 MPa (unboiled type II), and 9174.0 MPa (boiled type II) (Figure 28b).

4.6.3.2 Specific modulus of elasticity (SMOE) of LVL

The SMOE LVL made of unboiled and boiled veneers of sengon and jabon increased from pith to bark (Figure 29a-b). The average SMOE of unboiled and boiled sengon type I and type II were 16.3, 17.3, 15.9, and 17.6 $MNmkg^{-1}$, respectively (Figure 29a). The average SMOE of jabon were 15.7 $MNmkg^{-1}$ (unboiled type I), 17.5 $MNmkg^{-1}$ (boiled type I), 16.9 $MNmkg^{-1}$ (unboiled type II), and 18.2 $MNmkg^{-1}$ (boiled type II) (Figure 29b).

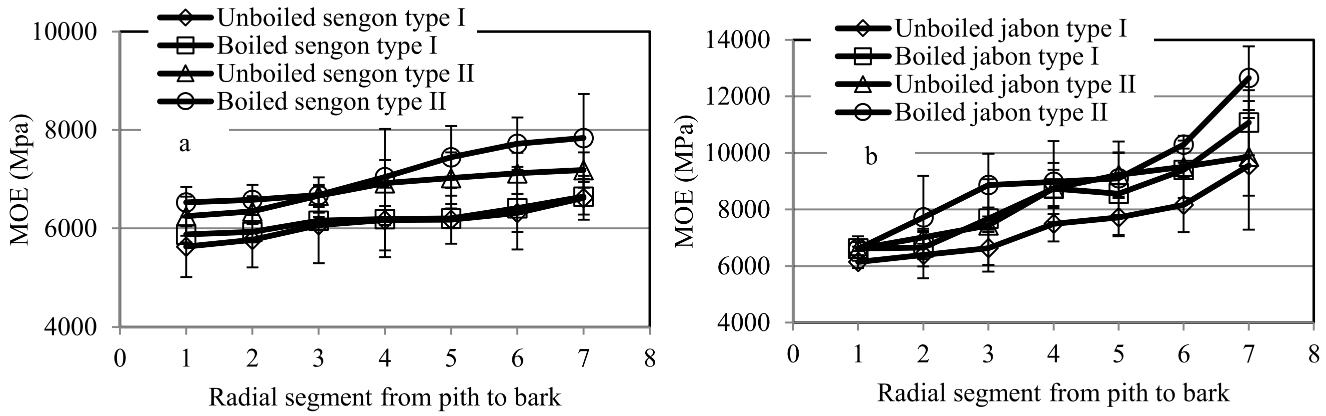

Figure 28 MOE values of LVL from pith to bark made of unboiled and boiled sengon (a) and jabon (b)

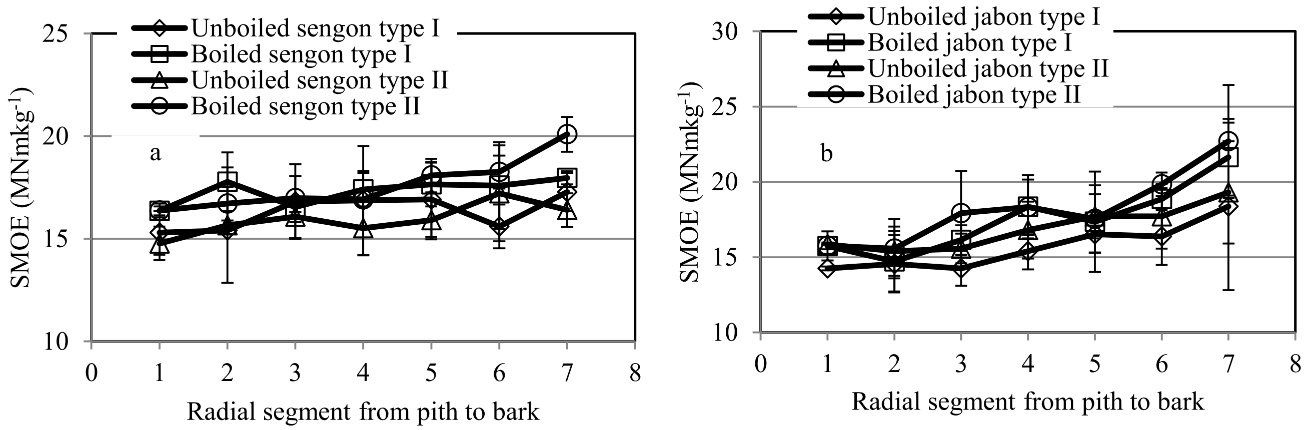

Figure 29 SMOE values of LVL from pith to bark made of unboiled and boiled sengon (a) and jabon (b)

4.6.3.3 Modulus of Rupture (MOR) of LVL

The same with glue bond strength and MOE, MOR values also increased from pith to bark for LVL made of unboiled and boiled veneers of sengon and jabon (Figure 30a-b).

The average MOR of unboiled and boiled sengon type I and type II were 36.2, 40.2, 40.2 and 42.9 MPa, respectively (Figure 30a). The average MOR of jabon were 50.7 MPa (unboiled jabon type I), 54.9 MPa (boiled jabon type I), 54.3 MPa (unboiled jabon type II), and 59.8 MPa (boiled jabon type II) (Figure 30b).

4.6.3.4 Specific modulus of rupture (SMOR) of LVL

The SMOR LVL made of unboiled and boiled veneers of sengon and jabon increased from pith to bark (Figure 31a-b). The average SMOR of unboiled and boiled sengon type I and type II were 0.098, 0.102, 0.104, and 0.105 $MNmkg^{-1}$, respectively (Figure 31a). The average SMOE of jabon were 0.107 $MNmkg^{-1}$

(unboiled type I), 0.115 $MNmkg^{-1}$ (boiled type I), 0.110 $MNmkg^{-1}$ (unboiled type II), and 0.118 $MNmkg^{-1}$ (boiled type II) (Figure 31b).

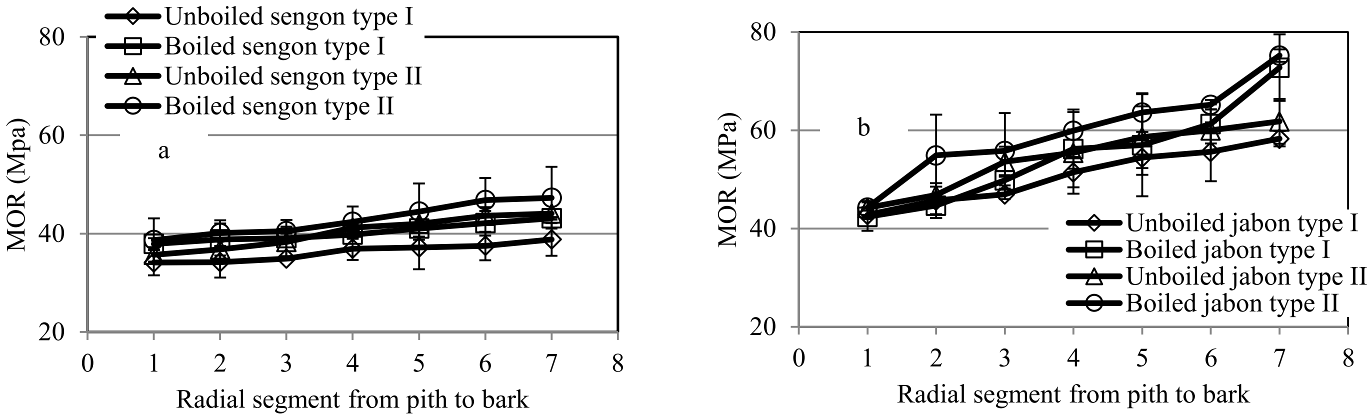

Figure 30 MOR values of LVL from pith to bark made from unboiled and boiled sengon (a) and jabon (b)

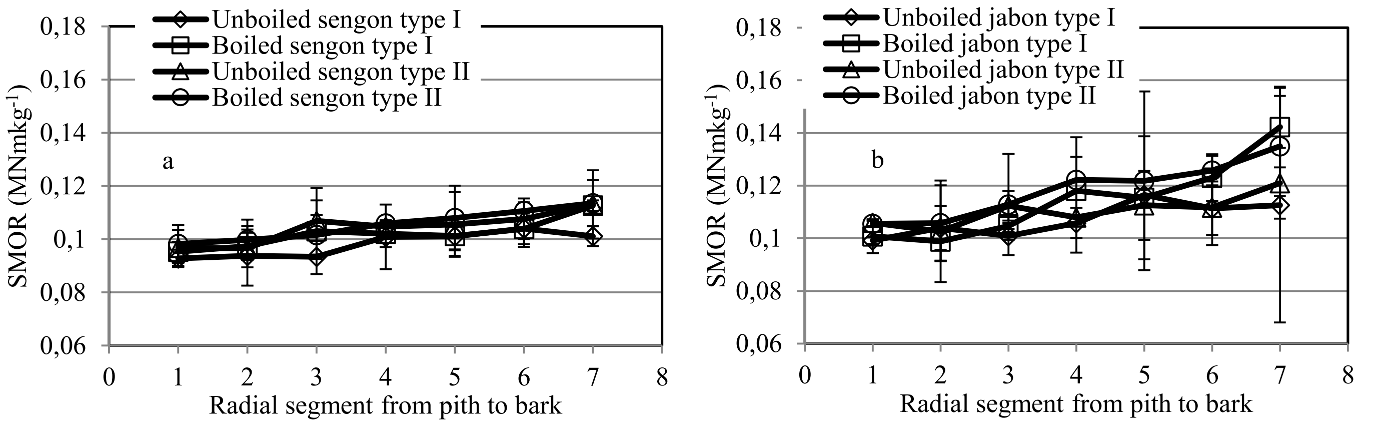

Figure 31 SMOR values of LVL from pith to bark made from unboiled and boiled sengon (a) and jabon (b)

The SMOE and SMOR were influenced by the lathe check (Figure 32 and 33). This suggested that the lathe checks may cause a possible deal of local stresses on tensile side of the bending specimen, and determine the bending failure of LVL when the lathe checks were situated under the maximum bending moment. The lack of proper connection among the fiber elements could be the reason of the frequent rupture on the tensile side. The frequency of lathe check had a statistically significant, negative correlation to SMOE and SMOR of sengon and jabon, and its correlation coefficients according to the lines in Figure 32 and 33 are summarized in Table 11 (for SMOE) and Table 12 (for SMOR).

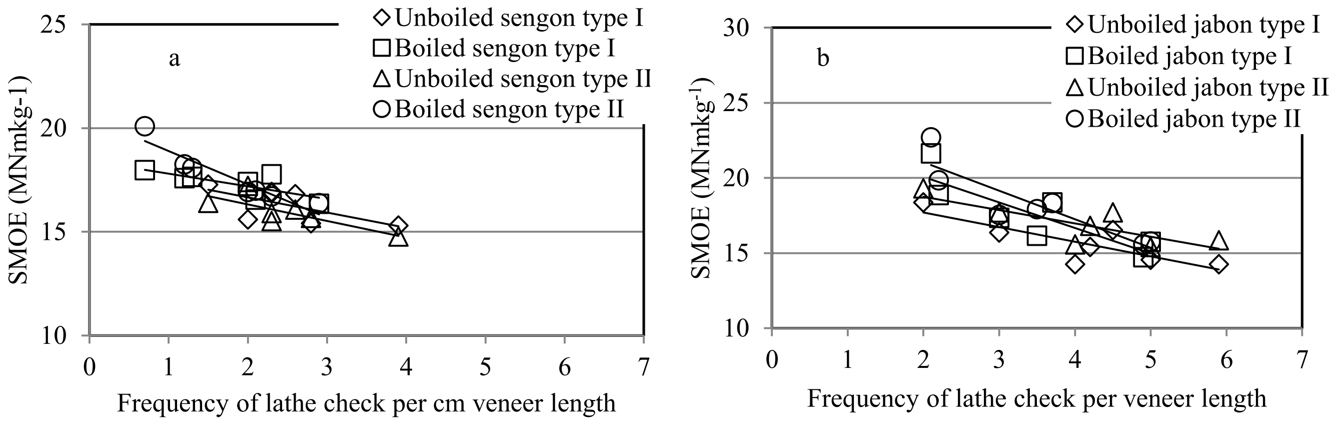

Figure 32 The effect of lathe check frequency on the SMOE LVL of unboiled and boiled sengon (a) and jabon (b)

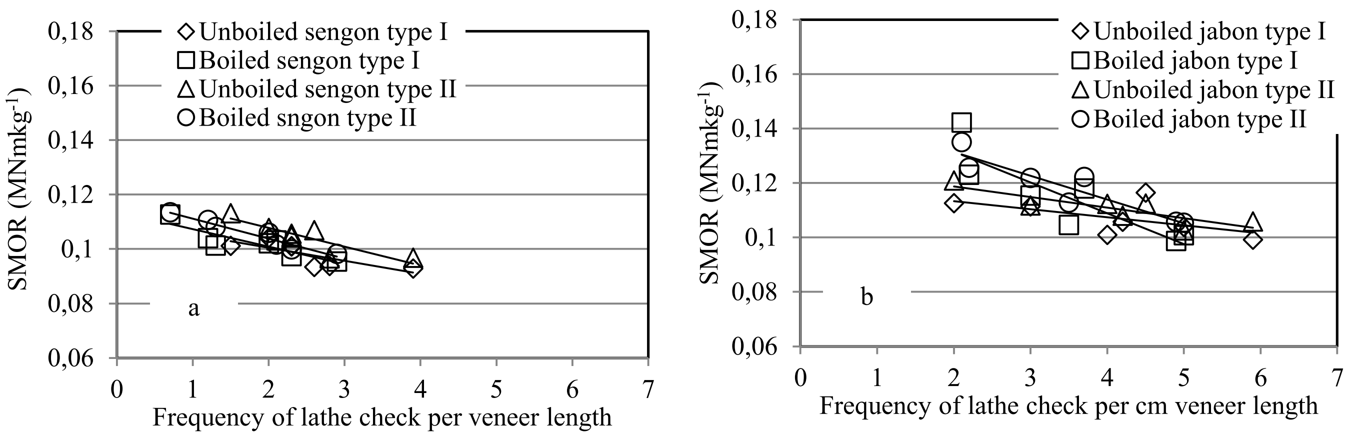

Figure 33 The effect of lathe check frequency on the SMOR LVL of unboiled and boiled sengon (a) and jabon (b)

Table 11 Linear regression equation and determination coefficients according to Figure 32 (Y = SMOE, X = frequency of lathe check, R^2 = determination coefficient)

	Linear regression	R^2
Unboiled sengon type I	Y = 18.132-0.7328X	0.43
Boiled sengon type I	Y = 18.416-0.6114X	0.54
Unboiled sengon type II	Y = 17.923-0.7988X	0.62
Boiled sengon type II	Y = 20.502-1.6075X	0.88
Unboiled jabon type I	Y=19.633-0.9689X	0.67
Boiled jabon type I	Y=23.464-1.6985X	0.72
Unboiled jabon type II	Y=20.534-0.8882X	0.63
Boiled jabon type II	Y=24.826-1.8918X	0.80

The results from Table 11 show that there are negative correlation between lathe check frequency and glue bond strength. The SMOE LVL type I were lower compared to LVL type II (by the average value of 5.8%). The same with SMOR, the results from Table 12 shows the same trend. SMOR LVL type I were lower compare to MOR LVL type II (by the average value of 3.2%).

Table 12 Linear regression equation and determination coefficients according to Figure 33 (Y = SMOR, X = frequency of lathe check, R^2 = determination coefficient)

	Linear regression	R^2
Unboiled sengon type I	Y=0.1102-0.0048X	0.61
Boiled sengon type I	Y=0.1136-0.0064X	0.76
Unboiled sengon type II	Y=0.1216-0.0069X	0.76
Boiled sengon type II	Y=0.1185-0.0074X	0.94
Unboiled jabon type I	Y=0.1193-0.003X	0.35
Boiled jabon type I	Y = 0.1541-0.0113X	0.75
Unboiled jabon type II	Y=0.1264-0.0039X	0.72
Boiled jabon type II	Y=0.1487-0.0087X	0.86

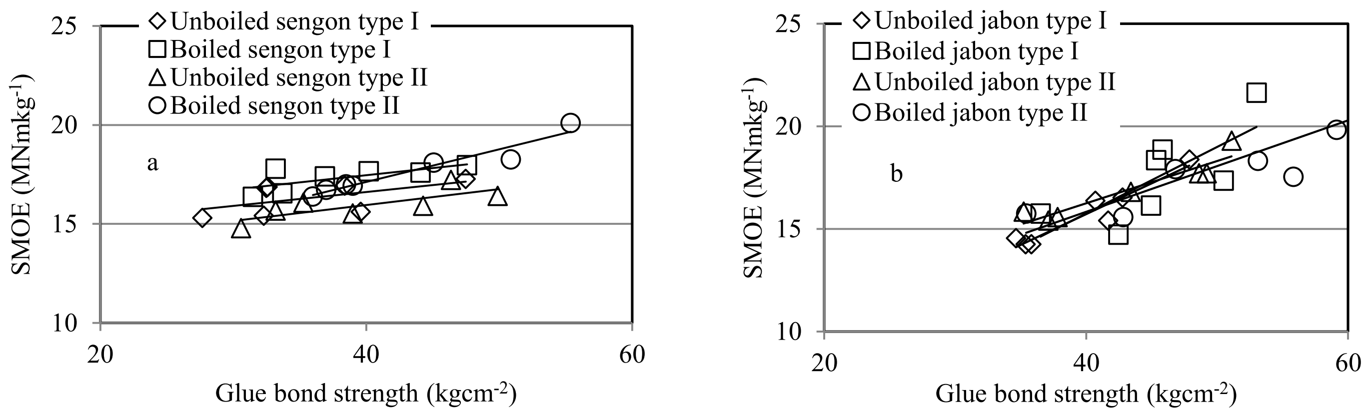

Figure 34 Relation between glue bond strength and SMOE LVL of unboiled and boiled sengon (a) and jabon (b)

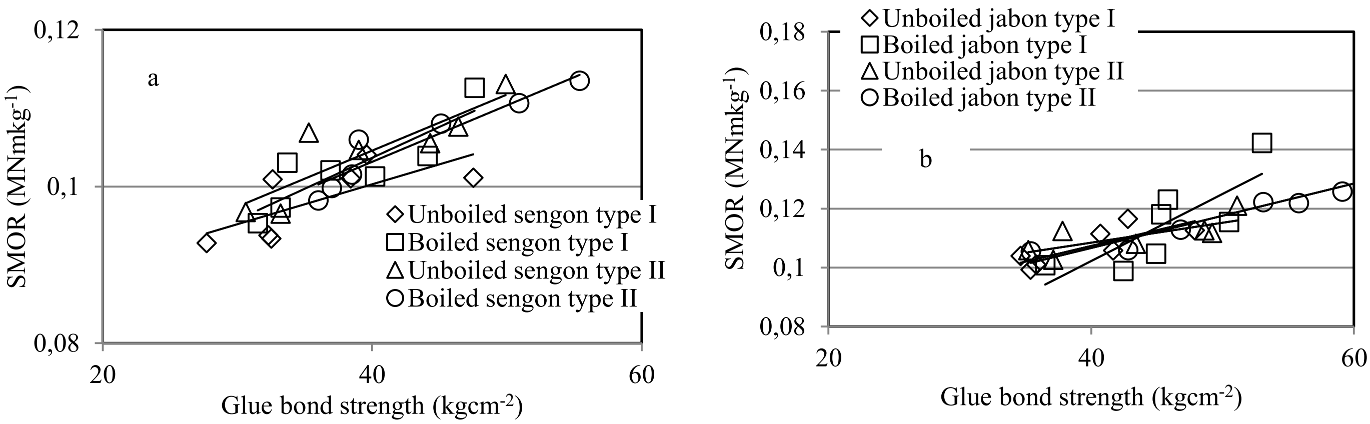

Figure 35 Relation between glue bond strength and SMOR LVL of unboiled and boiled sengon (a) and jabon (b)

Table 13 Linear regression equation and determination coefficients according to Figure 34 (Y = SMOE, X = glue bond strength, R^2 = determination coefficient)

	Linear regression	R^2
Unboiled sengon type I	Y = 13.79+0.0704X	0.30
Boiled sengon type I	Y = 14.558+0.0725X	0.49
Unboiled sengon type II	Y=12.754+0.0799X	0.58
Boiled sengon type II	Y=10.513+0.1651X	0.93
Unboiled jabon type I	Y = 2.805+0.3239X	0.56
Boiled jabon type I	Y = 3.7326+0.2999X	0.91
Unboiled jabon type II	Y=8.0274+0.2055X	0.89
Boiled jabon type II	Y=6.9316+0.2227X	0.74

Table 14 Linear regression equation and determination coefficients according to Figure 35 (Y = SMOR, X = glue bond strength, R^2 = determination coefficient)

	Linear regression	R^2
Unboiled sengon type I	Y = 0.08+0.0005X	0.51
Boiled sengon type I	Y=0.0721+0.0008X	0.74
Unboiled sengon type II	Y = 0.076+0.0007X	0.75
Boiled sengon type II	Y = 0.0744+0.0007X	0.90
Unboiled jabon type I	Y=0.0649+0.0011X	0.64
Boiled jabon type I	Y=0.011+0.0023X	0.64
Unboiled jabon type II	Y=0.0813+0.0007X	0.57
Boiled jabon type II	Y=0.0628+0.0011X	0.91

The results in Figure 34 and 35 show that both SMOE and SMOR increased with an increase in glue bond strength. The SMOE and SMOR of sengon and jabon LVL decreased with increasing in the lathe check frequency of the veneers. Higher glue bond strengths were also obtained for sengon and jabon LVL manufactured from veneers having lower frequency of lathe checks (Figure 34 and 35). The glue bond strength had a statistically significant, negative correlation to SMOE and SMOR of sengon and jabon, and its correlation coefficients according to the lines in Figure 34 and 35 are summarized in Table 13 (for SMOE) and Table 14 (for SMOR).

The same with the correlation between frequency lathe check and SMOE and SMOR, the correlation between glue bond strength and SMOE and SMOR showed the same trend. This study proved that boiling treatment prior to peeling (by boiling sengon and jabon logs in 75°C water for 4h) and application of type II layout have resulted small improvement in increasing glue bond, SMOE and SMOR of sengon and jabon LVL. A large set of samples in upcoming research could help to verify these trends more accurately. An optimum adhesive penetration could allow better internal surface contact for chemical bonding, mechanical interlocking and stress transfer between layers (Scheikl 2002). High glue bond strength induced excellent stress transfer in LVL that could lead to high SMOE and SMOR. Type II layout provided not only chemical bonding but also mechanical interlocking between two layers that could resist shearing and tensile stress during bending test.

4.7 Results and Discussion for poplar and Douglas-fir LVL

4.7.1 LVL Density

A tight correlation was found between density of poplar solid wood (Reuling *et al*. 2013) and LVL (Figure 36). LVL of 3 mm had a higher density value than that of 5.25 mm.

The ANOVA (Appendix 1) shows that juvenility, poplar cultivars and veneer thickness had significant influences on density ($p<0.01$). The average density of poplar LVL (Appendix 2) made of "mature" veneers, (408 $\pm$ 37) kgm^{-3}, was significantly higher than that of LVL made of "juvenile" veneers, (401 $\pm$ 37) kg m^{-3}. However, this difference was not verified for each cultivar (Appendix 3). It was also found that this difference was still limited since it only amounted to less than 2.6% of the increase which was expected since the way samples were performed. The density of poplar LVL (Appendix 2) made from 3 mm veneer, (415 $\pm$ 35) kgm^{-3}, and 5.25 mm veneer, (395 $\pm$ 40) kgm^{-3}, was significantly different.

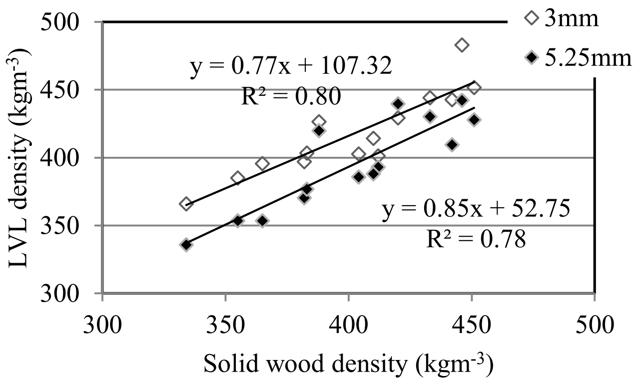

Figure 36 Correlation between LVL and solid wood density of 14 poplar cultivars at (8.5±0.5) % moisture content

LVL density is naturally more influenced by cultivar density itself. This is in line with several results in the literature (H'ng *et al*. 2010; Daoui *et al*. 2011; De Melo and Del Menezzi 2014). The thinner the veneer is the more numerous are the glue lines and the greater is the amount of glue used. Thus, the observed discrepancy between the densities of 3 and 5.25 mm LVL was systematic (difference in intercept of linear regressions about 55 kgm^{-3} see Figure 36). It was mainly due to the removal of three glue lines between the two layups. Finally, LVLs made with thicker veneer were significantly lighter (5% on average) when each process parameter was constant (Table 15).

ANOVA (Appendix 4) shows that juvenility and veneer thickness had significant effect to douglas-fir LVL density ($p<0.01$). Average value of LVL density is presented in Appendix 5. LVL from mature veneers (583 $\pm$ 36) kgm^{-3} presented a significantly higher density compare to LVL from juvenile (522 $\pm$ 27) kgm^{-3}. LVL density made of mature veneers was significantly higher than LVL made of juvenile veneers. This was due to veneer density itself.

Table 15 The increasing percentage of dynamic MOE, static MOE, MOR, density, SMOE and SMOR value of 3 mm and 5.25 mm LVL of poplar cultivars made of juvenile and mature veneers

		Dynamic MOE (MPa)	Static MOE (MPa)	MOR (MPa)	Density kgm^{-3}	SMOE (MNm/kg)	SMOR (MNm/kg)
LVL 5.25mm	Mature	9431	9104	54	400	22.7	0.136
	Juvenile	8126	7736	45	390	19.8	0.115
gain in %		+16.1	+17.7	+20	+2.6	+12.8	+15.4
LVL 3mm	Mature	9233	8769	55	417	21.0	0.132
	Juvenile	8174	7628	47	412	18.5	0.115
gain in %		+13.0	+15.0	+17.0	+1.2	+11.9	+12.9

Table 16 The increasing percentage of dynamic MOE, static MOE, MOR and density value of 3 mm and 5.25 mm LVL of Douglas-fir made of juvenile to mature veneers

		Dynamic MOE (Mpa)	Static MOE (Mpa)	MOR (MPa)	Density (kgm^{-3})
LVL 5.25mm	Mature	14899	14202	65	573
	Juvenile	13651	13222	59	514
gain in %		+9	+7	+15	+11
LVL 3mm	Mature	15061	14834	60	596
	Juvenile	13321	12148	54	532
gain in %		+13	+22	+11	+12

Density (561 $\pm$ 45) kgm^{-3} of Douglas-fir LVL made of 3 mm veneers had a significantly higher density (542 $\pm$ 42) kgm^{-3} than LVL made of 5.25 mm. The thicker veneer used to produce LVL would result in lesser glue line compare to LVL from thinner veneer. This lesser glue line would cause a lower density of LVL. The same with poplar, Douglas-fir LVL made of thicker veneer were significantly lighter (4% on average) when each process parameter was constant (Table 16). This result was different from Palka (1961) who found that Douglas-fir plywood from 2.54 mm veneer has the lowest density compare to 3.6 mm and 5.1 mm veneers. However, these results were in line with several results in the literature (H'eng *et al*. 2010; Daoui *et al*. 2011; De Melo and Del menezzi 2014).

4.7.2 Modulus of Elasticity (MOE)

4.7.2.1 Static MOE

The ANOVA (Appendix 1), showed that juvenility, poplar cultivar and veneer thickness had a significant influence on poplar static MOE ($p<0.01$). In Appendix 2, 'Brenta' had the highest value of static MOE (9439 MPa), while 'I214' had the lowest (6713 MPa).

Duncan's multiple comparison test (Appendix 2) show that the MOE static value for mature poplar LVL (8880 MPa) was statistically higher than for juvenile poplar LVL (7664 MPa). It also shows that there was a statistical difference between cultivars which could be mostly attributed to wood density. Indeed, r^2 between static MOE and density reached 0.6, while between MOR and density reached 0.7 when using data from Appendix 3.

Duncan's multiple comparison test (Appendix 2) shows that the poplar MOE static values for 3 mm and 5.25 mm are statistically different. It is interesting to note that for such a large number of samples, the effect of the veneer thickness on MOE was not negative since the average MOE increased from 8202 MPa for 3 mm to 8416 MPa for the 5.25 mm veneer. Figure 37 shows that the static MOE values between 3 mm and 5.25 mm LVL were well correlated (R^2=0.7) but this link was highly dependent on the cultivar. Furthermore, the use of thicker veneers could reduce adhesive consumption, and simplify and accelerate the production of panels with their high mechanical properties.

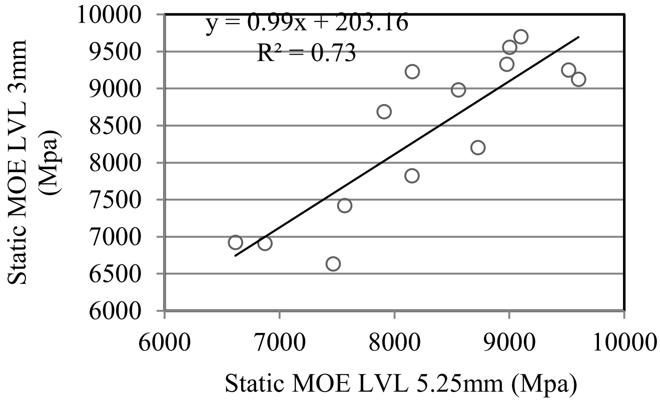

Figure 37 Correlation between 14 poplar cultivars static MOE of LVL made of 3 mm and 5.25 mm veneers (in flatwise direction)

The ANOVA (Appendix 1) shows that the sample position factor in poplar did not have a significant effect on static MOE. Mean flatwise static MOE (8267 MPa) was not statistically different from the mean edgewise MOE (8279 MPa). MOE is measured in a zone of pure bending (local modulus EN408). This is why the MOE values between flatwise and edgewise positions were quite the same. Different from the results of Bing measurements for which shear deformation was considered. Shear deformations are different since shear modulus differs due to wood orthotropy and slightly to lathe check orientation. This is also the expected reason why some differences in MOE can be seen in Appendix 3.

The ANOVA and Duncan's multiple comparison test results in poplar were in agreement with observations in the literature regarding the effect of juvenile wood on solid wood and LVL stiffness (Kretschmann *et al.* 1993; Kretschmann 1997; Nazerian *et al.* 2011).

ANOVA (Appendix 4) shows that, juvenility and interaction between juvenility and veneer thickness had significant effect to static MOE of Douglas-fir LVL ($p<0.01$). Average value of Douglas-fir static MOE are presented in Appendix 5. Static MOE (14484 $\pm$ 2204 Mpa) of LVL made of mature veneers was significantly higher compare to that of LVL made of juvenile (12735 ± 1574 Mpa).

Appendix 5, shows that Douglas-fir static MOE (14834 ± 2401 Mpa) of LVL made of 3 mm mature veneers was the highest, while static MOE (12148 ± 1464 Mpa) of LVL made of 3mm juvenile veneers was the lowest. In this study, veneer thickness as single factor did not provide significant effect on static MOE. This result corresponds to Youngquist *et al*. (1984), where a reasonable increase of veneer thickness does not affect static MOE.

The ANOVA (Appendix 4) shows that, the sample position factor did not have a significant effect on static MOE of Douglas-fir LVL. Mean flatwise static MOE was (13498 ± 2281) Mpa and mean edgewise static MOE was (13594 ± 1877) Mpa. This result was in line with De Souza *et al*. (2011) who concluded that loading position (flatwise and edgewise) does not reveal clear trend MOE of LVL of *Pinus oocarpa* and *Pinus kesiya*

4.7.2.2 Dynamic MOE

The same with poplar static MOE, the ANOVA (Appendix 1) showed that all factors significantly influenced poplar dynamic MOE ($p<0.01$), except veneer thickness.

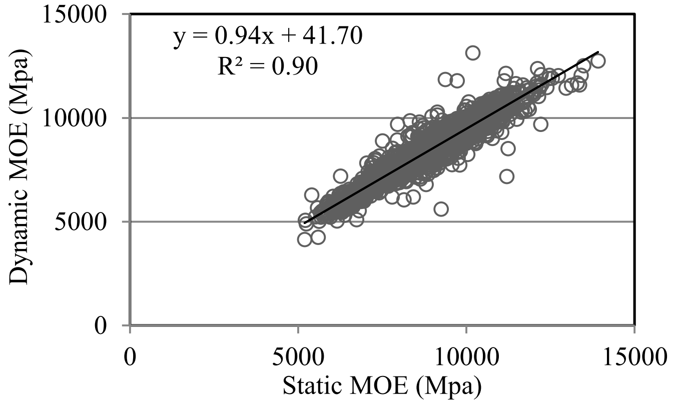

Figure 38 Correlation between dynamic MOE (vibration method) and static MOE (four-point bending test) for LVL (1808 samples) made of 14 poplar cultivars

Poplar LVL made of mature veneer (9298 MPa) resulted in a higher dynamic MOE value than for juvenile LVL (8158 MPa) (Appendix 2). Figure 38 shows an excellent correlation (r^2 = 0.90) between poplar static MOE and dynamic MOE for 1808 samples made of 3 mm and 5.25 mm thick veneers (LVL in flatwise and edgewise direction) even though there could be significant differences between the two MOE measurements according to Duncan's comparison test (Appendix 2).

The ANOVA (Appendix 4) shows that only juvenility significantly influenced Douglas-fir dynamic MOE ($p<0.01$). Average value of dynamic MOE are presented in Appendix 5. Douglas-fir LVL from mature veneers had higher dynamic MOE (14971 ± 1999 MPa) than dynamic MOE (13501 ± 1701 MPa) of LVL from juvenile.

Figure 39 shows a strong correlation (r^2 = 0.74) between Douglas-fir static MOE and dynamic MOE for 140 samples made of 3 mm and 5.25 mm thick veneers (LVL in flatwise and edgewise direction). Figure 38 and 39 indicate that BING (vibrating method) was a reliable non-destructive instrument to help predicting LVL MOE of poplar and Douglas-fir both for 3mm and 5.25mm veneer. Our results indicated that dynamic MOE was higher compared to static MOE. It was also noted in other studies that dynamic MOE (using Timoshenko approximation) is slightly higher than static MOE on poplar and beech (El-Haouzali 2009; Daoui *et al*. 2011). This phenomenon could be due to in dynamic MOE, the values were results from Timoshenko model by taking into account the bending moment, shear and rotational inertia.

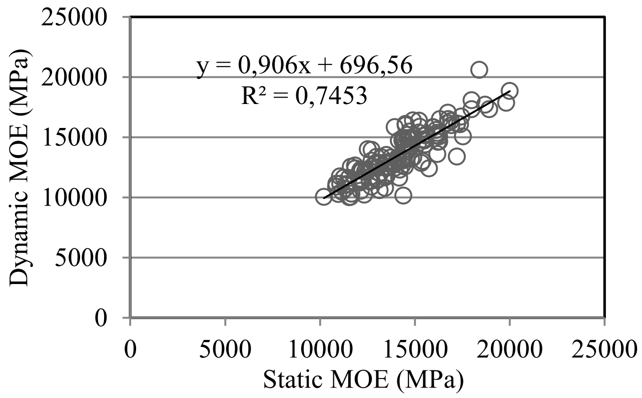

Figure 39 Correlation between dynamic MOE (vibration method) and static MOE (four-point bending test) for LVL (140 samples) made of Douglas-fir

4.7.3 Modulus of Rupture (MOR)

The ANOVA (Table 18), showed that all factors significantly influenced poplar MOR (p<0.01). LVL made of mature veneer (55 MPa) resulted in a higher MOR value than juvenile veneer (47 MPa).

The strength (MOR) of laminated wood assembled with high density veneers tends to be greater than that made of low density veneers, which was also observed for solid wood samples by (Reuling *et al*. 2013).

According to Duncan's multiple ranges (Appendix 2), 'Alcinde' and 'Lambro' had the same highest value for MOR (58 MPa), while 'Dvina', 'Triplo' and 'I214' had approximately the same value (45 MPa) considered the lowest. The average MOR values for 5.25 mm LVL (49.6 MPa) and 3 mm LVL (51.4 MPa) were statistically different (Appendix 2). The flatwise position (52 MPa) gave a higher MOR value than the edgewise position (49 MPa). According to Duncan's multiple ranges (Appendix 2), those values were statistically different.

The effect of lamination improved the tensile limit of these cultivars by about 20% on average compared to solid wood (Rahayu *et al*. 2013). Poplar LVL properties can be influenced considerably by the cultivar, the glue type and the veneer thickness (El-Haouzali 2009). According to El-Haouzali (2009), the site does not provide any significant effect.

Poplar LVL made of mature veneer resulted in a higher MOR value than juvenile veneer. Indeed, because of the specific physical and mechanical properties of juvenile wood, its proportion can have a significant impact on wood mechanical properties such as lumber strength (Panshin and de Zeeuw 1980).

The average poplar MOR values for 5.25 mm and 3 mm LVL were statistically different (Appendix 2) in line with the results of H'ng *et al*. (2010) who reported that LVL with thinner veneers (15 plies) had better mechanical performances compared to those of thicker veneers (11 plies). However, the improvement was still limited in that case and could be attributed mainly to the upgrading of lamination effects and to the reduction in lathe check depth. This improvement was also limited because the material used was almost free of defect such as knots.

As observed in the literature (Daoui *et al*. 2011; El-Haouzali 2009), the flatwise position gave a higher MOR value than the edgewise position. It was due to multiple aspects such as the number of veneer layers, the adhesive and the pressure during manufacture had led to higher MOR values in flatwise position.

The ANOVA (Appendix 4) shows that all factors significantly influenced Douglas-fir MOR LVL ($p<0.01$). Average value of MOR are presented in Appendix 5, MOR (57 $\pm$ 9 MPa) of Douglas-fir LVL made of juvenile veneers was significantly lower than MOR (63 $\pm$ 9 MPa) of LVL made of mature. This corresponds to results from many authors (Barrett and Kellogg 1989; Kretschmann 1993; Nazerian *et al*. 2011).

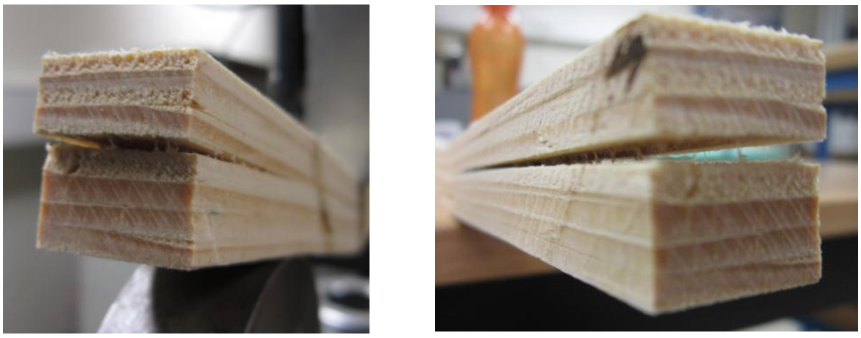

Figure 40 Douglas-fir LVL failure (break on glue line) after destructive bending strength test by Instron

Douglas-fir LVL MOR (57 Mpa) of LVL 3mm was significantly lower than MOR (63 Mpa) of LVL 5.25mm. The LVL 3mm suffered severe failure on glue line after destructive bending strength test by INSRON (Figure 40). Although, those samples were excluded from the statistical analysis, we suspected the LVL 3 mm had lower shearing strength compare to LVL 5.25 mm. The results of this work were in line with Echols and Currier (1973) who find that MOR of solid Douglas-fir is higher compared to 5-ply LVL Douglas-fir and MOR of 5-ply LVL is higher compared to 7-ply LVL Douglas-fir.

Doulgas fir LVL MOR (58 Mpa) of flatwise position was significantly lower compare to MOR (62 Mpa) of edgewise position. It was due to most of wood failure on flatwise direction was shear failures. This phenomenon is also noted by Krestchmann *et al.* (1993) who states flatwise bending strength of Douglas fir LVL is 11% less compare to edgewise LVL samples.

4.7.4 Specific MOE (SMOE) and Specific MOR (SMOR)

Several researchers have used specific modulus of rupture (SMOR) and specific modulus of elasticity (SMOE) to evaluate MOE and MOR results by taking into account the effect of density on flexural properties (Bao *et al*. 2001; Bal and Bektaş 2012). As for MOE, the ANOVA (Appendix 1) showed that veneer thickness, poplar cultivars and juvenility had significant effects on SMOE.

For SMOR, only veneer thickness did not show any significant effect, while other factors did (comparable to MOR). The Duncan test (Appendix 2) also showed that the statistical analyses between MOE and SMOE and between MOR and SMOR were similar, except for veneer thickness.

The veneer thickness, poplar cultivar and juvenility factors had significant effects on SMOE, independently from density. Anatomical factors such as fiber length, microfibril angle etc., also probably contributed to this effect.

Veneer thickness showed a significant effect for MOR but not for SMOR. This shows that, in this context, the use of thick veneers is not penalizing for intrinsic LVL mechanical properties.

4.7.5 Structure application

The advantage of using veneers taken from mature part was obvious, since mechanical properties were improved by 15 to 20% for a comparable density (Table 15). This proves that there is an effect due to juvenility for each poplar cultivar. Therefore, users should consider juvenility in estimating LVL mechanical properties.

Dynamic MOE, static MOE, MOR and in a smaller proportion density were lower for LVL made of juvenile veneers than for LVL made of mature veneers. This was in agreement with Kretschmann *et al*. (1993). A significant difference was found between Southern Pine and Douglas Fir LVL manufactured with mature or juvenile material. The ratio of juvenile to mature material was approximately 0.8 for strength and stiffness, which was comparable with ours.

According to static MOE values of poplar cultivars and the results of Duncan's multiple comparison test (Appendix 2) for static MOE values, 3 categories were established. 'Taro', 'Lambro', 'Soligo', 'Brenta' and 'Alcinde' Poplar cultivars could be considered as suitable for structural application (blue colored in Appendix 2), whilst 'Lena', 'Trichobel', 'Mella', 'Koster' and 'Dvina' should be used with careful sample selection (red colored). 'Polargo', 'Triplo', 'A4A' and 'I214' should not be selected for such purposes (yellow colored). Poplar cultivars with static MOE values more than 9000 MPa and according to Duncan analysis had 'A' and 'B' letters were classified in blue colored, while poplar cultivars with values more than 8000 MPa (had 'C' and 'D' letters) were classified in red colored. Poplar cultivars with less than 8000 MPa (had 'E', 'F' and 'G') were classified in yellow colored.

The increases on percentage of Douglas-fir LVL bending strength originated from juvenile and mature veneers were described on Table 16. The advantage of using veneers taken from mature part was the improvement in bending strength by 7 to 22%. Dynamic MOE, static MOE, MOR and density were lower for LVL made of juvenile veneers than for LVL made of mature veneers. This was in agreement with Kretschmann *et al*. (1993). This proves that there is an effect of juvenility on Douglas-fir LVL. Therefore, producers should consider minimize utilizing juvenile veneer in LVL Douglas-fir.

The advantage of using Douglas-fir 5.25 mm was the improvement in bending strength by 0.6-9% (Table 16). It was noted in this study that effect of the veneer thickness on the stiffness or strength is positive. This result was in line with Echols and Currier (1973). The use of thick veneers appears to be not penalizing to LVL bending strength for this species in the range of parameters in use. Consequently, the idea of using thicker veneers to reduce the adhesive consumption without altering their mechanical properties has promising prospect.

4.8 The correlation between fiber/tracheid length of fast growing wood species and bending properties

Juvenile wood has significantly lower strength and stiffness, more longitudinal shrinkage, and less radial and tangential shrinkage than mature wood. It was due to its tracheid characteristics (Pearson and Gilmore 1971; Bendtsen 1978; Bendtsen and Senft 1986). Results on Chapter 2 regarding fiber length of sengon near pith and near bark were 770 and 1336 µm, respectively. While jabon fiber lengths were 753 µm (near pith) and 1642 µm (near bark). The fiber lengths of 'soligo' were 1058 µm (near pith) and 1348 µm (near bark). Douglas-fir tracheid lengths for juvenile and mature wood were 1200 and 3359 µm, respectively. The increase of tracheid length was followed by the increase of MOR LVL made of juvenile veneers to mature veneers. The percentage gain MOR LVL between juvenile (near pith) to mature wood (near bark) for sengon, jabon, 'soligo' and douglas-fir were 10%, 27%, 22% and 10%, respectively. This trend was also observed by Kiaei *et al.* (2013) who found that there was a relationship between MOR of *Pinus eldarica* solid wood and tracheid length (R^2=0.47)

4.9 Conclusion

The glue bond strength, MOE and MOR of sengon and jabon LVL increased from pith to bark. The advantage of using veneers from poplar mature wood was proved with an improvement of 15 to 20% on average for mechanical properties, with almost the same panel weight. Douglas-fir LVL made of mature veneers had higher bending strength compare to LVL made of juvenile veneers. Utilization of mature veneers in producing Douglas-fir LVL appears to improve bending strength from 7 to 22%.

Boiling treatment prior to peeling (in 75°C water for 4h) and application of type II layout have successfully increase glue bond and bending strength of sengon and jabon LVL. The glue bond strength, MOE and MOR of sengon and jabon LVL were decreased as the frequency of lathe check increased. The increase of glue bond increased sengon and jabon LVL bending strength.

The use of thicker veneers in poplar and Douglas-fir LVL, reduced the use of adhesive, and simplified and accelerated the production of panels without altering their mechanical properties. The sample position did not give significant effect on static MOE, SMOE and density of poplar LVL. The dynamic MOE, MOR and SMOR of poplar LVL for flatwise were always a little higher. LVL made of 3mm veneers of Douglas-fir has lower bending strength compared to

LVL made of 5.25mm veneers. The sample position did not give significant effect on all parameters measured of Douglas-fir LVL

Some cultivars have a real potential for structural applications (‘Lambro’, ‘Soligo’, ‘Alcinde’, ‘Brenta’ and ‘Taro’), some should be used with careful sample selection (‘Lena’, ‘Trichobel’, ‘Mella’, ‘Koster’ and ‘Dvina’), while ‘Polargo’, ‘A4A’, ‘I-214’ and ‘Triplo’ should be excluded.

The resonance technique is a reliable tool for estimating LVL MOE and avoiding destructive test. It is particularly useful for poplar and douglas-fir.

5 DETERMINATION OF SENGON AND JABON LVL SPECIFIC MODULUS OF ELASTICITY BY MODELLING PEELING AND EVOLUTION OF RAW MATERIAL PROPERTIES ON RADIAL SEGMENT BASIS

French summary

Le lamibois (LVL) est un produit d'ingénierie bois fabriqué à base de placages collés ensembles couche par couche afin de former des panneaux ou des poutres. Ces placages sont généralement obtenus à partir d'un processus déroulage qui consiste à usiner dans le sens tangentiel des billions de l'écorce vers son cœur. Cependant, la production du lamibois de haute qualité fait face à deux principaux problèmes : 1) la qualité des placages (état de surface et fissuration) ; 2) la présence d'un taux important de bois juvénile.

Les propriétés mécaniques du lamibois dépendent fortement des propriétés mécaniques de chaque couche. Le bois juvenile est créé au début de la croissance radiale (âge cambial faible), par conséquent il est présent proche de la moelle. Le bois juvénile a habituellement une plus faible densité et des propriétés mécaniques moindres que celles le bois mature.

Durant le processus de déroulage, on peut facilement séparer les placages issus de bois mature de ceux issus de bois juvénile. Cependant, il est difficile d'appréhender l'impact du bois juvénile sur les propriétés du lamibois (LVL) expérimentalement, en raison des nombreux facteurs influençant les propriétés mécaniques pendant la croissance du bois. Nous utiliserons un modèle qui considère l'impact du bois juvénile sur le produit d'ingénierie qu'est le lamibois (LVL).

Le modèle développé par Girardon *et al.* (2016) utilise de nombreuses propriétés intrinsèques au matériau bois extraites de la littérature sur le peuplier (Bao *et al.* 2001; Bjurhager *et al.* 2008; Bremaud *et al.* 2013; Fang *et al.* 2006; Hein *et al.* 2013; Rahayu *et al.* 2015). Le peuplier est considéré comme une essence à croissance rapide en France. Il est typiquement utilisé dans les procédés de déroulage. Le modèle développé utilise le logiciel Wolfram Mathematic (2015). Il y a quatre étapes pour la construction du modèle de Girardon *et al.* (2016) : 1) la détermination du MOE suivant la longueur de déroulement du placage ; 2) le tri des placages juvéniles et matures. L'âge de transition entre le bois juvénile et le bois mature est calculé à partir des cernes de croissance annuel ; 3) le placage de 20 mm d'épaisseur est assemblé numériquement en un panneau de LVL; et 4) les panneaux de lamibois sont coupés virtuellement en échantillon, puis le module élastique spécifique est calculé à partir des propriétés mécaniques de chaque couche des panneaux de LVL.

L'objectif de cette étude est d'estimer le module élastique spécifique (SMOE) du lamibois produit à partir du sengon et du jabon. Les résultats sur le peuplier (Girardon *et al.* 2016; Paillassa *et al.* 2013) sont présentés pour comparaison.

Ce nouveau modèle analytique permet de prédire le comportement mécanique d'un panneau en lamibois de sengon et jabon. Cette étude montre une

estimation correcte du comportement mécanique par le modèle développé comparé aux données expérimentales. Le modèle, comporte une approche stochastique, cette approche permet d'estimer un comportement moyen des panneaux de lamibois sans avoir à calculer toutes les combinaisons possibles d'assemblage des placages de LVL. En effet, le comportement apparent du panneau de lamibois est inhérent à la position et aux caractéristiques mécaniques des couches qui le composent. Le modèle permet également de prévoir le comportement des panneaux de lamibois selon l'épaisseur de déroulage des placages ainsi que de la direction de chargement. En effet, les résultats montrent aucune influence de la direction du chargement sur la moyenne des SMOE, cependant, il met en lumière la différence du coefficient de variation entre un chargement sur chant et un chargement à plat du panneau. Ce coefficient est également influencé par l'épaisseur du placage. Le coefficient de variation du SMOE entre sengon et jabon proche de la moelle et proche de l'écorce sont plus ou moins uniformes. Cela est dû à l'âge cambial faible des échantillons dans lesquelles la proportion de bois mature est faible voire nulle. La question sur le tri des placages provenant de bois juvénile ou de bois mature ne peut donc pas être tranchée. Le modèle ne pourra être amélioré qu'en menant des campagnes de mesures complémentaires afin de déterminer le module d'élasticité spécifique fiable pour le bois mature de sengon et de jabon.

5.1 Introduction

LVL is an engineered wood product made of veneer sheets glued together to form panels or beams. Veneers are mainly obtained from a rotary peeling process which consists of peeling a log from the outside to the core. However, the production of high quality LVL would be faced against two main problems: 1) veneer surface quality; 2) presence of important rate of juvenile wood.

Mechanical properties of LVL are strongly dependent on the mechanical properties of each layer. Juvenile is wood created at the beginning of the radial growth, hence consider as wood near pith. Juvenile wood usually has a lower density and mechanical properties than mature wood.

The rotary peeling process can easily separate mature wood from juvenile wood by sorting the veneers. However, the impact of juvenile wood on LVL is difficult to apprehend experimentally, due to the many factors which have an effect on mechanical properties during timber growth cycles. In this work, we propose to use a model which considers the impact of juvenile wood.

The model is developed by Girardon *et al.* (2016). The model uses numerous measured properties from the literature on poplar (Bao *et al.* 2001; Bjurhager *et al.* 2008; Bremaud *et al.* 2013; Fang *et al.* 2006; Hein *et al.* 2013; Rahayu *et al.* 2015). It is due to poplar wood species are fast growing species in France and typically utilized in peeling. The model is developed using Wolfram Mathematic software (2015). There are four steps to build the model Girardon *et al.* (2016) : 1) determine the MOE along the veneer length; 2) separate juvenile veneers from mature. Transition age between juvenile and mature are calculated from annual growth ring; 3) each veneer is assembled into LVL with 20 mm thickness; and 4) LVL are cut into test sample, then effective MOE is calculated from each layer properties.

The objectives of this study were 1) to estimate specific MOE of LVL from 5 years old sengon and jabon; and 2) to determine coefficient variation of specific MOE LVL from 5 years old sengon and jabon. In this study, the results on poplar (Girardon *et al*. 2016; Paillassa *et al*. 2013) were presented as comparison.

5.1.1 Mechanical property dependency

The longitudinal elastic modulus of wood is influenced by many parameters such as microfibril angle, density and moisture content (Cave and Walker 1994; Cousins 1976; Evans and Ilic 2001; Evans *et al*. 2000). As a first step, this study focuses on several main parameters, which are density and modulus of elasticity. Their variations according to segmented ring are taken into account in the model by interpolating experimental data from Chapter 2. A sigmoid function has been fitted on their values. Sigmoid functions allow both to smooth experimental data and provide monotonous curves which have an asymptotic behavior at the boundary of the measurements.

5.1.1.1 Density of sengon and jabon solid wood

Wood density is an important parameter, relate to many properties like stiffness and strength. The variation of wood density is high due to genetic, environment and sylvicultural management. Based on the results on Chapter 2, the densities of sengon and jabon solid wood varied from pith to bark. The density values sengon and jabon base on experimental data (results from Chapter 2) and model are presented on Figure 42. The average density of 5 years old sengon and jabon were 315.3 and 407.8 kg m^{-3}, respectively.

A sigmoid function for sengon (Equations 3) was fitted (R^2 = 0.959) to the experimental values for modelling purposes:

$$\rho\ (C_a) = 240 + \left(\frac{98}{1+e^{-0.080889(C_a-220)}}\right) + \left(\frac{55}{1+e^{-0.10928(C_a-80)}}\right) \ldots\ldots\ldots\ldots\ldots (3)$$

While a sigmoid function for jabon (Equation 4) was fitted (R^2 = 0.922) to the experimental values for modelling purposes:

$$\rho\ (C_a) = 233.93 + \left(\frac{339.1}{1+e^{-0.018969(C_a-168.158)}}\right) \ldots\ldots\ldots\ldots (4)$$

where density (ρ in kg m^{-3}) is deduced from segmented ring (Ca in radius from pith (mm)).

The results (Figure 41) was corresponded to Bendtsen (1978) in which the density increase from pith to bark. However, the results were slightly difference with Paillassa *et al*. (2013) and Senft and Bendtsen (1986) for poplar species. The specific gravity decreases during the very first years before reach constant value.

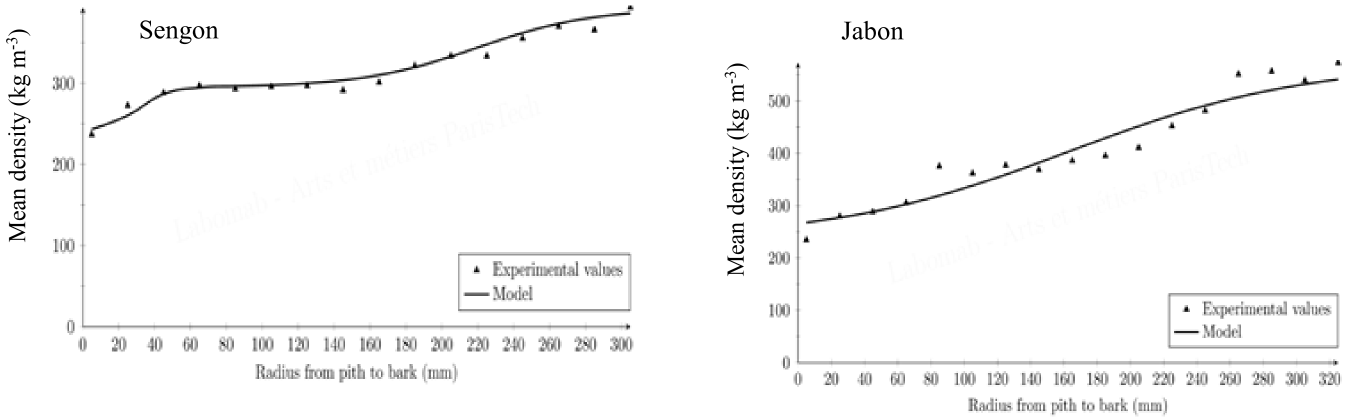

Figure 41 The average sengon (left) and jabc
on segmented ring

5.1.1.2 Modulus of elasticity of sengon and jabon solid wood

Modulus of elasticity of sengon and jabon solid wood from pith to bark are presented on Figure 42.

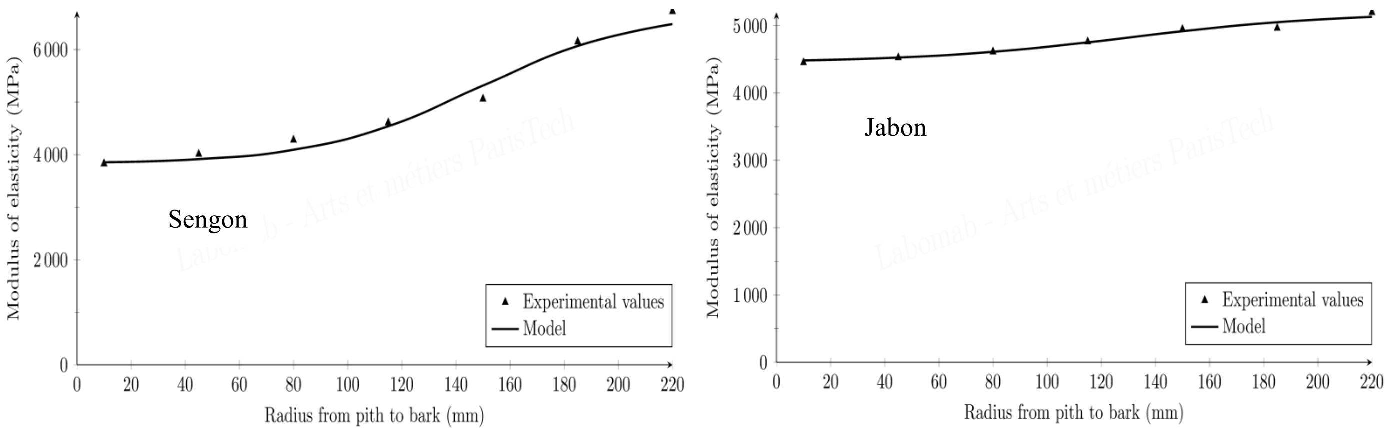

Figure 42 The average of solid wood MOE of sengon (left) and jabon (right) based on segmented ring

The values tended to increase from pith to bark. The experimental data came from the results on Chapter 2. A sigmoid function for sengon (Equations 5) was fitted (R^2 = 0.968) to the experimental values for modelling purposes:

$$MOE\ (C_a) = 4452 + \left(\frac{745.89}{1+e^{-0.02575(C_a-180.851)}}\right) \ldots\ldots\ldots\ldots\ldots\ (5)$$

While a sigmoid function for jabon (Equation 6) was fitted (R^2 = 0.975) to the experimental values for modelling purposes:

$$MOE\ (C_a) = 3826.92 + \left(\frac{2898.96}{1+e^{-0.088497(C_a-148.446)}}\right) \ldots\ldots\ldots\ldots\ (6)$$

where MOE (MOE in MPa) is deduced from segmented ring (Ca in radius from pith (mm)).

MOE of veneer would influence MOE of LVL. The properties of cell wall material (specifically MFA) and the amount of cell wall (density) both affect the mechanical properties of wood (MOE longitudinal). Therefore, the MOE solid wood evolution from pith to bark was important in our model.

5.1.1.3 Specific Modulus of Elasticity of sengon and jabon LVL

Several researchers have used specific modulus of rupture (SMOR) and specific modulus of elasticity (SMOE) to evaluate MOE and MOR results by taking into account the effect of density on flexural properties (Bao *et al*. 2001; Bal and Bektaş 2012). SMOE were directly obtained by dividing MOE with density. The above relationships will enable us to obtain the specific modulus of elasticity according to the radial position in the log.

5.2 Model building

The model was presented in Girardon *et al.* (2016) using Wolfram Mathematica Software (2015). The model consists of four different phases (Figure 43) (Girardon *et al*. 2016).

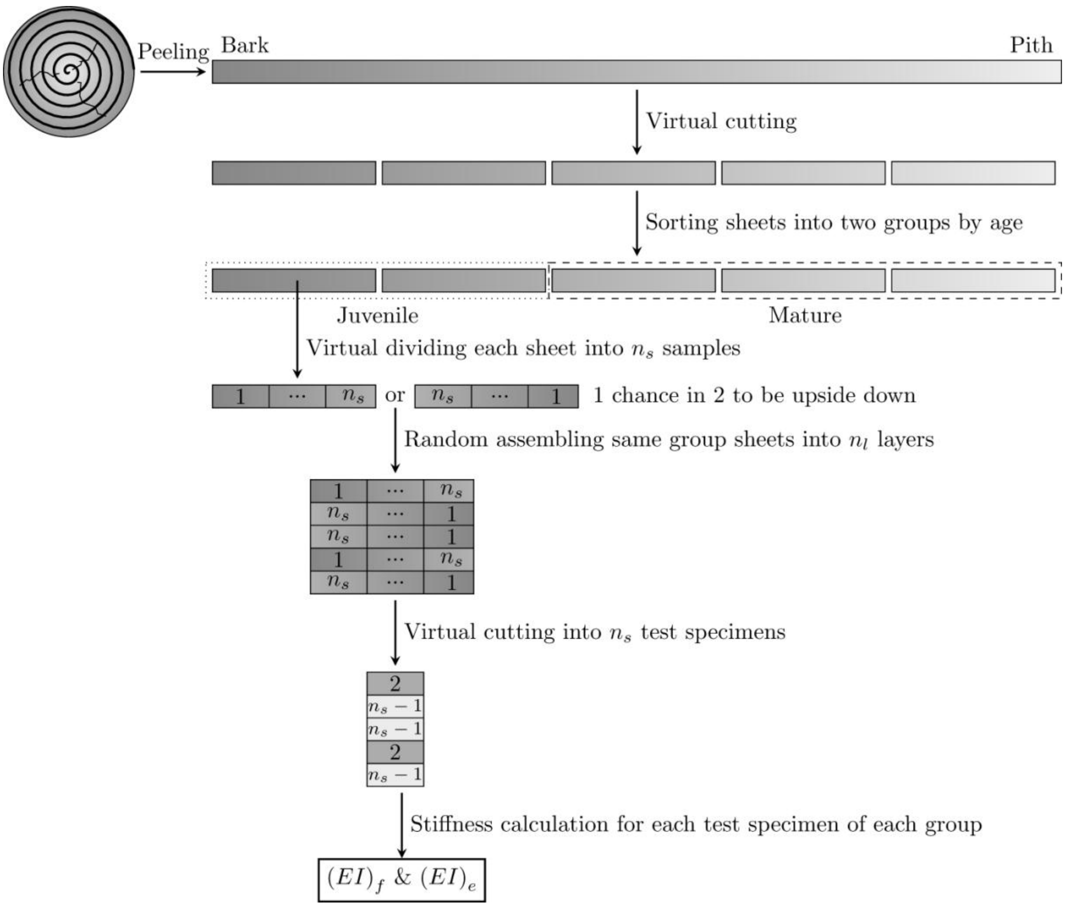

Figure 43 Virtual peeling and assembly process (shades of grey correspond to local cambial age of veneer) (Girardon *et al*. 2016)

The phases are : 1) to determine the modulus of elasticity along veneer length using the equations above developed by Girardon *et al*. (2016); 2) to divide veneers into two groups, “juvenile” and “mature”. The width of 500 mm is used, based on Rahayu *et al*. (2015). The demarcation points between juvenile and mature were based on fiber length trait (taken from Chapter 2). The demarcation point of 5 years old sengon and jabon were after 7 years old. Each veneer is virtually subdivided into ns subsamples of 20 mm thickness (the final thickness of the LVL samples); 3) for each LVL samples the veneers are assembled into nl layers to represent a LVL panel of 20 mm thickness. The number of veneer layers depends on the thickness of the veneers. Seven layers of 3 mm and four layers of 5.25 mm were produced. It is assumed that veneers are selected randomly in each category in accordance with Rahayu *et al*. (2015); and 4) to cut 20 mm thickness LVL samples. The specific modulus of elasticity of each LVL sample is calculated from each layer’s properties as described below.

5.2.1 Virtual peeling

The first step is to determine the maximum veneer length depending on the log diameter. In cross-section, the peeling process corresponds to following a spiral curve (Figure 44). The equation of a spiral in polar coordinates is given by Equation (7), where r_s is the spiral radius (mm) with respect to the angle θ (in rad), ri is the initial log radius (in mm) and t is the peeling thickness (in mm).

$$r_s(\theta) = r_i - t.\frac{\theta}{2\pi} \quad \text{……………………..(7)}$$

The length of this curve can be calculated by the integration of Equation (10), which corresponds to the veneer length. Second-order length is neglected due to linear variations in radius with respect to the angle. Thus the veneer length is determined by the following Equation (8):

$$l(r_i, r_f, w) = \int_{2\pi\frac{r_f}{t}}^{2\pi\frac{r_i}{t}} \sqrt{r_s'(\theta)^2 + r_s(\theta)^2 d\theta} \quad \text{…………(8)}$$

Where l (in mm) is the veneer length and r_f (in mm) the final log radius.

The integration domain depends on both the final and the initial log radius. Indeed, logs are not peeled up to the log center, there remains a peeler core of r_f radius. Initial and final log radii were chosen to be respectively 280 and 60 mm.

Affectation of mechanical properties

Using the above equations (Equation 3 to 6), it is then possible to determine the wood’s modulus of elasticity along the peeling sheet by composing them (Equation 9) to obtain parametric coordinates on segmented ring basis:

$$\begin{cases} l = l\left(r_i(C_a), r_f, w\right) \\ \frac{E}{\rho} = \frac{E(r_i)}{\rho(r_i)} \end{cases} \quad \text{…………………..(9)}$$

Where l (in mm) is the veneer length and E (in MPa) is the modulus of elasticity. These values are parametrized by the segmented ring (C_a)

5.2.2 Calculation of Flatwise and Edgewise modulus of elasticity

Since each layer in the LVL sample has a different modulus of elasticity along its length, it is necessary to compute a specific modulus of elasticity for each LVL samples. The value of SMOE depends on the loading direction, because the impact of each layer on the mechanical behavior of the LVL is different in flatwise or edgewise configuration. In the model, SMOE of LVL is considered higher than that of SMOE solid wood. This is a prerogative in European standard (EN 14374) concerning LVL panels.

5.2.2.1 Edgewise

In an edgewise bending test, each layer can be considered as independent. Thus, according to Equation 10 the specific modulus of elasticity is determined by calculating the sum of the SMOE of each layer, as in the following Equation

$$(SMOE)_e = \frac{\sum_{i=1}^{n_l} E_i l_i}{l_t \rho_t} \text{………………………(10)}$$

Where : SMOEi = Specific modulus of elasticity of the ith layer (MPa); Ii= Local inertia of the ith layer (mm^4); $It = Inertia\ of\ the\ homogeneous\ section$ (mm^4); n_l = number of layers and ρt = density of the ith layer (kg m^{-3})

5.2.2.2 Flatwise

In a flatwise bending test, the location of layers with different mechanical properties has more influence on global properties than in an edgewise bending test, due to a different stress rate between surface and core layers.

To calculate the specific modulus of elasticity in the flatwise direction, the position of neutral axis has to be determined thanks to the following Equation 11 (Figure 44):

$$Z_0 = \frac{\sum_{i=1}^{n_l} Z_{0,i} E_i S_i}{\sum_{i=1}^{n_l} E_i S_i} \text{……………………(11)}$$

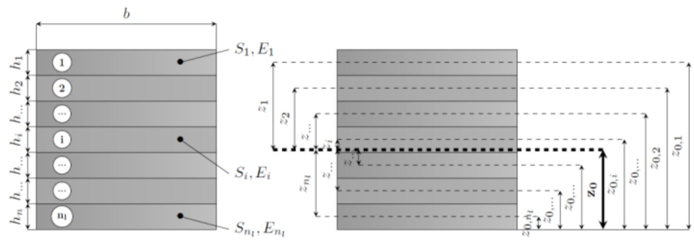

Figure 44 Geometrical and mechanical properties of LVL in a specimen cross-section

In accordance with Figure 45: Z_0 = Distance from the neutral axis to an arbitrary reference (mm); $z0$= Distance from the ith layer netral axis to an arbitrary reference (mm); zi= Distance from the ith layer netral axis to the global neutral axis (mm)

Thus, the distance between each layer's neutral axis and the global neutral axis, zi is deduced by Equation 12:

$$z_i = z_{0,i} - z_0 \text{ .... (12)}$$

Then the specific modulus of elasticity can be determined by the following Equation 13:

$$(SMOE)_f = \frac{\sum_{i=1}^{n_l} E_i I_i + S_i z_i^2}{I_t \rho_t} \text{......................(13)}$$

Where: SMOEi = Specific modulus of elasticity of the i^th^ layer (MPa); Ii = Inertia of the i^th^ layer (mm^4); $It = Inertia\ of\ the\ whole\ section$ (mm^4); Si = Section of the i^th^ layer (mm^2); zi = Distance from the i^th^ layer neutral axis to the neutral axis (mm); and ρt = density of the i^th^ layer (kg m^{-3})

5.2.3 Stochastic approach

Since in virtual peeling process the layout is based on a randomized assembly process, the process is repeated a thousand times to identify and enhance a tendency. Indeed, the peeling process always gives the same veneer for a given thickness value, but there are several combinations of veneer arrangements after the primary cutting. These combinations are high due to the possibility to turn each veneer upside-down. The veneer position influences the flatwise SMOE whereas it does not impact the edgewise SMOE. Consequently, a great number of processes have to be performed to obtain results close to experimental conditions. The number of possible combinations for a single nl layer LVL is given by Equation 14 :

$$n_{comb} = \frac{n_l! 2^{n_l}}{2} \text{.............. (14)}$$

Where, $ncomb$ is the number of possible combinations and nl is the number of layers. Symmetric cases are considered in the number of combinations; therefore the number is divided by two.

According to the log size used in this study, the total amount of sengon and jabon veneer sheets were 147 and 133 veneer sheets respectively for juvenile group. Due to the numerous ways to choose nl sheets from a set of 147 and 133 veneer sheets, a stochastic approach is chosen in order to obtain results within a reasonable computing time. The number of possible combinations is determined with binomial coefficients, which gives the following results (Equation 15) for the studied cases (4 layers of 5.25 mm thickness and 7 layers of 3 mm thickness over a total number of veneer sheets of 147 and 133):

$$\begin{cases} \binom{4}{147} \approx 1.87\ x\ 10^7 \\ \binom{7}{147} \approx 5.46\ x\ 10^{10} \\ \binom{4}{133} \approx 1.24\ x\ 10^7 \\ \binom{7}{133} \approx 1.24\ x\ 10^{11} \text{.....................15} \end{cases}$$

5.3 Results and discussion

The model can be used to predict the specific modulus of elasticity of a parameterized LVL sample. It could be used with different scenarios but requires validation through a comparison with experimental data, which is done in the following.

5.3.1 Experimental results

A summary of the results from Chapter 4 is shown in Table 17. Specific MOE were resulted from destructive testing by INSTRON in flatwise direction. Moreover, the sengon and jabon LVL were made of 3 mm veneers. The same with MOE solid wood, the specific MOE of LVL tended to increase from pith to bark.

Table 17 Specific MOE ($MPa.m^3.kg^{-1}$) LVL of sengon and jabon based on experimental data (Chapter 4) from pith to bark

Segment	Sengon	Jabon
1 (pith)	15.33 ± 0.84	14.25 ± 0.12
2	15.56 ± 1.82	14.54 ± 1.91
3	15.78 ± 0.34	14.25 ± 1.16
4	15.58 ± 1.87	16.04 ± 1.16
5	15.57 ± 0.37	15.86 ± 1.16
6	15.39 ± 1.28	16.37 ± 1.89
7 (bark)	16.74 ± 0.02	18.37 ± 5.56
Average	15.71 ± 2.53	15.67 ± 1.85

5.3.2 Model results

The model was computed based on parameters (Chapter 3) : initial log radius: 280 mm; kernel log radius: 60 mm; veneer thicknesses: 3 and 5.25 mm; veneer length: 500 mm; LVL sample width: 20 mm.

Figure 45 and 46 show the distribution of LVL samples with respect to the specific modulus of elasticity. Common statistical values are given in Table 18 and Table 19. In LVL from 3 mm flatwise, sengon had similar coefficient variation between flatwise (2.55%) and edgewise (2.82%). While for jabon the flatwise (5.10%) coefficient variation was higher than edgewise (1.45%). The coefficient variation SMOE was higher in a flatwise configuration than in an edgewise configuration, due to the greater influence of border layers in flatwise cases.

Coefficient variation also increased between 3 mm and 5.25 mm LVL thicknesses because of the number of layers used. The lesser the layers there were, the greater influence they had. These results were in line with Girardon *et al.* (2016) who find the same trend for poplar LVL.

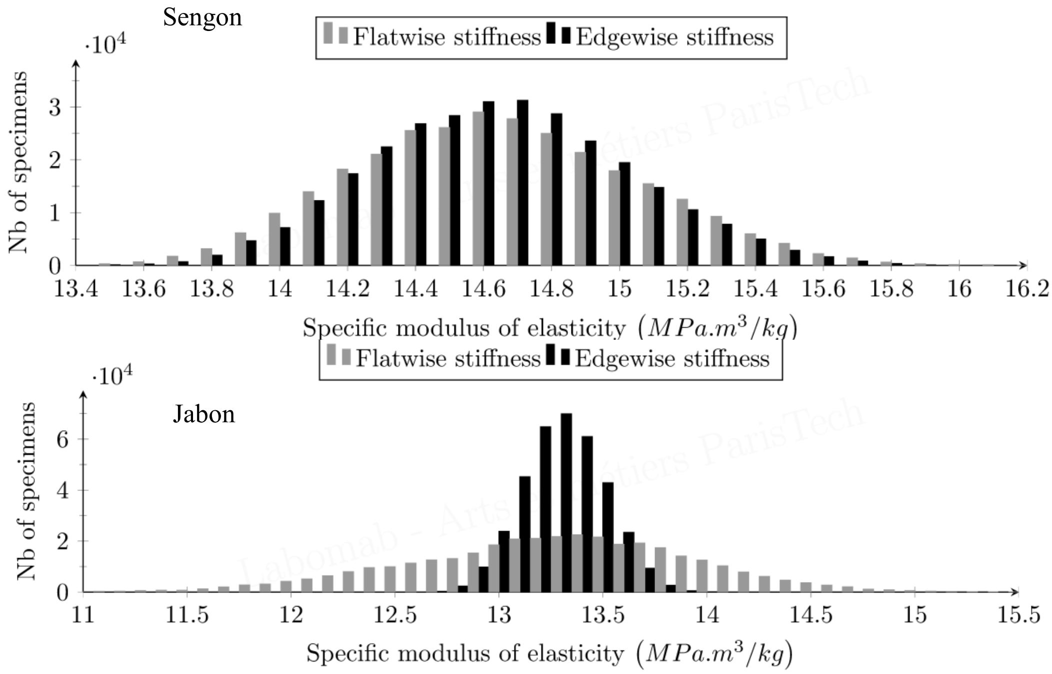

Figure 45 Specific MOE of sengon (above) and jabon (below) LVL made of 3 mm veneer

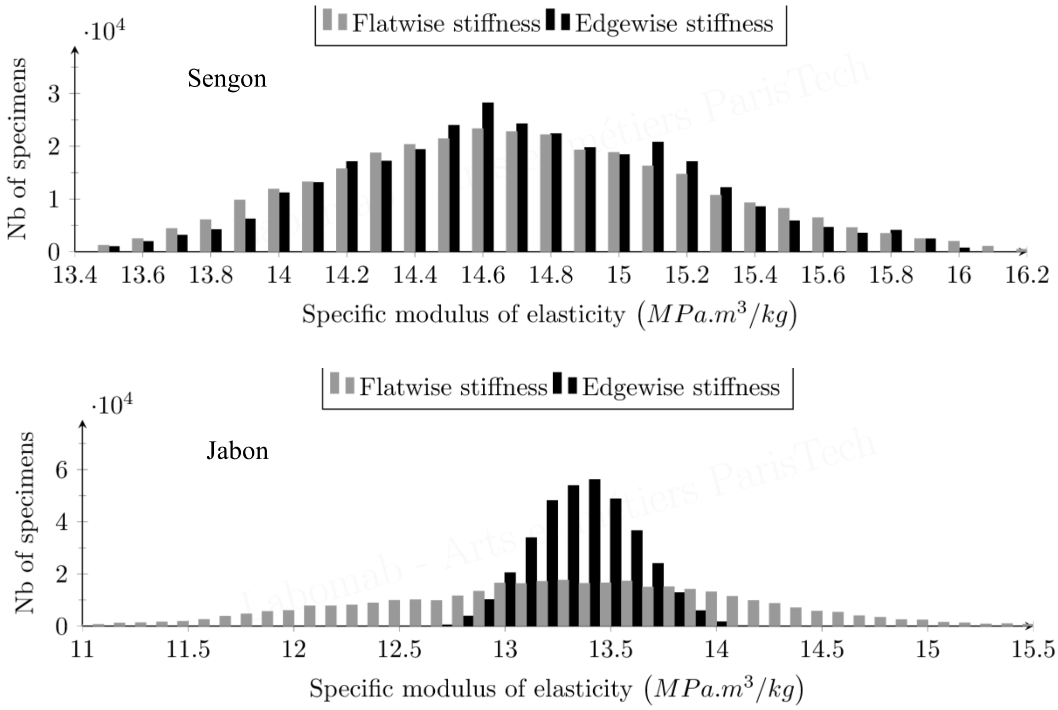

Figure 46 Specific MOE of sengon (above) and jabon (below) LVL made of 5.25 mm veneer

Table 18 Specific MOE (from the model) of sengon LVL

	3 mm		5.25 mm	
	Edgewise	Flatwise	Edgewise	Flatwise
Min	13.56	13.51	13.46	13.47
Max	15.96	16.19	16.13	16.56
Average	14.70	14.69	14.76	14.75
STD	0.37	0.41	0.49	0.53
COV (%)	2.55	2.82	3.29	3.58

Table 19 Specific MOE (from the model) of jabon LVL

	3 mm		5.25 mm	
	Edgewise	Flatwise	Edgewise	Flatwise
Min	12.75	10.80	12.69	10.45
Max	14.05	15.77	14.13	16.03
Average	13.35	13.31	13.41	13.33
STD	0.19	0.68	0.24	0.86
COV (%)	1.45	5.10	1.78	6.42

A comparison between experimental and model specific MOE values can be made (see Table 17, 18 and 19**)**, where the measurements are classified into groups according to sheet thicknesses (3 and 5.25 mm). The comparison showed that specific MOE were systematically lower than experimental ones, and that the standard deviations were higher for the experimental data. These results were corresponded with Girardon *et al*. (2016). LVL from wood near pith also showed a significantly lower SMOE in both the model and experimental result, compare to wood near bark. As mentioned before, the model is based on the assumption that all sengon and jabon behaved in the same way in terms of growth and juvenile – mature transition, and thus the coefficient of variation were obviously lower than in the experimental results

The experimental ratio between the specific MOE of wood near bark and wood near pith for sengon and jabon were 0.92 and 0.78, respectively. These values were higher than the model prediction (0.83 for sengon and 0.68 for jabon). By considering this, values resulted from the model were close or similar to those experimental data.

Several reasons could explain these observations. In this study, young age logs were used which led to no portion of mature wood. From the model point of view, there was a lack of experimental input data for mature wood, entailing an assumption of steady parameters. By doing so, the specific MOE of mature wood was not available in the model. Therefore, the absence of the mature wood could lead to specific MOE could be underestimated in this study.

The coefficient variation of sengon and jabon were considered low (less than 10%), the variation of specific MOE between wood near pith and wood near bark were less or uniform. The recommendation of sorting the veneers to separate juvenile from mature for 5 years old sengon and jabon were not needed. However the further research on sengon and jabon which had mature wood portion was essential.

The results were different from Girardon *et al*. (2016), who found the coefficient variations in poplar are more than 10%. The separation poplar veneer between juvenile and mature is highly recommended.

5.4 Conclusion

This study use a new model to predict SMOE LVL behavior. This model was based on experimental measurements of sengon and jabon log, which were used in a simulated peeling process. This study showed a correct mechanical behavior prediction by the developed model compared to experimental data. The model, featuring a stochastic approach, was also able to predict LVL behavior according to veneer thickness and loading direction. Indeed, model results show no influence of these parameters on the average SMOE. However, the model showed that the coefficient variation was higher for flatwise than for edgewise bending. Greater veneer thickness also increased the coefficient. The coefficient variation of specific MOE between sengon and jabon wood near pith and wood near bark were low or uniform. The recommendation of sorting the veneers to separate juvenile from mature for 5 years old sengon and jabon were not needed. Model accuracy could be improved by leading a measurement campaign to determine a reliable specific modulus of elasticity for sengon and jabon. This model could be used to highlight the unnecessity of sorting veneer of 5 years old sengon and jabon in an industrial process.

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6 GENERAL DISCUSSION

Nowadays the wood requirement in world society is increasing every year. So that, since few decades, both France and Indonesia have planted fast growing forests mainly for paper, particle board, light packaging, fiberboard or energy production but not so much for construction purposes. At the same time environmental concerns have dramatically grown, especially in some inter-tropical countries where natural forests reach more and more difficulties to resist to the demand both of energy and of wood material. Moreover, various Engineered Wood Product (EWP) has been developed and manufactured all around the world, especially designed for construction, showing much lower mechanical and physical variability than solid lumber.

In Indonesia, the log production from natural forest in 2008 is 8 million m^3, while in 2012 is 5.3 million m^3 (BPS 2013). This condition makes wood industries have to find other sources of raw material to fulfill their demand. One of them is woods from community forest. According to Ditjen RLPS of Ministry of Environment and Forestry (2006), the total area of community forest in Indonesia is 1.3 million ha and become 3.6 million ha on 2009. The community forest was dominantly planted with fast growing tree species, e.g. jabon (*Anthocephalus cadamba* Miq.), sengon (*Falcataria moluccana*), and other species

Plantation forests are dominantly planted by Poplar (*Populus* sp) and Douglas fir (*Psedotsuga menzii*) in France. France is the largest grower of poplar in Europe. Average annual poplar harvesting between 2007 and 2011 reached 2.4 million m^3 (FCBA 2013). Poplar plantation in France and Italy is considered as an important wood resource. Poplars plantations cover 240,000 hectares of France lands that annually produces 1.5 million cubic meters round wood. In Italy, poplar plantations with annual production of 1.8 million cubic meters cover 120,000 hectares of its lands (Spinelli *et al*. 2005). According to FAO (2011), plywood and veneer still account for the largest share of poplar products with 59.9% of total production. One of the major advantages of growing poplars for various products is their rapid growth rate, enabling their production in relatively short rotations (McIvor 2012). Douglas-fir (*Pseudotsuga menzii*) is known by its ability to produce high wood volume in European countries (Podrazsky *et al*. 2013). It was categorized as fast growing species (Rowell *et al*. 2005) which is capable of rapid early growth rate resulting in a large portion of juvenile wood (Zobel and Sprague 1998).

With the emergence of a rapidly grown plantation timber resource throughout the world, a larger proportion of available timber will be found in the form of juvenile wood. In order to be able to use this material, it is first required that a working knowledge of the juvenile wood component be gained. This knowledge will then allow the manufacturing sector to modify existing procedures and/or techniques to more fully utilize this juvenile material.

The presence of juvenile wood can reduce mechanical properties as well as cause problems of warping, excessive shrinking and swelling, fuzzy grain, and general instability in the manufacture and use of the wood. These problems may show up in the wood when sawing, veneering, drying and machining (Maeglin 1987). Therefore the determination of transition age between juvenile and mature wood is essential. Based on the results on Chapter 2, by using segmented regression analysis, according to fiber length, transition age of 5, 6 and 7 years old of sengon and jabon were occurred ranging from 17 to 18 radial segment and ranging from 18 to 20 radial segment, respectively. The transition age of poplar cultivars and Douglas-fir, occurred from 12 and 13 years old and occurred from 18 and 20 years old, respectively. The portion of juvenile wood both in sengon and jabon at dbh at the age of 5, 6 and 7 years old were 100 %. Poplar cultivars and Douglas-fir contained 52% and 77 % of juvenile wood portion, respectively.

In order to increase added value of fast growing species, we proposed to produce Laminated Veneer Lumber (LVL). LVL have some advantages: 1) Less lumber defect (rotted knots, cracks and other defects) because the common lumber defects have been dispersed during production; 2) Stable in dimension and more resistant to warp, twist, bow, and cup; 3) Available in large dimensions (LVL can be as long as 8000 mm, as thick as 300 mm, as wide as 1200 mm); and 4) High elastic modulus and bending stress. Also this approach were based on the research conducted by Pugel *et al.* (1990), juvenile wood can be made of composite products. Kretshmann *et al.* (1993) also showed the result indicating that it was possible to make LVL from juvenile wood veneer. However, the production of high quality LVL would be faced against two main problems: one of them is veneer quality.

In order to enhance the quality of sengon and jabon veneers, boiling treatment (boiling logs in 75°C water for 4h) prior was used prior to peeling. However pretreatment prior to peeling was not applied for poplar. In general, 3 mm sengon and jabon veneers from 5 years old boiled sengon and jabon logs had better veneer quality (lower lathe check frequency, better surface roughness however better wettability) than unboiled logs. The frequency, depth and length of lathe check, surface roughness and contact angle were influenced by juvenility. The frequency of lathe check and surface roughness of sengon and jabon veneers decreased from pith to bark, while the value of length and depth of lathe check and contact angle tended slightly increase from pith to bark. In most of samples, frequency of lathe check and surface roughness were correlated negatively with equilibrium contact angle except for boiled jabon.

Sengon, jabon, poplar and doulgas-fir logs were peeled to produce LVL. Before peeling, sengon and jabon logs were boiled in 75°C water for 4h (results from Chapter 3). Veneers resulted from peeling process were separated juvenile from mature veneers based on fiber length traits (the results from chapter 2). The results showed that the glue bond strength, SMOE and SMOR of sengon and jabon LVL increased from pith to bark. The advantage of using veneers from poplar mature wood was proved with an improvement of 15 to 20% on average for mechanical properties, with almost the same panel weight. Douglas-fir LVL made of mature veneers had higher bending strength compare to LVL made of juvenile veneers. Utilization of mature veneers in producing douglas-fir LVL appears to improve bending strength from 7 to 22%. Boiling treatment prior to peeling (in 75°C water for 4h) and application of type II layout (loose-loose side layout) have successfully increase glue bond and bending strength of sengon and jabon LVL. The glue bond strength, SMOE and SMOR of sengon and jabon LVL were decreased as the frequency of lathe check increased. The increase of glue bond could increase sengon and jabon LVL bending strength.

The use of thicker veneers in poplar and Douglas-fir LVL, reduced the use of adhesive and simplified and accelerated the production of panels without altering their mechanical properties. Some cultivars have a real potential for structural applications (‘Lambro’, ‘Soligo’, ‘Alcinde’, ‘Brenta’ and ‘Taro’), some should be used with careful sample selection (‘Lena’, ‘Trichobel’, ‘Mella’, ‘Koster’ and ‘Dvina’), while ‘Polargo’, ‘A4A’, ‘I-214’ and ‘Triplo’ should be excluded.

The average values of glue bond strength, MOE and MOR values of boiled sengon type II LVL were 43.1 kg cm^{-2}, 7121.4 MPa and 42.9 MPa, respectively. While the average values of glue bond and bending properties of boiled jabon type II LVL were 50.7 kg cm^{-2}, 9174.0 MPa and 59.8 MPa, respectively. Those values were higher than MOE and MOR being required in SNI 01-6240-2000 by the values of 7000 MPa and 21.5 MPa, respectively. While, the glue bond strength values of sengon and jabon were higher than glue bond values in SNI 01-5008.2-2000 by the value of 7 kg cm^{-2}. Therefore, the sengon and jabon LVL made from boiled veneers with type II layout met the requirements of SNI.

Mechanical properties of LVL are strongly dependent on the mechanical properties of each layer. The rotary peeling process can easily separate mature wood from juvenile wood by sorting the veneers by their radial position. However, the impact of juvenile wood on LVL is difficult to apprehend experimentally, due to the many factors which have an effect on mechanical properties during timber growth cycles. In this work, the model developed by Girardon in Girardon *et al* (2016) to estimate specific MOE was used.

The model is based on the assumption that sengon and jabon behave in the same way in terms of growth and juvenile – mature transition. The model, featuring a stochastic approach, was able to predict LVL behavior according to veneer thickness and loading direction. Indeed, model results show no influence of these parameters on the average SMOE. However, the model showed that the coefficient variation was higher for flatwise than for edgewise bending. Greater veneer thickness also increased the coefficient. The coefficient variation of sengon and jabon were considered low (less than 10%), the variation of specific MOE between wood near pith and wood near bark were less or uniform. The recommendation of sorting the veneers to separate juvenile from mature for 5 years old sengon and jabon were not needed. The results were different from Girardon *et al*. (2016), who found the coefficient variations in poplar are more than 10%. Model accuracy could be improved by leading a measurement campaign to determine a reliable specific modulus of elasticity for sengon and jabon. From a practical perspective, this model could be used to highlight the unnecessity of sorting veneer of sengon and jabon in an industrial process. Therefore, based on the results (Chapter 2 to 5), we concluded that 5 years old sengon and jabon could be used as LVL raw material without separation juvenile veneers from mature veneers after peeling process. Different from sengon and jabon, the separation poplar and Douglas-fir juvenile from mature veneers was important.

French summary

La consommation de bois en France et en Indonésie est en croissance pérenne depuis plusieurs décennies. Afin de proposer un volume compatible avec la demande, des stratégies de plantations ont été privilégies. Ce type de sylviculture dynamique présente l'avantage de fournir un volume important de bois mais elle s'accompagne d'une modification des propriétés intrinsèques du matériau puisque la proportion de bois juvénile y est très importante. Le bois juvénile est globalement plus délicat à mettre en œuvre puisqu'il se caractérise par des déformations au séchage importantes, des propriétés mécaniques moindres à densité égale, des fibres plus courtes, un rendement pour la pâte à papier moindre.

L'enjeu de cette étude était d'évaluer les performances potentielles de 4 essences majeures susceptibles de présenter une part importante de bois juvénile pour des applications constructives puisque ce marché est un débouché essentiel.

La première étape a consisté à déterminer de l'âge de transition entre le bois juvénile et bois mature. Basé sur les résultats du Chapitre 2, en utilisant l'analyse de régression segmentée sur l'évolution de la longueur de fibre depuis la moelle jusqu'à l'écorce, l'âge de transition des arbres de sengon et jabon a été estimé entre le 17ème et le 18ème segment. Pour les peupliers et le douglas, la même méthode a permis d'estimer cet âge respectivement à 12 et 18 ans. Cette transition identifiée, il a été possible d'estimer une proportion moyenne de bois juvénile pour les échantillonnages réalisés sur ses 4 essences : 100% pour le sengon et le jabon, 77% pour le douglas, 52% pour les cultivars de peuplier. Ces premiers résultats sont en soit intéressant puisqu'ils révèlent que du bois adulte est présent dans les plantations française mais pas dans les plantations indonésiennes.

La fabrication de produits d'ingénierie bois constitue une bonne manière de valoriser la ressource puisqu'ils offrent des produits stables, homogènes et adaptables (dimensions et performances) au besoin. C'est le cas du LVL qui permet de distribuer les défauts dans la structure et de maitriser les propriétés du produit par un empilement judicieux des placages. De plus, le LVL étant obtenu après déroulage, il est relativement simple de trier les placages de bois adulte et les placages de bois juvénile. La qualité du placage est essentielle dans la maitrise du procédé et l'impact du bois juvénile est susceptible de dégrader cette qualité.

Des billons de chaque essence ont été déroulés et les placages ont été triés depuis le cœur jusqu'à l'écorce (en plusieurs segments pour le sengon et le jabon et en 2 catégories pour le Douglas et les peupliers). L'état de surface (Ra), la fissuration (profondeur, fréquence, longueur) et la mouillabilité ont été mesurées pour chaque échantillon (Chapitre 3). La fréquence, la profondeur et la longueur des fissures, la rugosité superficielle et l'angle de contact sont influencés par la juvénilité. La fréquence de fissuration, la rugosité superficielle, et l'angle de contact des placages du sengon, du jabon ont diminué de la moelle à l'écorce, tandis que la longueur et la profondeur de fissure augmentent légèrement de la moelle à l'écorcer. Le fait d'étuver ces bois semble favorable pour la fissuration, l'état de surface et la mouillabilité.

Les placages produits ont permis de fabriquer plus d'un Miller d'échantillons qui ont été testés mécaniquement de manière non destructive (BING) et destructive. Les résultats ont montré que la résistance du joint de colle, le module élastique spécifique (SMOE) et la contrainte à la rupture spécifique (SMOR) du lamibois de sengon et jabon sont accru de la moelle à l'écorce. L'étuvage avant le déroulage (dans l'eau 75°C pour 4h) et l'utilisation de LVL du type II (« fissures sur fissures ») ont permis d'améliorer également la résistance du joint de colle, le SMOE et le SMOR du LVL de sengon et de jabon. Ces propriétés diminuent lorsque la fréquence de fissuration augmente.

L'avantage d'utiliser des placages de peuplier mature a été également prouvé avec une amélioration de 15 à 20 % en moyenne pour des propriétés mécaniques, pour un poids des panneaux comparables. Le LVL de douglas réalisé à partir de placages mature présente une résistance à la flexion plus élevée que celui fabriqué à partir de placages juvéniles. L'utilisation des placages matures dans la production du lamibois de douglas améliore la résistance à la flexion de 7 à 22%.

L'utilisation des placages plus épais dans le lamibois de peuplier et de douglas, réduite l'utilisation de l'adhésif, et simplifie la production des panneaux sans pénaliser leurs propriétés mécaniques. Quelques cultivars ont un vrai potentiel pour des applications structurelles (Lambro, Soligo, Alcinde, Brenta, et Taro), certains devraient être utilisés avec une sélection des échantillons (Lena, Trichobel, Mella, Koster, et Dvina), tandis que Polargo, A4A, I-214 et Triplo devrait être exclus.

Les valeurs moyennes de la résistance du joint de colle, du MOE et du MOR de lamibois du sengon étuvé de type II étaient 43.1 kg cm^{-2}, 7121.4 MPa et 42.9 MPa, respectivement. Tandis que les valeurs moyennes de la résistance du joint de colle et les propriétés de flexion du LVL de jabon étuvé type II étaient 50.7 kg cm^{-2}, 9174.0 MPa et 59.8 MPa, respectivement. Ces valeurs sont plus élevées que le MOE et le MOR étant nécessaires dans SNI 01-6240-2000 par les valeurs de 7000 MPa et 21.5 MPa, respectivement. De plus, les valeurs de la résistance du joint de colle du sengon et jabon étaient plus hautes que des valeurs requises dans SNI 01-5008.2-2000 (7 kg cm^{-2}).

Les propriétés mécaniques du lamibois dépendent fortement des propriétés mécaniques de chaque couche. L'impact du bois juvénile seul sur le lamibois est difficile à appréhender expérimentalement en raison de nombreux facteurs qui ont un effet sur des propriétés mécaniques pendant des cycles de croissance de bois. Dans ce travail, l'utilisation d'un nouveau modèle analytique pour estimer MOE spécifique du lamibois de sengon et jabon ont été proposé.

Ce nouveau modèle analytique permet de prédire le comportement mécanique d'un panneau en lamibois de sengon et jabon. Cette étude montre une estimation correcte du comportement mécanique par le modèle développé comparé aux données expérimentales. Le modèle, comporte une approche stochastique, cette approche permet d'estimer un comportement moyen des panneaux de lamibois sans avoir à calculer toutes les combinaisons possibles d'assemblage des placages de LVL. Le modèle permet également de prévoir le comportement des panneaux de lamibois selon l'épaisseur de déroulage des placages ainsi que de la direction de chargement. Le coefficient de variation du SMOE entre sengon et jabon proche de la moelle et proche de l'écorce sont plus ou moins uniformes. Cela est dû à l'âge cambial faible des échantillons dans lesquelles la proportion de bois mature est faible voire nulle. La question sur le tri des placages provenant de bois juvénile ou de bois mature ne peut donc pas être tranchée. Le modèle ne pourra être amélioré qu'en menant des campagnes de mesures complémentaires afin de déterminer le module d'élasticité spécifique fiable pour le bois mature de sengon et de jabon.

7 CONCLUSION AND SUGGESTIONS

7.1 Conclusion

According to fiber length, transition age of 5, 6 and 7 years old of sengon and jabon were occured ranging from 17 to 18 radial segment and ranging from 18 to 20 radial segment, respectively. The transition age of poplar cultivars and douglas-fir, occurred from 12 and 13 years old and occurred from 18 and 20 years old, respectively. The portions of juvenile wood both in sengon and jabon at dbh at the age of 5, 6 and 7 years old were 100 %. Poplar cultivars and douglas-fir contained 52% and 77 % of juvenile wood protion, respectively.

The frequency, depth and length of lathe check, surface roughness and wettability were influenced by juvenility. The frequency of lathe check, surface roughness and wettability decreased from pith to bark, while for length and depth of lathe check, the values slightly increasing from pith to bark.

The results showed that the glue bond strength, MOE and MOR of sengon and jabon LVL increased from pith to bark. The advantage of using veneers from poplar mature wood was proved with an improvement of 15 to 20% on average for mechanical properties, with almost the same panel weight. Douglas-fir LVL made of mature veneers had higher bending strength compare to LVL made of juvenile veneers. Utilization of mature veneers in producing douglas-fir LVL appears to improve bending strength from 7 to 22%. The glue bond strength, MOE and MOR of sengon and jabon LVL were decreased as the frequency of lathe check increased. The increase of glue bond could increase sengon and jabon LVL bending strength.

The model was able to predict SMOE LVL behavior according to veneer thickness and loading direction from pith to bark. The coefficient variations of sengon and jabon LVL were less than 10%. The recommendation to separate 5 years old sengon and jabon juvenile from mature veneers was not necessary.

7.2 Suggestions

The suggestions for the upcoming research are:

1. The research concerning dendrochronology of sengon, jabon, poplar cultivars and douglas-fir in order to explain their wood properties
2. Based on this research results, sengon and jabon LVL have met the SNI requirements, however, there are still some other properties to be studied thoroughly such as durability and machining properties. Also, the research regarding treatments to improve veneer qualities of fast growing wood species in order to obtain durable LVL for construction
3. Dissemination the utilization LVL made of fast growing species for light construction propose to community for preserving natural forest

LIST OF PUBLICATIONS

The publications during the PhD period were as follow :

1. Darmawan W, Nandika D, **Rahayu I**, Fourier M, Marchal R. 2013. Determination of juvenile and mature transition ring for fast growing sengon and jabon wood. *J Indian Acad Wood Sci*. DOI 10.1007:s13196-013-0091-x
2. **Rahayu I**, Denaud L, Butaud JB, Pot G, Legrand G. 2013. Qualités Technologiques des Panneaux Contreplaqués et LVL realises avec Les Nouveaux Cultivars de Peuplier. *Foret Entreprise* No. 213. ISSN:0752-5974 (France)
3. **Rahayu I**, Darmawan N, Nugroho N, Nandika D, Marchal R. 2014. Demarcation Point between Juvenile and Mature Wood in Sengon (*Falcataria molluccana*) and Jabon (*Antocephalus cadamba*). *J Trop For Sci.* 26 (3):331-339 ISSN 0128-1283 (Malaysia)
4. **Rahayu I**, Denaud L, Marchal R, Nugroho N, Darmawan W. 2015. Ten new poplar cultivars provide laminated veneer lumber for structural application. *Ann For Sci.* 72:705-715 DOI 10.1007/s13595-014-0422-0 ISSN: 1286-4560 (Print) 1297-966X (Online) (France)
5. **Rahayu I**, Darmawan W, Nugroho N, Marchal R. 2015. The Effect of Jabon Veneer Quality on Laminated Veneer Lumber Glue Bond and Bending Strength. *Jurnal Ilmu dan Teknologi Kayu Tropis* (accepted)
6. Girardon S, Denaud L, Pot G, **Rahayu I**. 2016. Determination of poplar LVL effective modulus of elasticity by modelling peeling and evolution of raw material properties on cambial age basis. *Ann For Sci.* (accepted)

LIST OF INTERNATIONAL SYMPOSIUM

The international symposium during the PhD period were as follow :

1. **Rahayu I**, Denaud L, Marchal R, Darmawan W. 2013. Correlation between Radial Variation and Mechanical Properties of Laminated Veneer Lumber made from 14 Poplar Cultivars. Proceeding of IUFRO symposium Memowood (Measurement methods and modeling approaches for predicting future wood properties). Nancy (France), 1-4 October 2013.
2. **Rahayu I**, Marchal R, Darmawan W, Denaud L. 2014. Juvenility and Veneer Thickness Effect on Mechanical Properties of Poplar LVL. Journee Deuxiemme Anne de Doctorant, MINES ParisTech June,25-26 2014
3. **Rahayu I**, Denaud L, Ruelle J, Darmawan W. 2014. The effect of radial position and veneer thickness on mechanical properties of fast growing species laminated veneer lumber. International Symposium of Indonesian Wood Research Society at Medan in November 2014
4. **Rahayu I**, Darmawan W, Nugroho N, Marchal R. 2015. Characteristic of Veneer Quality of Rotary Cut Jabon Veneers and Their Effect on LVL Glue Bond and Bending Strength. International Symposium of Indonesian Wood Research Society at Bandung in November 2015

REFFERENCES

[ASTM] American Society for Testing and Materials. 2008. Annual books of ASTM standards. Volume 04.10. Wood. D 143. Section Four. Unites States (US) : ASTM International, West Conshohocken

Abdel-Gadir AY, Krahmer RL. 1993. Estimating the Age of demarcation of juvenile and mature wood in Douglas-fir. *Wood Fiber Sci*. 25: 242–249

Acevedo A, Bustos C, Lasserre, Gacitua, William JP. 2012. Nose bar pressure effect in the lathe check morphology to *Eucalyptus nitens* veneers**.** *Maderas Cienc. Tecnol.* [online]. 1(3): 289-301

Alteyrac J, Cloutier A, Zhang SY. 2006. Characterization of juvenile wood to mature wood transition age in black spruce (*Picea mariana* (Mill.) BSP) at different stand densities and sampling heights. *Wood Sci Technol*. 40: 124–138

Anonymous. 1998. Forintek Canada Corp, Wood-based panel products technology roadmap: Special report. Forest Industries and Building Products, Canada, ISSN 0381-7733. URL: <http://strategis.ic.gc.ca/SSI/fb/engmap.pdf> (accessed 21.05.2015)

Aydin I. 2004. Activation of wood surface for gluebonds by mechanical pretreatment and its effect on some properties of veneer surfaces and plywood panels. *Appl Sur Sci*. 233:268-274

Aydin I, Colakoglu G, Hiziroglu S. 2005. Surface characteristics of Spruce veneers and shear strength of plywood as a function of log temperature in peeling process. *Int J Solids Struc*. 43(2006):6140-6147

Ayrilmis N, Candan Z, Akbulut T, Balqiz OD. 2010. Effect of sanding on surface properties of Medium Density Fiberboard. *Drvna Industrija* 61 (3):175-181

[BPS] Badan Pusat Statistik. 2013. Statistik Pengusaha Hak Pengusahaan Hutan. Badan Pusat Statistik. Jakarta

Bal BC, Bektas I. 2012. The effects of wood species, load sirection and adhesives on bending properties of laminated veneer lumber. *BioResources* 7(3):3104-3112

Baldan A. 2012. Adhesion phenomena in bonded joints. *Int J Adhesion and Adhesives*. 38(7): 95-116

Baldwin RF. 1995. Plywood and Veneer–Based Products: Manufacturing Practices. United States (US): Miller Freeman Inc. San Fransisco

Bao FC, Jiang ZH, Jiang XM, Lu XX, Lou XQ, Zhang SY. 2001. Differences in wood properties between juvenile wood and mature wood in 10 species grown in China. *J Wood Sci Technol*. 35 (4):363-375

Barrett JD, Kellogg RM. 1989. Strength and stiffness of dimension lumber. In: Second growth Douglas-fir: its management and conversion for value. Canada (CA). Special publication No. SP-32, Forintek Canada Corp Vancouver, BC. 50-58

Berkel A, Bozkurt Y, Goker Y. 1969. On the manufacture of veneer from different oak species grown in Turkey. Turkey (TR). Istambul University, Faculty of Forestry, Pub. No.: 1430. 152p (in Turkish)

Bendtsen BA. 1978. Properties of wood from improved and intensively managed trees. *For Prod J*. 28(10):61 – 72

Bendtsen BA, Senft JF. 1986. Mechanical and anatomical properties in individual growth rings of plantation-grown eastern cottonwood and loblolly pine. *Wood Fiber Sci.* 18(1):23 – 28

Berthelot A, Reuling D, Robert G, Bouvet A, Lanvin JD, Legrand G, Moreau J, Denaud L, Paillassa E. 2013. Qualités du bois des nouveaux cultivars de peuplier. France (FR). Forest Privee Francaise, FCBA Institut Technologique, Art et Metiers ParisTech

Biblis EJ. 1990. Properties and grade yield of lumber from a 27-year-old slash pine plantation. *For Prod J.* 40(3):21–24

Biblis EJ, Meldahl R, Pitt D. 2004. Predicting flexural properties of dimension lumber from 40-year-old loblolly pine plantation stands. *For Prod J.* 54:109-113

Bjurhager I, Berglund LA, Bardage SL, Sundberg B (2008) Mechanical characterization of juvenile European aspen (Populus tremula) and hybrid aspen (Populus tremula Populus tremuloides) using full-field strain measurements. *J Wood Sci.* 54:349-355

Bodig J, Jayne BA. 1993. Mechanics of wood and wood composites. United State (US):Krieger Publication Co. Malabar Florida USA. ISBN :0894647776

Bordonne PA. 1989. Module dynamique et frottement intérieur dans le bois : mesures sur poutres flottantes en vibration naturelle [Dissertation] Institute National Polytechnique de Lorraine, Nancy, France.104 p

Bremaud I, Ruelle J, Thibaut A, Thibaut B. 2013. Changes in viscoelastic vibrational properties between compression and normal wood: roles of microfibril angle and of lignin. *Holz.* 67(1):75-85

Bowyer JL, Shmulsky R, Haygreen JG. 2007. Forest Product and Wood Science: An Introduction. United Kingdom (GB) : Blackwell Publishing. Oxford

Bozkurt Y, Goker Y. 1986. Composite wood products technology. Turkey (TR). Istanbul University, Faculty of Forestry, Pub. No.: 3401. 316p (in Turkish)

Brancheriau L, Bailleres H. 2002. Natural vibration analyses of clear wooden beams: a theoretical review. *Wood Sci Technol.* 36:347–365

Bucur V. 2006. Acoustics of wood. Germany (DE): Springer Verlag Berlin Heidelberg, Germany, p284

Bustos C, Mohammad M, Hernandez RE, Beauregard R. 2003. Effects of Curing Time and End Pressure on The Tensile Strength of Finger-Jointed Black Spruce Lumber. *For Prod J.* 53(11/12):85-89

Cave I, Walker J. 1994. Stiffness of wood in fast-grown plantation softwoods: the influence of microfibril angle. *For Prod J.* 44:43

Cousins W. 1976. Elastic modulus of lignin as related to moisture content. *Wood Sci Technol.* 10:9-17

[CIRAD] La recherce agronomique pour le developpement (2011) Tropix 7. France (FR): CIRAD

Cumming, J.D., Fischer, C., Dickinson, F.E., 1969. Rotary veneer cutting characteristics of young-growth redwood. *For Prod J.* 19 (11), 26-30

Cumming JD, Collett BM. 1970. Determining lathe settings for optimum veneer quality. *For Prod J.* 20 (11), 20-27

Darmawan W, Nandika D, Rahayu I, Fourier M, Marchal R. 2013. Determination of juvenile and mature transition ring for fast growing sengon and jabon wood. *J Indian Acad Wood Sci.* DOI 10.1007:s13196-013-0091-x

Darmawan W, Nandika D, Massijaya Y, Kabe A, Rahayu I, Denaud L, Ozarska B. 2015. Lathe check characteristics of fast growing sengon veneers and their effect on LVL glue-bond and bending strength. *J Mat Processing Technol.* 215(2015):181-188

Darusman D, Hardjanto. 2006. Kontribusi hutan rakyat dalam kesinambungan industri kehutanan (Contribution of community forest on sustainable forestry industries). Prosiding Seminar Hasil Litbang Hasil Hutan. Bogor.

Daoui A, Descamps C, Marchal R, Zerizer A. 2011. Influence of veneer quality on beech LVL mechanical properties. *Maderas Cienc. Tecnol.* 13(1):69–83

Denaud L-E, Bl´eron L, Ratle A, Marchal R (2007) Online control of wood peeling process: Acoustical and vibratory measurements of lathe checks frequency. *Ann For Sci* 64:569–575

De Melo R, Del Menezzi CHS (2014) Influence of veneer thickness on the properties of LVL from Paticá (*Schizolobium amazonicum*) plantation trees. *Eur J Wood Prod*. 72:191-198 DOI 10.1007/s00107-013-0770-8

De Souza F, Del Menezzi CHS, Bortoletto Junior G (2011) Material properties and nondestructive evaluation of LVL made from Pinus oocarpa and P. kesiya. *Eur J Wood Prod.* 69:183-192. doi:10.1007/s00107-010-0415-0

DeVallance DB, Funck JW, Reeb JE. 2007. Douglas-fir plywood gluebond quality as influenced by veneer roughness, lathe checks, and annual ring characteristics. *For Prod J.* 57(1/2):21-28

Di Lucca CM. 1989. Juvenile-mature wood transition. In Second Growth Douglas-fir : Its Management and Conversion for Value. Canada (CA). Special Publication No. SP-32. R.M. Kellog (Ed.). Forintek Canada Corporation, Vancouver, British Colombia, Canada. Pp. 23-38

Direktorat BPPHH Ditjen BUK. 2014. Statistik Kehutanan tahun 2013. Jakarta (ID): Kementerian Kehutanan. Jakarta

Direktorat Jenderal Rehabilitasi Lahan dan Perhutani Sosial. 2006. Data Potensi Hutan Rakyat di Indonesia. Jakarta (ID) : Direktorat Jenderal Rehabilitasi Lahan dan Perhutanan Sosial, Departemen Kehutanan

Dundar T, Akbulut T, Korkut S. 2008. The effects of some manufacturing factors on surface roughness of sliced Makore´ (Tieghemella heckelii Pierre Ex A.Chev.) and rotary-cut beech (*Fagus orientalis* L.) Veneers. *Build Env.* 43:469–474

Dupleix A, Denaud L, Bleron L, Marchal R, Hughes M. 2013. The effect of log heating temperature on the peeling process and veneer quality: beech, birch, and spruce case studies**.** *Eur J Wood Prod*. 71 (2), 63-171

[EN] The European Standard. 2004. EN 789 :Timber structures – test methods – determination of mechanical properties of wood based panels. United Kingdom (UK) London

Echols RM, Currier RA. 1973. Comparative properties of Douglas-fir made from parallel-LVL vs solid wood. *For Prod J*. 23(2):45-47

El-Haouzali H. 2009. Effets cultivar et station sur les propriétés mécaniques de LVL et contreplaqués issus du déroulage de peupliers [Dissertation]. France (FR) : Sciences des Métiers de l'Ingénieur, Arts et Métiers, Cluny

Elbez G. 1978. Study of wettability of wood. *Holz.* 32(3):82-92

Erdil YZ, Kasal A, Zhang JL, Efe H, Dizel T. 2009. Comparison of mechanical properties of solid wood and laminated veneer lumber fabricated from Turkish beech, Scotch pine, and Lombardy poplar. *For Prod J.* 59(6):55-60

Evans R, Ilic J. 2001. Rapid prediction of wood stiffness from microfibril angle and density. *For Prod J.* 51:53

Evans R, Ilic J, Matheson C, Schimleck L, Blakemore P, others Rapid estimation of solid wood stiffness using SilviScan. 2000. In: Proceedings of 26th Forest Products Research Conference: Research developments and industrial applications and Wood Waste Forum, Clayton, Victoria, Australia, 19-21 June 2000., 2000. pp 394 49-50

[FAO] Food and Agriculture Organization. 2011. Information of Poplar and Willow. http://www.fao.org/forestry/ipc/69994/en/. Accessed June, 20th 2013

[FCBA] Foret Cellulose Bois-construction Ameublement. 2013. Mémento 2013. France (FR): FCBA Institute Technologiques

Fang S, Yang W, Tian Y. 2006. Clonal and within-tree variation in microfibril angle in poplar clones. *New For.* 31:373-383

Faust TD, Rice JT. 1986. Effect of veneer surface roughness on gluebond quality in southern pine plywood. *For Prod J.* 36(4):57-62

Faust TD. 1987. Real time measurement of veneer surface roughness by image analysis. *For Prod J.* 37(6):34-40

Feihl O. 1986. Veneer cutting manual. Canada (CA):Forintek Canada Corp., Special publication SP 510, ISBN 0-86488-507-1

Forbes CL. 1997. Understanding and minimizing veneer checking on furniture panels. United State (US) Wood Prod. Notes. Dept. of Wood and Paper Sci., College of Forest Resources, North Carolina State Univ., Raleigh, North Carolina. 4pp

Gardner DJ, Generalla NC, Gunnells DW, Wolcott MP. 1991. Dynamic wettability of wood. *Langmuir* 7(11):2498-2502

Gavrilovic-Grmusa I, Dunky M, Miljkovic J, Djiporovic M. 2012. Influence of the viscosity of UF resins on the radial and tangential penetration into Poplar wood and the shear strength of adhesive joints. *Holz.* 66(7):849-856. Doi:10.1515/hf-2011-0177

Gindl M, Reiterer A, Sinn G, Stanzl-Tschegg SE. 2004. Effet of surface ageing on wettability, surface chemistry and adhesion of wood. *Holz als Roh-und Werkstoff* 62(4):273-280

Girardon S, Denaud L, Pot G, Rahayu I. 2016. Determination of poplar LVL effective modulus of 1 elasticity by modelling peeling and evolution of raw material properties on cambial age basis. *Ann For Sci.* (accepted)

Goker Y, Akbulut T. 1992. Factor influencing some of the properties of particleboard and plywood. In: The Proceedings of the First International Forest Industry Congress, vol. 1, Karadeniz Technical University, Trabzon, Turkey, 22–25 September 1992. pp. 269–287

Gray V. 1962. The wettability of wood. *For Prod J.* 12(9);452-461

Gupta RC, Bist BS. 1981. Effect of peeling variables on strength of plywood. Part 1. Effect of heating log. *Holzforschung un Holzverwertung* 33 (1), 6–8

H'ng PS, Paridah MT, Chin KL (2010) Bending strength of LVL produced from Keruing (*Dipterocarpus* sp) reinforced with low density wood species. *Asian J Sci Res.* 3(2):118-125. ISSN 1992-1454

Haines DW, Leban JM, Herbé C. 1996. Determination of Young's modulus for spruce, fir and isotropic materials by the resonance flexure method with comparisons to static flexure and other dynamic methods. *Wood Sci and Technol.* 30:253-263

Harding OV, Orange RP. 1998. The effect of juvenile wood and lay up practice on various properties of radiata pine laminated veneer lumber. *For Prod J.* 48 (7/8):63-70

Hein PRG, Brancheriau L, Lima JT, Rosado AM, Gril J, Chaix G. 2010. Clonal and environmental variation of structural timbers of *Eucalyptus* for growth, density and dynamic properties. *Cerne, Lavras, Suplemento* 16:74-81

Hein PRG, Silva J, Brancheriau L. 2013. Correlations among microfibril angle, density, modulus of elasticity, modulus of rupture and shrinkage in 6-year-old *Eucalyptus urophyll* and *E. grandis* . *Maderas Cienc Tecnol.* 15:171-182

Hecker M. 1995. Peeled veneer from Douglas fir influence of round wood storage, cooking and peeling temperature on surface roughness. In: The Proceedings of the 12th International Wood Machining Seminar; Kyoto, October 1-10, 1995. Japan

Hendarto B, Shayan E, Ozarska B, Carr R. 2006. Analysis of roughness of a sanded wood surface. *Int J Adv Manufacturing Tech.* 28(7-8):775-780

Hill CAS. 2006. Wood modification chemical, thermal and othe processes. United Kindom (UK) : John Wiley and Sons Ltd, The Atrium, Southern Gate, Chichester, England

[JAS] Japanese Agricultural Standard SE 11 No. 237. 2003. Japanese Agricultural Standard for structural laminated veneer lumber. Japan (JP): Japanese Agricultural Standard Association

[JIS] Japanese Industrial Standard. 2001. Geometric Product Specification : Surface Texture Profile Method. Japan (JP): Japanese Agricultural Standard Association

Jorgensen RN. 1968. Steam bending of Hickory. United State (US):Forest Products Laboratory, U.S. Department of Agriculture

Jung J, Day J. 1981. Strength of Fasteners in Paralel Laminated Veneer. United State (US):Forest Product Laboratory. Research Paper FPL report No 389. United State of Department of Agricultur USA

Kabe A, Darmawan W, Massijaya MY. 2013. Characteristics of jabon rotary cut veneers. *JIPI* 18(3):133-139. ISSN 0853-4217

Kamala BS, Kumar P, Rao RV, Sharma SN. 1999. Performance test of laminated veneers lumber (LVL) from rubber wood for different physical and mechanical properties. *Holz Roh Werkst* 57:114–116

Kantay R, Akbulut T, Korkut S. 2003. Effect of peeling temperature on surface roughness of rotary cut veneer manufactured beech. Turkey (TR) Review of Faculty of Forestry, Istanbul University, Series A 53(2):1–11 (with English abstract)

Kiaei M, Bakhshi R, Veylaki S. 2012. Determination of fibre length and juvenile and mature wood zones in *Acer velutinum* Boiss. tress grown in iran. *J Forestry Stud in Cina* 14:323–326

Kiaei M, Sadegh AN, Moya R. 2013. Site variation of tracheid fatures ans statis bending strength in *Pinus eldarica* wood. *Cellulose Chem Technol.* 47(1-2):49-59

Kilic M, Hiziroglu S, Burdurlu E. 2006. Effect of machining on surface roughness of wood. *Build Env.* 41(8):1074-1078. DOI:10.1016/j.buildenv.2005.05.008

Kilic M, Burdurlu E, Aslan A, Altun S, Tumerdem O. 2009. The effect of surface roughness on tensile strength of the medium density board (MDF) overlaid with polyvinyl chloride (PVC). *Mat Des.* 30(10):4580-4583. DOI:10.1016/j.matdes.2009.03.029

Koch P. 1966. Straight studs from Southern Pine veneer cores. United State (US) Res. Pap. SO-25. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station

Kollmann F, Kuenzi EW, Stamm AJ. 1975. Principles of wood science and technology II: wood based materials. United State (US): Springer Berlin Heidelberg. New York. pp. 123-132

Koubaa A, Isabel N, Shu Yin Z, Beaulieu J, Bousquet J. 2005. Transition from juvenile to mature wood in black spruce (*Picea mariana* (MILL.). *Wood Fiber Sci.* 37(3):445–455

Kretschmann DE, Bendtsen BA. 1992. Ultimate tensile stress and modulus of elasticity of fastgrown plantation loblolly pine lumber. *Wood Fiber Sci.* 24(2):189–203

Kretschmann DE, Moody RC, Pellerin RF, Bendtsen BA, Cahill JM, McAlister RH, Sharp DW. 1993. Effect of various proportion of juvenile wood on laminated veneer lumber. United State (US) Forest Product Laboratory Research Paper FPL-RP-521

Kretschmann DE. 1997. Effect of juvenile wood on shear parallel and compression perpendicular-to-grain strength for loblolly pine. Timber Management toward Wood Quality and End-product Value CTIA/TUFRO International Wood Quality Workshop, pp.23-631. Montreal, PQ, August 18-22

Langum CE, Yadama V, Lowwel E. 2009. Physical and mechanical properties of young-growth Douglas-fir and western hamlock from western Washington. *For Prod J.* 59(11/12):37-47

Lebow PK, Winandy JE. 1998. The role of grade and thickness in the degradation of fire-retardant-treated plywood. *For Prod J.* 48(6):88–94

Leney L. 1960. A photographic study of veneer formation. *For.Prod. J* 10:133-139

Lutz JF. 1974. Techniques for peeling process, slicing, drying veneer. United State (US) FPL, Forest Ser. USDA, 228 pp

Lutz JF. 1978. Wood veneer: Log selection, cutting and drying. United State (US) Forest Service, US Department of Agriculture, Technical Bulletin No. 1577. 137p.

MacPeak MD, Burkart LF, Weldon D. 1990. Comparison of grade, yield, and mechanical properties of lumber produced from young fast-grown and older slow-grown planted slash pine. *For Prod J.* 40(1):11–14

Maeglin RR. 1987. Juvenile wood, tension wood and growth stress effect on processing hardwoods. Proceeding of the 15th Annual Symposium of the Hardwood Research Council. 1—12 May 1987, Memphis

Magoss E. 2008. General regularities of wood surface roughness. *Acta Silviculture Ligneria Hung* 4:81-93

Marchal R, Mothe F, Denaud L, Thibaut B, Bleron L. 2009. Cutting forces in wood machining — basics and applications in industrial processes. *Holz* 63:157-167

Martawijaya A, Kartasujana I, Kadir K, Prawira SA. 2005. Indonesian Wood Atlas I. Bogor (ID): Forest Product Research, Bogor

Martin G, Grussenmeyer H, Becker G. 2006. The suitability of Douglas fir (Pseudotsuga menzii) in stone ground wood mechanical pulping operation for supercalendered magazine paper grade. http://www.tappi.org/content/events/07impc/07impc56.pdf [November 6, 2014]

McCool JI. 1987. Relating profile instrument measurments to the functional performance of rough surface. *J Tribology* 106:264-270

McIvor I. 2012. Chapter 10 of the Poplar and Willow book available on-line at http://www.fao.org/forestry/ipc/32608/en/

Ministry of Environment and Forestry (Direktorat BPPHH Ditjen BUK). 2014. Forestry Statistics of Indonesia 2013. Jakarta (ID): Ministry of Environment and Forestry, Jakarta, Indonesia

Mummery L. 1993. Surface texture analysis: the handbook. Germany (DE):Muhlhausen, Germany Hommelwerke. 106p

Nazerian M, Ghalenho MD, Kashkooli AB. 2011. Effect of wood species, amount of juvenile wood and heat treatment on mechanical and physical properties of laminated veneer lumber. *J Appl Sci*. 11(6):980-987

Nurbaity RA. 2012. Etude de la déroulabilité de 14 cultivars de peupliers : Analyse des efforts de coupe et de l'état de surface des placages [Thesis]. France (FR) : Sciences et Technologies du Vivant et de l'Environnement, Mention Aliments et bioproduits, Nutrition, Santé, Spécialité BF2E Bois, Fibres, Énergie, Environnement

Ouis D. 1999. Vibrational and acoustical experiments on logs of spruce. *Wood Sci and Technol* 33(2):151-184

Ozen R. 1981. Various factors which affect some of the physical and mechanical properties of plywood. Turkey (TR) Karadeniz Technical University, Faculty of Forestry, Trabzon, Turkey, Pub. No.: 120 (in Turkish)

Paillassa E. 2013. Qualité du bois des nouveaux cultivars de peuplier. *Foret entreprise* no. 213 (novembre-decembre):16-19

Palka LC. 1961. Factors influencing the strength properties of Douglas-fir plywood normal to glueline [Thesis]. Unites State (US): The University of British Colombia. Pp108

Palka LC, Holmes B. 1973. Effect of log diameter and clearance angle on the peel quality of 0.125-inch-thick Douglas-fir veneer. *For Prod J*. 23(7):33-41

Palka LC. 1974. Veneer cutting review - factors affecting and models describing the process. Canada (CA) Canadian Forestry Service, Western Forest Products Laboratory, Information Report VP-X-135, pp 1 – 54

Palubicki B, Marchal R, Butaud JC, Denaud LE, Bléron L, Collet R, Kowaluk G. 2010. A method of lathe check measurement; SMOF device and its software. *Eur J Wood Prod*. 68: 151-159

Panshin AJ, de Zeeuw. 1980. Textbook of Wood Technology. Fourth Edition. United State (US): Mcgraw Hill Book Company. New York

Pearson RG, Gilmore RC. 1971. Characterization of the strength of juvenile wood of loblolly pine. *For Prod J*. 21(1):23 – 31

Peck EC. 1957. Bending solid wood to form. United States (US). Departement of Agricullture Forest Service. Wisconsin

Peszlen I. 1994. Influence of age on selected anatomical properties of populous clones. *IAWA J* 15(3):311-321

Peters C, Mergen A. 1971. Measuring wood surface smoothness : a review. *For Prod J*. 20(12):40-43

Petri EM. 1987. Handbook of adhesive and sealants. United States (US): McGraw-Hill. New York.

Pugel AD, Price EW, Hse CY. 1990. Composite from Southern Pine Juvenile Wood Part 2. Durability and Dimensional Stability. *For Prod J*. 40(3):57-61

Podrazsky V, Zahradnik D, Pulkrab K, Kubeček J, Peňa JFB. 2013: Value production of Douglas-fir (*Pseudotsuga menziessii* (MIRB.) FRANCO) on acid sites of the School forest Hůrky (Hodnotova produkce douglasky tisoliste (*Pseudotsuga menziessii* (MIRB.) FRANCO) na kyselych stanovištich školniho polesi Hůrky, Pisecko). *Zpravy lesnickeho vyzkumu* 58(3): 226-232. (in Czech)

Pot G, Denaud L, Collet R, 2015, Numerical study of the influence of veneer lathe checks on the elastic mechanical properties of laminated veneer lumber (LVL) made of beech, *Holtzforshung*, 69 (3), pp.247-376.

Rahayu I, Denaud L, Butaud JC, Pot G, Legrand G. 2013. Qualités technologiques des panneaux contreplaqués et LVL realizes avec les nouveaux cultivars de peuplier. *Foret entreprise* no. 213 (novembre-decembre):39-42

Rahayu I, Darmawan W, Nugroho N, Nandika D, Marchal R. 2014. Demarcation point between juvenile and mature wood Sengon (*Falcataria moluccana*) and Jabon (*Anthocephalus cadamba*). *J Trop For Sci*. 26(3):331-339

Rahayu I, Denaud L, Marchal R, Darmawan W. 2015. Ten new poplar cultivars provide laminated veneer lumber for structural application. *Ann For Sci*. 72:705-715 doi:10.1007/s13595-014-0422-0

Ranta-Maunus A. 1995. Laminated veneer lumber and other structural sections. In: Timber Engineering STEP 1. Netherland (NL): Centrum Hout, The Netherlands, A9:(1-7)

Rathke J, Sinn G. 2013. Evaluating the wettability of MUF resins and pMDI on two different OSB raw materials. *Eur J Wood Prod*. 71(3):335-342

Resch H, Parker R. 1979. Heat conditioning veneer blocks. Research Bulletin 29. United State (US) Forest Research Laboratory, Oregon State University, Corvallis, Oregon

Reuling D, Lanvin JD, Bouvet A. 2013. Caractéristiques mécaniques du bois des nouveaux cultivars de peuplier. *Foret entreprise* no. 213 (novembre-decembre):25-29

Richter K, Feist WC, Knaebe MT. 1995. The effect of surface roughness on the performance of finishes. Part 1. Roughness characterization and stain performance. *For Prod J*. 45(7/8):91-97

Rohumaa A, Hunt CG, Hughes M, Frihart CR, Logern J. 2013. The influence of lathe check depth and orientation on the bond quality of phenol-formaldehyde bonded birch plywood. *Holz*. http://dx.doi.org/10.1515/hf-2012-0161 [November 26, 2015]

Rowell RM, Pettersen R, Han JS, Rowell JS, Tshabalala MA. 2005. Handbook of Wood Chemistry and Wood Composite. United State (US): CRC Press, Boca Raton London New York Washington DC

SAS Institute. 1990. SAS procedures guide, vol 2, version 6, 4th ed. United State (US): SAS Institute Inc. Cary, NC

[SNI] Standar Nasional Indonesia 01-6240-2000. 2000. Standar Nasional Indonesia untuk Venir Lamina. Indonesia (ID): Badan Standarisasi Nasional

[SNI] Standar Nasional Indonesia 01-5008.2-2000. 2000. Standar Nasional Indonesia untuk Kayu Lapis Penggunaan Umum. Indonesia (ID): Badan Standarisasi Nasional

Sauter UH, Mutz R, Munro D. 1999. Determining Juvenile-Mature Wood Transition in Scots Pine using Latewood Density. *Wood Fiber Sci.* 31(4):416–425

Scheikl M. 2002. Properties of the glueline – microstructure of the glueline In: Wood Adhesion and Glued Products:Glued Wood Products State of The Art Report. Johansson CJ, Pizzi T, Van Leemput M (Eds). Belgium (BE). Cost Action E13:111-113

Senft JF, Bendtsen BA. 1986. Juvenile wood: processing and structural products considerations. In: Series: Conference Proceedings

Sherington I, Smith EH. 1987. Parameters for characterizing the surface topography of engineering components. *Proc. Instn. Mech. Engrs* 2015(C4):297-306

Sernek M. 2002. Comparative analysis of inactivated wood surfaces [Dissertation]. Unites States (US) : Virginia Polythecnic Institute and State University Virginia

Shi SQ, Gardner DJ. 2001. Dynamic adhesive wettability of wood. *Wood Fiber Sci.* 33(1):58-68

Shukla SR, Kamdem DP. 2007. Properties of laminated veneer lumber (LVL) made with low density hardwood species: effect of the pressure duration. *Holz Roh- Werkst* 66:119-127

Sofuoglu SD. 2015. Using artificial neural networks to model the surface roughness wooden edge-glued panels made of scotch pine (*Pinus sylvestris* L.) in machining process with computer numerical control. *BioResorces* 10(4):6797-6808

Sudarmo MK. 1957 Tabel hasil sementara *Anthocephalus cadamba* Miq. (jabon). Pengumuman No. 59. Bogor (ID): Lembaga Penelitian Kehutanan, Bogor, Indonesia. 13p

Suh JS, Kim SK. 1988. Effects of softwood log pretreatments on the veneer peeling, drying properties and plywood properties. *The Research Reports of the Forestry Research Institute* 37: 63-71

Suharlan A, Sumarna K, Sudiono J. 1975. Tabel tegakan sepuluh jenis kayu industri. Bogor (ID): Laporan Lembaga Penelitian Hutan, Bogor, Indonesia. 39p

Sulaiman O, Salim N, Hashim R, Yusof LHM, Razak W, Yunus NYM, Hashim WS, Azmy MH. 2009. Evaluation in the suitability of some adhesives for laminated veneer lumber from oil palm trunks. *Mat Des.* 30:3572-3580

Sumarna K. 1961. Tabel tegakan normal sementara untuk *Albizia falcataria*. Pengumuman No. 77. Bogor (ID): Lembaga Penelitian Kehutanan, Bogor, Indonesia

[TAPPI] Technical Association for Pulp and Paper Industry. 1991. Tappi Test Methods: Morphological characteristics of pulp fibre under microscope (T 401 om-88). United State (US): Tappi Press, Atlanta

Tabarsa T, Ashori A, Gholamzadeh M. 2011. Evaluation of surface roughness and mechanical properties of particle board panels made from bagasse composite. *Composite Part B* 42(5):1330-1335. DOI:10.1016/jcompositesb.2010.12.018

Tanritanir E, Hiziroglu S, As N. 2006. Effect of steaming time on surface roughness of beech veneer. *Build Env.* 41:1494–1497

Taylor JB, Carrano AL, Lemaster RL. 1999. Quantification of process parameters in a wood sending operation. *For Prod J.* 49(5):41–6

Tenorio C, Moya R, Munoz F. 2011. Comparative study on physical and mechanical properties of laminated veneer lumber and plywood panels made of wood from fast growing Gmelina arborea trees. *J Wood Sci* 57:134-139

Thibaut B. 1988. Le processus de coupe du bois par deroulage [Dissertation]. France (FR) : Universite des sciences et Technique du Languedoc

Thibaut B, Beauchene J. 2004. Links between wood machining phenomena and wood mechanical properties : the case of 0°/90° orthogonal cutting of green wood. Austria (AU). Proceeding of the 2nd International Symposium on Wood Machining, Vienna, Austria. Pp 149-160

Tiryaki S, Malkocoglu A, Ozsahin S. 2014. Using artificial neural networks to model the surface roughness of wood in machining process. *Cons Build Mat.* 66:329-335. DOI:10.1016/j.conbuildmat.2014.05.098

Trung LV. 2014. Determining the optimum conditions for bending wood (Radiata Pine) applying microwave softening technique [Dissertation]. Australia (AU) : Melbourne School of Land and Environment, The University of Melbourne, Melbourne

Tsoumis G. 1991. Science and Technology of Wood (Structure, Properties, Utilization). United State (US): Van Nostrand Reinhold. New York

Vick CB. 1999. Adhesive Bonding of Wood Materials (Chapter) in Wood Handbook. United States (US): Forest Product Society

Vorburger TV, Teague EC. 1981. Optical technique for on-line measurement of surface topography. *Prec Eng.* 3. p61

Wang X, Ross RJ, Brashaw BK, Verney SA, Forsman JW, Erickson JR. 2003. Flexural properties of LVL manufactured from ultrasonically rated red maple veneer. FPL Res. Note FPL-RN-0288. United State (US): United State Department of Agriculture USA

Wolfram Research I. 2015. Mathematica, Version 10.2.

Yang KC, Hazenberg G. 1994. Impact of spacing on tracheid length, relative density and growth-rate of juvenile wood and mature wood in *Picea mariana*. *Can J For Res.* 24 : 996-1007

Yuan Y, Lee TR. 2013. Contact angle and wetting properties. *Surface Sci Tech. Springer*: 3-34

Youngquist JA, Laufenberg TL, Bryant BS. 1984. End jointing of LVL for structural use. *For Prod J.* 34:25-32

Zobel BJ, Sprague JR. 1998. Juvenile wood in forest trees. Germany (DE): Springer-Verlag Berlin Heidelberg

APPENDIX

Appendix 1 P-values of variance analysis from poplar cultivars LVL

Source	Dynamic MOE	Static MOE	MOR	Density	SMOE	SMOR
	Pr > F	**Pr > F**	**Pr > F**	**Pr > F**	**Pr > F**	**Pr > F**
Veneer thickness (1)	0.4614	0.0028	<.0001	<.0001	<.0001	0.1247
Poplar cultivars (2)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
1* 2	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Juvenility (3)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
1* 3	0.191	0.2771	0.0668	0.2199	0.1444	0.0271
2* 3	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
1* 2* 3	<.0001	<.0001	<.0001	0.0019	<.0001	<.0001
Load direction (4)	<.0001	0.9435	<.0001	0.7307	0.8374	<.0001
1 * 4	0.0112	0.9724	0.3674	0.9554	0.9957	0.1351
2 * 4	0.0057	0.0517	<.0001	1	0.0529	<.0001
1 * 2* 4	0.5305	0.5072	0.0351	1	0.3541	0.0079
3 * 4	0.6903	0.9458	0.0245	0.7611	0.8191	0.0196
1* 3* 4	0.2135	0.455	0.3333	0.623	0.6429	0.4661
2 * 3* 4	0.3214	0.8268	0.5822	1	0.7771	0.4372
1* 2* 3* 4	0.5616	0.2761	0.4846	0.9999	0.1052	0.3776

Appendix 2 Duncan multiple comparison test for poplar LVL : the effects of veneer thickness, cultivar, juvenility and sample position on dynamic MOE, static MOE, MOR, SMOE, SMOR and density (Results are expresses as the mean values. Different letters (A, B, etc) in the same column indicate that is a significant difference between source of variance at a 95% confidence level (p≤0.05))

Veneer Thickness

Source of variance	n	Dynamic MOE	Static MOE	MOR	SMOE	SMOR	Density
3 mm	1203	8707.18A	8201.54B	51.40A	19.8 B	0.124 A	414.58A
5 mm	604	8774.34A	8415.64A	49.58B	21.3 A	0.126 A	394.91B

Juvenlity

Source of variance	n	Dynamic MOE	Static MOE	MOR	SMOE	SMOR	Density
Mature	905	9298.49A	8879.95A	55.00A	21.6 A	0.134 A	408.25A
Juvenile	902	8157.86B	7664.24B	46.57B	19.0 B	0.115 B	401.26B

Sample Position

Source of variance	n	Dynamic MOE	Static MOE	MOR	SMOE	SMOR	Density
Flatwise	949	8654.64B	8267.40A	52.53A	20.3 A	0.129 A	407.91A
Edgewise	858	8811.50A	8278.70A	48.86B	20.2 A	0.12 B	408.11A

Cultivar

Source of variance	n	Dynamic MOE	Static MOE	MOR	SMOE	SMOR	Density
I-214	120	7039.62I	6712.90G	44.57E	18.9E	0.126CD	354.97J
A4A	166	7539.84G	7140.15F	47.15D	18.5E	0.122EF	384.26H
Triplo	158	7272.14H	6851.37G	45.28E	17.6F	0.116G	389.74G
Polargo	145	7916.65F	7410.27E	47.88D	18.9E	0.121EF	395.48F
Dvina	114	8540.33E	8043.88D	44.94E	20.2D	0.113H	397.13F
Koster	120	8838.47D	8546.63C	53.98C	20.2D	0.127C	424.05D
Mella	115	8781.34D	8220.44D	47.66D	20.6C	0.12F	398.48F
Trichobel	154	9158.40C	8660.39C	46.59D	23.1A	0.124DE	375.86I
Lena	120	9253.98C	8701.81C	55.76B	20D	0.129C	433.22C
Alcinde	128	9569.85B	9185.20B	57.98A	20.9C	0.132B	439.47B
Brenta	116	9760.09AB	9439.11A	56.31B	23.3A	0.139A	405.34E
Soligo	117	9897.93A	9197.90B	56.64AB	19.8D	0.122EF	467.77A
Lambro	116	9754.91AB	9437.09 A	57.98A	21.9B	0.134B	430.16C
Taro	118	9903.12A	9273.68AB	52.97C	20.9C	0.119F	442.44B

Appendix 3 Density, Static MOE, MOR, SMOE and SMOR values of each poplar cultivar LVL made of juvenile and mature veneers

Cultivars	Sample number		Density (kgm^{-3})		Static MOE (MPa)	
	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature
I-214	60	60	355 ± 17.6	362 ± 20.0	6034.2 ± 474.6	7391.6 ± 616.6
Triplo	79	79	391 ± 23.2	388 ± 17.8	6452.3 ± 667.1	7250.4 ± 550.5
A4A	71	95	375 ± 20.9	391 ± 24.1	6363.7 ± 717.6	7720.4 ± 984
Polargo	76	69	402 ± 25.3	389 ± 43.3	6926.5 ± 865.2	7943.1 ± 760.5
Dvina	58	56	393 ± 14.6	401 ± 13.6	7639.3 ± 588.8	8462.9 ± 632.7
Mella	58	57	402 ± 12.8	395 ± 10.1	7876.6 ± 660.3	8570.4 ± 619.6
Koster	60	60	416 ± 16.0	433 ± 18.2	7832.9 ± 815.7	9260.7 ± 564.2
Trichobel	75	79	364 ± 21.2	388 ± 21.0	8142.5 ± 745.2	9152.1 ± 1105.1
Lena	59	61	428 ± 31.5	438 ± 15.7	7765.6 ± 1270.9	9607.3 ± 1013.5
Alcinde	68	60	432 ± 22.5	448 ± 18.4	8631.9 ± 556.2	9812.3 ± 930.7
Soligo	60	57	476 ± 33.8	459 ± 25.7	8545.2 ± 1024	9884.9 ± 642.7
Taro	61	57	427 ± 28.8	459 ± 36.8	8303 ± 943.4	10312.5 ± 1073
Lambro	59	57	429 ± 23.7	432 ± 24.8	8598.3 ± 743	10305.3 ± 925.4
Brenta	58	58	405 ± 17.0	406 ± 13.7	8808.6 ± 658.6	10069.3 ± 517

Cultivars	MOR(MPa)		SMOE($MNmkg^{-1}$)		SMOR($MNmkg^{-1}$)	
	Juvenile	Mature	Juvenile	Mature	Juvenile	Mature
I-214	42.0 ± 4.70	47.1 ± 4.88	17.4 ± 1.95	20.4 ± 1.50	0.121 ± 0.0150	0.130 ± 0.0143
Triplo	43.3 ± 5.47	47.2 ± 4.00	16.5 ± 1.34	18.7 ± 1.81	0.111 ± 0.0112	0.122 ± 0.0118
A4A	42.3 ± 5.85	50.8 ± 6.85	16.9 ± 1.54	19.7 ± 2.02	0.113 ± 0.0147	0.130 ± 0.0155
Polargo	43.7 ± 5.49	52.5 ± 6.95	17.3 ± 2.29	20.6 ± 2.21	0.109 ± 0.0137	0.135 ± 0.0134
Dvina	42.6 ± 5.49	47.3 ± 7.82	19.4 ± 1.38	21.1 ± 1.18	0.108 ± 0.0124	0.118 ± 0.0177
Mella	45.1 ± 5.58	50.2 ± 4.33	19.6 ± 1.70	21.7 ± 1.52	0.112 ± 0.0138	0.127 ± 0.00975
Koster	49.0 ± 6.34	58.9 ± 5.54	18.9 ± 2.13	21.4 ± 1.55	0.118 ± 0.0162	0.136 ± 0.0138
Trichobel	42.2 ± 4.98	50.8 ± 5.40	22.4 ± 2.09	23.6 ± 2.89	0.116 ± 0.0143	0.131 ± 0.0116
Lena	50.8 ± 6.00	60.5 ± 6.79	18.1 ± 1.85	21.9 ± 1.94	0.119 ± 0.0127	0.138 ± 0.0141
Alcinde	52.0 ± 5.46	64.8 ± 6.26	20.0 ± 1.65	21.9 ± 1.64	0.120 ± 0.0122	0.144 ± 0.0124
Soligo	49.7 ± 7.08	64.0 ± 6.04	18.1 ± 2.95	21.6 ± 1.62	0.105 ± 0.0162	0.139 ± 0.0135
Taro	48.2 ± 6.42	58.0 ± 7.00	19.4 ± 1.70	22.5 ± 1.96	0.113 ± 0.0131	0.126 ± 0.0116
Lambro	51.5 ± 7.35	64.7 ± 7.59	20.1 ± 1.67	23.8 ± 1.56	0.120 ± 0.0150	0.150 ± 0.0135
Brenta	52.5 ± 6.72	60.2 ± 5.34	21.7 ± 1.24	24.8 ± 1.38	0.129 ± 0.0153	0.148 ± 0.0135

Appendix 4 P-value of the variance analysis from douglas-fir LVL

Source	Density Pr > F	Static MOE Pr > F	Dynamic MOE Pr > F	MOR Pr > F
Juvenility (1)	<.0001*	<.0001*	<.0001*	<.0001*
Veneer Thickness (2)	<.0001*	0.5476	0.7566	0.0003*
(1)*(2)	0.5927	0.0064*	0.4595	0.8217
Loading Position (3)	0.8298	0.9072	0.2181	0.0062*
(1)*(3)	0.1069	0.5582	0.7262	0.0219*
(2)*(3)	0.2996	0.2373	0.7631	0.0385*
(1)*(2)*(3)	0.3897	0.5213	0.9183	0.4189

(*p≤0.05 indicate that the single or interaction factors provide an significant effect at a 95% confidence level)

Appendix 5 Duncan multiple comparison test for douglas-fir LVL : The effect of veneer thickness, juvenility and sample position on dynamis MOE, static MOE, MOR and density (Results are expresses as the mean values. Different letters (A, B, etc) in the same column indicate that is a significant difference between source of variance at a 95% confidence level ($p \leq 0.05$))

Juvelinity					
Source of variance	N	Density (kgm^{-3})	Static MOE (Mpa)	Dynamic MOE (Mpa)	MOR (Mpa)
Mature	65	583.3 A	14483.6 A	14971.3 A	62.90 A
Juvenile	75	522.2 B	12735.2 B	13501.1 B	56.90 B

Veneer thickness					
Source of variance	N	Density (kgm^{-3})	Static MOE (Mpa)	Dynamic MOE (Mpa)	MOR (Mpa)
3mm	63	561A	13384.6A	14122.1A	57B
5.25mm	77	542B	13679.8A	14234.1A	62A

Loading position					
Source of variance	N	Density (kgm^{-3})	Static MOE (Mpa)	Dynamic MOE (Mpa)	MOR (Mpa)
Edgewise	71	553A	13594A	14412A	62A
Flatwise	69	548A	13498A	13949A	58B

Juvelinity*veneer thickness		
Source of variance	N	Static Moe (Mpa)
Mature*3mm	29	14834A
Mature*5.25mm	36	14202A
Juvenile*5.25mm	41	13222B
Juvenile*3mm	34	12148C

(Results are expresses as the mean values. Different letters (A, B, etc) in the same column indicate that is a significant difference between source of variance at a 95% confidence level ($p \leq 0.05$))

CURRICULUM VITAE

The author was born in Bogor on April 22, 1974 as the oldest child of two siblings of H. Isbadi, SH (Alm) and Aini Mariam, S.Kp. The author got Bachelor Degree of Forestry in 1997 at Faculty of Forestry, Bogor Agricultural University. In 2001, the author got her Master Degree of Forestry Science at the same university. Since 2005, the author devoted herself on the almamater as the lecturer. Starting PhD program in 2011, the author got a scholarship of Double Degree program between Indonesia and France, funded by Indonesian Dorectorate General of Higher Education and Campus France. Bogor Agricultural University is the host university collaborated with Art et Metiérs ParisTech Cluny, France as the partner university, under joint supervision of Prof. I Wayan Darmawan, Dr. Loui Denaud, Dr. Naresworo Nugroho and Prof. Remy Marchal

The publications in the form of articles in journals and symposium papers during the PhD period were as follow :

1. **Rahayu I**, Denaud L, Butaud JB, Pot G, Legrand G. 2013. Qualités Technologiques des Panneaux Contreplaqués et LVL realises avec Les Nouveaux Cultivars de Peuplier. *Foret Entreprise* No. 213. ISSN:0752-5974 (France)
2. **Rahayu I**, Darmawan N, Nugroho N, Nandika D, Marchal R. 2014. Demarcation Point between Juvenile and Mature Wood in Sengon (*Falcataria molluccana*) and Jabon (*Antocephalus cadamba*). *J Trop For Sci* 26 (3):331-339 ISSN 0128-1283 (Malaysia)
3. **Rahayu I**, Denaud L, Marchal R, Nugroho N, Darmawan W. 2015. Ten new poplar cultivars provide laminated veneer lumber for structural application. *Ann For Sci* 72:705-715 DOI 10.1007/s13595-014-0422-0 ISSN: 1286-4560 (Print) 1297-966X (Online) (France)
4. **Rahayu I**, Darmawan W, Nugroho N, Marchal R. 2015. The Effect of Jabon Veneer Quality on Laminated Veneer Lumber Glue Bond and Bending Strength. *Jurnal Ilmu dan Teknologi Kayu Tropis* (accepted)
5. Girardon S, Denaud L, Pot G, **Rahayu I**. 2016. Determination of poplar LVL effective modulus of elasticity by modelling peeling and evolution of raw material properties on cambial age basis. *Annal of Forest Science* (accepted)
6. **Rahayu I**, Denaud L, Marchal R, Darmawan W. 2013. Correlation between Radial Variation and Mechanical Properties of Laminated Veneer Lumber made from 14 Poplar Cultivars. Proceeding of IUFRO symposium Memowood (Measurement methods and modeling approaches for predicting future wood properties). Nancy (France), 1-4 October 2013.
7. **Rahayu I**, Marchal R, Darmawan W, Denaud L. 2014. Juvenility and Veneer Thickness Effect on Mechanical Properties of Poplar LVL. Journee Deuxiemme Anne de Doctorant, MINES ParisTech June,25-26 2014
8. **Rahayu I**, Darmawan W, Nugroho N, Marchal R. 2015. Characteristic of Veneer Quality of Rotary Cut Jabon Veneers and Their Effect on LVL Glue Bond and Bending Strength. International Symposium of Indonesian Wood Research Society at Bandung in November 2015

CHARACTERISTICS OF LATHE CHECK AND SURFACE ROUGHNESS OF FAST GROWING WOOD VENEERS AND THEIR PERFORMANCE ON LAMINATED VENEER LUMBER

RESUME :
Pour répondre à la demande croissante de bois et pour préserver les forêts primaires, les méthodes de sylviculture les plus dynamiques ont été privilégiées de manière générale sur la planète.. Les objectifs de la recherche étaient 1) déterminer le point de démarcation/ âge de transition entre le bois juvénile et le bois mature sur sengon (Falcataria moluccana), jabon(Anthocephalus cadamba Miq.), peuplier (Populus sp) et douglas (Psedotsuga menziesii); 2) analyser l'effet de la juvénilité sur un fissuration cyclique, la rugosité et de mouillage; 3) analyser l'effet de la fissuration cyclique et juvénilité sur la résistance à l'adhérence de la colle et les propriétés mécaniques du LVL en flexion; et 4) appliquer un nouveau modèle analytique pour estimer la variation du module d'élasticité du lamibois (sengon et jabon) depuis la moelle vers l'écorce. A partir de la longueur des fibres, le point de démarcation entre le bois juvénile et le bois mature ont été estimés. Pour les essences sengon and jabon, les placages obtenus à partir du cœur des arbres, réputés juvéniles, sont plus fissurés plus rugueux et avec une haute mouillabilité comparativement à ceux obtenus à partir du bois près de l'écorce (plus mature). Une phase d'étuvage préliminaire des bois dans un bain d'eau chaude à 75°C pendant 4 heures a permis d'améliorer sensiblement la qualité des placages en diminuant la fissuration, la rugosité et s'accompagne d'une augmentation de la mouillabilité. La résistance à l'adhérence de la colle, et les modules élastiques et de rupture spécifiques (SMOE et SMOR) du LVL (jabon et sengon) diminuent à mesure que la fréquence de fissure augmente ou en partant de l'écorce vers la moelle. L'avantage de l'utilisation de placages en peuplier de bois mature a été prouvé avec une amélioration de 15 à 20% en moyenne pour les propriétés mécaniques, pour un poids de panneau comparable. Pour le douglas, l'utilisation de placages de bois mature dans la constitution des panneaux de LVL permet également d'améliorer les performances en flexion (de 7 à 22 % sur el MOR). Le modèle analytique a été utilisé afin de prédire les variations du module élastique allant de la moelle à l'écorce. Il permet à partir d'un grand nombre de combinaisons d'estimer le potentiel issu d'une ressource donnée. Pour le contexte de l'étude qui représente bien le potentiel sylvicole de l'Indonésie, la proportion de bois juvénile étant quasi-totale (100%), l'action de trier les placages n'est pas apparue comme pertinente.

Mots clés : espèces à croissance rapide, juvénile, fissuration cyclique, rugosité, lamibois.

ABSTRACT : The development of plantation and community forest to meet wood demand in society has produced fast growing wood species. The research objectives were 1) to determine demarcation point/transition age between juvenile and mature wood on sengon (*Falcataria moluccana*), jabon (*Anthocephalus cadamba* Miq.), poplar (*Populus* sp) and douglas fir (*Psedotsuga menzii*); 2) to analyze the effect of juvenility on lathe check, surface roughness and wettability; 3) to analyze the effect of lathe check and juvenility on glue bond strength and laminated veneer lumber (LVL) bending properties; and 4) to apply a new analytical model to determine the variation of specific MOE LVL values of sengon and jabon from pith to bark. Based on fiber length trait, the demarcation point between juvenile and mature wood were approximately at radial segments 17^{th} (sengon) and at radial segment 24^{th} (jabon). While, transition age of poplar cultivars and douglas-fir, transition age happened approximately at 12 years old and 18 years old, respectively. The results showed that wood near pith on sengon and jabon resulted veneers with higher lathe check, rougher surface and high wettability, while wood near bark resulted veneers with lower lathe check, smoother surface and low wettability. Glue bond strength, Specific MOE (SMOE) and Specific MOR (Modulus of Rupture) of sengon and jabon LVL were decreased as the frequency of lathe check increased or those strength values increased from pith to bark. The advantage of using poplar veneers from mature wood was proved with an improvement of 15 to 20% on average for mechanical properties, while for douglas-fir, was 7 to 22%. An analytical model was used to predict the variation of the LVL mechanical characteristics using different scenarios. According to the context of this study assumed to be close to the Indonesian resource there is no need to sort veneers since most of the tree is juvenile wood for logs no older than 7.

Keywords : fast growing species, juvenile, lathe check, surface roughness, laminated veneer lumber