MECHANICAL AND PHYSICAL PROPERTIES OF PARTICLEBOARD MADE FROM 4-YEAR-OLD RUBBERWOOD OF RRIM 2000 SERIES CLONES

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Received January 2010

PARIDAH MT, SAIFULAZRY SOA, JALALUDDIN H, ZAIDON A & RAHIM S. 2010. Mechanical and physical properties of particleboard made from 4-year-old rubberwood of RRIM 2000 series clones. Rubber trees are normally felled after 25 years. With the drastic depletion of rubberwood supply, the Malaysian Rubber Board has identified new clones of rubberwood from RRIM 2000 series that are expected to be suitable for timber and latex production. In this study, particleboards were made from 4-year-old RRIM 2000 series rubberwood clones. The clones—RRIM 2002, RRIM 2020 and RRIM 2025 were compared with the currently available clone, PB 260, that is used by most rubberwood processing plants in Malaysia. The board was fabricated using E1 grade urea formaldehyde resin to a density of 700 kg m^{-3} and board performance was determined according to JIS A 5908-2003. The study revealed that it was technically feasible to use 4-year-old rubberwood from the RRIM 2000 series clones, especially RRIM 2002, for making particleboard which is comparable to that made from the mature (25-year-old) PB 260 clone.

Keywords: Young wood, RRIM 2002, RRIM 2020, RRIM 2025, PB 260

PARIDAH MT, SAIFULAZRY SOA, JALALUDDIN H, ZAIDON A & RAHIM S. 2010. Ciri-ciri mekanik dan fizikal papan serpai yang diperbuat daripada pokok getah berusia empat tahun daripada klon siri RRIM 2000. Pokok getah biasanya ditebang selepas 25 tahun. Dengan kekurangan bekalan kayu getah yang mendadak, Lembaga Getah Malaysia telah mengenal pasti klon baru getah daripada siri RRIM 2000 yang dijangka sesuai untuk penghasilan kayu dan getah asli. Dalam kajian ini, papan serpai dihasilkan menggunakan beberapa klon siri RRIM 2000 yang berusia empat tahun. Klon RRIM 2002, RRIM 2020 dan RRIM 2025 dibandingkan dengan klon sedia ada iaitu PB 260 yang diguna pakai oleh kebanyakan kilang pemprosesan kayu getah di Malaysia. Papan serpai berketumpatan 700 kg m^{-3} dihasilkan menggunakan perekat urea formaldehid gred E1 dan prestasi papan ditentukan berdasarkan standard JIS A 5908-2003. Secara teknikalnya, kajian ini menunjukkan bahawa kayu getah daripada klon siri RRIM 2000 berusia empat tahun khususnya klon RRIM 2002 boleh digunakan untuk membuat papan serpai. Ciri-ciri papan serpai daripada klon RRIM 2002 adalah setanding dengan papan serpai yang dihasilkan daripada klon PB 260 yang telah matang (berusia 25 tahun).

INTRODUCTION

When a tree is young, it often contains no heartwood. The most common age at which transformation from sapwood to heartwood occurs is between 14 and 18 years (Hillis 1987). The young wood is known to have different properties from mature wood. The former is lower in quality due to shorter cells with high proportion of cells having thin wall (Haygreen & Bowyer 1996), greater microfibril angle (Noskowiak 1963, Zobel & Kellison 1972) and high longitudinal shrinkage (McAllister & Clark 1991). These give low specific gravity which leads to lower strength in comparison with mature wood. Young wood has higher hygroscopicity, is less stable and contains higher moisture content. These inherent properties often give rise to problems when using young wood either as lumber, veneer products or for pulp and paper production. On the contrary, Pugel *et al.* (1990) found that flakeboard, particleboard and fibreboard panels made from young wood were comparable in strength and durability with those

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made from mature wood. However, thickness swelling and linear expansion were significantly greater in young wood panels.

Wood density affects the property of particleboards since it determines the amount of particles that is required to produce the boards. The higher the wood density the lesser the amount of wood needed to achieve a certain board density, which leads to lower compaction and vice versa. Boards made with higher compaction ratio usually have higher strength. According to Mitlin (1969), particleboards made from wood chips must be compressed to at least 5% above the natural density of the wood to attain minimal acceptable properties. Compaction ratio also affects other aspects of inter-particle bonding such as surface contact. Greater surface contact provides greater efficiency of load transfer, thus, resulting in better board strength. Besides resin and processing parameters, other factors such as wood strength, particle geometry, surface roughness and surface wettability have considerable effects on board performance. Stronger particles result in higher strength. The slenderness ratio, particle shape, particle size, particle surface characteristic and particle orientation can influence the performance of particleboards (Wang & Lam 1999, Avramidis & Mansfield 2005, Seyoum 2005, Semple *et al.* 2007, Sackey *et al.* 2008). Turner (1954) conducted studies on the effects of particle size and shape on strength properties of particleboards made using four different particle configurations. He found that flakes of 7.6 cm long and 0.38 to 0.50 cm thick had the optimum board strength. In a related study, Post (1958, 1961) found an increase in modulus of rupture (MOR) of oak flakeboards with increasing flake length of 1.3 to 10.2 cm but the rate of increment decreased with lengths greater than 5 cm. The degree of particle orientation also has a strong effect on the modulus of elasticity (MOE) and MOR of the boards.

This paper evaluates the performance of particleboard made from young rubberwood of clone RRIM 2000 series and compares it with that from mature PB 260 clone. The paper also highlights the effects of compaction ratio and particle geometry on the mechanical and physical properties of the panels.

MATERIALS AND METHODS

Material

Three rubber clones from the RRIM 2000 series were used in this study, namely, RRIM 2002, RRIM 2020 and RRIM 2025. The 4-year-old trees were obtained from the RRIM experimental station in Tok Dor Besut, Terengganu, Malaysia. A total of 30 trees from each clone were felled and cut into 1.5 m billet size. For comparison, rubberwood chips from a commercial fibreboard plant were used. This rubberwood came from clone PB 260 trees of approximately 25 years old.

Preparation of raw material

The logs of RRIM 2000 series clones were processed separately. The 1.5 m billets from each clone were fed into a Pallmann drum-chipper, then into a Pallman knife-ring flaker. Since the PB 260 clone (control) was obtained in chip form, the chips were directly fed into a knife-ring flaker. The wood particles were sorted using a circulating vibrator screen to separate the wood particles into various particle sizes retained at 0.5, 1.0 and 2.0 mm sieve sizes. Only particles of sizes > 0.5 to < 2.0 mm were used. The particles were dried in an oven maintained at 80 ± 2 °C until moisture content of 5 to 6% was reached.

Manufacture of particleboard

Homogeneous (single layer) particleboards of 340 × 340 × 10 mm in size were manufactured using particles from four rubberwood clones: PB 260, RRIM 2002, RRIM 2020 and RRIM 2025. Six replicates of particleboard with a target density of 700 kg m^{-3} were made from each clone with a total of 24 boards. The particles were sprayed with 10% (w/w of oven-dry weight particles) E1-grade urea formaldehyde (65%, solids) resin. One per cent (w/w of resin solids) ammonium chloride was used as hardener and wax was added at 1% (w/w) of oven-dry weight particles. The mat was manually formed and cold pressed for 5 min. The mats were then hot pressed for 6 min at 165 °C to 10 mm thickness. The boards were conditioned at ambient temperature and 65% relative humidity until they achieved equilibrium moisture content prior to cutting into test specimens.

Evaluation of particleboard performance

The test specimens were evaluated according to the JIS A5908-2003 (JIS 2003), one of the most popular standards referred to by the Malaysian panel manufacturers. The cutting pattern and size for test specimens are shown in Figure 1 and Table 1 respectively. Three-point static bending and internal bond (IB) tests were conducted on dry specimens using an Instron Universal Testing Machine. The percentages of thickness swelling (TS) and water absorption (WA) of the panels were determined by soaking the specimens in cold water for 24 hours and the increases in thickness and weight were recorded. The data were statistically analysed using analysis of variance (ANOVA) for the effects of rubberwood clones. The means were further separated using least significant difference (LSD) method.

Surface wettability

The wettability of rubberwood surfaces was evaluated by the measurement of the contact angle of liquid based on the methods outlined by Adamson and Gast (1997) using AB Lorentzen and Wettre (L–W) surface wettability tester.

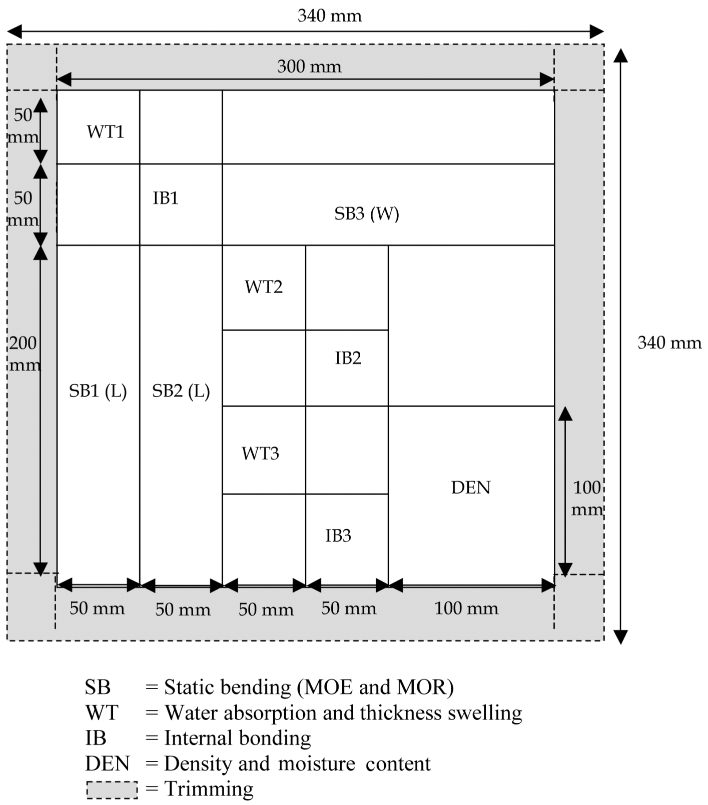

Figure 1 Cutting pattern of test specimens

Table 1 Cutting size of test specimens

Test	Size of sample (mm)	No. of sample tested per board
Static bending	200 × 50 × 10	3
Internal bonding (IB)	50 × 50 × 10	3
Thickness swelling (TS)	50 × 50 × 10	3
Water absorption (WA)	50 × 50 × 10	3
Density and moisture content	100 × 100 × 10	3

Size of specimens is according to JIS 5908-2003.

RESULTS AND DISCUSSION

Table 2 shows that with the exception of WA and IB, MOE, MOR and TS were significantly affected by rubberwood clones. MOE and TS were greatly affected as shown by the highly significant level ($p \leq 0.01$).

Bending properties

RRIM 2002 and RRIM 2020 particleboards (Table 3) had higher MOR values which were comparable with the control (mature PB 260). Boards made from RRIM 2025 clone were the weakest. A similar result was seen in MOE except that MOE of boards made from RRIM 2002 was comparable with that from PB 260. Wood properties influence the composite performance especially MOE and MOR (Maloney 1977, Haygreen & Bowyer 1996). This was clearly seen in this study whereby boards that were produced from mature wood (PB 260) had higher MOE and MOR compared with boards made from wood of younger trees (RRIM 2000 series). This is in agreement with the study by Pazdrowski and Spalwa-Neyman (2003) who found that mature and young wood of the same species and specific gravity varied in both MOE and MOR, with the latter being significantly lower in bending strength. Particles that originated from mature wood (in this case PB 260) are stronger due to thicker cell wall, thus, resulting in boards with better properties.

Table 4 shows that PB 260 produces thicker cell wall, smaller lumen, higher specific gravity and thinner fibres. Unlike PB 260, the young clones had shorter (except for RRIM 2002) and thinner fibres. As the load was applied perpendicular to the board surface, it creates compression stress on the top side of the board which transformed into tension stress at the bottom after exceeding the middle portion. Since load stresses are transferred from one particle to another, the length of fibres in the particles functions as a medium for load transfer. Longer fibres will be able to support greater stress, thus, resulting in greater MOE and MOR. Since the RRIM 2025 clone has the shortest fibre, it is expected that boards made from this clone have lower MOR (20.3 MPa) and MOE (2112 MPa). Even though RRIM 2002 had longer fibre compared with PB 260, its thinner cell wall and lower specific gravity caused it to have lower particle strength, hence, resulting in lower board strength.

Apart from the basic properties of wood, surface contacts also have a strong influence on board performance. One of the indicators of surface contact is the compaction ratio. Higher compaction ratio can normally be obtained using wood with lower specific gravity. Due to the greater volume of particles needed to produce board of a specific density, the resulting board would have higher surface contact among the particles. To produce satisfactory contact between particles, it is usually necessary to compress the board to 1.2–1.6 times that of the required specific gravity (Suchsland & Xu 1959, 1989).

Since young wood have relatively lower specific gravity, more material is required for the same board density which results in better compaction ratio and good surface contact. Among the 4-year-old clones studied, the RRIM 2002 and RRIM 2020 are expected to give relatively high compaction ratio and better surface contact as a consequence of their low specific gravity. This enhances load transfer, thus, giving rise to higher board strength. Such behaviour was not seen in RRIM 2025 (Table 3) which had slightly higher specific gravity. Even though the mature PB 260 had relatively low compaction ratio, the wood itself is much stronger as a result

Table 2 Summary of ANOVA for the effects of different clones on the properties of particleboard

Property	MOE	MOR	IB	TS	WA
Df	3	3	3	3	3
Mean square	315878	22.1	0.215	41.7	91.03
F value	5.39	2.66	2.35	11.19	1.77
Pr > F	0.0022 ***	0.05 **	0.0804 ns	0.001 ***	0.1609 ns

ns = Not significant at $p > 0.05$; ** = significant at $p \leq 0.01$; *** = highly significant at $p \leq 0.001$
MOE = modulus of elasticity, MOR = modulus of rupture, IB = internal bond, TS = thickness swelling, WA = water absorption

of cell thickening upon maturity (as found in heartwood), hence, giving rise to the strength of the particleboard.

Particle geometry also has an effect on the overall particleboard properties and can interact with other process variables (Mottet 1967, Nelson 1997). The difference between particle geometry generated from mature PB 260 and the young RRIM 2000 series was obvious. The former had clean-cut edges as well as tapered and rectangular-end particles (Figure 2a). On the contrary, the 4-year-old clones were generally much 'fibrous' with rough surface particles (Figures 2b–d). These fibrous-like particles create a different effect on inter-particle bonding and inevitably affect the board properties. Fibrillation and rough surface give poor surface quality to particles. According to Schneider and Conway (1969), the semicircular-end particles gave the lowest performance followed by pointed-end particles and flat end-tapered particles and the best performance was shown by rectangular particles. They pointed out that 'damaged' or 'wounded' particles in addition to the semicircular-end particles could reduce the mechanical performance of boards. In this study, such behaviour was not observed. Apparently, immense fibrillation that had occurred in particles of young RRIM 2000 series clone had a positive effect on board mechanical properties whereby the 'fibrillated' particles provided a greater surface area for contact, thus, greater stress could be transferred efficiently. This gave greater strength to the board.

The longer and narrower particles generated from young wood may be another contributing factor to the high mechanical strength. The particles had greater slenderness ratio and better inter-particle bonding which resulted in high MOR, MOE and IB values found in

Table 3 Strength and stiffness of particleboard produced from various clones of rubberwood

Clone	Compaction ratio[a]	MOE (MPa)	MOR (MPa)
RRIM 2002	1.23	2373 a (322)	22.5 a (3.03)
RRIM 2020	1.21	2201 b (181)	21.7 ab (2.50)
RRIM 2025	1.19	2112 b (263)	20.3 b (3.02)
PB 260 (control)	1.16	2381 a (170)	22.8 a (2.94)
LSD		161	1.9

Values are average of 18 specimens. Values in parentheses indicate standard deviations.
[a]Board density / wood density
LSD = least significant difference; means followed by the same letter in the same column are not significantly different at $p \leq 0.05$.

Table 4 Wood density and fibre morphology of different clones of rubberwood

Clone	Specific gravity	Fibre length (mm)	Fibre diameter (μm)	Fibre wall thickness (μm)	Lumen diameter (μm)
RRIM 2002	0.570	1.44	33	4.7	24
RRIM 2020	0.580	1.23	31	4.5	22
RRIM2025	0.589	1.16	29	4.2	21
PB260 (control)	0.601	1.35	27	6.0	14

Source: Saifulazry (2007)

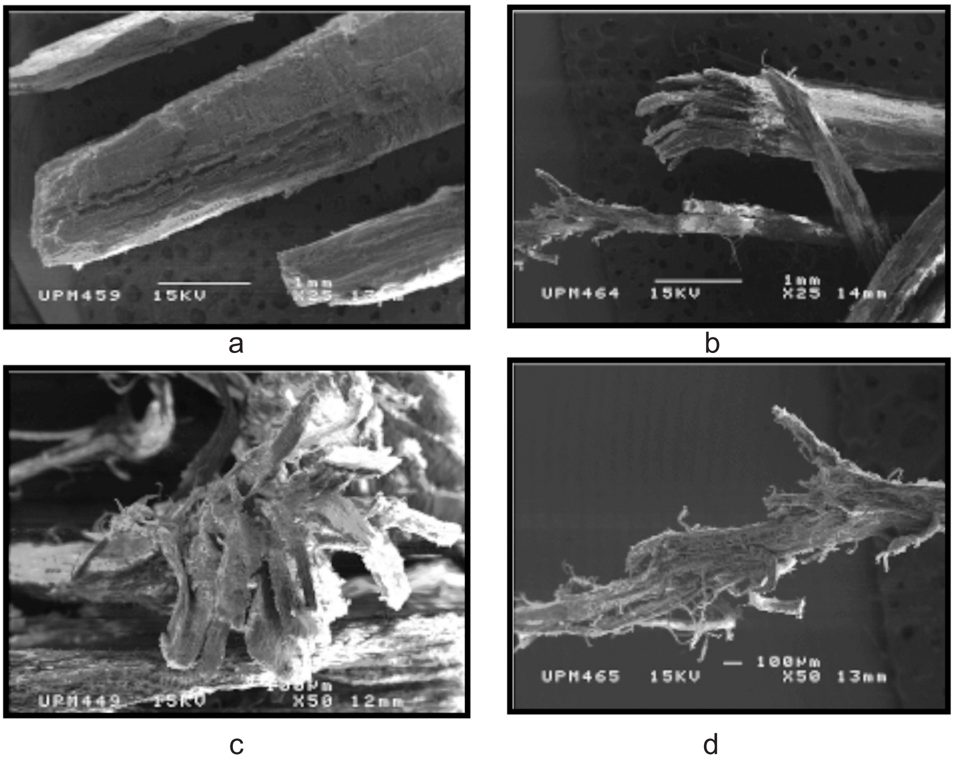

Figure 2 Particle geometry of rubberwood from (a) 25-year-old PB 260 clone—rectangular, flat end and tapered shape and (b–d) 4-year-old RRIM 2000 series—shredded ends with irregular shapes and highly fibrillated

the boards of young RRIM 2000 series clones. This is in agreement with Barnes (2001) and Yadama (2002) who found that particles must be sufficiently long to allow adequate overlap for transfer of applied stress from one particle to the next. The resin used must have tensile and shear properties that are at least as good as those of the wood particle in order to transfer the applied stress.

Internal bonding properties

It is well understood that the adhesion of porous materials involves mechanical interlocking, physical attraction and chemical bonding (Wellons 1980). In a real situation, the bonding mechanism probably occurs in combination. The wettability of rubberwood from RRIM 2000 series was comparable with that of PB 260 with complete absorption of water droplet within 7–9 s, implying that good adhesion would occur between particles. This was evident in the IB values obtained from the boards. As shown in Figure 3, generally all clones produced panels with excellent IB.

Dimensional stability properties

There are four major parameters that affect particleboard dimensional properties: board density, particle geometry, resin and wax and pressing condition (Razali 1985). As expected, panels produced from mature clone PB 260 exhibited the lowest thickness swelling and water absorption(Table 5). The TS of the panels differed significantly between the 4-year-old clones but not the WA. The trend of TS directly followed that of the compaction ratio. Higher compaction ratio (RRIM 2002) gave higher TS and WA due to the presence of more materials in a given volume. Pressing of the board to higher than the material density caused higher residual stress and this led to springback phenomenon (Kelly 1977). The extent of swelling was relatively smaller in both RRIM 2020 and RRIM 2025 which depicted the trend found in compaction ratio. Since young wood contains mainly sapwood, the increment in moisture absorption and swelling of the boards are inevitable. Unlike young wood, mature wood contains mainly heartwood

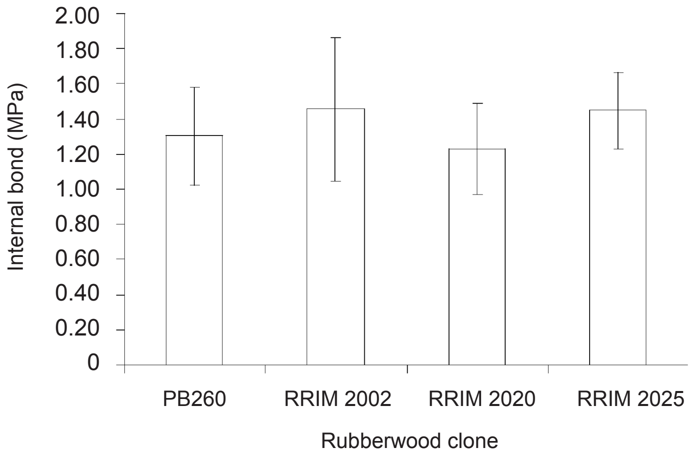

Figure 3 Internal bond properties of particleboard produced from various clones of rubberwood

Table 5 Compaction ratio, thickness swelling and water absorption of particleboards from various rubberwood clones after 24-hour cold water soaking

Clone	Compaction ratio[a]	TS (%)	WA (%)
RRIM 2002	1.23	22.7 a	65.4 a
RRIM 2020	1.21	21.4 b	65.1 a
RRIM 2025	1.19	20.0 c	61.6 a
PB 260 (control)	1.16	19.3 c	61.1 a
LSD		1.28	4.77

Values are average of 18 specimens. Values in parentheses indicate standard deviations.
[a]Board density/wood density
LSD = least significant difference; means followed with the same letter in the same column are not significantly different at $p \le 0.05$.
TS = thickness swelling, WA = water absorption

that has smaller lumen, thicker cell wall and contains high amounts of extractives that provide resistance to moisture penetration.

CONCLUSIONS

Except for WA and IB, all board properties (MOE, MOR and thickness swelling) were found to be significantly affected by tree clone. Among the 4-year-old RRIM 2000 series clones, RRIM 2002 showed superior quality wood comparable with that of the control (commercial 25-year-old PB 260). Age of tree had some influence on board strength and stability. However, the effects were more apparent in the latter. Due to the particle geometry of the young clones, more efficient surface contact was obtained which resulted in substantial improvement in MOR and MOE.

ACKNOWLEDGEMENTS

This research was supported by the Ministry of Technology and Innovation of Malaysia (MOSTI) PR-IRPA (No: 03-04-01-0781-PR/05). The authors would like to acknowledge MA Mohd Nasaruddin of the Malaysian Rubber Board and MY Nor Yuziah of Malayan Adhesives and Chemicals for their assistance throughout the study.

REFERENCES

Adamson AW & Gast AP. 1997. *Physical Chemistry of Surfaces*. Sixth edition. University of Southern California, Los Angeles.

Avramidis S & Mansfield SD. 2005. On some physical properties of six aspens clones. *Holzforschung* 59: 54–58.

Barnes D. 2001. A model of the effect of strand length and strand thickness on the strength properties of oriented wood composites. *Forest Products Journal* 51: 36–46.

Haygreen JG & Bowyer JL 1996. *Forest Products and Wood Science: An Introduction*. Third edition. The Iowa State University Press, Iowa.

Hillis WE. 1987. *Heartwood and Tree Exudates*. Springer-Verlaq, New York.

JIS (Japanese Industrial Standard). 2003. *JIS A 5908. Standard Test Methods for Evaluating Particleboard Properties*. First English edition. Japan Standards Association, Tokyo.

Kelly M. 1977. *Critical Literature Review of Relationships Between Processing Parameters and Physical Properties of Particleboard*. USDA Forest Service Forest Product Laboratory General Technical Report Paper FPL-10. North Carolina State University, Raleigh.

Maloney TM. 1977. *Modern Particle Board and Dry Process Fibreboard Manufacturing*. Miller Freeman Publications, San Francisco.

McAllister RH & Clark A. 1991. Effect of geographic location and seed source on the bending properties of juvenile and mature loblolly pine. *Forest Products Journal* 41: 39–42.

Mitlin L. 1969. *Particleboard Manufacture and Application*. Pressmedia Ltd., Kent.

Mottet AL. 1967. The particle geometry factor in particleboard manufacturing. Pp. 23–73 in *Proceedings of First Symposium on Particleboard*. 1–3 March 1967, Washington DC.

Nelson S. 1997. Structural composite lumber. Pp. 147–172 in Smulski S (Ed.) *Engineered Wood Products: A Guide for Specifiers, Designers and Users*. PFA Research Foundation, Madison.

Noskowiak AF. 1963. Spiral grain in trees—a review. *Forest Products Journal* 13: 266–277.

Pazdrowski W & Spalwa-Neyman S. 2003. Stage growth of trees and its effect on selected properties of Norway spruce wood (*Picea abies* (L.) Karst.) *Electronic Journal of Polish Agricultural Universities, Forestry* 6. http://www.ejpau.mediap1/volum 6/issue 2/foresty/art-02.html.

Post PW. 1958. Effect of particle geometry and resin content on bending strength of oak flakeboard. *Forest Products Journal* 8: 317–322.

Post PW. 1961. Relationship of flake size and resin content to mechanical and dimensional properties of flake board. *Forest Products Journal* 11: 34–37.

Pugel AD, Price EW & Hse CY. 1990. Composites from southern pine juvenile wood. Part II. *Forest Products Journal* 40: 57–61.

Razali AK. 1985. Origins of thickness swelling in particleboards. PhD thesis, University of Wales, Bangor.

Sackey EK, Semple KE, Oh SW & Smith GD. 2008. Improving core bond strength of particleboard through particle size redistribution. *Wood and Fiber Science* 40: 214–224.

Saifulazry SOA. 2007. Evaluation of the properties of 4-year-old rubberwood clone RRIM 2000 series for particleboard manufacture. MSc thesis, Universiti Putra Malaysia, Serdang.

Schneider GJ & Conway HD. 1969. Effect of fiber geometry and partial debonding on fiber-matrix bond stresses. *Journal of Composite Materials* 3: 116–135.

Semple KE, Vaillant MH, Kang KY, Oh SW, Smith GD & Mansfield SD. 2007. Evaluating the suitability of hybrid poplar clones for the manufacture of oriented strand boards. *Holzforschung* 61: 430–438.

Seyoum KH. 2005. Suitability of *Yushania alpina* for oriented particleboard. PhD thesis, Universiti Putra Malaysia, Serdang.

Suchsland O & Xu H. 1959. An analysis of the particleboard process. *Michigan State University Agriculture Experimental Station Quality Bulletin* 42: 351–372.

Suchsland O & Xu H. 1989. A simulation of horizontal density distribution in a flakeboard. *Forest Products Journal* 9: 52–60.

Turner HD. 1954. Effect of particle size and shape on strength and dimensional stability of resin-bonded wood particle panels. *Journal of Forest Products Research Society* 4: 210–223.

Wang K & Lam F. 1999. Quadratic RSM models of processing parameters for three layer oriented flakeboard. *Wood and Fiber Science* 31: 173–186.

Wellons JD. 1980. Wetability and gluability of Douglas-fir veneer. *Forest Products Journal* 30: 53–55.

Yadama V. 2002. Characterization and modelling of oriented strand composites. PhD thesis, Washington State University, Pullman.

Zobel BJ & Kellison RC. 1972. Short rotation forestry in the Southeastern United States. *Tappi* 55: 1205–1208.

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