# EFFECTS OF WOOD:CEMENT RATIO ON MECHANICAL AND PHYSICAL PROPERTIES OF THREE-LAYERED CEMENT-BONDED PARTICLEBOARDS FROM *LEUCAENA LEUCOCEPHALA*

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**MARZUKI AR, RAHIM S, HAMIDAH M & AHMAD RUSLAN R. 2011. Effects of wood:cement ratio on mechanical and physical properties of three-layered cement-bonded particleboards from *Leucaena leucocephala*.** Three-layered cement-bonded particleboards (CBPs) from 8- and 16-year-old *Leucaena leucocephala* trees were manufactured in the laboratory and examined for suitability as a construction material. Four wood–cement ratios, i.e. 1:1.75, 1:2.0, 1:2.25 and 1:2.5 were used. A combination of aluminium sulphate and sodium silicate was used as cement accelerator. Wood particles retained at 2 mm sieve size were used for the core layer and a combination of 1 and 0.5 mm were used for the outer layers. The mechanical and physical properties of the boards were evaluated based on MS 544: 2001. The modulus of rupture ranged from 7.68 to 11.22 MPa and modulus of elasticity, 2981 to 4002 MPa. The internal bond ranged from 0.59 to 0.90 MPa. The water absorption and thickness swelling after 24 hours soaking in water ranged from 12.42 to 19.04% and 0.38 to 0.70% respectively. Generally, the CBPs produced from 8-year-old trees gave better mechanical strength than the 16-year-olds.

Keywords: Modulus of rupture, modulus of elasticity, internal bond, thickness swelling

**MARZUKI AR, RAHIM S, HAMIDAH M & AHMAD RUSLAN R. 2011. Kesan nisbah kayu:simen terhadap ciri-ciri fizikal dan mekanik papan serpai tiga lapis berikatan simen daripada *Leucaena leucocephala*.** Papan serpai tiga lapis berikatan simen (CBP) yang dihasilkan daripada *Leucaena leucocephala* berusia 8 tahun dan 16 tahun dihasilkan di makmal dan dikaji kesesuaiannya sebagai bahan binaan. Empat nisbah kayu:simen iaitu 1:1.75, 1:2.0, 1:2.25 dan 1:2.5 digunakan. Campuran aluminium sulfat dan natrium silikat digunakan sebagai pencepat penghidratan simen. Serpai kayu yang tidak melepasi tapisan bersaiz 2 mm diguna untuk menghasilkan lapisan teras dan campuran serpai kayu bersaiz 1 mm dan 0.5 mm diguna untuk menghasilkan lapisan luar. Ciri-ciri fizikal dan mekanik papan dinilai berdasarkan MS 544: 2001. Nilai modulus kepecahan berjulat antara 7.68 MPa hingga 11.22 MPa manakala nilai modulus kekenyalan antara 2981 MPa hingga 4002 MPa. Nilai kekuatan ikatan dalaman adalah antara 0.59 MPa hingga 0.90 MPa. Nilai serapan air dan pembengkakan ketebalan setelah sampel direndam selama 24 jam di dalam air masing-masing berjulat antara 12.42% hingga 19.04% dan 0.38% hingga 0.70%. Secara umumnya, CBP yang dihasilkan daripada pokok berusia 8 tahun mempunyai kekuatan mekanik yang lebih baik daripada pokok berusia 16 tahun.

## INTRODUCTION

Cement-bonded particleboard (CBP) is defined as a panel manufactured from wood particles chemically treated and mixed with ordinary Portland cement. It is then compressed and cured in temperature-controlled conditions until the optimum hydration temperature of cement is achieved. The panel is used as internal as well as external partitions either in homes, offices or industrial buildings. The production of CBP in Malaysia began in 1982 with the establishment of Cemboard factory in Chembong, Negeri Sembilan using rubberwood as the wood aggregate (Gan & Rahim 1992).

Cement-bonded particleboard possesses both workability as wood-based panel product and durability as masonry construction material. Ideally, it is a suitable building material with its fast and dry concept for modern construction application. The panel with density approximately 1300 kg $m^{-3}$ is relatively lighter compared with clay and sand block which are widely used in housing and building construction. Moreover, many tropical countries have domestic cement production plants and wood supply, and such panel can be produced in small plants with relatively simple machinery (Pablo et al. 1990). Cement-bonded particleboard incorporating 2.5 to 3.0 parts of Portland cement to 1.0 part of wood particles (by weight) is reported to possess acceptable mechanical and physical properties (Bison-Werke & Greten 1977, Rahim et al. 1995). The advantages of CBP is its high resistance to fire, termites, fungi and other decaying agents, excellent sound attenuation and good weather resistance. It can accept a wide range of surface treatments such as painting, lamination and veneer (Dinwoodie 1983). In fact, this board has excellent workability as it can be sawn, drilled, nailed, sanded, glued and screwed with normal working tools (Rahim 1994).

Petai belalang is the common name for *Leucaena leucocephala*. The tree is fast growing, with density ranging from 600 to 1000 kg $m^{-3}$. The wood is hard and heavy, the sapwood light yellow and the heartwood yellow brown to dark brown (Kumar et al. 1998). It can be used for the manufacture of cement-bonded particleboard as an alternative replacement for rubberwood. Due to the increasing demand for rubberwood, the supply of rubberwood for wood-based industries is expected to be very competitive. This problem will become worse as the area planted with rubber trees in Malaysia was reduced from almost 2.0 million hectares in 1980 to only 1.25 million hectares in 2005 (Anonymous 2007). The wood–cement panel manufacturers need to find alternative wood species to overcome the shortage of rubberwood. *Leucaena leucocephala* is considered as one of the potential alternative raw materials for CBP manufacture.

This paper reports the feasibility of using *L. leucocephala* obtained from the Malaysian Agriculture Research and Development Institute (MARDI) in Kelantan. The trees have been used as shade trees for new plants and a source of food for ruminant animals. In practice, the trees are normally felled and burned or left to decay. At present, there is no commercial application for this tree in spite of its fast-growing traits.

## MATERIALS AND METHODS

### Wood materials

The wood materials used in this study were obtained from 8- and 16-year-old (8Y and 16Y) *L. leucocephala* trees. Ten logs were transported to Universiti Teknologi MARA (UiTM), Jengka, Pahang, Malaysia for the study. The wood was chipped into small wood particles using a drum chipper, followed by a knife ring flaker. The wood particles were screened using a rotary shaker to obtain wood particles retained at 2 mm sieve size as core and, retained at 0.5 and 1 mm sieve sizes as surface materials. The moisture contents of air-dried wood particles were between 15 and 18%.

The chemical composition and bulk density of *L. leucocephala* were measured according to the Technical Association of the Pulp and Paper Industry (TAPPI) Standard (Anonymous 1996). The particle size distribution, length and thickness of particles were determined using a multiple stage screener with different sizes of mesh. The sugar content was analysed using a titration method.

### Ordinary Portland cement

Ordinary Portland cement was used as an inorganic binder with a combination of aluminium sulphate and sodium silicate at 1.5 and 3% respectively (based on cement weight) as cement accelerators. Four ratios of wood to cement were used, i.e. 1:1.75, 1:2.0, 1:2.25 and 1:2.5, based on the air-dried weight of wood particles. The board was produced at dimensions of 450 × 450 × 10 mm at target density of 1300 kg $m^{-3}$. Three replications of cement-bonded particleboards were produced.

### Production of cement-bonded particleboard

The wood particles were placed in a cement mixer and calculated amounts of chemical additives and water were added and thoroughly mixed. An appropriate amount of ordinary Portland cement was added. Mixing continued until uniformity was obtained. The mixture was then manually consolidated in the mould and pressure was applied to the board until 10 mm thickness was achieved. The specific clamping pressure used was at least 25 kg $cm^{-2}$. The boards were clamped for 24 hours and hardened under controlled temperature of 65 ± 3 °C in a hardening chamber. After 24 hours, the pressure was released and the boards were removed from the moulds and then cured in a curing tank with controlled relative humidity of 83 to 96% for about one month to ensure complete hydration of cement. The cured panels were then trimmed and cut into different sizes as prescribed in the Malaysian Standards for bending strength, tensile strength, water absorption and thickness swelling tests. The mechanical and physical properties of the boards were tested in accordance with MS 544 (Anonymous 2001).

## RESULTS AND DISCUSSION

### Chemical composition

*Leucaena leucocephala* had lignin contents of 29 to 34% and holocellulose contents of 81 to 83% (Table 1). The sugar contents were 0.79 and 0.54% in 8Y and 16Y respectively. This is much lower compared with rubberwood (1–1.7%) and oil palm (11–33%) (Azizol & Rahim 1989). The amount of sugar in wood is an important factor to determine the compatibility between the wood species and cement as mineral binder. It is postulated that sugar contents above 0.5 to 0.8% would inhibit cement setting (Simatupang 1985, Weber 1985). However, in cement-bonded particleboard industry in Malaysia, the amount of sugar can be easily reduced through natural storage or soaking in water (Rahim & Wan Asma 1990, Rahim et al. 1995). In this study, the wood particles were air dried for about two weeks to reduce sugar content naturally before the manufacture of CBP.

### Bulk density

Table 2 shows the bulk density of 8Y and 16Y wood particles determined using fine and coarse particles. Fine particles were those retained at 1.0 and 0.5 mm sieve sizes. Coarse particles were those retained at 2.0 mm sieve size. Basically, the bulk density of fine particles was higher than that of coarse particles as there was less void in fine particles. The bulk density of 8Y particles were generally lower than that of 16Y. The value of bulk density in wood is an important factor to explain the compaction ratios of different wood to cement ratios. The compaction ratio is also influenced by wood to cement ratio.

### Particle size analysis

A similar trend of particle size distribution was observed for both ages (Figure 1). Most of the 8Y wood particles were retained at sieve sizes of

**Table 1** Chemical composition of *Leucaena leucocephala*

| Chemical component | Chemical content (%) | |
|---|---|---|
| | 8Y | 16Y |
| Cold water solubles | 5.01 | 2.01 |
| Hot water solubles | 1.65 | 1.42 |
| 1% NaOH solubles | 11.97 | 15.33 |
| Alcohol–benzene extractives | 1.51 | 3.29 |
| Lignin | 29.34 | 33.68 |
| Holocellulose | 83.37 | 81.55 |
| Ash | 0.88 | 0.63 |
| Sugar | 0.79 | 0.54 |

**Table 2** Bulk density of *Leucaena leucocephala*

| Bulk density (g/1000 $cm^3$) | 8Y | | 16Y | |
|---|---|---|---|---|
| | Fine | Coarse | Fine | Coarse |
| Average | 137.5 | 103.7 | 154.1 | 118.2 |

The moisture contents of air-dried wood particles ranged from 15 to 18%.

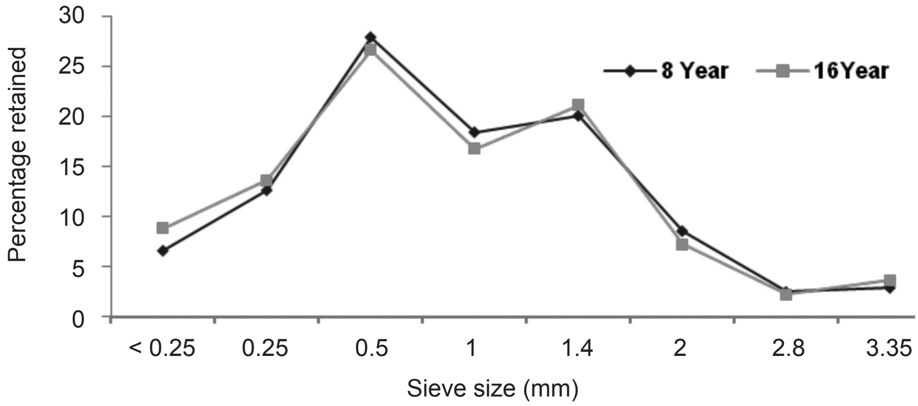


**Figure 1** Particle size distribution of 8- and 16-year-old *Leucaena leucocephala* trees

0.5 to 2.0 mm, which were almost 80% of the total weight. In this study, particle sizes within this range were used in the manufacture of CBP. As for the 16Y wood particles, almost 77% of the total weight was retained at sieve sizes of 0.5 to 2.0 mm. The particles that were retained at 3.35 mm sieve size were fed once again into the flaker to produce smaller particles. The average thickness and length of the flakes, based on at least 100 samples, were found to be 0.4 and 9.4 mm respectively (Table 3).

## Effects of wood to cement ratio on mechanical properties

Modulus of rupture (MOR) ranged from 7.68 to 11.22 MPa (Table 4). Boards manufactured using 8Y had exceptionally higher MOR values compared with 16Y at all wood to cement ratios. The optimum MOR of CBP was observed at higher amounts of wood compared with cement. In fact, the highest MOR value was obtained from 8Y board which was about 25% above the standard requirement in MS 544 (Anonymous 2001). Generally, the MOR of 8Y and 16Y CBP decreases as the proportion of cement increases. In this study, CBP manufactured from 8Y attained maximum MOR at the wood to cement ratio of

**Table 3** The thickness and length of 8Y and 16Y *Leucaena leucocephala* particles after being processed by knife ring flaker

| Age | Mean thickness (mm) | Mean length (mm) |
|---|---|---|
| 8Y | 0.398 | 9.58 |
| 16Y | 0.389 | 9.42 |

1:1.75. A similar trend was observed for boards made from 16Y. Earlier studies reported that the optimum wood to cement ratio was 1:2.5 to produce maximum bending strength of boards (Moslemi & Pfister 1987, Rahim et al. 1995).

In the present investigation, CBP made from lower cement content recorded higher MOR. In CBP manufacture, it is preferable to use cement as little as possible without affecting the physical and mechanical properties of the board. In most cases, higher contents of cement may cause brittleness of CBP and reduce the MOR. During board production and bulk density test, it was observed that 8Y wood particle had lower bulk density than 16Y. Thus, with high wood particles in the mixture, there were greater compaction and elimination of void spaces, resulting in better mechanical properties. As mentioned by Moslemi and Harmel (1988), high contents of cement might cause CBP to be brittle and increase the cost of materials. Lee (1985) also reported that at higher wood to cement ratios, the compaction ratio of mat to board thickness increased, leading to enhanced bending strength. The strength of CBP mostly varies according to particle size, wood species, wood density and type of cement used. At the same wood to cement ratio, 8Y CBP gave higher wood in mixture and compaction ratio, and improved board properties.

The ANOVA results in Table 4 showed that wood to cement ratio had significant effect at 5% level on MOR. However, there was no significant difference in the MORs of 16Y boards within the wood to cement ratios of 1:1.75, 1:2.0 and 1:2.25. Generally, wood to cement ratio of 1:1.75 for 8Y gave optimum mechanical properties of board. This result indicated the possibility of using young trees for better properties.

**Table 4** Mechanical and physical properties of 8Y and 16Y CBP

| W/C | Age | Density (kg m$^{-3}$) | MOR (MPa) | MOE (MPa) | IB (MPa) | TSw (%) | WA (%) |
|---|---|---|---|---|---|---|---|
| 1:1.75 | 8Y | 1246 | 11.22 a | 3453 b | 0.840 ab | 0.672 a | 12.42 c |
| | 16Y | 1263 | 10.21 a | 2941 b | 0.706 c | 0.700 a | 14.00 b |
| 1:2.00 | 8Y | 1267 | 10.47 ab | 3604 b | 0.902 a | 0.668 a | 14.58 b |
| | 16Y | 1273 | 9.40 a | 3524 a | 0.737 c | 0.640 ab | 15.68 a |
| 1:2.25 | 8Y | 1271 | 9.65 bc | 3558 b | 0.790 bc | 0.663 a | 15.50 b |
| | 16Y | 1297 | 9.31 a | 3427 a | 0.702 c | 0.560 b | 16.81 a |
| 1:2.50 | 8Y | 1265 | 8.95 c | 4002 a | 0.729 c | 0.651 a | 19.04 a |
| | 16Y | 1286 | 7.68 b | 3308 ab | 0.593 d | 0.380 c | 15.93 a |
| MS 544: 2001 | | | > 9.0 | > 3000 | > 0.5 | < 2.0 | < 30 |

MOR = Modulus of rupture, WA = water absorption, MOE = modulus of elasticity, TSw = thickness swelling, IB = internal bond, W/C = wood to cement ratio

Values were based on 15 samples. Values followed by the same letter within the column did not differ significantly based on Duncan's multiple range test.

A similar trend was observed for modulus of elasticity (MOE) where board manufactured from 8Y gave higher MOE compared with 16Y (Table 4). However, the MOE increased with increasing cement in mixture due to stronger bonding attributed to cement. The ANOVA results in Table 4 showed that the wood to cement ratio had significant effect on the MOE of the boards for both ages. The MOEs for CBP made using three wood to cement ratios were well above the MS minimum requirement of 3000 MPa. There was no significant effect on MOE for CBPs made from 8Y *L. leucocephala* for wood to cement ratios of 1:1.75 to 1:2.25. Similar findings were observed by Savastano et al. (2000) in which MOE decreased with increasing wood content and the greater the proportion of cement used, the higher the MOE.

The internal bond (IB) of the CBP generally exceeded 0.6 MPa, irrespective of the wood to cement ratio and age (Table 4). This is higher than 0.5 MPa as specified in the Malaysian Standard. The IB values of CBP produced from 8Y were more consistent and higher compared with those of 16Y. This may be related to the structure of the boards whereby the compaction ratio and bulk density were closely dependent on the wood to cement ratio. However, the maximum IB of 8Y and 16Y were observed at wood to cement ratio of 1:2.0. Hence, this result supports the fact that the wood to cement ratio is an important factor influencing the strength properties of CBP. The statistical analysis also showed that the wood to cement ratio had significant effect on IB of the boards.

Obviously, the mixture of 8Y and 16Y and wood to cement ratio of 1:2.0 were the most suitable to produce *L. leucocephala* CBP. However, the properties of CBP made from 1:1.75 to 1:2.25 wood to cement ratio for both ages of *L. leucocephala* were also within the range as stipulated in MS 544. These results show the potential of *L. leucocephala* as wood particles to replace the existing material.

## Effects of wood to cement ratio on physical properties

The physical properties consist of thickness swelling (TSw) and water absorption (WA) after soaking in water for 24 hours. The TSw values ranged from 0.38 to 0.70% and 0.65 to 0.67% for boards produced from 16Y and 8Y respectively. Wood to cement ratio and age were found to have significant effects on the physical properties of the boards. In general, boards containing more cement exhibited lower thickness swelling values and were more stable in dimension than those made from lower cement. The improvement of TSw might be due to the fact that the wood particles were well bonded and protected by the cement matrix when the cement ratio increased. This suggests that boards made from 16Y maintain higher stability in TSw than boards produced from 8Y. Although all the boards sprung back in response to water, the response was lower than 2% as stipulated in MS 544 for all wood to cement ratios and ages. The ANOVA showed that wood to cement ratio had significant effect on TSw for boards made from 16Y wood particles whereas no significant difference was found for 8Y.

The WA values ranged from 12.4 to 19.0% after 24 hours soaking in water (Table 4). Boards with higher cement generally recorded higher WA values. Generally, the WA of boards made from 8Y was lower than the boards from 16Y. However, the WA values for all ratios met the Malaysian Standard requirement. The ANOVA showed that after 24 hours of soaking, WA was significantly different between wood to cement ratio for 8Y and 16Y.

## CONCLUSIONS

The study showed the potential of producing cement-bonded particleboard from *L. leucocephala*. The best strength properties of CBPs were obtained from wood to cement ratio of 1:2.0 for both ages. Boards produced from 8Y showed better mechanical properties whereas 16Y, better resistance in water. Boards with low amount of cement are more economical as cement is more expensive than wood particles.

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