Sains Malaysiana 43(2)(2014): 219–225

Possibility of Improving the Properties of Mahang Wood (*Macaranga* sp.) through Phenolic *Compreg* Technique

(Kemungkinan untuk Meningkatkan Sifat Kayu Mahang (*Macaranga* sp.) melalui Teknik *Compreg* Fenolik)

A.F. ANG, A. ZAIDON*, E.S. BAKAR, S. MOHD HAMAMI, U.M.K. ANWAR & M. JAWAID

ABSTRACT

*Lesser known wood species (LKS) have the potentials to become alternative sources of timber supply for wood based industries if their properties can be improved. In this study, Mahang wood (*Macaranga *sp.) was impregnated 15% (w/v) low molecular weight phenol formaldehyde (LMWPF) followed by compressing in a hot press at 70, 60 and 50% compression ratios (CR). The treated wood was partially dried in an oven at 65°C until 10% moisture content and subsequently followed by curing at 150°*C *for 30 min in a hot press. The results showed that the phenolic* compreg *technique had successfully increased the dimensional stability and mechanical properties of the wood. The polymer retention calculated based on weight gain regardless of compression ratio was approximately 30%. The majority of the properties were improved by the degree of compression in a hot press. Nevertheless, thickness swelling and swelling coefficient increased which were due to spring back effect. As regards to specific strength (strength to density ratio), the* compreg *wood displayed lower strength and stiffness in lateral direction compared with untreated solid wood. However, the specific compressive strength perpendicular to grain and hardness of the* compreg *wood were superior than untreated solid wood. The treatment had also changed the wood into highly resistant to fungal decay.*

Keywords: Compression ratio; Mahang wood; phenol formaldehyde; Pycnoporus sanguineus*; swelling coefficient*

ABSTRAK

Spesies kayu kurang dikenali (LKS) mempunyai potensi untuk dijadikan sebagai bekalan kayu alternatif kepada industri kayu jika sifat mereka yang kurang baik dapat dipertingkatkan. Dalam kajian ini, compreg *Mahang diperbuat dengan pengisitepuan resin fenol formaldehid berat molekul rendah (LMWPF) (15% w/v) diikuti dengan mampatan di bawah haba pada kadar mampatan 70, 60 dan 50%. Kayu yang telah diisitepuan dengan resin dikering sebahagian pada suhu 65°C sehingga mencapai kelembapan 10% kemudian diikuti dengan kering sepenuhnya pada suhu 150°C selama 30 min di bawah penekan haba. Keputusan menunjukkan bahawa teknik* compreg *fenolik telah berjaya meningkatkan kestabilan dimensi dan sifat mekanikal kayu. Retensi polimer dikira berdasarkan peratus berat dapatan tanpa mengambil kira kadar mampatan adalah lebih kurang 30%. Majoriti sifat kayu telah ditingkatkan oleh darjah mampatan di dalam penekan haba. Walau bagaimanapun, peningkatan dalam pembengkakan tebal dan pekali pembengkakan adalah disebabkan oleh kesan pemantulan semula. Berkenaan kekuatan khusus (nisbah kekuatan kepada ketumpatan), kayu* compreg *menunjukkan kekuatan dan kekakuan yang lebih rendah dalam arah sisi berbanding kayu yang tidak dirawat. Walau bagaimanapun, kekuatan khusus bagi mampatan serenjang urat kayu dan kekerasan kayu* compreg *adalah lebih baik daripada kayu yang tidak dirawat. Rawatan ini juga telah mengubah kayu menjadi sangat tahan kepada kerosakan kulat.*

Kata kunci: Fenol formaldehid; kadar mampatan; kayu Mahang; pekali pembengkakan; Pycnoporus sanguineus

INTRODUCTION

The increasing population and well developed wood processing industries were the primary force leads to the continuously growth of the wood products (Abdul Samad et al. 2009). In Malaysia, the declining in supplies of forest resources has become worst after 1995 which causes scarcity of quality logs for wooden products. Consequently, manufacturers are attracted to use low density wood species from plantation such as rubberwood or oil palm wood as an alternative raw materials. Such plantation grown species are usually possessing low strength properties and non durable that limit their final applications. Besides the plantation grown species, there are some wood species in the forests (especially in secondary forests) that are still less concerned by the wood based industries (Yeom 1984).

The lesser known wood species (LKS) such as Mahang, Sesenduk and Terap (mixed light hardwood) that emerged in large quantity in secondary forests could become as potential alternative supply of raw materials for wood based industries. Most of the wood based industries in Malaysia reluctant to use these LKS due to the poor properties of these species. However, the disadvantages of LKS such as dimensional instability, inferior mechanical strength and low durability can be improved by treating the wood whether with or without changing the chemical nature of the wood (Norimoto & Gril 1993). Wood modifications either by bulking, internal coating or croslinking have shown promise in upgrading low quality timbers for potential applications (Ashaari et al. 1990a, 1990b; Islam et al. 2012). A cost effective method to improve the properties of wood involves the deposition of highly crosslinked polymer in cell wall which becomes non-leachable upon air drying. Impregnation of low molecular weight phenol formaldehyde (LMWPF) compound in the wood followed by compressed under heat (*compreg*) can improve the dimensional stability, mechanical strength and durability of the treated material (Furuno et al. 2004; Rowell & Konkol 1987; Shams et al. 2006).

In the present study, physical and mechanical properties and decay resistance of *compreg* Mahang wood against white rot fungi were assessed. Although the treatment may slightly increase the cost of processing but it could be reduced by monitoring the concentration of chemicals used with the development of optimum treatment method. Furthermore, the improved quality of the material may also offset the cost of processing. Hence, the possibility of treating these underutilized timber species is worth of investigation. Improvement in the properties of treated LKS will contribute to potential utilization of Mahang wood as new raw material to substitutes the traditional timber species for manufacturing of value added products such as flooring, paneling and furniture components.

MATERIALS AND METHODS

MATERIALS

Mahang *(Macaranga* sp.) wood was obtained from the Forest Research Institute, Malaysia. The treating solution used was phenol formaldehyde (PF, Mw 600) solution. The resin was obtained from the Malaysian Adhesives & Chemicals Sdn. Bhd., Malaysia with original concentration of 45%. The resin was further diluted to 15% w/v.

VACUUM-PRESSURE TREATMENT

Air dry wood was flat sawn into samples with the width is the tangential surface. Three groups of sample with different thicknesses were prepared. The first group comprised of samples with dimension 15 × 50 × 150 mm^3, the second group, 17 × 50 × 150 mm^3 and the third group 20 × 50 × 150 mm^3. Initial dimension, moisture content (MC) and density of each sample were determined. The impregnation process was carried out using vacuum-pressure method under 85 kPa vacuum for 15 min, followed by filling resin solution (15% w/v) and applying external pressure of 690 kPa for 30 min. Preliminary work showed that a duration of 30 min is sufficient to give a maximum resin loading in the treated samples. After impregnation, the samples were taken out and then wiped with cloth to remove excessive resin. The treated samples were then pre-cured at 65ºC in an oven until the treated samples attained MC of 10%. This took approximately 54 h. After pre-curing process, they were hot pressed at 150ºC for 30 min (Zaidon 2009) to a final thickness of 10 mm. The final (T_f) and initial thickness (T_i) of the samples determined the compression ratio (CR) of the *compreg* (1):

$$\text{CR}\ (\%) = 100\ (T_f / T_i). \tag{1}$$

After hot pressing, the weight of each sample was recorded to determine the resin WPG (2):

$$\text{WPG}\ (\%) = 100\ ((W_f - W_o) / W_o), \tag{2}$$

where, W_f is the final weight of treated wood (g) and W_o is the oven dried weight of untreated wood (g).

All samples were then conditioned in a conditioning room at RH 65±2% and temperature 25±2°C until constant weight.

DIMENSIONAL STABILITY

Dimensional stabilization was quantified by comparing the volumetric swelling coefficients and water absorption of treated and control specimens. Antiswelling efficiency (ASE) and reduction in water absorption (*R*) of treated samples were determined by soaking methods. The swelling process were done through 30 min vacuum followed by soaking in distilled water for 24 h (Ashaari et al. 1990a*)*. The moisture excluding efficiency (MEE) was determined by exposing in water vapour at 97% relative humidity. In this case, the exposure time was taken to be completed when the weight of the exposed samples reached constant (Rowell & Youngs 1981). For this test, oven-dried wafers measuring 20 × 20 mm^2 in cross sections and 10 mm were used. The weight and volume of samples before and after swelling process were measured. The swelling coefficient (*S*), thickness swelling TS, reduction in water absorption (*R*) and moisture excluding efficiency (MEE) were calculated using (3-6), respectively.

$$S\ (\%) = ((V_f - V_o)/V_o)) \times 100, \tag{3}$$

where, V_t is volume after soaking in water, % and V_o is volume oven-dry wood, %.

$$R\ (\%) = ((W_t - W_c) / W_c)) \times 100, \tag{4}$$

where, W_t is weight gain in treated wood due to water pickup after 24 h, % and W_c is weight gain in untreated wood under the same condition, %.

$$\text{TS}\ (\%) = [(T_f - T_o) / T_o)] \times 100, \tag{5}$$

where, T_f is thickness of wood after soaking in water, mm, and T_o is thickness of oven dried treated wood, mm.

$$\text{MEE}\ (\%) = 100\ (W_2 - W_1) / W_2, \tag{6}$$

FIGURE 1. Longitudinal section of *compreg* Mahang taken near the surface of sample. The resin solid content (arrow) was deposited in the cell lumens

where, W_1 is the weight gain in treated wood due to moisture pickup at 25°C, 97% RH for 7 day (g) and W_2 is the weight gain in untreated wood under the same conditions (g).

MECHANICAL PROPERTIES

Static bending, compression perpendicular to grain and hardness tests was performed according to the procedure specified in British Standard BS 373: 1957 (BSI 1957) with a modification of the specimen size. The specimen size for static bending, compression perpendicular to grain and hardness tests was 10 mm thick, 20 mm wide and 250 mm long; 10 mm thick, 20 mm wide and 20 mm long; and 10 mm thick × 40 mm wide × 60 mm long, respectively. Static bending specimens were tested under a static load with the crosshead speed of 5 mm/min. The test was carried out on 50 kN universal testing machine. Load deflection curves were recorded. Mechanical properties calculated from the load deflection curves included modulus of rapture (MOR) and modulus of elasticity (MOE). For compression perpendicular to grain test, the crosshead speed of this test was 0.5 mm/min. The properties computed were compressive stress at proportional limit (CSPL) and compressive stress at compression of 2.50 mm (CSmax). Janka indentation test was carried out for hardness. It was carried out by probing 11.3 mm diameter sphere onto the wide surface of the specimens. Load at which the ball had penetrated to one half its diameter was recorded.

DECAY RESISTANCE AGAINST WHITE ROT FUNGUS

The test on durability of treated and untreated Mahang wood against fungus was carried out in the laboratory by using the method specified in the American Standard of Testing Material (ASTM D2017-71) (ASTM 1972). Sample blocks were exposed to the white rot for 12 weeks and the weight loss (*WL*) was determined using (7). Untreated solid wood was used as control.

$$WL\ (\%) = 100\ ((W_o - W_c)\ /\ W_o), \qquad (7)$$

where, W_o is the weight of conditioned blocks before test (g) and W_c is the weight of conditioned blocks after test (g).

STATISTICAL ANALYSIS

Statistical analyses were performed on physical and mechanical property values to detect any changes in the treated material compared with untreated group. A complete randomized design with 4 levels of treatment and untreated was conducted where the treatment means were separated by using Tukey at $p< 0.05$.

RESULTS AND DISCUSSION

PHYSICAL PROPERTIES OF *COMPREG* MAHANG WOOD

Table 1 shows that the resin WPGs of treated wood were 27.2, 31.31 and 29.31%, respectively, for treated wood with 70, 60 and 50% CR. Generally, the density of treated wood increased markedly compared with the control group (Table 1). The density was 89-139% greater than untreated wood. The statistical analysis, however, showed that the WPG did not differ significantly among the compressed wood. The improvement in density was due to the densification caused by the compression. Figure 1 shows the distribution of resin in the wood structure. Almost all the lumens of ray and axial parenchyma cells were filled with resin. As shown in Figure 2, densification was evident by the deformations of cells which can be observed in cross section of the treated wood.

When immersed in water, the swelling coefficient of the *compreg* (8.05~9.01%) was slightly lower than untreated wood (9.55%) showing that some of the resin had penetrated and bulked the cell wall thus restraint the cell wall from further swollen. Rowell and Youngs (1981) revealed that compregnation process can reduce 80-90% swelling coefficient of the treated products. However this treatment is shown to be only effective for veneer type of treated sample instead of sawn solid wood. The discrepancy could be attributed to the tendency of the compressed sawn solid wood sample to spring back upon soaking in water. Rabiatol Adawiah et al. (2012) and Zaidon et al. (2010) found that spring back occurred even when wood strip was treated with higher concentration of phenol formaldehyde and the degree of compression significantly affect the spring back. The results of the TS reflects this phenomenon (Table 1). The incomplete penetration of the resin into the inner part of the wood may aggravate the circumstance. Figure 3 shows that the resin was concentrated only at the surface layer of the samples thus as a result it would only give limited effect on the dimensional stability.

The compregnation process had successfully increased the moisture excluding efficiency (MEE) (15.4 ~ 27.85%) when exposed to water vapour and the degree of efficiency increased with CR. Nevertheless, when subjected to soaking, the reduction in water absorption (R) for the treated wood increased from 67.54 to 71.63%. The statistical analyses showed that R was not affected by the CR. The results indicated that the polymer were also distributed in the cell lumens (Figure 1) and formed an internal coating to the treated wood. Lower MEE value attained by the treated wood compared to R value was probably attributed to the longer time of exposure to the water vapour. It was anticipated that water vapour slowly diffused into the wood through area which was not coated by the polymer.

MECHANICAL PROPERTIES OF *COMPREG* MAHANG WOOD

Table 2 summarises the mean mechanical properties of *compreg* Mahang wood and percent change in properties over untreated wood. The results showed that all properties tested for *compreg* Mahang wood were significantly higher compared with untreated wood indicating that the compregnation process had successfully enhanced the properties of Mahang wood. The static bending MOR was improved from 22 to 59% with the values ranged from 69.70 to 90.85 Nmm^{-2} compared with untreated MOR value of 57.27 Nmm^{-2}. The MOE (stiffness) of treated Mahang wood increased from 38 to 78% from its original stiffness of 6540 Nmm^{-2}. High percent change in compressive stresses were recorded for *compreg* Mahang wood over untreated wood samples with compressive stress at proportional limit (CSPL) values increased from 240 to 334% and maximum compressive stress (CS) values from 165 to 307% from its original values

TABLE 1. Physical properties of *compreg* Mahang wood

Physical properties	Compression ratio (%)			
	Untreated	70	60	50
WPG (%)	-	$27.2^{A1}\pm5.13$	$31.31^{A}\pm6.05$	$29.31^{A}\pm4.90$
Density (kgm^{-3})	$288^{C}\pm38.55$	$543^{B}\pm55.68$	$634^{A}\pm47.63$	$688^{A}\pm49.17$
S (%)	$9.55^{A}\pm0.74$	$8.05^{B}\pm0.99$	$8.86^{A}\pm2.01$	$9.01^{A}\pm1.81$
TS (%)	$3.16^{C}\pm0.51$	$6.03^{B}\pm0.73$	$7.07^{A}\pm1.84$	$6.88^{A}\pm1.48$
MEE (%)	-	$15.48^{B}\pm5.06$	$20.68^{A}\pm9.26$	$27.85^{A}\pm5.11$
(R, %)	-	$67.54^{A}\pm4.85$	$71.59^{A}\pm2.27$	$71.63^{A}\pm2.3$

[1] Means within rows followed by the same letter are not significant difference at $p > 0.05$

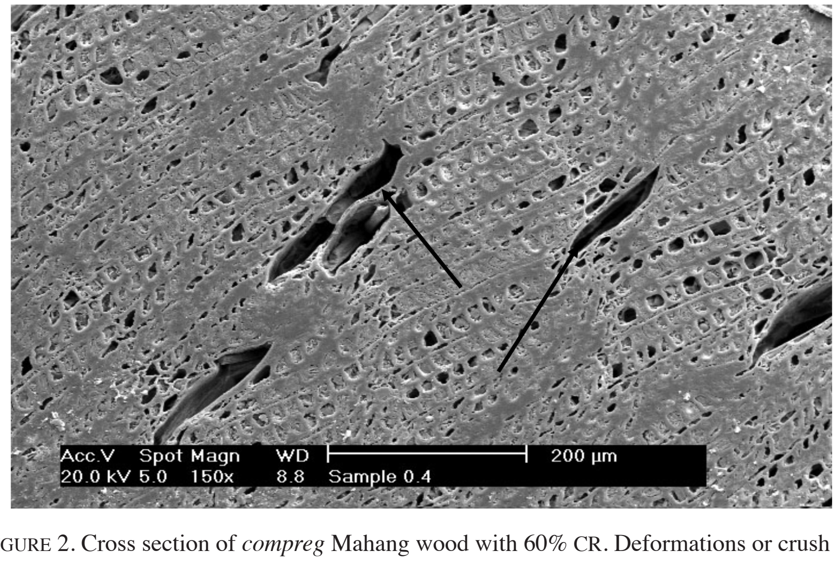

FIGURE 2. Cross section of *compreg* Mahang wood with 60% CR. Deformations or crush of cells in cross section of treated wood. Vessels or pores show conspicuous deformations

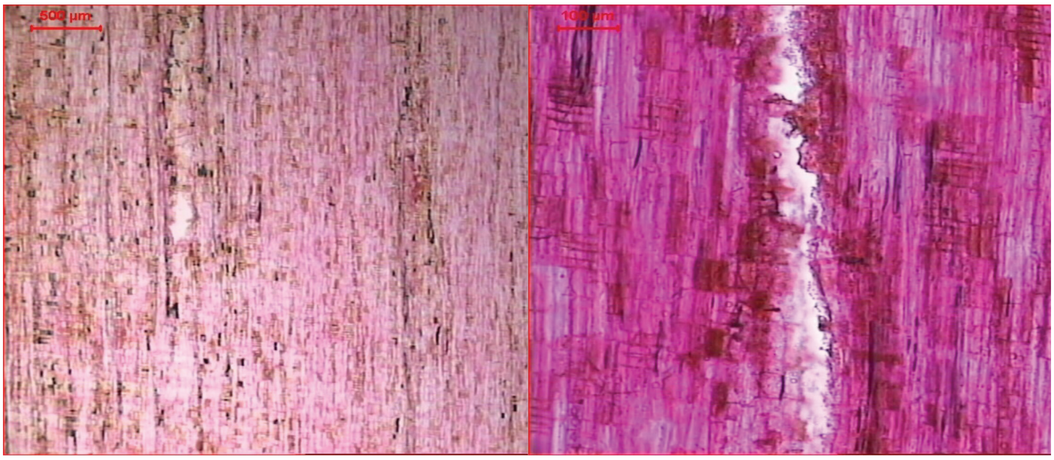

FIGURE 3. Longitudinal section of *compreg* Mahang wood taken from near the surface (left) from the central part of the treated sample (right). Weaker colour of safranine shows that the resin block the staining of the cells and stronger colour of safranine shows that the cells are well stained indicating that there is no resin presence

TABLE 2. Mechanical properties of *compreg* Mahang wood and percent change in properties over untreated solid wood

Mechanical properties		Compression ratios (%)		
	Untreated	70	60	50
MOR (Nmm^{-2})	57.27^{C}±4.5	69.70^{B1}±6.24	83.32^{AB}±14.0	90.85^{A}±16.3
% Change		22	45	59
MOE (Nmm^{-2})	6540^{C}±740	9013^{B}±107	11614^{A}±909	10462^{A}±737
% Change		38	78	60
CSPL (Nmm^{-2})	2.8^{B}±0.53	9.53^{A}±1.77	10.7^{A}±1.9	12.14^{A}±2.14
% Change		240	282	334
CSmax (Nmm^{-2})	5.65^{C}±1.0	14.96^{B}±2.73	19.35^{AB}±3.72	23.01^{A}±2.89
% Change		165	242	307
Hardness (kN)	1.25^{C}±0.21	2.1^{B}±0.69	2.72^{B}±1.0	4.58^{A}±1.89
% Change		68	118	266

[1] Means within rows followed by the same letter are not significant difference at $p > 0.05$
% change = percent changes in properties

of 2.8 and 5.65 Nmm^{-2}, respectively. The treatment process also improved the hardness of Mahang wood from 68 to 266% from 1.25 to 2.1~4.58 kN.

The results also showed that the degree of compression significantly affect MOR, MOE and hardness of the *compreg* Mahang wood. As a whole, it was found that the higher the compression process applied (lower CR), the higher the properties gained. This phenomenon was very much attributed to the increment of density (Table 1) due to the densification process (Rabiatol Adawiah et al. 2012; Shams et al. 2004; Welzbacher et al. 2005). The higher compression caused the void volume in the treated wood decreased to a much greater extent than those treated wood applied with low compression thus resulting in increase in density and at the same time the treated wood become more rigid and harden. However, for compressive stress values, the CR used in this study did not affect the properties.

It is also interesting to note that the increase in density of *compreg* Mahang wood yields only a slight increase in strength (MOR) and stiffness (MOE) in static bending. This is shown by the specific strength (i.e. ratio of mechanical value to density) values of *compreg* wood at different CRs and control (Table 3). The specific MOR and MOE values for *compreg* wood were 0.13 N m^{3}/kg mm^{-2} and between 15.21 and 18.32 N m^{3}/kg mm^{-2}, respectively. These values were lower compared with untreated wood, i.e. specific MOR, 0.20 N m^{3}/kg mm^{-2} and specific MOE 22.71 N m^{3}/kg mm^{-2}. Apparently the presence of PF polymer in the wood had changed the characteristics of the wood into plastic-like material (Kultikova 1999). However, the specific compressive stress perpendicular to the grain of treated wood was much higher than those of untreated. The specific CSPL values for *compreg* wood (0.017-0.018 N m^{3}/kg mm^{-2}) were approximately double than that of untreated wood (0.010 N m^{3}/kg mm^{-2}). The same goes to specific compressive stress at compression of 2.50 mm (CSmax). The treated wood (0.028-0.033 Nmm^{-2}/kgm^{-3}) had higher values compared with untreated (0.020 Nmm^{-2}/kgm^{-3}) wood and the values were slightly increased with the degree of compression. For hardness, the specific values of *compreg* wood was almost similar to the untreated but higher specific MOR was found for treated wood which was highly compressed (CR = 50%).

RESISTANCE OF *COMPREG* WOOD TOWARDS FUNGAL DECAY

The weight loss of *compreg* and untreated Mahang wood after 12 weeks of exposure to *P. sanguineus* is shown in Table 4. There was no weight loss in the treated wood as opposed to 17.51% for untreated wood. Figure 4 shows the colonization of the fungus on treated and untreated wood. The untreated wood was colonized by the fungus and the entire test block was covered by mycelium while no mycelium was observed on the surface of treated test block. The results showed that that phenolic *compreg* technique had successfully increased the resistance of Mahang wood to fungal decay by 100%.

CONCLUSION

The phenolic *compreg* treatment with 15% low molecular weight phenol formaldehyde had successfully increased the dimensional stability and mechanical properties of *Macaranga* wood. The polymer retention calculated based on weight gain regardless of compression ratio was approximately 30%. Majority of the properties were improved by the degree of compression in a hot press. Nevertheless, thickness swelling and swelling coefficient increased which was due to spring back effect. As regards to specific strength (strength to density ratio), the *compreg* wood displayed lower strength and stiffness in lateral direction compared with untreated wood. However, the specific compressive strength perpendicular to grain and hardness of the *compreg* wood were higher. The treatment had also changed the wood into highly resistant to fungal decay. We attributed that the developed *compreg* Mahang

TABLE 3. Specific strength of *compreg* mahang wood compared with untreated solid wood

CR	Density (kg/m^3)	MOR ($N\ m^3/kg\ mm^{-2}$)	MOE ($N\ m^3/kg\ mm^{-2}$)	CSPL ($N\ m^3/kg\ mm^{-2}$)	CSmax ($N\ m^3/kg\ mm^{-2}$)	Hardness ($N\ m^3/kg$)
Untreated	288	0.20	22.71	0.010	0.020	4.34
70	543	0.13	16.60	0.018	0.028	3.87
60	634	0.13	18.32	0.017	0.031	4.29
50	688	0.13	15.21	0.018	0.033	6.66

TABLE 4. Weight loss of *compreg* Mahang wood after exposure to *P. sanguineus* for 12 weeks

	Treatments			
	Untreated	70	60	50
Weight loss (%)	17.51±3.31	0.0±0.0	0.0±0.0	0.0±0.0

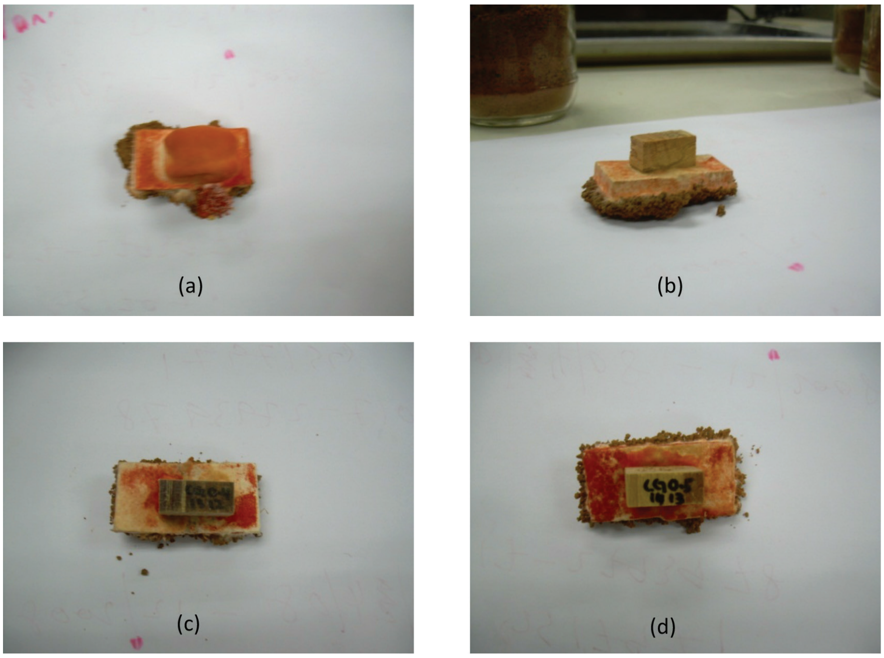

FIGURE 4. View of test blocks of *compreg* Mahang wood after 12 weeks exposure to *P. sanguineus* (a) untreated, (b) *compreg* with 70% CR, (c) *compreg* with 60% CR and (d) *compreg* with 50% CR

wood finds utilization in different applications such as parquet flooring, paneling and furniture components.

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A.F. Ang, A. Zaidon*, E.S. Bakar & S. Mohd Hamami
Faculty of Forestry
Universiti Putra Malaysia
43400 Serdang, Selangor D.E.
Malaysia

U.M.K. Anwar
Forest Research Institute Malaysia
52109 Kepong, Selangor D.E.
Malaysia

M. Jawaid
Institute of Tropical Forestry and Forest Products
Universiti Putra Malaysia
43400 Serdang, Selangor D.E.
Malaysia

*Corresponding author; email: zaidon@putra.upm.edu.my

Received: 2 January 2013
Accepted: 17 May 2013