Effects of Extended Heating Time and Post-urea Treatment on Formaldehyde Emission and Properties of Phenolic *Compreg* Rubberwood

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ABSTRACT

Effects of post-urea treatment and extended heating time after compregnation on the formaldehyde emission and properties of rubberwood were investigated in this work. Rubberwood strips having nominal dimensions of 150 mm x 50 mm x 5 mm were compregnated with medium molecular weight phenol formaldehyde (MmwPF, mw 2,000) and low molecular weight phenol formaldehyde (LmwPF, mw 600), respectively. Compregnated rubberwood were then soaked in urea solutions in different concentrations of 10%, 20% and 40%, respectively, for 1 minute. Extended heating times of 0, 12, and 24 hours under $100 \pm 2°C$ were applied to another set of rubberwood compregnated with LmwPF. Properties such as formaldehyde emission, mechanical and physical properties were also tested. Results showed that the post-urea treatment and extended heating time reduced the formaldehyde emission of the compregnated rubberwood. However, mechanical strength of compregnated rubberwood was not significantly affected by both the treatments. Improvements in water absorption (WA) and thickness swelling (TS) of compregnated rubberwood were observed when the heating time was lengthened. Nevertheless, the formaldehyde emission obtained is still far beyond the standard threshold limit of 0.16 – 2.0 mg/l. Thus, further study has to be conducted by lengthening the heating time and increasing the concentration of urea solution.

Keywords: Compreg, extended heating time, formaldehyde emission, phenol formaldehyde resin, post-urea treatment, rubberwood

INTRODUCTION

The potential of rubberwood as a source of timber has long been recognised in Malaysia. As an alternative timber species, the wood of this tree is marketed for a wide variety of end products such as furniture, flooring, wood based panels and indoor building components (Killmann & Hong, 2000; Lee *et al.,* 2014; Lee *et al.,* 2015). However, owing to its high starch content, the major problem in rubberwood utilisation is its low durability against insect and fungal attack (Khurshid, 2005). Rubberwood is naturally high in moisture and has a high tendency to warp when in use. In other words, its dimensional stability is poor. In relation to the matter mentioned, a number of studies called bulking treatment with phenol formaldehyde (PF) resin have been carried out to improve the dimensional stability, mechanical strength and durability of the wood. Impregnation with PF, followed by compressing at high temperatures, has been proven to be effective in enhancing the properties of the treated wood (Rabi'atol Adawiah *et al.,* 2012). The success of this treatment is dependent upon the molecular weight of PF resin, compressing ratio, pre-curing time, as well as the thickness of wood (Zaidon *et al.,* 2010).

Impregnation of rubberwood with low molecular weight phenol formaldehyde (LmwPF) resin through the *compreg* method can practically solve the imperfections of rubberwood. Nevertheless, the treatment of rubberwood with LmwPF leads to emission of considerable amount of formaldehyde from the products (Amarullah *et al.,* 2010).

Numerous studies have been done to reduce the emission of formaldehyde from wood-based products. One of the methods that can be used is to mix the treating solution with formaldehyde scavenger, such as urea, ammonium phosphate, potassium sulphite and sodium thiosulphate, to capture the free formaldehyde (Roffael, 1993). Urea, in particular, is preferred due to its low cost (Zaidon, 2009).

Urea has been incorporated into resin by various researchers with the effort to reduce formaldehyde emission of the wood-based products (Nur Izreen *et al.,* 2011; Purba *et al.,* 2014) and the results are encouraging. However, the addition of urea was found to have decreased the curing rate of PF resin. LmwPF has slower curing rate compared to amino-type resins and even medium molecular weight phenol formaldehyde (MmwPF) resin due to the presence of a greater amount of shorter chain oligomers in the system (He & Riedl, 2003). In this case, a post treatment is encouraged to reduce formaldehyde although there are limited literature reviews available on the effects of the post treatment. There are actually many advantages of post treatment. One of the notable advantages is the flexibility of using dosage that does not interfere with the curing system of the resin (Lum *et al.,* 2014). In another study, Amarullah *et al.* (2010) found that formaldehyde emission could be further reduced by extending curing time.

This paper reports on the effects of extended heating and post-urea treatment on formaldehyde emission, and the physical

and mechanical properties of rubberwood treated with low and medium weight phenolic resin.

MATERIALS AND METHODS

Preparation of Materials

Fresh and defect-free rubberwood (*Hevea brasiliensis*) obtained from Forest Research Institute Malaysia (FRIM) located in Kepong was used in this study. Rubberwood was cut into wood strips in a nominal dimension of 150 mm long x 50 mm wide x 5 mm thick. The cut samples were conditioned in a conditioning room at 25 ± 2°C and 65 ± 2% RH prior to impregnation process. Low molecular weight phenol formaldehyde (LmwPF, molecular weight of 600) and medium molecular weight phenol formaldehyde (MmwPF, molecular weight of 2,000) resins with solid content of 45% were used as the treating solutions in this study. Both phenol formaldehyde resins were specially synthesised at Malayan Adhesives and Chemical (MAC) Sdn. Bhd., Shah Alam. Urea in the form of granules, which was obtained from MAC, was incorporated into the resin and soaking agent to act as formaldehyde scavenger.

Impregnation and Compregnation Processes

For the impregnation process, the pre-weighed samples were first vacuumed at 689 kPa for 15 minutes. The samples were then left soaked in the solution for 30 minutes under atmospheric pressure. After the process was completed, the treated samples were taken out and blotted with paper towel to remove any excessive resin from the surface. The treated samples were then pre-cured in an oven at 65 ± 2°C for 6 hours. Subsequently after curing, the samples were compressed in a hot press at 150°C for 20 minutes at 80% compression ratio (CR). A set of 4 mm stopper bars were used to control the final thickness. The compression ratio was calculated using Equation 1:

$$CR\ (\%) = 100\ (T_f / T_i) \qquad [1]$$

where T_f = final thickness after compress (mm) and T_i = initial thickness (mm).

The *compreg* samples were then conditioned in a conditioning room at 25 ± 2°C and 65 ± 2% RH until a constant weight was achieved.

Extended Heating Time and Post-urea Treatment

Three treatments were involved in this study. The experimental design of the study is shown in Table 1. Treatment 1 (T1) involved impregnation with admixture of LmwPF resin + 10% urea (based on solid PF) and upon compression, the product (which is also known as *compreg*) was further heated in an oven. The extended heating time study was adopted and modified from the study by Amarullah *et al.* (2010) who heated the samples in an oven at a maintained temperature of 103 ± 2°C for different periods of 0 hour, 24 hours and 48 hours, respectively. Owing to the concern that prolonged heating at high temperatures may destroy the plasticising effect of the urea and PF (Forest Products Laboratory, 1943), shorter heating times were used in this study, namely 0 hour, 12 hours and 24 hours,

respectively. Ten percent urea admixed with 20%, 25% and 30% LmwPF, respectively, were prepared and used as treating solutions. After the impregnation process, the wood samples were further heated in an oven at a temperature of 103 ± 2ºC for durations of 0 hour, 12 hours and 24 hours, respectively, prior to the compregnation process. The *compreg* samples were then conditioned in a conditioning room at 25 ± 2°C and 65 ± 2% RH until a constant weight was achieved.

For Treatment 2 and Treatment 3 (see Table 1), the samples were impregnated with different concentrations of LmwPF and MmwPF, respectively, and the impregnated wood samples were soaked in the urea solution prior to the compregnation process. LmwPF, with concentrations of 20%, 25% and 30%, were prepared and used as treating solutions. The wood samples were impregnated with the treating solution separately using the vacuum pressure process as described in the above section. After impregnation, the wood samples were soaked in 10%, 20% and 40% urea (based on solid PF), respectively, for 1 minute,

followed by hot stacking at 125°C for 20 minutes. The urea concentrations used in this study were modified from an earlier study by Zaidon (2009) in order to reduce the formaldehyde emission of the treated wood. The final weight of each soaked sample was determined and this value was used to calculate urea spread (US) (Equation 2). The untreated samples were used for comparison purposes.

$$US\ (g/m^2)\ =\ [(W_f - W_i) \times C] / A \qquad [2]$$

where W_f = weight after hot stacking (g), W_i = weight after hot pressing before soaking (g), C = concentration of urea (%) and A = Total surface area of samples (m^2).

The soaked samples were then pre-cured in an oven at 65 ± 2°C for 6 hours prior to compregnation process. The same procedures were repeated for the wood samples treated using MmwPF at the concentrations of 10%, 15% and 20%, respectively. All of the *compreg* samples were conditioned in a conditioning room at 25 ± 2°C and 65 ± 2% RH until a constant weight was achieved.

TABLE 1
Experimental design of the study

Treatment	Treatment process	PF conc. (%)	Urea conc. (%)	heating time (h)
T1	Treatment with admixture of LmwPF and 10% urea, followed by extended heating in oven at 100°C	20, 25 and 30	-	0, 12 and 24
T2	Treatment with LmwPF, followed by soaking in urea solution	20, 25 and 30	10, 20 and 40	-
T3	Treatment with MmwPF, followed by soaking in urea solution	10, 15 and 20	10, 20 and 40	-

* PF = phenol formaldehyde; LmwPF = low molecular weight phenol formaldehyde; MmwPF = medium molecular weight phenol formaldehyde

Formaldehyde Emission Test

Formaldehyde emission of the treated samples was conducted in accordance with Malaysian Standards (MS 2005). A calibration curve was first produced from a standard formaldehyde solution by iodometric titration. Wood samples with a total surface area of approximately 1,800 cm^2 were placed in a desiccator having 300 ml of distilled water. The wood samples were kept in the desiccator for 24 hours at ambient temperature. The background formaldehyde was prepared using a desiccator containing no test samples. Formaldehyde absorbance in water was measured photometrically at 412nm wavelength. The concentration of formaldehyde was determined using the following equation:

$$G = f \times (A_d - A_b) \times 1800/S \quad [3]$$

Where G= concentration of formaldehyde due to test samples (mg/L), A_d = absorbance of the solution from the desiccator containing the test samples, A_b = absorbance of the background formaldehyde solution, f = slope of the calibration curve for the standard formaldehyde solution and S = surface area of the test samples (cm^2).

Evaluation of Mechanical Properties

The modulus of rupture (MOR) and modulus of elasticity (MOE) in static bending were tested according to the British Standard BS 373:1957 (BSI 1957), with a modification of the sample size. The test samples (150 mm long x 50 mm wide x 5 mm thickness) were cut from the *compreg* products and untreated rubberwood. Static bending was tested at a loading rate of 0.50 mm/min using universal testing machine (Instron 50 kN). The MOR and MOE were calculated using Equations 4 and 5, respectively.

$$MOE \ (Nmm^{-2}) = 3P_mL^3/2wh^2 \quad [4]$$

$$MOR \ (Nmm^{-2}) = P_1L^3/4Dwh^3 \quad [5]$$

where P_m = maximum breaking load (N), P_1 = load at proportional limit (N), L = span of the test samples (mm), D = deflection at mid-span resulting from P_1 (mm), w = width of the test samples (mm) and h = height of the test samples (mm).

Evaluation of Physical Properties

Five samples with the nominal size of 20 mm wide and 20 mm long and 4 mm thickness were cut from the *compreg* and untreated rubberwood. The thickness and weight of the samples were measured before submerging them in distilled water. The beaker with the content was vacuumed in a vacuum-pressure apparatus for 15 minutes. They were left soaked in the water under atmospheric pressure for 24 hours. Upon completion of the test, the test samples were taken out and blotted with paper, while the final thickness and weight were measured again. Thickness swelling (TS) and water absorption (WA) of the samples were then calculated using Equations 6 and 7, respectively.

$$TS \ (\%) = 100 \ [(T_2-T_1) / T_1] \quad [6]$$

$$WA \ (\%) = 100 \ [(W_2-W_1) / W_1] \quad [7]$$

where T_1 = thickness of the samples before immersing in water (mm), T_2 = thickness of the samples after immersing in water

(mm), W_1 = weight of the samples before immersing in water (mm) and W_2 = weight of the samples after immersing in water (mm).

Statistical Analysis

The data were analysed statistically to verify the significance of the variables in this study. The data were analysed using the analysis of variance (ANOVA) at 95% confident level ($P \leq 0.05$). Tukey's honest significant difference tests were then used to further determine the significant level of the average values for each treatment.

RESULTS AND DISCUSSION

Weight Percent Gain (WPG)

Fig.1 to Fig.3 show the WPG of the rubberwood treated using different treatments. From the results presented in Fig.1 and Fig.2, it was observed that with lower molecular weight, the WPG of the phenolic treated rubberwood increased. Meanwhile, the rubberwood treated with LmwPF showed the highest WPG (28.57%). Shams and Yano (2011) concluded that the short chain and lower viscosity of LmwPF attributed to the achievement of the highest WPG. LmwPF could easily penetrate the parenchyma cells compared to MmwPF. Johnson and Kamke (1994) also reported that the resin penetration behaviour is significantly influenced by the molar masses of polymers present in the resin. Hence, with the same solid content, resin with higher molar masses has higher value of mass per amount of substance and generally higher viscosity but lower wettability. These attributes will lead to poor penetration into wood surface compared to resin with lower molar masses (Nor Hafizah *et al.,* 2012).
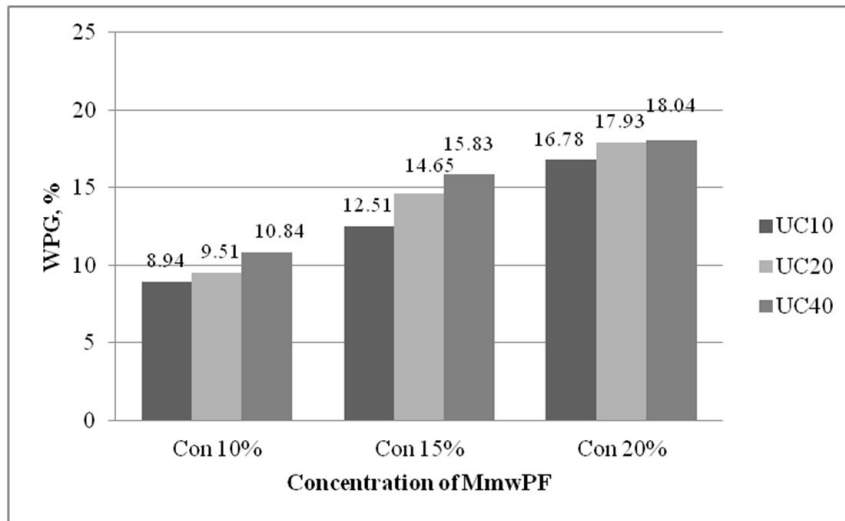
*UC10 = urea concentration of 10%; UC 20 = urea concentration of 20%; UC 40 = urea concentration of 40%

Fig.1 Weight percentage gain (WPG) of the medium molecular weight phenol formaldehyde (MmwPF) *compreg* rubberwood after the post-urea treatments.
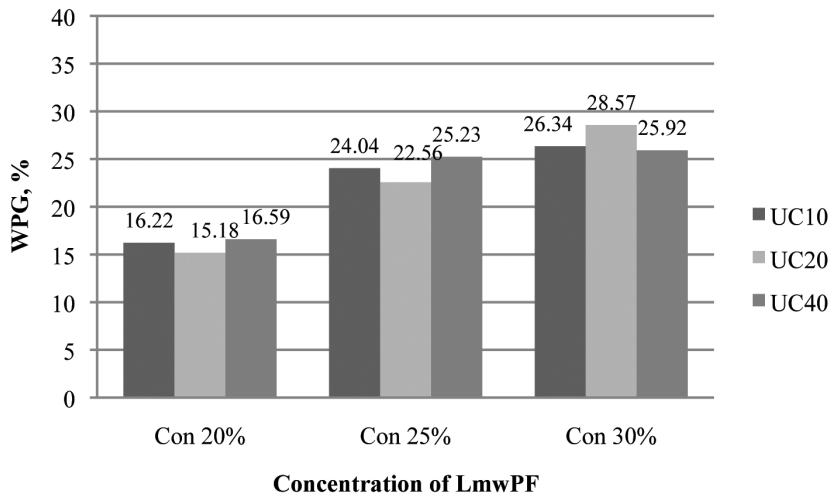
*UC10 = urea concentration of 10%; UC 20 = urea concentration of 20%; UC 40 = urea concentration of 40%

Fig.2 Weight percentage gain (WPG) of the low molecular weight phenol formaldehyde (LmwPF) *compreg* rubberwood after the post-urea treatments
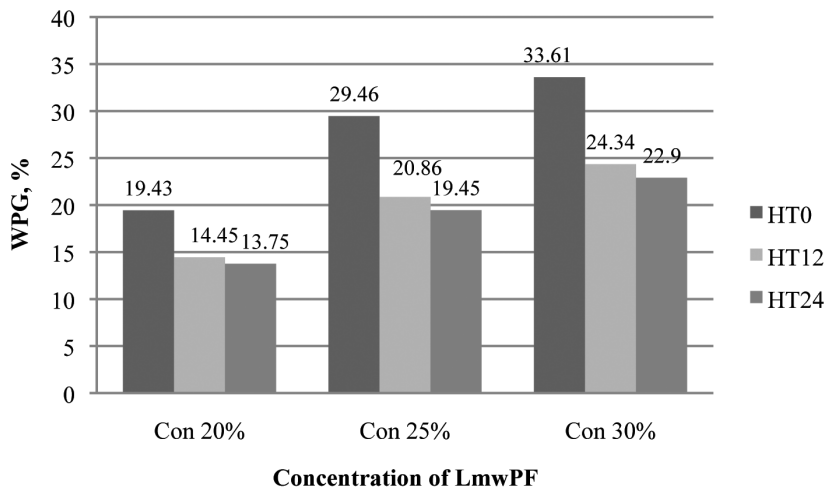
*HT0 = heating time of 0 hour; HT12 = heating time of 12 hours; HT24 = heating time of 24 hours

Fig.3 Weight percentage gain (WPG) of the low molecular weight phenol formaldehyde (LmwPF) *compreg* rubberwood at different extended heating times

On the other hand, the rubberwood treated with LmwPF followed by extended heating period was recorded to have slightly lower WPG than the rubberwood treated with LmwPF without extended heating time (Fig.3). This might be due to the loss of the moisture of resin through vaporisation before it was fully cured.

Effects of the Post Treatment on Formaldehyde Emission

Calibration curve from iodometric titration is illustrated in Fig.4. This graph has estimated slope which was used in determining formaldehyde emission of the samples. The slope obtained was $8.351x - 0.126$ with $r^2 = 0.999$. Fig.5 to Fig.7 show the formaldehyde emission of the rubberwood treated using different treatments. The formaldehyde emission of the samples was significantly reduced by incorporating urea in phenol formaldehyde, followed by extended heating of the *compreg* wood (Fig.5). Formaldehyde emission of the samples treated with 30% PF incorporated with urea (10% based on solid PF) was decreased up to only 7.90% as compared to the samples treated with 20% and 25% PF which recorded 30.21% and 30.63% reductions in formaldehyde emission, respectively. This is because of the higher concentration of the 30% PF applied. Urea was used to absorb some of the free formaldehyde in the resin system and to form cross-linked polymer of urea formaldehyde (Zaidon *et al.,* 2010). Formaldehyde emission is free formaldehyde partly released from the impregnated LmwPF resin of the treated rubberwood, which was not completely polymerised. Meanwhile, extended heating time after hot pressing enhanced the curing of the impregnated LmwPF and thus reduced the formaldehyde emission. These results are in agreement with Amarullah *et al.* (2010) who found that the formaldehyde emission of the oil palm wood decreased after 48 hours of extended heating in the oven.

For rubberwood compregnated with LmwPF, the formaldehyde emission was reduced around 40% with the presence of urea (Fig.6). The formaldehyde emission decreased with the increase in the concentration of urea solution. For rubberwood compregnated with MmwPF, the results showed that all *compreg* rubberwood with post-urea treatment
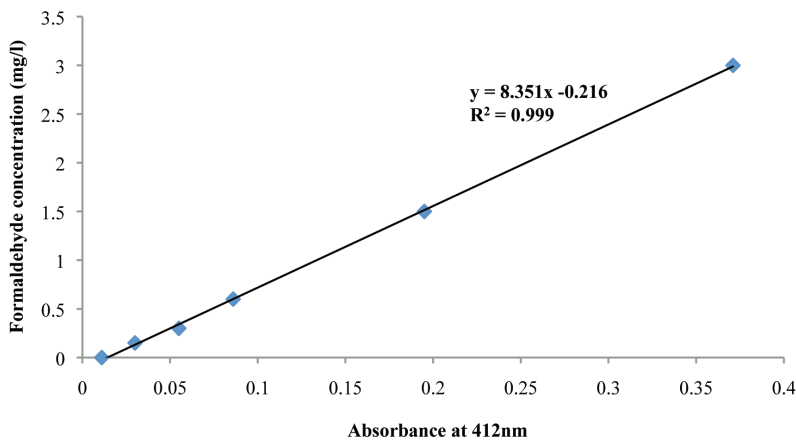
Fig.4 Calibration curve of standard formaldehyde concentration vs. absorbance using spectrophotometer

The graph shows:
- Y-axis: Formaldehyde concentration (mg/l), ranging from 0 to 3.5
- X-axis: Absorbance at 412nm, ranging from 0 to 0.4
- Equation: $y = 8.351x - 0.216$, $R^2 = 0.999$
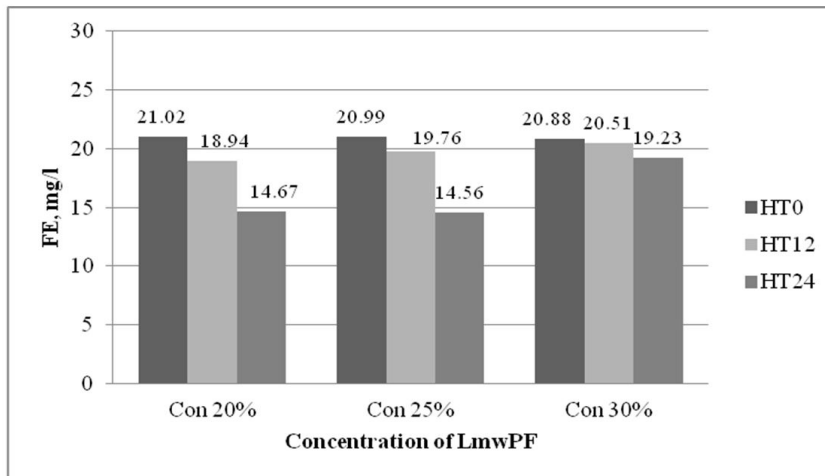
*HT0 = heating time of 0 hour; HT12 = heating time of 12 hours; HT24 = heating time of 24 hours

Fig.5 Formaldehyde emission (FE) of the low molecular weight phenol formaldehyde (LmwPF) *compreg* rubberwood at different extended heating times
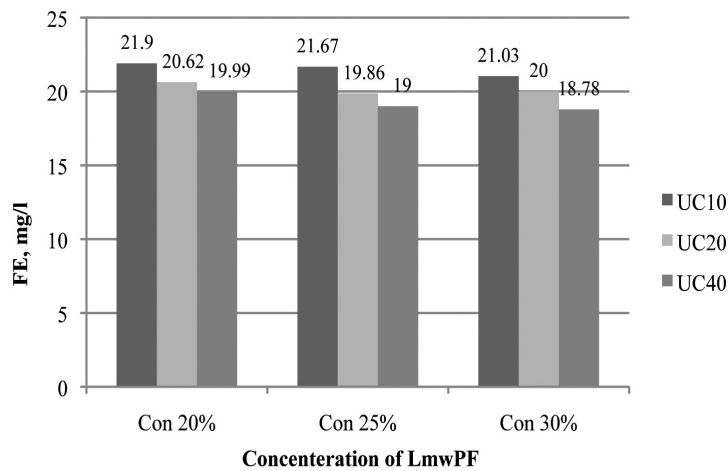
*UC10 = urea concentration of 10%; UC 20 = urea concentration of 20%; UC 40 = urea concentration of 40%

Fig.6 Formaldehyde emission (FE) of the low molecular weight phenol formaldehyde (LmwPF) *compreg* rubberwood after the post-urea treatments

recorded significantly lower formaldehyde emission compared to the untreated rubberwood (Fig.7). Formaldehyde emission was reduced by 92.4% to 0.341 mg/l compared to the untreated rubberwood which recorded formaldehyde emission of 4.46 mg/l. These results are in agreement with Rabi'atol Adawiah *et al*. (2012) who confirmed that the presence of urea had successfully reduced the formaldehyde emission of the treated samples by absorbing some of the free formaldehyde in the PF resin. Earlier work by Zaidon (2009) also showed that urea concentrations in the range of 10% to 30% were able to reduce the formaldehyde emission from impregnated and compregnated sesenduk wood. The results in Table 2 revealed that better urea spread was obtained as the concentration of urea increased. Thus, it is anticipated that urea acts as the formaldehyde catcher that slightly reduces the level of formaldehyde emission. Better urea spread means better uptake of urea by wood, exerting its effect as formaldehyde scavenger which brings down the formaldehyde emission.

TABLE 2
Urea spread of the rubberwood treated with different phenolic resins

PF Concentration (%)	Urea Concentration (%)	Urea spread (g/m^2)
MmwPF		
10	10	0.35 a ± 0.24
10	20	0.45 ab ± 0.13
10	40	0.59 ab ± 0.14
15	10	0.99 bc ± 0.31
15	20	1.03 bc ± 0.23
15	40	1.38 c ± 0.35
20	10	1.52 c ± 0.65
20	20	3.63 d ± 0.71
20	40	3.68 d ± 0.66
LmwPF		
20	10	0.33 a ± 0.14
20	20	0.41 ab ± 0.09
20	40	0.57 ab ± 0.11
25	10	0.60 ab ± 0.22
25	20	0.62 ab ± 0.31
25	40	0.78 bc ± 0.39
30	10	1.11 bc ± 0.44
30	20	1.52 c ± 0.58
30	40	2.53 c ± 0.50

*Values with different letter in the same row signifies significant difference p ≤ 0.05
** PF = phenol formaldehyde; LmwPF = low molecular weight phenol formaldehyde; MmwPF = medium molecular weight phenol formaldehyde

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TABLE 3
The average values of effects from the extended heating times on density, modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS) for *compreg* rubberwood

PF Conc. (%)	Extended heating time (h)	Density (kg/m³)	MOR (N mm⁻²)	MOE (N mm⁻²)	WA (%)	TS (%)
20	0	815.85 ab ± 69.68	91.42 a ± 18.42	7650 a ± 1978.4	9.41 b ± 3.41	2.67 ab ± 1.06
20	12	749.95 ab ± 31.11	86.41 a ± 23.95	7768 a ± 2203.3	6.02 b ± 1.36	1.97 ab ± 0.48
20	24	754.76 ab ± 60.46	97.98 a ± 18.77	8032 a ± 1576.1	7.18 b ± 2.31	1.23 b ± 0.56
25	0	853.52 ab ± 89.75	81.58 a ± 23.88	7861 a ± 1459.2	5.30 b ± 1.98	1.96 ab ± 1.02
25	12	810.55 ab ± 83.50	97.78 a ± 30.07	8784 a ± 2560.7	5.48 b ± 1.50	1.96 ab ± 0.82
25	24	805.29 ab ± 100.15	85.57 a ± 29.46	7861 a ± 2104.9	8.78 b ± 2.18	1.75 ab ± 0.74
30	0	880.59 b ± 77.82	95.54 a ± 19.02	8156 a ± 2109.6	5.48 b ± 2.43	1.31 b ± 1.06
30	12	768.63 ab ± 92.15	81.16 a ± 19.26	7970 a ± 1638.7	7.30 b ± 5.69	1.27 b ± 1.01
30	24	859.02 ab ± 64.93	92.73 a ± 38.11	8888 a ± 2543.4	6.89 b ± 4.29	1.18 b ± 0.57
untreated		598.48 a ± 72.68	69.64 a ± 20.33	7544 a ± 2371.8	72.77 a ± 18.54	4.25 a ± 2.17

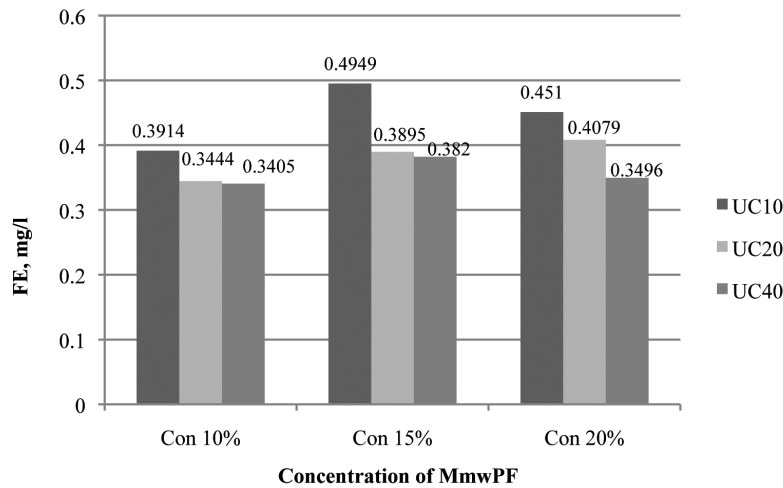*Values with different letters in the same column signify a significant difference p ≤ 0.05
** PF = phenol formaldehyde; LmwPF = low molecular weight phenol formaldehyde; MmwPF = medium molecular weight phenol formaldehyde

*UC10 = urea concentration of 10%; UC 20 = urea concentration of 20%; UC 40 = urea concentration of 40%

Fig.7 Formaldehyde emission (FE) of the medium molecular weight phenol formaldehyde (MmwPF) *compreg* rubberwood after the post-urea treatments

Effects of Extended Heating Time on Mechanical and Physical Properties

As shown in Table 3, the MOR of the *compreg* rubberwood at different treatment combinations did not differ significantly between all the treatments. In specific, the MOR values ranged from 91.04 Nmm^{-2} to 97.98 Nmm^{-2} for 20% PF, 81.58 Nmm^{-2} to 97.78 Nmm^{-2} for 25% PF, 81.16 Nmm^{-2} to 92.73 Nmm^{-2} for 30% PF and 69.64 Nmm^{-2} for the untreated rubberwood. Compared to the untreated rubberwood, the MOR values of the compreg rubberwood were shown to be slightly higher. The rubberwood treated with 20% PF, followed by heating of 24 hours, recorded the highest MOR value of 97.98 Nmm^{-2} or 40.7% of increment over the untreated rubberwood. This might be due to the resin polymer which bulked perfectly in the cell lumen of the strips and strengthened the structure of wood to withstand the load applied during the testing. Amarullah *et al.* (2010) suggested that the extended heating time had improved the curing behaviour of the PF resin in the wood and subsequently led to better properties. Table 3 shows that the MOE of all different treatment combinations did not differ significantly between each other. However, the MOE values of different treatment combinations were higher than that of the untreated rubberwood. The highest value obtained for the treatment combinations was the treatment of 30% PF and extended heating time of 24 hours, i.e. 8,888 Nmm^{-2} or 18% increment over the untreated rubberwood. This shows that the stiffness of the strips increased the mechanical anchorage of the phenolic resin in the cell lumen, in addition to the extended heating by 24 hours which made the strips to become elastic and helped in the formation of polymer.

TABLE 4
The average values of effects from the urea concentrations on density, modulus of rupture (MOR), modulus of elasticity (MOE), water absorption (WA) and thickness swelling (TS) for *compreg* rubberwood

PF Conc. (%)	Urea Conc. (%)	Density (kg/m³)	MOR (N mm⁻²)	MOE (N mm⁻²)	WA (%)	TS (%)
MmwPF						
10	10	714.9 ab ± 94.3	107.8 a ± 30.0	10919.5 a ± 3374.5	19.1 b ± 8.4	7.85 ab ± 0.81
10	20	696.9 ab ± 79.9	94.0 ab ± 23.9	7659.7 ab ± 2347.6	14.9 b ± 4.3	6.88 abc ± 0.75
10	40	763.2 ab ± 108.6	115.6 a ± 30.4	11253.6 a ± 4188.8	18.7 b ± 6.2	5.85 abc ± 1.09
15	10	1001.4 a ± 86.4	108.2 a ± 20.0	9712.4 ab ± 1788.6	23.8 b ± 17.8	6.82 abc ± 1.73
15	20	744.9 ab ± 78.8	107.0 a ± 20.7	9507.0 ab ± 2965.8	15.3 b ± 5.0	5.12 bc ± 0.31
15	40	753.1 ab ± 80.8	109.8 a ± 30.4	9994.7 ab ± 2965.8	16.1 b ± 4.1	5.20 bc ± 1.27
20	10	794.2 ab ± 62.7	115.3 a ± 23.3	10259.7 ab ± 2458.9	13.3 b ± 2.7	6.17 abc ± 0.88
20	20	785.7 ab ± 85.5	105.0 ab ± 37.0	10164.8 ab ± 3223.2	12.5 b ± 3.1	5.56 bc ± 0.75
20	40	817.7 ab ± 40.1	116.7 a ± 13.3	10322.0 ab ± 1302.8	11.8 b ± 2.4	4.99 c ± 2.93
untreated		572.7 b ± 53.2	69.3 b ± 12.0	6925.3 b ± 1723.4	80.6 a ± 13.6	8.47 a ± 0.73
LmwPF						
20	10	942.0 a ± 91.59	123.6 a ± 23.87	14219 a ± 2787.4	8.48 b ± 4.83	14.10 ab ± 13.48
20	20	907.4 a ± 80.68	124.8 a ± 26.10	11969 a ± 3465.7	6.03 b ± 1.64	28.87 a ± 0.52
20	40	879.8 a ± 77.19	109.8 ab ± 20.78	10868 a ± 3128.6	8.33 b ± 5.07	18.87 ab ± 13.54
25	10	933.4 a ± 72.46	109.1 ab ± 32.88	10516 a ± 1950.6	5.63 b ± 2.40	7.45 ab ± 12.33
25	20	899.0 a ± 93.74	105.9 ab ± 26.89	14165 a ± 1314.9	3.98 b ± 1.82	27.83 a ± 0.65
25	40	947.2 a ± 55.06	112.7 ab ± 16.57	11112 a ± 1531.0	3.92 b ± 1.49	28.17 a ± 0.86
30	10	937.7 a ± 81.61	116.5 ab ± 37.02	11461 a ± 2794.2	3.59 b ± 1.34	17.02 ab ± 13.90
30	20	958.1 a ± 87.66	112.0 ab ± 22.29	10929 a ± 2811.5	4.36 b ± 2.26	11.90 ab ± 14.44
30	40	920.9 a ± 105.60	122.1 a ± 39.91	11845 a ± 2768.3	3.44 b ± 1.01	17.22 ab ± 13.40
untreated		607.9 b ± 48.76	80.5 b ± 12.11	7820 a ± 1678.1	54.71 a ± 3.43	4.87 b ± 3.13

*Values with different letter in the same column signifies significant difference $p \leq 0.05$

**PF = phenol formaldehyde; LmwPF = low molecular weight phenol formaldehyde; MmwPF = medium molecular weight phenol formaldehyde

Meanwhile, the treated rubberwood had significantly lower WA value than the untreated strips. Due to its lowest PF concentration, rubberwood strip treated with 20% PF with 0 hour heating time was observed to have the highest WA value among all the treated strips. The results showed that the strips treated with LmwPF lowered the absorption of water into the wood. TS for the treated wood were significantly lower than that of the untreated wood. From Table 3, the TS value was shown to decrease with increasing heating time. As the heating time extended, the cross-linked polymer became hard, infusible and insoluble which could not be softened and melted (Hon, 2003). Furthermore, the extended heating also promotes higher resin polymerisation in the treated strips.

Effects of Post-Urea Treatment on Mechanical and Physical Properties

For the woods treated with MmwPF, no significant difference within the treated groups was found. However, significant difference was observed between the treated and untreated rubberwood (Table 4). In particular, the MOR of the treated groups increased by 34.02% to 40.06% compared to that of the untreated wood. On the other hand, the MOE values of the treated woods increased by 11.77% to 32.91% compared to that of the untreated woods. The wood treated with 20% PF and urea solution of 40% concentration showed the highest MOE value (10,322 Nmm^{-2}). The WA of the treated strips decreased around 70.48% to 85.35% compared to the untreated group

(Table 4). The lowest WA was recorded in the strip treated with 20% PF, followed by a post treatment of 40% urea. The TS of the treated rubberwood decreased around 6.66% to 40.5% compared to the untreated rubberwood. The lowest TS value of 5.00% was observed when the rubberwood treated with the highest PF and urea concentration (20% PF + 40% urea). Rubberwood treated with the highest concentration of PF and urea exhibited the best performance mainly because of the cell wall and lumen was filled with phenolic resin and covered with urea coating. Both PF and urea have plasticisation effect on the cell walls by deforming them without rupturing during compression. The compressed wood becomes stronger and more dimensionally stable once the resin is cured (Yano *et al*., 1997).

For the rubberwood treated with LmwPF, the highest MOR value was observed for the treatment of 20% of PF, followed by soaking in 20% urea solution which recorded 124.75 Nmm^{-2}. On the other hand, the highest MOE value of 14,219 Nmm^{-2} was recorded when the rubberwood was treated with 20% of PF, followed by soaking in 10% urea solution. Both the MOR and MOE values of the untreated rubberwood are significantly lower than that of the treated wood. The TS value of the treated rubberwood decreased with the increase in the PF and urea concentrations. All the treated rubberwood showed at least two-fold lower TS than the untreated rubberwood. Meanwhile, WA for the treated rubberwood showed a highly significant difference between the treated and untreated rubberwood. The

untreated rubberwood showed the highest WA value of 54.71%, while the lowest WA value of 3.44% was observed when the rubberwood was treated with 30% PF and soaked in 40% urea solution. Aside from the increasing PF concentration that imparted a better performance onto the treated wood, increasing the urea concentration during post treatment was also shown to have encouraging effect on the physical properties of treated wood. Nevertheless, the findings are dissimilar to the previous study conducted by Rabi'atol Adawiah *et al*. (2012) who reported that the presence of urea increased the viscosity of the resin solution, therefore limiting the penetration into the cell wall and adversely affecting the performance of the treated wood. However, Gabrielli and Kamke (2010) suggested that the higher viscosity of the resin solution might have caused less resin to be squeezed out during compression due to its slower movement through the wood structure. In this study, higher WPG obtained from the samples treated with higher urea concentration confirmed the point.

CONCLUSION

The results revealed that the post-urea treatment on the *compreg* wood rubberwood reduced the formaldehyde emission by 40% compared to the rubberwood without any post-urea treatment. The results also revealed that the post-urea treatment did not significantly affect the mechanical and physical properties of the *compreg* wood. The formaldehyde emission for the *compreg* rubberwood could be successfully reduced by incorporating urea in the treating solution followed by extended heating in an oven. Nevertheless, the formaldehyde emission obtained is still far beyond the standard threshold limit of 0.16 – 2.0 mg/l (Markessini *et al*., 2010). It was also found that the longer the heating time, the higher the reduction of formaldehyde emission would be. Hence, extended heating time did not significantly affect the MOR and MOE values of the wood although it reduced the WA and TS of the treated wood. It is expected that formaldehyde emission can be further reduced by lengthening the curing time of the resin, which in turn will help to increase the rate of polymerization by altering the hot-pressing compression schedule.

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