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Effects of Formaldehyde Catcher on Some Properties of Particleboard with Different Ratio of Surface to Core Layer

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ABSTRACT

Formaldehyde catcher is a chemical compound that reacts with formaldehyde to form a less harmful product. Various compounds and methods of application have been found effective to reduce formaldehyde emission. The objective of this study was to reduce the formaldehyde emission of particleboard by applying post-treatment formaldehyde catcher. In this study, three-layered particleboards with five different surface to core ratios were made using urea formaldehyde resin. Amino-compound formaldehyde catcher (40, 50 and 60 g^{-2}) was applied on the surface of the particleboard samples after 24 h conditioning. The samples were evaluated in accordance to Japanese Industrial Standard (JIS) for particleboard. JIS A 5908: JIS 5908 (2003) for mechanical properties and JIS A 1460 (2001) for formaldehyde emission. The data presented here were analysed using Analysis of Variance (ANOVA) and Tukey Honesty Significance Different Test (HSD) to determine the significant difference of the variables. Overall, particleboards applied with 60 g^{-2} of catcher show the lowest formaldehyde emission, with the lowest value achieving 0.163 mg L^{-1}. With 60 g^{-3} of catcher, formaldehyde emission of all the samples were able to be reduced to meet F**** class stated in JIS for particleboard. Higher dosage of formaldehyde catcher shows greater reduction in formaldehyde emission. In conclusion, application of post-treatment formaldehyde catcher was very effective in reducing formaldehyde emission of three-layered particleboard with little effect on the mechanical properties and thickness swelling.

Key words: Particleboard, rubberwood, urea formaldehyde, formaldehyde catcher, amino compound

INTRODUCTION

As predicted by Dunky (1998), Urea-formaldehyde (UF) resin is still the most used and important thermosetting resins today in wood industry. This is especially true for manufacturing particleboards, medium density fibreboard and plywood. In Malaysia, urea formaldehyde resin is still the main contributing binding agent to the particleboard industries (H'ng *et al.*, 2011).

There are numerous factors that make UF resin remain popular in the wood industry. The main benefits of UF resin are associated with its relativity cheap price and much lower curing temperature compare to other resins. Besides that, it is also very easy to use with varied curing parameters and has longer shelf life not to mention its water solubility and resistance to microorganisms (Anthony, 1996).

However, UF bonded particleboard has been related to high formaldehyde emission. Formaldehyde has been known to be detrimental to health. Formaldehyde gas used for biological decontamination is often neutralized with ammonia gas to form a relatively safe by product (Luftman, 2005). In 2006, the International Agency for Research on Cancer (IARC) has classified formaldehyde as "carcinogenic to humans" (WHO/IARC, 2006). Formaldehyde emission has become a hot issue worldwide. Particleboard manufacturer and researcher alike are putting a lot of effort to reduce formaldehyde emission by various means.

The most common methods to reduce formaldehyde emission from wood based products consist in decreasing the F/U (formaldehyde/urea) molar ratio, incorporation of other comonomers in the synthesis and adding formaldehyde scavengers to the particles before or after resin blending (Conner, 1996). Post treatment formaldehyde catcher can also be used to reduce formaldehyde emission desirably. Though there are limited literature reviews on the effects of post-treatment liquid formaldehyde catcher.

To act as formaldehyde catcher, formaldehyde reactive chemicals penetrate the boards leading to a tremendous decrease in the formaldehyde release of the boards (about 50%) (Roffael, 1993). There are actually many advantages by using post-treatment formaldehyde catcher. One notable advantage is the flexibility it provides to plant manager to vary its dosage. Thus, controlling the reduction of formaldehyde emission according to various standards available across the globe is much easy.

Nevertheless, the key advantage of using post-treatment catcher is the fact that it provides a much more favourable result than that of a straight resin system. Additionally, post-treatment formaldehyde catcher is sometime more effective than add-in catcher. By using post-treatment formaldehyde catcher, instead of using a very low molar ratio resin, one can achieve better results by using a system of an equivalent molar ratio which is a combination of a higher molar ratio UF resin and a formaldehyde catcher.

Besides all the benefits gained from the application of post treatment formaldehyde catcher, this method of application has a tendency to change the surface of the particleboard. This might affect the various properties of the particleboard. Lee *et al*. (2013) found that, particleboard treated with formaldehyde catcher on the surface reported more mass loss than the control against termite attack. Thus, this study was focused on finding out the effect of liquid formaldehyde catcher on the physical and mechanical properties of particleboard on different ratio of surface to core layer and the effectiveness of the formaldehyde catcher used.

MATERIALS AND METHODS

Raw materials preparation: Rubberwood (*Hevea brasiliensis*) species was selected for this study. After hot pressing, the density of particleboard will be about 5-40% higher than the density of used wood. Therefore, to avoid overly high weight of particleboards, woody species with low or medium density is appropriate and are chosen as the initial raw materials. The rubberwood particles were collected from a commercial particleboard plant in Negeri Sembilan. The particles collected are of two ranges of dimensions. The core layer contains rather coarse particles and the surface layer contains rather fine particles. The dimension of the surface layer particles were ranged from 2-5 mm long and 1-2 mm wide. On the other hand, the core layer particles were ranged from 10-30 mm long and 2-4 mm wide. Type E1 urea formaldehyde (E1UF) resin with the solid content of 61-65% supplied by Norsechem Resin Sdn. Bhd. was used as the binding agent. The viscosity (30°C, RV3 Sp. 100) of the resin used was ranges from 230 to 270. While the F/U ratio of the resin was 1.2. Other additives used were wax and hardener with the solid content of 60 and 25%, respectively. Ammonium chloride (NH_4Cl) was used to act as the hardener. The wax used was manufactured by Emulco Sdn. Bhd. The formaldehyde catcher used was amino compound in liquid form with the commercial code of Elite SF1155 manufactured by Elite Chemical Industries Sdn. Bhd. Three-layered particleboards were produced in this study with five different ratio of surface to core layer. For this study, three-layered particleboards of 340×340 mm dimensions and of 12 mm thicknesses with a target density of 680 kg m^{-3} were selected.

Particleboard manufacturing: The rubberwood particles were oven dried with the temperature of 60°C to obtain the Moisture Content (MC) of 3%. The rubberwood particles, resin, hardener and wax, were weighed according to particleboard manufacturing recipe. The particles were then put in the blender and sprayed with the adhesive mixture. The particles were allowed to be blended in the blender for 5 min to make sure that the mixture really mixed well.

The amount of UF resin, hardener and emulsified wax which were needed for the blending process differed between core layer and surface layer. It is due to the temperature difference between surface and core caused by the heat transfer from the surface to the core of particleboard. Also, different amounts of resin used are due to the difference in surface area of particles used in surface and core of particleboard. Resin usage for surface and core layer which are 10 and 7%, respectively based on the weight of the rubberwood particles. As for hardener, 1 and 3.8% of NH_4Cl was used for surface and core layer respectively based on the weight of the resin used. On the other hand, 0.5 and 0.7% of wax was used for core and surface layer respectively based on the weight of particles.

Soon after the blending and spraying process, the resinated particles were taken out from the blending machine. Then, the particles were spread evenly onto a 340×340 mm wooden mould with a caul plate as the base to form a loose mat. The mat formed was then pre-pressed manually to consolidate the thickness. Next, the mat was hot pressed in a thermal-oil heated hydraulic hot press machine with the temperature of 180°C with a specific pressure of 18 kg cm^{-2} to achieve target board thickness of 12 mm. The mat was pressed for 4½ min based on the recommendation of the resin supplier and the particleboard manufacturing factory located in Negeri Sembilan.

Experimental design: Three boards were produced for each type of particleboards in the experimental design which are 60 boards in total. Each of the particleboards was cut into six samples with the width of 50 mm each. The samples were then randomly selected and cut into nine FE samples (150×50×2 mm), five MC samples (50×50×12 mm), five TS samples (50×50×2 mm), five MOR samples (230×50×12 mm) and five IB samples (50×50×12 mm) for each type of particleboards. The samples were cut according to the required dimension stated in Japanese Industrial Standard (JIS) for particleboard depending on the types of properties evaluation.

The particleboards produced were conditioned for 24 h. After that, the particleboards were taken out from the conditioning room and formaldehyde catcher was applied on the surface of the boards. Three different dosage of the formaldehyde catcher which was 40, 50 and 60 g^{-3}, was applied directly onto the two surface layers of the boards using a sponge. The boards were then conditioned for another 7 days in a conditioning room maintained at a relative humidity of 65±5% and 20±2°C prior to properties evaluation. The experimental design for this study is summarised in Table 1.

Board evaluations: The boards produced were evaluated according to the Japanese Industrial Standard for particleboard. The physical and mechanical properties of the boards were tested based

Table 1: Experimental design to measure the effect of surface to core ratio and formaldehyde catcher dosage on particleboard properties

Treatment	Surface to core ratio (%)	Formaldehyde catcher (g^{-2})
Type 1	70:30	0
Type 2		40
Type 3		50
Type 4		60
Type 5	60:40	0
Type 6		40
Type 7		50
Type 8		60
Type 9	50:50	0
Type 10		40
Type 11		50
Type 12		60
Type 13	40:60	0
Type 14		40
Type 15		50
Type 16		60
Type 17	30:70	0
Type 18		40
Type 19		50
Type 20		60

on JIS A 5908: JIS 5908 (2003). On the other hand, the formaldehyde emission test was carried out according to JIS A 1460 (2001) All tests were carried out in Wood Composite Testing Laboratory, Universiti Putra Malaysia.

Data analysis: The physical and mechanical data presented here were analysed using Analysis of Variance (ANOVA) to determine the significant difference of the variables used on the properties, The mean were further analysed using Tukey Honesty Significance Different Test (HSD) to determine the significant level of variables used in this study.

RESULTS AND DISCUSSION

The board density varied from 674.70 to 735.23 kg m^{-3} with a mean density of 693.38 kg m^{-3} for targeted density of 680. Table 2 shows the mean values of physical and mechanical properties for all type of particleboard. These properties were corrected to the targeted density before subjected for statistical analysis. The equation for corrected strength properties is shown as below:

$$\text{Strength}_{cor} = \text{Strength}_{act} + (\text{Density}_{tar} - \text{Density}_{act}) \times \text{Radian of strength vs. Density} \quad (1)$$

Where:

Strength_{cor} = Strength corrected
Strength_{act} = Strength actual
Density_{tar} = Target density
Density_{act} = Density actual

Mechanical properties and thickness swelling: The Modulus of rupture (MOR) of all types of particleboard made was ranging from 13.32 to 21.35 Nmm^{-2}. Type 15 particleboard shows the highest value while Type 3 shows the lowest value. The minimum requirement for MOR specified in JIS A 5908: JIS 5908 (2003) is achieve 13 Nmm^{-2}. In general, all types of particleboards have achieved the minimum requirement specified in the standard with Type 3 particleboard having the lowest value which has only achieved 13.32 Nmm^{-2}. These results complied with the findings of H'ng *et al.* (2011) which stated that all the particleboard made with UF resin can easily achieve the minimum value required by the standard. Table 2 below summarised the results of mechanical tests and thickness swelling for all type of particleboard and also the mean comparison of MOR, IB and TS using HSD test.

As for Internal Bond (IB) strength, the highest value which is 2.62 Nmm^{-2}, comes from particleboards made with 50:50 surface to core ratio and with the application of 60 g^{-3} of formaldehyde catcher. Particleboards made with 70:30 surface to core ratio have the lowest value which is 1.20 Nmm^{-2}. Nonetheless, all types of particleboard have fulfilled the requirement according to JIS A 5908: JIS 5908 (2003) which stated that the minimum value required is 0.2 Nmm^{-2}.

The thickness swelling of particleboards produced was ranging from 10.25 to 17.56 %. Most of the boards made have failed to achieve the requirement stated in JIS A 5908: JIS 5908 (2003) which requires the thickness swelling not to exceed 12%. Ashori and Nourbakhsh (2008) found out that the thickness swelling of particleboard made with different species of wood all exceeded 12%

Table 2: Comparison of mechanical and physical properties of particleboard produced as a function of surface to core ratio and formaldehyde catcher dosage

Treatment	Surface to core ratio (%)	Formaldehyde catcher (g^{-2})	MC (%)		TS (%)		MOR (Nmm^{-2})		IB (Nmm^{-2})	
Type 1	70:30	0	5.26	(0.49)	14.74^{bcdef}	(0.78)	15.79^{abcd}	(1.38)	1.20^{a}	(0.24)
Type 2		40	5.39	(0.23)	11.89^{ab}	(1.41)	14.79^{ab}	(3.61)	1.52^{a}	(0.27)
Type 3		50	5.53	(0.31)	15.13^{bcdef}	(2.47)	13.32^{a}	(1.48)	1.58^{a}	(0.60)
Type 4		60	5.73	(0.80)	13.00^{abc}	(0.95)	16.43^{abcde}	(1.90)	1.49^{a}	(0.33)
Type 5	60:40	0	4.64	(0.55)	13.02^{abc}	(0.88)	19.56^{bcde}	(2.52)	1.62^{ab}	(0.52)
Type 6		40	6.06	(0.68)	14.28^{bcdef}	(1.38)	16.59^{abcde}	(1.35)	1.80^{ab}	(0.57)
Type 7		50	6.87	(0.69)	12.55^{ab}	(1.28)	17.57^{abcde}	(2.42)	1.77^{ab}	(0.24)
Type 8		60	5.38	(0.74)	10.25^{a}	(1.12)	20.88^{de}	(1.98)	1.92^{ab}	(0.35)
Type 9	50:50	0	5.89	(0.40)	14.92^{bcdef}	(1.54)	21.35^{e}	(2.55)	1.88^{ab}	(0.40)
Type 10		40	5.90	(0.47)	14.56^{bcdef}	(1.33)	14.47^{ab}	(1.36)	2.00^{ab}	(0.52)
Type 11		50	5.04	(0.12)	13.52^{abcde}	(0.98)	14.72^{ab}	(3.08)	2.06^{ab}	(0.49)
Type 12		60	6.04	(0.64)	13.23^{abcd}	(0.31)	17.07^{abcde}	(2.19)	2.62^{b}	(0.29)
Type 13	40:60	0	5.11	(0.37)	17.56^{def}	(1.98)	20.41^{cde}	(2.49)	2.19^{ab}	(0.28)
Type 14		40	6.55	(0.80)	15.30^{bcdef}	(1.21)	7.13^{abcde}	(1.87)	1.89^{ab}	(0.73)
Type 15		50	5.58	(0.36)	14.96^{bcdef}	(3.29)	21.29^{e}	(2.71)	1.60^{a}	(0.46)
Type 16		60	5.41	(0.29)	16.58^{cdef}	(0.39)	17.06^{abcde}	(3.43)	1.45^{a}	(0.66)
Type 17	30:70	0	5.38	(0.61)	16.95^{f}	(1.10)	17.31^{abcde}	(1.25)	1.67^{ab}	(0.28)
Type 18		40	6.41	(0.18)	17.36^{ef}	(1.66)	16.43^{abcde}	(2.11)	1.75^{ab}	(0.40)
Type 19		50	6.31	(0.98)	15.43^{bcdef}	(2.13)	15.50^{abc}	(1.10)	1.62^{ab}	(0.14)
Type 20		60	5.86	(0.80)	14.98^{bcdef}	(0.60)	16.66^{abcde}	(2.24)	2.04^{ab}	(0.36)

Note: Data is expressed as mean value. Within the same column, mean values followed by different letters are significantly different at $p<0.05$. The values in parentheses are standard deviations. [1]MC: Moisture content, [2]TS: Thickness swelling, [3]MOR: Modulus of rupture, [4]IB: Internal bond strength even for two hours immersion. However, this problem can be solved with post heat treatment of particleboard. With post heat treatment which is milder than the commercial thermal modification, the thickness swelling of particleboard can be significantly reduced (H'ng *et al.*, 2012). The lowest value of thickness swelling was observed for particleboard produced with 60:40 surface to core ratio. Generally, particleboards made with 40:60 and 30:70 surface to core ratio have higher thickness swelling than the other ratios. This is because core particles absorb more water compare to fine particles. Particleboards produced with more core particles have higher thickness swelling values for 2, 24 and 48 h immersions compare to those with more fine particles (Nemli and Ozturk, 2006).

As shown in Table 2, there is no significance difference on the MOR, IB and TS observed for all five ratios of surface to core layer and three different dosage of formaldehyde catcher.

Formaldehyde emission: The results of formaldehyde emission of all types of particleboard with and without the application of formaldehyde catcher are summarised in Table 3.

For the entire surface to core layer ratio, the formaldehyde emission of particleboard made without the application of formaldehyde catcher was ranging from 0.719 to 1.042 mg L^{-1}. The highest surface to core layer ratio has the highest formaldehyde emission which is 1.042 mg L^{-1}. Contrarily, the lowest surface to core layer ratio has the lowest formaldehyde emission which is 0.719 mg L^{-1}. The higher the surface to core layer the higher the formaldehyde emission. This is because fine particles used as the surface layer needed more resin than the coarse particles used as the core layer. Nemli and Ozturk (2006) also stated in their study that the increase of fine particles increases the formaldehyde content in the particleboard. This is because fine particles can be compressed easily during the hot pressing. Hence, higher surface to core layer resulted in more

Table 3: Formaldehyde emission from particleboards hot-pressed with different surface to core ratio and application of different dosage of formaldehyde catcher

Treatment	Surface to core ratio	Formaldehyde catcher (g^{-2})	Formaldehyde emission (mg L^{-1})
Type 1	7:3	0	1.042
Type 2		40	0.417
Type 3		50	0.392
Type 4		60	0.294
Type 5	6:4	0	0.982
Type 6		40	0.427
Type 7		50	0.308
Type 8		60	0.214
Type 9	5:5	0	0.950
Type 10		40	0.371
Type 11		50	0.345
Type 12		60	0.219
Type 13	4:6	0	0.875
Type 14		40	0.293
Type 15		50	0.184
Type 16		60	0.163
Type 17	3:7	0	0.719
Type 18		40	0.347
Type 19		50	0.260
Type 20		60	0.203

compact and tighter structures. Consequently, less formaldehyde is released from particleboards produced with higher surface to core ratio during hot pressing and storage.

With the application of 40 g^{-2} of formaldehyde on the surface layers, the formaldehyde emission drops about 50 to 65 %. However, the values still have not met the requirement stated in JIS A 5908: JIS 5908 (2003) for F**** particleboard.

As shown in Table 3, with the increases of the dosage of formaldehyde catcher the formaldehyde emission decreases. Particleboards post treated with 60 g^{-2} of formaldehyde catcher show desirable results. All the values are below 0.3 mg L^{-1} which have comply with the JIS for F**** particleboard. The formaldehyde catcher applied acts as a barrier against the free formaldehyde in particleboard.

The amino compound formaldehyde catcher has the ability to reduce formaldehyde emission because the ammonia present can enter into multiple reactions inside particleboard. It can enter the particleboard and react with the free acid inside the particleboard and raise the pH values of the panel (Roffael and Menzel, 1980). As is known, the resistance to hydrolysis of aminoplastic resin generally drops with decreasing pH in the acid range. Besides that, the ammonia can react with the free formaldehyde in particleboard to form hexamethylene tetramine which entrap the formaldehyde evolved.

CONCLUSION

The post-treatment formaldehyde catcher which contain amino compound has successfully reduced the formaldehyde emission from particleboard with favourable results. As indicated by the study, particleboards post treated with 60 g^{-2} liquid formaldehyde catchers have the lowest formaldehyde emission. This shows that, higher dosage of formaldehyde catcher will further decrease the formaldehyde emission considerably, with insignificant effect on the mechanical properties and thickness swelling of particleboard. The effect of different ratio of surface to core layer on formaldehyde emission and performance of particleboard is insignificant as long as the resin content used for both surface layer and core layer remain the same.

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