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Research paper



Mechanical Properties and Formaldehyde Emission of Rubberwood Particleboard Using Emulsified Methylene Diphenyl Diisocyanate (EMDI) Binder at Different Press Factor Continuous Press

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Abstract

Rubberwood particleboard with low formaldehyde emission is a must in wood based paneling industry especially for export market such as in Japan, Korean, European countries and North America Region. Avoiding of urea formaldehyde binder and substitute it with emulsion isocyanate resin is an alternative in particleboard production. However, the low tackiness and sticking to steel belt during transferring and pressing in actual particleboard production contributes to surface defects as well as variation in mechanical properties of the final product. The results revealed that a correlation speed and press factor is necessary in order to improve mechanical properties and to keep the physical performance of boards within a limited range of values. Various speeds of press factors were studied at 15.0, 14.5, 14.0, 13.5 sec/mm to study the effect to the bending, internal bonding, screw withdrawal, surface soundness, thickness swelling, moisture content properties and formaldehyde emission of particleboard. At higher production speed (lower press factor), bending, internal bonding, MOE and edge screw withdrawals properties of particleboard was decrease by 3% to 13%. Thickness swelling and moisture content were increased in final particleboard production. Emission of formaldehyde was below than 0.15 mg/L (JIS A 1460) at all speeds of press factor which is extremely low.

Keywords: *Particleboard, Formaldehyde, Emission, Polyurethane, EMDI*

1. Introduction

In Malaysia, rubberwood (*Hevea brasiliensis*) is one of the popular raw wood materials which commonly used by manufacturer to produce composite wood panels such as fiberboard and particleboards [1]. With the availability of rubberwood especially from the 50 km radius from the vicinity surrounded by FELDA plantation area, HeveaBoard Berhad, one of known high quality particleboard producer in Malaysia were also using this material as their most important raw materials for particleboard. With the aim of producing high quality product for export market, high properties particleboard with low formaldehyde emission is the main focus in operation for this company.

Similar to wood composite industry in many other countries, formaldehyde based adhesives are also widely used in Malaysia and in case of particleboard, urea formaldehyde is the most commonly used binder due to its fast curing time, clear color and low cost [1,2]. However, it has also a high reversibility of the amino methylene link, which explains the low resistance of urea formaldehyde resin against the influence of water and moisture which subsequently being one of the reason for its formaldehyde emission when hardened and in service [3]. The fundamental mechanism in formaldehyde emission from urea formaldehyde bonded particleboard is simply related to unreached free formaldehyde from the binder and hydrolysis of partially and completely cured adhesive. Several conditions of formaldehyde could be present such as monomeric by hydrogen bonding of formaldehyde to the wood or as polymeric (solid) formaldehyde as well as loosely bound formaldehyde which could be easily releases by hydrolytic reaction [1,4].

With lower formaldehyde emission board requirements, lower molar ratio of urea formaldehyde resin was introduced to the market. This glue was developed to meet the requirement of E0 (F***) mean 0.5mg/L max 0.7mg/L and Super E0 (F****) mean 0.3mg/L max 0.4mg/L as required in JIS A 5908 [5]. This basically affects the production speed of operation, reduce the production output and subsequently increase the operation cost. As lowest requirement of formaldehyde emission currently is F**** (mean 0.3mg/L, max 0.4mg/L) and tested according to JIS A 1460 test method, the effort to produce particleboard with lower than this emission level may require substitution of urea formaldehyde based resin to other available material such as polyurethane binders.

Isocyanate resin were introduced in German particleboard industry in early 1970's and since then the use of MDI (4,4 - methylenediphenylisocyanate) binders has grown significantly [6]. MDI binders generally sold to engineered wood product plant as PMDI (polymeric MDI) and EMDI (emulsion of PMDI in water) [6]. Despite the early development and introduction of this binder to particleboard industry in European country, development of 100% particleboard using MDI binders in Malaysia is still not

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available in industrial scale. This is due to lack of demand from market of No Added Formaldehyde (NAF) and Ultra Low Emitting Formaldehyde (ULEF) particleboard in this region. It is also due to the fact that producing board using these binders will give extra challenge in accommodating low tackiness of mat formation as well as risk of sticking to hot press steel belt especially to continuous pressing line that having transferring point of mat cake from forming belt to transfer belt and subsequently from transfer belt to hot press steel belt. It will result in additional operation cost as MDI binders is expensive as well as additional cost of release agent to avoid sticking. On the other hands, tackifier agent is required to accommodate and avoid mat cake disturbance compare to traditional urea formaldehyde based resin. Consequently, the purpose of this paper is to evaluate mechanical properties and formaldehyde emission of rubber wood particleboard produced using EMDI at different speed of continuous press system. This may help in future development and optimization as level of mechanical properties and formaldehyde emission baseline will be develop with actual industrial scale machinery. It will also provide basic information for customer on advantage of product that can be offered to them by alternatively change the binding agent and this premium grade particleboard will open new opportunities and special market in this region.

Press factor is defined as pressing time per thickness of board during hot pressing. It is important to minimize duration taken to cure the EMDI in particleboard. It is due to the ability of heat transfer between particles and accelerates the reaction between the isocyanate and hydroxyl to form polyurethane which bind wood and EMDI.

Table 1: Mechanical properties and formaldehyde emission of EMDI particleboard at different press factor.

Press Factor (s/mm)	Density (kg/m3)	Bending Widthwise (N/mm2)	MOE Widthwise (N/mm2)	IB (N/mm2)	Screw Face (N)	Screw EDGE (N)	2 hr. Thickness Swelling (%)	24 hr. Thickness Swelling (%)	Moisture Content (%)	7 Days Condition Desiccators (mg/L)	14 Days Condition Desiccators (mg/L)
15.0	692	16.0	2917	0.90	1040	940	0.85	4.15	5.15	0.12	0.06
14.5	693	15.6	2800	0.82	1136	886	0.89	4.26	5.42	0.14	0.07
14.0	690	15.4	2787	0.77	1121	879	0.99	4.34	5.28	0.14	0.07
13.5	696	15.5	2678	0.78	1033	880	1.03	4.69	5.72	0.13	0.08

2. Material and Methods

Commercial particleboard plant was used to produce particleboard using 100% EMDI to surface and core layer by using rubber wood as raw material. The process flow is as per normal particleboard production parameter with early adjustment by conducting preliminary trial run to evaluate machine capability in producing EMDI particleboard. Subsequently adjustment on machinery such as piping system installation, transfer belt, press curve, temperature, IWC and other necessary work was carried out through multiple trial run before actual trial run were carried out at different press speed. Multiple lab scale board were also produced before pilot scale trial were carried out and results from journal title Isocyanate Resin for Particleboard: EMDI vs PMDI [6] were also evaluated. This to ensure final board properties is meeting targeted value.

EMDI and internal release agent for this trial were purchased from Huntsman (Singapore) Pte Ltd while other material is standard supply for plant operation. Board were produced for 18mm nominal thickness with approximately 18.4mm raw board thickness out from press. All board was sanded before testing and testing method is according

to EN standard for bending, IB, thickness swelling and Moisture Content. JIS A 1460 [7] were used for formaldehyde emission test using desiccator method while screw test is according to GB standard (China) as requested by potential customer.

Target density after sanding is 690 kg/m3 and EMDI dosing is fixed at approximately 4%. This is again based on safe dosing level after considering targeted properties and results evaluation from previous study done in this area as mentioned in paragraph 1. Press factor during trial were adjusted from 15.0s/mm, 14.5s/mm, 14.0s/mm and 13.5s/mm to evaluate the results.

3. Results and discussion

Press factor at 15.0s/mm, 14.5s/mm, 14.0s/mm and 13.5s/mm is referred to the pressing time for every mm thickness of particleboard. Higher press factor demonstrated longer pressing time which contribute to the higher heat transfer supplied into the board between the hot steel belts. It reflects the curing time of the EMDI due to the curing of isocyanate is based as *in-situ* polymerization to form a network between EMDI and wood.

Table 1 displays test results of the sample according to the various press factors.

3.1. Bending Strength and MOE

The results depicted the bending strength decreased when press factor were reduced. This is due to the shorter curing time given to the EMDI during pressing process. This might affect the crosslinking density of EMDI and wood. The decreasing of strength can be seen at 15 to 14 s/mm, however at 13.5s/mm the bending strength increased (Figure 1). The increment in bending at press factor 13.5s/mm is due to the additional input of density to avoid results to drop below than 15 N/mm2. Bending requirement at 15N/mm2 is the minimum strength accepted by company standard.

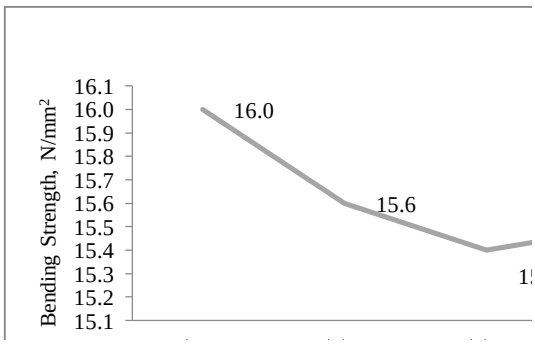

Figure 1: Bending Strength of EMDI particleboard at different press factor.

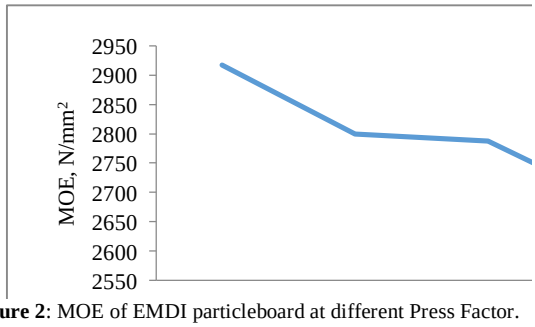

Figure 2: MOE of EMDI particleboard at different Press Factor.

Results of MOE (Figure 2) clearly show reduction of modulus when press factor were reduced. It shows similar trend compared to the bending. However, at 13.5s/mm the MOE still reduced although the bending increased. It can be translated as at higher density the particleboard contributes to the internal brittleness of board. This might due to the reaction of isocyanates and water from EMDI to form isocyanurates. This is because the water has difficulties to be released during pressing. It can be seen from moisture content at final product. Press factor at 13.5s/mm the MC is 5.72% which is higher compared to the others. This phenomenon contributes to the brittleness of particleboard and reduces the MOE.

3.2 Internal bonding (IB)

Internal bonding (IB) is the bonding strength within the core layer of particleboard. This bonding is contributed by cross linking of urethane and compatibility of EMDI/wood. This bonding depends to the surface area wetted by EMDI on the core layer. From internal bonding testing, failure of bonding was found in core layer. This is due to the core layer received least heat compared to the surface layer (SL) top and bottom layers. This condition will limit the in-situ reaction between isocyanate and wood to form urethane linkage. Figure 3 shows the internal bonding of particle at various press factors. It shows that the internal bond of particleboard reduced at lower press factor. This was due to the limitation of heat received to the core layer.

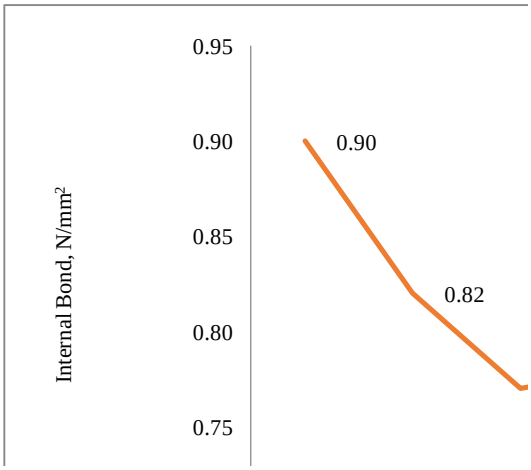

Figure 3: Internal bond of EMDI particleboard at different press factor.

3.3 Screw withdrawal (Surface and Edge).

Screw withdrawal is to determine the holding power of screw inserted to the surface or edge of particleboard. It is crucial especially for furniture industry as normal particleboard joining method is by using either dowels insertion or screw insertion. Screw withdrawal depends to the internal bond strength because the holding strength is measured in perpendicular forces.

Screw face is to demonstrate the strength of screw holding at the surface layer. Screw edge demonstrates the strength of screw hold at core layer. It was found that screw face has higher strength compared to the screw edge. This is because of surface layer has better strength due to higher cross linking of urethane. Higher heat received during press and higher density at surface layer compared to the core layer.

Figure 4 shows that screw edge is reduced at lower press factor. This is explained by shorter curing time once press was operated at lower press factor. The screw edge holding was reduced from 940N to 880N at PF 15.0s/mm and 13.5s/mm respectively.

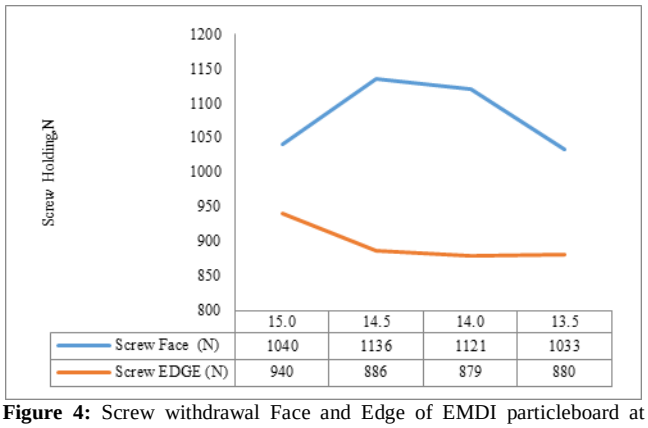

Figure 4: Screw withdrawal Face and Edge of EMDI particleboard at different press factor.

3.4 Thickness Swelling and Moisture Content

Thickness swelling is the ability of particleboard to adsorb the water. Lower thickness swelling demonstrated the resistance of particleboard from deform due to the present of water. Generally, thickness swelling of particleboard bonded with EMDI for all press factors are lower compared to standard particleboard in the market. At 2 hrs and 24 hrs immersion in water, highest swelling recorded at PF 13.5s/mm is 1.02% and 4.6%. It might due to the shorter curing time during pressing (Figure 5).

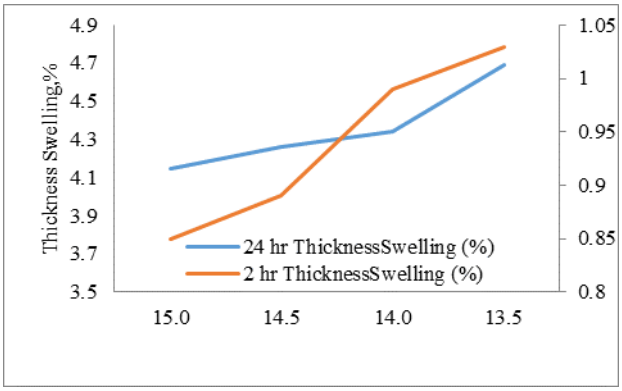

Figure 5: 2 hrs **t**hicknesses swelling of EMDI particleboard at different press factor.

water added during blending. Water was added during blending to control the mat moisture to form a mat cake. During pressing, the amount of water was decreased due to the condensation during heating and press process. However not all of water can be released in hot press.

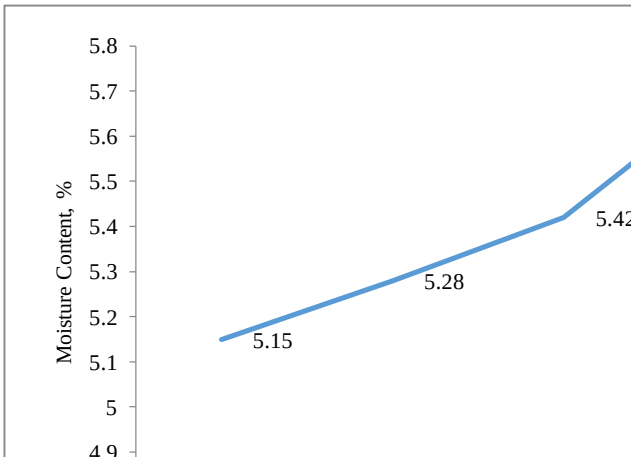

Figure 6: Moisture Content of EMDI particleboard at different press factor.

From Figure 6, lower press factor shows higher moisture content. However, the moisture content at 13.5s/mm drastically increased due to the higher density of particleboard. It was caused by the low evaporation of water due to the higher compactness of board. In addition to that, the exposure to heat is shorter due to shorter pressing time.

3.5 Formaldehyde Emission

Conventional particleboard was bonded using urea formaldehyde. Therefore, formaldehyde emission is emitted from the remaining formaldehyde from condensation reaction and from rubber wood sugar's hydrolysis. Since EMDI was used in this research, formaldehyde is expected to be released by hydrolysis reaction of wood. Two cycle of formaldehyde emission were performed using desiccator methods. From Figure 7, generally, it shows that EMDI particleboard formaldehyde emission is extremely low compared to the conventional urea formaldehyde binder's board. After 7 days of conditioning, EMDI particleboard samples had higher emission of formaldehyde compared to the 14 days due to the reduction of hydrolysis process in rubber wood combined with the high temperature of heat and water during pressing. Conditioning after pressing provides time to the particleboard to release formaldehyde naturally. Press factor did not contribute any significance data of emission in both 7 days and 14 days of conditioning.

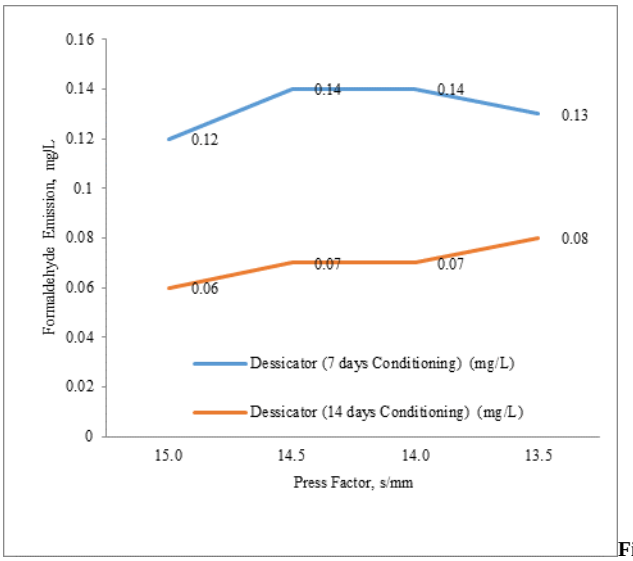

Figure 7: Formaldehyde emission of EMDI particleboard at different press factor.

4. Conclusion

This study found that formaldehyde emission of rubberwood particleboard bonded with EMDI is extremely low at approximately 0.1mg/L using JIS A 1460 test method. It is three times lower than mean requirement of F**** particleboard which is 0.3mg/L as required in JIS 5908. As emission level is very low, press factor does not contribute significance data of emission in both 7 days and 14 days conditioning. Bending, MOE, IB and screw edge holding or rubber wood particleboard bonded using EMDI were reduced when press operated from slower to faster operation speed (higher press factor to lower press factor). Higher press factor demonstrated longer pressing time which contribute to the higher heat transfer supplied into the board between the hot steel belts. It reflects the curing time of the EMDI due to the curing of isocyanate is based as *in-situ* polymerization to form a network between EMDI and wood. Shorter curing time given to the EMDI during pressing process will reduce the crosslinking density of EMDI and wood. Core layer received least heat compared to the SL top and bottom layers. This condition will limit the in-situ reaction between isocyanate and wood to form urethane linkage particleboard reduced at lower press factor. This is due to the limitation of heat received to the core layer. Subsequently this also explains the increment of thickness swelling results as well as higher board moisture content.

Acknowledgements

The authors were thankful to HeveaBoard Berhad for allowing full access of plant operation equipment and laboratory to be use for this project. The research also involved plant operation staff, Hunstman team, and several equipment modification and installation to make EMDI particleboard in pilot scale successful. Furthermore, raw material supplies and cost of capacity loss in development of this product has been borne by the company. This includes all Universiti Teknologi MARA and Universiti Kuala Lumpur lecturers and students for expertise and guidance given throughout the project.

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