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Original Article

Effect of Panel Density and Resin Content on Properties of Medium Density Fiberboard[1]

Min-Kug Hong[2] · Muhammad Adly Rahandi Lubis[2] · Byung-Dae Park[2,3†]

ABSTRACT

This study was conducted to evaluate the effect of panel density and resin content on properties of medium density fiberboard (MDF) to obtain some insights on MDF properties as a function of panel density and resin content. MDF panels with different panel densities such as 650, 700, 750 and 800 kg/m^3 were manufactured by adjusting the amount of wood fibers in the mat forming. MDF panels were also fabricated by spraying 8, 10, 12, and 14% of urea-formaldehyde (UF) resins onto wood fibers in a drum-type mechanical blender to fabricate MDF panels with a target density of 650 kg/m^3. As the panel density and resin content increased, the internal bonding (IB) strength of MDF panel consistently increased. Modulus of rupture (MOR), modulus of elasticity (MOE) and screw withdrawal resistance (SWR) had a similar trend to the IB strength. In physical properties, thickness swelling (TS) and water absorption (WA) decreased with an increase in both panel density and resin content. In addition, the formaldehyde emission (FE) which increased as the panel density and resin content became greater. In overall, the panel density of MDF had more significant effect than the resin content in all properties of MDF panels, indicating that it was better to adjust the panel density rather than the resin content for MDF manufacture.

Keywords : medium density fiberboard, panel density, resin content, properties

1. INTRODUCTION

In recent years, there is a large demand for wood-based composite panel, such as plywood, particleboard, and fiberboard in many countries. Fiberboard is a wood-based composite product formed by combining wood fibers with a binder and by hot-pressing the mixture under high temperature and pressure (Thoemen *et al*., 2010). In general, fiberboard can be classified depending on panel density. Low-density fiberboard has a density less than 400 kg/m^3, medium density fiberboard (MDF) has a density range of 400～800 kg/m^3, high-density fiberboard called (HDF) has a density range of 800～1100 kg/m^3 (Suchsland and Woodson, 1986). The first commercial mass production of MDF has been made in 1965 in Deposit, New York, United States of

[1] Date Received June 29, 2017, Date Accepted July 15, 2017
[2] Department of Wood and Paper Sciences, Kyungpook National University, Daegu 41566, Republic of Korea
[3] Institute of Agricultural Science and Technology, Kyungpook National University, Daegu 41566, Republic of Korea
† Corresponding author: Byung-Dae Park (e-mail: byungdae@knu.ac.kr)

America (Raddin and Brooks, 1965; Williams, 1995). Since then, its global production rapidly increased, owing to its greater tolerance of raw materials, uniform properties, and outstanding secondary processability. In addition, homogenous edges of MDF allow precise machining and finishing techniques to be applied. Thus, MDF is an excellent substitute for solid wood in many interior and exterior applications such as furniture, cabinets, molding, window, door frames and wall paneling.

There are several parameters influencing the properties of MDF, and it can be classified into three categories. Firstly, wood-related parameters are wood species, density, fiber length, moisture content (MC) of fiber, strength of the fiber tissue, wettability of fiber surface, and surface free energy (Cai *et al*., 2006). Secondly, resin-related parameters include resin types, resin reactivity, chemical structure and composition of resin, degree of condensation, molar mass distribution, formaldehyde/urea (F/U) mole ratio, viscosity, level of adhesive spread, and rate of resin curing (Chow and Zhao, 1992). Thirdly, manufacture process-related parameters are hot-pressing temperature, applied pressure, and press time, mat moisture content (MC), and assembly time (Déneši *et al*., 2012). In particular, panel density and resin content could be the most important factors, affecting the properties of MDF.

The panel density of MDF is a significant factor that influences MDF performance and cost production. High panel density generally requires a greater amount of materials, including fiber, resin, and wax. Panel density is also closely related to the rate of compression of panel (Cai *et al*., 2006). An increase in the panel density and high rate of compression of panel resulted in an increase in the bond strength. A lot of researches have been conducted to investigate the effect of panel density on the MDF properties. Wong *et al*. (2000) reported that an increase in the panel density of MDF led to a corresponding increase in the internal bonding (IB) strength, modulus of rupture (MOR), modulus of elasticity (MOE), and screw withdrawal resistance (SWR), and concluded that these properties of MDF were entirely dependent on the core density and mean density. In addition, the interrelated effect of various mat MCs on manufacturing MDF panels with different target densities was also done by Cai *et al*. (2006). They reported that the maximum core steam pressure and core temperature generated during hot-pressing were shown to be linearly related with panel density and mat MC. Both panel density and mat MC influenced to the IB strength. In addition, they found that the delamination of MDF panel was occurred when the mat MC exceeded 15.3% after the resin blending. Therefore, the optimized mat MC for maximum IB strength was shifted to lower values when the panel density increased.

In MDF manufacturing, resin represents at least 29% of the cost of a panel. Resin efficiency is a significant factor that influences cost and performance of MDF (Cyr *et al*., 2006). The resin should have sufficient cure by the end of the hot-pressing. The mobility of the resins can influence its distribution and penetration in the wood cells during the hot-pressing. Bond strength due to resin curing and its interaction with the wood fibers is crucial for the physical and mechanical performance of the panel (Thoemen *et al*., 2010). After pressing, the resins can be found either covering the fibers surface as a coating or having penetrated within the fiber.

Although many researches on the influence of MDF panel density have been done, however, studies regarding properties of MDF depending on panel density and resin content have not been investigated yet. Therefore, this study was performed to investigate the influence of panel density and resin content to MDF properties and to extrapolate the physical and mechanical properties of MDF as function of panel density and resin content.

2. MATERIALS and METHODS

2.1 Materials

Virgin fibers were made of Pitch pine (*Pinus rigida* Mill.), and produced by refiner method. Urea-Formaldehyde (UF) resins (61% solid) and emulsion wax (40% solid) were used as bonding agent. All materials were supplied from a commercial MDF mill (Hansol Home Deco, Iksan, Republic of Korea).

2.2 Methods

2.2.1 MDF Preparation

To produce MDF panels at different panel densities, 12% of UF resins based on the oven-dry mass of fibers were sprayed onto wood fibers in a drum-type mechanical blender at different target densities of 650, 700, 750 and 800 kg/m^3. Approximately 1% of emulsion wax was also added. Both the resin and wax were sprayed by peristaltic pump at 50 RPM into a drum blender through an atomized nozzle. The spraying was done with addition of air pressure at 4 kgf/cm^2. Furthermore, the blended fibers were formed into mats through an air blower into a 400 × 300 mm mat forming box. Finally, the pre-pressed mats were hot-pressed at 180℃ under 25 kgf/cm^2 of pressure for four minutes to get the final product. The final thickness was adjusted to 12 mm using two stop-bars in the hot press. The same methods were used to produce MDF panels at different resin contents of 8, 10, 12, and 14% based on the oven-dry mass of fibers with 650 kg/m^3 of the target density.

2.2.2 Determination of MDF Properties

Density, IB strength, MOR, MOE and SWR of MDF were measured by the procedure of a Korean Standard (KS F 3200, 2006). All mechanical properties were measured using a universal testing machine (H50KS, HOUNSFIELD, Redhill, England). TS and WA of MDF samples were also measured by the procedures of the standard. To determine TS and WA, the specimens were soaked for 24 h in water and then measured the thickness and weight after removing water on the surface. Formaldehyde emission (FE) from MDF was also measured by

Table 1. Mat MC of MDF at different target densities

Target panel density (kg/m^3)	Actual panel density (kg/m^3)	Mat MC (%)
650	650	12.2
700	688	13.9
750	743	14.6
800	793	15.6

the standard procedure using the 24 h desiccator method. Furthermore, 300 mℓ of distilled water was prepared in a glass beaker. Subsequently, the specimens were placed in desiccator at 20 ± 2℃ for 24 h. And then, 25 mℓ of aliquot solution was pipetted into 100-mℓ of flask. Subsequently, 25 mℓ of acetyl acetone-acetic acid ammonium solution was added into the flask and then mixed. The solution then was heated for 10 min at 65 ± 2℃ in water bath. Finally, the solution was cooled until room temperature before further analysis. Formaldehyde emission was analyzed using the UV-visible spectrophotometer (Optizen 3220UV, Mecasys, Korea) at 412 nm of wavelength.

3. RESULTS and DISCUSSION

3.1. Effect of Panel Density on MDF Properties

Fig. 1 shows IB strength of MDF samples as a function of panel density. As expected, the IB strength of MDF panels became greater with an increase in the panel density. Furthermore, an increase in the MDF panel density by 1 kg/m^3 led to an increase of the IB strength by 0.0004 MPa. This result indicates that the IB strength

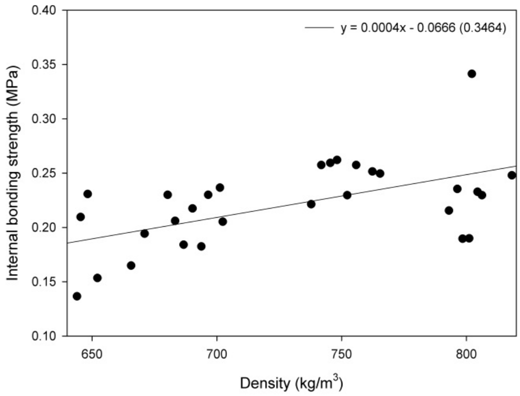

Fig. 1. IB strength of MDF panels at different target panel densities.

of MDF can be improved by increasing the panel density. The reason is probably due to the high rate of compression from high panel density which could increase the contact area between fibers and decrease the pores of fibers (Cai *et al*., 2006). Commonly, higher panel density generated greater mat pressure during the initial hot-pressing stage, which led to the surface mat consolidation. This result could be explained by that higher mat MC was obtained with an increase in the panel density of MDF (Table 1). High mat MC generally results in greater rate of consolidation, faster heat transmission into the core, and higher overall plasticization of the fibers, thus eventually enhances rapid curing of resin and setting of the panel.

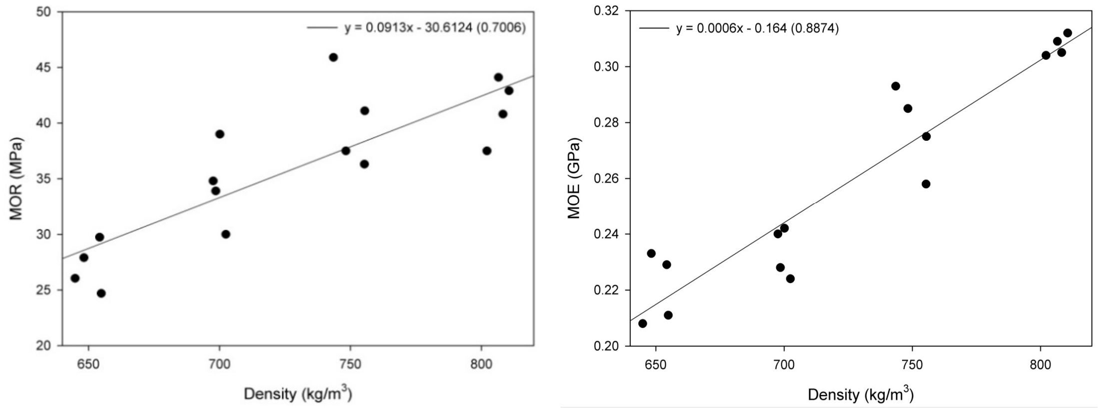

Fig. 2. MOR and MOE values of MDF panels at different target densities.

In addition, a study reported that the rate of moisture diffusion in MDF panels is affected by the moisture level (Koponen, 1984). However, delamination of the panel will probably occur if the mat MC exceeds 15.3% (Cai *et al*., 2006). In addition, several similar results were also reported that panel density of MDF had positive relationship with mechanical properties of the panel (Woodson, 1977; Wong *et al*., 2000). They also pointed that the density was the most important factor affecting the IB strength.

As shown in Fig. 2, both MOR and MOE of MDF panels increased as the panel density became greater. As expected, these results had a positive correlation and similar trend to the IB strength. Based on the correlation, an increase in the panel density of MDF by 1 kg/m^3 led to an increasing of the MOR by 0.0913 MPa and MOE by 0.0006 GPa. This is probably due to higher bending resistance of MDF panel resulted from high panel density. Several works reported that increasing MDF panel density resulted in an increase in bending resistance because of high rate of compression and consolidation (Wong *et al*., 2000; Ganev *et al*., 2005). Thus, these results also showed that the panel density did influence the MOR and MOE of MDF.

Fig. 3 displays the results of SWR of MDF panels which have positive correlation with panel density. The results pointed out that an increase in the panel density of MDF by 1 kg/m^3 led to increasing the surface of SWR by 1.6328 N, the edge of SWR by 1.2370 N, respectively. The SWR of MDF panels also became greater with an increase in the panel density of MDF as same reason IB strength. In addition, some researchers reported that the IB strength had effects on the SWR of MDF panel (Eckelman, 1988; Rajak *et al*., 1993; Cha, 2013).

TS and WA values of MDF panels at different target densities were displayed in Fig. 4. The results showed that both TS and WA had negative correlations with the panel density. This implied that both properties became greater

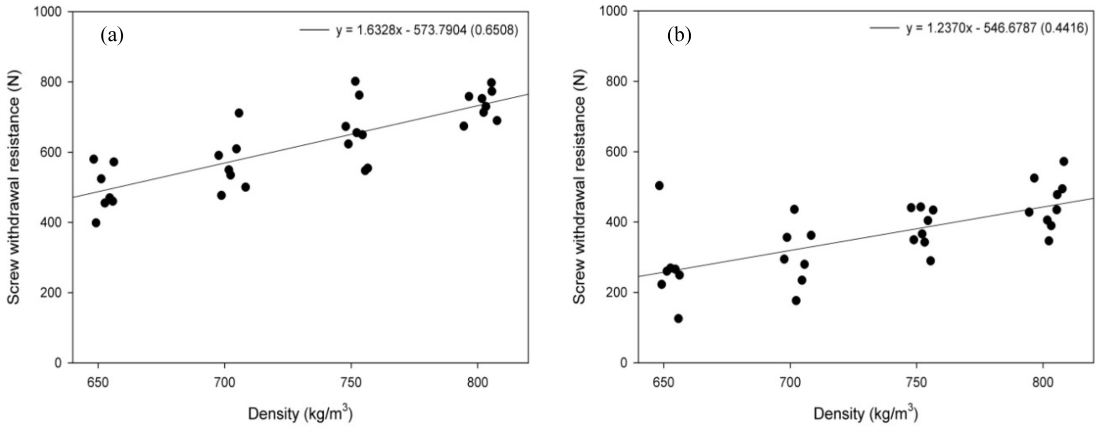

Fig. 3. SWR values of MDF panels at different target densities; (a) Surface SWR, and (b) edge SWR.

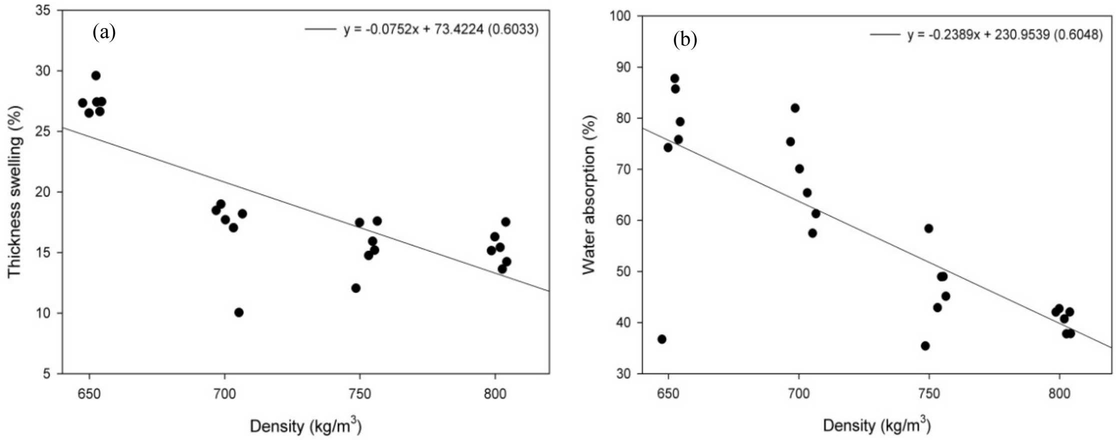

Fig. 4. TS (a) and WA (b) values of MDF panels at different panel densities.

with an increase in the MDF panel density. A further increase in the panel density of MDF by 1 kg/m^3 led to a decrease in the TS by 0.0752%, and the WA by 0.2389%, respectively. These results could be explained by that high rate of compression during hot-pressing resulted in a decrease in the panel porosity. In addition, one of the possible reasons for these results might be due to the prevention of water penetration into the panels by UF resins and wax.

As expected, the FE of MDF panels at different target densities increased as the panel density became higher (Fig. 5). The FE value was in the range of E1 grade level. The result pointed out that an increase in the panel density of MDF by 1 kg/m^3 led to increasing the FE by 0.002 mg/L. This could be explained from mat MC values which became greater with an increase in panel density. An increasing of the mat MC leads to higher mat compression dur-

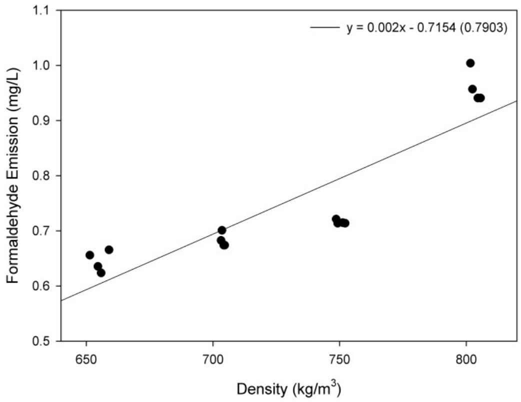

Fig. 5. FE value of MDF panels at different panel densities.

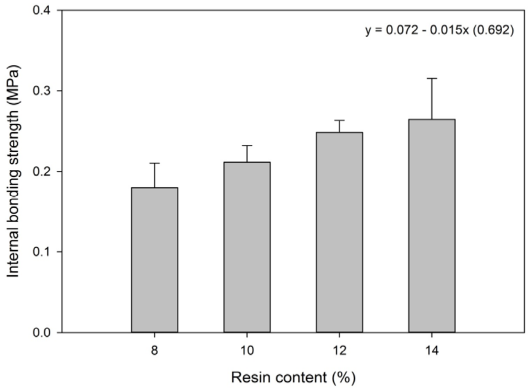

Fig. 6. IB strength value of MDF panels at different resin contents.

ing hot-pressing, which consequently increases the panel density of MDF (Table 1).

3.2. Effect of Resin Content on MDF Properties

The resin content is another parameter of controlling MDF properties. Higher strength and dimensional stability are normally expected with greater resin content. However, the minimum amount of resins is normally used by taking high cost of resins into consideration. Thus, we attempted to investigate the effect of resin content on MDF properties. As shown in Fig. 6, IB strength has a positive correlation with resin content. The result displayed that the IB strength value could be improved by 0.015 MPa with an increased in the resin content by 1%. When the impact of the panel density and resin content was compared, this study found that the effect of resin content was more significant than panel density. The resin content had an R^2 of 0.692 (Fig. 6) whereas the panel density had only 0.346 (Fig. 1). This finding is compatible with the results reported by Thoemen *et al*. (2010). They found that IB strength due to resin curing and resin interaction with the wood fibers was much more critical for the physical and mechanical performance of the panel.

Fig. 7 displays both MOR and MOE values, which have positive correlations with resin content. This shows that MOR and MOE values are getting higher by increasing the resin content on the panel. In particular an increase in the resin content by 1% led to an increase of MOR by 1.16 MPa and MOE by 0.0045 GPa, respectively. However, MDF panels made of different resin contents had lower MOR and MOE values compared to those made of different panel densities. Both MOR and MOE values of MDF made of different target densities also had higher R^2 compared to those made of different resin contents. The R^2 of MOR and MOE values of MDF made of different target densities are 0.700 and 0.887, respectively

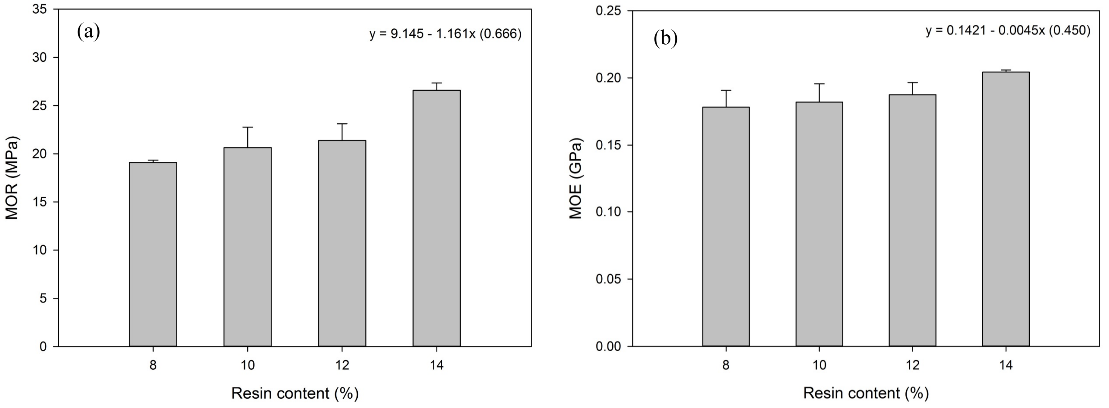

Fig. 7. Properties of MDF panels at different resin contents; (a) MOR and (b) MOE.

(Fig. 2); whereas for MDF made of different resin contents are 0.666 and 0.450, respectively (Fig. 7). Higher panel density commonly generated greater mat compression during the initial hot-pressing stage, which eventually led to higher surface mat consolidation, and then resulted in high MOR and MOE values (Cai *et al*., 2006).

Further evaluation was accomplished to evaluate the effect of different resin content on both surface and edge screw withdrawal resistance (SWR) values of MDF panels. The results showed that both surface and edge SWR values had positive correlations with resin content (Fig. 8). Surface SWR had a higher value than that of the edge SWR. The results showed that an increase of the resin content in MDF by 1% led to an increase in the surface of SWR by 15.263 N, and the edge of SWR by 11.935 N, respectively. As mentioned earlier, the SWR of MDF panels also became greater with an increase in IB strength. In addition, some researchers reported that the IB strength had positive effects on the SWR of MDF panel (Eckelman, 1988; Rajak *et al*., 1993; Cha, 2013). However, we found that both surface and edge SWR values of MDF made of different resin contents had lower R^2 compared to those made of different target densities. The R^2 of surface and edge SWR values of MDF made of different target densities were 0.651 and 0.442, respectively (Fig. 3); whereas for MDF made of different resin contents were 0.396 and 0.126, respectively (Fig. 8). This indicates that panel density gives more significant impact to the surface and edge SWR compared to that of the resin content.

Thickness swelling (TS) and water absorption (WA) are the properties to assess the water soaking and dimensional stability of MDF panel. It is expected that both TS and WA values decreases linearly with an increase in the resin content. Fig. 9 displays that TS and WA values could be improved by 0.76% and 2.92%, respectively, with an increase in the resin content by 1%. This improvement could be due to

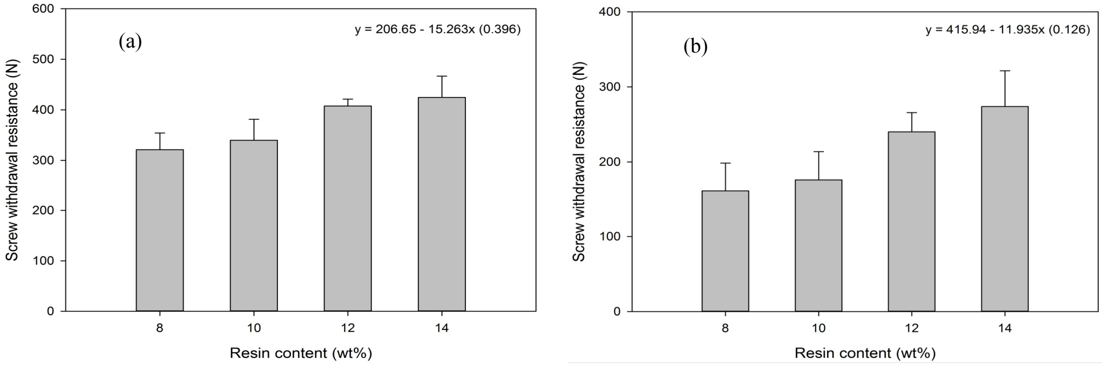

Fig. 8. SWR values of MDF panels at different resin contents; (a) Surface SWR and (b) edge SWR.

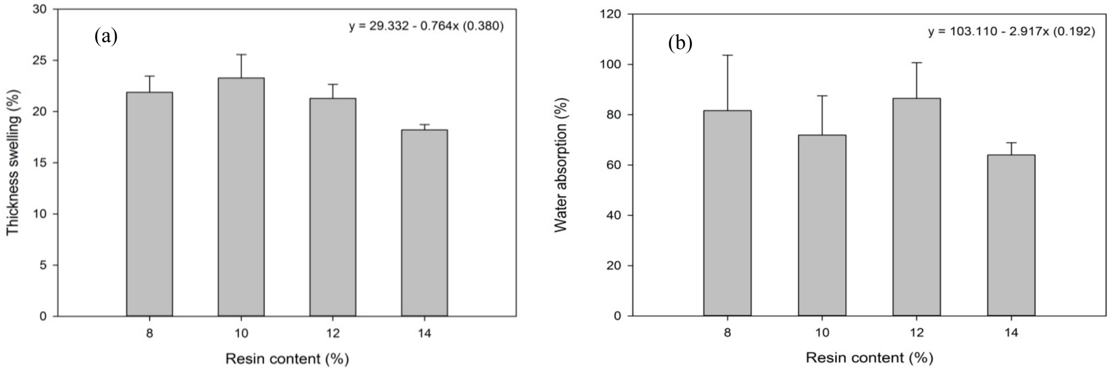

Fig. 9. TS (a) and WA (b) of MDF panels at different resin contents.

that greater resin content provided more bonds between fibers which prevented water absorption. These bonds between fibers upon the resin curing could improve the dimensional stability of MDF panel (Ali *et al*., 2013; Cai *et al*., 2006). However, we found that both TS and WA values of MDF made at different resin contents had lower R^2 compared to those made at different panel densities. The R^2 of TS and WA values of MDF made of different panel densities are 0.603 and 0.605, respectively (Fig. 4); whereas those values are 0.380 and 0.192, respectively, for MDF made at different resin contents (Fig. 9). This indicates that the panel density has more significant impact to the surface and edge SWR compared to the resin content.

Higher resin content obviously emitted more formaldehyde emission (FE) from MDF panel (Fig. 10). However, we found that the FE value of MDF made of different resin contents was below the E1 grade level (≤ 1.5 mg/ℓ). The result also showed that an increase in the resin content by 1% led to an increase in the FE of MDF by 0.035 mg/ℓ. Several studies have reported that UF resins can be found either cov-

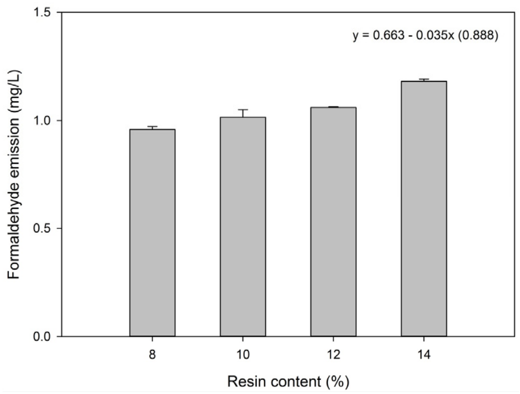

Fig. 10. FE value of MDF panels at different resin contents.

ering the fibers surface as a coating or having penetrated within the fibers after hot-pressing (Xing *et al*., 2004; Grigsby *et al*., 2004). The resins then emitted formaldehyde from MDF panel.

4. CONCLUSION

This study was conducted to understand the influences of the panel density and resin content to the properties of MDF panels. The following conclusions were obtained from this study:

1. Mechanical properties of MDF can be improved by increasing panel density and resin content. An increase in these two parameters improved IB strength of MDF MOR, MOE and SWR values also had positive correlations to these parameters and had similar trend to the IB strength.
2. Physical properties of MDF can also be improved by increasing panel density and resin content. TS and WA of MDF panels had a negative correlation to these parameters, indicating that the dimensional stability of MDF was improved by increasing panel density and resin content.
3. As the panel density and resin content of MDF increase, the FE values of MDF panels consistently increase. In this study, all MDF panels had FE values in the range of E1 grade level.
4. The panel density of MDF had more significant effect than the resin content in all properties of MDF panels.

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