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Full Length Research Article

Hydrolytic Stability of Sengon-Oriented Strand Board Bonded with Hybrid Phenol-Formaldehyde/Polymeric Methylene Diphenyl Diisocyanate Adhesives

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ABSTRACT

The hydrolytic stability of oriented strand board (OSB) is critical to guarantee good performance in humid conditions over the long term. The adhesive system impacts hydrolytic stability in addition to the wood strands. This study aims to investigate the hydrolytic stability of OSB bonded with a hybrid adhesive based on phenol-formaldehyde (PF) and polymeric methylene diphenyl diisocyanate (pMDI) modified with NaOH and $CaCO_3$ catalyst. PF was mixed with each catalyst at approximately 1% of the PF solids content. The pMDI was added to the mixture at 2.5% and 5% of the PF solid content. The hybrid PF/pMDI adhesives were then used for OSB production. The hydrolytic stability of OSB samples was tested at 25°C and 100°C and compared with OSB using unmodified PF as a control. After hydrolysis, OSBs with hybrid PF/pMDI adhesives had lower weight loss than control adhesives at both temperatures. The pH indicates no significant polymer dissolution from the board into the hydrolysis solution. Hybrid PF/pMDI adhesives with a $CaCO_3$ catalyst obtain significantly lower thickness swelling values. The findings of this study have significant implications for developing high-performance, environmentally-friendly OSB products.

1. Introduction

Oriented strand board (OSB) is a lignocellulosic composite widely used as a construction material due to its structural integrity and cost-effectiveness. OSB was made from parallel arranged strands mixed with thermosetting adhesives that are hot pressed (SBA 2005). The prospects for OSB product development are increasingly attractive. World OSB consumption in 2018–2022 increased from 32.1 million m^3 to 37.7 million m^3, with the highest growth in that period occurring in the Asian Region, up to 175% (FAO 2024). The increase may be related to the advantages of OSB, including an easy manufacturing process, overcoming knot defects in raw materials, homogeneous characteristics, properties isotropic, abundant in supply, cheap in price, and quite high shear strength (Febrianto et al. 2017; Shmulsky and Jones 2011).

Although OSB consumption continues to increase, commercial OSB production in Indonesia has not been reported. Several studies have developed OSB using sengon wood as raw

material (Baskara et al. 2022; Hidayat et al. 2011; Maulana et al. 2024). The potential use of sengon wood as raw material for OSB is rated quite well. Sengon is one of the largest produced fast-growing wood species in Indonesia, with total production reaching 152,014 m^3 (BPS 2022). One of the advantages of sengon wood for OSB production is the low variation in wood strand density. This is because sengon wood has diffuse-porous vessels, so the density of the wood is not particularly influenced by changes in growth rate (Alia-Syahirah et al. 2019). In addition, higher surface wettability is usually exhibited by wood with diffuse-porous vessels (Laskowska and Kozakiewicz 2017), an advantage that benefits the OSB bonding process.

The adhesive is an important factor in making OSB. The use of 10% phenol formaldehyde (PF) adhesive content on steam-pretreated sengon OSB produces great OSB dimensional stability and meets the CSA 0437.0 standard (Grade O-1) but has low internal bonding (IB) (Maulana et al. 2024). PF resins have been widely utilized in the wood sector because of their exceptional water resistance (Hunt et al. 2010). Meanwhile, sengon OSB with 3–7% polymeric methylene diphenyl di-isocyanate (pMDI) adhesive content shows good mechanical properties but has low dimensional stability (Baskara et al. 2022). Malanit et al. (2010) stated that pMDI adhesives could improve bonding strength and hydrolytic stability. Although the adhesives used in manufacturing OSB panels may possess waterproof properties, the wood material is not inherently waterproof. Consequently, when OSB panels are subjected to prolonged direct exposure to water, they inevitably absorb water and subsequently undergo swelling, thereby reducing the hydrolytic stability of the panel.

Hydrolytic stability pertains to the capacity of a substance to endure and withstand chemical breakdown when in contact with water. Hence, it is imperative to design adhesives that can endure hydrolytic breakdown to enhance the moisture resistance of OSB. There are multiple approaches to enhance the performance of adhesives. Previous studies show that PF adhesive with NaOH and $CaCO_3$ catalysts can increase adhesive strength values and meet SNI 01-5008.2 standards (Fitrianum et al. 2023). In addition, considering the respective advantages of PF and pMDI adhesives in previous studies, modification of the adhesive system on sengon OSB using both adhesives may result in better adhesive performance by leveraging their complementary properties. However, the hydrolytic stability of PF adhesive with the addition of NaOH and $CaCO_3$ catalysts and the employment of the PF/pMDI hybrid adhesive system to sengon OSB has not been reported to date.

This study investigated the hydrolytic stability of OSB panels bonded with a hybrid PF/pMDI adhesive system. The assessment included measuring the change in weight loss, pH, water absorption, thickness swelling, and functional group of the OSB after hydrolysis. Furthermore, the results of this study could optimize the utilization value of sengon wood as raw material for durable and water-resistant OSB products with greater hydrolysis stability, which provides a significant economic impact.

2. Materials and Methods

2.1. Materials

The primary material used in this research is sengon (*Paraserianthes falcataria* (L.) Nielsen) wood strands. Sengon logs for making strands were harvested from local plantation forests in Bogor, Indonesia. The adhesive used was PF with a solids content of 47.39% (PT.

Pamolite Adhesive, Probolinggo, Indonesia). Other materials used include liquid paraffin, distilled water, 20 w/v% NaOH, and 20 w/v% $CaCO_3$, obtained from a local chemical store in Bogor, Indonesia. A solution of pMDI with a solids content of 99.47% was purchased from PT. Anugerah Raya Kencana in Serpong, Indonesia.

2.2. Characterization of Hybrid PF/pMDI Adhesives

Hybrid PF/pMDI adhesive was formulated under five different circumstances, as outlined in **Table 1**. Two catalysts, NaOH (20% w/v) and $CaCO_3$ (20% w/v) solution, were prepared by combining 200 g of technical grade NaOH and technical grade $CaCO_3$, respectively, with 1000 mL of distilled water. The fundamental characteristics of hybrid PF/pMDI adhesives were assessed, including their solids content, viscosity, pH, and gelation time. Each measurement was carried out in three repetitions.

The solids content was determined by dehydrating 1 g of the sample in an oven at 105°C for 3 hours. The weight after dehydration was divided by the original weight. The mean viscosity of hybrid PF/pMDI adhesives was measured using a rotational rheometer (RheolabQC, AntonPaar, Austria) with a spindle No. 27 at a temperature of 25 ± 2°C and a constant shear rate of 100 s^{-1} for a duration of 120 s. The gelation time of hybrid PF/pMDI adhesives was determined by immersing them in boiling water and measuring the time it took to solidify using a gelation time meter (GT-6, Techne Inc., USA) at a rotation speed of 10 rpm. The pH of hybrid PF/pMDI adhesives was measured at 25 ± 2°C using a digital pH meter (OrionStar A111, ThermoScientific, USA).

Table 1. Adhesive formulation of neat PF and Hybrid PF/MDI

Type of Hardener	PF resin (g)	NaOH (g)	$CaCO_3$ (g)	pMDI (g)
Control	100	-	-	-
N-2.5	100	2.5	-	1.2
N-5.0	100	2.5	-	2.5
C-2.5	100	-	2.5	1.2
C-5.0	100	-	2.5	2.5

The change in functional groups of liquid and cured PF/pMDI adhesives was examined using Fourier transform infrared (FTIR) spectroscopy (SpectrumTwo, Perkin Elmer Inc., USA). The samples were analyzed using the Attenuated Total Reflectance (ATR) method at 25 ± 2°C. The analysis was conducted over 400 to 4000 cm^{-1} with an average of 16 scans at a resolution of 4 cm^{-1} for each sample. The examination was carried out in three repetitions.

2.3. Fabrication of OSB Bonded with Hybrid PF/pMDI Adhesives

The Sengon wood strands underwent steam treatment in an autoclave at 126°C and a pressure of 0.14 MPa for an hour. The strands were left to dry in the air for approximately five days and then placed in an oven at 60°C for approximately 14 days until the moisture content dropped to less than 5%. OSB panels with dimensions (length × width × thickness) of 25.0 cm × 25.0 cm × 1.2 cm were produced using different PF/pMDI adhesive formulations, as shown in **Table 1**. The sengon wood strands were mixed with 10% hybrid PF/pMDI resin content. About 1% of liquid paraffin was applied as wax relative to the weight of the sengon wood strands. The

strand mats were subsequently created with a shelling ratio of 1:2:1 (Maulana et al. 2019). The mats underwent a hot-pressing process at 170°C, with a precise pressure of 2.45 MPa for 9 minutes. The OSB panels were subjected to a controlled environment with a temperature of 25–30°C and a relative humidity of 60–65 % for approximately 14 days until they achieved a moisture content that was in equilibrium with their surroundings.

2.4. Hydrolysis of OSB

Samples with dimensions of approximately 1 cm × 1 cm × 1.2 cm were extracted from OSB panels. The samples were submerged in water at a weight ratio of 1-part OSB sample to 10-part water. The hydrolysis of OSB was conducted in triplicate at temperatures of 25°C and 100°C for an hour, with continuous stirring at a speed of 200 rpm (Hotplate Stirrer MS H280 Pro, DLAB Scientific, China). The solid suspension underwent filtration utilizing a vacuum filter system and a Whatman filter paper No.1 with a diameter of 90 mm (Whatman 1 Cat #1001-090, Cytiva, USA). Afterward, the solid suspension was dried in an oven at 105°C for 3 hours.

2.5. Evaluation of Hydrolytic Stability of OSB

The stability of OSB against hydrolysis was assessed by measuring the weight loss, pH, water absorption, thickness swelling, and functional group changes of OSB following hydrolysis. The weight reduction was determined using the approach described by previous studies (Lubis et al. 2019a, 2020, 2021). The acidity of the hydrolyzed filtrate was measured using a digital pH meter (OrionStar A111, ThermoScientific, USA). The alterations in functional groups of OSB following hydrolysis were examined utilizing FTIR spectroscopy (SpectrumTwo, Perkin Elmer Inc., USA). The samples were analyzed using the Attenuated Total Reflectance (ATR) method at 25 ± 2°C. The analysis was conducted over 400 to 4000 cm^{-1} with an average of 16 scans at a resolution of 4 cm^{-1} for each sample.

2.6. Data Analysis

The obtained data were analyzed using a completely randomized design with two factors: the type of catalyst and the level of pMDI added to the PF adhesive. Each treatment was carried out three times. The analysis of variance (ANOVA) with a confidence level of 95% was carried out using Microsoft Excel 2019 (Microsoft Excel, Microsoft, USA) and IBM SPSS Statistics 20 (IBM SPSS Statistics 20, SPSS Inc., USA). Duncan's Multiple Range Test (DMRT) was carried out to determine the significant differences between treatments on parameters that showed a significant effect.

3. Results and Discussion

3.1. Properties of Hybrid PF/pMDI Adhesives

The adhesive solids content quantifies the quantity of particles present in the glue. Increasing the number of adhesive particles that interact with the wood during the gluing process will enhance the bond's strength. **Table 2** displays the mean solids content values obtained from the control and treated PF glue experiments. The control PF adhesive had an average solids content of 46.00%, whereas the hybrid PF/pMDI with different catalysts resulted in a solids content ranging from

46.78% to 47.62%. The analysis of variance (ANOVA) reveals that only the catalyst types significantly affect the resultant solids content, and the pMDI content and the interaction between variables do not significantly affect it. Duncan's multiple range tests showed that each solids content of the control PF adhesive, hybrid PF/pMDI N, and hybrid PF/pMDI C were significantly different, with the control adhesive having the lowest value and the hybrid PF/pMDI N having the highest value. A hybrid PF/pMDI adhesive system could increase the solids content compared with the standard solids content for PF adhesives, around 40–45% (BSN 1998). The solids content of hybrid PF/pMDI is also clearly higher than PF modified only by adding 1% NaOH and $CaCO_3$ catalyst, which reduces the solids content to 44.1–44.5% (Fitrianum et al. 2023). The higher value of solids content of PF/pMDI N could be caused by stronger basic properties and the very reactive nature of NaOH compared to $CaCO_3$ (Amin 2019), making it possible for hybrid PF/pMDI adhesives with a NaOH catalyst to harden faster and the particle content to be higher is related to the condensation reaction in the adhesive. In addition, the acidity factor plays a significant role in the bonding process, especially if the material being bonded contains high extractive materials (Maulana et al. 2021).

The time needed for the accelerator to transform the adhesive into soft gel is known as the gelation time. **Table 2** displays the outcomes of the adhesive's gelation time test at 135°C. Analysis of variance shows that the type of catalyst used in the PF/pMDI hybrid adhesive significantly affects gelation time. In contrast, the level of pMDI and interactions between factors have no significant effect. The average gelation time of PF/pMDI hybrid adhesive with NaOH catalyst was 9.35 minutes, and the average gelation time of PF/pMDI hybrid adhesive with $CaCO_3$ catalyst was 11.62 minutes. The gelation time of the PF/pMDI hybrid adhesive was shorter than that of the control PF, which had a gelation time of 14.17 minutes. Based on Duncan's multiple range test, each gelation time value of control PF, PF/pMDI N, and PF/pMDI C differed significantly. The faster gelation time suggests less hot pressing is required in the composite panel manufacturing process for the adhesive to cure. However, the adhesive will coagulate more quickly due to the short gelation time, which will reduce the adhesive's shelf life (Santoso et al. 2019). SNI 06-4567 states that the gelation time for PF storage is around 30–60 minutes at 25°C (BSN 1998). This is also related to the value of the resulting solids content, where the value will be inversely proportional. The higher the solids content of an adhesive, the shorter the gelation time (Fitrianum et al. 2023).

The average viscosity value affects the adhesive's shelf life and capacity to enter the wood's pores. High solids content and high viscosity adhesives could establish optimal bonding, leading to adequate adherence (Maloney 1993). The viscosity values of hybrid PF/pMDI adhesives with various treatments tested at room temperature (25°C) are shown in **Table 2**. The results of the ANOVA showed that the interaction between the factors of catalyst type and pMDI content significantly influences the adhesive's viscosity and cohesive strength. Duncan's further test results showed that hybrid PF/pMDI adhesives made with different types of catalysts and pMDI concentrations had significantly different viscosities. Hybrid PF/pMDI adhesive with the highest viscosity was made using 2.5% NaOH and pMDI catalyst (N-2.5), followed by control (K), N-5.0, C-2.5, and C-5.0. This can occur due to the addition of a NaOH catalyst, which is very reactive (Amin 2019) and can increase the number of particles contained in the adhesive, as well as the reaction of the PF adhesive with pMDI, which influences the viscosity of the adhesive. A high viscosity value can affect the shelf life of the adhesive, where the higher the value, the shorter the shelf life (Anggini et al. 2022). The standard optimum viscosity value of PF adhesive required by

SNI 06- 4567 is between 130–300 mPa·s at 25°C (BSN 1998). Test results show that PF and hybrid PF/pMDI adhesives at room temperature (25°C) have adhesive viscosity values ranging from 206.62–250.24 mPa·s. This value shows that all adhesive formulas have viscosity values that comply with SNI 06-4567 standards (BSN 1998).

Table 2. Basic properties of PF and Hybrid PF/MDI adhesives

Catalyst Type	Adhesive Characteristics					
	Solids Content (%)	Gelation Time (min) (T=135 ℃)	Average viscosity (mPa·s) (T=25 ℃)		pH	
			pMDI 2.5%	pMDI 5.0%	pMDI 2.5%	pMDI 5.0%
Control	46.00[a]* ± 0.68	14.17[c] ± 0.96	239.48[c] ± 0.67		12.40[d] ± 0.03	
NaOH	47.37[c] ± 0.28	9.35[a] ± 1.54	250.24[d] ± 4.30	219.71[b] ± 5.86	12.35[c] ± 0.01	12.34[c] ± 0.03
$CaCO_3$	46.76[b] ± 0.42	11.62[b] ± 2.03	218.91[b] ± 1.82	206.63[a] ± 6.88	12.12[a] ± 0.04	12.27[b] ± 0.03

Note: * values with different letters were significantly different.

The pH tests are performed to ascertain the adhesive's alkalinity. Furthermore, to sustain the adhesive's curing reaction and allow the liquid adhesive to remain stable during storage, PF adhesive must be kept in an alkaline environment, i.e., pH 10.54 (Fink 2013; Santoso et al. 2019). The results of ANOVA showed that the interaction between the factors of catalyst type and pMDI content significantly affects the pH value. Duncan's further test results showed that hybrid PF/pMDI adhesives made with different catalysts and pMDI concentrations had significantly different pH values. The control adhesive had the highest pH value compared to the other adhesives, while the lowest was the C2.5 adhesive (**Table 2**). A decrease in the pH value occurred when $CaCO_3$ was added due to the natural nature of this catalyst. $CaCO_3$ had a pH of 9.91; thus, it will reduce the final pH value when mixed with PF. The pH value of adhesives with various treatments shows the alkaline properties of the adhesive, and the results obtained comply with SNI 06-4567-1998, namely around 10.0–13.0 (BSN 1998).

3.2. Weight Loss of OSB After Hydrolysis

The weight loss (WL) after hydrolysis at 100°C was much higher than at 25°C (**Fig. 1**). This explains that at higher temperatures, the OSB material will be more easily degraded due to the chemical structural properties of wood, such as extractives and cellulose which are easily degraded starting at 20°C (Lubis et al. 2018, 2020; Purwita et al. 2020). The control OSB provides the highest WL at both temperatures after hydrolysis compared to the WL of OSB with hybrid PF/pMDI adhesives. The results of ANOVA showed that the interaction between catalyst type and pMDI content significantly influenced the WL of OSB at 100°C. Duncan's further test results showed that the OSB bonded with the control PF adhesive had the highest WL and significantly differed from the hybrid PF/pMDI adhesives formula. The OSB bonded with hybrid PF/pMDI adhesives N-2.5 provides the lowest WL due to the very reactive nature of NaOH, thus providing good adhesion bonds with pMDI and greater stability toward hydrolysis (**Fig. 1**).

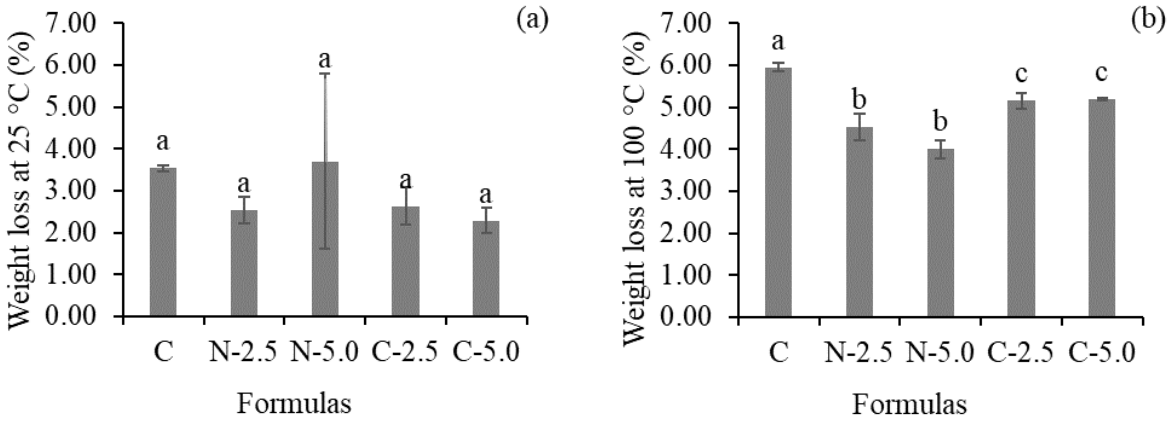

Fig. 1. Weight loss of hydrolyzed OSBs with control PF (C) and hybrid PF/pMDI (N-2.5; N-5.0; C-2.5; C-5.0) at a temperature of (a) 25°C and (b) 100°C. Different lowercase letters above the bar indicate significantly different values.

Hydrolysis at 25°C did not show any variations in values on each factor or interactions between factors. However, adhesives with added $CaCO_3$ provided lower WL values than other formulations. These lower WL values were supported by the phenolic-based nature of PF adhesive, which tends to be more chemically stable, and its hydrophilic properties are higher melamine formaldehyde (MF) and urea-formaldehyde (UF) adhesive. This property makes PF adhesive more resistant to hydrolysis even when applied to wood-based composites.

3.3. pH of the Hydrolyzed Solutions

The pH value of the hydrolyzed solution from the hydrolysis test on OSB bonded with various adhesive formulations ranged from 7.09–7.59 at 25°C and ranged from 7.29–7.88 at 100°C (**Fig. 2**).

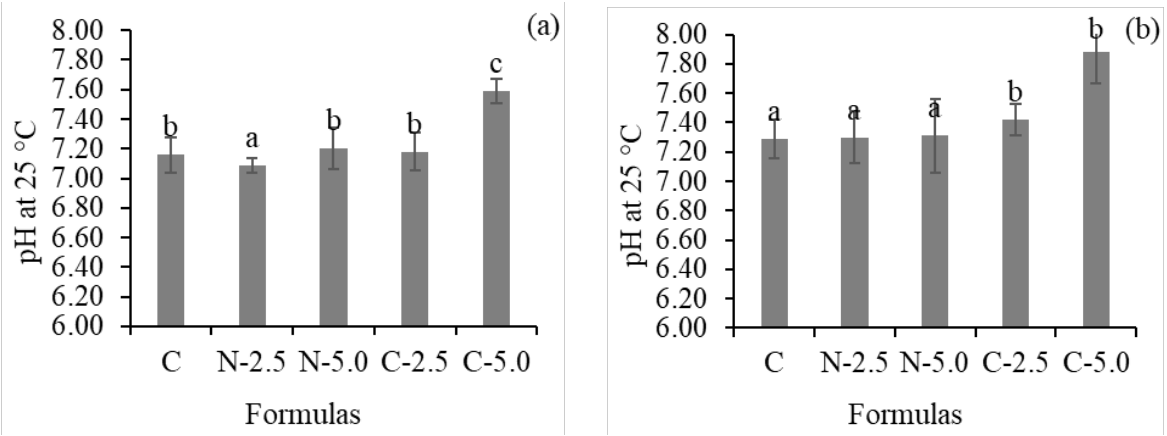

Fig. 2. pH value of hydrolyzed Ca OSBs bonded with PF (C) and hybrid PF/pMDI adhesives (N-2.5; N-5.0; C-2.5; C-5.0) at a temperature of (a) 25°C and (b) 100°C. Different lowercase letters above the bar indicate significantly different values.

The graphs show an increase in the pH value for the OSB hydrolysis solution using adhesive with additional catalyst and pMDI. In particular, OSB bonded with C-5.0 resulted in the highest pH value compared to other adhesives. However, the values obtained are not much different from one another. The average pH value produced is still close to the neutral pH value, meaning there

is no significant polymer dissolution from the board into the hydrolysis solution. This also explains that using hybrid PF/pMDI adhesive on OSB produces good adhesion bonds and correlates with its resistance to water and temperature. The results of the variance analysis show that the interaction between the two factors has a significant influence at 25°C. In contrast, at 100°C, only the catalyst type factor has a significant value.

3.4. Water Absorption and Thickness Swelling of OSB

Water absorption (WA) is one of the parameters determining the dimensional stability of OSB. The WA value of sengon-OSB ranged from 41.53–56.75% after 2 hours of soaking (**Table 3**). The results of the ANOVA showed that the interaction between catalyst type and pMDI content has no significant effect on WA. However, each factor has a significant impact on WA. Duncan's further test results showed that adding the $CaCO_3$ catalyst type significantly differed from the NaOH catalyst, and adding 5.0% pMDI significantly differed from adding 2.5% MDI. This indicates that adding pMDI to the adhesive can increase the resistance to WA of OSB due to forming a urethane bond between pMDI and PF adhesive (Lubis et al. 2019b). The $CaCO_3$ catalyst type provides a lower WA value than the NaOH catalyst (**Table 3**). $CaCO_3$ can act as a catalyst that can reduce the water absorption capacity of composite boards, function as a reinforcement for composite materials, and be useful for increasing stiffness (Laksana and Waluyo 2021).

Table 3. Water absorption of OSBs bonded with hybrid PF/pMDI

Type of catalyst	Level of pMDI			
	0%	2.5%	5.0%	Average
Control *	42.53 ± 1.98	-	-	42.53 ± 1.98[a]
NaOH	-	56.75 ± 3.35	55.45 ± 2.85	56.10 ± 3.10[b]
$CaCO_3$	-	50.34 ± 2.67	36.64 ± 2.75	43.49 ± 2.71[c]
Average	42.53 ± 1.98	53.55 ± 9.01	46.05 ± 2.80	

Note: * values with different letters were significantly different.

Thickness swelling (TS) is the addition of a resulting thickness dimension immersion expressed in percent (%). The TS obtained was 12.58–20.99% after 2 hours of soaking (**Table 4**). As the soaking time increases, the TS value is directly proportional to the WA value. This occurs because the amount of water absorbed by the test sample increases, resulting in the expansion of cell walls and changes in sample dimensions.

Table 4. Thickness swelling of OSBs bonded with hybrid PF/pMDI

Type of catalyst	Level of pMDI			
	0%	2.5%	5.0%	Average
Control *	16.78 ± 2.45	-	-	16.78 ± 2.45[a]
NaOH	-	20.99 ± 4.74	20.5 ± 3.34	20.79 ± 4.04[b]
$CaCO_3$	-	12.58 ± 3.67	14.01 ± 4.50	13.30 ± 4.09[c]
Average	16.78 ± 2.45	16.79 ± 4.21	17.30 ± 3.92	

Note: * values with different letters were significantly different.

The results of the ANOVA showed that the catalyst type factor has a significant influence on TS. In contrast, the pMDI content and the interaction between the two factors do not significantly influence 2-hour TS. Duncan's further test showed that adding the $CaCO_3$ catalyst gave the lowest TS value and was significantly different compared to adding NaOH as a catalyst

to the adhesive (**Table 4**). Hybrid PF/pMDI adhesives with the addition of $CaCO_3$ catalyst provide lower TS values than adhesives with NaOH. This correlates with the properties of $CaCO_3$, which can increase the water absorption resistance of the board and improve the interfacial bond on the board, preventing the formation of cavities in the board and increasing the effectiveness of its adhesive strength.

3.5. Functional Groups of OSB after Hydrolysis

Fig. 3. displays FTIR spectra of hybrid PF/pMDI adhesive after hydrolysis at 25°C and 100°C. A wavenumber of 3600–3200 cm^{-1} indicates the presence of OH groups in the hybrid PF/pMDI adhesive (Lubis et al. 2019b). The phenolic hydroxyl absorption peak is 3300 cm^{-1} (Kopal et al. 2020). The strong absorption peak between 1460–1600 cm^{-1} can be attributed to the C=C stretching vibration of benzene aromatics contained in PF and pMDI adhesives (Talabi et al. 2018). In addition, the absorption peak at 1000–1033 cm^{-1} can be assigned to the aliphatic hydroxyl group of phenol-formaldehyde resin (Alonso et al. 2011; Foyer et al. 2016). Overall, there was no significant difference in intensity between the treatments given to the hybrid PF/pMDI adhesive. Wavenumbers between 1340–1470 cm^{-1} indicate the presence of the CH_2 group, which comes from the CH_2OH compound, a reaction between formalin and phenol (Foyer et al. 2016; Lubis et al. 2019b). There is a change in wavenumber intensity in solid samples after hydrolysis at 100°C compared to 25°C (**Fig. 3b**). Apart from that, at the wavenumber 2922 cm^{-1}, the CH functional group appears, which comes from the CH_2 compound in the solid state (Poljanšek and Krajnc 2005). Another peak at 1435 cm^{-1} can be caused by CH_2 bending vibrations, which indicate the presence of methylene groups in the adhesive due to the reaction between phenol and formalin (Chen et al. 2008; Lee et al. 2003).

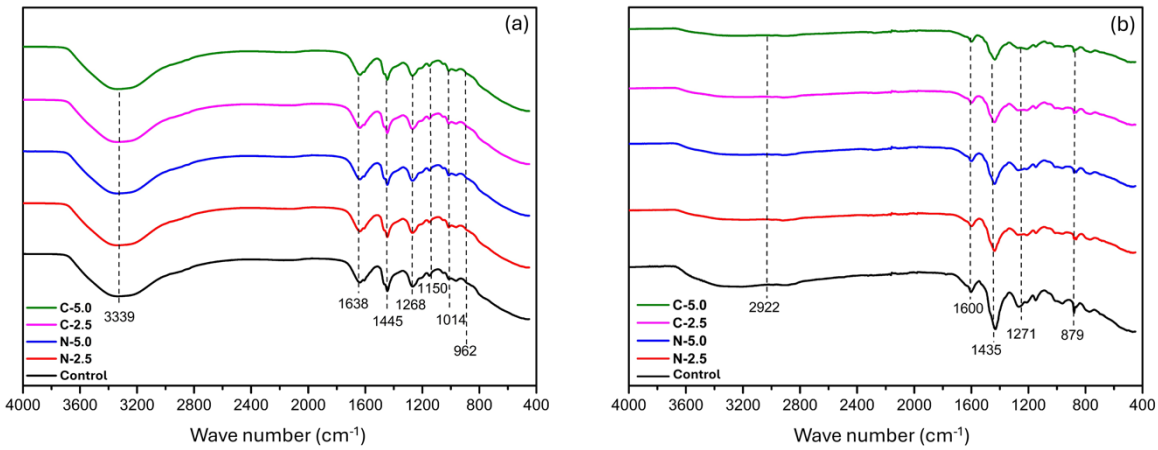

Fig. 3. FTIR spectra of hybrid PF/pMDI adhesive after hydrolysis at (a) 25°C and (b) 100°C.

Functional group analysis was conducted on each OSB bonded with hybrid PF/pMDI adhesive after hydrolysis at 25°C and 100°C. The test results are shown in **Fig. 4**. The phenolic hydroxyl absorption peak located at 3339 cm^{-1} was found in each test sample. The strong intensity was seen in samples of sengon and OSB bonded with control PF (C) adhesive. The strong absorption peak at 3200–3600 cm^{-1} can be attributed to the stretching vibration of the hydroxyl (OH) group (He and Riedl 2004). Wave numbers between 2800-3000 cm^{-1} can be associated with the presence of ring groups (CH) (Hu et al. 2022). The peak located at wave number 1727 cm^{-1} is the stretch of the urethane carbonyl group (C=O), indicating a urethane structure in pMDI adhesive

(Wang et al. 2016). The peak in the range 1050–1300 cm^{-1} is the C–O functional group with solid intensity. Functional group analysis was conducted on each OSB sample with PF-MDI hybrid adhesive before and after hydrolysis tests at 25°C and 100°C. The phenolic hydroxyl absorption peak located at 3331 cm^{-1} was found in each test sample, which can be attributed to the stretching vibration of the hydroxyl (OH) group. Wave numbers between 2800–3000 cm^{-1} can be attributed to the presence of CH groups. Apart from that, the peak located in the range 1030–1300 cm^{-1} associated with C-O-C asymmetric stretching vibrations of aliphatic ethers was found to have a stronger intensity on the hybrid PF/pMDI. The appearance of these bands indicates a cross-linking reaction of the hydroxyl groups between the cell walls and hybrid PF/pMDI resin in OSB (Huang et al. 2020).

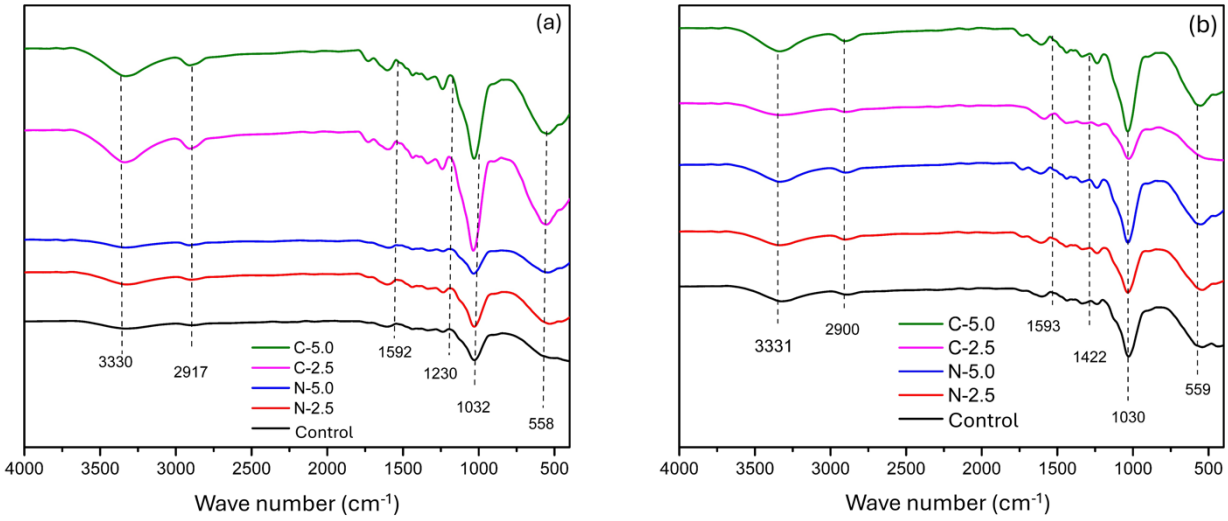

Fig. 4. FTIR Spectra of OSB after hydrolysis at (a) 25°C and (b) 100°C.

4. Conclusions

This work investigates the hydrolytic stability of OSB bonded with a hybrid PF/pMDI adhesives mixed with NaOH (N) and $CaCO_3$ (C) catalyst. OSB bonded with control PF (C) yields the weight loss (WL) after hydrolysis at 25°C and 100°C, compared to the WL of OSB bonded with hybrid PF/pMDI adhesives. The C-2.5 formula had a WL that was not substantially different from the C-5.0 formula. Nevertheless, adhesives using $CaCO_3$ as an additive exhibit lower WL values than other compositions. The pH of hydrolyzed solutions ranged from 7.09–7.88, originating from the PF and pMDI. The phenolic-based composition of PF adhesive supports this claim, as it is known to be more chemically stable and has higher hydrophilic qualities. The results of this study have significant implications for the advancement of high-performance and eco-friendly OSB products.

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