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ORIGINAL ARTICLE

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Properties of particleboard produced using a sealed press

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Abstract In this study, different properties of experimental particleboard produced using a sealed press were determined and were compared with those for particleboard produced using a conventional press. Three types of binder, namely urea formaldehyde (UF), melamine formaldehyde (MUF), and polymethylene diphenyl diisocyanate (PMDI), were used for board production. For the UF-bonded boards produced using the sealed press, the modulus of rupture and the internal bond strength (IB) decreased due to the high temperature and steam pressure used in comparison to the conditions in a conventional press. However, MUF- and PMDI-bonded boards had improved IB and thickness swelling (TS). For the PMDI-bonded boards, especially, the TS was further improved and IB was increased by using a sealed press. PMDI is known to possess superior properties and was confirmed to achieve good properties when used as a binder for particleboards produced using a sealed press.

Key words Particleboard · Sealed press · Melamine urea resin · Polymethylene diphenyl diisocyanate · Thickness swelling

Introduction

It is crucially important that particleboards retain their low thickness swelling (TS). There are two major causes of thickness changes in particleboard: one is the hygroscopic nature of the wood raw materials (particles) and the other is the recovery of compressive deformation of the particles. They are compressed during pressing, and return to their original state as they absorb moisture after pressing. In this study, the latter cause was the focus. In a previous study,[1] particleboards were produced using a sealed press (Fig. 1) with melamine formaldehyde resin as a binder to improve TS. A sealed press was used as the pressing method to fix the compressive deformation of the particleboards. With a sealed press, the steam generated from a particleboard placed inside the press is trapped within the shield. As the saturation steam pressure increases, the particleboard is processed at a high temperature and steam pressure. The TS of particleboards is improved when the particleboards are processed at high temperatures and steam pressures because the compressive deformation that particles undergo during the pressing process is fixed.[2] As reported in our previous article,[1] TS was successfully improved using a sealed press. Nevertheless, there are some disadvantages of the sealed press, e.g., some binders deteriorate due to the high temperatures and steam pressures inside the sealed press.[1,3] Thus, in this study, the optimum production conditions for avoiding binder deterioration and other unfavorable phenomena were identified by establishing rigorous conditions for testing particleboards based on the results of our previous study.[1]

Particleboards were produced with various pressing times and mat moisture contents in order to identify the best way to efficiently ensure TS. These factors are important for the fixation of compressive deformation.[2] Urea formaldehyde resin (UF), melamine urea formaldehyde resin (MUF), and polymethylene diphenyl diisocyanate (PMDI) were used as binders. It is important to examine the properties of the particleboards bonded with these binders as they were not used in our previous study.[1] In particular, as PMDI is known to provide superior TS,[4] particleboards produced with a sealed press and using PMDI as a binder are expected to possess far superior TS.

The particleboards produced using these three types of binders were compared to examine how the respective production factors affected the particleboard properties. These

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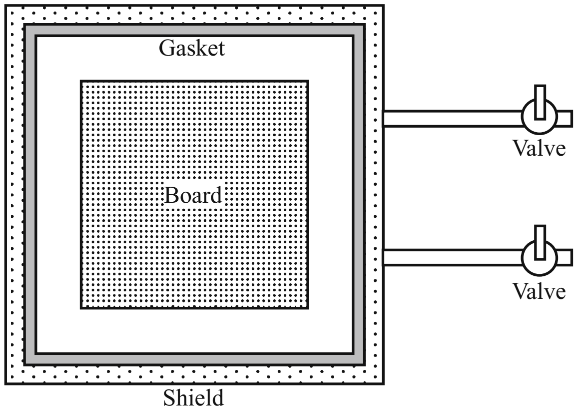

Fig. 1. Schematic of the sealed press

factors were the press method (PM) (sealed press or open press), the pressing time (PT), and the mat moisture content (MMC). In addition, analyses of variance were conducted for the respective binders. As there has been little research on particleboards produced using a sealed press, it is important to identify the correlation between these factors and the properties of particleboards produced using a sealed press.

Materials and methods

Particleboards were produced from commercially manufactured particles from waste wood supplied by Japan Novopan. UF (J-Chemical, UB-K16, 60% solid content) and MUF (J-Chemical, MB-K10, 60% solid content) were used at 7% based on the oven-dry particle weight for particleboard production in addition to using 10% aqueous ammonium chloride solution as hardener. Meanwhile, PMDI (Sumika Bayer Urethane, Sumidur 44V20) was also used as a binder, being sprayed at a ratio of 2% to the oven-dry particle weight. The particleboard dimensions were 30 cm × 30 cm × 1 cm with a target particleboard density of 0.70 g/cm^3.

Two different presses were employed: one was a sealed press with a shield around its outer rim (Fig. 1) and the other was a conventional open press. With a sealed press, valves were opened during the last 30 s of the pressing time to release the steam inside the shield. For example, when the pressing time was 5 min, the valves were closed during the first 4 min and 30 s to create a high steam pressure state inside the shield, and then the valves were opened during the last 30 s to release the steam and depressurize the inside of the shield. The hot platen temperature was set at 180°C and the two hot pressing times were set at 5 and 10 min. After the binders were applied to the particles, the predetermined amount of water was sprayed to create three levels of mat moisture content, i.e., 10%, 15%, and 20%, in order to achieve high steam pressure in the sealed press. One particleboard specimen was produced for each set of production conditions. The produced particleboard specimens are referred to by the type of binder used, e.g., those bonded with UF are called UF boards.

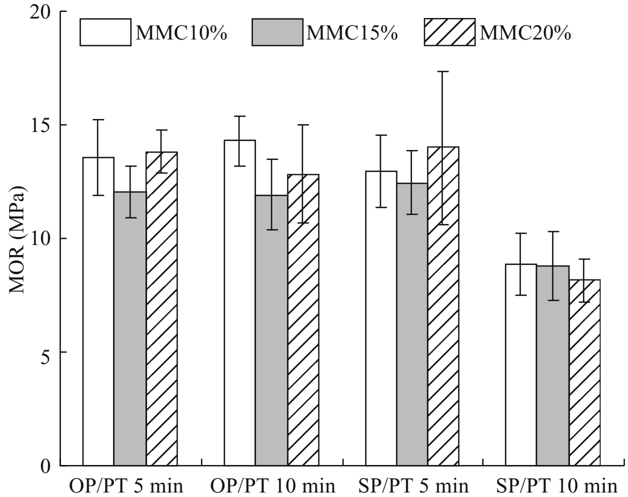

Fig. 2. Effects of production conditions on the modulus of rupture (*MOR*) of particleboard bonded with urea formaldehyde resin. *MMC*, mat moisture content; *OP*, open pressing (conventional pressing); *SP*, sealed pressing (see Fig. 1.); *PT*, pressing time. *Vertical bars* denote standard deviations

The produced particleboards were kept in a constant temperature and humidity chamber at 20°C and 65% relative humidity, and after the mass had become constant the respective tests were performed. The modulus of rupture (MOR), internal bond strength (IB), and TS were measured in accordance with JIS A 5908:2003.[5] The number of specimens tested for MOR, IB, and TS were five, eight, and seven, respectively. For the PMDI boards, however, five specimens were tested for IB and TS.

Results and discussion

Properties of particleboard bonded with UF

MOR results for the UF boards are shown in Fig. 2. The UF board specimens were classified by production conditions into four groups, i.e., pressed for 5 min in an open press (OP/PT 5 min), pressed for 10 min in an open press (OP/PT 10 min), pressed for 5 min in a sealed press (SP/PT 5 min), and pressed for 10 min in a sealed press (SP/PT 10 min), and the correlation between MMC (three different moisture levels) and MOR for the respective specimens is shown in the figure. MOR was almost constant for all the specimen groups irrespective of MMC level, although MOR was low for the SP/PT 10 min specimens irrespective of MMC level. As this experiment was designed for three-way layout, an analysis of variance was conducted; the significance and ratios of MOR are shown in Table 1. The factors which affected MOR were PM and PT, as well as the interaction between PM and PT (PM × PT). The effects of these factors on MOR are described below; figures in parentheses denote the 95% confidence interval. With respect to PM, MOR was 10.9 (±0.634) MPa for the sealed press and 13.1 (±0.634) MPa for the open press, showing that MOR decreased due to the use of a sealed press. With respect to

Table 1. Results of analysis of variance on particleboard properties

Binders	Factors	MOR		IB		TS	
		Significance	ρ (%)	Significance	ρ (%)	Significance	ρ (%)
UF	PM	**	28.1	**	31.9	N.S.	–
	PT	**	31.1	**	17.4	N.S.	–
	MMC	N.S.	–	**	33.4	N.S.	–
	PM × PT	**	27.9	*	7.4	N.S.	–
	PM × MMC	N.S.	–	N.S.	–	N.S.	–
	PT × MCC	N.S.	–	*	5.2	N.S.	–
	Error		12.8		4.7		
MUF	PM	N.S.	–	**	29.9	**	84.6
	PT	N.S.	–	N.S.	–	N.S.	–
	MMC	N.S.	–	**	65.2	N.S.	–
	PM × PT	N.S.	–	N.S.	–	N.S.	–
	PM × MMC	N.S.	–	N.S.	–	N.S.	–
	PT × MMC	N.S.	–	N.S.	–	N.S.	–
	Error				4.9		15.4
PMDI	PM	N.S.	–	*	66.8	*	72.9
	PT	N.S.	–	N.S.	–	N.S.	–
	MMC	N.S.	–	N.S.	–	N.S.	–
	PM × PT	N.S.	–	N.S.	–	N.S.	–
	PM × MMC	N.S.	–	N.S.	–	N.S.	–
	PT × MMC	N.S.	–	N.S.	–	N.S.	–
	Error				33.2		27.1

PM, press method; PT, pressing time; MMC, mat moisture content; MOR, modulus of rupture; IB, internal bond strength; TS, thickness swelling; UF, urea formaldehyde resin; MUF, melamine urea formaldehyde resin; PMDI, polymethylene diphenyl diisocyanate; ρ, contribution ratio
*Significant at the 5% level; **significant at the 1% level; N.S., not significant

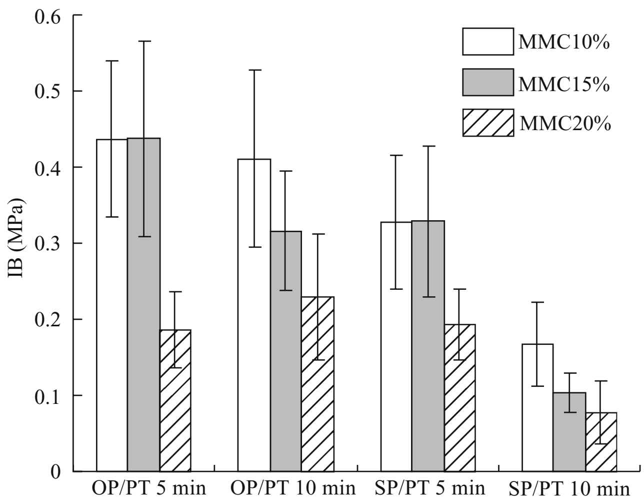

Fig. 3. Effects of production conditions on the internal bond strength (*IB*) of particleboard bonded with urea formaldehyde resin

PT, MOR was 13.1 (±0.634) MPa for the specimens pressed for 5 min and 10.8 (±0.634) MPa for those pressed for 10 min, showing that MOR decreased as a result of a longer pressing time. The result obtained for PM × PT is that MOR decreased with a longer pressing time when a sealed press was used. As the ratios of PM, PT, and PM × PT were approximately 30%, as shown in Table 1, it was concluded that these factors caused the decrease in MOR at approximately the same ratio.

The results obtained for IB are shown in Fig. 3. The IB of UF board specimens with 20% MMC was low in all the specimen groups. For the SP/PT 10 min specimens, IB was much lower than that of the other specimens. An analysis of variance was also conducted for IB, and its significance and ratios are shown in Table 1. The factors which affected IB were PM, PT, MMC, PM × PT, and PT × MMC. Considering that PM × PT and PT × MMC are negligible because of their low ratios, the effects of only the PM, PT, and MMC factors are described below. With respect to PM, IB was 0.336 (± 0.0249) MPa for the open press and 0.200 (± 0.0249) MPa for the sealed press, showing that IB decreased due to the use of a sealed press. When PT was increased from 5 to 10 min, IB decreased from 0.318 (±0.0249) MPa to 0.217 (±0.0249) MPa. Meanwhile, IB was 0.336 (±0.0306) MPa for 10% MMC, 0.296 (±0.0306) MPa for 15% MMC, and 0.172 (±0.0306) MPa for 20% MMC, showing that IB decreased as MMC increased. The decrease in IB was particularly conspicuous when MMC was 20%. As shown in Table 1, the ratios of the factors which reduced IB were approximately 30% for PM and MMC, respectively, and approximately 17% for PT, showing that PM and MMC were the major factors.

The TS values of almost all the UF boards were around 40%, irrespective of particleboard production conditions (data not shown); as a result, the analysis of variance found no significant factors (Table 1).

These results revealed that MOR and IB of the UF boards decreased when produced using a sealed press with a long pressing time and high MMC. Since the ratios of PM and MMC for MOR and IB were particularly high, they greatly affected the decrease of MOR and IB. It is difficult to produce particleboards at high temperatures and steam pressures using a sealed press with high MMC when UF is used as a binder. It is assumed that MOR and IB decreased because UF was partially decomposed under the above conditions.[3] Despite the decrease of IB of the UF board, TS did

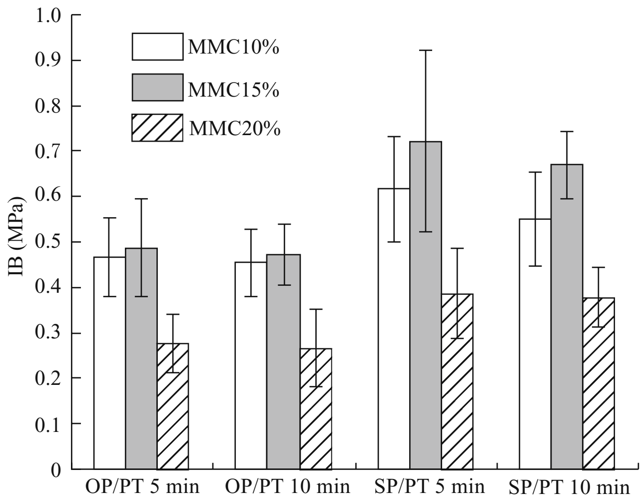

Fig. 4. Effects of production conditions on internal bond strength (*IB*) of particleboard bonded with melamine urea formaldehyde resin

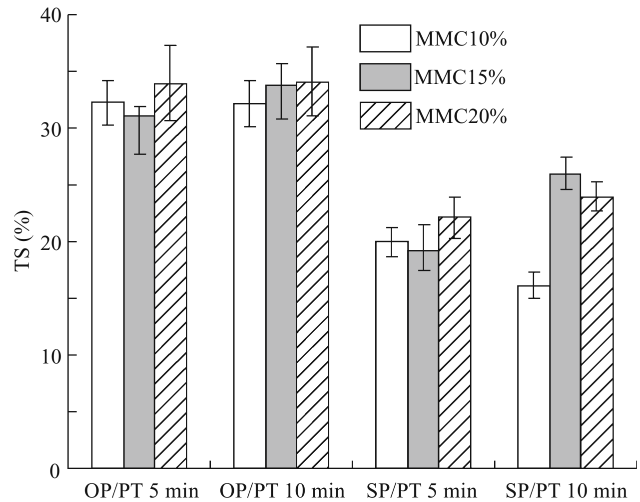

Fig. 5. Effects of production conditions on the thickness swelling (*TS*) of particleboard bonded with melamine urea formaldehyde resin

not increase. However, no further decrease of TS was observed, meaning that the fixation of compressive deformation of the particleboard was achieved by the sealed press because the fixation of compressive deformation of the particles is not related to binder decomposition, which helped to avoid increases in TS. On the other hand, the decomposition of UF, which lowers the bonding strength of particles, adversely increases TS. These positive and negative factors of TS counterbalanced each other, resulting in no effect of these factors on TS.

Properties of particleboard bonded with MUF

The MOR values of almost all the MUF boards were around 15 MPa, irrespective of particleboard production conditions (data not shown); as a result, the analysis of variance found no significant factors (Table 1).

The results obtained for IB of the MUF boards are shown in Fig. 4. IB at 20% MMC was low in all the specimen groups. A comparison of the specimens of all the MMC levels showed that the sealed press generally produced a higher IB than the open press did. The significance and ratios of IB obtained by analysis of variance are shown in Table 1, where IB was 0.554 (±0.0247) MPa for the sealed press and 0.404 (±0.0247) MPa for the open press. These results show that the sealed press produced higher IB than the open press, the opposite of the case for UF boards. On the other hand, IB was 0.552 (±0.0303) MPa for 10% MMC, 0.588 (±0.0303) MPa for 15% MMC, and 0.302 (±0.0303) MPa for 20% MMC, showing that IB greatly decreased when MMC was 20%, as was also the case for UF boards. As shown in Table 1, the ratios were 29.9% for PM and 65.2% for MMC, showing that MMC affected IB more than PM did. Specifically, for the MUF board, use of the sealed press improved IB, but IB decreased when MMC was increased to 20%. Since the ratio of MMC was high, it is assumed that this IB decrease was caused by the high MMC level of the MUF board.

The results obtained for TS of the MUF board are shown in Fig. 5. The TS values of all the specimens produced using the sealed press were lower than those of specimens produced using the open press, showing that the sealed press decreased TS. For SP/PT 10 min specimens, TS increased with increasing MMC; however, TS of the remaining specimens was roughly constant, irrespective of MMC. The significance and ratios of TS obtained by analysis of variance are shown in Table 1. PM was the only significant factor affecting TS, and TS was 32.9(±3.46)% for the open press and 21.2(±3.46)% for the sealed press, showing that the sealed press decreased TS. Although no significant factor was found for TS of the UF board, PM was found to be the significant factor for TS of the MUF board, with its ratio being as high as 84.6%, as shown in Table 1. Thus, use of the sealed press greatly reduced TS of the MUF boards.

For UF boards, the sealed press caused decomposition of the binder and could not improve the particleboard properties. For the MUF boards, on the other hand, the sealed press successfully improved both IB and TS. With the sealed press, particleboards are inevitably produced at high temperatures and steam pressures; however, as MUF did not decompose, unlike UF did, the compressive deformation of the particleboards during the pressing process was fixed while in the sealed press, and hence TS of the MUF boards was improved. In addition, as the fixation of compressive deformation enhanced the bonding strength of the particles, IB was also improved. Thus, MUF was shown to be an effective binder for the sealed press. It was expected that the particles would soften with increasing MMC because the effective adhesion area between the particles would be enhanced, the bonding strength would be improved,[6] and the high MMC would improve the fixation of compressive deformation.[2] However, IB of the MUF boards actually decreased when MMC was 20%. Thus, it is essential to produce particleboards with an appropriate MMC.

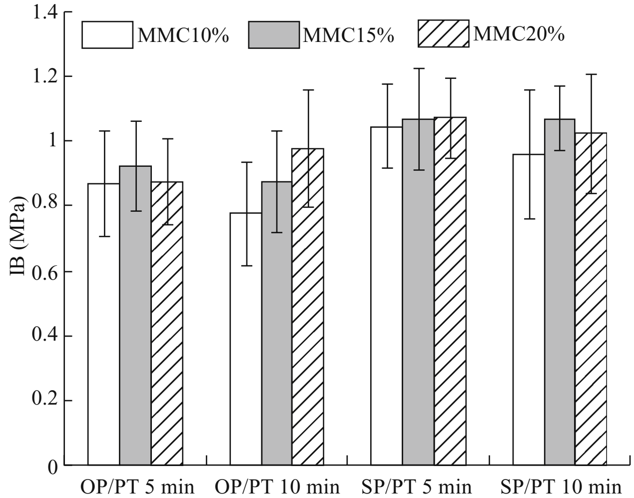

Fig. 6. Effects of production conditions on internal bond strength (*IB*) of particleboard bonded with polymethylene diphenyl diisocyanate resin

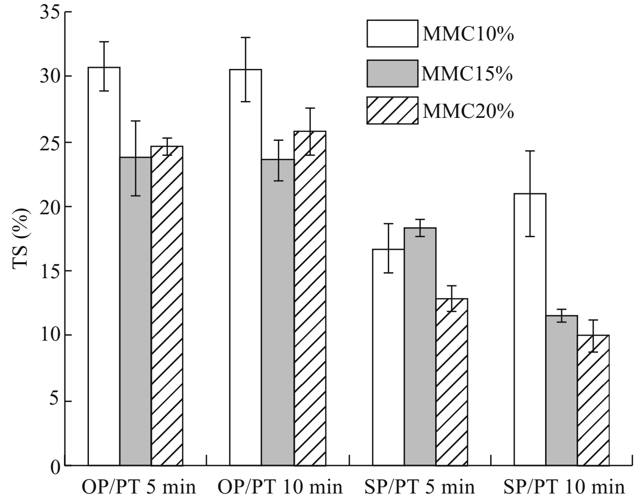

Fig. 7. Effects of production conditions on thickness swelling (*TS*) of particleboard bonded with polymethylene diphenyl diisocyanate resin

Properties of particleboard bonded with PMDI

The MOR values of almost all the PMDI boards were around 23 MPa, irrespective of the particleboard production conditions (data not shown); as a result, the analysis of variance found no significant factors (Table 1).

The results obtained for IB of the PMDI boards are shown in Fig. 6. For the OP/PT 10 min PMDI board, IB increased with increasing MMC. However, IB was almost constant for the remaining specimens irrespective of MMC. In addition, IB of particleboards produced using the sealed press was higher than IB of those produced using the open press. The significance and ratios of IB obtained by analysis of variance are shown in Table 1. The effect of PM was determined to be a significant factor, and IB was 1.04 (±0.0948) MPa for the sealed press and 0.882 (±0.0948) MPa for the open press, proving that the sealed press effectively increased IB.

The results obtained for TS of the PMDI boards are shown in Fig. 7. The TS values of the specimens produced using the sealed press were lower than the TS values of those produced using the open press. In addition, TS tended to decrease with increasing MMC for all the specimens, irrespective of the production conditions. The significance and ratios of factors affecting TS obtained by analysis of variance are shown in Table 1. PM was determined to be a significant factor, and TS was 15.1(±5.00)% for the sealed press and 26.5(±5.00)% for the open press, proving that the sealed press greatly decreased TS. In general, PMDI boards possess low TS,[4] and this was enhanced by using the sealed press. The amount of PMDI used when producing particleboard specimens was only 2% of the weight of particles, from which the low TS of PMDI is naturally apparent. In addition, IB of the PMDI boards did not decrease even when they were produced using a sealed press with high MMC, unlike the results for particleboard specimens using UF and MUF as binders. Thus, using the sealed press enhanced the PMDI board properties.

As shown in Table 1, neither MMC nor PT affected TS. However, as shown in Fig. 7, TS clearly decreased when the specimens were produced using the sealed press for 10 min at 15% and 20% MMC. TS of the SP/PT 10 min specimens at 20% MMC was 10%, which was markedly low and could not be achieved with the MUF boards. Under these particular conditions, PT and MMC played an important role in reducing TS of the PMDI board.

Conclusions

The following results were obtained by testing the different types of particleboards bonded with UF, MUF, or PMDI and fabricated using either a sealed press or an open press.

1. For the UF boards, MOR and IB decreased when produced using the sealed press with a long pressing time. As particleboards are produced at high temperatures and steam pressures in a sealed press, UF was partially decomposed during the pressing process, and so the particleboard properties were not enhanced.
2. For the MUF boards, using the sealed press increased IB and decreased TS. This is because MUF, which is relatively stable even at the high temperatures and steam pressures found in a sealed press, was not decomposed, unlike UF.
3. For the PMDI boards, using the sealed press increased IB and decreased TS. This is because the compressive deformation of particles was fixed at high temperatures and steam pressures during the pressing process in the sealed press. MUF and PMDI are thus suitable binders for use in a sealed press, and PMDI was confirmed to be superior.

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