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ORIGINAL ARTICLE

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Effects of sealed press on improving the properties of particleboard

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Abstract To improve the properties of particleboard, boards were produced using a sealed press. With the sealed press, boards were processed under high-temperature and high-pressure steam. This increased the saturation temperature, causing a dramatic rise in temperature inside the board, faster curing of the binder, and a shorter pressing time. The boards were bonded with urea formaldehyde resin, melamine urea formaldehyde resin, or poly(methylene diphenyl diisocyanate) (PMDI). The sealed press improved the internal bond strength and thickness swelling of boards regardless of the binder used during the reduced pressing time. The increased bonding strength improved the board properties, allowing PMDI with a lower resin content to be used for bonding the boards.

Key words Particleboard · Sealed press · Melamine urea resin · Poly(methylene diphenyl diisocyanate) · Pressing time

Introduction

In general, a sealed press is used with a steam-injection press in order to trap steam within the shield.[1] Inoue et al. applied the sealed press without a steam-injection press to the fixation of wood compressive deformation.[2] Their study suggested that the thickness swelling (TS) of particleboards (hereafter called "boards") was improved using the sealed press. Accordingly, a sealed press was used to improve the TS of the boards in our previous study.[3] As a result, the TS of boards produced under high-temperature and high-pressure steam improved. However, the mechanical properties deteriorated due to the decomposition of binder under high-temperature and high-pressure steam.[4]

Therefore, in another previous study,[5] boards were produced using a sealed press with three binders, i.e., urea formaldehyde resin (UF), melamine urea formaldehyde resin (MUF), and poly(methylene diphenyl diisocyanate) (PMDI), to improve the TS (Fig. 1). Boards were produced under high-temperature and high-pressure steam in the sealed press; the steam generated from the boards was trapped within the shield. The effects of the binders on the TS were studied. This production process fixed the compressive deformation of boards during pressing, thus decreasing the TS of boards bonded with MUF and PMDI.[2] Therefore, the sealed press is effective in decreasing the TS of boards bonded with MUF and PMDI. However, the TS of boards bonded with UF did not decrease. This was due to decomposition of UF under high-temperature and high-pressure steam.[4]

When boards are produced using an open press, the core layer temperature rises to around 100°C, which is the boiling point of water, where it remains for a while until rising above 100°C.[6] This is because the steam generated inside the board penetrates the core layer and remains at 100°C until all the water has evaporated. Thus, to quickly raise the temperature inside the board core layer, it is crucial to raise the saturated steam temperature by increasing the saturated steam pressure. A higher saturation temperature causes the temperature inside the board core layer to rise more quickly, and so the board can be pressed in a shorter time and produced more efficiently. The sealed press efficiently increases the saturated steam pressure inside the shield, and hence the saturation temperature; thus, the temperature inside the board rises faster than with the open press. In short, the sealed press reduces the pressing time. In this research, experiments were conducted to study the pressing time using a sealed press. Other ways of reducing the pressing time for board production include the use of a steam injection press[7] and a high-frequency press,[8] but these require complex installations. In contrast, the sealed press is simple to install and is very practical to use. Thus, it would be very useful if it can reduce the pressing time.

Although PMDI has superior properties, it is expensive and the amount used (resin content) should be kept to a minimum. PMDI is resistant to decomposition at high temperature and pressure, and so is a suitable binder for the sealed press and is expected to improve bonding strength.

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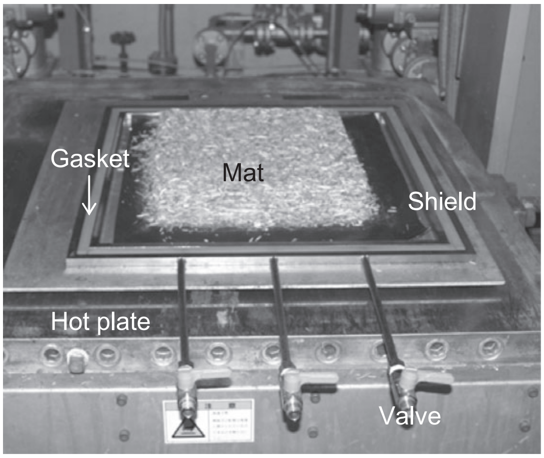

Fig. 1. Shield of sealed press with a mat on the hot plate

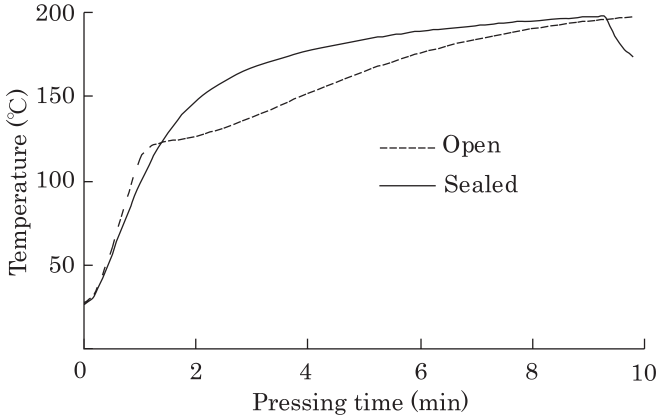

Fig. 2. Relationships between pressing time and temperature of the core layer at the center of a board bonded with poly(methylene diphenyl diisocyanate) (PMDI)

With the sealed press, the required PMDI properties are expected to be retained even when less resin is used, because the sealed press greatly improves the bonding strength of binders. Thus, we examined the performance of the sealed press with reduced amounts of PMDI.

Materials and methods

Board production using a sealed press

Core layer particles made from wood waste (Japan Novopan) with a moisture content of approximately 6% were used as raw materials. UF (J-Chemical, UB-K16, 60% solid content) and MUF (J-Chemical, MB-K10, 60% solid content) were used as binders. In addition, 10% aqueous ammonium chloride solution was used as a resin hardener, and was applied to the respective binders at a 10% weight ratio. The binders were sprayed at a ratio of 7% resin content (solid content basis) to the weight of particles. PMDI (Sumika Bayer Urethane, Sumijule 44V20) with a resin content of 2% was also used as a binder.

The board dimensions were $30 \times 30 \times 1$ cm with a target board density of 0.7 g/cm^3. Specifically, boards were produced using the three binders UF, MUF, and PMDI. The boards were designated by the type of binder used, e.g., those bonded with UF were called UF boards.

Two different presses were employed: a sealed press (Fig. 1) and an open press. With the 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-pressure state inside the shield, then opened during the last 30 s to release the steam and depressurize the inside of the shield. The hot pressing conditions used a hot plate temperature of 190°C and pressing times of 2, 3, 4, 5, and 10 min. During board processing, the temperature of the core layer in the center of the boards was measured using a thermocouple. One board was produced for each production condition.

Reduction of amount of PMDI

To examine the feasibility of reducing the amount of PMDI used, boards were produced as described in the preceding section except that the resin content was set at 1%, 2%, and 3%. The hot pressing conditions used a hot plate temperature of 190°C and a pressing time of 4 min, and both the sealed press and open press were used.

Property tests

The produced boards were kept in a constant temperature and humidity chamber at 20°C and 65% relative humidity, and after the mass had become constant, the tests were performed. The modulus of rupture (MOR), internal bond strength (IB), and TS were measured in accordance with JIS A 5908:2003. The number of specimens tested for MOR, IB, and TS were 5, 8, and 7, respectively.

Results and discussion

Temperature behavior inside the board

The temperature behaviors of the core layer of only the PMDI boards produced using either the open press or the sealed press are shown in Fig. 2; the temperature behavior for other binders (UF and MUF) was almost the same as that of PMDI. The core layer temperature increased up to 100°C at 1 min pressing time with no significant difference in temperature rise between the two presses. Thereafter, however, the temperature rise differed depending on the press. With the open press, the temperature increased gradually from 1 to 2 min pressing time, and reached 124°C. The temperature increase slightly accelerated after 2 min, reaching 162°C at 5 min and 187°C at 8 min. With the sealed press, on the other hand, the temperature increased sharply at 1 min pressing time, reached 145°C at 2 min, 167°C at 3 min, and 180°C at 5 min. Specifically, the core layer

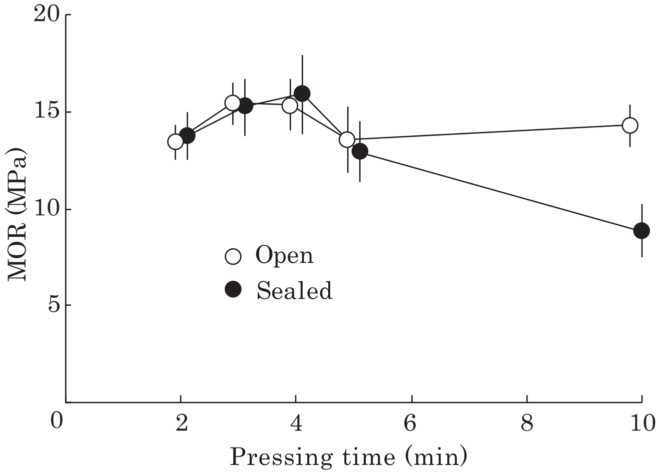

Fig. 3. Relationships between pressing time and modulus of rupture (*MOR*) of board bonded with urea formaldehyde resin (UF). Vertical bars denote standard deviations

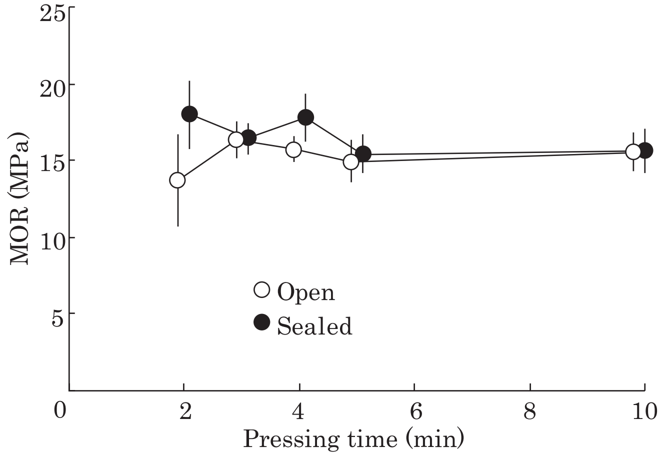

Fig. 4. Relationships between pressing time and MOR of the board bonded with melamine urea formaldehyde resin (MUF)

temperature for the sealed press increased faster than for the open press.

When using the open press, water in the outer parts of the board heated by the hot plates turned into steam and moved toward the core layer of the board. This steam supplied heat of vaporization to the core layer, where the water also turned into steam. Subsequently, the steam that had accumulated in the core layer moved toward the board edges and was emitted. The temperature stayed at around 120°C until all the water inside had evaporated. However, the temperature behavior for the sealed press shows that the temperature rose above 120°C quickly and did not pause at 120°C. This is because, with the sealed press, the saturated steam pressure inside the shield increased, causing the saturation temperature to rise above 120°C. Thus, the pressing time can be reduced by using the sealed press.

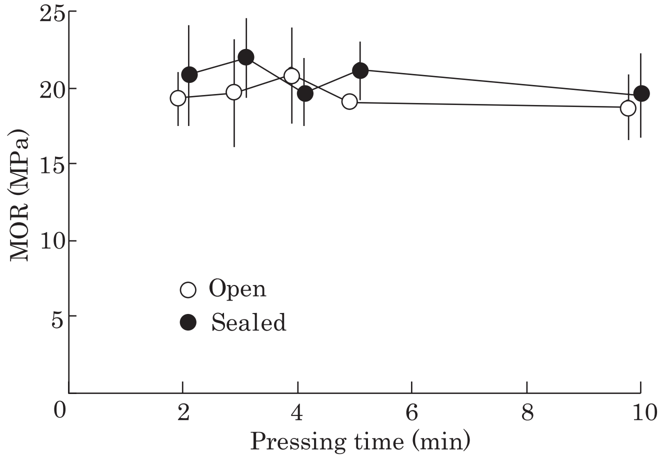

Fig. 5. Relationships between pressing time and MOR of board bonded with poly(methylene diphenyl diisocyanate) (PMDI)

Modulus of rupture

The relationship between the pressing time and MOR of the UF board is shown in Fig. 3. From 2 to 5 min pressing time, MOR was similar for both presses. At 10 min, MOR for the sealed press decreased. The relationship between the pressing time and MOR for the MUF board is shown in Fig. 4. The MOR for the sealed press tended to be higher than that for the open press until 4 min (except for the value at 3 min), then the values were similar for both presses from 5 min onward. With the sealed press, MOR reached a maximum of 18.0 MPa at 2 min, a value that was not exceeded by the open press at any pressing time. This resulted in a reduced pressing time using the sealed pressing, with optimum MOR properties achieved by pressing for only 2 min. The relationship between the pressing time and MOR for the PMDI board is shown in Fig. 5. The MOR values were almost constant regardless of the pressing time, showing no major difference between the presses. Thus, except for the MUF board, the sealed press did not significantly improve the MOR when using a shorter pressing time.

Internal bond strength

The relationship between the pressing time and IB for the UF board is shown in Fig. 6. For the open press, IB was considerably low at 2 min pressing time, but became almost constant at 3 min and thereafter. Meanwhile, IB at 2 min for the sealed press was 0.52 MPa, whereas that at 4 min for the open press was 0.41 MPa. The higher value of the former shows that the sealed press resulted in a reduced pressing time and improved IB. Here, the core layer temperature for the sealed press was 132°C at 2 min, while that for the open press was 121°C at 4 min and 131°C at 5 min, as shown in Fig. 2. As for the UF board, IB reached the maximum when the core layer temperature became 130°C. On the other hand, IB for the sealed press decreased with increasing pressing time. This is presumably because UF was partially

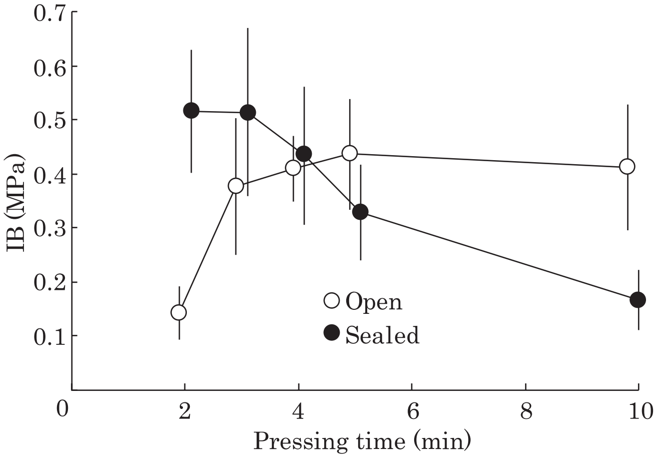

Fig. 6. Relationships between pressing time and internal bond strength (*IB*) of board bonded with UF

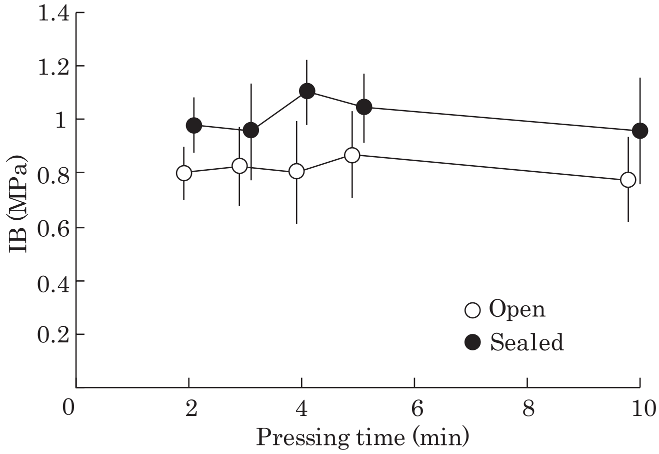

Fig. 8. Relationships between pressing time and IB of board bonded with PMDI

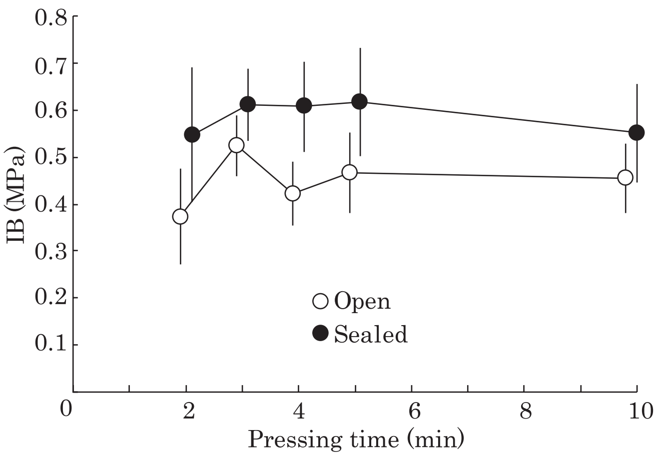

Fig. 7. Relationships between pressing time and IB of board bonded with MUF

decomposed by prolonged exposure to high-temperature and high-pressure steam.[4]

The relationship between the pressing time and IB for the MUF board is shown in Fig. 7. IB for the sealed press was higher than that for the open press at all pressing times. Unlike with the UF board, IB was generally constant regardless of the pressing time for both presses. IB at 2 min for the sealed press was 0.55 MPa, whereas that at 5 min for the open press was 0.47 MPa. Thus, the sealed press effectively improved IB with a shorter pressing time.

The relationship between the pressing time and IB for the PMDI board is shown in Fig. 8. As with the MUF board, IB for the sealed press was generally higher than that for the open press. In addition, IB was almost constant for both presses with respect to pressing time. IB for the sealed press reached approximately 0.98 MPa at 2 min, whereas that for the open press remained approximately 0.80 MPa, regardless of the pressing time. Thus, for PMDI boards also, the sealed press improved IB with a shorter pressing time.

With respect to IB, the sealed press generally improved the properties for all boards, regardless of the binder used, and it is clearly possible to reduce the pressing time. For UF boards, in particular, a reduced pressing time was effective. In addition, in this study, the thickness of the board was just 10 mm, which is relatively thin. For thicker boards, the sealed press would be even more effective in reducing pressing time. Although IB of the UF board produced using the sealed press decreased with increasing pressing time, that of the MUF board and the PMDI board did not. This is presumably because the latter binders suffered little decomposition.[4] Particles plasticize under high-temperature and high-pressure steam, and this strengthens the adhesion between the particles, increases the effective bonding area, and hence enhances the bonding strength.[9] In addition, the compressive deformation occurring to the particles is fixed under high-temperature and high-pressure steam,[2] by which the bonding strength is enhanced. These factors also helped improve IB for the sealed press.

Thickness swelling

The relationship between the pressing time and TS for the UF board is shown in Fig. 9. TS for the sealed press was lower than that for the open press for all pressing times, showing the effectiveness of the sealed press. With the open press, the minimum percentage of TS was 43.0% at 5 min, whereas with the sealed press, TS had already reached 34.3% at 2 min. This shows that the sealed press yielded lower TS than the open press for a shorter pressing time, confirming that the sealed press was able to reduce the pressing time as a result.

The relationship between the pressing time and TS for the MUF board is shown in Fig. 10. As with the UF board, TS for the sealed press was lower throughout than that for the open press, showing that the sealed press improved TS for a shorter pressing time. In general, the TS for the MUF board was lower than that for the UF board, particularly

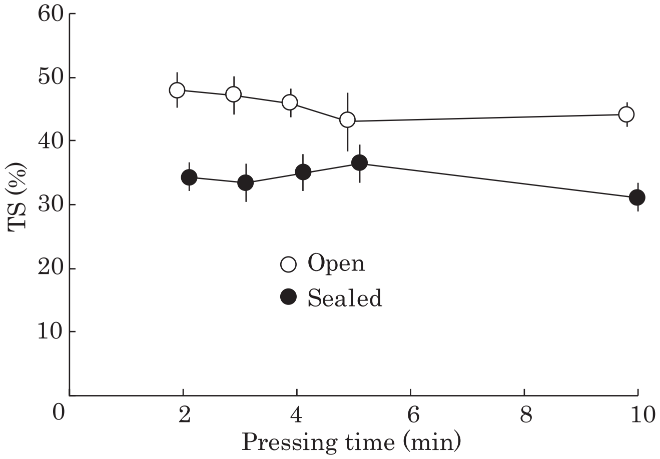

Fig. 9. Relationships between pressing time and thickness swelling (*TS*) of board bonded with UF

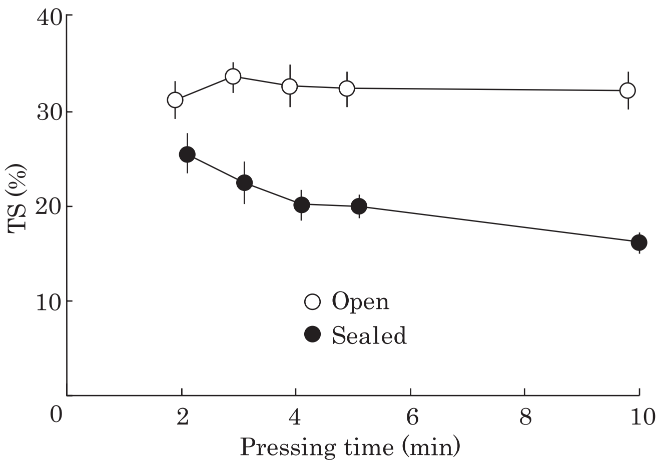

Fig. 10. Relationships between pressing time and TS of board bonded with MUF

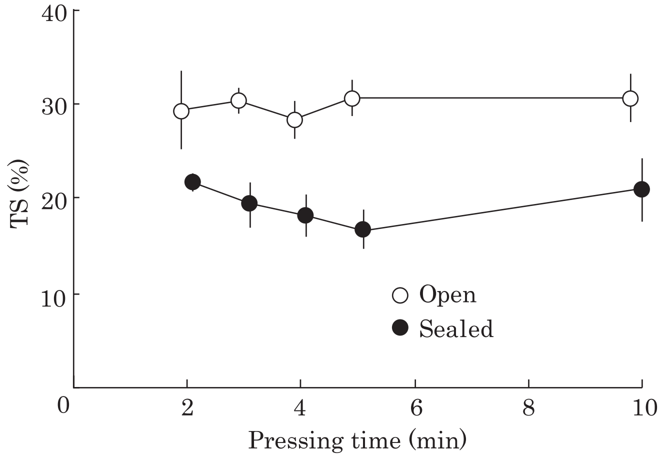

Fig. 11. Relationships between pressing time and TS of board bonded with PMDI

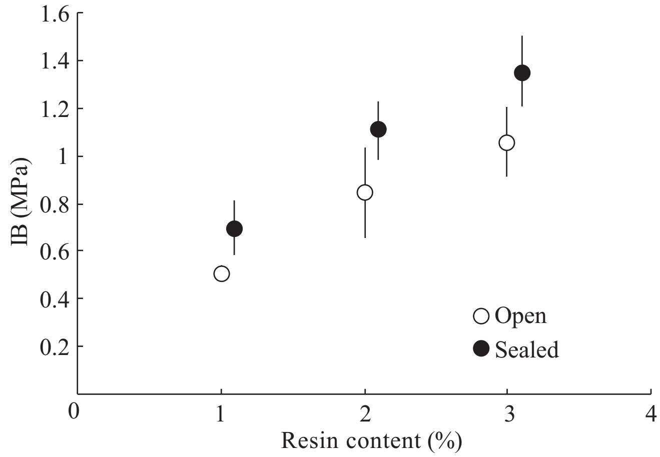

Fig. 12. Relationships between resin content and IB of board bonded with PMDI

when the sealed press was used and the board was pressed for a longer time.

Figure 11 shows the relationship between the pressing time and TS for the PMDI board. For pressing times of 2–10 min, TS for the open press remained at around 30%, whereas that for the sealed press varied between 22% and 17%. Thus, the sealed press gave decreased TS for a shorter pressing time.

As with IB, the sealed press fixed the compressive deformation and yielded lower TS than that obtained by the open press for a shorter pressing time for all the boards, regardless of the binder used. For the MUF and the PMDI boards, in particular, the bonding strength was enhanced by using the sealed pressing, and this is considered to be one of the factors which brought about the decreased TS, as described earlier.

Effect of reducing PMDI quantities

The relationship between the resin content of PMDI and MOR revealed that the MOR of boards using the open press was almost the same as that of boards using the sealed press for each resin content (data not shown). As PMDI with a reduced resin content was able to maintain acceptable levels of MOR, the amount of PMDI can be reduced if good properties are confirmed for IB and TS as well.

The relationship between the resin content and IB is shown in Fig. 12. With a higher resin content, IB increased for both presses. For all levels of resin content, IB for the sealed press was higher than that for the open press, and the difference in the two IB values increased with resin content. The IB when using the open press with 2% resin content was almost the same as that for the sealed press with 1% resin content. The relationship between the resin content and TS is shown in Fig. 13. With higher resin content, TS decreased for both presses. TS for the sealed press was lower than that for the open press for all values of resin content. Here also, TS for the open press with 2% resin content was roughly the same as that for the sealed press with 1% resin content.

Thus, the sealed press enhanced the board properties, including IB and TS, and so PMDI with less resin content

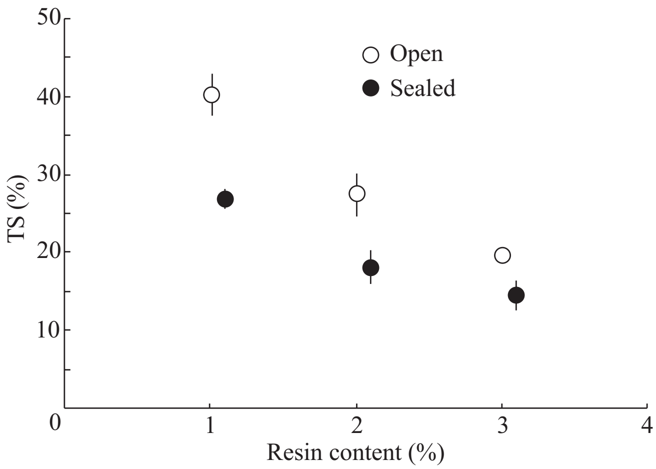

Fig. 13. Relationships between resin content and TS of board bonded with PMDI

can be used. As this binder is expensive, the proven feasibility of a lower resin content of PMDI is a very useful result.

Conclusions

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

1. With the sealed press, the temperature inside the board during pressing increased faster than that with the open press.
2. Regarding MOR, the sealed press did not result in a reduced pressing time for either the UF or PMDI board, but did result in a reduced pressing time and improved MOR for the MUF board. In particular, the MOR of the UF board was lower at 10 min.
3. Regarding IB and TS, the sealed press successfully yielded excellent properties for a shorter pressing time for all board types.
4. The sealed press effectively enhanced the properties of PMDI boards, allowing resin with a reduced content of PMDI to be used.

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