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ORIGINAL ARTICLE

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Development of an air-injection press for preventing blowout of particleboard II: improvement of board properties using small-diameter holes for air injection

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Abstract An air-injection press, which has holes punched in the heating plates, injects high-pressure air through the holes of one plate into boards during press heating. The air-injection press can manufacture boards from high-moisture-content particles by controlling blowouts of the boards. In this study, boards were manufactured from particles that had a moisture content of 25% by using the air-injection press, which reduced the required pressing time. Boards manufactured by injecting air through holes of 5 mm in diameter were of poor quality with a low internal bond strength of only 0.31 MPa. When the hole diameter was reduced to 1 mm, the internal bond strength increased to 0.44 MPa. A high air-injection pressure of 0.55 MPa also resulted in improved board properties over those for boards manufactured at lower pressures. This was probably because a large amount of binder was released from boards through the 5-mm holes, together with water vapor, during air injection; the small-diameter holes reduced the release of binder, resulting in better board properties.

Key words Air-injection press · Particleboard · Blowout · Board properties · Moisture content

Introduction

When manufacturing particleboard, vapor can become trapped between the wood particles during the hot pressing process and can cause a blowout effect on the board when the pressure is released. Since this damage occurs at the final stage of the manufacturing process, all the preceding stages are wasted, causing a sharp drop in productivity. The most effective method developed thus far for preventing blowout is to use particles with low moisture content.

In the previous study, a hot press that discharges the vapor trapped inside the board was developed and prevented blowout.[1] The press has holes punched in the upper and lower heating plates. High-pressure air is injected through the holes of one plate to the inside of the board and is discharged from the holes of the other plate. The high-pressure air forces out trapped vapor and prevents blowout of the board. This press is called an air-injection press.

The previous report outlined the features of the air-injection press.[1] Boards were manufactured from wood particles containing 25% moisture by using urea-formaldehyde resin as the binder. At least 10 min of hot pressing was needed to manufacture 10-mm-thick boards without using the air-injection press; the air-injection press reduced the pressing time to 6 min, showing the effectiveness of the air-injection press in reducing the pressing time. In general, board manufactured from particles with high moisture content when using urea-formaldehyde resin has poor properties,[2] and the original air-injection press could not improve these properties.[1] This study aims to improve board properties by modifying the air-injection press by reducing the diameter of the holes from 5 mm in the previous study[1] to 1 mm in the current study. Since the air-injection press injects high-pressure air to discharge vapor trapped within the board, it was estimated that large holes could discharge vapor better than small holes, for a given number of holes. However, large holes resulted in discharge of the binder as well as vapor and resulted in poor board properties. Therefore, the hole size was reduced to 1 mm to prevent the binder from being discharged, tubercles from forming on the board surface,[1] and particles of the mat-like board from falling the inside of the holes during hot pressing. The relationship between the air injection pressure of the air-injection press and the properties of the board was also investigated.

Experimental

Effects of small holes on board properties

Air-injection presses with two hole sizes [5 mm ($\phi 5$) and 1 mm ($\phi 1$)] were prepared for injecting air. The $\phi 5$ holes

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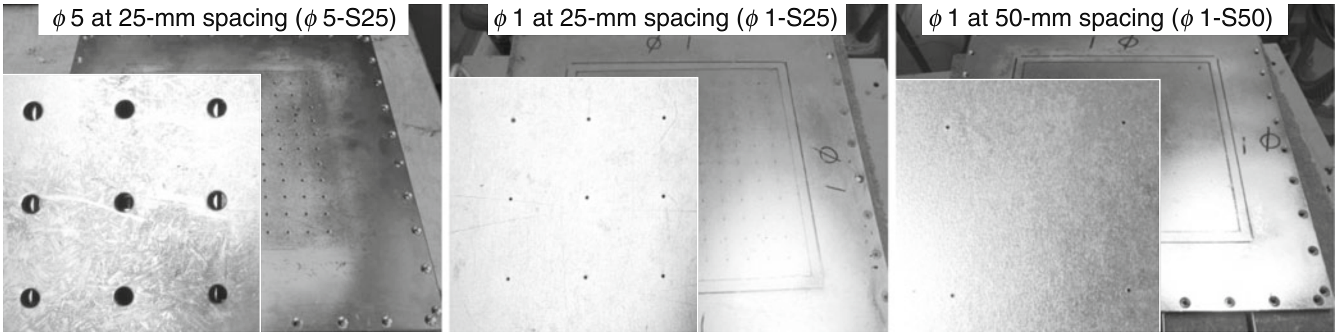

Fig. 1. The diameter and spacing of holes of the air-injection press. *ϕ5-S25*, air-injection hole diameter 5 mm, 25-mm spacing; *ϕ1-S25*, air-injection hole diameter 1 mm, 25-mm spacing; *ϕ1-S50*, air-injection hole diameter 1 mm, 50-mm spacing

were arranged at a spacing of 25 mm between the centers of adjacent holes. Presses with ϕ1 holes had a hole spacing of 25 or 50 mm (Fig. 1), resulting in 121 or 36 holes in an area of 250 × 250 mm, respectively. Holes were also punched in the caul plate through which the high-pressure air and vapor were discharged.[1] The diameter and spacing of the holes on the caul plate were the same as those of the lower plate through which the air was injected. Thus, the caul plates also had 121 (25-mm spacing) or 36 holes (50-mm spacing) in an area of 250 × 250 mm. Grooves that were 1 mm deep and 1.5 mm wide were also cut connecting the holes on one side of the caul plate to release the high-pressure air. Although the actual air-injection press has holes in the hot plates, the device described above is referred to as an air-injection press in this study.[1]

The particles used in the experiment were manufactured from wood waste for manufacturing core layers (Japan Novopan Industrial). The mean length (standard deviation) of 200 particles measured was 15.4 (6.69) mm.[1] The binder used was a urea-formaldehyde resin (Oshika, UB-K16, resin content: 60%, viscosity: 0.14 Pa·s). As a curing agent, 10% ammonium chloride solution was added to the binder to constitute 10% by the binder. In general, urea-formaldehyde resin is difficult to cure under high-temperature and high-pressure steam.[2] If the air-injection press proved to be effective in curing urea-formaldehyde resin under high-temperature and high-pressure steam, it would likely be more effective in curing other resins. In addition, urea-formaldehyde resin is used widely for commercial board manufacture. It is very important that the air-injection press is effective in curing urea-formaldehyde resin under high-temperature and high-pressure steam. The resultant binder mixture was added to the particles to constitute 10% (by weight). To adjust the moisture content of the particles to 25%, a predetermined amount of water was sprayed onto the particles prior to spraying the binder. The dimensions of the board were 300 × 300 × 10 mm, and the target board density was 0.7 g/cm^3. One board was manufactured for each manufacturing condition. The pressing temperature was 190°C and the pressing time was 6, 8, or 10 min. The injection of high-pressure air was started after the press had thoroughly compressed the board, that is, when the thickness of the board reached 10 mm. For example, when the pressing time was 6 min, the air was injected during the first 5 min and 45 s and not during the last 15 s. High-pressure air at 0.55 MPa was injected and released through holes of the same size and spacing: (1) ϕ5 at 25-mm spacing, (2) ϕ1 at 25-mm spacing, and (3) ϕ1 at 50-mm spacing. Boards manufactured using holes of ϕ5 at 25-mm spacing, ϕ1 at 25-mm spacing, and ϕ1 at 50-mm spacing are referred to here as ϕ5-S25, ϕ1-S25, and ϕ1-S50, respectively. The temperature of the boards was monitored by installing thermocouples in the middle layer at one end of each board.[1]

Effects of high-pressure air on board properties

To analyze the effects of high-pressure air injection on board properties, boards were manufactured by injecting air at 0.55, 0.4, or 0.2 MPa. The moisture content of the particles after spraying the binder was adjusted to 25%. The pressing time was 6 or 8 min, and the pressing temperature was 190°C. The hole diameter was 1 mm and the spacing was 25 mm (ϕ1-S25). The same board dimensions and methods as those described above were used for injecting the air and monitoring board temperature.[1]

Property tests

The moisture content of the boards manufactured was adjusted by leaving them in a thermo-hygrostat (20°C, relative humidity: 65%) until the weight had stabilized before testing. The modulus of rupture, the internal bond strength, and thickness swelling were determined according to JIS A 5908:2003.[3] The number of specimens was 5, 8, and 7, respectively. The boards manufactured using the ϕ5 holes had many tubercles formed on both surfaces due to the holes in the press.[1] The modulus of rupture was determined without removing the tubercles, but the internal bond strength and thickness swelling were measured after removing the tubercles by using a knife and smoothing the board surface.[1] Tubercles formed by ϕ1 holes were very small and almost invisible and so were not removed prior to the tests.

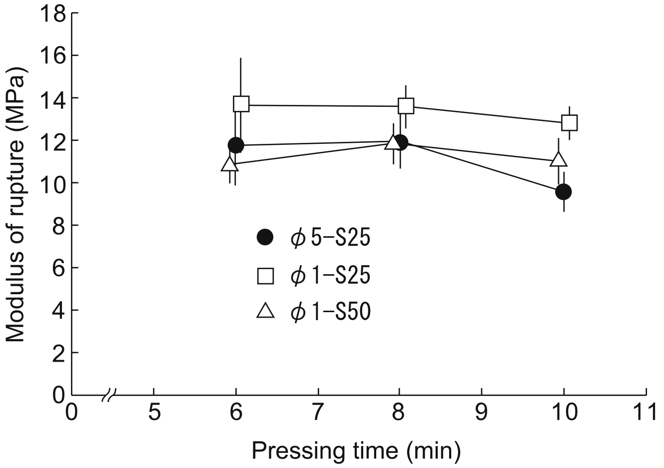

Fig. 2. Relationship between pressing time and modulus of rupture. *Bars* indicate standard deviations

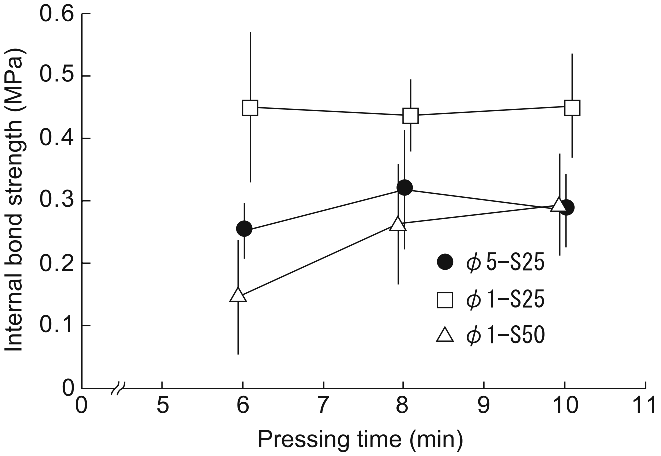

Fig. 3. Relationship between pressing time and internal bond strength

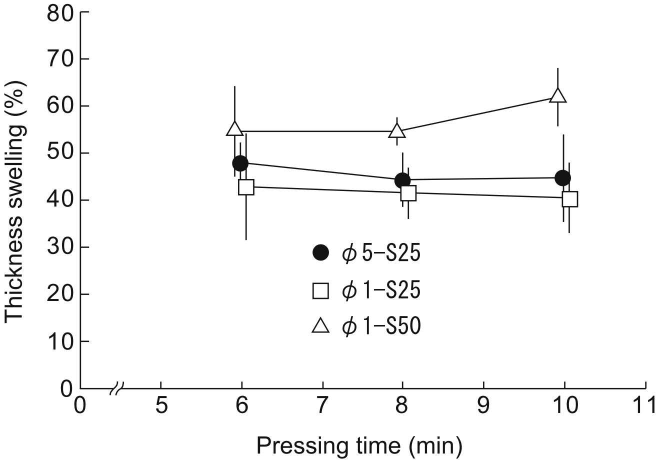

Fig. 4. Relationship between pressing time and thickness swelling

Results and discussion

Effects of small holes on board properties

Figure 2 shows the modulus of rupture of the boards. The modulus of rupture of ϕ5-S25 was about 12 MPa when the board was pressed for 6 or 8 min, but dropped to 9.5 MPa when it was pressed for 10 min. On the other hand, the modulus of rupture of ϕ1-S25 was about 13 MPa for all pressing times. The area of one hole was about 20 mm^2 in ϕ5-S25 and 0.79 mm^2 in ϕ1-S25, i.e., the former was 25 times larger than the latter. It was first estimated that large holes would better allow the release of vapor and be advantageous for manufacturing boards. However, the small holes were found to produce boards with a higher modulus of rupture than the large holes, showing that large holes are not advantageous.

The modulus of rupture of ϕ1-S50 was about 11 MPa for all pressing times and was lower than the value for ϕ1-S25. The total hole area was about 95 mm^2 in ϕ1-S25 (with 121 holes) and about 28 mm^2 in ϕ1-S50 (with 36 holes), i.e., the former was about 3.3 times larger than the latter. The total hole area in ϕ5-S25 was 2375 mm^2. The results suggest that there is an optimum size and spacing of holes for manufacturing boards with a high modulus of rupture; these factors will be investigated and clarified in further studies.

The internal bond strengths of the boards are shown in Fig. 3. The internal bond strength of ϕ5-S25 was about 0.3 MPa for all pressing times, whereas that of ϕ1-S25 was 0.43 MPa for all pressing times. Thus, just as for the modulus of rupture, ϕ1-S25 showed better internal bond strength than ϕ5-S25 did. The modulus of rupture is affected not only by the bonding strength of the binder but also by the size of the particles used,[4] among other factors. On the other hand, the internal bond strength directly reflects the bonding strength of the binder.[5] The internal bond strength increased by 43% by reducing the size of the holes from 5 mm to 1 mm, showing that smaller holes were more effective for improving the bonding strength of the binder. The internal bond strength of ϕ1-S50 was lower than that of ϕ1-S25. The value was particularly low when the board was pressed for only 6 min, probably because vapor was not sufficiently discharged and the binder did not harden completely.

The thickness swelling values of the boards are shown in Fig. 4. The thickness swelling of ϕ5-S25 was 45%, and that of ϕ1-S25 was 41%. Although the value of ϕ1-S25 was lower than that of ϕ5-S25, it was larger than the value predicted from the high internal bond strength of ϕ1-S25 (Fig. 3). The results show that the internal bond strength must be improved to reduce thickness swelling. The thickness swelling of ϕ1-S50 was larger than for the other two boards. The high thickness swelling for the pressing time of 6 min was likely attributable to the low internal bond strength. The internal bond strength of ϕ1-S50 for a pressing time of 10 min was 0.29 MPa and was similar to that of ϕ5-S25. However, the thickness swelling differed between the two and was larger for ϕ1-S50 than for ϕ5-S25. Internal bond strength is determined by the rupture at the weakest layer,[5] which is generally the center layer. The internal bond strength at the center layer was the same in both boards,

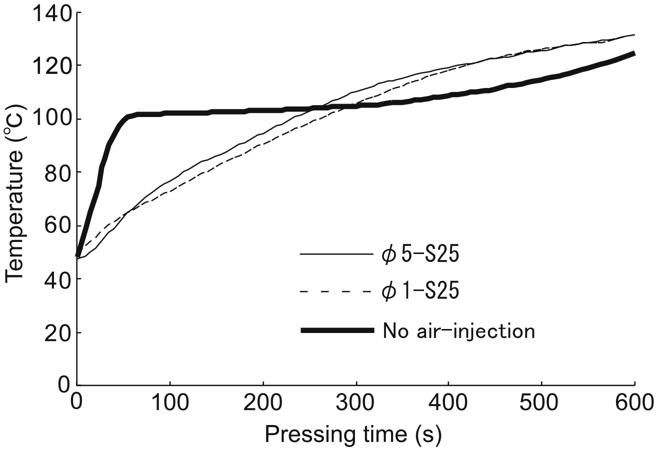

Fig. 5. Relationship between pressing time and temperature at the center of the boards

but the internal bond strength of the other parts may have been higher in ϕ5-S25 than in ϕ1-S50. In the former, vapor was released thoroughly from all parts, enabling the binder to harden completely. On the other hand, vapor may have remained in ϕ1-S50 and delayed the hardening of the binder, which may have resulted in the high thickness swelling of ϕ1-S50.

As described above, it was first predicted that ϕ5-S25 would result in the quick release of water vapor, quick hardening of the binder, and thus better board properties than ϕ1-S25. However, in practice, ϕ1-S25 had better properties than ϕ5-S25. The temperature behavior of the boards during hot pressing was monitored and is shown in Fig. 5; there was no major difference between ϕ5-S25 and ϕ1-S25. Thus, the better properties of ϕ1-S25 compared with ϕ5-S25 were not attributable to quicker hardening of the binder caused by a faster temperature rise. On the other hand, the temperature change for no air-injection (ordinary board manufacturing) was different from that of the above two boards. The temperature in the case of no air-injection was higher than that of both ϕ5-S25 and ϕ1-S25 from 0 until 250 or 290 s. After 250 or 290 s, the former became slightly lower than the latter, but, as described in the previous study,[1] the former internal bond strength was lower than that of the latter.

Figure 6 shows ϕ1 holes in the caul plate (where the air was released) clogged with binder after board production. The binder did not stick in the holes in the lower heating plate because the binder was released from the board by the high-pressure air and became stuck in the holes in the caul plate. Discharge of the binder together with the high-pressure air reduces the amount of binder remaining in the board and thus results in impaired board properties. The total hole area is much larger for ϕ5-S25 than for ϕ1-S25, and thus the amount of discharged binder is larger in the former and the board properties are poorer. Both ϕ1-S25 and ϕ5-S25 could be manufactured by hot pressing for 6 min but not for 4 min. This shows that large holes cannot shorten the required pressing time. As a result, ϕ1-S25 was better than ϕ5-S25.

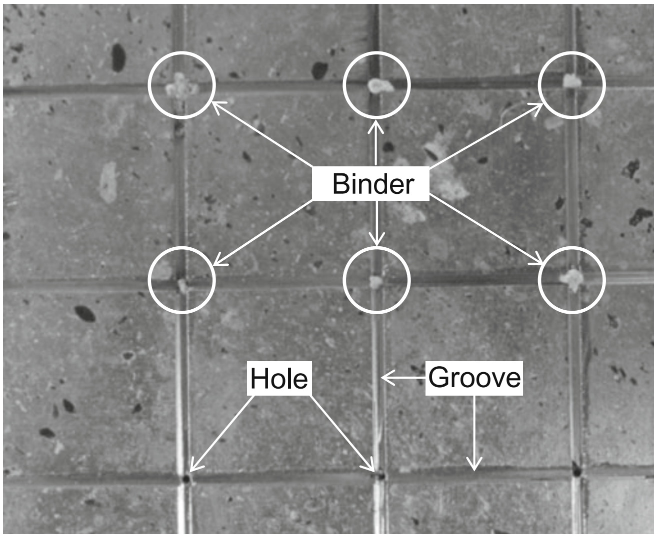

Fig. 6. Holes clogged with adhesive in the grooved caul plate of ϕ1-S25

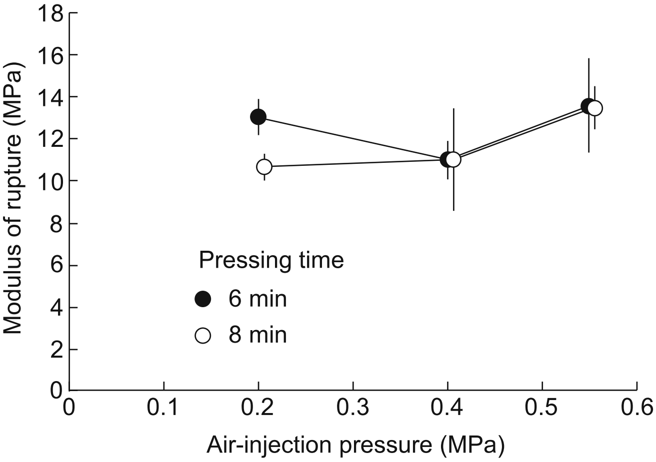

Fig. 7. Relationship between air-injection pressure and modulus of rupture for ϕ1-S25

Effects of high-pressure air on board properties

If the high-pressure air forces out the binder from the boards, the amount of binder discharged from the board can be reduced by lowering the air-injection pressure. Boards were manufactured by using lower air-injection pressures with holes of ϕ1-S25 and pressing time of 6 or 8 min.

The resultant modulus of rupture is shown in Fig. 7. Although there were small differences, the modulus of rupture was within the range of about 11–13 MPa for all air-injection pressures, showing that the air-injection pressure did not greatly affect the modulus of rupture.

The internal bond strength is shown in Fig. 8. Unlike the modulus of rupture, the internal bond strength was the highest at an air-injection pressure of 0.55 MPa, and was 0.44 and 0.43 MPa when pressed for 6 and 8 min, respectively. Due to the performance of the compressor, the air-injection pressure could not be raised above 0.55 MPa. At an air-injection pressure of 0.2 MPa, the internal bond strength was 0.20 and

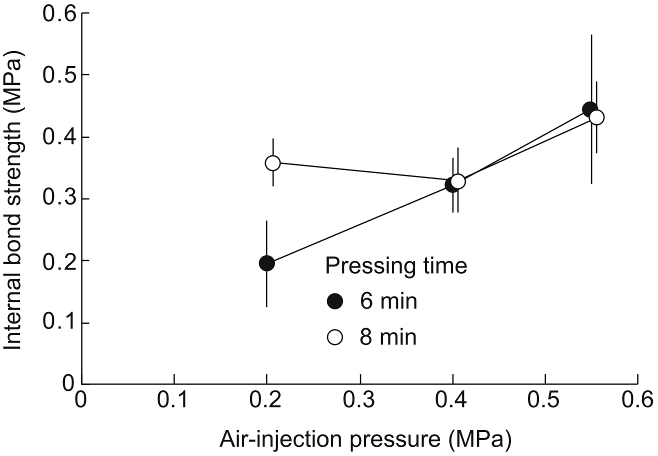

Fig. 8. Relationship between air-injection pressure and internal bond strength for ϕ1-S25

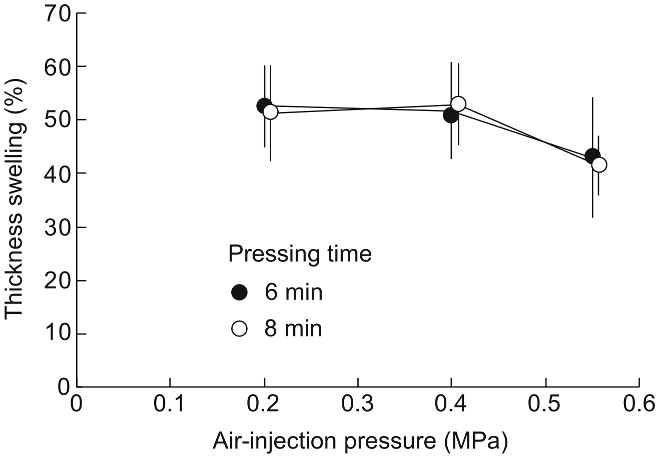

Fig. 9. Relationship between air-injection pressure and thickness swelling for ϕ1-S25

0.36 MPa for pressing times of 6 and 8 min, respectively. This low strength value, particularly for the pressing time of 6 min, was likely because the low air-injection pressure was unable to discharge vapor thoroughly from the board in such a short pressing time and the binder could not harden sufficiently. The board that was pressed for 8 min showed improved internal bond strength because the binder hardened further.

The internal bond strength of ϕ5-S25, which was manufactured by injecting air at 0.55 MPa, was about 0.3 MPa (Fig. 3). This was equivalent to the internal bond strength of ϕ1-S25 manufactured by injecting air at 0.4 MPa (Fig. 8). The total area of the holes in ϕ5-S25 was 25 times larger than that of ϕ1-S25. The internal bond strength increased by reducing the total hole area, i.e., by reducing the hole size from ϕ5 to ϕ1. However, the internal bond strength was found to drop even in the ϕ1 press when the air-injection pressure was lowered. The small holes reduced the amount of binder discharged from the board but also reduced the amount of vapor released. Therefore, the air-injection pressure had to be increased to sufficiently discharge vapor. In the future, we will examine the relationships among air-injection pressure and the diameter and spacing of holes to determine the optimum conditions.

The thickness swelling of boards is shown in Fig. 9. The same trends were observed with pressing times of 6 and 8 min with a thickness swelling of about 52% at air-injection pressures of 0.2 and 0.4 MPa. The thickness swelling was reduced to about 42% by increasing the air-injection pressure to 0.55 MPa. As shown in Fig. 8, the internal bond strength increased at an air-injection pressure of 0.55 MPa. The low thickness swelling values at 0.55 MPa were likely due to the high internal bond strength. High air-injection pressure was found to also reduce thickness swelling and improve dimensional stability.

Conclusions

1. The properties of the boards were improved by reducing the hole diameter from 5 to 1 mm. For example, the internal bond strength was improved from 0.30 MPa to 0.44 MPa.
2. In presses that had 5-mm and 1-mm holes, boards could not be manufactured by pressing for only 4 min, but boards could be manufactured by pressing for 6 min. Therefore, reducing the diameter of the holes did not negate the effect of the air-injection press in reducing pressing time.
3. Small holes prevented the binder from being discharged from the board, which likely led to the improved board properties.
4. Small holes could not improve the board properties when the air-injection pressure was lowered. A high air-injection pressure of 0.55 MPa resulted in improved board properties.

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