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ORIGINAL ARTICLE

Development of an air-injection press for preventing blowout of particleboard (III): effects of pressing temperature on board performance

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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 particleboards and discharges the air and vapor through the other plate during press heating. The press can manufacture particleboards from high-moisture particles by preventing blowouts of the boards. In this study, the effects of pressing temperature were investigated by pressing boards at 190, 210, and 230°C. The internal bond strength increased from 0.43 to 0.60 MPa by raising the temperature from 190 to 210°C, but did not increase further when the temperature was raised to 230°C. Raising the temperature from 190 to 210°C also helped improve the thickness swelling. No relationship was found between the modulus of rupture and pressing temperature.

Keywords Air-injection press · Particleboard · Blowout · Pressing temperature · Board performance

Introduction

When manufacturing particleboard, vapor can become trapped between the wood particles during the hot pressing process and causes a blowout effect on the board when the pressure of the press is released [1, 2]. Since this damage occurs at the final stage of the manufacturing process, all preceding procedures are wasted and productivity is severely reduced. The effective method at present for preventing blowout is to use completely dry particles [3].

In a previous study [4], we developed a hot press that discharges the vapor trapped inside the board and thus prevents blowout. 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.

In a subsequent study [5], we investigated the effects of the diameter of injection holes on the performance of the boards. We estimated that large holes of 5 mm in diameter could discharge vapor better than small holes of 1 mm in diameter and would prevent blowouts more effectively. However, the study showed that 1 mm holes actually prevent blowouts effectively and result in higher internal bond strength than 5 mm holes. This is likely because large holes cause discharge of the binder as well as vapor, whereas the smaller 1 mm holes reduced the discharge of binder and increased the internal bond strength.

In the present study, the pressing was further modified to improve the performance of boards. The effects of the pressing temperature on board performance were investigated. Higher pressing temperature was considered to accelerate the hardening of the binder and thus improve board performance.

Experimental method

Board manufacturing

An air-injection press with holes of 1 mm in diameter was prepared. The holes were arranged on the lower plate at the spacing of 25 mm between the centers of adjacent holes,

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resulting in 121 holes in an area of 250 × 250 mm through which air was injected (Fig. 1). Holes were also punched on the caul plate (upper plate) through which the high-pressure air and vapor was discharged. The diameter and spacing of the holes on the caul plate was the same as that of the lower plate, so there were also 121 holes on the caul plate in an area of 250 × 250 mm. Grooves that were 1.5 mm deep and 1 mm wide were also cut connecting the holes on one side of the caul plate to release the high-pressure air (see [4]). Although the actual air-injection press has holes in the hot plates, it is difficult to punch holes in the plates. Therefore, an air-injection device was developed, and was placed on the hot press for the experiments (Figs. 1, 2). The device was also shown in [4]. The device does not have a heater but is heated by the hot press (Fig. 2). The entire set is referred to as an air-injection press in this study.

The particles used in the experiment were manufactured from wood waste for manufacturing core layers (Japan Novopan Industrial Co., Ltd.). The mean length (standard deviation) of 200 particles measured was 15.4 (6.69) mm. The binder used was a urea–formaldehyde resin (Oshika Co., Ltd., resin content: 65%, viscosity: 0.14 Pa s). Curing agent of 10% ammonium chloride solution was added to the binder to constitute 10% (by weight). The resulting binder mixture was added to the particles to constitute 10% (by oven-dried weight). To adjust the moisture content of the particles to 25%, a predetermined amount of water was sprayed on the particles prior to spraying the binder. The dimensions of the board were 300 × 300 × 10 mm, and the target board density was 0.70 g/cm^3.

To investigate the effects of pressing temperature on board performance, boards were manufactured by pressing at 190, 210 and 230°C. For boards manufactured by injecting air, the boards were pressed at these temperatures for 4, 6, 8 and 10 min. The pressure of the air was 0.55 MPa. The injection of high-pressure air was started after the press had thoroughly compressed the board, i.e., when the thickness of the board reached 10 mm. The air injection was stopped for the final 15 s of the pressing time. On the other hand, for boards manufactured by not injecting air, the boards were pressed just until they became firm in order to determine the pressing time needed for manufacturing the boards. Therefore, there was only one pressing time for each pressing temperature. The boards manufactured and their pressing times are shown in Table 1. One board was manufactured for each condition. The temperature of the boards was monitored by installing thermocouples in the middle layer at one end of each board [4].

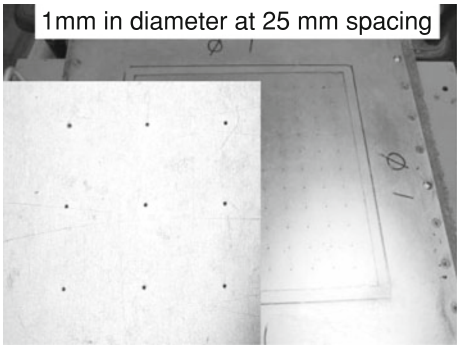

Fig. 1 The air-injection device of the air-injection holes of 1 mm in diameter with 25-mm spacing

Board performance tests

The moisture content of the boards manufactured was adjusted before the tests by leaving them in a thermo-hygrostat at 20°C and 65% relative humidity until the weight stabilized. The modulus of rupture, internal bond strength and thickness swelling were determined according to JIS A 5908:2003 [6]. The number of specimens was 5, 8 and 7, respectively.

Results and discussion

Pressing temperature and reducing the pressing time

Table 1 shows the pressing temperature and the success or the failure of board manufacturing. Without air injection,

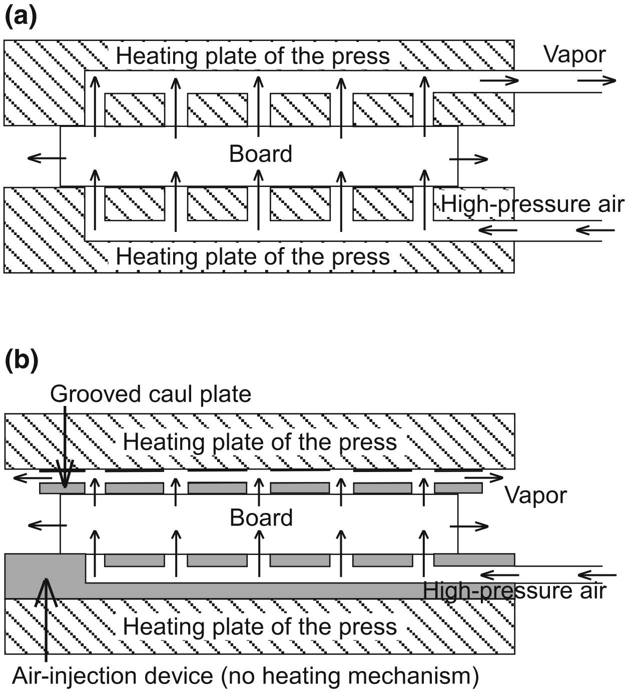

Fig. 2 Schematic diagram of the air-injection press (**a**) and laboratory air-injection press (air-injection device, grooved caul plate and hot press) (**b**) for preventing board blowout

Table 1 Success of board manufacture

Pressing time (min)	Pressing temperature (°C)					
	190		210		230	
	No air injection	Air injection	No air injection	Air injection	No air injection	Air injection
4		Not successful		Not successful		Not successful
6		Successful	Not successful	Successful	Not successful	Successful
8	Not successful	Successful	Successful	Successful	Successful	Successful
10	Successful	Successful		Successful		Successful

"Successful" indicates that it was possible to manufacture the board

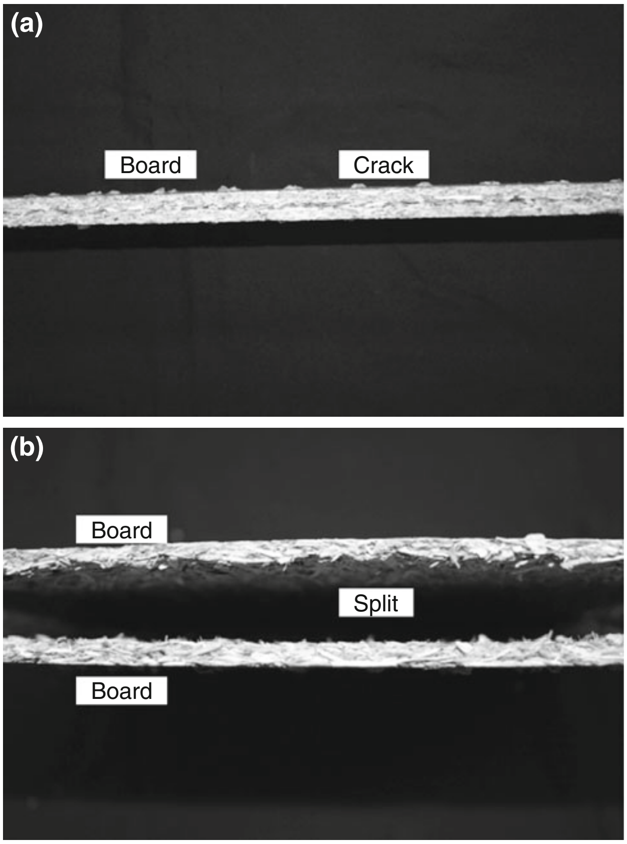

Fig. 3 Failure of board manufacture. **a** There is a crack within the board. **b** The board split completely

pressing at 190°C for 8 min was insufficient for manufacturing the board, and it required 10 min. Board manufacturing was deemed a failure when the binder inside the board did not harden sufficiently, resulting in cracks and breakage of the board (Fig. 3). When pressed at 210 or 230°C, the boards could be manufactured without air injection in 8 min, reducing the pressing time from that at 190°C. When air was injected, 6 min of pressing time was sufficient for manufacturing the boards at 190, 210 or 230°C. The pressing time could not be reduced further even by raising the pressing temperature to 230°C.

Modulus of rupture

Figure 4 plots the modulus of rupture against pressing time. The modulus of rupture of the board manufactured by not injecting air was larger than that manufactured by injecting air. On the other hand, the modulus of rupture of the boards manufactured by injecting air was within the range of 13.1–16.5 MPa irrespective of the pressing temperature, showing no distinct relationship between the modulus of rupture and pressing time and temperature. Air injection lowered the modulus of rupture, possibly because it reduced the density at the surface [4]. Furthermore, it lowered the temperature of the lower plate through which air was injected [4], and slowed the hardening of the binder near the lower plate. Another possible factor that may have lowered the strength at the surface was that the air discharged the binder from the surface near the lower plate, reducing the amount of binder. Because the modulus of rupture of a board depends on the strength at the surface [7], a drop in the strength at the surface results in a drop in the modulus of rupture of the board. Thus, the drop in the modulus of rupture caused by air injection was likely because of the reduction in strength at the surfaces. The modulus of rupture must be increased by injecting air in the future.

Internal bond strength

The relationship between the pressing time and internal bond strength is shown in Fig. 5. Unlike the modulus of rupture, the boards manufactured by injecting air had higher internal bond strength than those manufactured by not injecting air. For example, the internal bond strength of the board manufactured by pressing at 190°C (no air injection) was 0.32 MPa, and was 0.45 MPa in boards manufactured by pressing at the same temperature for 10 min and air injection.

Figure 6 plots the temperature in the middle layer of the board against pressing time. The time needed to reach 100°C was shorter without air injection than with air injection at all pressing temperatures. At the pressing

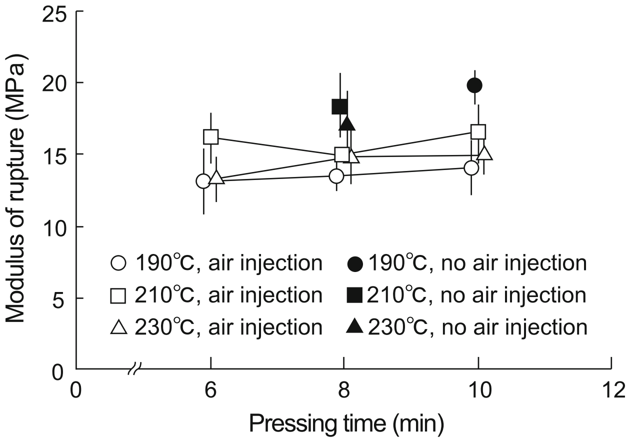

Fig. 4 Relationships between pressing time and modulus of rupture at pressing temperatures of 190, 210 and 230°C. Effects of air injection or no air injection on modulus of rupture

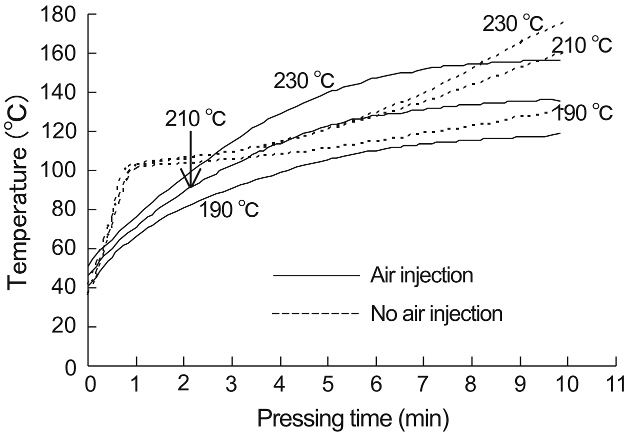

Fig. 6 Relationships between pressing time and temperature behavior of the center of the board at pressing temperatures of 190, 210 and 230°C. Effects of air injection or no air injection on temperature behavior

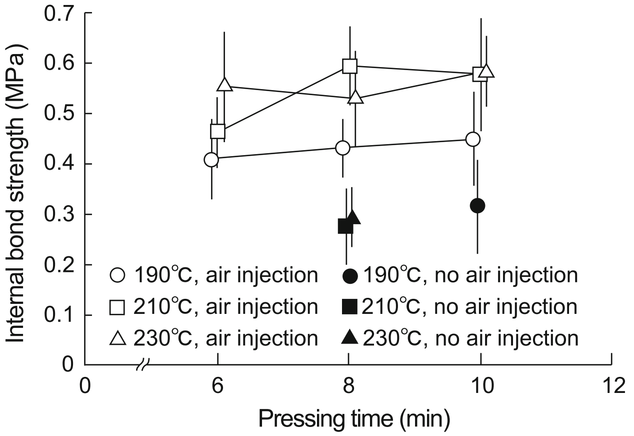

Fig. 5 Relationships between pressing time and internal bond strength at pressing temperatures of 190, 210 and 230°C. Effects of air injection or no air injection on internal bond strength

temperature of 190°C, the temperature in the middle layer was lower when air was injected than when not injected. Although the low temperature should have delayed the hardening of the binder, the internal bond strength was higher in those boards manufactured by injecting air. The air injection lowered the temperature of the middle layer but increased the internal bond strength by forcing out vapor. The forcing out vapor is more important than the high temperature for improving the internal bond strength.

When no air was injected, the temperature of the middle layer rose similarly for all pressing temperatures until 1 min of pressing, or until the temperature of the middle layer reached 100°C [8]. After 1 min, the higher the pressing temperature, the higher the temperature of the middle layer. [8] The internal bond strength was 0.27–0.32 MPa regardless of the pressing temperature for boards manufactured by not injecting air.

When air was injected, the temperature of the middle layer was higher at the pressing temperature of 210°C than at 190°C. The internal bond strength of the boards pressed at 210°C was higher than that of the boards pressed at 190°C. A big difference in internal bond strength was observed between them. For example, the internal bond strengths of the boards pressed at 210 and 190°C for 8 min were 0.60 and 0.43 MPa, respectively. When the pressing temperature was raised to 230°C, the temperature of the middle layer was higher than that of the boards pressed at 210°C, but the internal bond strength did not increase. The internal bond strength of the boards pressed at 230°C was almost the same as that of the boards pressed at 210°C.

The experiment showed that the optimum pressing temperature of the air-injection press in terms of internal bond strength is 210°C. Note, however, that the air-injection device used in this experiment was not equipped with a heater and heat was applied from the hot press (Fig. 2). The optimum pressing temperature in this study was 210°C, but may have been different if the air-injection device had been equipped with a heater. We will install a heater to the air-injection device and investigate the optimum pressing temperature. In addition, this experiment just started, and it is necessary to make the optimum device and to find the optimum pressing conditions.

The modulus of rupture was 18.4 MPa in the board manufactured by not injecting air and was 15.0 MPa in the board manufactured by injecting air (Fig. 4, pressing time 8 min, pressing at 210°C). The air injection reduced the modulus of rupture by 21%. On the other hand, the internal bond strengths of the boards were 0.27 and 0.60 MPa, respectively. The air injection increased the internal bond strengths by 2.2 times. The air injection reduced the modulus of rupture and increased the internal bond

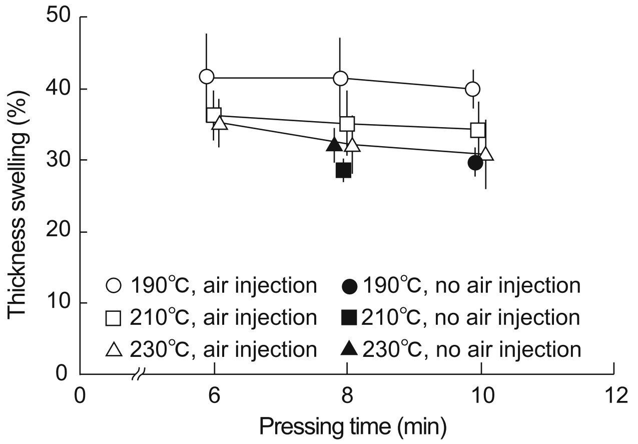

Fig. 7 Relationships between pressing time and thickness swelling at pressing temperatures of 190, 210 and 230°C. Effects of air injection or no air injection on thickness swelling

strength. The effect of increasing the internal bond strength was larger than the reduction of modulus of rupture. The air injection also reduced the pressing time. Thus, the advantages of air injection, which include a remarkable increase of internal bond strength, and shortened pressing time, outweigh the disadvantage of a drop in the modulus of rupture.

Thickness swelling

Figure 7 plots the thickness swelling of the boards against pressing time. The thickness swelling of the boards manufactured by injecting air and pressing at 190°C was about 40%. On the other hand, the boards manufactured by not injecting air showed thickness swelling values of about 30% regardless of the pressing temperature. The thickness swelling of the boards manufactured by non-injection of air was estimated to be higher than in the case with air injection because the former internal bond strength was lower. However, the results were the contrary, and the thickness swelling was lower when air was not injected. The conventional method of manufacturing boards (without air injection) from high moisture content particles has been reported to suppress thickness swelling [9]. This is because wood particles are plasticized under high-temperature and high-pressure vapor conditions, and the contact between wood particles was improved. The improved contact is likely to have prevented water from infiltrating into the board [10]. In this study, the conditions during the board manufacture when air was not injected were the same as those for producing boards from high moisture content particles, resulting in low thickness swelling. However, the temperature inside the board was low when it was pressed at 190°C and air was injected (Fig. 6). The board was not exposed to the high-temperature and high-pressure vapor conditions, and thus the contact between particles was not improved. The boards that were manufactured by injecting air and pressing at 210 or 230°C were heated sufficiently thoroughly, were exposed to the high-temperature and high-pressure vapor conditions, and were compressed and fixed. The high internal bond strengths of the 210 and 230°C boards were also a cause for the low thickness swelling.

Conclusions

In this study, the optimum pressing temperature was determined. The following results were also obtained.

1. The air injection reduced the modulus of rupture. There was not a clear relationship between the modulus of rupture and pressing temperature when the boards were manufactured by injecting air.
2. Contrary to the modulus of rupture, the air injection increased the internal bond strength. Raise of the pressing temperature from 190 to 210°C further increased the internal bond strength from 0.43 to 0.60 MPa. However, raising the temperature to 230°C did not increase the internal bond strength.
3. At pressing temperatures of 190 and 210°C, the air injection lowered the temperature of the middle layer of the boards.
4. The thickness swelling was lower at pressing temperatures of 210 and 230°C than at 190°C when air was injected. The high-pressing temperatures reduced, i.e., improved, the thickness swelling.
5. The air injection decreased the modulus of rupture but increased the internal bond strength. The increase in internal bond strength was much larger than the drop in modulus of rupture, showing the effectiveness of the air injection. The air injection also reduced the necessary pressing time. The air injection was shown to be effective because the advantages outweighed the disadvantage.

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