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ORIGINAL ARTICLE

Hideaki Korai · Nan Ling · Takayoshi Osada
Osamu Yasuda · Atsushi Sumida

Development of an air-injection press for preventing blowout of particleboard I: effects of an air-injection press on board properties

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Abstract An air-injection press was developed to prevent particleboard from blowing out during the manufacturing process. The air-injection press, which has holes punched in the heating plates, injects high-pressure air into the board through the holes of one plate and releases the air through the holes of the other plate. The high-pressure air forces out vapor trapped within the board, thus preventing blowout. The newly developed press reduced the pressing time required for manufacturing board from high-moisture-content particles. However, the manufactured boards exhibited mechanical properties and dimensional stability inferior to conventionally manufactured boards.

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

Introduction

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

This article describes the development of a hot press that discharges the vapor trapped inside the board and prevents blowout from occurring. A schematic of the press is presented in Fig. 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. The press is called an air-injection press. The air-injection press is similar to the steam-injection press;[1] the difference between the two is that the air-injection press injects high-pressure air whereas the steam-injection press injects high-pressure steam. The purposes of these two types of presses are completely different. The purpose of the steam-injection press is to manufacture thick board or to reduce the pressing time, whereas that of the air-injection press is to prevent the blowout of the board. There is a great difference between the two techniques.

The air-injection press is expected to be suitable for manufacturing board even from high-moisture-content (high-MC) wood particles. This advantage enables the development of an innovative method for manufacturing boards. The manufacturing process for boards involves drying the wood particles, spraying on a binder, and then hot pressing the particles into a board. Here, energy efficiency is the key. Energy is used for drying the particles, which need to be cooled to room temperature before spraying on the binder. After the binder is applied, the particles are hot pressed using additional energy. Energy use is inefficient because the process involves heating, cooling, and reheating. If the particles could be dried while being hot pressed, energy consumption would be sharply reduced. The drying process is crucial for preventing blowout of the board, but the energy efficiency can be sharply improved if boards are manufactured directly from high-MC particles by using the air-injection press.

In Japan, particleboards were once produced from green wood. Today, most boards are produced using particles from wood waste. Wood waste contains much less moisture than green wood and requires less energy for drying the particles.[2] According to a survey of board manufacturers, the moisture content of particles produced from wood waste was about 20%. The air-injection press is considered feasible for manufacturing boards directly from wood particles

H. Korai (✉) · N. Ling
Forestry and Forest Products Research Institute, Tsukuba 305-8687, Japan
Tel. +81-29-829-8293; Fax +81-29-873-3797
e-mail: korai@ffpri.affrc.go.jp

T. Osada · O. Yasuda · A. Sumida
Co-operative Union Swood, Kakamigahara 509-0108, Japan

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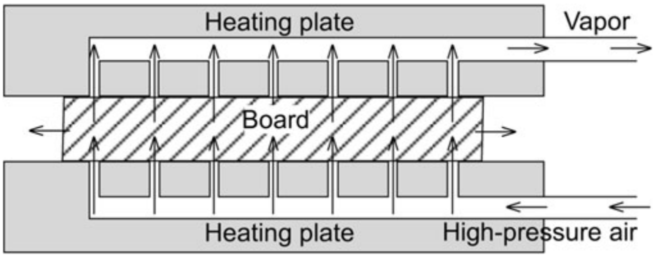

Fig. 1. Schematic of the air-injection press for preventing board blowout

that have a moisture content of about 20%, making it possible to eliminate the drying process and thus construct an energy-saving line for manufacturing board. In this study, an air-injection press was developed to prevent blowout, and the boards were manufactured from high-MC particles (25% moisture content).

Materials and methods

Structure of the air-injection press

As shown in Fig. 1, the air-injection press has holes punched in the heating plates of the press through which high-pressure air is injected and vapor is discharged. High-pressure air at room temperature is injected from the holes in one plate, and vapor is released together with the high-pressure air through the holes in the other plate. In this experiment, holes were not punched in the heating plates of the press, but instead a device with holes punched in it was installed on the lower heating plate of the press through which air was injected (Figs. 2, 3). The device had no heating mechanism; heat was transmitted from the heating plates by narrow grid bars inside. The diameter of each hole was 5 mm (ϕ5) and the pitch between the centers of two adjacent holes was 2.5 cm (Fig. 2). There were 121 holes punched over an area of 25 × 25 cm. Also, a caul plate with dimensions of 25 × 25 cm with 121 holes punched in it (ϕ5, pitch: 2.5 cm) was placed on top of the board, through which air was injected and vapor was released. On one side of the caul plate, grooves were cut so as to connect the holes (Fig. 3) to release the air and vapor. Although actual air-injection presses have holes in the heating plates, the device described above is referred to as the air-injection press in this study (Fig. 3).

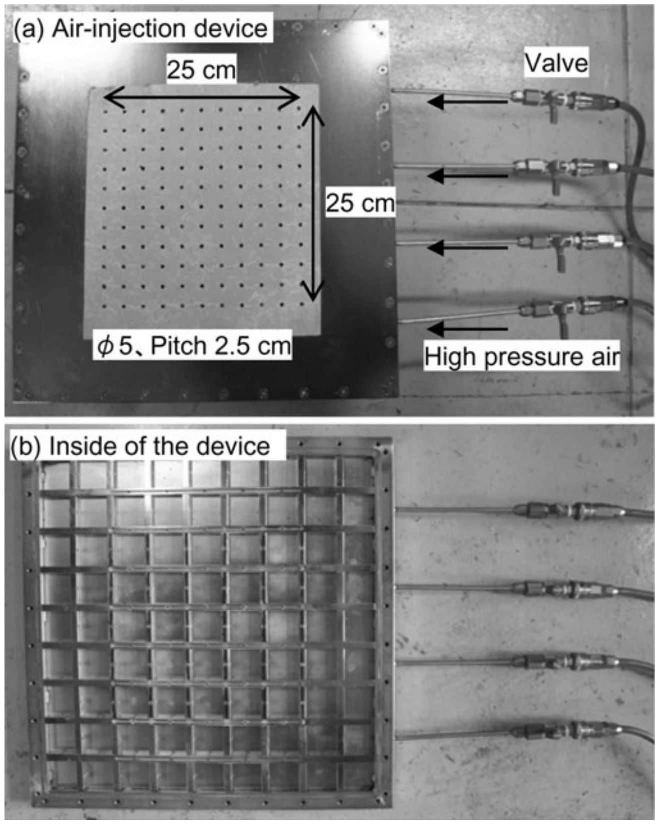

Fig. 2. The air-injection device proposed in this study (**a**) and the inside of the device (without the punched plate) (**b**)

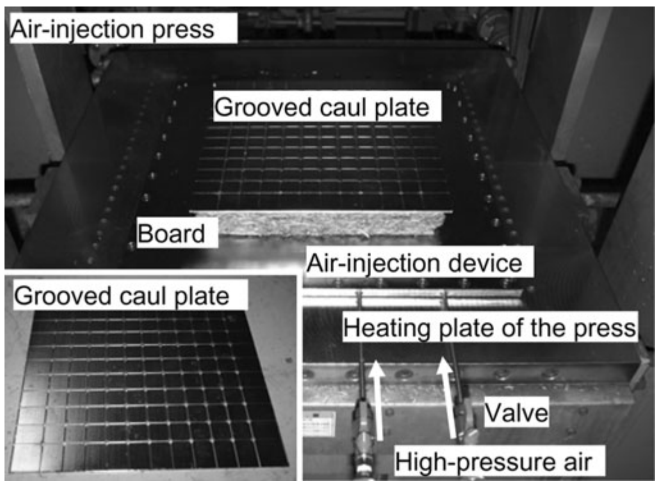

Fig. 3. The air-injection press (air-injection device, grooved caul plate and hot press)

Experimental board manufacture

The particles used in the experiment were produced from wood waste for manufacturing core layers (Japan Novopan). The average length of the particles was 15.4 (6.69) mm (Fig. 4). The number in parentheses indicates the standard deviation. The number of particle specimens measured was 200. The binder used was a urea-formaldehyde resin (Oshika, solid content: 65%, viscosity: 0.21 Pa·s). Ammonium chloride solution (10%) was added to the binder as a curing agent so as to constitute 10% of the binder. The resultant binder was added to the particles so as to account for 7% of the particle oven-dry weight. To adjust the moisture content of the particles to 25%, a predetermined amount of water was sprayed on the particles prior to binder spraying. In general, urea-formaldehyde resin is difficult to cure under high-temperature and high-pressure steam.[3] If the air-injection press proved to be effective in curing urea-formaldehyde resin under high-temperature and high-pressure steam, it would be more effective in curing other

Table 1. Particleboard production conditions

Board	AID	HPA	MC (%)	PT (min)	Purpose
No. 1	Not used	No air-injection	14	4, 6, 8, 10	Control
No. 2	Not used	No air-injection	25	8, 10, 12	High-MC
No. 3	Used	No air-injection	14	4, 6, 8	Effect of air-injection device, Low-MC
No. 4	Used	Air-injection	14	4, 6, 8	Effect of high-pressure air-injection, Low-MC
No. 5	Used	Air-injection	25	8, 10, 12, 14	Effect of high-pressure air-injection, High-MC
No. 6	Used	No air-injection	25	4, 6, 8, 10	Effect of no high-pressure air-injection, High-MC

AID, air-injection device; HPA, high-pressure (0.55 MPa) air-injection; MC, moisture content; PT, pressing time

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 dimensions of the board were 30 × 30 × 1 cm, and the target board density was 0.7 g/cm^3. One board was manufactured for each manufacturing condition.

First, to assess the binder properties of the urea-formaldehyde resin, a board was manufactured from low-moisture particles without using the air-injection device or spraying water but instead using the standard method. The moisture content of the particles was about 11% before the binder was sprayed and about 14% (low-MC) after it was sprayed. The board was manufactured by setting the temperature of the heating plates at 190°C and the pressing time at 4–8 min (Table 1, experimental condition no. 1). No. 1 was a control board, and the properties of board no. 1 were the target in this study. Then, to understand the properties of boards manufactured from high-MC particles using the urea-formaldehyde resin, a board was manufactured without using the air-injection device but instead using an ordinary press and spraying a predetermined amount of water to adjust the moisture content of the particles to 25% (Table 1, no. 2). The properties of the boards manufactured from high-MC were presumably low.

Next, a board was manufactured by spraying the urea-formaldehyde resin but not spraying water and by using the air-injection device but not injecting high-pressure air. The moisture content of the particles was 11%, which increased to 14% after the binder was sprayed. The temperature of the heating plates was set at 190°C, and the pressing time was 4–8 min (Table 1, no. 3). The air-injection device had no heating mechanism (Fig. 2). This absence of heating mechanism might cause a reduction of board properties. To assess the effect of no heating mechanism, board no. 3 was manufactured by no injecting high-pressure air. To compare board properties, a board was also manufactured by injecting high-pressure air (0.55 MPa) (Table 1, no. 4).

A board was then manufactured by adjusting the moisture content to 25% and injecting high-pressure air (0.55 MPa) from the bottom during hot pressing (Table 1, no. 5). Board no. 5 was manufactured to assess the effect of high-pressure air-injection. The air-injection 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 30 s of the pressing time. For comparison, a board was also manufactured without injecting air (Table 1, no. 6). The temperature of the heating plates was set at 190°C, and the pressing time was 4–8 min (Table 1, nos. 5 and 6). The temperature of the boards was monitored by installing thermocouples at the bottom surface, the center, and the upper surface on one end of each board (Fig. 5).

Fig. 4. Particles used in this study

Board property testing

The boards manufactured as described above were adjusted for moisture content by placing them in a thermohygrostat (20°C, relative humidity: 65%) until the weight stabilized before they were tested. The modulus of rupture, the internal bond strength, and the thickness swelling were determined according to JIS A 5908:2003.[4] The number of specimens tested was 5, 8, and 7, respectively. The boards that were manufactured using the air-injection press had many tubercles formed on both surfaces (Fig. 6) due to the holes in the press. The modulus of rupture was determined without removing the tubercles, but the internal bond strength and the thickness swelling were measured after removing the tubercles using a knife and smoothing the board surface. Prior to measuring the internal bond strength, the density profile was determined for four specimens using a density profile measuring system (GreCon, DA-X). In

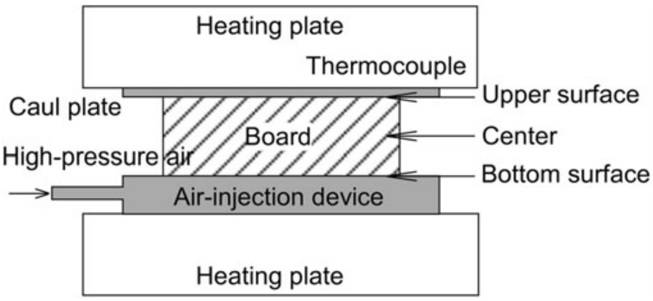

Fig. 5. Temperature measurement points on the board. The temperature of the boards was monitored by installing thermocouples at the bottom surface, center, and upper surface on one end of each board

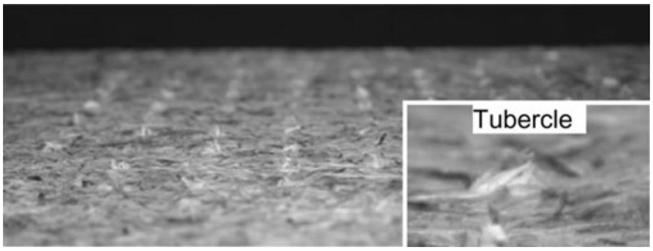

Fig. 6. Surface of the board manufactured using the air-injection press. Tubercles were formed on both surfaces due to the holes in the press

Table 2. Properties of control board no. 1

PT (min)	MOR (MPa)	IB (MPa)	TS (%)
4	20.6 (0.738)	0.799 (0.0741)	28.7 (0.951)
6	21.4 (2.28)	0.929 (0.0436)	30.4 (1.75)
8	20.6 (1.48)	0.590 (0.156)	35.8 (1.72)
10	20.0 (1.23)	0.620 (0.136)	35.3 (2.66)

Numbers in parentheses indicate standard deviations
MOR, modulus of rupture; IB, internal bond strength; TS, thickness swelling

view of the possible nonuniformity of board density, a calculation was made by dividing the measured density along the thickness direction by the mean board density of the specimen to yield the relative density.

Results and discussion

Effects of air-injection press on board properties

Table 2 shows the properties of the board manufactured from low-MC particles and without using the air-injection press but instead using an ordinary hot press (board no. 1). The modulus of rupture and the internal bond strength of board no. 1 were approximately 20 MPa and 0.590–0.929 MPa, respectively. Based on the standard modulus of rupture and internal bond strength values in the JIS Standards, the manufactured board was assessed as being type 18. Thickness swelling was 28.7–35.8%, which was large, likely because urea-formaldehyde resin was used and all particles used were those for manufacturing core layers and were large. Irrespective of the pressing time, the modulus of rupture was almost constant at about 20 MPa. On the other hand, internal bond strength (0.929 MPa) was greatest at 6 min, and thickness swelling (28.7%) was smallest at 4 min. Based on internal bond strength and thickness swelling, the optimum pressing time using urea-formaldehyde resin was from 4 to 6 min. These properties were used as a standard in this study.

In general, particleboard that is manufactured using urea-formaldehyde resin has reduced properties when high-MC (about 25%) particles are used.[5] The resin used in this study was likely to have a similar characteristic, and the effects of high-MC were assessed by manufacturing a board under condition no. 2. The properties of the board are shown in Table 3. When the MC was high, a board could not be manufactured using a pressing time of 8 min or less, and the particles had to be pressed for at least 10 min. The modulus of rupture (14.4 and 12.4 MPa) and internal bond strength (0.166 and 0.147 MPa) were significantly lower than the values shown in Table 2 (board no. 1), and the thickness swelling (37.8% and 41.8%) was much larger. The density profiles of boards no. 1 and 2 are shown in Fig. 7. Since the profiles were little affected by pressing time, density profiles for a reasonable pressing time are shown in the figure. Board no. 2, which was manufactured from high-MC particles, showed high density at the surface and low density in the core. This density profile should have

Table 3. Properties of board no. 2

Pressing time (min)	MOR (MPa)	IB (MPa)	TS (%)
8	It was impossible to manufacture the particleboard		
10	14.4 (0.861)	0.166 (0.0530)	37.8 (3.46)
12	12.4 (1.56)	0.147 (0.0246)	41.8 (6.43)

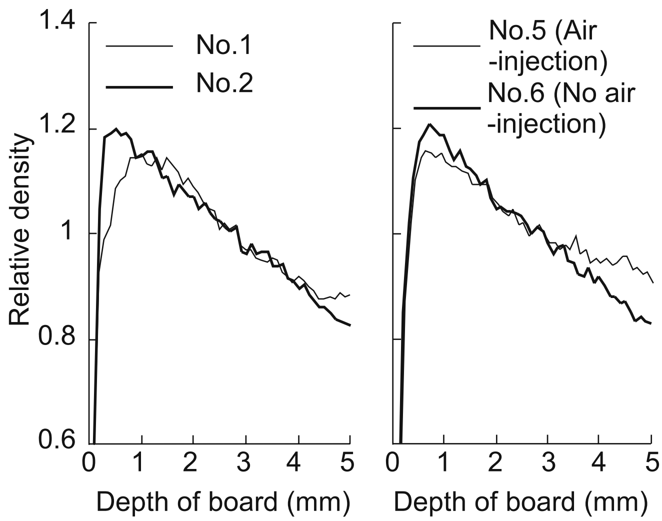

Fig. 7. Effects of pressing conditions on density profile. Relative density is the density at each depth divided by the mean board density. Boards no. 1, 2, 5, and 6 are defined in Table 1

Table 4. Properties of boards no. 3 (no air-injection) and 4 (air-injection)

PT (min)	MOR (MPa)		IB (MPa)		TS (%)	
	No air-injection	Air-injection	No air-injection	Air-injection	No air-injection	Air-injection
4	20.8 (2.21)	17.6 (1.04)	0.868 (0.0981)	0.818 (0.0884)	31.0 (2.16)	34.6 (3.17)
6	19.1 (2.60)	19.9 (2.55)	0.862 (0.143)	0.753 (0.109)	30.5 (3.98)	32.1 (3.42)
8	19.0 (1.97)	19.1 (1.78)	0.826 (0.0853)	0.760 (0.131)	32.0 (2.36)	34.1 (5.22)

Table 5. Success of board manufacture for boards no. 5 and 6

Pressing time (min)	Air-injection (no. 5)		No air-injection (no .6)	
	Successful or not	MOR (MPa)	Successful or not	MOR (MPa)
4	Not successful			
6	Successful	11.3 (0.36)		
8	Successful	10.8 (2.31)	Not successful	
10	Successful	10.9 (0.93)	Successful	13.6 (1.42)
12			Successful	13.8 (2.28)
14			Successful	12.6 (0.89)

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

resulted in an increase in the modulus of rupture and a decrease in the internal bond strength,[6] but the modulus of rupture of board no. 2 was much smaller than that of no. 1. The internal bond strength of board no. 2 was lower than that expected from the decrease in core density. Therefore, it was concluded that high-MC particles result in reduced board properties when urea-formaldehyde resin is used.

In this study, an air-injection device was installed next to the heating plates. The device had no heating mechanism (Fig. 2); thus, there were concerns that the heat transmitted to the particles might be insufficient and result in reduced board properties. To investigate the effects of the air-injection device on the properties of the boards, board no. 3 (no air-injection) and board no. 4 (air injection) were manufactured from low-MC particles using the air-injection device. The results are shown in Table 4. They were similar to those shown in Table 2 (board no. 1), indicating that the air-injection device with low-MC particles did not cause any serious reduction in properties. Injection of high-pressure air with low-MC particles did not cause much difference in the modulus of rupture, internal bond strength, or thickness swelling.

Boards from high-MC particles using the air-injection press

Boards were manufactured from high-MC particles using the air-injection press. The success of board manufacture is shown in Table 5 for each pressing time. Board no. 6 could not be manufactured in 8 min; however, the air-injection enabled the manufacture of board no. 5 in 6 min. When the caul plate (Fig. 3) was not used in the device and the air and vapor were not released from the upper surface of the board, boards could not be manufactured in 6 min. This showed that the caul plate played an important role in discharging the air and vapor from the upper surface of the board. The air-injection press could manufacture particleboard in a short time even from particles with a high-MC.

The air-injection may have changed the temperature distribution inside the boards. The temperature behavior is shown in Figs. 8 and 9. When air was not injected, the temperature changed as in the ordinary production method.[7] On the other hand, when air was injected, the temperature changed in a different way to that of the ordinary method. The temperature at the bottom of the board rose sharply to about 160°C in 350 s without air-injection, but remained constant at about 110°C when air was injected. The temperature changes at the center of the board were also different. When air was not injected, the temperature reached 100°C in about 60 s, was constant until the moisture evaporated completely, and gradually rose thereafter. When air was injected, the temperature at the center of the board gradually increased from about 60°C and reached 120°C in 500 s. As shown in Table 5, air-injection, the board was successfully manufactured by pressing for 6 min (360 s), and the temperature at the center was 96.6°C at the end of the process. On the other hand, when air was not injected, a pressing time of 6 min could not manufacture a board, although the temperature at the center reached 114.9°C. The air-injection made it possible to manufacture a board even though the temperature at the center was low.

The density profiles of boards no. 5 and 6, which are examples of processes without and with air-injection, respectively, are shown in Fig. 7. In general, a density profile is bilaterally symmetrical.[8] The air-injection press was

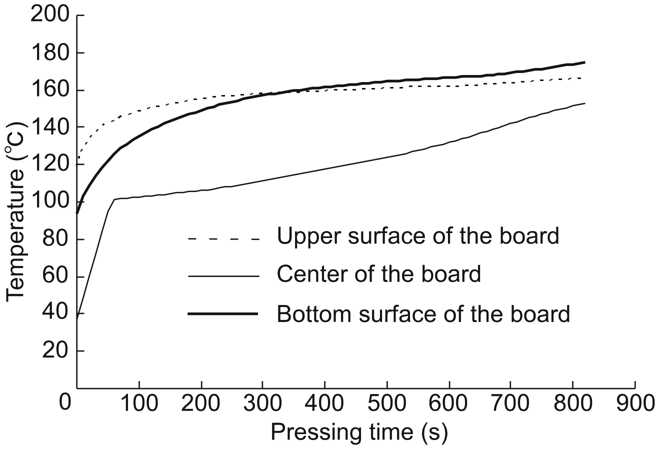

Fig. 8. Relationship between pressing time and temperature of particleboard manufactured without high-pressure air-injection at plate temperature of 190°C. The temperature of the boards was monitored by installing thermocouples at the bottom surface, center, and upper surface on one end of each board. Temperature measurement points are shown in Fig. 5

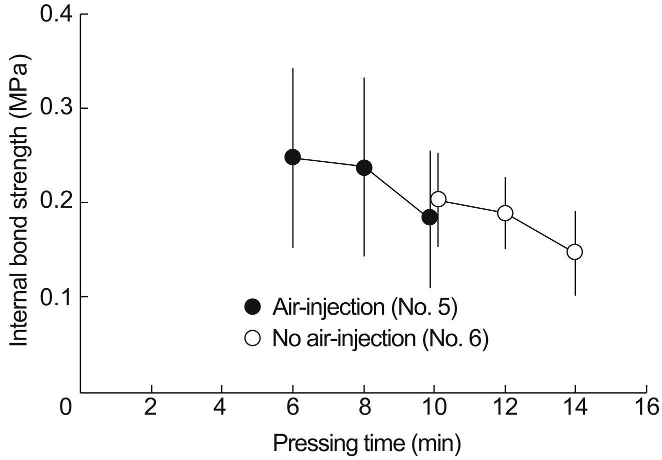

Fig. 10. Relationships between pressing time and internal bond strength. *Vertical bars* indicate standard deviations

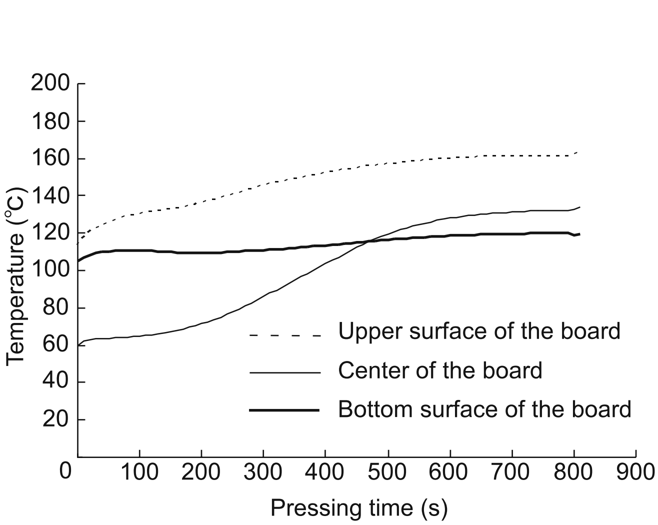

Fig. 9. Relationship between pressing time and temperature of board manufactured with high-pressure air-injection at plate temperature of 190°C

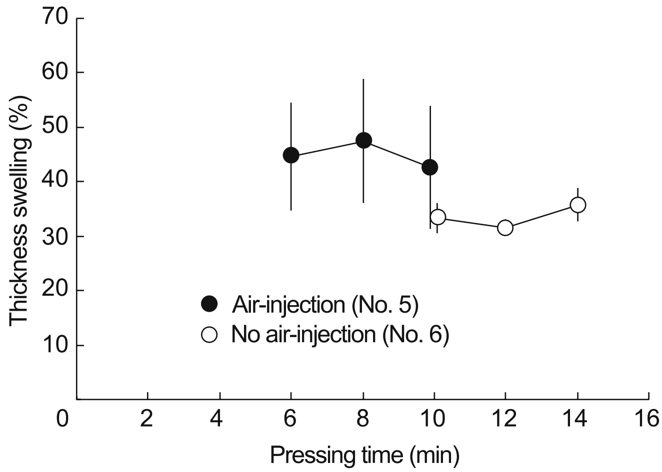

Fig. 11. Relationships between pressing time and thickness swelling. *Vertical bars* indicate standard deviations

initially suspected of possibly affecting the symmetry of the density profile, but the actual measurements showed a symmetrical density distribution and thus only one of the sides is shown in the figure. Board no. 6 showed higher density at the surface and lower density in the core than board no. 5. This suggested that board no. 6 would have a larger modulus of rupture and lower internal bond strength than board no. 5.

The modulus of rupture of board no. 5 was about 11 MPa for all pressing times, and that of board no. 6 was about 14 MPa for all pressing times (Table 5), demonstrating that the air-injection slightly reduced the modulus of rupture, as was suspected from the respective density profiles. The relationships between the pressing time and the internal bond strength are shown in Fig. 10. As illustrated in the figure, the effects of air-injection were not apparent. The trends of the density profiles suggested that the air-injection might increase the internal bond strength; however, the internal bond strength did not change. There were not differences in the internal bond strengths of boards no. 5 and 6. This suggested that the bonding strength of board no. 5 presumably was lower than that of no. 6 as regards lower density in the core layer of no. 6. The relationships between pressing time and thickness swelling are shown in Fig. 11. The air-injection caused an increase in thickness swelling and thus a decrease in dimensional change. The properties of the board manufactured by injecting air were lower than those shown in Table 2 (board no. 1) and similar to those shown in Table 3 (board no. 2). The air-injection reduced the pressing time for manufacturing board from high-MC particles but could not improve the properties of the board.

Conclusions

1. The air-injection press enabled the manufacture of particleboard using particles with high-MC, and also reduced the required pressing time. The air-injection press was shown to be effective for preventing the blowout effect.
2. The properties of board manufactured from high-MC particles using the air-injection press were much reduced compared to those of the control board. In particular, the internal bond strength was much lower. The air-injection press could not improve the properties of the boards.

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