J Wood Sci (2013) 59:42–49
DOI 10.1007/s10086-012-1298-y

ORIGINAL ARTICLE

Blowout conditions and properties of isocyanate resin bonded particleboard manufactured from high-moisture particles using an air-injection press

Hideaki Korai · Hiroshi Saotome

Received: 21 June 2012 / Accepted: 14 September 2012 / Published online: 22 November 2012

Abstract Blowouts of particleboards were artificially induced by increasing the vapor pressure inside the boards. Isocyanate resin bonded boards were manufactured from high-moisture particles, and the blowouts and board properties were analyzed. Boards with a high resin content of 5 % showed high bonding strength and did not blow out when pressed at 190 °C, but blew out at a raised temperature of 210 °C to increase vapor pressure inside the boards, thereby showing that blowout occurred when vapor pressure inside the boards exceeded the bonding strength of isocyanate resin. Boards with a low resin content of 2.5 % had low bonding strength and blew out when manufactured without air injection, but were successfully manufactured with air injection that prevents blowouts. However, the injection of high-pressure air reduced the strength properties of the board and increased the coefficient of variation, likely due to the discharge of isocyanate resin from the boards. Therefore, very small local blowouts occurred inside the boards, which lowered the strength properties of some specimens and led to a large coefficient of variation. When the pressure of injected air was lowered, the strength properties increased and the coefficient of variation decreased. This was possibly because the low-pressure air allowed isocyanate resin to remain in the boards, resulting in virtually no parts showing very low-strength properties.

Keywords Particleboard · Air-injection press · High-moisture particle · Isocyanate resin · Blowout

H. Korai (✉) · H. Saotome
Forestry and Forest Products Research Institute,
Tsukuba 305-8687, Japan
e-mail: korai@ffpri.affrc.go.jp

Introduction

In previous studies [1–3], a hot press that discharges vapor trapped inside particleboards was developed to prevent blowout. The press (with holes punched through its upper and lower heating plates) injects high-pressure air through the lower plate holes into the board and then discharges the air through the upper plate and along the edges of the board during hot pressing. The injected air discharges vapor trapped inside the boards and prevents blowout. The press is called an air-injection press and can be used to manufacture boards from particles having a high-moisture content of 25 % (high-moisture particles) by preventing blowout. Today, particleboards produced mainly from wood waste have a moisture content of about 20 %. The air-injection press can be used to manufacture boards from the particles of such high-moisture content without drying the particles in advance, resulting in energy saving [1].

The air-injection press has been tested for manufacturing boards from high-moisture particles using urea–formaldehyde resin as the binder [1–3]. The boards manufactured using the air-injection press initially showed a low bonding strength due to the high-moisture particles [4, 5]. The air-injection press has thus been improved to increase the bonding strength [1–3].

Isocyanate resin, on the other hand, allows boards to be manufactured from high-moisture particles without lowering the bonding strength [4, 6]. Therefore, isocyanate resin is likely to be more effective than urea–formaldehyde resin for high-moisture particles. In this study, isocyanate resin bonded boards were manufactured from high-moisture particles using an air-injection press, and the blowout conditions and board properties were evaluated.

Since isocyanate resin is expensive, the total cost of board production must be reduced. When using an air-injection press, it is not necessary to dry particles in advance, thereby reducing the cost [1]. Moreover, isocyanate resin releases carbon dioxide during hot pressing [6] and is more prone to blowouts than urea–formaldehyde resin [7]. Therefore, the air-injection press should also prove effective in preventing the blowouts of isocyanate resin bonded boards.

Experimental method

Particleboard manufacture

The boards were manufactured from particles produced from the wood waste for core layer of particleboard (Japan Novopan Industrial Co. Ltd.). Refer to previous study [1] for shape and dimension of particles. The board dimensions were 300 × 300 × 10 mm. The target density was 0.7 g/cm^3. Distance bars were used to control the thickness. Isocyanate resin (Sumika Bayer Urethane Co. Ltd., Sumidur 44V20) was used as the binder, and 5 % of the oven-dry weight of the particles was added (resin content: 5 %). A predetermined amount of water was sprayed on the particles before spraying isocyanate resin to adjust the moisture content to 25 %. Table 1 summarizes the board numbers and conditions of board manufacture. Board no. 1 was manufactured by being pressed for 2 to 8 min at 190 °C using an ordinary hot press (Fig. 1a). Board no. 2 was manufactured with a metal frame to seal the edges of the board in order to trap vapor and induce blowout (Figs. 1b, 2) [8]. Board no. 3 and board no. 4 were pressed at 210 °C without and with a frame (Fig. 1a, b), respectively.

The resin content was then lowered to 2.5 % to reduce the bonding strength of isocyanate resin. The moisture content of the particles was 25 %, pressing time was 4 to 12 min, and the pressing temperature was 190 °C. Table 2 summarizes the board numbers and conditions of board manufacture. Board no. 5 and board no. 6 were manufactured using an ordinary hot press without and with a frame (Fig. 1a, b), and board no. 7 and board no. 8 were manufactured using an air-injection press without and with a frame (Fig. 1c, d), respectively. The pressure of injected air was 0.55 MPa at room temperature. The injection of high-pressure air was started when the board thickness reached 10 mm and stopped for the final 15 s of pressing time. The air-injection holes on the lower plate were 1 mm in diameter, with spacing of 25 mm between the centers of

Table 1 Board nos., conditions of manufacture, and properties of board nos. 1 to 4

Board no.	Pressing temperature (°C)	Frame (yes/no)	Hot press[a]	Board properties	Pressing time (min)			
					2	4	6	8
No. 1	190	No	Fig. 1a	S/NS	NS[b]	S	S	S
				MOR (MPa)		15.7 (1.47)	17.9 (1.55)	16.2 (0.96)
				IB (MPa)		0.842 (0.17)	0.866 (0.15)	0.802 (0.13)
				TS (%)		15.6 (1.10)	14.7 (1.26)	17.7 (1.37)
No. 2	190	Yes	Fig. 1b	S/NS	NS[b]	S	S	NM
				MOR (MPa)		18.1 (2.32)	19.4 (3.29)	
				IB (MPa)		0.847 (0.09)	0.924 (0.19)	
				TS (%)		13.1 (1.16)	10.7 (0.85)	
No. 3	210	No	Fig. 1a	S/NS	NS[b]	S	NM	NM
				MOR (MPa)		17.3 (1.88)		
				IB (MPa)		0.636 (0.05)		
				TS (%)		16.6 (1.89)		
No. 4	210	Yes	Fig. 1b	S/NS		NS[c]	S	NM
				MOR (MPa)			20.4 (0.99)	
				IB (MPa)			0.903 (0.23)	
				TS (%)			13.7 (0.72)	

Particleboards were manufactured with resin content of 5 % using an ordinary hot press

The numbers in parentheses denote standard deviations

S/NS successful (S) or not successful (NS), *NM* not manufactured, *MOR* modulus of rupture, *IB* internal bond, *TS* thickness swelling

[a] See Fig. 1

[b] The center of the board was not cured

[c] Blowout

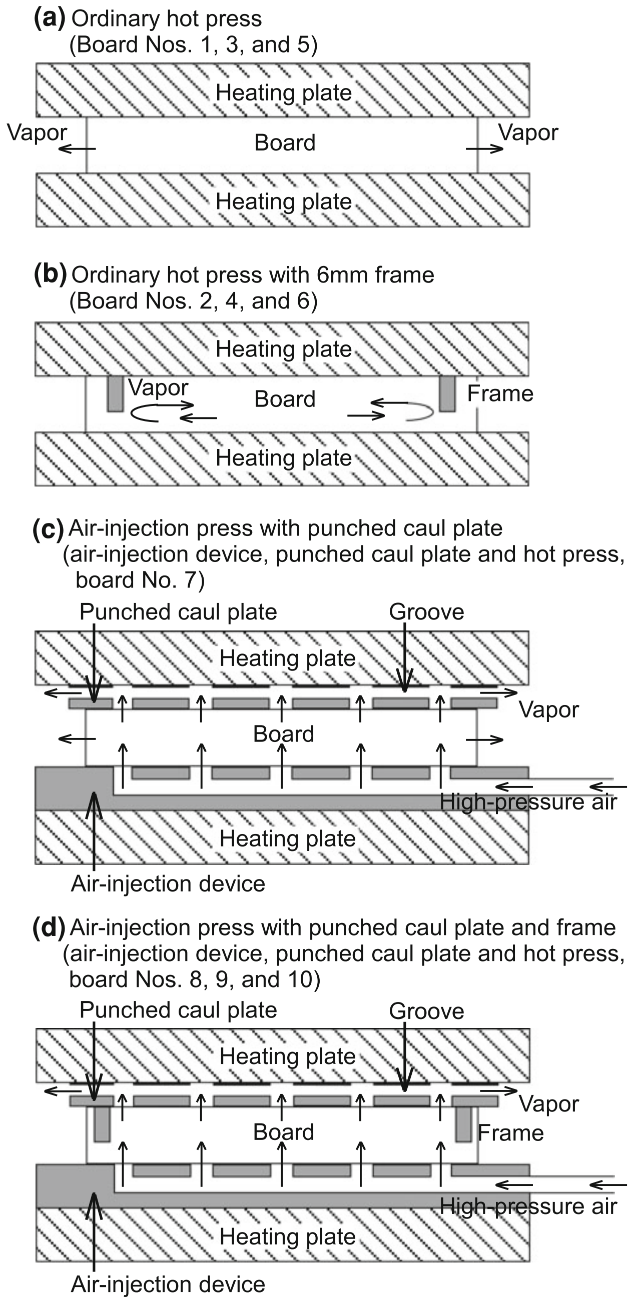

Fig. 1 Hot presses used for manufacturing boards. Board nos. 1 to 10 are shown in Tables 1 to 3

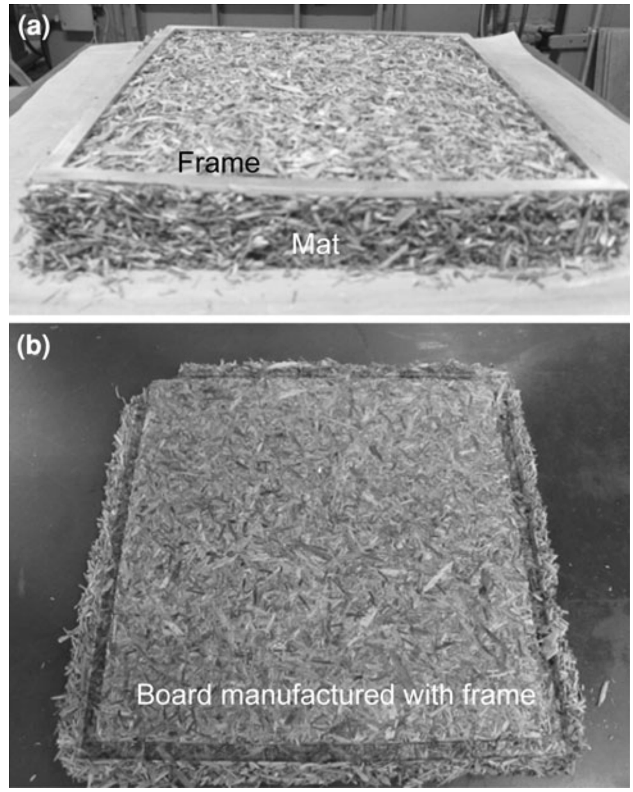

Fig. 2 Manufacture of a particleboard by placing a frame (**a**) and the manufactured board (**b**)

adjacent holes. There were 121 holes in an area of 250 × 250 mm. The caul plates also had 121 holes in an area of 250 × 250 mm. Grooves measuring 1.5 mm deep and 1 mm wide were also cut to connect the holes on one side of the caul plate to release the high-pressure air and vapor. The diameter and spacing of the air-injection holes were the same as those of the air-discharge holes.

Board no. 9 and board no. 10 were manufactured with a resin content of 2.5 %, pressed at 190 °C for 4 to 12 min, followed by air injection and placement of the frame (Fig. 1d), but with the air-injection pressure being reduced to 0.40 and 0.20 MPa, respectively (Table 3). The particles had a moisture content of 25 %.

One board was manufactured for each condition. Many boards were manufactured to evaluate the effects of this study as a preliminary experiment. Therefore, one board was enough for each condition.

Property tests

The manufactured boards were left in a thermo-hygrostat at 20 °C and 65 % relative humidity until the weight stabilized. The modulus of rupture (MOR), internal bond (IB), and thickness swelling (TS) were determined according to JIS A 5908 [9]. There were five, eight, and seven test specimens (board nos. 1 to 10), respectively.

Results and discussion

Effects of vapor inside the board on the occurrence of blowout

Blowouts are bursts caused by vapor inadvertently trapped inside a board during hot pressing when the hot press is opened. Therefore, blowouts should not occur if the

Table 2 Board nos., conditions of manufacture, and properties of board no. 5 to board no. 8

Board no.	Pressing method	Frame (yes/no)	Hot press[a]	Board properties	Pressing time (min)				
					4	6	8	10	12
No. 5	Ordinary	No	Fig. 1a	S/NS	S	S	S	NM	NM
				MOR (MPa)	17.7 (2.79)	20.1 (1.88)	18.4 (2.51)		
				IB (MPa)	0.561 (0.12)	0.670 (0.15)	0.642 (0.11)		
				TS (%)	21.3 (1.50)	23.6 (1.92)	22.6 (2.15)		
No. 6	Ordinary	Yes	Fig. 1b	S/NS	NS[b]	NS[b]	NS[b]	NM	NM
No. 7	Air injection	No	Fig. 1c	S/NS	NS[c]	NS[c]	NS[c]	NM	NM
No. 8	Air injection	Yes	Fig. 1d	S/NS		NS[b]	S	S	S
				MOR (MPa)			12.6 (6.01)	7.47 (2.41)	12.6 (1.68)
				IB (MPa)			0.202 (0.18)	0.221 (0.11)	0.322 (0.16)
				TS (%)			45.3 (9.19)	50.8 (7.29)	39.4 (8.30)

Particleboards were manufactured with resin content of 2.5 % by pressing at 190 °C, *S/NS* successful (S) or not successful (NS)

The numbers in parentheses indicate standard deviations

NM not manufactured, *MOR* modulus of rupture, *IB* internal bond, *TS* thickness swelling

[a] See Fig. 1

[b] Blowout

[c] Fragile (see Fig. 3)

Table 3 Board nos., conditions of manufacture, and properties of board no. 5 and board nos. 8 to 10

Board no.	Air-injection pressure (MPa)	Frame (yes/no)	Board properties	Pressing time (min)				
				4	6	8	10	12
No. 5	0	No	S/NS	S	S	S	NM	NM
			MOR (MPa)	17.7	20.1	18.4		
			IB (MPa)	0.561	0.670	0.642		
			TS (%)	21.3	23.6	22.6		
No. 8	0.55	Yes	S/NS		NS[a]	S	S	S
			MOR (MPa)			12.6	7.47	12.6
			IB (MPa)			0.202	0.221	0.322
			TS (%)			45.3	50.8	39.4
No. 9	0.40	Yes	S/NS	NS[a]	S	S	S	NM
			MOR (MPa)		14.6	15.0	15.6	
			IB (MPa)		0.495	0.456	0.471	
			TS (%)		35.6	32.3	35.0	
No. 10	0.20	Yes	S/NS	NS[a]	S	S	S	NM
			MOR (MPa)		14.5	15.4	14.7	
			IB (MPa)		0.213	0.423	0.459	
			TS (%)		38.7	37.5	42.5	

Particleboards were manufactured with resin content of 2.5 % by pressing at 190 °C using an air-injection press

S/NS successful (S) or not successful (NS), *NM* not manufactured, *MOR* modulus of rupture, *IB* internal bond, *TS* thickness swelling

[a] Blowout

bonding strength among particles exceeds the pressure of trapped vapor [10, 11]. Boards of high bonding strength were manufactured with a high resin content of 5 %. Table 1 shows results of successful and not successful board manufacture. S (successful) denotes successful board manufacture; NS (not successful) denotes unsuccessful manufacture due to no curing at the center of the board or blowout. Board no. 1 and board no. 2 were compared to determine the effects of the frame. Blowouts hardly occur in small boards (300 × 300 mm) manufactured from even high-moisture particles using isocyanate resin [8]. This is possibly because small boards allow vapor to discharge from the board. In order to examine the effects of the air-injection press on preventing blowouts, a condition that induces blowouts needs to be created. Boards were manufactured with the frame. The frame inhibited vapor from escaping from the board, and the board blew out (Fig. 1b). Board no. 1 was manufactured without a frame, thereby allowing vapor to escape from the edges. Board no. 1 was successfully manufactured in 4 min although the particles had moisture content as high as 25 %. However, board no. 1 was not manufactured in 2 min, since the center of the board was not cured due to short pressing time. In a previous study [1], urea–formaldehyde resin required 10 min for the manufacture of boards from high-moisture particles, but isocyanate resin required much less time. Board no. 2 was manufactured with a frame, and was predicted to blow out. However, blowout did not occur, and so the board was successfully manufactured in 4 and 6 min, showing no difference from board no. 1 in terms of pressing time. This was likely due to the high bonding strength of isocyanate resin producing (even among high-moisture particles) [6]. It presumably exceeded the vapor pressure in the board [11]. Table 1 lists the properties of the boards. The IB of board no. 1 was about 0.8 MPa, respectively, irrespective of pressing time. When considering atmospheric pressure of 0.1 MPa, the pressure inside the board must exceed vapor pressure of 0.9 MPa [0.8 MPa (IB) + 0.1 MPa (atmospheric pressure)] to induce blowout. On the other hand, the saturated temperature at saturated vapor pressure of 0.9 MPa is 171 °C. The temperature at the core of the board was likely to have been lower than the set pressing temperature of 190 °C and probably lower than the saturated temperature of 171 °C; thus, vapor pressure inside the board was lower than the sum (0.9 MPa) of IB and atmospheric pressure, and so the board presumably did not blow out.

The temperature was raised from 190 to 210 °C to increase the vapor pressure inside the board, and blowouts were examined. Board no. 3 and board no. 4 were also compared to determine the effects of the frame. Board no. 3 was manufactured without a frame and was successfully manufactured in 4 min because vapor was able to escape from the edges. Conversely, board no. 4 was manufactured with a frame and blew out in 4 min due to trapped vapor. However, the board did not blow out in 6 min. This was likely due to the gradual release of vapor trapped inside the board during the longer pressing process, resulting in reduced vapor pressure and no blowout.

The investigation showed that boards blow out due to a rise in vapor pressure inside the board. Isocyanate resin is known to produce carbon dioxide during its curing and is believed to be more vulnerable to blowouts than urea–formaldehyde resin [7]. However, this study showed that the high bonding strength of isocyanate resin prevented blowouts. On the other hand, the board inside during hot pressing is a high-temperature and high-pressure vapor atmosphere, which may inhibit the curing of urea–formaldehyde resin. This reduces bonding strength [5, 12] and causes blowouts. However, the curing of isocyanate resin is hardly affected by high-temperature and high-pressure vapor, and so the bonding strength remains strong [4, 12]. Therefore, isocyanate resin may not be vulnerable to blowouts.

Effects of the air-injection press on preventing blowouts

Table 2 shows results of successful and not successful board manufacture, and lists the manufacture conditions of boards with a reduced resin content of 2.5 % to decrease the bonding strength. Board no. 5 and board no. 6 were compared to investigate the effects of the frame using an ordinary hot press. Board no. 5 was successfully manufactured without a frame in 4 min like board no. 1. Due to blowouts, board no. 6 was not manufactured with a frame in 4, 6, and 8 min. Table 1 shows that board no. 2 was successfully manufactured in 4 and 6 min. The only difference between board no. 6 and board no. 2 was the resin content of 2.5 and 5 %, respectively. All other conditions were the same. Board no. 6 had low resin content and thus had low bonding strength [13]; consequently, it could not resist the vapor pressure and blew out, irrespective of the pressing time. Conversely, board no. 2 had a high resin content and thus high bonding strength [13], resisted the vapor pressure, and did not blow out in 4 and 6 min.

Board no. 7 and board no. 8 were compared to investigate the effects of the frame using an air-injection press. Board no. 7 was manufactured without a frame and did not blow out, but became very soft at the edges and fragile throughout (Fig. 3). This was likely because the injection of high-pressure air discharged isocyanate resin together with vapor from the edges of the board, leaving an insufficient isocyanate resin within the board [2]. However, board no. 8, which was manufactured with a frame, blew out in 6 min, but did not blow out in 8 min, and was successfully manufactured. The frame presumably prevented isocyanate resin from escaping from the edges.

In previous studies [1–3], urea–formaldehyde resin was used, and the air-injection press reduced the pressing time. In this study, however, board no. 5 was successfully manufactured in 4 min, using an ordinary hot press, and board no. 8 required 8 min using an air-injection press. Isocyanate resin could be used to manufacture boards from high-moisture particles in a short time, even without using an air-injection press. As listed in Table 2, board no. 5 had

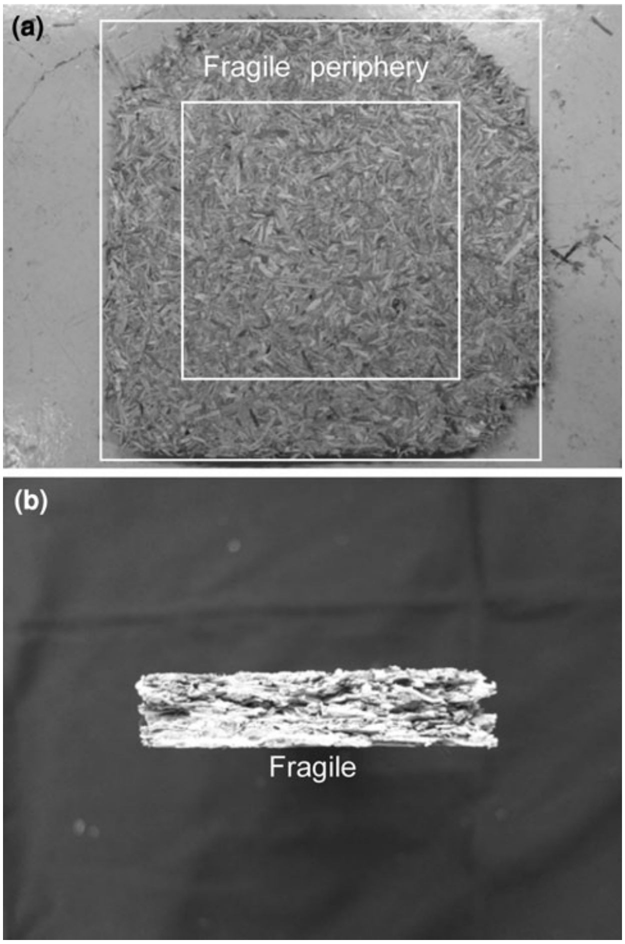

Fig. 3 Particleboard with fragile periphery (**a**) and a side view (**b**)

better properties than board no. 8, suggesting that the air-injection press had adversely impaired the board properties. The frame prevented isocyanate resin from escaping from the edges of the board, but it escaped from the upper plate of the air-injection press, resulting in lowered bonding strength due to less isocyanate resin. The results show that isocyanate resin does not cause blowouts, requires a short pressing time, and can be used to manufacture high-property boards from high-moisture particles without using an air-injection press. However, the board size should be noted. In this study, small boards measuring 300 × 300 mm were manufactured. Due to this small size, vapor easily escaped from the edges, allowing board no. 5 to be manufactured in 4 min without blowouts. The boards produced in mills are much larger, however, making it more difficult for vapor to escape from the edges. Boards manufactured in mills from high-moisture particles, such as board no. 6, may be vulnerable to blowouts. Therefore, board no. 6 was manufactured with a frame to inhibit the release of vapor from the edges and should be compared with board no. 8. Board no. 6 could not be manufactured with any pressing time, while board no. 8 was manufactured in 8 min, demonstrating the effectiveness of the air-injection press. The remaining issue is how to improve the properties of board no. 8.

Table 4 Coefficients of variation of MOR, IB and TS of board no. 5 and board nos. 8 to 10

Board no.	Board properties	Pressing time (min)				
		4	6	8	10	12
No. 5	MOR	15.8	9.37	13.6		
	IB	22.0	22.8	16.6		
	TS	7.05	8.16	9.52		
No. 8	MOR			47.6	32.2	13.4
	IB			88.4	51.4	49.9
	TS			20.3	14.4	21.1
No. 9	MOR		59.4	18.6	7.15	
	IB		51.1	41.3	14.1	
	TS		30.1	9.84	12.8	
No. 10	MOR		15.9	14.5	15.3	
	IB		32.9	35.3	44.6	
	TS		24.2	19.4	22.1	

Particleboards were manufactured with resin content of 2.5 % by pressing at 190 °C by using an air-injection press

MOR modulus of rupture, *IB* internal bond, *TS* thickness swelling

Effects of air-injection pressure on board properties

To improve the properties of board no. 8, isocyanate resin is needed to retain within the board. Boards were manufactured by lowering the air-injection pressure. Table 3 lists the results; Table 4 shows the coefficient of variation, but not the standard deviation. Board no. 5 and board no. 8 in Tables 3 and 4 are the same as board no. 5 and board no. 8 in Table 2.

Board no. 8 was manufactured by injecting air at 0.55 MPa, but could not be manufactured in 6 min. Conversely, board no. 9 and board no. 10, which were manufactured by injecting air at reduced pressures of 0.40 and 0.20 MPa, respectively, could be manufactured in 6 min. Board no. 5 was manufactured without injecting air; thus the air pressure was 0 MPa. The target properties of board no. 8 to board no. 10 were similar to the properties of board no. 5.

As shown in Table 4, for board no. 5, the coefficient of variation was 9.37 to 15.8 % for MOR and 16.6 to 22.8 % for IB. For board no. 8, the coefficient of variation for MOR was 47.6 % in 8 min and 32.2 % in 10 min. The coefficient of variation of board no. 8 was even larger for IB at 88.4 % in 8 min. The coefficients of variation of board no. 8, board no. 9, and board no. 10 were generally larger than those of board no. 5, particularly for MOR and IB, and also to a lesser extent for TS.

Board no. 8, which was manufactured by injecting high-pressure air of 0.55 MPa, could be manufactured as a

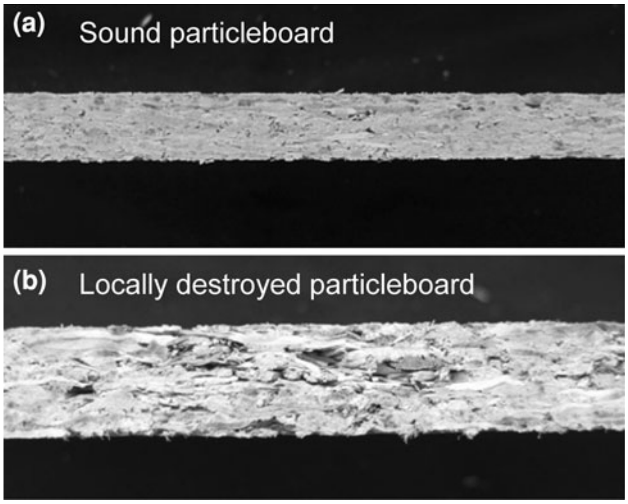

Fig. 4 Sound particleboard (**a**) and locally destroyed particleboard (**b**)

board, but probably suffered local destruction of the bonding points (Fig. 4). There were low MOR and IB at the points of local destruction and high MOR and IB in sound sections. The large differences including high and low values in MOR and IB resulted in large coefficients of variation.

The coefficients of variation for MOR and IB of board no. 9 and board no. 10, which were manufactured by injecting air of reduced pressure, were larger than those of board no. 5, but smaller than those of board no. 8. The coefficients of variation for MOR and IB of board no. 9 (manufactured with air-injected at 0.40 MPa) were large at 59.4 and 51.1 % in 6 min, respectively, and were reduced to 7.15 and 14.1 % in 10 min, respectively. The MOR and IB of board no. 9 in 10 min were 15.6 and 0.471 MPa, respectively, which was higher compared with those of board no. 8. The coefficient of variation for MOR of board no. 10 (manufactured with air-injected at 0.20 MPa) was about 15 % and the coefficient of variation for IB was 32.9 to 44.6 % irrespective of pressing time. The coefficients of variation of board no. 10 were generally lower than those of board no. 8, and the MOR and IB of board no. 10 were generally larger than those of board no. 8.

The investigation showed that both MOR and IB could be increased and the coefficient of variation could be reduced by lowering the air-injection pressure under 0.55 MPa. The lower air-injection pressure allowed isocyanate resin to remain in the board and reduced the local destruction of bonding points. Therefore, both MOR and IB of board no. 9 and board no. 10 were higher than those of board no. 8, and the coefficients of variation of board no. 9 and board no. 10 were smaller than those of board no. 8. However, MOR and IB of board no. 9 and board no. 10 were lower than those of board no. 5, and the coefficients of variation were larger. Lowering the air-injection pressure reduced the local destruction of bonding points, but some points were still destroyed. As high-moisture particles were used, the hydrophobic isocyanate resin did not penetrate into the particles, but remained on the surface. Therefore, the anchor effect of the isocyanate resin was not fully manifested presumably, resulting in reduced bonding strength. Moreover, air injection blew the isocyanate resin away from the particle surface and caused a local reduction of bonding strength, thereby presumably further reducing the bonding strength. The reduced bonding strength was lower than the vapor pressure. As a result, small local blowouts occurred and caused the local destruction of bonding points. Lowering the air pressure could prevent local destruction somewhat, but not entirely. An important future task is to prevent the local destruction of bonding points.

In previous studies [1–3], air injection increased the IB of urea–formaldehyde resin bonded boards manufactured from high-moisture particles. The urea–formaldehyde resin is hydrophilic, prone to excessive penetration into high-moisture particles, and thus inhibits curing under high-moisture conditions [4]. The air injection prevented such penetration and inhibition, thereby improving the IB of the boards. This was opposite of the results obtained for isocyanate resin.

Conclusions

Isocyanate resin bonded boards were manufactured from high-moisture particles. The blowout conditions and properties of the boards were analyzed, and the following results were obtained:

1. Boards were found to blow out when vapor pressure inside the boards presumably exceeded the bonding strength of isocyanate resin.
2. The air-injection press prevented the blowouts of boards. However, high air-injection pressure is likely to discharge isocyanate resin from the boards, causing local and sharp decreases in bonding strength, and resultant local blowouts. Therefore, the strength values were very low at certain local points, thus increasing the coefficient of variation.
3. Lowered air-injection pressure increased the bonding strength and reduced the coefficients of variation. This was possibly because low air pressure allowed isocyanate resin to remain inside the boards and reduced the bonding points of low strength.

Acknowledgments This study was supported by grants from the "Research and development projects for application in promoting new policies of agriculture, forestry, and fisheries" from the Ministry of Agriculture, Forestry and Fisheries. The authors express their gratitude to Mr. Hashimoto of Bayer Material Science for providing the binders, Mr. Kazuo Hattori of Japan Novopan Industrial Co. Ltd. for providing wood particles for particleboards, which was helpful in conducting the experiment in this study.

References

1. Korai H, Ling N, Osada T, Yasuda O, Sumida A (2011) Development of an air-injection press for preventing blowout of particleboard I: effects of an air-injection press on board properties. J Wood Sci 57:401–407
2. Korai H, Ling N (2011) Development of an air-injection press for preventing blowout of particleboard II: improvement of board properties using small diameter holes for air injection. J Wood Sci 57:507–511
3. Korai H, Saotome H, Iida T, Hamano T, Kawarada K (2012) Development of an air-injection press for preventing blowout of particleboard III: effects of pressing temperature on board performance. J Wood Sci 58:216–221
4. Tamura Y (1985) Recent development on wood bonding (in Japanese). Mokuzai Gakkaishi 31:521–527
5. Umemura K, Kawai S, Ueno R, Mizuno Y, Sasaki H (1996) Curing behavior of wood adhesives under high-pressure steam II. Urea resin. Mokuzai Gakkaishi 42:65–73
6. Kawai S, Suda H, Nakaji M, Sasaki H (1986) Production technology for low-density particleboard II. Effects of particle moisture content and resin content on board properties (in Japanese). Mokuzai Gakkaishi 32:876–882
7. Fukino M, Horie H, Shimokune N, Ogawa N (2007) Production technology for strand-particle board (SPB) III. Effects of isocyanate adhesives (EMDI) on physical properties and blisters (in Japanese). Mokuzai Gakkaishi 53:187–193
8. Saotome H, Korai H, Iida T, Hamano T, Kawarada K (2012) Development of an air-injection press for preventing blowout of particleboard II. Effects of air-injection press on performance of board manufactured from low moisture content particles (in Japanese). In: The proceedings of the 29th annual meeting of Wood Technological Association of Japan (Oral), 12 Oct to 13 Oct 2011, Okayama, pp 43–44
9. Japanese Industrial Standards (2003) JIS standard specification for particleboard, JIS A 5908. Japanese Standards Association, Tokyo
10. Malony TM (1986) Modern particleboard and dry-process fiberboard manufacturing. Miller Freeman Publications Inc., San Francisco, p 306
11. Malony TM (1986) Modern particleboard and dry-process fiberboard manufacturing. Miller Freeman Publications Inc., San Francisco, pp 519–520
12. Sasaki H (1996) Function of water vapor in manufacturing wood composites and the application (in Japanese). J Soc Mater Sci, Japan 45:363–368
13. Koichi Hori (1971) Effects of resin and furnish distribution in layered particleboard (in Japanese). Wood Ind 26:207–212