Effect of cooking conditions on fiber bonding in dry-formed binderless hardboard

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Abstract

Binderless dry-formed hardboards were manufactured in the laboratory from refined Masonite pulp cooked for 2.5 minutes at steam pressures varying from 200 to 500 psi. Increasing steam pressure caused a general improvement in mechanical and physical properties except that linear expansion increased with increasing steam pressures and that bending strength and stiffness peaked at 400 psi steam pressure. Statistical analysis shows that the fines content of the furnish, which increases with higher steam pressures, may be responsible for the improvement of board properties.

The results of a number of practical experiments on dry-formed binderless hardboard, manufactured from Masonite gun stock, indicate that such boards can develop properties equal or superior to those of boards made from the same furnish by conventional wet-forming processes (7-9). While the fiber-to-fiber bonds are developed in the hot-press, important preconditions for such bonding are created during the pulping stage. A single Masonite gun cycle was used in the previous experiments (7-9), arbitrarily chosen on the severe side of common practice. The results, therefore, allow no conclusions with regard to the potential of binderless board quality development. The present study is an attempt to gauge the effect of pulping conditions on bond development by using a series of different pulping cycles.

Objective

It was the objective of this study to investigate the effect of the thermal severity of both gun cycles and digester cycles on the bond quality of binderless dry-formed S2S hardboard, and to interpret the results in view of various fiber bonding concepts.

Experimental procedure

Pulping

The raw material was green, mixed southern hardwood chips, unscreened. They were of a lower quality than the chips used for the earlier studies.

Cooking and refining conditions are listed in Table 1. Both gun and digester were pilot plant size devices located at the laboratory of Masonite Corporation in St. Charles, Ill. (Fig. 1). The gun pressures listed are those maintained for the 2.5-minute cycles. At the end of each cycle, the pressure was raised for a few seconds to blow the fibers out of the gun (for discussion of the basic Masonite pulping process see reference 10). The digester was a batch type device. Upon pressure release, the chips were removed and immediately passed through the refiner (Bauer, double disk). The plate settings listed are final settings resulting from some experimentation trying to produce pulp of uniform characteristics at each cooking pressure, as judged by visual evaluation.

Board manufacture

The pulp was used unscreened. It was dried at 220°F until bone dry. Mats were formed on a laboratory vacuum-screen former (12- by 12-in.). The mesh size of the screen was 22 openings per linear inch.

The "washed" pulp was prepared as follows:

1. 1500 g of fiber diluted in 11.5 gallons of hot water (160°F), stirred for 1 minute;
2. The pulp was drained on vacuum sheet former;
3. The above steps were repeated twice, using 80°F water;
4. After the third washing, the mat was dewatered in the cold press at 800 psi;
5. Pulp was dried at 220°F.

It is our judgment that the loss of fines during the washing procedure was minimal.

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The dry-formed mats were pressed at a platen temperature of 420° to 440°F for about 80 seconds. The press cycle was so selected that boards of a density of 1.0 g/cm³ resulted without developing gas blisters. Typical examples of press cycles are shown in Figure 2. Pressure was adjusted up or down from these values to reach the target density. Board thickness was 1/8 inch. Ten boards were made from unwashed pulp for each of the six cooking cycles and two from the washed pulp. The properties tested are indicated in Table 2.

Results

Figures 3 and 4 and Table 2 present a summary of the results of the standard tests performed on the experimental boards. The mechanical test results (modulus of elasticity (MOE), modulus of rupture (MOR), and internal bond (IB)) are based on regression equations and represent averages adjusted to a board density of 1.0 g/cm.[3] The results of the physical tests (water absorption (WA), and linear expansion (LE)) are simple averages. Exposure interval for LE tests was 50 percent to 93 percent relative humidity.

It is clear that increasing the severity of the pulping conditions has a beneficial effect on most board properties. However, beyond 400 psi gun pressure, MOE and MOR drop considerably and WA does not improve. The improvement of IB is significant even at the highest pressure level. LE is the only property which does not benefit from more severe pulping conditions. It increases

TABLE 1. — *Design of experiment.*

	Cooking pressure	Cooking cycle	Refiner plate setting
	(psi)	(min.)	(in.)
Masonite gun			
	200	2.5	.065
	300	2.5	.045
	400	2.5	.065
	500	2.5	.065
Digester			
	200	2.5	.040
	300	2.5	.065

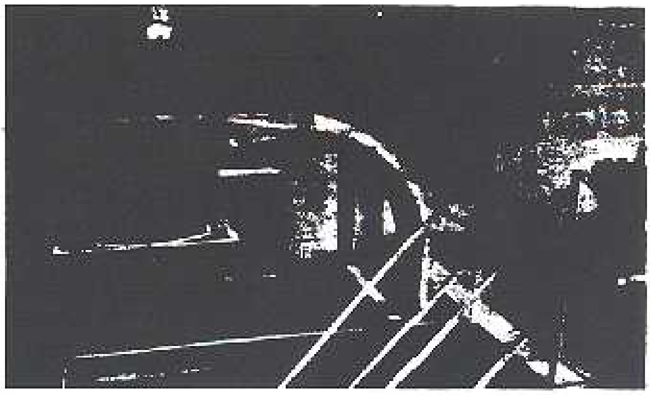

Figure 1. — Laboratory Masonite gun (right) with discharge tube and steam separator (left). Photo courtesy of the Masonite Corporation.

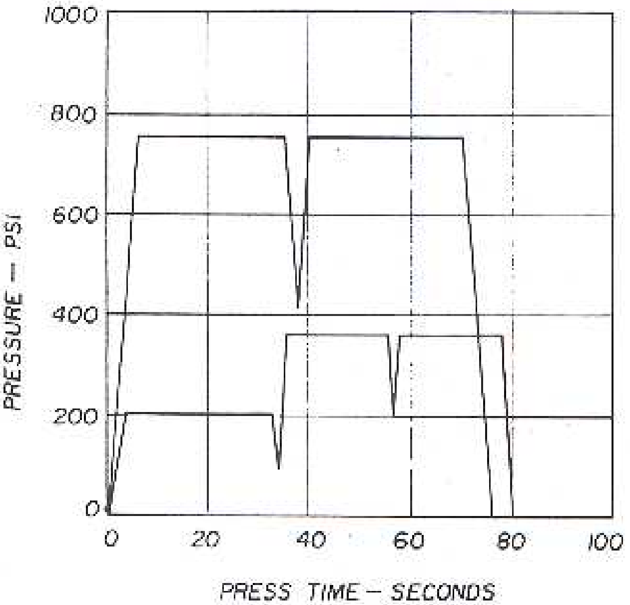

Figure 2. — Typical press cycles for 1/8-inch experimental hardboard.

TABLE 2. — *Summary of test results.*

	Pressure	Pulp	MOE	MOR	IB	WA (wt.)	WA (vol.)	WA (TS)	LE	Fines
	(psi)		(1,000 psi)	---------- (psi)	----------	----------	----------	(%)	----------	----------
Masonite gun	200	unwashed	366	2,150	93	199	193	145	.379	.51
		washed	255	1,700	60	114	132	102	.317	
	300	unwashed	452	2,610	135	105	113	59	.478	19.3
		washed	263	1,920	45	90	99	72	.365	
	400	unwashed	538	3,010	364	43	44	23	.511	25.0
		washed	378	3,120	89	31	35	28	.391	
	500	unwashed	431	1,910	441	36	36	14	.979	33.9
		washed	156	1,080	235	31	32	27	.760	
Digester	200	unwashed	331	2,170	100	127	137	97	.448	20.0
		washed	251	1,750	42	143	156	113	.326	
	300	unwashed	405	2,060	142	71	73	50	.407	23.2
		washed	261	1,840	47	69	76	52	.358	

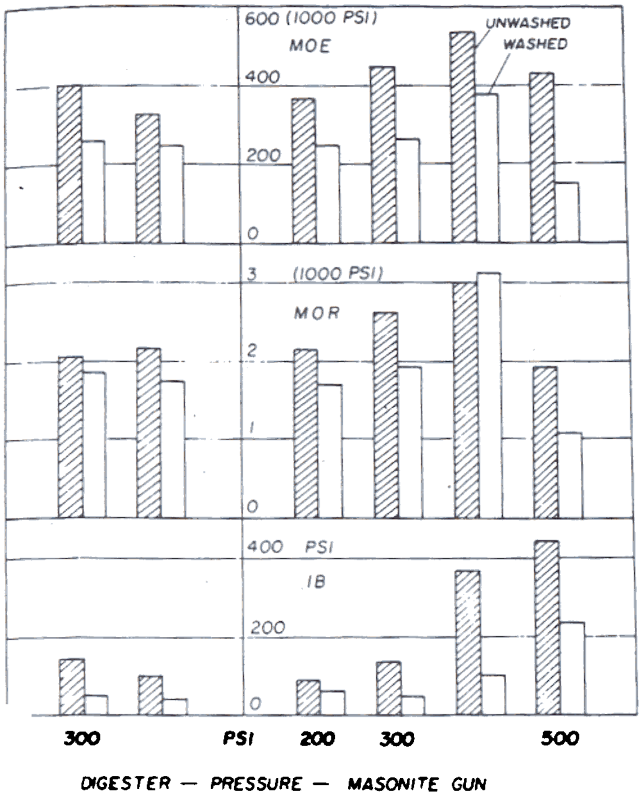

Figure 3. — Summary of MOE, MOR, and IB of boards made from unwashed and washed digester pulp (left of vertical line) and Masonite gun pulp (right of vertical line).

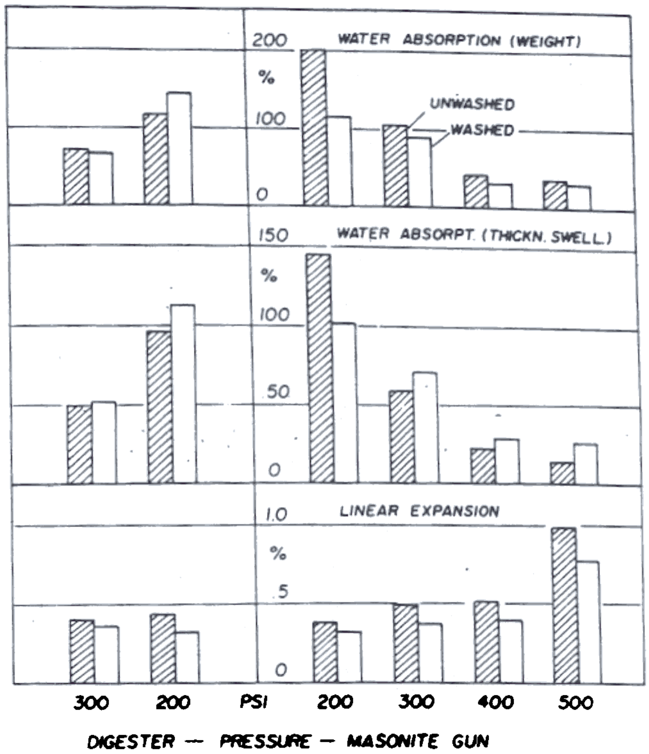

Figure 4. — Summary of WA, TS, and LE of boards made from unwashed and washed digester pulp (left of vertical line) and Masonite gun pulp (right of vertical line).

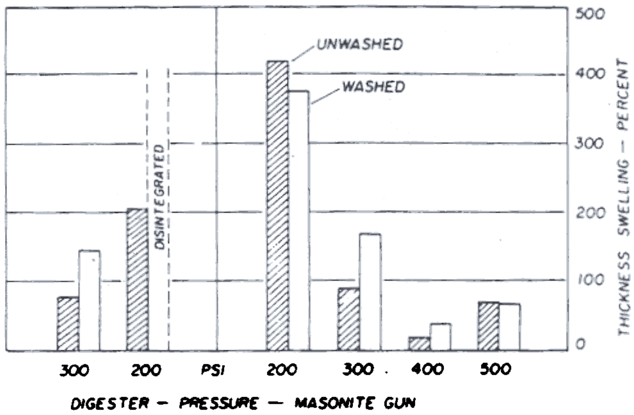

Figure 5. — Permanent thickness swelling of 2- by 2- inch samples after 5 minutes of boiling and subsequent redrying.

most significantly between 400 and 500 psi gun pressure.

The digester series is incomplete because the higher pressures could not be developed. The results up to 300 psi are fairly comparable to those of the gun series. No conclusions can be drawn with regard to any trends beyond 300 psi. The digester results will, therefore, be excluded from further analysis.

Boards from unwashed pulps are superior in terms of mechanical properties, but inferior in physical properties to those made from washed pulps.

Figure 5 shows the residual or permanent thickness swelling (TS) of 2- by 2-inch samples after 5 minutes of boiling in water followed by drying at 185° to 195°F. The improvements at higher gun pressures are remarkable (Fig. 6).

Discussion

There still is no clear undisputed theory on the role of lignin and hemicelluloses and their derivatives in the formation of fiberbonds in hardboard manufacture (4). While pretreatment and pressing conditions may favor one or the other or a combination of bonding agents, the Masonite gun cycle generates additional variables that may strongly interact with binder activation. One of these is the fiber size distribution as measured by the Bauer-McNett fiber classification. A graphical presentation of the results of this test on our experimental Masonite gun stock is shown in Figure 7. The higher the gun pressure, the larger is the fines component (through 100 mesh screen) and the smaller is the coarse component (on 6 mesh screen). Higher gun pressures, therefore, reduce the average fiber length. The fiber fraction passing through a 100 mesh screen showed a very strong correlation with some of the board properties (Fig. 8), which allows the following interpretations:

1. Increasing IB and decreasing WA and TS with increasing fines content suggest that this fines content is the seat of strong adhesive properties, which become available under high-temperature pressing conditions. These adhesive properties could be in the form of actual bonding agents being associated with the fine particles, or in the form of these particles acting as fillers of voids, thus improving the total contact between fibers, or a combination of the two (3);

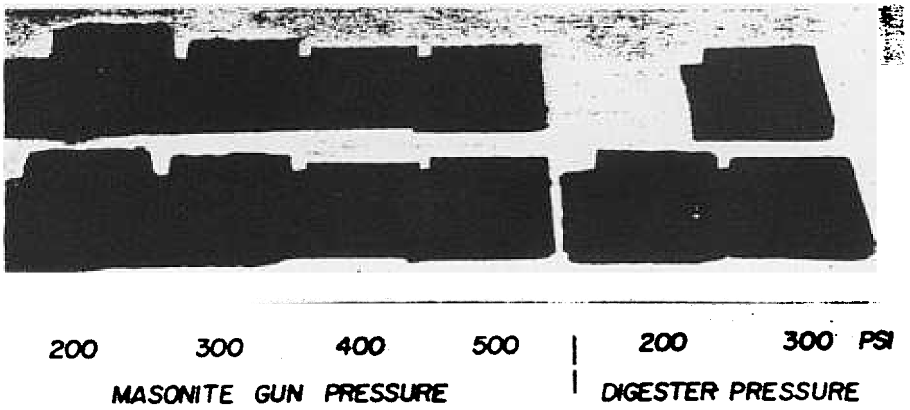

Figure 6. — Redried samples after boiling. Upper series made from washed pulp; lower series from unwashed pulp.

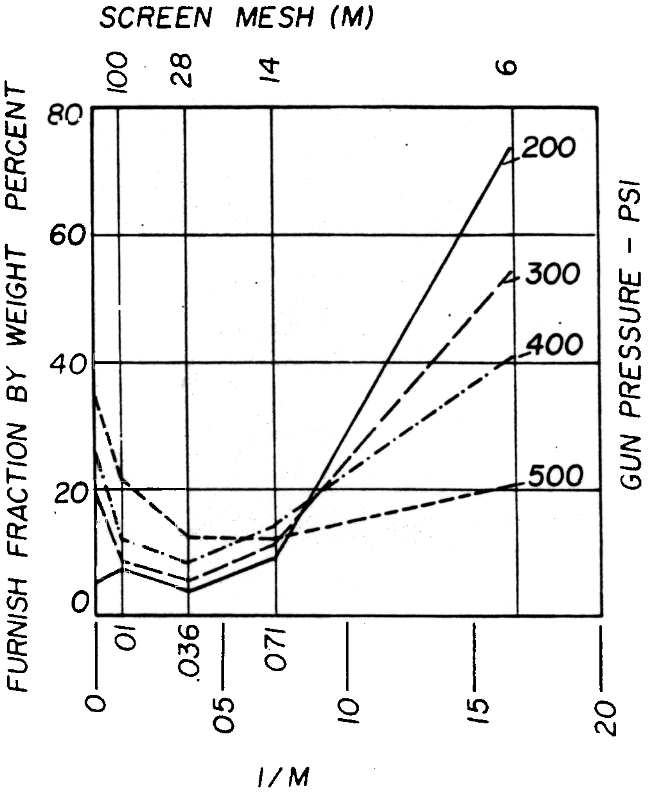

Figure 7. — Bauer-McNett classifications of experimental Masonite gun fiber furnishes.

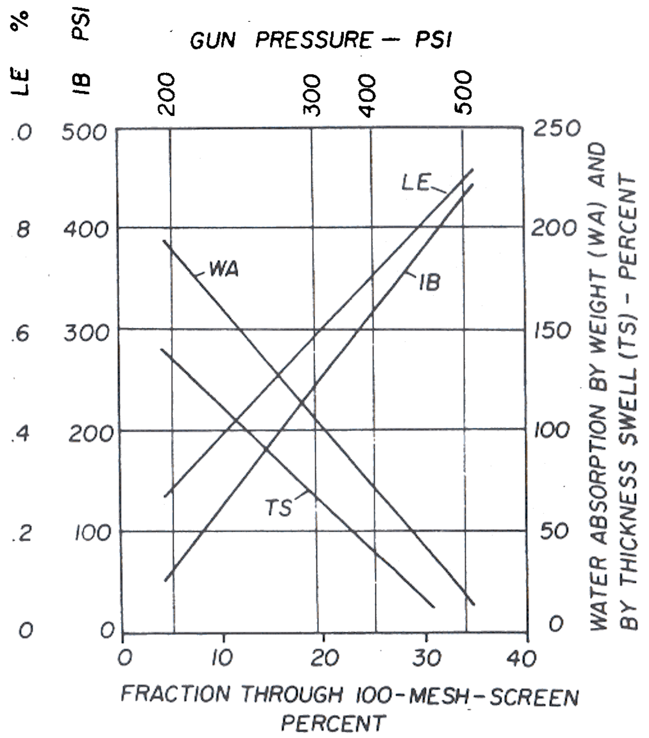

Figure 8. — Relationships between board properties and fines content. R-values are: WA = −.96; TS = −.97; LE = −.85; IB = −.91.

2. The strong positive correlation between LE and fines content is possibly a consequence of an increasing vertical or z-component of the orientation of the shorter fibers (5,6). Such vertical orientation components would also have a restraining effect on TS;

3. The fact that MOE and MOR do not consistently increase with increasing fines fraction is possibly due to the reduction of long fibers, which are essential in bending strength development. At pressures in excess of 400 psi, the strength-reducing effect of shorter fiber length dominates over the bonding improvement associated with increasing fines content. This is consistent with Pecina's findings (3);

4. The inferiority of the mechanical properties of boards made from washed stock points to either the importance of hemicelluloses as a bonding agent or to losses in the washing process of some of the fines fraction, or a combination of both. Horn (1) has found hemicelluloses to be the major bonding agents in press dried paper sheets made from high yield pulp and suggests that the role of lignin is one of protector of the vulnerable hemicellulose bonds, provided that press conditions allow sufficient flow of lignin.

An interpretation of Figure 5 would tend to be in concert with these conclusions. The great stability of boards made from 400 and 500 psi gun stock suggests the action of the lignin as a bond protector. Gun pressure of 200 psi is clearly too low to force fiber separation in the middle lamella (2), and thus, lignin would not be available for that function.

Conclusions

Note: The digester experiment was incomplete. The conclusions, therefore, apply only to the Masonite gun series.

1. Increase in gun pressure within the range of 200 to 500 psi is beneficial to most board properties. At 500 psi, there are some significant declines in MOE and MOR and significant increases in LE. Therefore, 400 psi gun pressure appears to be an optimum condition, given all other variables;

2. The fines content of the pulp is significantly affected by gun pressure, and in turn is an important variable in bond and bending strength development;

3. Results seem to indicate that hemicelluloses are important adhesive compounds and that lignin plays an important role in board stability under severe exposure conditions.

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