Double-backer bonding technology

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A double-backer bonding simulator examines the effects of linerboard and medium properties on bonding.

Good consistent bonding between liners and medium is essential to box performance. This fact is reinforced by a recent survey of box plant managers, which listed bonding on the corrugator as the number one factor affecting box performance. Recent efforts to understand bonding causes have been unsuccessful, however, because the basic properties of linerboard and medium which govern the high-speed development of green and final bonding in the single-facing and double-backing operations are not well defined.

Careful evaluation of the effects of varying component properties, adhesive properties, and combining conditions can help determine factors which are crucial to green and final bond formation. Such information will help guide efforts to maintain liner and medium properties at proper levels as papermaking efforts seek to improve the compressive strength and other characteristics of the board.

Research already has shown that low pin adhesion levels, glue skips, and streaks impair the ability of the board to resist stacking loads. Bonding defects can severely reduce stacking performance, particularly under long-term loads and high humidity conditions.

Bonding variability is a major contributor to quality variations and box plant waste. In an effort to correct the problem, Sprague (*1*) stressed the need to achieve adequate bonds on a consistent basis, with starch control as a secondary objective. He notes that we spend most of our money on fiber and only 1-2% on starch. Yet one load of rejected boxes or a single percentage point increase in waste will pay for a lot of starch.

Gluing plays a very important role in the double-backing process. The rate at which the bonds set up determines how fast the double-backer can operate, which is why a better understanding of the variables affecting bond development is necessary. In this research, we sought to understand the board properties which govern the high-speed development of green and final bond strength in the double-backing operations.

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Background

During the corrugating process, medium and liner are combined in the single-facer and double-backer sections of the corrugator to produce combined board. In the single-facer, the medium is fluted and adhesive applied to the flute tips. The medium is then combined with the liner under high pressure, creating single-faced board. The single-faced web travels along a bridge to the double-backer section where another liner is attached to produce combined board. After application of the adhesive to the single-faced medium tips, the single-faced web and double-faced liner are joined together in the hot plate section under lower pressure. In this section, the glue line is heated and gelatination of the adhesive occurs.

Thayer and Thomas (*2, 3*) note that the maximum corrugating speed in the double-backer is determined by the time required to form a sufficiently strong bond that will resist slitting and cut-off stresses. Their temperature measurements on the inside surface of the double-face liner show that the glue line temperature increases to 100°C (212°F) and remains at that temperature while the water in the starch adhesive evaporates. After most of the glue line water is gone, the temperature rises and approaches the temperature of the hot plate. Thus, temperature is a critical variable and involves the preheating of the liner and medium and the hot plate temperature.

Williams *et al.* (*4*) divide bond formation into three steps. In the first stage, the bond has a low cohesive strength and is unable to bond paper unless left in a stress-free condition. Greater cohesive strength is developed in the second stage, when the starch begins to gelatinize and increase in viscosity. In the third stage the solids content, viscosity, and cohesive strength of the adhesive increase to the point where the bond strength exceeds the fiber bond strength.

For convenience, three regions in the glue line can be defined: exterior, fillet, and high strength region in the center of the glue line (*4*). The exterior region on the outer edge does not contribute to the strength of the bond. The adhesive in the fillet region contacts both liner and medium and is almost completely gelled if sufficient moisture is present. A substantial portion of the bond strength originates in the fillet region. In the center region, the adhesive will also be completely gelled and in intimate contact with liner and medium. These conditions promote bond strength.

The linerboard and medium properties which are important for good bonding are those which affect wetting, penetration of the adhesive, and the fiber-to-fiber bond strength of the components (*5*). Component properties which were listed included:

1. A porous surface which has many uniformly distributed pore openings
2. A rough surface which provides a greater surface area for bonding than a smooth surface
3. A surface which is easily wet by an aqueous adhesive
4. The strongest fiber-to-fiber bond consistent with other properties.

Hoke and Daub (*6*) reported that porosity, roughness, and sheet density are important properties affecting the absorption of starch suspensions by paper. Porosity affects penetration, and the depth of penetration may reach twice the average fiber diameter. Rougher surfaces favor better anchoring of the adhesive in the effective glue line region. The sheet density affects the heat conductivity of the paper and, hence, the heating up of the adhesive. Thus, higher densities can be favorable if the sheet does not heat up excessively.

Daub *et al.* (*7, 8*) have shown that porosity is the controlling paper property for the absorption of water into paper under pressure application forces. They indicate that properties affecting capillary penetration include density, porosity, roughness, and interfacial energy of the surface.

Briefly summarized, the liner and medium properties which may be expected to influence adhesion include wettability, porosity, roughness, and density, in addition to the internal fiber bonding strength of the sheet.

Equipment

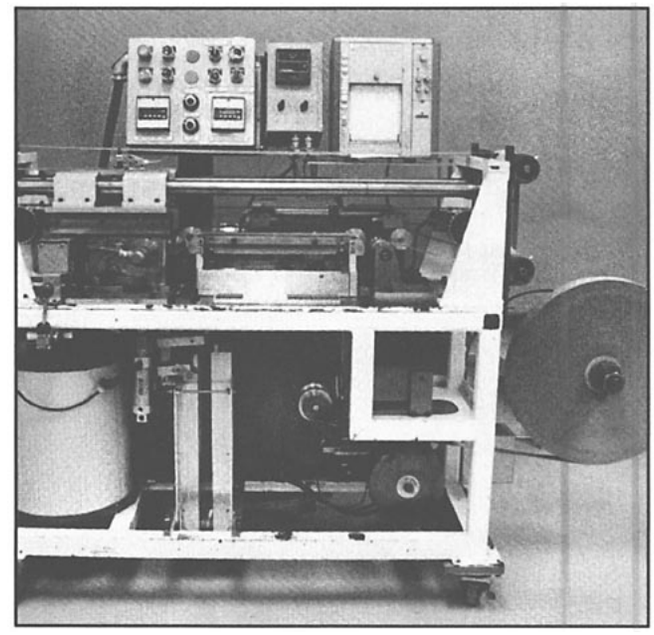
A double-backer bonding simulator, which measures double-backer bond development, was developed at the Institute of Paper Science and Technology. It was originally developed to study cold corrugating (*9*) and was then modified to evaluate double-backer bonding using conventional starch adhesives. The simulator is shown in **Fig. 1.**

Combining conditions which can be controlled on the simulator include:

1. Liner and medium preheat temperature and preheat time
2. Adhesive type, temperature, and application rate
3. Hot plate temperature
4. Combining time over hot plate
5. Liner and single-face board speed both before and after the hot plate section.

The simulation process begins when the carriage, moving at a preset speed, carries a 5.1 cm × 12.7 cm (2 in. × 5 in.) piece of single-faced board over an infrared preheater and a glue roll where adhesive is applied. The carriage then brings the single-faced board sample into contact with the double-backer liner, which is also preheated. Next, the carriage pauses for a predetermined period of time over the hot plate where additional heat and pressure are applied. The hot plate then drops away from the combined board, the carriage resumes moving forward at a lower speed, and the liner is pulled away from the flute tips. The force required to break each bond is measured by a load cell and recorded on a chart recorder. When carriage speeds and time under pressure are selected, the double-backer simulator can simulate a broad range of corrugator speeds. A schematic of the operation of the simulator is shown in **Fig. 2.**

1. Double-backer simulator



A bond strength vs. time chart obtained during a typical test is shown in **Fig. 3.** Each peak represents a bond being broken—the higher the peak, the stronger the bond. Two bonding parameters are obtained from the strength vs. time curves, namely, induction time and slope (rate of bond development). Induction time is defined as the time between initial liner-medium contact and first observable bond strength. The induction time includes the time that the single-faced board and liner are in contact with the hot plate section (hot plate residence time). The slope of the strength-time curve defines the rate at which bond strength develops. A short induction time (fast green bond formation) and a large slope (fast final bond formation) is desirable. A third parameter, 5-lb load time, can be calculated from the induction time and slope, as shown in the equation below. The 5-lb load time is a measure of the time needed to attain a bond strength of 22.3 N (5 lb).

$$\text{5 lb load time} = (22.3\ \text{N}/\text{rate of bond development}) + \text{induction time} \quad (1)$$

Operational factors

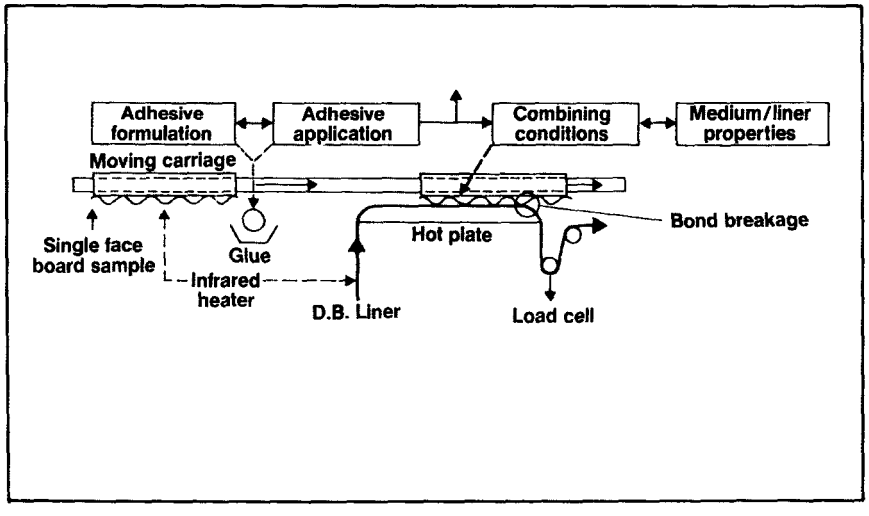
Tests were conducted to determine the effect of changes in operational factors on induction time, rate of bond development and 5-lb load time. Three operational factors were observed: hot plate temperature, hot plate residence

I. Effects of changes in operational factors on induction time, rate of bond development and 5 lb load time

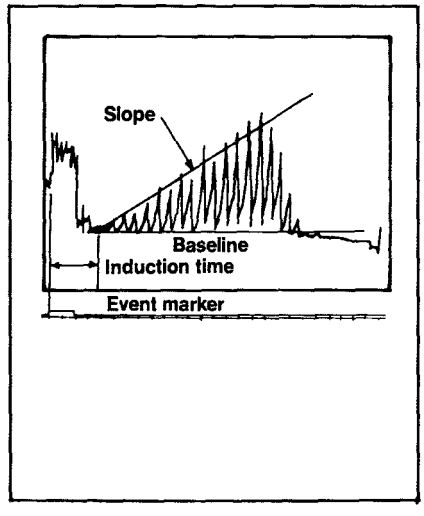
	Induction time, s			Rate of development, N/s			5 lb Load time, s		
	No. of samples	Mean	Std. dev.*	No. of samples	Mean	Std. dev.*	No. of samples	Mean	Std. dev.*
Hot Plate Temperature[a]									
110 °C	4	9.03	1.24	4	1.39	0.48	4	26.88	6.28
118 °C	5	7.69	1.29	5	2.83	0.90	5	16.77	4.55
127 °C	4	6.95	0.89	4	3.08	0.33	4	14.24	1.21
Hot Plate Residence Time[b]									
3.5 s	4	8.34	1.51	4	2.12	0.25	4	18.93	1.83
4.0 s	5	7.69	1.29	5	2.83	0.90	5	16.77	4.55
5.5 s	3	7 45	1.20	3	2.71	0.11	3	15.68	0.87
Adhesive Temperature[c]									
33 °C	4	8.58	1.75	4	2.99	0.72	4	16.37	1.28
39 °C	5	7.69	1.29	5	2.83	0.90	5	16.77	4.55

[a]Hot Plate Residence Time = 4.0 s, Adhesive Temperature = 39 °C
[b]Hot Plate Temperature = 118 °C, Adhesive Temperature = 39 °C
[c]Hot Plate Temperature = 118 °C, Hot Plate Residence Time = 4.0 s
*Standard deviation of a single observation.

2. Schematic of the double-backer bonding simulator



3. Typical bond strength vs. time output of double-backer simulator showing induction time and slope



time, and adhesive temperature. Each of these factors were varied while keeping the other two factors constant. For example, samples were tested with hot plate temperatures of 110°C, 118°C, and 127°C, while the hot plate residence time was held constant at 4.0 s and adhesive temperature was held at 39°C. **Table I** lists the effects of the changes in all three operational factors on induction time, rate of bond development, and 5-lb load time.

After analyzing the results using a statistical pair-wise comparison between the means, one factor proved to be significant. The hot plate temperature change between 110°C and 118°C was statistically significant at the 95% confidence level for both rate of bond development and 5-lb load time. As the hot plate temperature was increased, the rate of bond development increased, and the 5-lb load time decreased. This shows that for a temperature increase within the range 110-118°C, a sufficient green bond strength can be produced more rapidly.

The results also show statistically that the hot plate residence time does not have a significant effect on the double-backer bonding parameters for the range tested. The results show that there is no difference between a hot plate residence time of 3.5 s and 4.0 s. Therefore, decreasing the length of the hot plate section in this range does not affect the bonding parameters.

An analysis of the changes in adhesive temperature showed that there were no significant changes in the induction time, rate of bond development, or 5-lb load time when the adhesive temperature was increased.

Based on these operational factor experiments, it is concluded that for the ranges tested the only statistically significant factor is hot plate temperature. The results

show that an increase in hot plate temperature between 110°C and 118°C increased the rate of bond development and decreased the 5-lb load time. Hot plate residence time and adhesive temperature did not have an effect on the induction time, rate of bond development, or 5-lb load time.

Linerboard bonding results

Twenty-three linerboards were evaluated on the double-backer simulator using two single-faced board samples made with mediums of different porosity and density, and similar water drop values. The Gurley porosity value was 20 s for Medium A and 12 s for Medium B.

Tests were conducted to evaluate the surface and receptivity characteristics of the wire side of the liners. Five specimens of each linerboard were combined with each of the mediums. The induction times on the average were slightly less for the liners combined with Medium A (the less porous medium). Also, the average rate of bond development was greater when the liners were combined with Medium A. Thus, the onset of bonding was faster and the rate of bond development more rapid with Medium A. These results indicate that linerboards combined with the less porous medium (Medium A) could be run at a faster double-backing speed than with the more porous medium (Medium B). This may be the result of water in the adhesive being absorbed too quickly into the flute tips in the case of the more porous medium.

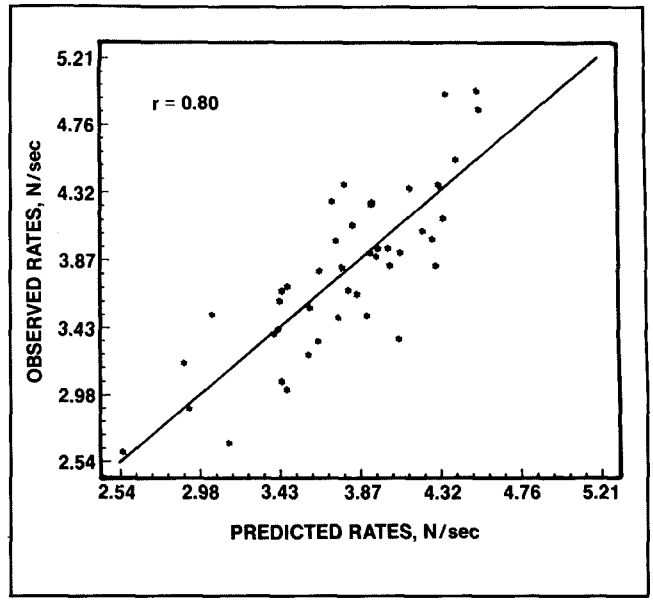
A multiple regression was performed on the linerboard results, combining the data for the tests with both mediums. The results show that the rate of bond development (slope) depends on Bristow roughness index (*10*), lactic acid water drop, and Gurley porosity of the linerboard (*5–8*). All of these factors—Bristow roughness index, lactic acid water drop, and Gurley porosity—were statistically significant at the 0.01 significance level. **Figure 4** shows the observed vs. predicted rate of bond development values for this multiple regression; the correlation coefficient is 0.80.

The regression equation was used to show the effects of changes in linerboard porosity, surface roughness, and surface wettability on rate of bond development. To analyze the effects of these properties, we selected values to cover the ranges for the linerboard properties and calculated the rate of bond development values. The rate of bond development values were then converted to relative double-backer speeds, assuming a 24.4 meter (80 ft) double-backer section.

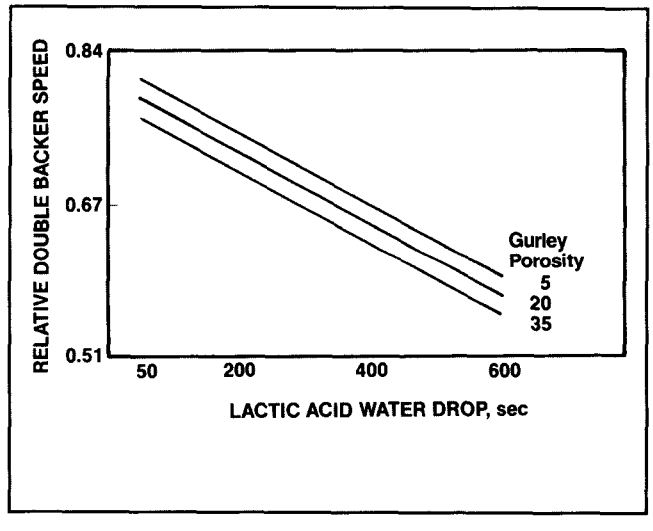
When linerboard lactic acid water drop and Gurley porosity number decreased, relative double-backer speeds increased, as shown in **Fig. 5**. Thus, higher double-backer speeds should be attained with more porous linerboards, which are more receptive to water. The more porous and wettable surfaces will promote adhesive penetration and, hence, faster bonding.

Decreases in lactic acid water drop and roughness index increased double-backer speeds, as indicated in **Fig. 6**. These results suggest that the linerboard surface should be porous and easily wet but not too rough to achieve higher double-backer speeds. Too rough a liner surface will reduce the contact area between medium and liner and slow up bond strength development.

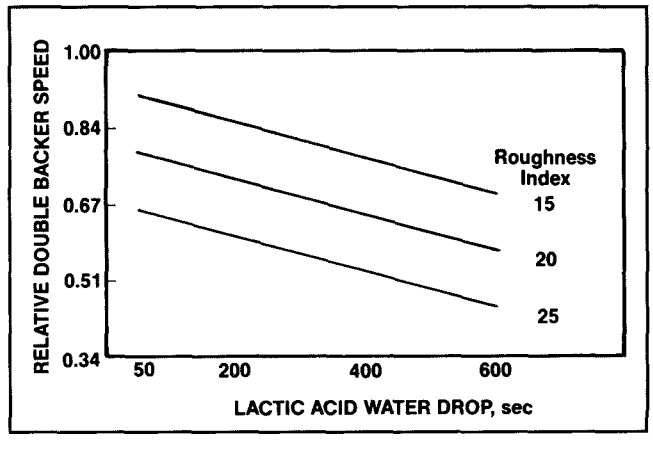
4. Observed vs. predicted rate of bond development for various linerboards



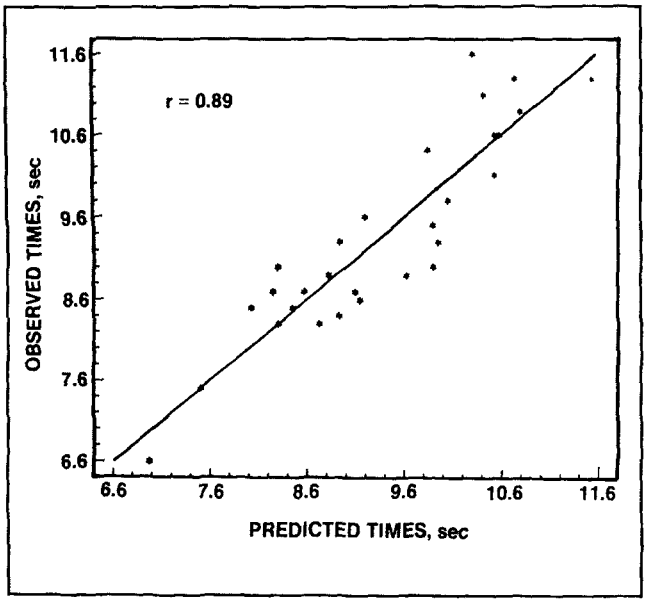
5. Relative double-backer speeds increase as linerboard lactic acid water drop and Gurley porosity number decrease.



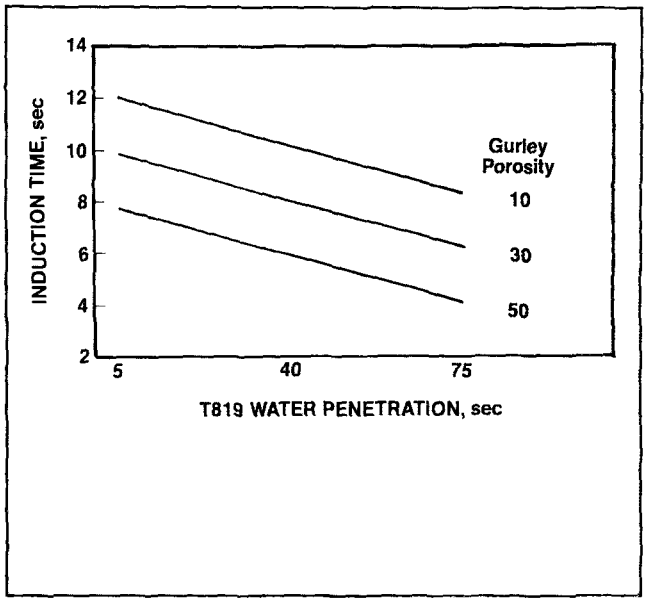
6. Relative double-backer speed increases as linerboard lactic acid water drop and Bristow roughness index decrease.



7. Observed vs. predicted induction times for various mediums



8. Induction time decreases as water penetration times and Gurley porosity number of mediums increase.



The times to start bonding, or induction times, were subjected to a similar analysis. However, the results indicate that the variations in induction time were not sensitive to linerboard properties. Medium properties appeared to have more influence on induction time.

Medium bonding results

Using two different adhesives, a wide array of mediums were combined with one selected linerboard. For these experiments only medium properties, such as porosity, smoothness, water drop, and water penetration (flotation type), were varied. To simulate the conditions experienced by the medium during corrugating, several medium properties were remeasured after being calendered to about the same caliper reduction as occurs in the corrugator. Also, a "flute-tip water drop" test was performed on a piece of single-faced board made from each medium. (This test is similar to the TAPPI Test Method T 492 water drop test except that a smaller drop size, 0.005 mL, is placed directly on the flute tip.)

The data from these trials were evaluated after combining the results for the two adhesives. A simple linear regression analysis between adhesives showed that the induction times were well correlated ($r = 0.81$), while the rate of bonding (slope) was not ($r = 0.27$). This indicates that the time necessary to initiate bonding (induction time) depends more on medium properties than does the rate at which bond strength develops (slope).

A multiple regression analysis was performed using the combined medium data. Induction times were related to Gurley porosity, water penetration (TAPPI Test Method T 819) and flute-tip water drop; these factors were statistically significant at the 0.01 level. The correlation coefficient was 0.89. **Figure 7** shows the observed vs. predicted induction time values for this multiple regression. Reasonable agreement between predicted and observed values was obtained considering material and test variability.

Figure 8 shows that increases in water penetration time and Gurley porosity decrease the induction times. Somewhat unexpectedly, these results indicate that faster bonding at the double-backer is promoted by less porous and less wettable medium. However, current results on single-face bonding indicate that more porous and wettable mediums develop higher single-face bond strength. We speculate these differences in behavior are caused by the different combining conditions in the single-facer and double-backer.

Because of water absorption in the medium flute tip region, the onset of bond strength development will be delayed until the adhesive in the fillet region gels. Once bonding begins to develop, the rate of strength increase is influenced strongly by the wettability and porosity of the liner. In our current tests, the liner surface strength was exceeded as the bond strength increased, which is another indication that the rate of bond strength development is dependent on moisture absorption into the liner.

With too much water absorption into the medium in the flute tip region, the thin adhesive film in the tip region does not develop much strength, so induction times are longer. The main development of bond strength probably occurs in the fillet region under these circumstances.

Conclusions

The results of this study indicate that:

1. Linerboard properties mainly affect the rate of bond development. The induction times did not appear to be greatly influenced by variations in the linerboard properties. The rate of bond strength development is dependent on moisture absorption and heat transfer through the liner.
2. Linerboard surfaces which are porous, easy to wet, and not too rough promote higher rates of bond strength development and, hence, higher double-backer speeds.

3. Medium properties were better related to changes in induction time on the simulator. These results suggest that absorption of water from the starch by the hot medium flute tips greatly affects how fast bonding strength is initiated.
4. Low induction times (faster bonding rates) were favored by mediums which were less wettable and less porous. It is speculated that, with too much moisture migration into the medium in the flute tip region, the thin adhesive film in this region does not develop much strength, so induction times are longer.□

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This research was carried out at the Institute of Paper Science and Technology, Atlanta, Ga. The Fourdrinier Kraft Board Group funded this project, and their support is gratefully acknowledged. The assistance and advice of K. Schrampfer, C. Smith, G. Hoffman, and E. Hoerschelman has been most helpful.

Received for review Nov. 1, 1989.

Accepted Dec. 12, 1989.