

Opening the operating window of impulse drying—Part I: The effect of ambient pressure at the nip opening

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WEB DELAMINATION IS A major concern during the impulse drying of linerboard, while it is of less concern for lighter-weight grades. When delamination occurs, it manifests itself as a “blister” within or on the heated surface of the sheet. The blister normally results in a localized loss of sheet density and strength. The onset of blister formation can be detected by this loss of strength as characterized by the out-of-plane specific elastic modulus (1).

Delamination has been known to occur almost since the inception of the impulse drying concept (2, 3). However, many believed that it could be overcome by proper control of ingoing sheet characteristics and dryer parameters (4, 5). While this has been accomplished, the operating window is still somewhat restrictive.

Delamination results from the flashing of water into steam as the nip pressure is removed (6). This steam is unable to escape from the sheet fast enough to prevent internal pressure from building past the internal bond strength of the paper. This pressure results in rupture of the bonds, causing the characteristic blisters to form as the steam vents to the atmosphere (3, 4, 7–12). Orloff, Boerner, and Lindsay have shown that the critical temperature (T_c) for delamination is directly related to the permeability of the sheet (5, 11). This implies that as passageways for steam escape are increased, T_c increases, lending credence to the steam/pressure mechanism of delamination.

Additional work by the Institute of Paper Science and Technology showed that other parameters also influenced delamination. These parameters are as follows:

- press temperature
- nip pressure (13)
- nip residence time (6)
- nip pressure profile (13)
- initial sheet and felt moisture content (14)
- sheet basis weight (5)
- refining level (6)
- press roll surface material
- the hydrodynamic specific surface area of the sheet.

Institute researchers also determined that delamination was related to how energy was transferred to the sheet. They found that press surface materials having sufficiently low “thermal mass” could be operated at higher temperatures than press surfaces made of high-thermal-mass materials, such as steel (4, 7, 8, 15–17).

Researchers also found that the hydrodynamic specific surface area of the sheet was related to delamination. Sheets with a low specific surface area, having a very open structure allowing for greater steam release, tend to resist delamination (3, 13, 18, 19).

Most of the focus of previous research has been to control the physical aspects of the sheet to make it less susceptible to delamination, or to modify the roll surface properties to control heat flux. No work has attempted to control the cause of

IMPULSE DRYING

ABSTRACT

The application of increased ambient pressure during and after the nip-opening process of impulse drying inhibits sheet delamination.

Handsheets, simulating 205-g/m² linerboard with a hydrodynamic specific surface area of 29.5 m²/g and a solids content of 35%, were impulse dried at press surface temperatures of 120–330°C. When the nip opened to 1 atm ambient pressure, sheets delaminated at and above a press surface temperature of 140°C. At successively higher press surface temperatures, the ambient pressure at the nip opening could be raised to a level above which sheet delamination did not occur. This “critical” ambient pressure, found to be a function of press surface temperature, ranged up to 411 kPa (absolute) for a press surface temperature of 330°C.

Moisture ratio change was a linear function of press surface temperature and was independent of ambient pressure at nip opening. As long as the sheets were not delaminated, their strength was also independent of ambient pressure at the nip opening.

Application:

This research forms the basis of current efforts to commercialize impulse drying for application to board grades. The results of pilot experiments will be presented at the 1998 TAPPI Engineering Conference.

delamination, i.e., flash vaporization. Work along these lines is presented in this paper.

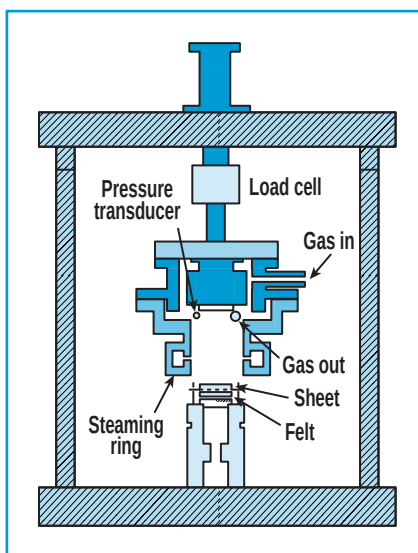
EXPERIMENTAL

Hypothesis

The authors believe that during impulse drying, water in the web is heated and pressurized so that it exists as a subcooled liquid just prior to the nip opening. As the nip is

Stage	Parameter	Value
Pulp	Species,	
	% southern hard pine	93
	% gum	7
	Kappa number	102
Sheet	Weight-weighted fiber length, mm	2.3
	Basis weight, g/m ²	205
	Ingoing solids, %	35
	Ingoing density, g/cm ³	0.7
Felt	CSF, mL	400
	Hydrodynamic specific surface, m ² /g	29.5
	Hydrodynamic specific volume, cm ³ /g	0.823
	Ingoing temp., °C	85
Impulse drying	Sample designation	BXC5
	Ingoing moisture, %	16
Impulse drying	Platen material	Carbon steel
	Peak nip pressure, kPa	4135
	Nip dwell time, ms	60

I. Experimental parameters that were held constant



1. Laboratory-scale high-ambient-pressure impulse dryer (HAPID)

KEYWORDS

Acacia, ambient conditions, delamination, liner boards, moisture content, nip, Pinus, platens, presses, pressure, shock drying, surface temperature.

opened, the water in the web continues to be heated by contact with the hot press roll surface while experiencing a sudden drop in restraining pressure. These conditions lead to a sudden increase in internal web pressure and rapid flashing of the sub-cooled liquid to vapor. The pressure difference (or pressure differential)

between the inside and out-

side of the web can cause the disruption of the fiber network. In addition, vapor that lacks a clear path to exit the sheet and is trapped inside the web may prolong the time during which this extreme pressure difference is experienced. The net result is that the fiber network ruptures, resulting in the phenomenon known as *delamination*.

It is hypothesized that reduction of the pressure difference and suppression or reduction of vapor formation during the nip opening would result in suppression of delamination. It is further proposed that the pressure difference may be significantly reduced by opening the nip to ambient pressures that are significantly higher than 1 atm.

Experimental matrix

In this exploratory work, a minimal number of parameters were varied to test the hypothesis. Furnish type (unbleached softwood kraft), basis weight, press impulse, solids content, initial wet pressing technique, and platen type were held constant, as shown in **Table I**. A detailed description of the experimental conditions

and experimental methods was reported by Krause (20) and in a recent U.S. patent (21).

Platen temperature and ambient pressure at the nip opening were the only parameters that were varied in these experiments.

Experimental plan

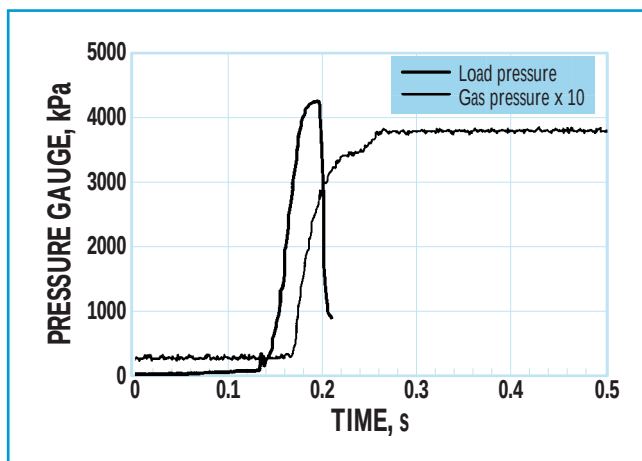
The critical temperature (platen surface temperature above which sheets delaminate) was determined for the case where the ambient pressure at the nip opening was set at 1 atm. This was accomplished by impulse drying at successively higher platen surface temperatures from 120°C until the sheets delaminated. Ten replicate experiments were conducted at each temperature. As in previous work at the Institute, delamination was verified by both visual inspection and out-of-plane ultrasonic testing methods.

At successively higher platen surface temperatures above the critical temperature as defined in the previous paragraph, the ambient pressure at the nip opening was incrementally increased until sheet delamination was suppressed. The ambient pressure, so determined, was defined as the "critical ambient pressure" associated with the specific platen surface temperature. Once this critical ambient pressure was determined over the range of platen surface temperatures, a functional relationship was determined.

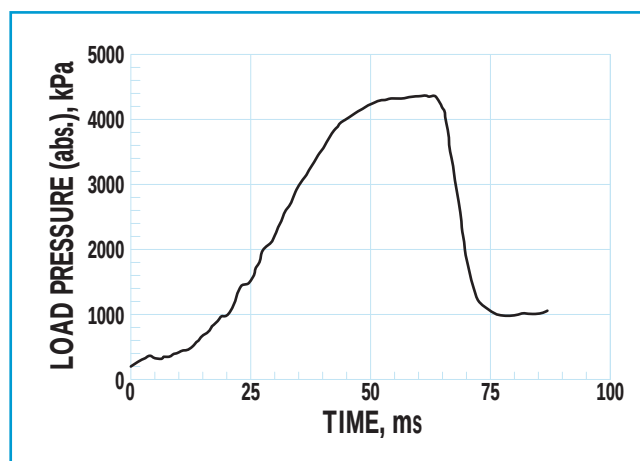
APPARATUS

Figure 1 shows the laboratory-scale high-ambient-pressure impulse dryer (HAPID) that was constructed. The device simulates an impulse drying roll press or shoe press, where the nip can be made to open at any desired gas pressure and temperature.

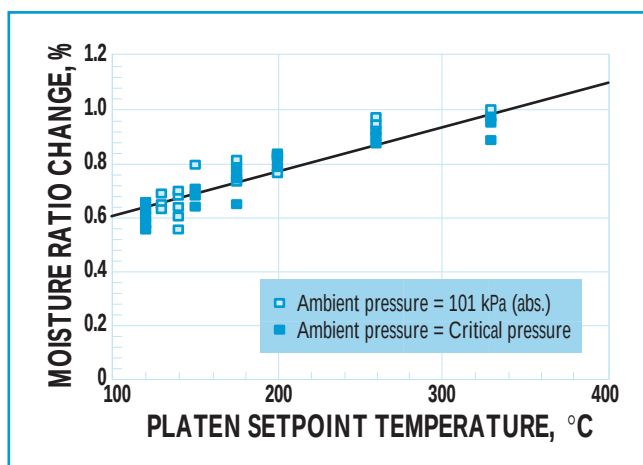
To control ambient pressure at the nip opening, the HAPID unit operates so that midway during the press impulse, a valve is rapidly opened; this allows nitrogen gas at a



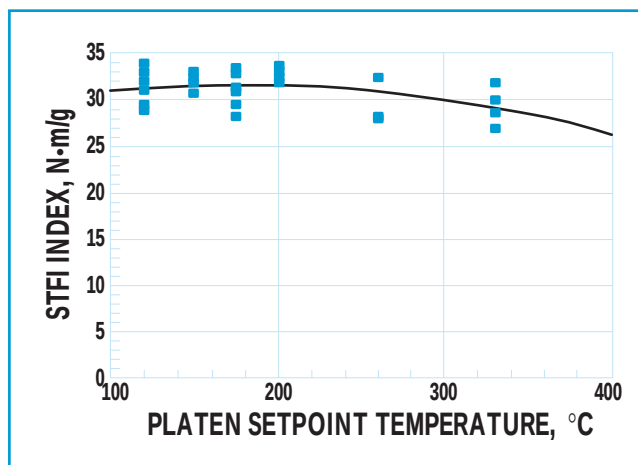
2. Load pressure and gas pressure vs. time during a HAPID experiment



3. Load pressure as experienced by a sheet that was impulse dried in the HAPID apparatus at an ambient pressure of 1000 kPa (absolute)



4. Moisture ratio change as a function of platen setpoint temperature at an ambient pressure of 101 kPa (absolute) and at the corresponding critical pressures



5. Compression strength as a function of platen setpoint temperature at the corresponding critical pressures

prescribed pressure to fill the chamber surrounding the impulse dryer. **Figure 2** shows typical load and gas pressure vs. time during a HAPID experiment.

The impulse-dried sheet experiences a higher-than-normal ambient pressure as it comes into contact with the surrounding nitrogen. **Figure 3** shows the pressure that the sheet would experience if it were opened to an ambient pressure of 1000 kPa absolute (131 psig).

RESULTS AND DISCUSSION

Table II shows the critical ambient pressure as a function of platen setpoint temperature in these experiments. The setpoint temperature was the temperature on the back side of the platen. This setpoint temperature, which deviates slightly from the platen surface temperature, was used because the surface thermocouple was inoperative during these preliminary experiments.

Case	Platen setpoint temp., °C	Critical ambient pressure, kPa (abs.)
1	150	~110
2	175	152
3	200	170
4	260	315
5	330	411

II. Critical ambient pressure from HAPID experiments

It is a significant result that by opening the impulse drying nip to elevated ambient pressures, the platen surface temperature could be significantly increased without experiencing sheet delamination. The experiments further showed that water removal was independent of ambient pressure and linearly dependent on platen temperature. This result is shown graphically in **Fig. 4**.

Of even more importance, when the ambient pressure was equal to the critical pressures, as defined in Table II, the STFI compression strength was at least constant over the platen setpoint temperature range of 120–200°C; in fact, the compression strength may reach a maximum value at 200°C. See Fig. 5.

CONCLUSIONS

Delamination of simulated linerboard resulting from the severe conditions seen in impulse drying can be suppressed. This suppression was achieved by pressurizing the atmosphere surrounding the sheet with compressed nitrogen after the close of the nip but before nip opening. The amount of pressure required varied nonlinearly with platen temperature. Sheets dried in this manner showed the characteristic increase in moisture ratio change with tempera-

ture of impulse drying and showed the physical properties of undelaminated sheets. These results directly support the flash vaporization theory for delamination and suggest methods for opening the process operating window of impulse drying technology, such as those methods suggested in a recent U.S. patent (21).

The work has significant implications for commercializing impulse drying for linerboard. The research showed that the ambient pressure to which the nip opens is a major variable influencing the critical impulse drying temperature. The work suggests that by sufficiently increasing the ambient pressure at the nip opening, the press roll surface temperature can be increased without inducing web delamination. The resulting increased press roll temperatures should result in increased water removal as well as optimized

STFI compression strength. In a more general way, the work points out the importance of properly designing and controlling the nip opening process. TJ

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