Impulse drying: heterogeneous press-roll surfaces offer new product opportunities

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ABSTRACT *The problem of delamination during impulse drying of heavyweight webs is well documented. Laboratory-scale experiments demonstrate that high levels of water can be removed without delaminating the sheet by using a press roll coated with a low-thermal-mass ceramic. The experiments also suggest that heterogeneous roll surfaces composed of metal and ceramics can be used to develop unique heterogeneous web structures that may have application in several important markets.*

KEYWORDS
Ceramic coatings
Delamination
Press rolls
Sheets
Shock drying
Water removal
Webs

The impulse-drying process uses a heated roll press to activate a more-efficient water removal mechanism. During the process, wet paper is brought into contact with a hot press roll, typically heated to between 200° (400°F) and 400°C (700°F), while pressures between 3 MPa (400 psi) and 5 MPa (700 psi) are maintained in the sheet for 15-30 ms. High-pressure steam is generated at the interface between the wet sheet and the heated roll. As the steam expands, it displaces liquid water from the sheet into a press felt. Since most of the water is removed in the liquid phase—as opposed to conventional drying where all of the water is evaporated—there is a large energy saving.

Because the impulse-drying process is terminated before the sheet is completely dry, water remaining in the sheet can flash to vapor during nip decompression. Excessive flash evaporation in a sheet with low vapor permeability results in sheet delamination. Research at IPST has shown that by reducing the temperature within the sheet just prior to opening the nip, flash evaporation can be reduced and sheet delamination suppressed. Efforts to reduce sheet temperature have led to the design of an impermeable low-thermal-mass press-roll surface. The roll surface provides a high heat flux during nip compression, while suppressing heat transfer during later stages of the process.

Findings of recent impulse-drying research

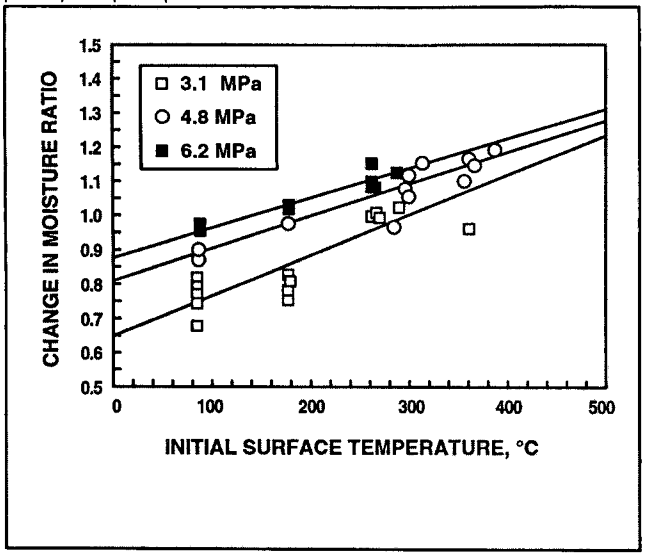
Impulse-drying simulations were conducted[1] to compare the performance of a low-thermal-mass roll surface (zirconium oxide coated) with that of a high-thermal-mass surface (steel). Linerboard sheets (205 g/m^2) were preheated to 85°C and then impulse dried at a constant dwell time (20 ms) at three peak pressures (3.1 MPa, 4.8 MPa, 6.2 MPa) using platens with initial temperatures ranging from 85°C to 500°C. The ingoing solids of the linerboard sheets was 30%.

Figures 1 and 2 show the water removal, expressed as the change in moisture ratio, for the steel and the ZrO_2-coated platens, respectively. In all cases, water removal increased with increasing initial temperature of the platen surface. A regression analysis on the data showed that, except at the lowest pressure, water removal was independent of platen type. At a given initial platen-surface temperature, the ZrO_2 surface should transfer significantly less energy to the sheet than the steel surface. Hence, water removal must be independent of the total energy transfer to the sheet. Because water removal increases with increasing initial temperature of the platen surface, it is likely that water removal is controlled by the magnitude of the heat flux at the beginning of the process.

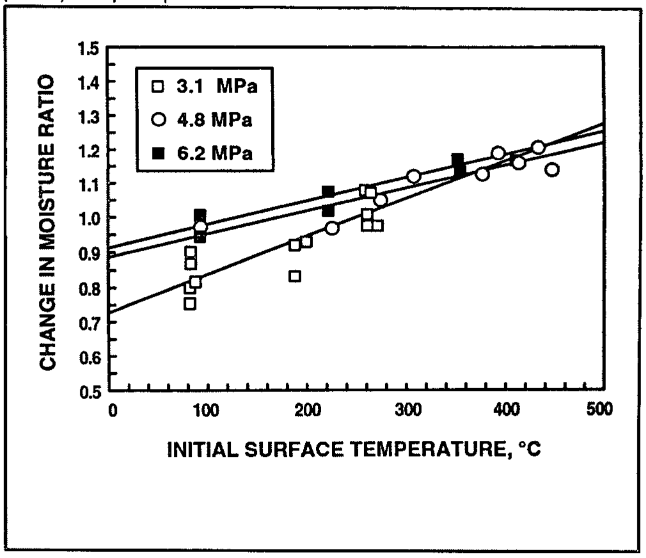
Sheet delamination limits the operating temperature of impulse-drying roll surfaces and, consequently, limits water removal. Hence, roll surfaces were evaluated using two key performance variables: water removal and delamination control. Sheet de-

[1] Orloff, D. I., Proceedings of the 77th Annual Meeting of the Technical Section of CPPA, CPPA, Montreal, 1991, p. B9-B25.

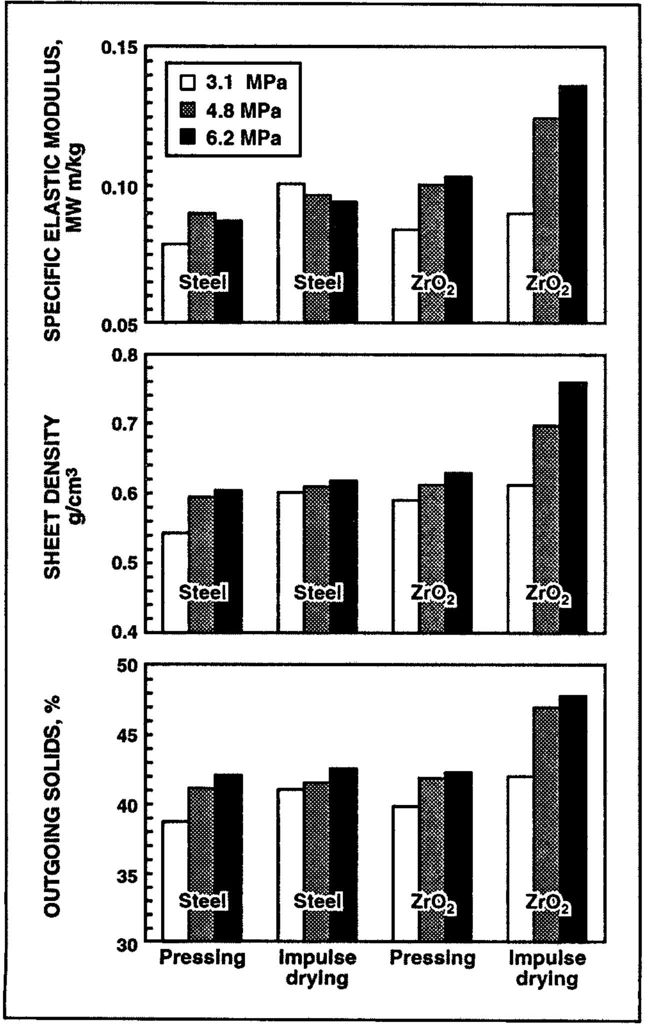
1. Change in moisture ratio as a function of initial temperature (steel platen) and peak pressure



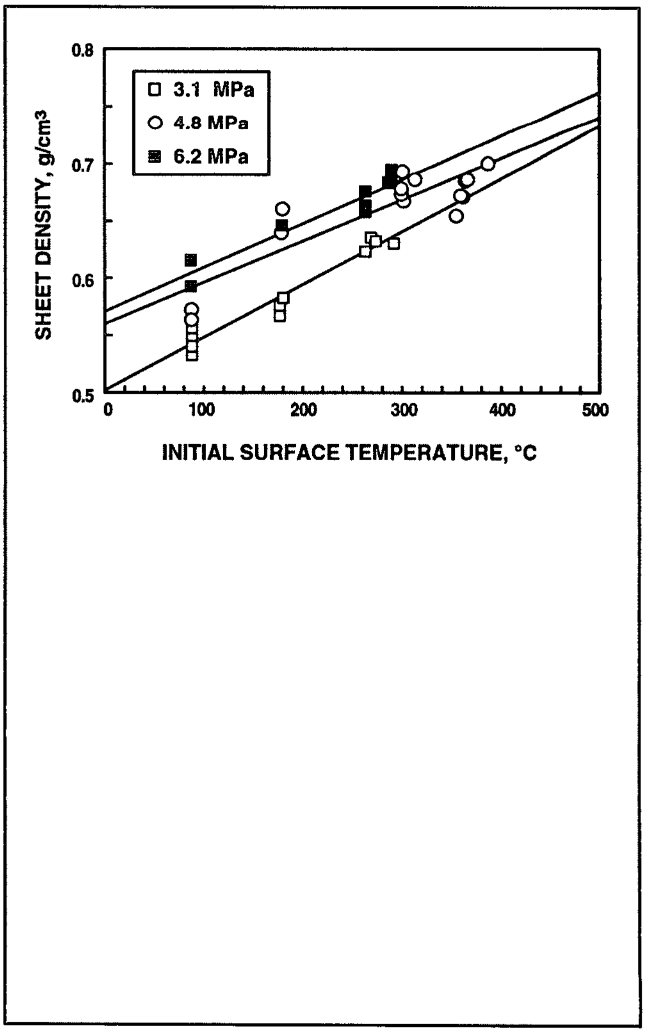
2. Change in moisture ratio as a function of initial temperature (ZrO_2 platen) and peak pressure



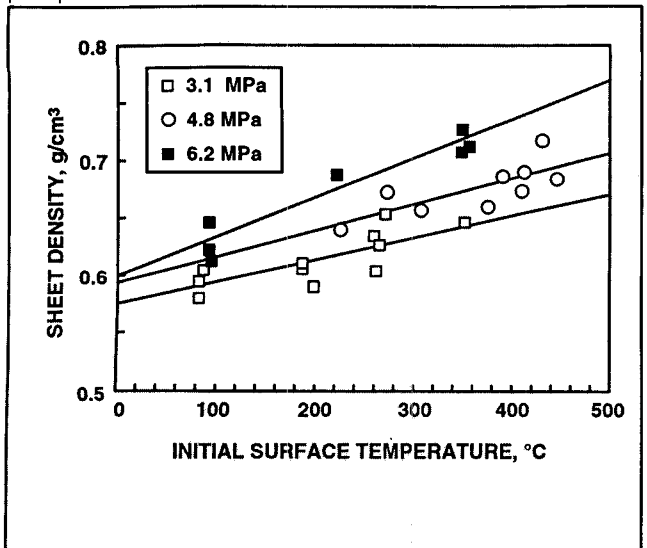
3. Maximum specific elastic modulus, maximum sheet density, and maximum outgoing solids as functions of peak pressure for each platen surface. (Maximum is defined here as the highest value obtained without sheet delamination.) Results are presented for both wet pressing and impulse drying.



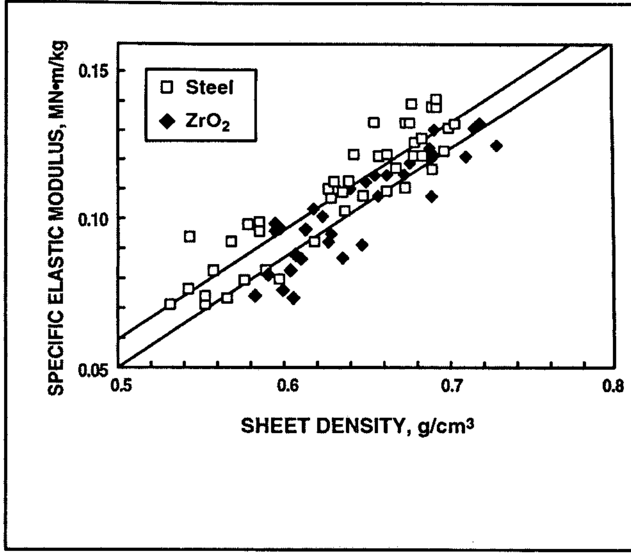
4. Sheet density as a function of initial temperature (steel platen) and peak pressure



5. Sheet density as a function of initial temperature (ZrO_2 platen) and peak pressure



6. Specific elastic modulus for impulse drying as a function of sheet density for the steel platen and the ZrO_2 platen



lamination was detected and quantified using z-direction ultrasound. The threshold platen-surface temperature above which sheet delamination occurred also was determined. The ZrO_2-coated platen substantially increased the operating temperature limit at peak pressures of 4.8 MPa and 6.2 MPa, resulting in significantly improved water removal.

The two platen materials also were compared in terms of maximum outgoing solids, maximum sheet density, and maximum specific elastic modulus at the operating temperature limits. These results are listed in **Fig. 3** along with results for single-felted wet pressing. Pressing results were similar for both platen types. Impulse drying with a steel surface showed no improvement over single-felted wet pressing because of sheet delamination. However, impulse drying with the ZrO_2-coated platen at high peak pressures showed significant improvement over single-felted wet pressing.

While water-removal efficiency is important, another key advantage of the impulse-drying process is the enhanced development of sheet properties. **Figures 4 and 5** show sheet density as measured ultrasonically for steel and ZrO_2, respectively. Sheet density is seen to be a function of initial platen temperature, but density also tended to be higher when the prototype platen was used. This result is consistent with the postulate that the prototype platen reduced the extent of flash evaporation, which would otherwise result in midlayer bulk.

The out-of-plane specific elastic modulus has been shown to be proportional to standard destructive strength tests such as the STFI compressive strength test.[2] Analysis of the current results showed that the specific elastic modulus was a function of sheet density and platen type, as shown in **Fig. 6**. For a given sheet density, the ZrO_2 surface resulted in slightly lower modulus, again suggesting a difference in internal sheet structure. Although sheet strength at a given sheet density was lower, the prototype platen allowed operation at much higher temperatures, resulting in improved sheet density and strength.

Experiments using heterogeneous platen

Objectives

Comparative experiments with steel and ceramic platens have shown that the low thermal mass of the platen surface controls flash evaporation, which in turn controls sheet delamination. Experiments also showed that water removal was independent of platen material at a given platen temperature and that low-thermal-mass ceramic platens can be operated at temperatures significantly higher than those for steel platens without inducing sheet delamination.

Comparing the performance of the two platen materials in terms of water removal and delamination control requires that a number of sheet variables remain fixed. Although this was achieved in the previous work,[1] a demonstration of the influence of different platen materials on the same sheet would be convincing. Hence, the influence of platen materials on sheet delamination was demonstrated by impulse drying sheets with a platen surface containing regions of both high and low thermal mass.

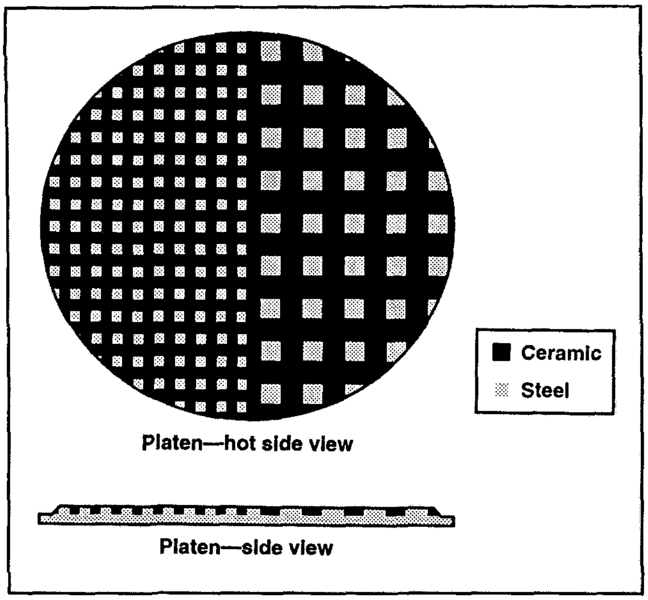
Figure 7 shows the design of a heterogeneous platen used in the experiments. A steel platen was machined such that one-half of the platen was covered by 6.35 mm (1/4 in.) square steel regions while the other half was covered by 3.175 mm (1/8 in.) square steel regions. After machining, the platens were plasma sprayed with a zirconium oxide, ground such that there were equal areas of steel and ceramic, and coated with a high-temperature polymeric release agent to seal the pores of the ceramic and reduce the free energy of the surface.

Equipment

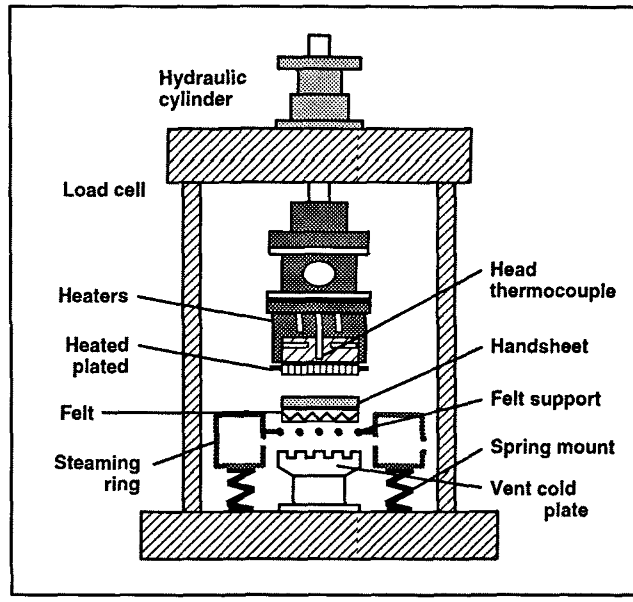
Figure 8 is a schematic of the electrohydraulic press used to simulate impulse drying. The system was

[2]Orloff, D. I., High-intensity drying processes—impulse drying, Report 5 for the Department of Energy (Contract FGO2-85CE40738, DOE/CE/40738-T5), DOE, Washington, DC, September 1990.

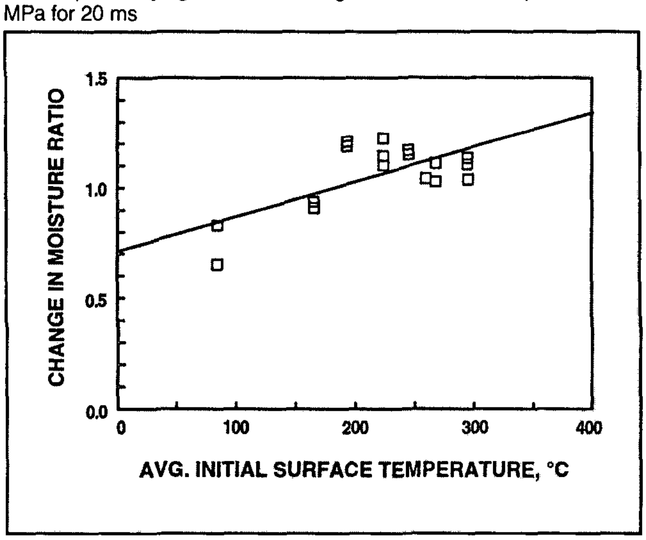
7. *Heterogeneous platen*



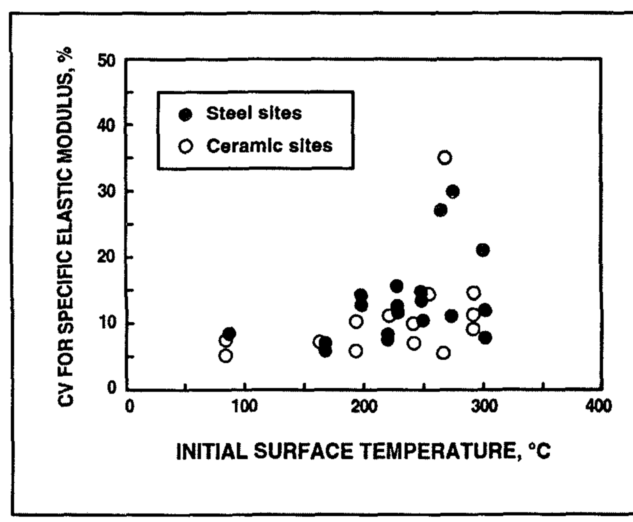
8. Electrohydraulic press



9. Change in moisture ratio as a function of average initial temperature after impulse drying with the heterogeneous steel/ZrO_2 platen at 3.8 MPa for 20 ms



10. Coefficient of variation for specific elastic modulus as a function of initial surface temperature of steel sites and ceramic sites



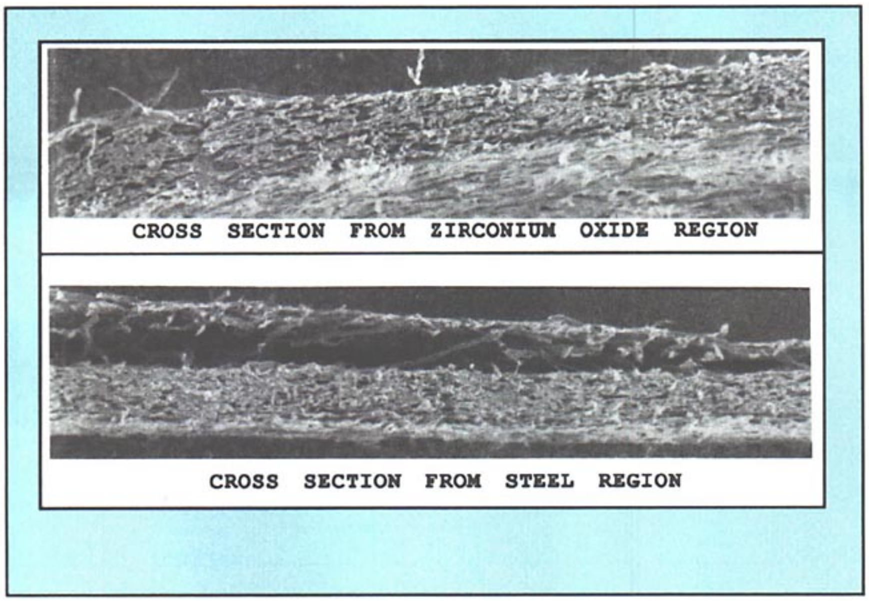
designed so that heated platens made from various materials could be evaluated. Linerboard handsheets (205 g/m^2) were formed on a British sheet mold and pressed to 30% solids. Handsheets were then placed onto Nomex press felts containing 16% moisture. The handsheet/press-felt combination was placed onto a wire support, where radially injected steam raised its temperature to 85°C. After preheating, the hydraulic system was activated, resulting in a 20-ms pressure pulse with a peak pressure of 3.8 MPa and an impulse of 0.034 MPa•s.

A series of impulse-drying experiments was performed in which the initial platen temperature was varied from 84°C to 295°C. Measuring the surface temperature of both ceramic and steel regions, it was found that the steel was always slightly higher in temperature than the ceramic. At a low steel surface temperature of 84°C, the ceramic was 1°C less. As the initial temperature of the steel was raised to 299°C, the ceramic was found to be 9°C less. All reported surface temperatures are averages.

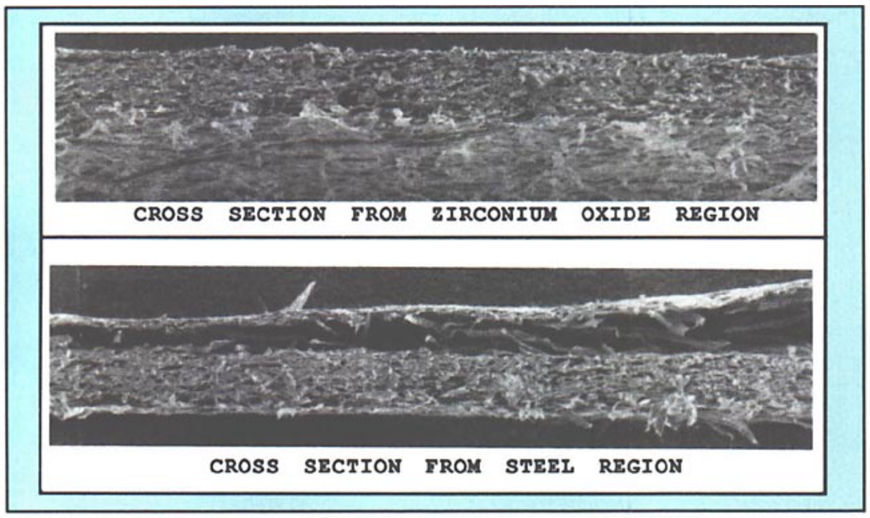
Results

The heterogeneous platen was designed so that the surface contained equal areas of ceramic and steel. The water removal induced by the platen was expected to be the sum of water removed by each area. The water removed by the heterogeneous platen as a function of average initial platen-surface temperature is shown in **Fig. 9**. Comparison with the data in Figs. 1 and 2 shows excellent agreement.

11. Photomicrographs of heterogeneous sheet after impulse drying with steel/ZrO_2 platen at an initial surface temperature of 211°C. Top: cross section of sheet after contact with ZrO_2-coated region; bottom: cross section of sheet after contact with steel region.



12. Photomicrographs of heterogeneous sheet after impulse drying with steel/ZrO_2 platen at an initial surface temperature of 242°C. Top: cross section of sheet after contact with ZrO_2-coated region; bottom: cross section of sheet after contact with steel region.



The basic objective of the experiment was to show that regions of the handsheet beneath the steel would delaminate, while regions beneath the ceramic would not. As in previous work, z-direction ultrasound was used to quantify delamination. A 9.52-mm-diam. (3/8 in.) transducer recorded z-directional specific elastic modulus at 30 locations per sheet. Fifteen locations were directly under the 6.35-mm (1/4 in.) square steel sites, while 15 locations were directly under ceramic sites.

Coefficients of variation for the specific elastic modulus are plotted as a function of initial surface temperature in **Fig. 10**. Previous research has shown that the onset of sheet delamination corresponds to an abrupt increase in the coefficient of variation of the specific elastic modulus. As seen in Fig. 10, delamination under steel sites was observed when the temperature exceeded 200°C, while delamination under the ceramic site was not observed until the temperature exceeded 250°C.

Visual observation of the sheets confirmed the ultrasound findings. No visible delamination was noted at average surface temperatures below 165°C. For average surface temperatures between 165°C and 250°C, sheets visibly delaminated *only in* regions of the sheet in direct contact with the steel sites of the platen. At average surface temperatures in excess of 250°C, large regions of the sheets exposed to both ceramic and steel showed visible signs of delamination.

The photomicrographs in **Figs. 11 and 12** show cross sections of typical sheets after contact with ceramic or steel regions of the platen at two different temperatures. The micrographs confirm that the regions in contact with the ceramic did not delaminate, while the regions in contact with the steel did.

The photomicrographs and previous data show that sheet properties such as bond strength and bulk can be engineered into sheets at specific localized regions. The ability to develop patterned web structures may have applications in several paper and nonwovens markets. For example, patterned heterogeneous impulse-drying press rolls could be used to manufacture patterned towels or to produce a paper replacement for plastic bubble wrap.□

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