Institute of Paper Science and Technology

IMPULSE DRYING: CERAMIC ROLL SURFACE DEVELOPMENT

Project 3470

Report 1

A Yearly Progress Report
to
THE U.S. DEPARTMENT OF ENERGY

September, 1990

Atlanta, Georgia

NOTICE & DISCLAIMER

INSTITUTE OF PAPER SCIENCE AND TECHNOLOGY

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By

David I. Orloff

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BASIC UNITS AND CONVERSIONS

Mass	Kilograms (kg) = 2.20462 pound mass (lb_m) Ton = 2000 lb_m.
Length	Meters (m) = 3.2808 feet (ft).
Time	Second (s) = 1000 milliseconds (ms).
Volume	Cubic meters (m^3) = 10^6 milliliters (mL).
Force	Newton (N) = 0.22481 pound force (lb_f).
Pressure	Pascal (Pa) = 0.000145 pounds per square inch(psi). MegaPascal (MPa) = 1 x 10^{+6} Pascal.
Temperature	Degree Celsius (°C) Degree Fahrenheit (°F) = °C x (9/5) + 32.
Energy	Joule (J) = 9.486 x 10^{-4} British Thermal Units (Btu). Quad = 1 x 10^{+15} Btu.
Power	Watt (W) = 1 J/s Watt (W) = 9.486 x 10^{-4} (Btu/s).

SYMBOLS AND ABREVIATIONS

α	Thermal diffusivity, m^2/s.
BWT	Sheet basis weight, grams per square meter (gsm). TAPPI Method T410 OM-88.
C'	Constant defined in Reference 13.
C_P	Specific heat, $W \cdot s/g \cdot {}^{\circ}K$.
CSF	Canadian standard freeness, (mL). TAPPI Method T227 OM-85.
CVSEM	Coefficient of variation of the specific elastic modulus, (%).
Felt Moist.	Ingoing felt moisture, (%).
I	Impulse, (MPa·s).
INDEX	Compressive strength measured by STFI method, (N·m/g).
K	Ratio of the thermal conductivity to the square root of the thermal diffusivity.
λ	Thermal conductivity, $W/m \cdot {}^{\circ}K$.
MRC	Sheet moisture ratio change = sheet weight loss/ sheet dry weight.
Parker Printsurf	Surface roughness as measured by Parker Printsurf method, (micrometers).
Q	Heat flux, W.
ρ	Density, g/m^3.
%Sin	Ingoing sheet solids, (%).
SEM	Specific elastic modulus, MN·m/kg.
Solids In	Ingoing solids, (%).
STFI Index	Compressive strength measured by STFI method, (N·m/g). Tappi Method T826 pm.86.
T_{ps}	Initial platen surface temperature, °C.

T_{ph}	Sheet preheat temperature, °C.
USWK	Unbleached softwood kraft.
V	Pore volume fraction.

IMPULSE DRYING: CERAMIC ROLL SURFACE DEVELOPMENT

SUMMARY

Impulse drying is an innovative process for drying paper that holds great promise for reducing the energy consumed during the manufacture of paper and similar web products. Impulse drying occurs when a wet paper web passes through a press nip in which one of the rolls is heated to a high temperature. A steam layer adjacent to the heated surface grows and displaces water from the sheet in a very efficient manner. The energy required for water removal is very much less than that required for conventional evaporative drying. Hence, it has been projected that wide commercialization of impulse drying would result in at least a 10% industrywide energy saving.

Research supported by the Office of Industrial Programs of the Department of Energy has demonstrated the potential of the impulse drying process as part of a larger study of novel pressing and drying technologies. Previous annual reports have documented the effectiveness of impulse drying for energy efficient water removal in several commercially important paper grades. The conditions required for impulse drying have also been extensively characterized. Impulse drying has been shown to improve several important properties of paper, thereby creating opportunities for fiber savings during paper manufacture- by using less fiber, for example, or by using recycled fiber or fiber manufactured with alternative pulping processes. Tests have been completed that elucidate the unique displacement mechanism of water removal in the impulse drying process. A pilot roll press has been designed, installed and used to examine impulse drying under conditions that simulate commercial press conditions.

Pilot press trials demonstrated that heavyweight grades experience delamination under a variety of high-intensity drying conditions. Subsequent laboratory scale studies, using an electrohydraulic press to simulate impulse drying, demonstrated the effect of paper furnish properties and process conditions on delamination susceptibility. Sheet temperature profile measurements recorded during impulse drying simulations suggested that delamination occurs when superheated water remaining in the partially dried sheet flashes to steam during nip depressurization.

Early attempts to suppress delamination by modification of the heated roll surface were met with little success. While porous metal surfaces resulted in suppression of delamination, they exhibited significantly lower water removal. The results of this earlier work have been reported in previous reports.

This report covers work completed between October, 1988 and September, 1989. During this period, pilot press trials demonstrated that newsprint as well as linerboard experience delamination. Hence, the major focus of the research was the resolution of the delamination problem. In order to document potential process improvements, measurement methods were developed to quantify sheet delamination. Using these methods, low thermal diffusivity ceramic roll surfaces were shown to extend the range of impulse drying operating conditions while avoiding sheet delamination. As compared to steel surfaces, ceramics were found to provide significantly higher water removal without inducing sheet delamination.

As a working hypothesis, it is believed that these low thermal diffusivity ceramic roll surfaces function by maintaining a high heat flux at the beginning of the process while reducing the heat flux toward the end of the process. The reduced heat flux results in lower average sheet temperatures, less violent flash evaporation, and elimination of sheet delamination.

Work continues on the development of these ceramic surfaces, both in terms of understanding the mechanism of operation and demonstrating the technology on the pilot press.

OVERVIEW AND OBJECTIVES

The Pulp and Paper industry is one of the largest industrial consumers of energy in the United States (1-3). Based on thirty million BTU's per ton of paper produced and annual production of 76 million tons, a total of 2.3 Quads are consumed by the industry annually. Drying is the largest single energy user in the papermaking process and accounts for about one quarter of the energy used.

The impulse drying process under development at the Institute of Paper Science and Technology employs a heated roll press to activate a new, more efficient, water removal mechanism. During the process, wet paper is brought into contact with a hot metal roll, typically heated to between 200°C (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 times of 15 to 30 milliseconds. The water removal mechanism is different from that involved in conventional evaporative drying processes. Previous research at the Institute has demonstrated that during impulse drying, high pressure steam is generated rapidly at or near the interface between the sheet and the heated roll surface. As moisture is converted to steam by heat transferred from the hot roll, the steam layer grows and displaces liquid water from the sheet into a water receiver, typically a press felt. As 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 savings.

In addition to its impact on energy consumption, impulse drying also has a beneficial effect on sheet properties. Surface fiber conformability and interfiber bonding are enhanced by transient contact between the sheet and the hot surface. As the impulse drying process is terminated before the sheet is completely dried, flash evaporation of residual liquid within the sheet results in a distinctive density profile through the sheet, characterized by dense surface layers and a bulky midlayer. For many grades and conditions, this translates into improved physical properties. For other grades, flash evaporation can cause delamination of the sheet.

In early simulations, Arenander and Wahren (4) and Burton (5,6) reported delamination during intense impulse drying. Thereafter, delamination was viewed as a phenomena that would be encountered only under extreme conditions which could easily be avoided in commercial practice.

During a recent joint feasibility study by Beloit Corporation, Weyerhauser Corporation and The Institute of Paper Science and Technology, delamination emerged as a major problem. As reported by Crouse, Woo, and Sprague (7), various degrees of delamination were experienced with linerboard dried at press roll surface temperatures above 150°C. When delamination was avoided by operating below this limit, water removal efficiencies were not significantly different from those obtained by conventional pressing. Hence, it was concluded that to realize the potential of impulse drying, it would be necessary to alleviate delamination.

In preliminary work, Lavery (2) found that several commercially important grades, including lightweight southern pine linerboard, lightweight coated rawstock, writing papers, and newsprint did not delaminate at commercially useful temperatures (below 370°C) when impulse dried from 50% solids.

Lavery (3) conducted a study to determine whether refining to increase the flow resistance of southern pine kraft linerboard would induce delamination. Pulp refined in a valley beater from 700 mL to 200 mL CSF was used to form handsheets at a basis weight of 200 gsm at an initial solids level of 35%. Impulse drying experiments were conducted at a platen temperature of 370°C, a peak pressure of 2.7 MPa, a dwell time of 30 ms, without pre-heating. Lavery found visual signs of delamination when the pulp was refined to a Canadian Standard Freeness of 600 mL or lower. Based on this data, he postulated that very thick or highly refined sheets would exhibit greater resistance to flow of vapor than coarse sheets. If the flow resistance of the web was large, the high pressure steam produced during impulse drying would not dissipate before the mechanical restraint on the sheet was relieved. The sheet would not be strong enough to constrain the pressurized vapor and blistering or delamination would result.

Orloff (8) established a database documenting the range of acceptable operating conditions for several grades, weights and furnishes. Platen temperature vs. dwell time maps were developed to show conditions that resulted in delamination. These maps generally showed that as the platen surface temperature increased, the onset of delamination occurred at shorter dwell times. Orloff also found that average strength measurements, such as the STFI compressive strength index, do not adequately detect the onset of delamination.

Burkhead (9) investigated the influence of felt moisture and peak pressure on delamination. The work showed that delamination was more likely to occur at either very low or very high felt moisture ratios. Burkhead also found that independent of felt moisture ratio, delamination did not occur unless a threshold pressure was exceeded.

Using a linerboard furnish, additional experiments by Orloff (8) showed that the threshold pressure increased as the dwell time decreased. In these experiments, felt moisture had no effect on delamination.

Based on the hypothesis that delamination occurs when excess energy is transferred to the sheet, Santkuyl (10) and Orloff (8) investigated various alternate platen materials that were expected to alter the heat flux to the sheet during the impulse drying event. These included two solid platens: one of steel and one of aluminum, as well as two porous platens made from sintered stainless steel, at two different porosities. Although the heat flux from the aluminum platen was expected to be substantially higher than that for the steel platen, the effect on delamination was found to be negligible. The porous platens were expected to result in a lower heat flux and to provide venting of steam generated at the platen /sheet interface. Experiments with the porous platens showed no evidence of delamination. However, water removal was substantially lower than that obtained with the solid platens. Analysis of the mass of water transferred to the felt compared to the mass of water lost from the sheet confirmed that significant steam venting occurred. Venting and the associated reduction in steam pressure are consistent with the observation of reduced water removal. However, the question remained as to whether the elimination of delamination was due to the lower heat flux or steam venting.

The work performed during the current period focused on resolving the delamination problem for heavy weight grades. Key to this activity was the development of a quantitative measure of delamination and further exploration of alternate platen materials for delamination control.

PROGRESS IN IMPULSE DRYING RESEARCH

PLANS FOR THE PERIOD

The overall objective of this project was to improve the process to a level suitable for commercialization. Commercialization is currently impeded by two process deviations, sheet delamination during drying of heavyweight grades, and two-sidedness in drying lightweight grades. The research goals for the period from October, 1988, through September, 1989 were to remove these impediments. Alternative impulse drying roll surfaces materials were evaluated for their ability to suppress sheet delamination. In addition, drying conditions required to avoid two-sidedness in lightweight grades were identified.

QUANTIFICATION OF SHEET DELAMINATION

Throughout the course of the research program delamination has been assessed by visual observation. However, it was recognized that developing a quantitative measure for delamination was a necessity. With this in mind, samples generated during early stages of the investigation were saved so that when an acceptable test was established, delamination could be quantified.

An optimum test would have the characteristics of being: non-destructive, sensitive to the onset of delamination, predictive of standard destructive tests and efficient. To meet these objectives, an out-of-plane ultrasonic test method (11) has been employed in which the speed of sound through paper is measured between 3/8" diameter soft platens. Using the measured sonic velocity, localized specific elastic modulus (SEM) can be determined.

Measurements in visibly delaminated vs. non delaminated zones show that the specific modulus is very sensitive to the presence of delamination. In early experiments, a total of 50 random specific modulus measurements on sheets impulse dried at a given operating condition were used to generate SEM histograms. Comparison of the histograms with visual observation showed that delamination results in an increase in the coefficient of variation of the SEM (CVSEM).

As an example, Figure 1 shows the SEM histogram of a 155 gsm linerboard sample impulse dried for 63 ms at an initial platen temperature of 260°C. The sample showed no visual evidence of delamination and exhibited a 12.3% CVSEM. As shown in Figure 2, increasing the dwell time to 100 ms resulted in visible delamination and an increase in the CVSEM to 28.9%. The CVSEM has been used throughout this work as the key indicator of delamination.

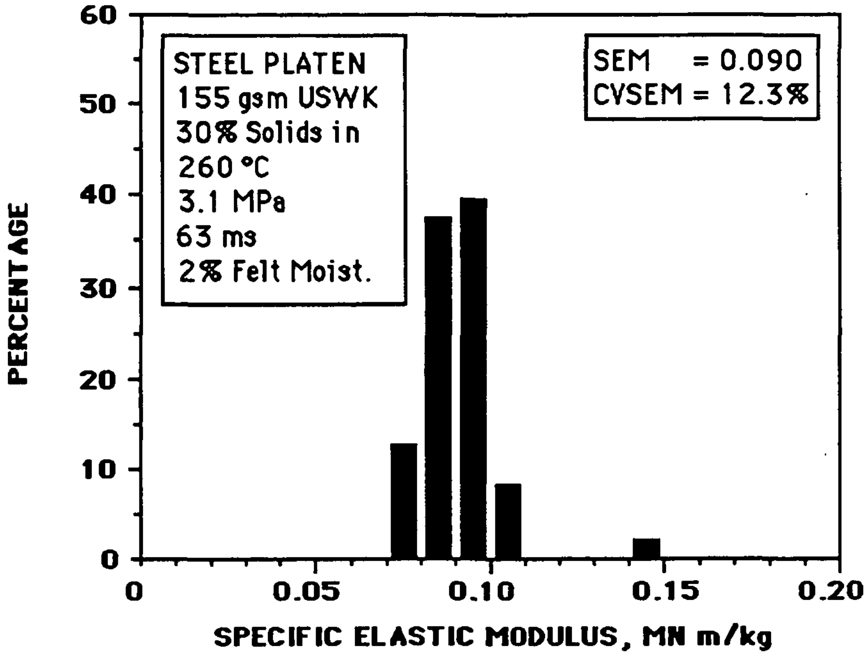

Figure 1. Specific elastic modulus histogram for case of no visible delamination.

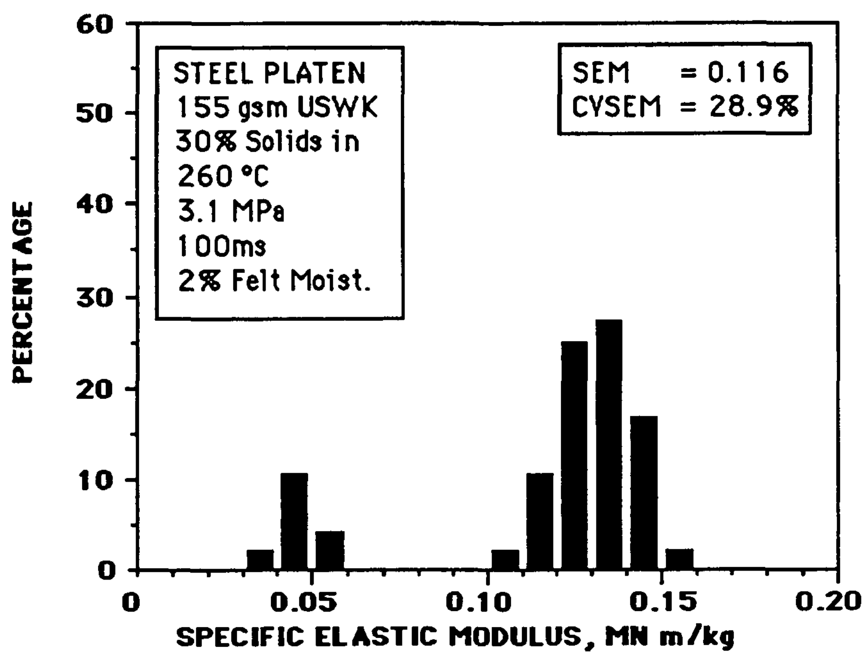

Figure 2. Specific elastic modulus histogram for case of visible delamination.

In early work, Lavery used the STFI compression test to detect delamination. Hence, a comparison of the ultrasonic test method to the STFI compressive strength test is of interest. Samples impulse dried with steel and ceramic platens were tested at the same locations on each sheet by both methods. Figure 3 shows the correlation of the test results in which each data point represents a minimum of eight individual measurements. As expected, an increase in specific elastic modulus was also observed as an increase in the STFI index.

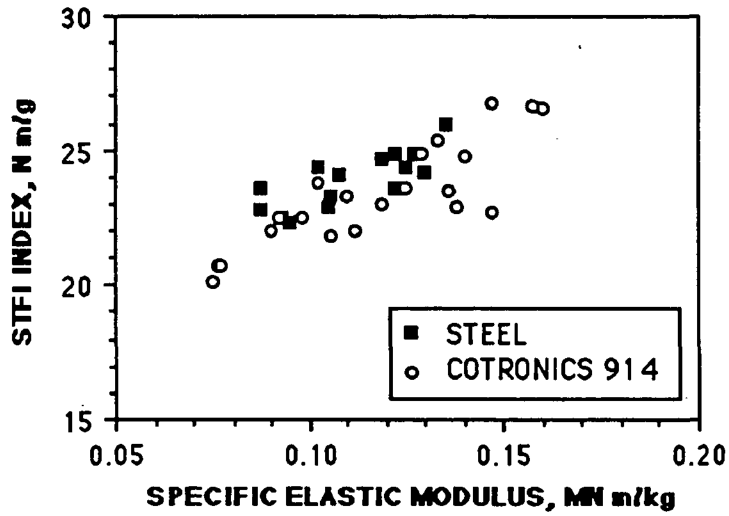

Figure 3. Comparison of specific elastic modulus and STFI Index for samples impulse dried with steel and Cotronics (type 914) ceramic platens.

A comparison of the coefficients of variation of the measurements is shown on Figure 4. Note that a large variability in modulus corresponds to a much smaller variability in index. Hence, the modulus is expected to be a more sensitive indicator of delamination.

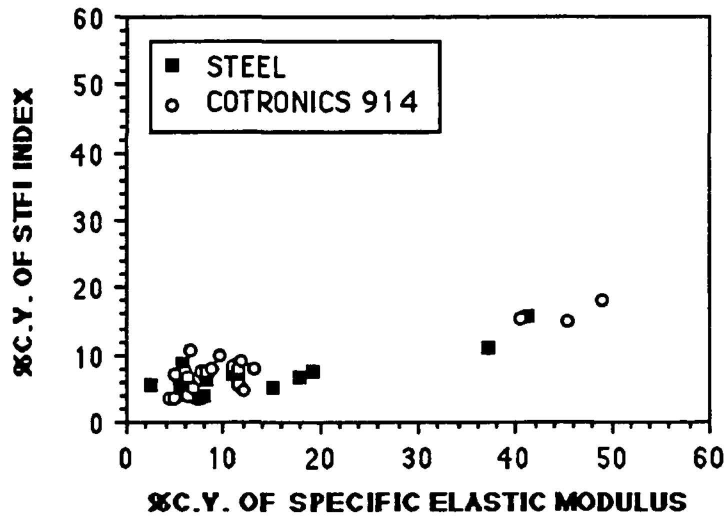

Figure 4. Comparison of coefficients of variation of specific elastic modulus and STFI index for samples impulse dried with steel and Cotronics (type 914) ceramic platens.

PILOT STEEL ROLL IMPULSE DRYING

Linerboard Grade

Pilot scale experiments were performed on the first roll-set of the Institute's pilot scale impulse dryer which is shown in schematic form in Figure 5. Comparison experiments using identical paper were performed on the laboratory-scale electrohydraulic press shown in Figure 6. The purpose of these experiments was to assess the scale up of delamination data from the one-dimensional electrohydraulic press to the two-dimensional pilot impulse dryer and to investigate the effect of two nip drying on delamination. In both cases a heated surface composed of chrome plated steel was used and initial felt moisture was maintained at 16%. All experiments were conducted with the paper initially at room temperature. Wet paper for these experiments was produced from a 56% yield Unbleached Southern Softwood Kraft furnish that was refined to 650 ml CSF and formed on Black Clawson Kennedy's pilot paper machine. As with laboratory scale experiments, a silicone release agent was routinely sprayed onto the heated roll to prevent sticking.

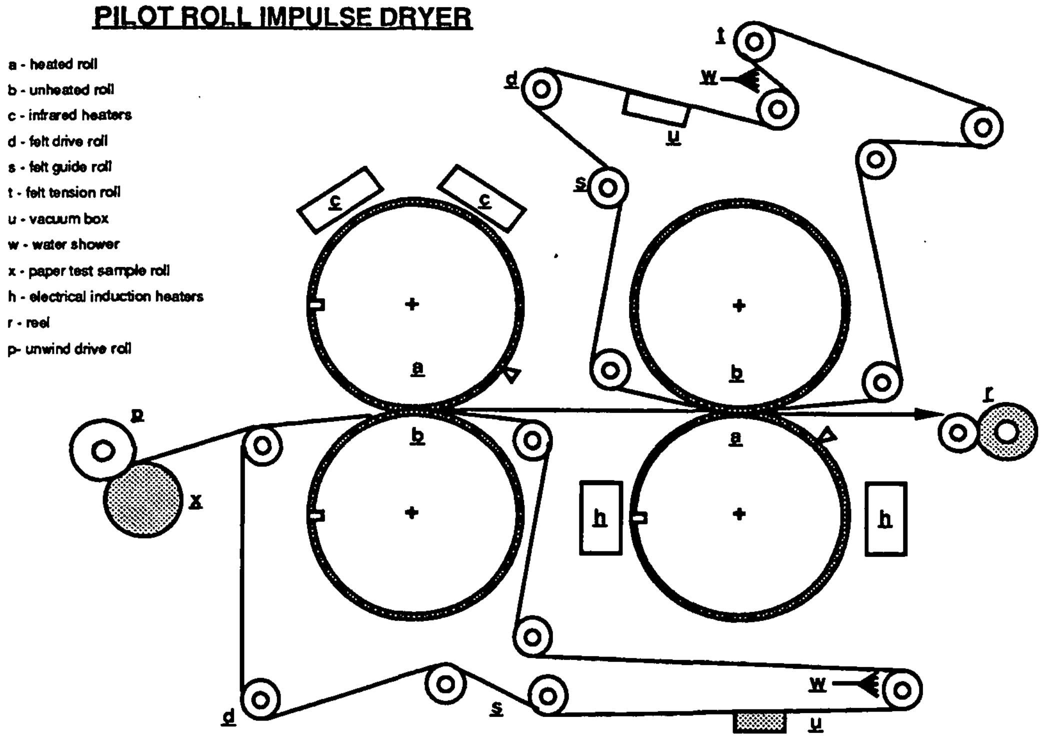

Figure 5. Pilot scale two nip impulse dryer.

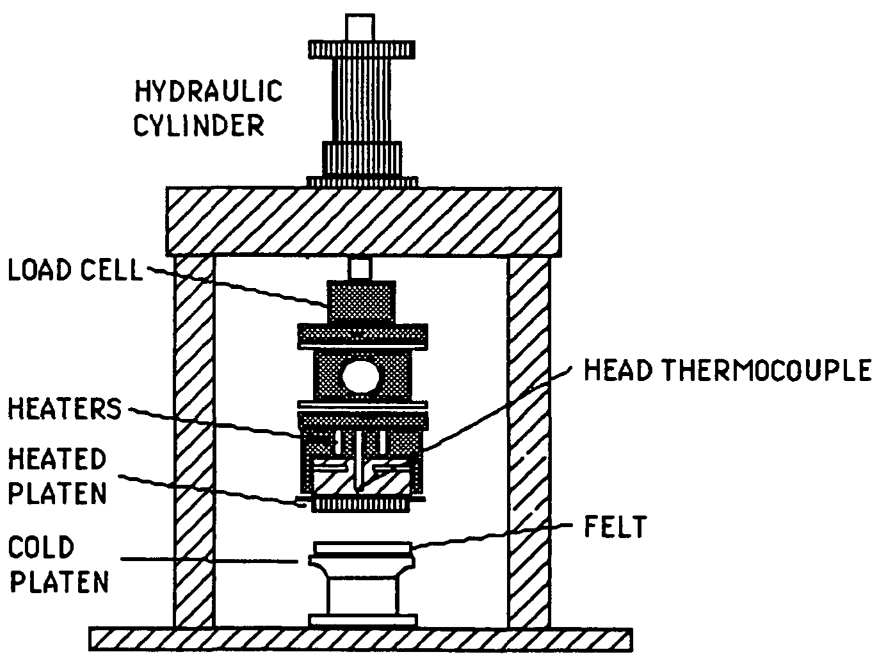

Figure 6. Electrohydraulic Press.

Much of the work on understanding delamination has been done on the laboratory scale, as the laboratory scale equipment was much more productive than the pilot equipment. Concern has been raised regarding whether the two dimensional nature of the pilot dryer could be adequately modeled on the one dimensional laboratory scale simulator, especially for the phenomena of delamination. To address this issue, rolls of linerboard were formed at three different weights and impulse dried under similar conditions on both the pilot and laboratory scale driers. Results, shown in Figures 7 and 8, suggest that the pilot dryer may be more susceptible to delamination than the laboratory scale dryer. In particular, it was noted that at a dwell time of 30 ms the electrohydraulic press simulation resulted in no visual delamination and a CVSEM of 16.8%. Operating under the same conditions, the pilot press resulted in visible delamination and a CVSEM of 23.9%. This result cautions that while the electrohydraulic press may be used to identify potential solutions to the delamination problem, early implementation on the pilot dryer will be necessary to demonstrate a solution.

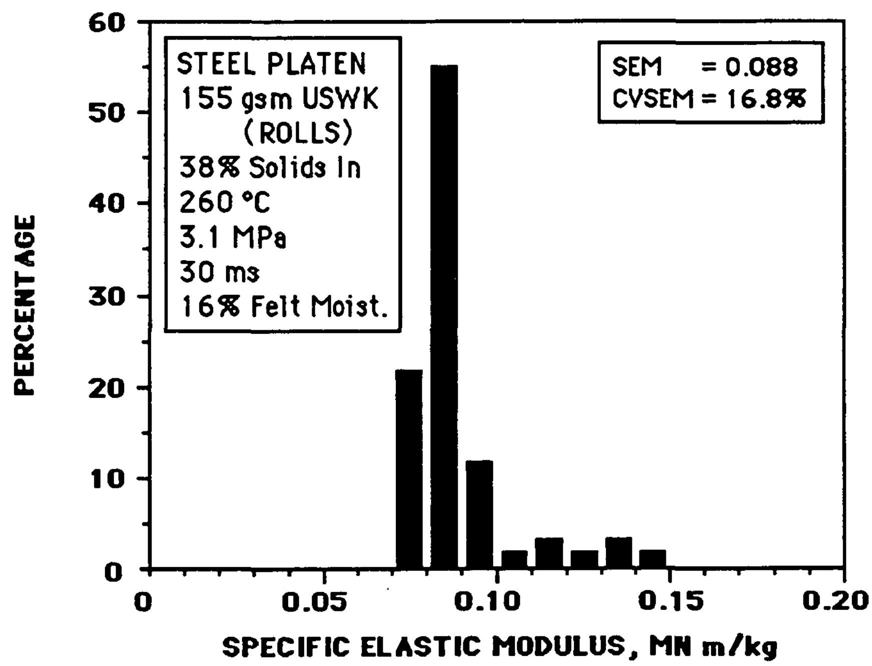

Figure 7. Specific elastic modulus histogram for a sample impulse dryed on the electrohydraulic press.

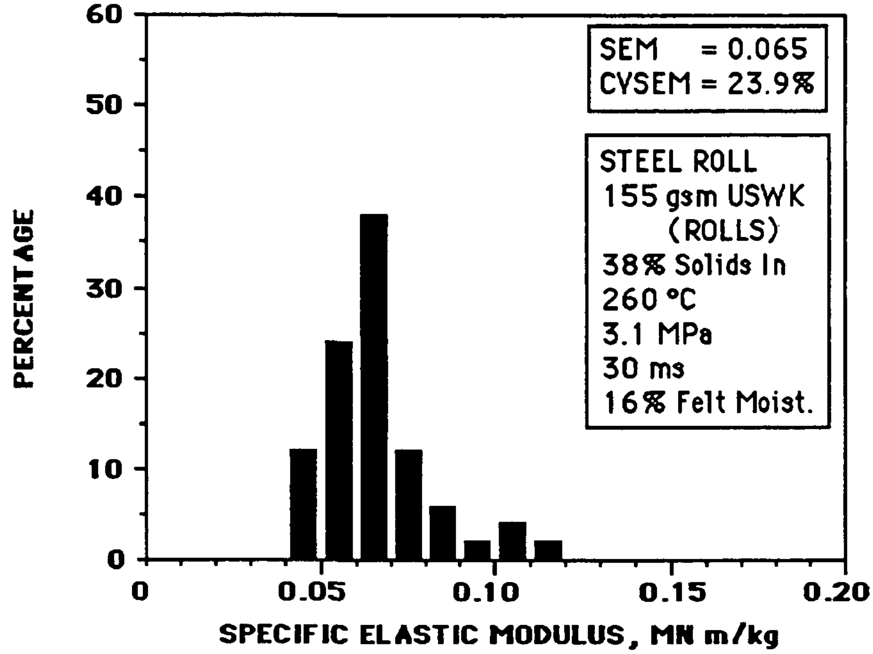

Figure 8. Specific elastic modulus histogram for a sample dryed on the pilot impulse dryer.

In early pilot dryer trials, delamination was visibly less apparent after going through a second impulse drying nip. To confirm this, sheets dried on the first set of pilot impulse drying rolls were compared to sheets exposed to both nips. Ultrasonic tests, represented in Figures 9 and 10, show that the second nip can heal delamination for nip residence times of 110 ms. However, no improvement was noted at nip residence times shorter than 50 ms. As commercial operation requires dwell times shorter than 50 ms, the two nip solution to delamination proves to be impractical.

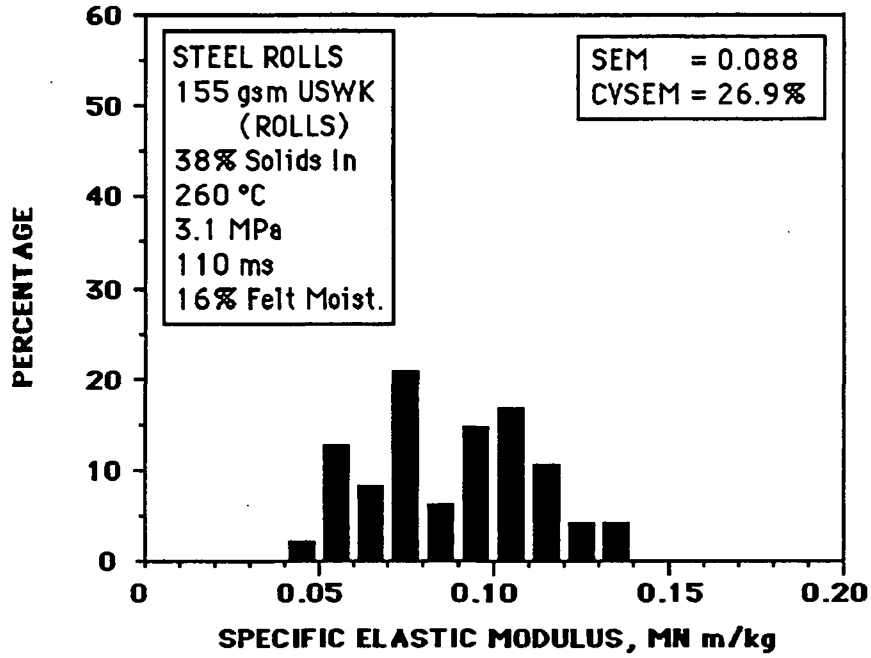

Figure 9. Specific elastic modulus histogram for sample dried on the first nip of the pilot impulse dryer for 110 ms.

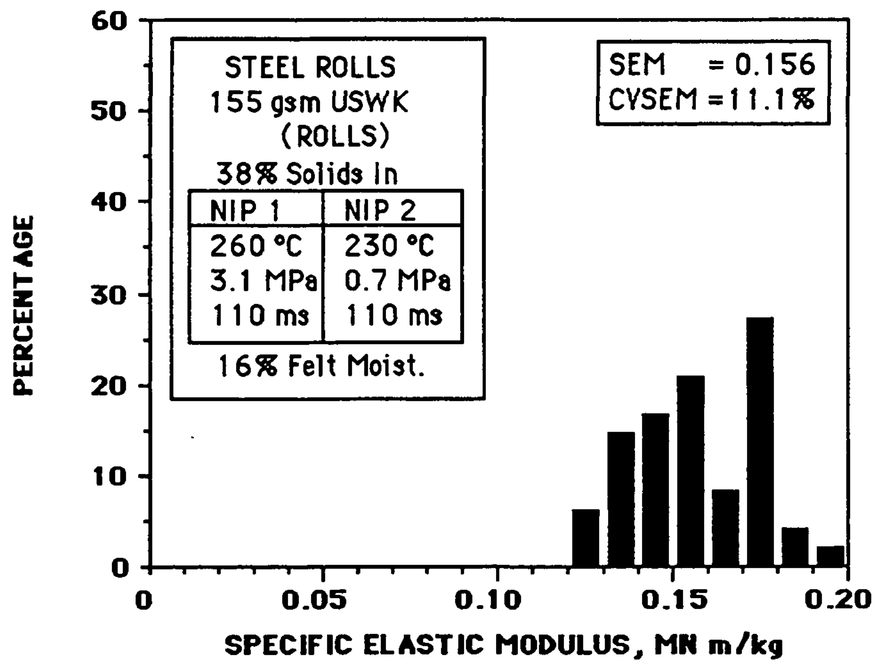

Figure 10. Specific elastic modulus histogram for sample dried on both nips of the pilot impulse dryer for 110 ms.

Newsprint Grade

Achieving single sidedness has been perceived as the major objective for two-sided impulse drying of light weight grades such as newsprint. To achieve this objective two major tasks were addressed: determining, on the laboratory scale, the influence of process variables on two sidedness, and on the pilot scale demonstration of the impulse drying of newsprint and assessment of the printing characteristics of the product.

Laboratory scale experiments on the electrohydraulic press were focused on determining the influence of first and second nip impulse drying conditions on the similarity of both sides of the paper. Surface roughness, as measured by Parker Printsurf (12), was used as an indication of surface properties. As shown in Figure 11, the results of the study were that the roughness difference between sides could be minimized by reducing the peak pressure of the second nip to the minimum required to sustain impulse drying.

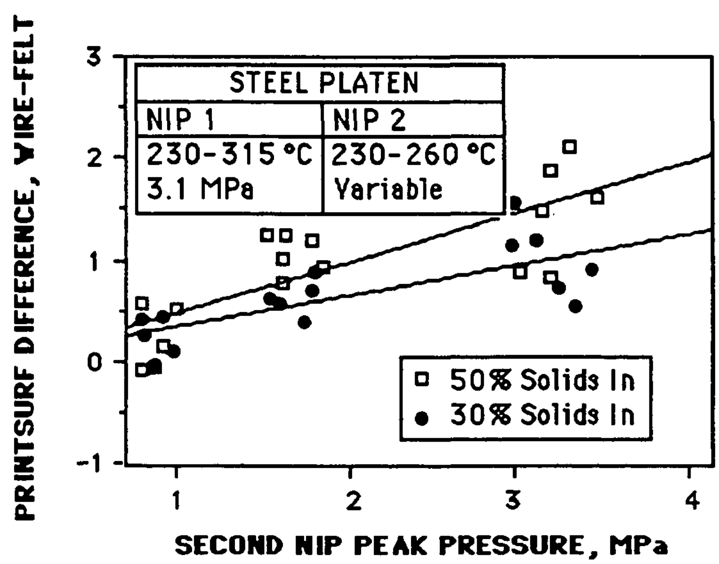

Figure 11. Sidedness as measured by Parker Printsurf difference vs. second nip pressure for 50 gsm newsprint impulse dried on the electrohydraulic press for 20 ms at 16% felt moisture.

It was also determined that surface roughness was primarily controlled by the temperature of the first nip with improved surface roughness being achieved at higher platen temperatures. Minimum Parker Printsurf (S-10) readings of 6.0 µm were achieved in this study. It was also concluded that excessively high densities, resulting from high first nip platen temperatures, could be avoided by reducing the peak pressure of the first nip. Although delamination was not expected for these light weight sheets, it was observed for some process conditions.

To demonstrate two nip drying of newsprint, pilot dryer trials were implemented. Rolls of wet newsprint formed on the Black Clawson pilot paper machine were impulse dried on the Institute's pilot impulse dryer. Impulse drying process conditions, chosen through laboratory simulations, proved to be successful in minimizing sidedness. Although impulse drying conditions were mild, there was visible indication of delamination after the first nip. Application of the second nip typically eliminated all visible evidence of delamination. After impulse drying, sheets were finish dried on a drum dryer and soft calendared at Valmet Corporation. The calendared sheets were then offset printed on the Western Michigan University sheet-fed press.

The offset printing evaluation showed that impulse dried sheets had superior ink-lay compared to control sheets dried entirely on the drum dryer. However, comparison of the impulse dried sheets to commercial newsprint showed that the ink-lay and mottle exhibited by the impulse dried sheets was inferior to commercial sheets. Further analysis indicated that poor sheet formation was the cause of the problem.

Even though the second nip appeared to heal delamination induced in the first nip, it was felt that resolution of the delamination problem would be a prudent step prior to demonstration of impulse drying of other lightweight grades.

ALTERNATIVE ROLL SURFACE DEVELOPMENT

Ceramic Surfaces- Preliminary Experiments

A series of laboratory scale experiments were conducted to identify equipment modifications that would minimize the delamination problem. These experiments were performed on the electrohydraulic press. Experiments were conducted with handsheets initially at room temperature. Handsheets were formed on a British sheet mold at a basis weight of 155 gsm from a 56% yield Unbleached Southern Softwood Kraft furnish refined to 650 ml CSF. Ingoing felt moisture was typically 2%. In addition, a fluorocarbon release agent was routinely sprayed on the heated platen to prevent sticking.

From previous research (8) it was surmised that delamination might be controlled by reducing the temperature within the sheet just prior to opening of the nip. In early work (8,10), the Institute explored porous stainless steel platen materials having very low thermal diffusivity. Although impulse drying with these materials resulted in no delamination, a large penalty in terms of water removal was observed.

Hence, the objective was to develop a platen material that would reduce the likelihood of delamination without sacrificing water removal efficiency. To this end, various ceramics and ceramic/metal composites were investigated. Early results showed that low thermal diffusivity platen materials had the potential for significantly extending the impulse drying operating range without delamination and at the same time achieving excellent water removal.

These early experiments were performed with a nonporous machinable glass (type 914) ceramic manufactured by the Cotronics Corporation of Brooklyn, New York. Thermophysical property measurements of samples of this ceramic were determined by the Properties Research Laboratory of West Lafayette, Indiana. Figures 12 and 13 show the measured thermal properties as a function of temperature.

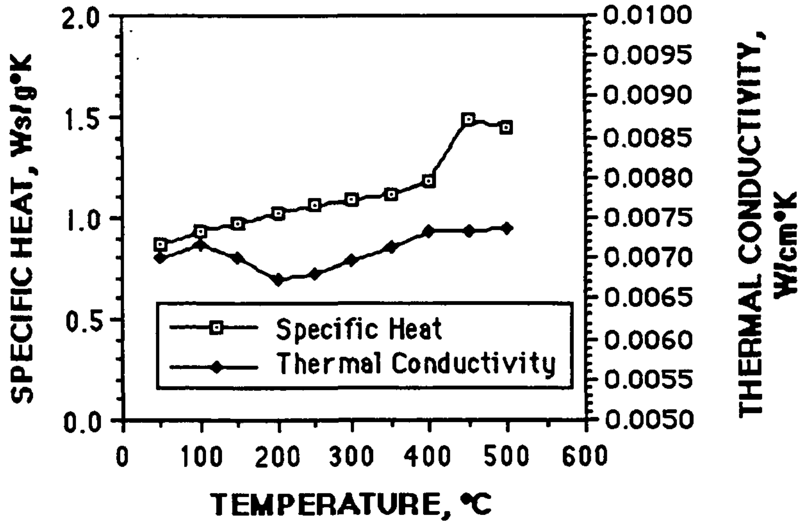

Figure 12. Specific heat and Thermal conductivity vs. Temperature for Cotronics (type 914) machinable glass ceramic.

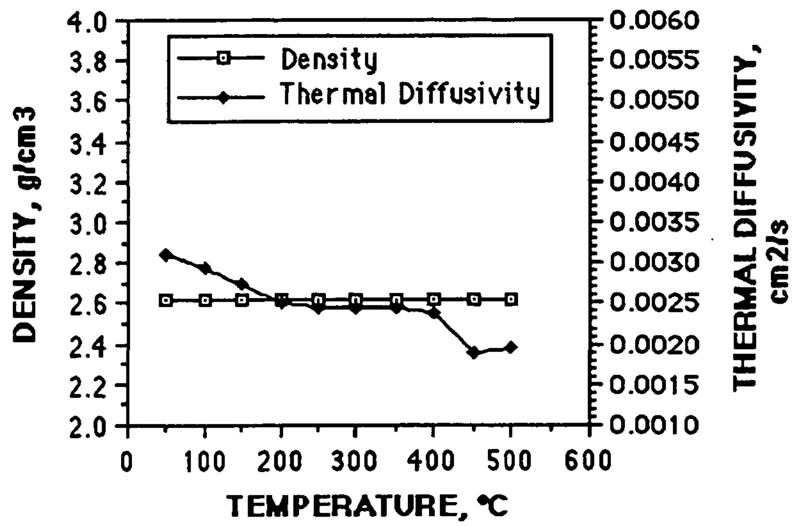

Figure 13. Density and Thermal diffusivity vs. Temperature for Cotronics (type 914) machinable glass ceramic.

For comparison, typical thermal properties of the steel used in fabricating the steel platens are shown in Figures 14 and 15.

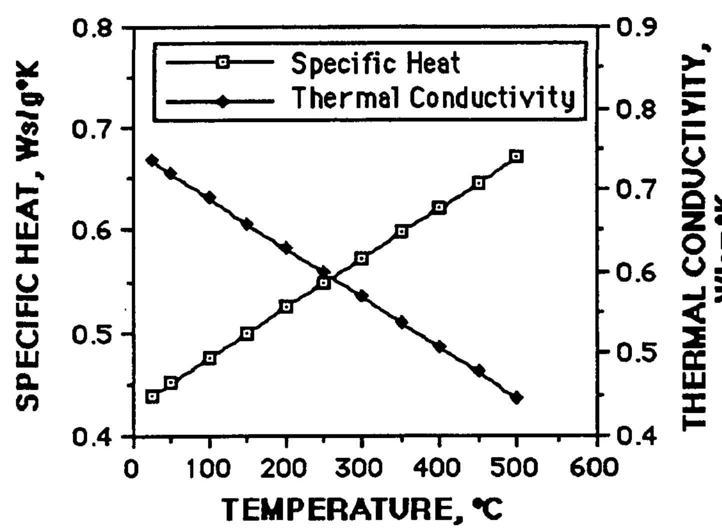

Figure 14. Specific heat and Thermal conductivity vs. Temperature for typical steel used in fabricating the steel platen.

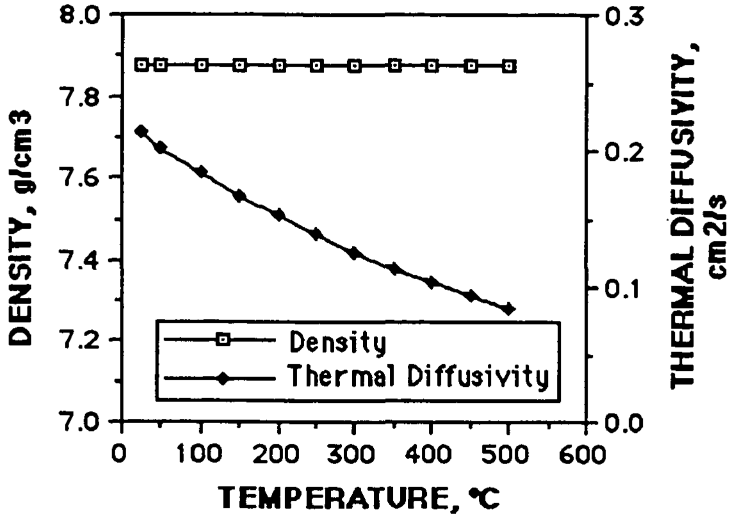

Figure 15. Density and Thermal diffusivity vs. Temperature for typical steel used in fabricating the steel platen.

In the temperature range of interest in impulse drying (200-400°C), the thermal conductivity of the ceramic is almost one hundred times lower than steel, while the thermal diffusivity is fifty times lower. Because of its high thermal diffusivity and conductivity, a steel platen will provide high surface temperature throughout the impulse drying event. In contrast, it was hypothesized that the low thermal diffusivity and conductivity of the ceramic platen would result in a rapid drop of platen surface temperature during the impulse drying event. It was further hypothesized that this temperature drop would result in: a substantial reduction of the heat flux to the sheet, lower average sheet temperature and consequently, less flash evaporation during nip decompression. Theoretical calculations by Lindsay (13) confirmed that the Cotronics (type 914) ceramic platen would reduce heat flux to the sheet by about 50%.

Initial experiments compared the impulse drying performance of the Cotronics (type 914) ceramic platen to a steel platen. In these experiments, initial platen temperature was 260°C, while the peak pressure was 3.1 MPa. Dwell time was varied from a low of 70 ms to a high of 200 ms. Experiments were conduced with 155 gsm handsheets produced from a 56% yield Unbleached Southern Softwood Kraft furnish refined to 630 mL CSF. Initial felt moisture was maintained at 2% while sheet ingoing solids was 30%. As in previous experiments, both platens were routinely sprayed with a fluorocarbon release agent.

For each five inch diameter impulse dried sample, twelve ultrasonic measurements were used to determine the SEM and CVSEM. Sheet weight data was taken just before and just after impulsing, while oven dried sheet weights were taken after drying at 110°C for 100 seconds on the finish drying simulator.

After impulse drying and prior to finish drying, each sample was visibly inspected and coded to reflect the extent of delamination.

Figure 16 shows a comparison of SEM for both platen types as a function of impulse. Also shown are data for the ceramic platen where initial platen temperature was raised to 315°C. Impulse is defined as the integral of the pressure vs. time curve. The figure shows that the specific elastic modulus increases with increasing impulse as long as the sample does not delaminate. With an initial platen temperature of 260°C, the steel platen caused delamination at an impulse of 0.22 MPa·s (100 ms). At a similar initial platen temperature and impulse, the ceramic platen showed no signs of delamination. With an increase in initial platen temperature to 315°C, the ceramic platen resisted causing delamination until an impulse of 0.38 MPa·s (175 ms).

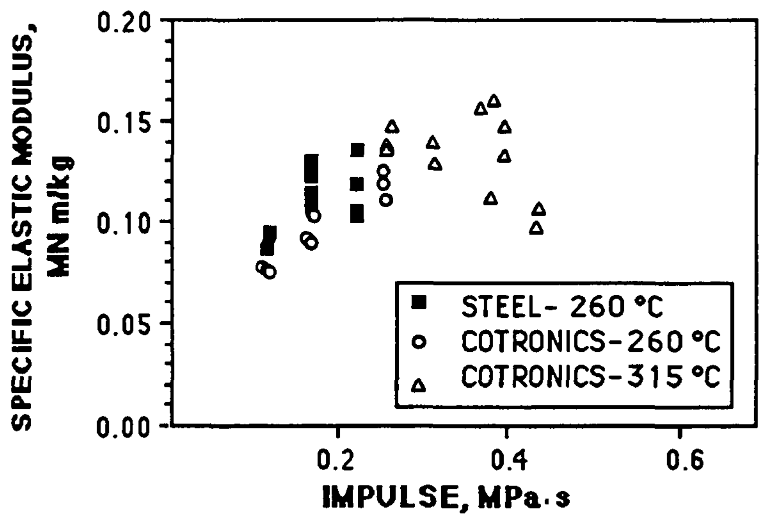

Figure 16. Specific elastic modulus vs. Impulse for 155 gsm linerboard impulse dried with steel and Cotronics (type 914) ceramic platens.

The extent of water removal, expressed as a moisture ratio change, was found to increase with impulse as shown on Figure 17.

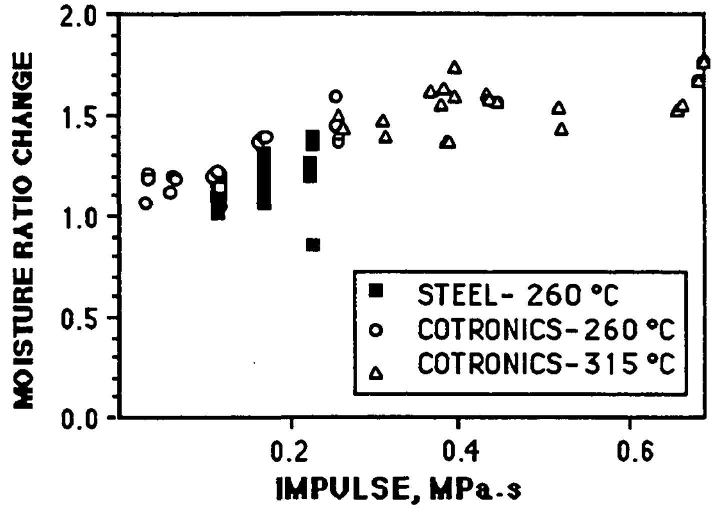

Figure 17. Sheet moisture ratio change vs. impulse for steel and Cotronics (type 914) ceramic platens.

It was decided to assess platen performance by determining the extent of delamination for a given amount of water removal. In Figure 18, the CVSEM was used as the measure of delamination. A high variation occurs when an impulse dried sheet just begins to show delamination (i.e., some regions of the sheet are solid, while others are delaminated). Referring to Figure 18, at an initial platen temperature of 260°C, the steel platen caused delamination when the sheet moisture ratio change exceeded a value of 1.2. At the same initial platen temperature and sheet moisture ratio change, the ceramic platen showed no evidence of delamination. By raising the ceramic initial platen temperature to 315°C, sheet moisture ratio changes of 1.5 could be obtained without delamination.

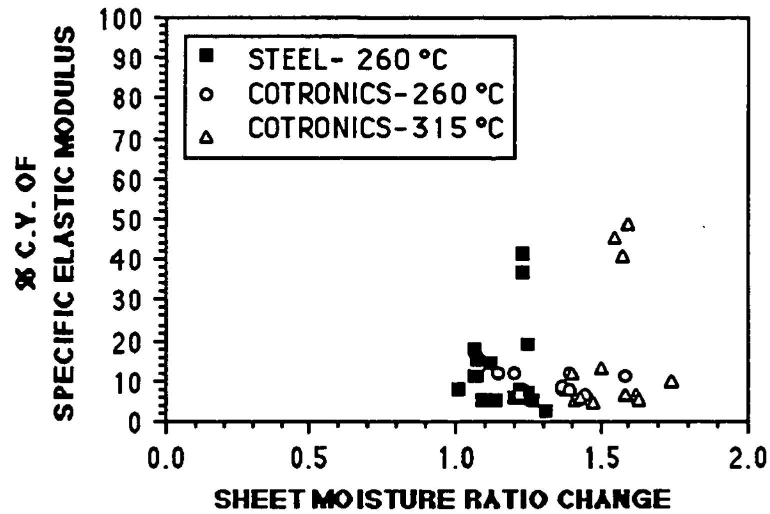

Figure 18. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for steel and Cotronics (type 914) ceramic platens where dwell time was a variable.

These experiments clearly suggest that the ceramic impulse drying surface has distinct advantages over steel surfaces. For completeness, specific elastic modulus histograms for samples impulsed with steel and ceramic platens are shown in Figures 19 and 20.

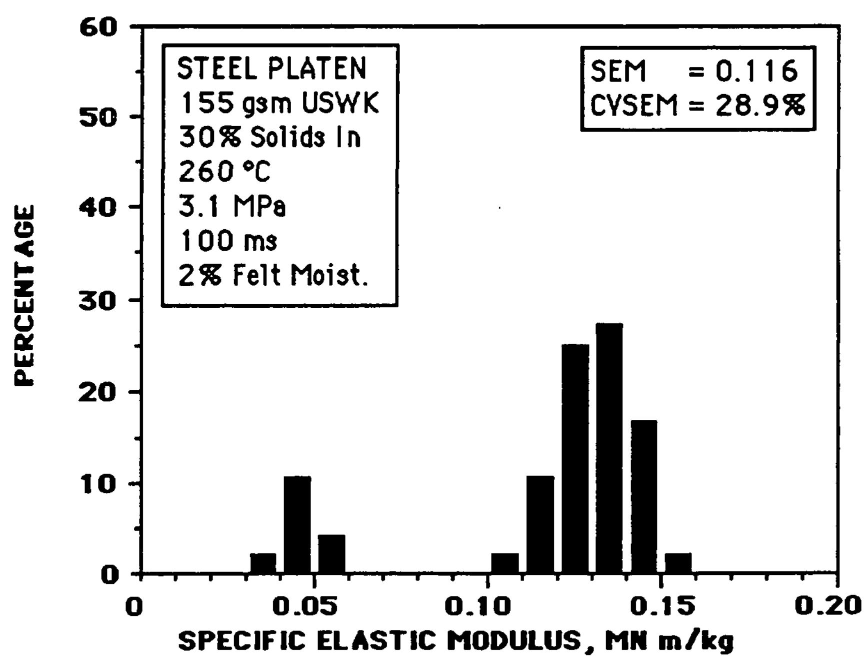

Figure 19. Specific elastic modulus histogram for sample impulse dried for 100 ms at an initial platen temperature of 260°C using the steel platen.

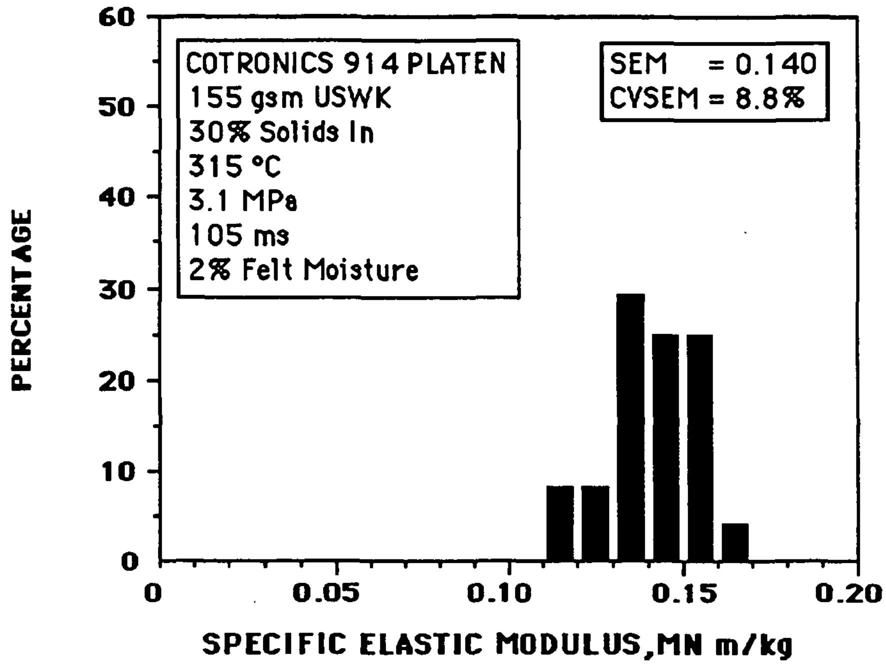

Figure 20. Specific elastic modulus histogram for sample impulse dried for 105 ms at an initial platen temperature of 315°C using the Cotronics (type 914) ceramic platen.

Verification of Previous Experiments:

In order to confirm and extend the previous results, a series of experiments was performed at various platen temperatures at a dwell time of 110 ms (corresponding to an impulse of 0.30 MPa·s. Figure 21 shows that sheets impulse dried using the steel platen experienced a drop in the specific elastic modulus at initial platen temperatures in excess of 200°C. The modulus of sheets dried with the ceramic platen were still showing improved strength at initial platen temperatures of 320°C. Sheets dried with the steel platen showed visible signs of delamination at initial platen surface temperatures of 200°C and higher, while sheets dried with the ceramic platen showed no visible signs of delamination.

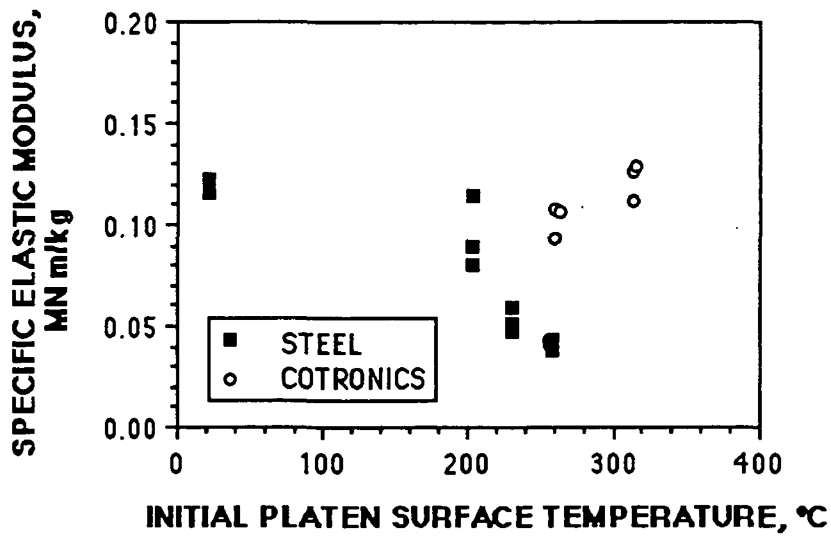

Figure 21. Specific elastic modulus vs. Initial platen temperature for samples impulse dried for 110 ms using the steel and Cotronics (type 914) ceramic platens.

Figure 22 shows the effect of initial platen surface temperature on water removal. By raising the ceramic platen to a temperature of 320°C, an equal amount of water was removed as could have been removed with the steel platen at 200°C. The ceramic platen resulted in no visible delamination, while sheets dried with the steel platen were clearly delaminated.

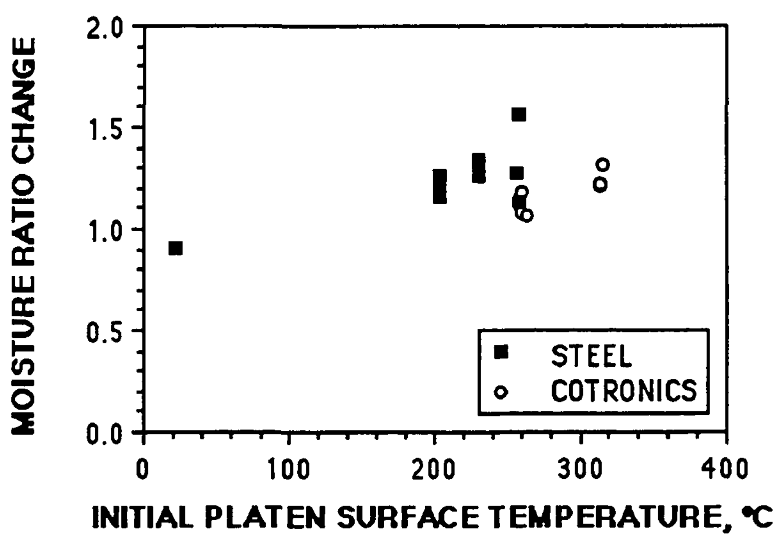

Figure 22, Sheet moisture ratio change vs. Initial platen surface temperature for samples impulse dried for 110 ms using the steel and Cotronics (type 914) ceramic platens.

Graphing the coefficient of variation of the specific elastic modulus vs. sheet moisture ratio change, the performance of the two platen materials can be compared more easily. Figure 23 shows the performance comparison. In these experiments, the ceramic platen achieved a moisture ratio change of 1.3 without delamination. In contrast, the steel platen caused high coefficients of variation of the specific elastic modulus consistent with visual delamination at sheet moisture ratio change in excess of 1.1. Hence, these experiments confirmed the finding that the ceramic surfaces outperformed steel surfaces.

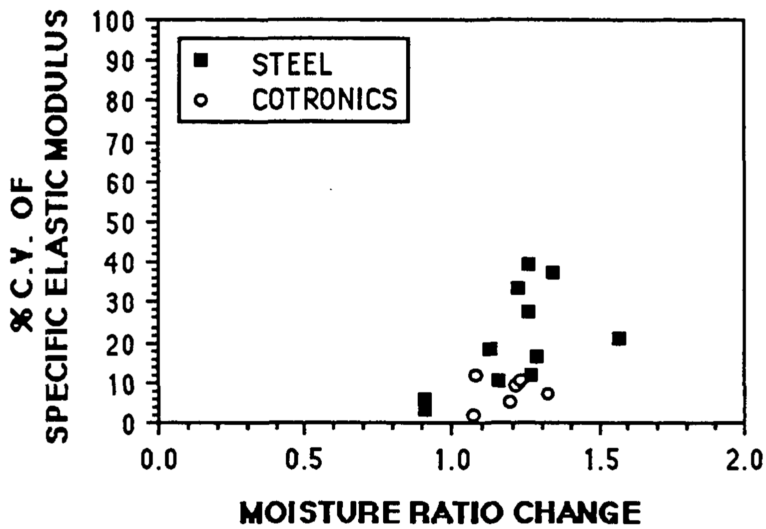

Figure 23. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for steel and Cotronics (type 914) ceramic platens where initial platen surface temperature was a variable.

Review of the figures show that the steel platen resulted in delamination at 200°C, while samples impulse dried using the ceramic platen showed no signs of delamination up to a platen temperature of 315°C. As in the previous experiments, the ceramic platen provided the same level of water removal, but without delamination.

Performance Of Plasma Sprayed Ceramics

Because of advantages of manufacture, the ceramic impulse drying roll would be fabricated by plasma spray-coating a ceramic onto a metal roll. A coating made from a mixture of 92% zirconium oxide and 8% yttrium oxide was fabricated by the Fisher-Barton Company of Watertown, Wisconsin, to have

$^{1}/_{100}$ the thermal diffusivity of steel. First, a roughened steel substrate was plasma-sprayed with a 5 mil bond coat composed of a nickel chromium mixture. A 17 mil coating of the zirconium oxide yttrium oxide mixture was then plasma-sprayed onto the bond coat at a porosity of about 5%. The platen was then diamond ground to a 40 rms smoothness. The purpose of the bond coat was to provide a thermal expansion transition between the steel and the ceramic to minimize the chance of spalling.

Thermal property measurements of an early version of the platen showed that properties similar to the Cotronics (type 914) glass ceramic would be achieved.

In previous experiments ceramic platens resulted in higher maximum water removal (without delamination) than steel platens. These results were obtained with 155 gsm linerboard impulse dried at on felts whose initial moisture was 4% or less. In a later set of experiments, with the plasma-sprayed zirconium oxide platen, the effect of basis weight and initial felt moisture was explored. In these experiments, sheets initially at room temperature (25°C) and 30% ingoing solids were impulse dried at various dwell times for the levels and factors shown in Table 1. Initial platen surface temperature was held constant at 315°C, while peak pressure was kept constant at 3.1 MPa.

TABLE 1

FACTOR	LEVEL 1	LEVEL 2	LEVEL 3
Basis Weight, gsm	155	205	
Felt Moisture, %	4	10	16
Platen Type	Steel	ZrO_2	

As in previous experiments, handsheets were made from a 56% yield Unbleached Southern Softwood Kraft furnish refined to 650 mL CSF, the wire side of the sheet was in contact with the heated platen, and the unvented bottom platen was used.

In order to eliminate potential release agent effects, these experiments were conducted without release agents. A spring loaded mechanism was also used to minimize rewet by rapidly separating the sheet from the felt as the electrohydraulic press depressurized. In addition, the felts were characterized by measuring the air permeability. The thirty felts used in these experiments had an average air permeability of 8.3 ft^3/ft^2/min with a variation of 9%.

Figure 24 shows typical pressure data for the conditions of these experiments.

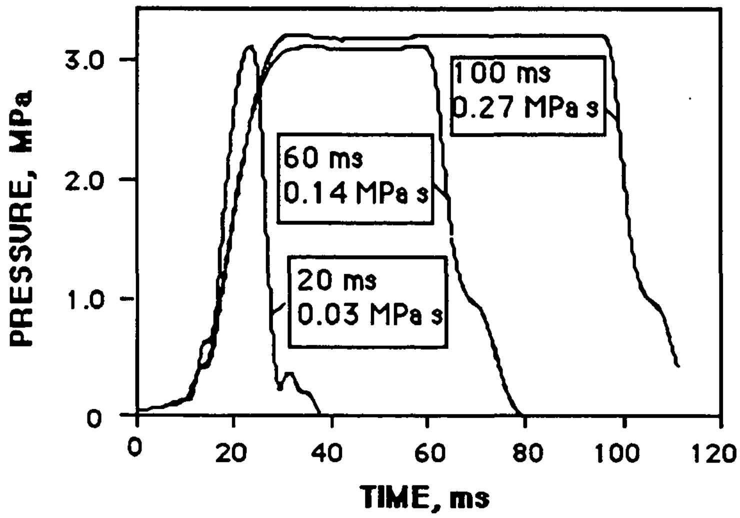

Figure 24. Typical pressure curves.

Comparison of visible delamination to the results of the ultrasound measurements showed that 96% of the samples that exceeded a CVSEM of 10% showed visible signs of delamination. Hence, a CVSEM of 10% was used as a delamination criteria.

For each experimental condition of: basis weight, percent felt moisture, and platen type, water removal and delamination data were accumulated at various dwell times. As expected, Figure 25 shows that sheet moisture ratio change increased with increasing dwell time.

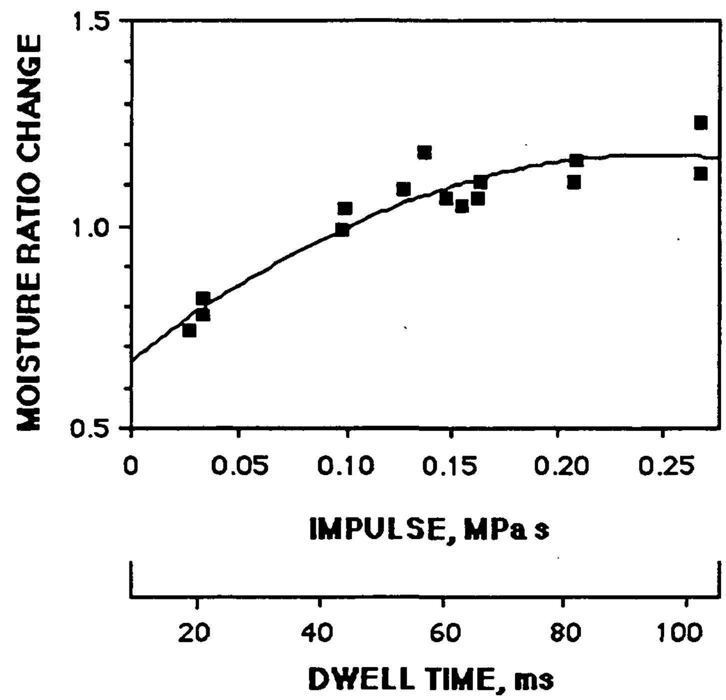

Figure 25. Moisture ratio change vs. Dwell time (Impulse) for 205 gsm linerboard impulse dried by a zirconium oxide platen at 16% initial felt moisture.

From the same data set, a performance map of delamination vs. water removal was also graphed, as shown in Figure 26.

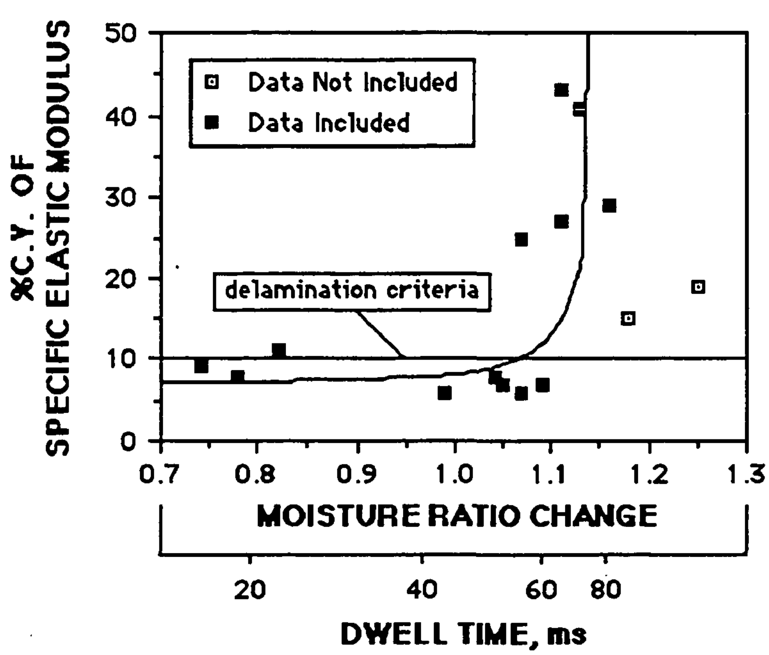

Figure 26. Coefficient of variation of specific elastic modulus vs. Moisture ratio change (Dwell time) impulse drying 205 gsm linerboard sheets with 16% moisture felts and the zirconium oxide platen.

The plot showed two regions of delamination, at about 20 ms and above 55 ms. The two boundaries, confirmed via visual observation, are termed the "first" and "second" boundaries, respectively. In order to define the "second" boundary more rigorously, the data was fit to the following form:

$$CVSEM = \frac{A}{1 - \left[\frac{MRC}{B}\right]^{n}}$$

Where the constants: A, B, and n are determined by the method of least squares. At dwell times greater than that of the "second" boundary, the coefficient of variation may drop as blisters expand to cover the entire sample. For the purpose of defining the "second" boundary, data in this category were not included. Once the constants were determined, the "second" boundary was found by finding the intersection of the fitted curve with the delamination criteria curve defined by:

$$CVSEM_{del.crit.} = 10$$

For the above example:

$$A = 7.29, \quad B = 1.16, \; n = 15.$$

And the maximum moisture change is:

$$MRC_{maximum} = 1.06$$

With a correlation coefficient of 0.45. For these experiments, the correlation coefficients varied from a low of 0.27 to a high of 0.97. Higher correlation coefficients can be achieved by increasing the number of samples per test condition, and by decreasing the variability of initial sheet moisture.

Table 2 shows the average and standard deviation for the major independent variables of the experiment. As water removal and delamination are strong functions of the initial state of the sheet, care was taken to maintain a low variability of basis weight and initial sheet moisture. Similarly, the variability of platen temperature, peak pressure, and percent felt moisture were also kept low.

TABLE 2

EXPERIMENT NUMBER.	PLATEN TEMP, °C		PEAK PRESS,PSI		INGOING SOLIDS,%		BASIS WT, GSM		FELT MOIST,%	
	AVE	STD	AVE	STD	AVE	STD	AVE	STD	AVE	STD
S/155/4	316	1	433	69	31.2	0.9	162	5	4.1	0.4
S/155/10	316	1	453	20	32.7	0.8	162	4	8.0	4.9
S/155/16	317	1	461	19	32.1	0.9	164	5	15.4	1.2
S/205/4	316	1	476	7	31.6	0.8	212	6	4.3	0.7
S/205/10	316	1	451	12	31.6	0.8	218	8	9.9	0.9
S/205/16	317	1	456	13	32.4	1.4	215	7	15.4	0.6
Z/155/4	325	6	450	8	32.7	1.4	160	6	3.8	0.5
Z/155/10	322	7	434	34	31.5	0.7	162	4	9.4	1.9
Z/155/16	323	7	443	37	31.9	0.9	164	4	16.0	2.1
Z/205/4	328	4	446	4	31.8	1.4	215	6	4.0	0.9
Z/205/10	322	7	448	19	31.5	0.6	212	6	9.1	1.6
Z/205/16	322	7	442	24	31.9	0.8	219	7	18.3	2.0

For both platen materials, a multiple regression was used to correlate moisture ratio change as a function of: impulse, basis weight, %solids in, % felt moisture. For both platens, felt moisture had no effect on water removal. The following correlations were developed:

CHROME PLATED STEEL PLATEN

$$MRC = 3.52+3.770(I)-0.002(BWT)-0.074(\%S_{in})$$

ZIRCONIUM OXIDE PLATEN

$$MRC = 3.48+2.030(I)-0.002(BWT)-0.073(\%S_{in})$$

Where:

MRC	= Moisture ratio change
I	= Impulse, MPa·s
BWT	= Sheet basis weight, gsm
$\%S_{in}$	= Ingoing sheet solids, %

It was noted that a decrease in platen thermal diffusivity reduced the water removal at a given impulse. Figures 27 through 30 show the raw data as compared to the regressions.

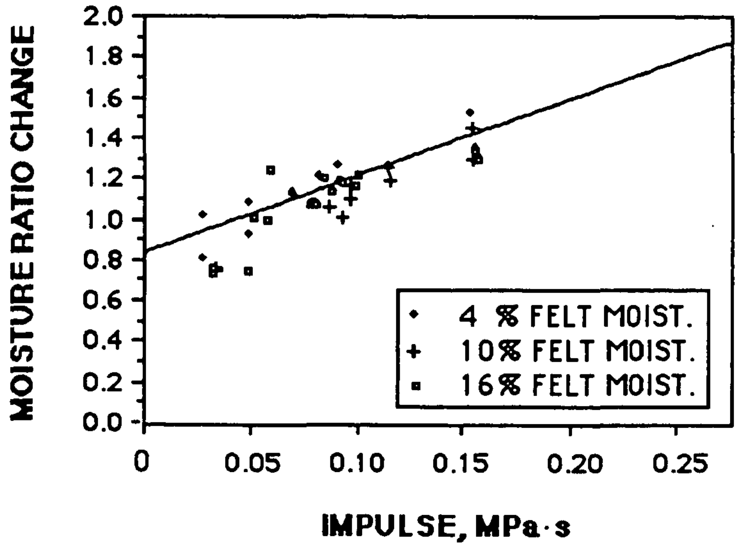

Figure 27. Moisture ratio change vs. Impulse for 155 gsm linerboard impulse dried by a steel platen at 315 °C Initial platen surface temperature at various initial felt moisture.

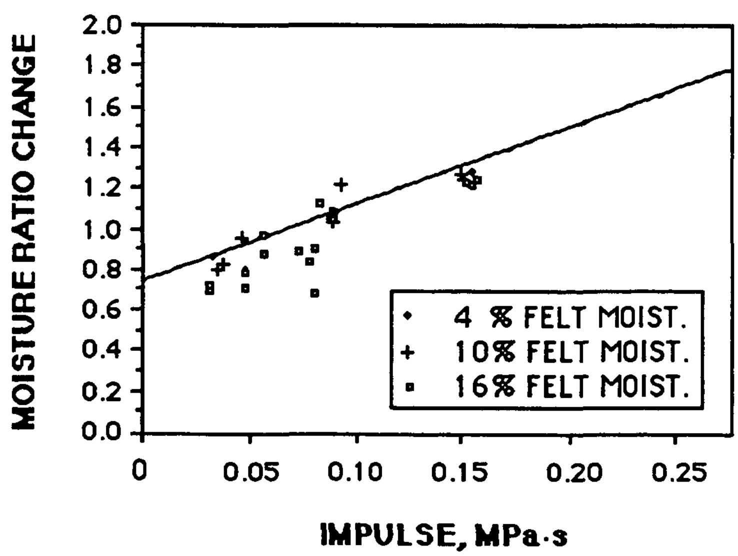

Figure 28. Moisture ratio change vs. Impulse for 205 gsm linerboard impulse dried by a steel platen at 315 °C Initial platen surface temperature at various initial felt moisture.

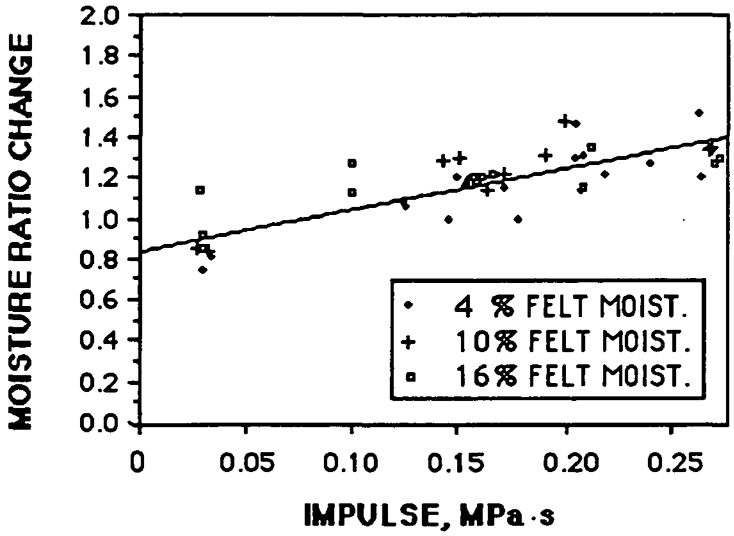

Figure 29. Moisture ratio change vs. Impulse for 155 gsm linerboard impulse dried by a zirconium oxide platen at 315 °C Initial platen surface temperature various initial felt moisture.

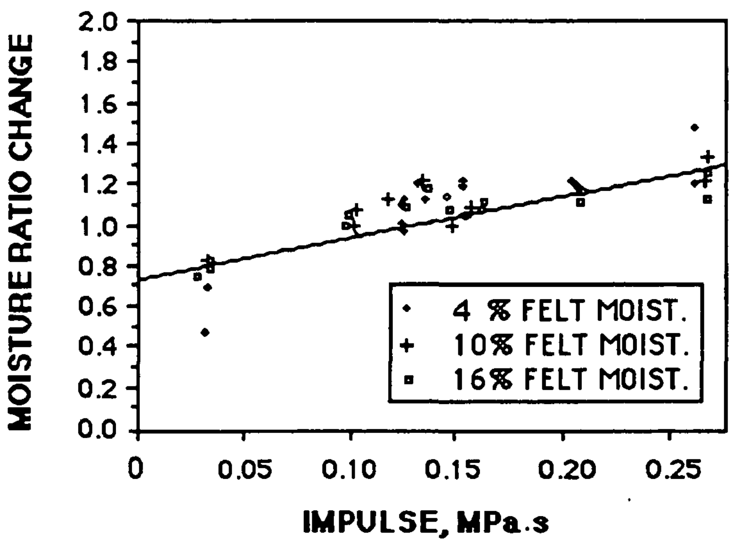

Figure 30. Moisture ratio change vs. Impulse for 205 gsm linerboard impulse dried by a zirconium oxide platen at 315 °C Initial platen surface temperature at various initial felt moisture.

Felt moisture was very important, however, with regard to delamination. Figures 31 and 32 show comparisons of the maximum moisture ratio change as a function of felt moisture for the steel and zirconium oxide platens. Optimum performance seemed to be achieved at an intermediate value of felt moisture. Under all conditions, higher maximum moisture ratio change was obtained with the zirconium oxide platen.

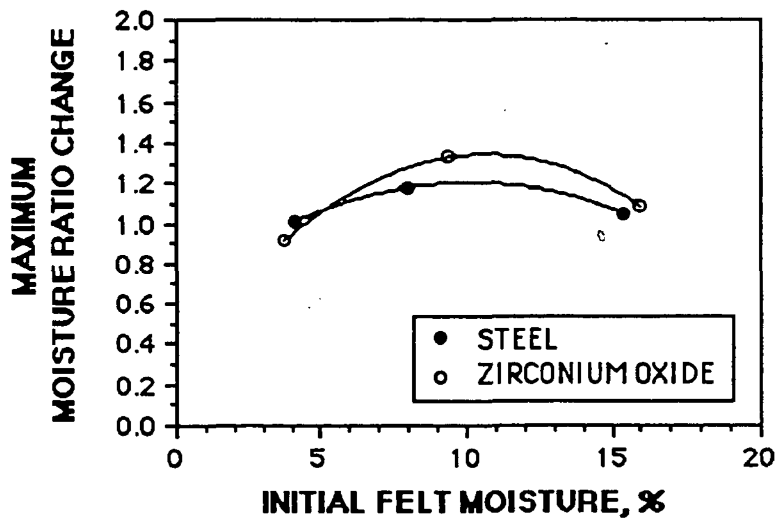

Figure 31. Maximum moisture ratio change vs. Initial felt moisture for 155 gsm linerboard impulse dried with steel and zirconium oxide platens at 315 °C Initial platen surface temperature.

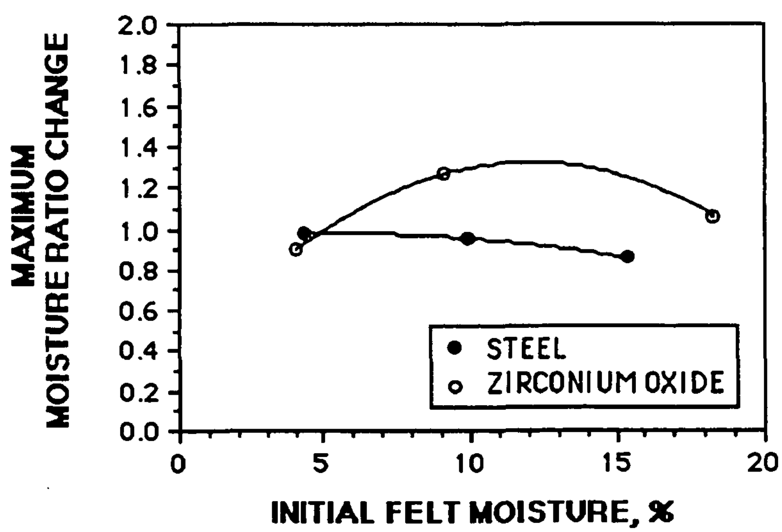

Figure 32. Maximum moisture ratio change vs. Initial felt moisture for 205 gsm linerboard impulse dried with steel and zirconium oxide platens at 315 °C Initial platen surface temperature.

It should be noted, however, that in order to achieve higher water removal, longer dwell times were required. This effect is shown in Figures 33 and 34.

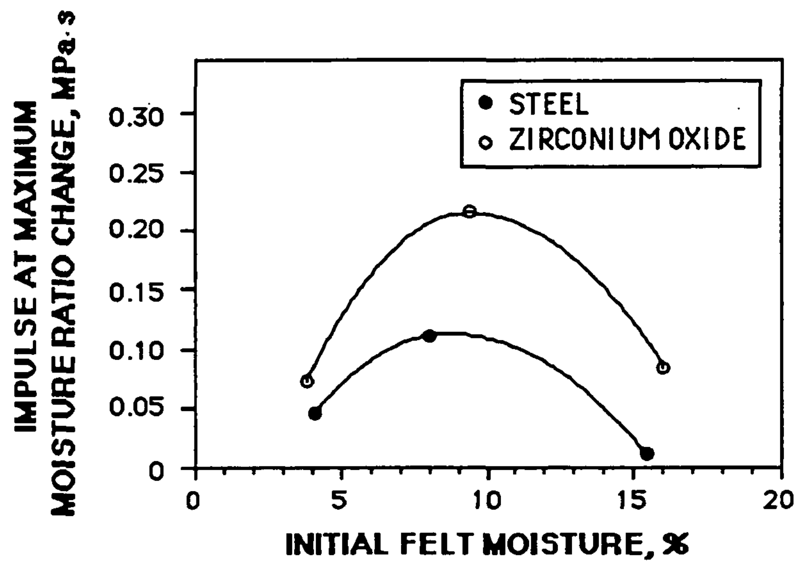

Figure 33. Impulse at maximum moisture ratio change vs. Initial felt moisture for 155 gsm linerboard impulse dried with steel and zirconium oxide platens at 315 °C Initial platen surface temperature.

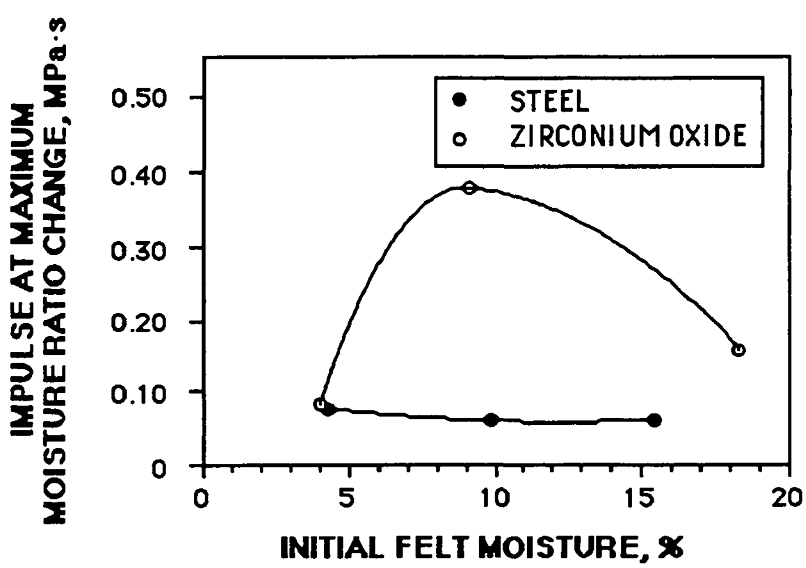

Figure 34. Impulse at maximum moisture ratio change vs. Initial felt moisture for 205 gsm linerboard impulse dried with steel and zirconium oxide platens at 315 °C Initial platen surface temperature.

The following conclusions were drawn from this set of experiments:

- Experiments without a release agent showed that the zirconium oxide surface was more susceptible to sticking than the chrome plated steel surface. In future work, a high temperature release agent should be identified that solves the sticking problem and which can be used on the pilot rolls as well as on the electrohydraulic press.

- Previous experiments with ceramic platens have examined dwell times in excess of 50 ms. The current fixed temperature experiments, at dwell times from 20 to 100 ms, demonstrate two regions of delamination. The first delamination region occurs at about 20 ms, while the dwell time where the second region begins depends on: basis weight, felt moisture and the thermal diffusivity of the platen surface.

- Water removal was a function of: platen surface material, dwell time, basis weight, and initial sheet moisture. Maximum water removal (without delamination) was a strong function of platen surface material, initial felt moisture and basis weight.

- The present fixed temperature experiments demonstrate that improved performance can be obtained with the zirconium oxide platen and that improvement results from the effect of platen surface thermal diffusivity on the dwell time where the second delamination region begins. As commercially practical dwell times are in the range of 20 to 25 ms, the first boundary is of more practical significance.

Based on current technology, extended nips can be designed with a maximum nip width of about 0.25 m (10 inches). At design linerboard production speeds of 760 mpm (2500 fpm) single nip impulse drying would be constrained to a maximum dwell time of 20 ms. In current practice, a steam box is typically used to raise the temperature of the sheet prior to pressing. Preheating has the effect of improving water removal by reducing the viscosity of the water within the sheet. Hence, to demonstrate practicality, impulse drying should show an improvement over conventional pressing, where the sheet has been preheated. With these facts in mind, additional impulse drying experiments were conducted at dwell times of 20 ms with preheating.

These short dwell time experiments were conducted to compare the performance of impulse drying to that of single felted pressing for a range of conditions including: preheat temperature, basis weight, felt moisture, and platen materials. The experiments were also designed to determine if the presence of release agents influences delamination and water removal.

The first objective was addressed by conducting a set of factorial experiments in which critical factors were systematically varied between their high and low levels. Table 3 specifies the conditions that were run. At each condition, a range of initial platen temperatures was run to allow assessment of water removal and delamination performance.

TABLE 3

FACTOR	LOW LEVEL	HIGH LEVEL
Basis Weight, gsm	155	205
Ingoing Felt Moisture, %	4	16
Ingoing Sheet Temperature,°C	25	82
Platen Type	Steel	ZrO_2

In these experiments, sheets and felts were preheated with steam to the same temperature prior to impulse drying. Ingoing solids, prior to preheating, was held constant at 32%, while peak pressure and dwell time were held constant at 3.1 MPa and 20 ms, respectively.

As in previous experiments, handsheets were made from 56% yield Unbleached Southern Softwood Kraft furnish refined to 650 mL CSF, the wire side of the sheet was in contact with the heated platen, and the unvented bottom platen was used.

In order to eliminate any release agent effects, these experiments were conducted without release agents. In addition, the felts were characterized by measuring the air permeability. The 30 felts used in these experiments had an average air permeability of 7.9 $ft^3/ft^2/min$ with a variation of 8%.

Frequently, in these experiments, the sheet was observed to stick to the heated platen as the nip opened. Due to the lengthened time of contact between stuck sheets and the heated platen, water removal data for these cases would be expected to be in error. Hence, the data was reviewed and data points discarded when sticking was observed.

To improve future experimental productivity, a series of experiments was conducted, in which the steel and zirconium oxide platens were coated with a high temperature polymeric release agent (Frekote) manufactured by the Dexter Corporation.

Steam preheating experiments were carried out to determine the gain of water by the sheet and the felt as a result of preheating. Based on presteaming conditions of 30% solids and 16% felt moisture, actual conditions after steaming and just before impulsing would be 30.1% solids and 16.8% felt moisture. As these errors were considered to be small, data of the present experiment was not corrected for this effect.

Table 4 shows the average and standard deviation for the major independent variables of these experiments.

TABLE 4

EXPERIMENT NUMBER	IMPULSE PSI SEC		PEAK PRESS, PSI		BASIS WT, GSM		INGOING SOLIDS, %		FELT MOIST, %	
	AVE	STD	AVE	STD	AVE	STD	AVE	STD	AVE	STD
S/S/155/4	4.0	0.2	445	17	159	6	32.2	1.6	3.1	1.0
S/S/205/4	3.9	0.1	436	6	210	5	32.5	3.1	3.9	0.9
Z/R/155/4	3.7	0.1	462	10	156	8	33.2	1.0	3.9	2.0
Z/S/155/4	4.3	0.6	478	66	161	6	31.9	1.0	3.8	1.5
Z/R/155/16	3.9	0.3	441	27	155	12	31.7	0.6	16.3	1.1
Z/S/155/16	4.3	0.5	483	60	161	5	31.6	0.7	18.3	2.6
Z/R/205/4	3.5	0.1	435	10	213	6	31.1	0.8	4.1	0.3
Z/S/205/4	4.0	0.5	460	46	217	9	31.9	1.0	3.7	0.8
Z/R/205/16	3.6	0.2	437	17	214	7	31.7	1.1	17.8	1.3
Z/S/205/16	3.9	0.1	456	12	199	8	32.1	1.6	16.4	1.2
Z-RA/S/205/16	3.9	0.1	449	9	195	30	29.8	1.4	14.5	1.8
S-RA/S/205/16	4.1	0.1	459	12	214	12	30.9	1.4	16.0	0.3

Analysis of the experiments performed without release agent demonstrated that sticking was a major experimental problem at short dwell times. Discarding of data from sheets that stuck to the heated platen resulted in a substantial loss of data, especially for the steel platen case. For the ceramic platen, enough data survived so that water removal could be correlated to: platen surface temperature, basis weight, felt moisture and preheat temperature. As there was some variation in ingoing solids and impulse, these variables were also included in the correlation. The following correlation, with a correlation coefficient of $R^2=0.91$, was obtained. Note that felt moisture did not affect water removal.

$$MRC = 2.408 + 0.0018(T_{ps}) + 3.626(I) + 0.0054(T_{ph}) - 0.002(BWT) - 0.064(\%S_{in})$$

Where:

MRC	= Moisture ratio change
T_{ps}	= Initial platen surface temperature, °C
I	= Impulse, MPa·s
T_{ph}	= Sheet preheat temperature, °C
BWT	= Sheet basis weight, gsm
$\%S_{in}$	= Ingoing sheet solids, %

The data used in the correlation is shown in Figures 35 and 36. Preheating the sheet significantly improved water removal at all platen temperatures.

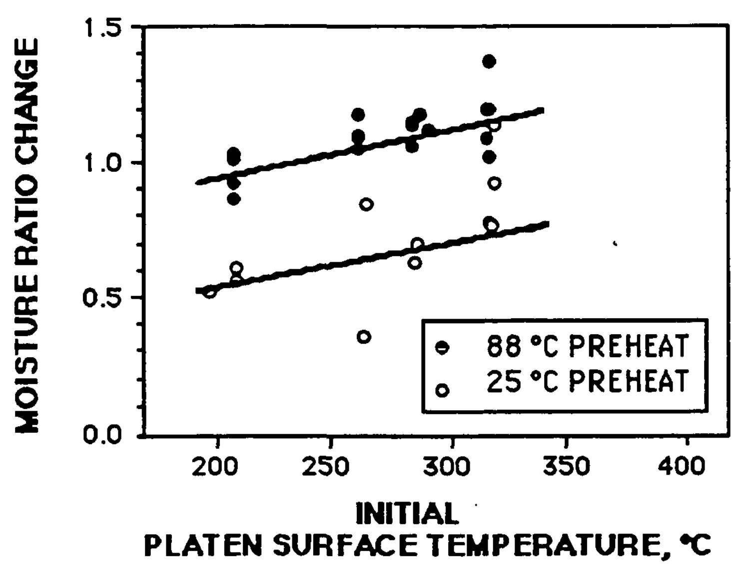

Figure 35. Moisture ratio change vs. Initial platen surface temperature for 155 gsm linerboard impulse dried by a zirconium oxide platen for 20 ms at various ingoing sheet temperature.

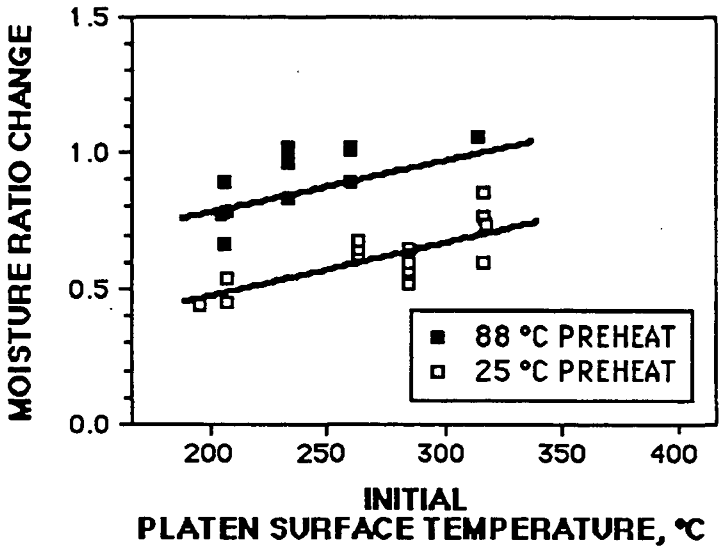

Figure 36. Moisture ratio change vs. Initial platen surface temperature for 205 gsm linerboard impulse dried by a zirconium oxide platen for 20 ms at various ingoing sheet temperature.

Performance maps of delamination vs. water removal show that above a critical temperature impulse drying results in sheet delamination. Typical performance maps for steel and zirconium oxide platens are shown in Figures 37 and 38.

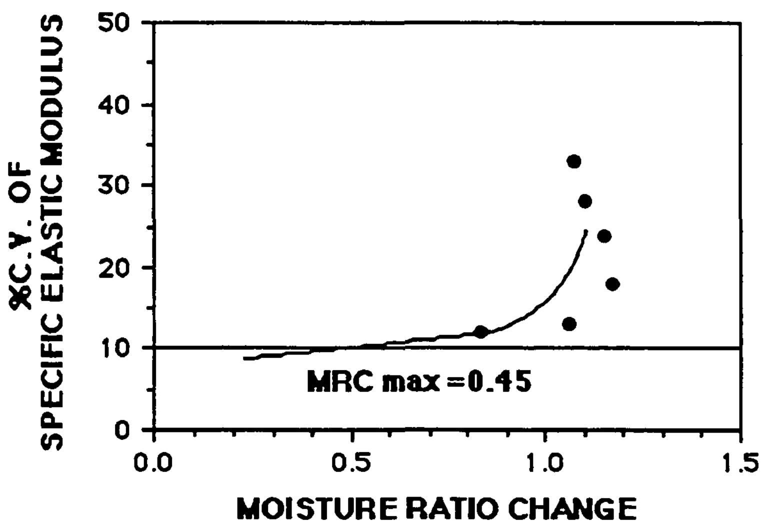

Figure 37. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for 205 gsm linerboard sheets preheated to 88 °C and impulse dried using a steel platen (without release agent) and 4% moisture felts for 20 ms.

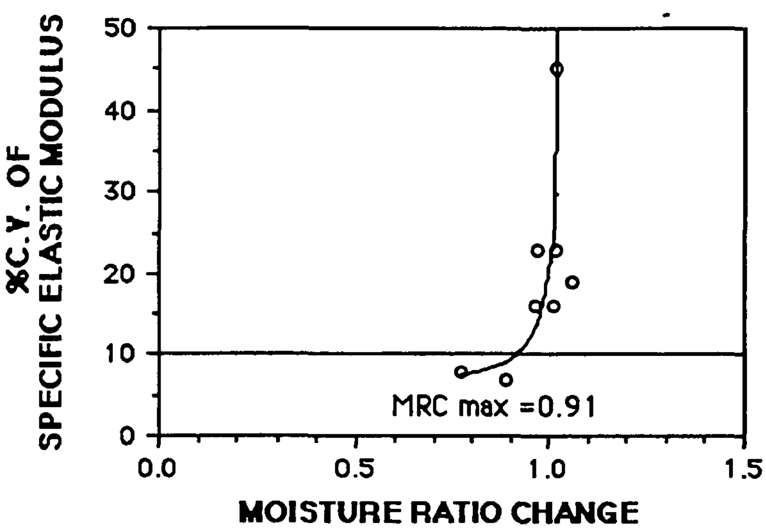

Figure 38. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for 205 gsm linerboard sheets preheated to 88 °C and impulse dried using a zirconium oxide platen (without release agent) and 4% moisture felts for 20 ms.

Use of zirconium oxide typically resulted in a substantial improvement in maximum moisture ratio change. For the conditions shown in Figures 37 and 38, maximum moisture ratio change was increased from 0.45 to 0.92. Water removal vs. initial platen surface temperature, for these cases, is shown on Figure 39. For these limited experiments, the temperature dependence of water removal was found to be similar for both platen types.

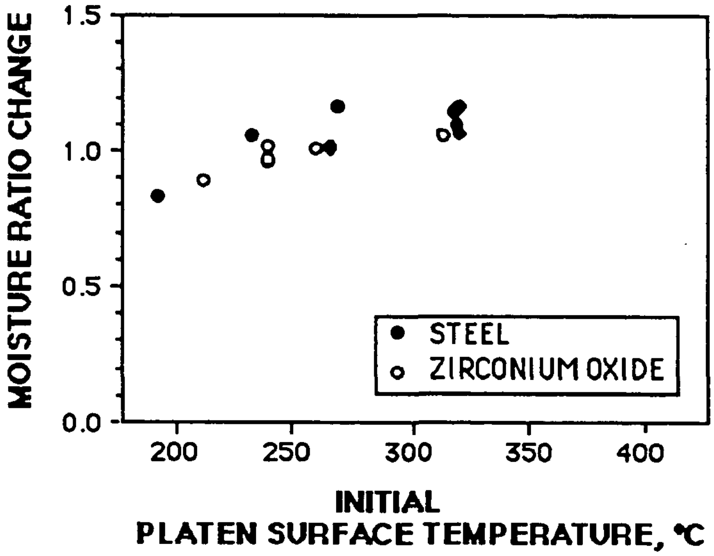

Figure 39. Moisture ratio change vs. Initial platen surface temperature for 205 gsm linerboard sheets preheated to 88 °C and impulse dried with steel and zirconium oxide platens (without release agent) and 4% moisture felts for 20 ms.

The second objective was met by conducting experiments with platens coated with a high temperature release agent. This release agent was chosen as it resists decomposition at temperature below 375°C. Figure 40 shows the effect of initial platen surface temperature on water removal for these coated platens.

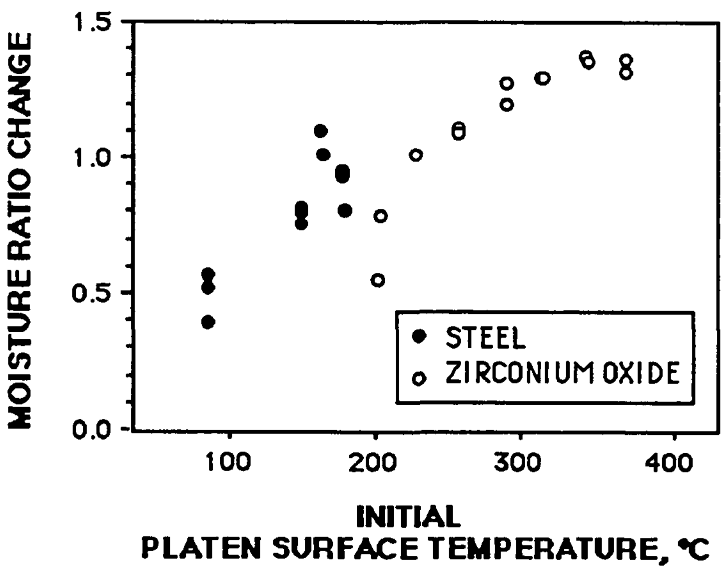

Figure 40. Moisture ratio change vs. Initial platen surface temperature for 205 gsm linerboard sheets preheated to 88 °C and impulse dried with steel and zirconium oxide platens (with Frekote release agent) and 16% moisture felts for 20 ms.

The response of water removal to initial platen surface temperature was similar to that obtained with uncoated platens. As previously observed, platen material had little effect on the temperature dependence of water removal. The figure includes data obtained at a platen temperature equal to the initial sheet temperature, which simulates conventional hot pressing. Note that without the release agent, sticking would have precluded obtaining this low temperature data. It was concluded that the release agent improves experimental productivity without affecting process performance.

Corresponding performance maps are shown in Figures 41 and 42.

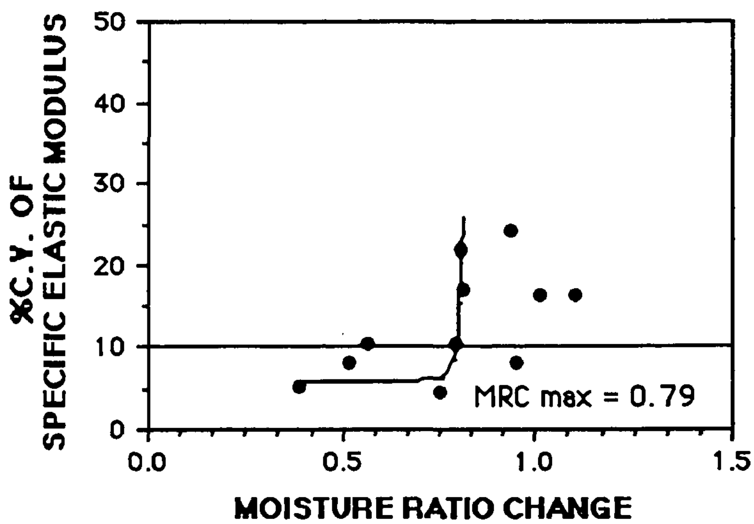

Figure 41. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for 205 gsm linerboard sheets preheated to 88 °C and impulse dried with the steel platen (with Frekote release agent) with 16% moisture felts for 20 ms.

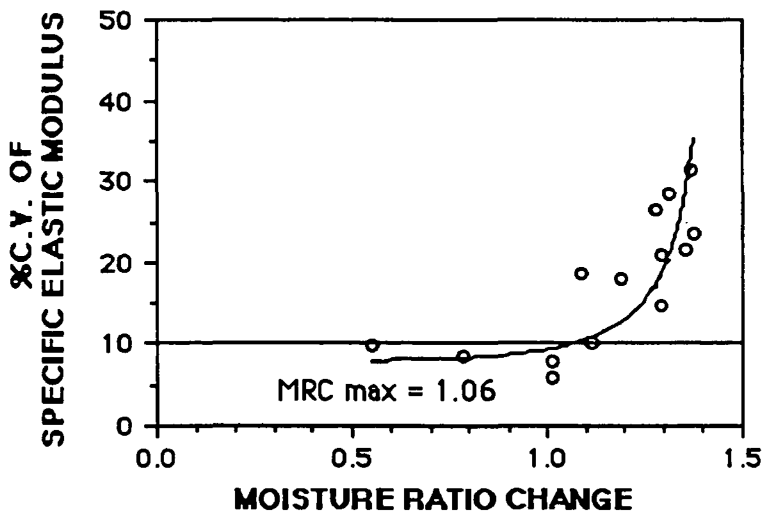

Figure 42. Coefficient of variation of specific elastic modulus vs. Moisture ratio change for 205 gsm linerboard sheets preheated to 88 °C and impulse dried with the zirconium oxide platen (with Frekote release agent) with 16% moisture felts for 20 ms.

Again, use of the zirconium oxide platen allowed a higher initial platen surface temperature without delaminating the sheet. This resulted in an improvement in maximum moisture ratio change of from 0.79 to 1.06. It should be noted that single nip hot pressing would have resulted in a moisture ratio change of 0.5. Hence, impulse drying with a zirconium oxide roll would be expected to improve water removal by 112 percent over single nip hot pressing. Likewise, the zirconium oxide roll technology is expected to improve water removal by 34% as compared to impulse drying with a steel roll.

As listed below, a number of important conclusions can be drawn from these short dwell time experiments.

- Impulse drying results in enhanced water removal compared to conventional single felted hot pressing.
- Preheating the sheet improves water removal at all platen temperatures.
- Increasing felt moisture from 4% to 16% had no effect on water removal.
- Water removal has a measurable dependence on ingoing sheet moisture. Hence, future experiments should be designed to reduce the variability of ingoing solids to improve the accuracy of maximum moisture ratio determination.

- At similar conditions of dwell time and peak pressure, the zirconium oxide platen consistently out performed the steel platen in terms of maximum moisture ratio. With the zirconium oxide platen, the process could be run at higher initial platen surface temperatures before sheet delamination occurred.

- The high temperature release agent improved experimental productivity without otherwise influencing the process. The release agent also has the benefit of sealing the pores of the zirconium oxide platen thereby eliminating the potential for absorption of water into the pores of the ceramic surface. Absorbed water would be evaporated from the roll surface after nip depressurization resulting in less efficient energy utilization.

Optimization Of Ceramic Roll Surfaces

The experimental results of the previous sections of this report suggest that by reducing the thermal diffusivity of the heated surface of impulse drying roll, significant improvements in delamination free water removal can be achieved. Hence, it is of interest to investigate ways of further reducing the thermal properties of these ceramic surfaces.

Plasma-sprayed ceramic surfaces can be made with porosity from 5% to about 30%. The properties of the surface will be a function of the properties of the component ceramics and the porosity of the surface. The following equations define the key properties of interest.

$$\rho = \rho_{SOLID} [1-V]$$

$$C_P = C_{P\ SOLID}$$

$$\lambda = \lambda_{SOLID}\left[\frac{1}{1+C'V}\right]$$

Where the variables are defined as:

V = Pore volume fraction

ρ = Density, g/m^3

C_p = Specific heat, Ws/g^oK

λ = Thermal conductivity, W/m^oK

C' = 14, Empirical constant (see Reference 14)

From these equations, the thermal diffusivity of the coating can be calculated as:

$$\alpha = \frac{\lambda}{\rho\ C_p} = \left[\frac{\lambda}{\rho\, C_p}\right]_{SOLID} \left[\frac{1}{\{1+C'V\}\{1-V\}}\right]$$

where the thermal diffusivity is given in units of m^2/s.

The following data for solid yttrium stabilized zirconium oxide was used in subsequent calculations:

$$\rho_{SOLID} = 4.05 \times 10^{+6}\ g/m^3$$

$$C_{PSOLID} = 0.5\ Ws/g^oK$$

$$\lambda_{SOLID} = 2.25\ W/m^oK$$

Hence, the influence of porosity on thermal diffusivity can be calculated as shown in Figure 43.

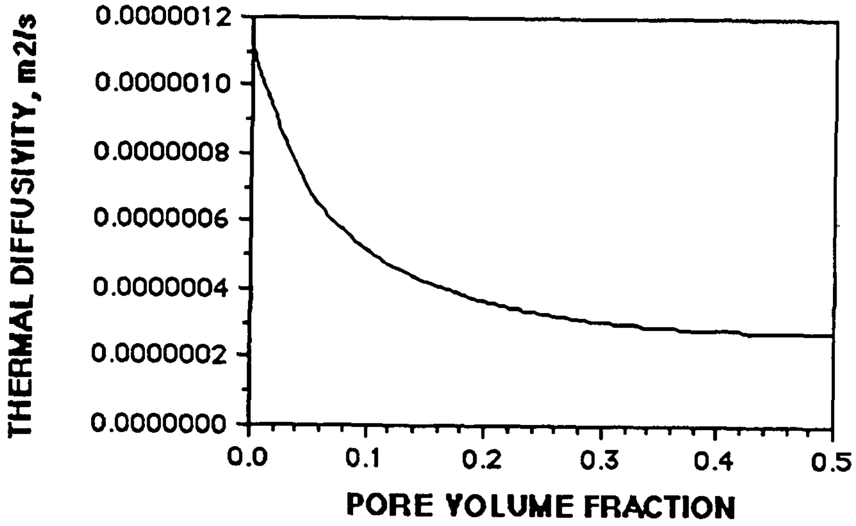

Figure 43. Thermal diffusivity vs. Pore volume fraction for plasma sprayed yttrium stabilized zirconium oxide as predicted from Reference 14.

The actual heat and mass transfer in the nip is quite complicated. However, by assuming conduction dominant heat transfer from the platen to the paper, the heat flux from the platen relative to the heat flux from a steel platen at the same platen temperature can be calculated using equations developed by Carslaw and Jaeger (15) as:

$$\frac{Q}{Q_{STEEL}} = \frac{K}{K_{STEEL}} \left[\frac{K_{STEEL}+K_{PAPER}}{K+K_{PAPER}} \right]$$

Where K is defined as;

$$K = \frac{\lambda}{\sqrt{\alpha}}$$

Assuming the following values for steel and for paper,

$\lambda_{STEEL} = 57.5\ W/m°K$ $\qquad$ $\lambda_{PAPER} = 0.4\ W/m°K$

$\alpha_{STEEL} = 1.3 \times 10^{-5}\ m^2/s$ $\qquad$ $\alpha_{STEEL} = 1.3 \times 10^{-7}\ m^2/s$

The heat flux of the ceramic platens relative to a steel platen can be determined as a function of the porosity of the coating as shown in Figure 44.

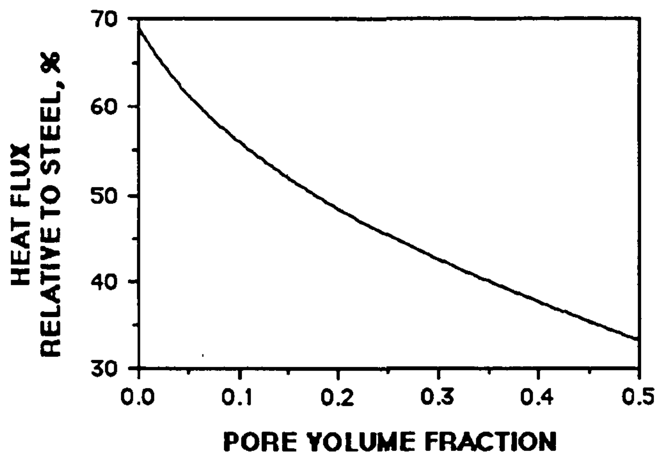

Figure 44. Predicted heat flux relative to steel vs. Pore volume fraction for zirconium oxide platens.

Hence, according to this simplified model, a ceramic coating of 5% porosity would be expected to result in a 40% lower heat flux than a steel platen operating at the same temperature. By increasing the porosity to 30%, heat flux should be 60% lower than for steel. This concept will be used to achieve improved performance on the electrohydraulic press and will be used to design a ceramic coated roll for the pilot dryer.

PLANS FOR THE COMING YEAR

Institute research has focused on developing an understanding of the phenomena of delamination in terms of its cause and remediation. As presented in this report, excellent progress has been made in identifying ceramic roll surfaces which show promise for minimizing the potential for delamination.

It is believed that these ceramic roll surfaces function by maintaining a high heat flux at the beginning of the process while reducing the heat flux toward the end of the process. Reduced heat flux leads to lower average sheet temperatures, less violent flash evaporation, and elimination of sheet delamination.

In the coming year, DOE sponsored research will focus on: developing an understanding of the mechanism of operation of ceramic surfaces for delamination control, demonstrating the technology on the pilot scale for a range of furnishes and grades, and exploring various concepts to further improve the performance of impulse drying surfaces.

In particular, the following tasks will be accomplished:

1. Using the electrohydraulic press, a master drying curve will be developed to show the influence of operating conditions such as: ingoing sheet moisture, preheat temperature, impulse and initial platen temperature on the impulse drying performance of plasma sprayed zirconium oxide surfaces for 205 gsm linerboard. In addition, heat flux measurements during the impulse drying process will be used to determine the mechanism of operation of the ceramic surfaces and their energy efficiency.

2. An existing steel pilot roll will be coated with an optimized ceramic coating for evaluation on the infrared heated nip of the pilot dryer. Maximum moisture ratio change will be determined for the ceramic coated roll and contrasted to the performance of a steel roll for a typical linerboard furnish.

3. The range of applicability for various grades, furnishes, and process conditions will be investigated on the pilot press.

4. Various concepts, to improve the performance of impulse drying roll surfaces will be explored on the electrohydraulic press impulse drying simulator.

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