Using thermal barrier coatings to eliminate overdried paper edges

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ABSTRACT

A new technique solves the problem of overdried paper edges, which are common on many paper machines and are usually caused by the overheated ends of dryer cans. A thermal barrier coating is applied on the outside surfaces of some of the drying cylinders by a plasma spray process. In laboratory trials, this ceramic coating reduced the surface temperature of a cast-iron coupon by 6°C for every 100 µm of coating thickness. In commercial applications, the coating, which is composed of zirconia, has proven effective in preventing the paper edges from overdrying. The coating can be applied during a scheduled shutdown, it is durable, and it requires no maintenance.

Application:

The thermal barrier coating permanently eliminates overdried edges, improving product quality, extending trim widths, and precluding problems that could otherwise arise in calendering and printing.

DESPITE THE MANY IMPROVEMENTS made to drying sections over the years, the tendency to overdry the edges of paper is a problem that remains to be solved. The problem of overdried edges affects almost all grades of paper. Overdried edges can lead to edge tears and snap-offs and can contribute to problems with dimensional stability, such as cockle, curl, and grainy edges. These defects can cause problems during sizing, coating, calendering, winding, and converting operations, as well as in the press rooms.

Overdried edges are commonly caused by overheated ends of drying cylinders. Cool, wet paper passing over steam-heated cylinders cools the cylinder surfaces, but the paper does not contact the cylinder ends. The temperature at the edge of the cylinder can be much higher than temperatures under the wet sheet. From the overheated edges, the heat flows towards the paper, overdrying the paper for several inches.

Numerous ways to overcome to the problem have been proposed, patented, and used (*1–3*). The most commonly adopted solutions are those that mask the problem or correct it after it has occurred. Methods include the modification of the basis weight or the moisture profile coming out of the forming and pressing sections and the use of dryer bars, internal insulation, and remoisturizing showers.

In this report, we describe a new technique that eliminates overdried edges and is easy to apply, inspect, and maintain. In this approach, the solution is designed to prevent overdried paper edges from forming rather than to camouflage a deficient moisture profile or correct it after it has occurred.

A NEW APPROACH

A new solution to the problem of overdried edges has been developed jointly by Paprican and ProTeC, a company that specializes in plasma spray coating processes. In this approach, a thermal barrier coating is applied in a very thin layer on the outside surface of the drying cylinder where overheating occurs. The coating is applied such that its thickness tapers down to nothing at the inside edge to eliminate the problem of a step change in thickness. The coating insulates the overheated edge of the cylinder and reduces the amount of heat transferred in the coated area.

Thermal barrier coatings of this kind have been used in the aerospace industry for over twenty years to prevent engine components from overheating. In such applications, the temperature excursions are far more extreme than those in paper drying sections.

Theory

In paper machine drying cylinders, steam condenses on the inner surface of the cylinder. Heat is transferred by conduction through the cylinder wall to the paper. The basic formula that describes this transfer is:

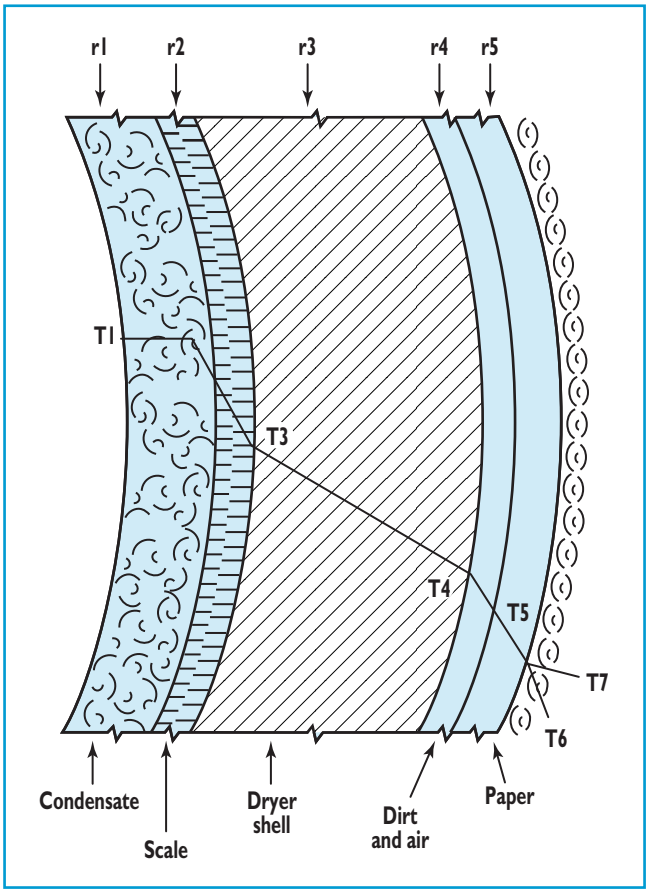
$$Q = U \times A \times (T_s - T_p) \qquad (1)$$

where

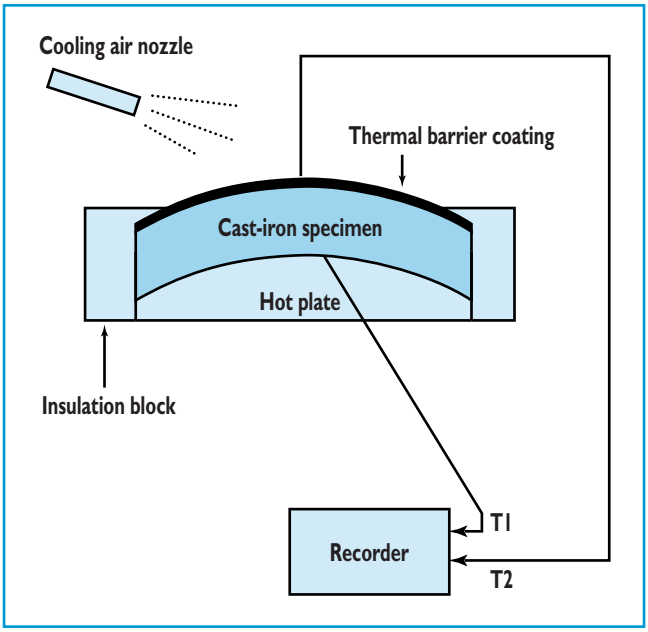
Q = rate of heat flow from steam to the paper, kJ/h
U = overall heat transfer coefficient, kJ/h/m^2 per °C
A = dryer surface area in contact with the paper, m^2
T_s = steam temperature, °C
T_p = paper temperature, °C.

The overall heat transfer coefficient is low when there are large resistances to heat transfer. **Figure 1** illustrates the principal resistances to heat transfer in the cylinder drying of paper. These resistances are:

- Condensate layer
- Scale inside the dryer
- Dryer shell metal
- Dirt or fiber buildup on the outside surface



1. Heat transfer through the dryer cylinder, where the numbered r labels indicate different stages of resistance and the numbered T positions indicate specific points as the temperature decreases.

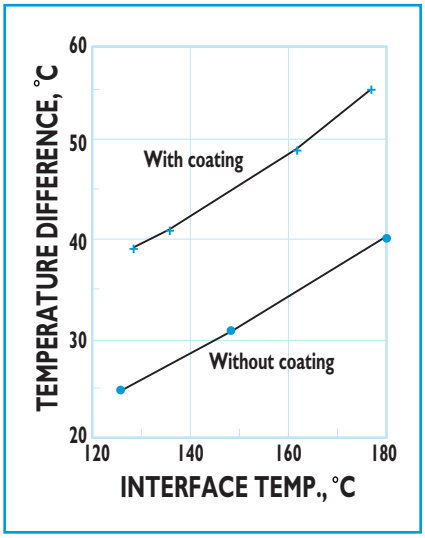


2. In the experimental setup, the hot plate heats the cast-iron coupon, and the temperatures at the bottom and top of the sample are recorded before and after the thermal barrier coating is applied.

• Thin air film between the shell and the sheet.

Drying rates can be increased by eliminating any of these resistances. For example, the thickness of the condensate layer can be minimized through efficient siphon operation. The outside surface of the cylinders can be kept as clean as possible to reduce the film of air and dirt, which acts as an effective insulating layer.

Conversely, additional resistances to heat transfer decrease the drying rate. An insulating thermal barrier coating on the surface of the dryer will add resistance to heat transfer and slow the drying rate. If the coating is applied at the appropriate locations on enough cylinders, the high drying rate that overdries the paper edges can be eliminated.



3. Temperature difference between hot and cold cast-iron surfaces vs. the temperature at the interface between the cast-iron coupon and the hot plate.

Experimental procedures

The concept was first tested and developed using the small bench-scale experimental setup shown in **Fig. 2**.

For simulating the heat transfer in steam-heated cylinders, a 1.25-in.-thick sample of cast iron (Grade 35) was placed over a hot plate. Thermocouples were attached to the top and bottom surfaces of the sample. The temperature of the hot plate could be adjusted to change the bottom surface temperature of the cast-iron coupon. As a result, the sample's temperature could be varied over the range representative of the inside of a typical drying cylinder (which is 125–180°C for steam pressures in the range of 20–130 psig).

To regulate the heat flux from the hot plate, compressed air blown over the top side of the specimen cooled the cast iron. This cooling simulates the thermal sink created as wet paper passes over a dryer cylinder. The temperatures of the inside and outside surfaces of a typical drying cylinder are different by some 20–40°C.

Some cast-iron specimens were then coated by a thermal spray process. Various insulating materials were tested at different spraying parameters. The effectiveness of the insulating material is a complex function of its thickness,

porosity, and thermal conductivity. The temperature drops between the hot and cold faces were compared for coated and uncoated samples at constant heat flux and constant cast-iron surface temperature at the hot plate.

Based on the bench-scale test results and other concerns, the thermal barrier coating selected was partially stabilized zirconia (zirconium oxide, ZrO_2). **Figure 3** shows that this material applied at a thickness of around 300 μm gives a temperature drop of 35–55°C for a hot face temperature ranging from 120°C to 180°C.

At the same hot surface temperature and the same cooling conditions, the coated surface is 15°C cooler than the uncoated surface. Coatings of various thicknesses were applied to cast-iron specimens, and the reduction in surface temperature was found to be approximately 6°C for every 100 μm of zirconia thickness. For practical reasons, the coating thickness is limited to around 300 μm.

Coating characteristics

Zirconia is white, it has good wear resistance, and it has a low thermal conductivity (approximately 1 W/m per C°, as opposed to 47 W/m per C° for cast iron). It is the preferred material for thermal barrier coatings for gas turbines in the aerospace industry. The ZrO_2 is stabilized with 7% yttria (yttrium oxide, Y_2O_3).

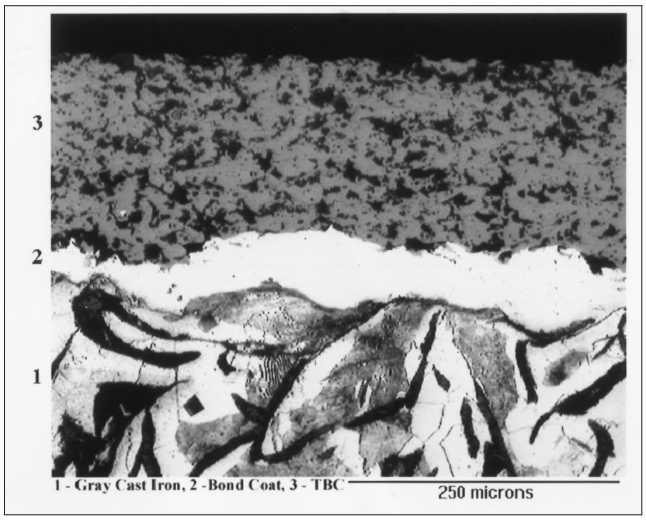
Before the thermal barrier coating is applied, the cast iron is coated with a bond coat at a thickness of about 60 μm. The coating microstructure was studied with an optical microscope. **Figure 4** shows a cross section of the duplex thermal barrier coating.

Applying the coating at a mill

The first question is, which drying cylinders are to be coated? This decision is based on surveys of the dryer section, examinations of sheet profiles, insight gained from discussions with mill personnel, and, in some cases, computer simulations. This information also helps determine the width of the coating on each drying cylinder to be treated. Typically, from five to ten cylinders will be treated, and the width of the coating will be 6–12 in.

The coating is applied during a scheduled shutdown. It takes one hour to treat each cylinder end. The dryer section has to be operated at crawl speed, and the drying fabrics must be removed or pushed out of the way. The drying cylinders are lightly sandblasted (**Fig. 5**), but the sandblasting equipment has a vacuum system that recuperates the grit.

After the cylinders are cleaned with a solvent, the bond coat and the ceramic thermal barrier coating are applied with a portable plasma-spraying system (**Fig. 6**). The coating is applied widely enough for its outside edge to exceed the width of the paper run by 1–2 in. The coating is lightly sanded by hand after it has been affixed.



4. Microstructure of the thermal barrier coating (A) with the bond coat (B) on top of the gray cast iron (C).



5. A drying cylinder is sandblasted in preparation for the ceramic coating.

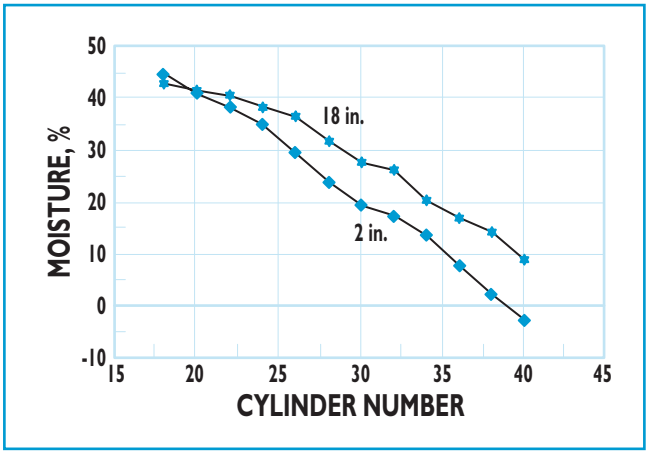


6. The portable plasma spray torch applies ceramic coating to the cylinder.

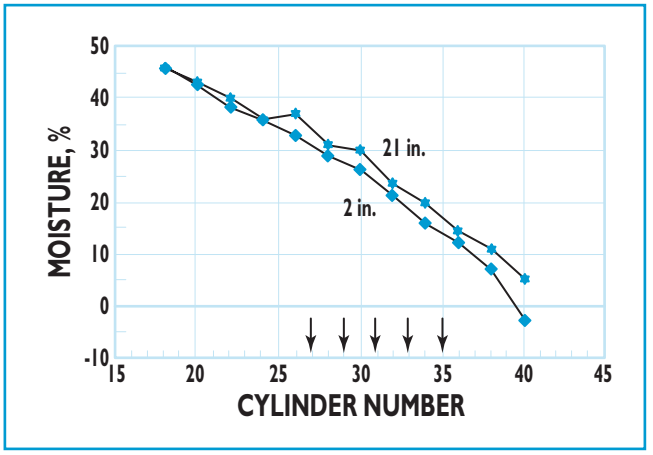


7. The drying cylinder has just been coated with ceramic at the edges. The excess powder has not yet been dusted off.

A coated cylinder is shown in **Fig. 7**. The coating is permanent and will not detach or wear out, but it can be removed by sanding or grinding if necessary. Doctor blades should not be used on the coating, because they will wear out against the ceramic surface.



8. This profile of sheet moisture was prepared before the thermal barrier coating was applied. The two curves are based on measurements made at 2 in. and 18 in. from the edge of the sheet (44.7 g/m², 1138 m/min).

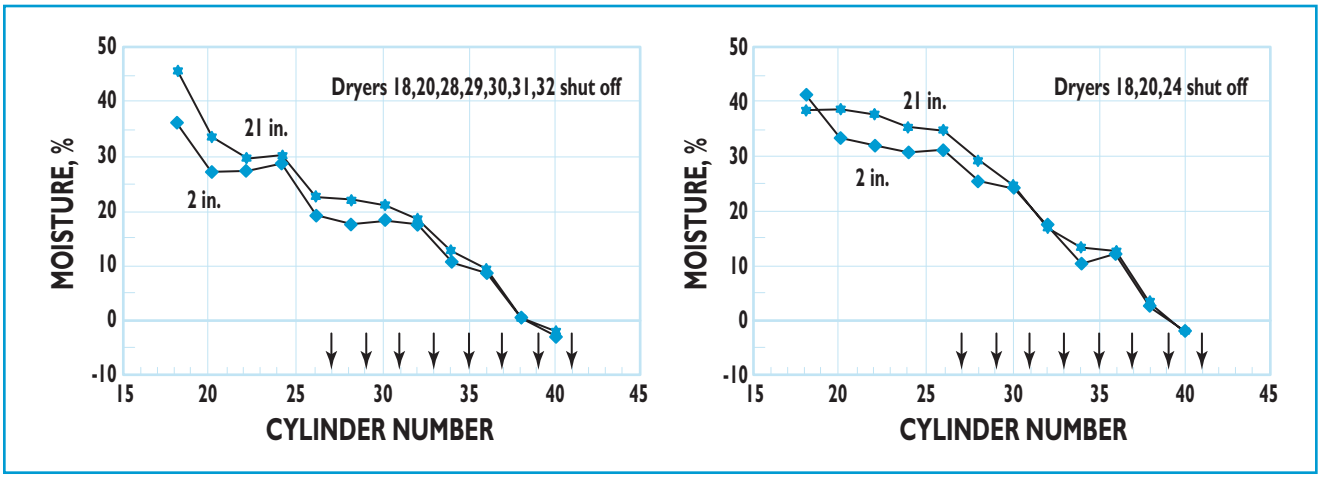


9. Five cylinders were treated, and the moisture was measured again, this time at 2 in. and 21 in. from the edge of the sheet. Arrows indicate which cylinders were coated. (48.4 g/m², 1153 m/min)

RESULTS FROM COMMERCIAL APPLICATIONS

The thermal barrier coating has been applied at three Canadian mills, which manufacture newsprint or groundwood specialty papers. No operating problems related to the coatings have been experienced at any of these mills. The first application was done almost three years ago, and the thermal barrier coatings remain intact and clean. The results from the most recent installation are presented here.

In regard to this third installation, the paper machine makes newsprint and has a dryer section with 43 drying cylinders. A moisture profile was determined before any thermal barrier coating was applied. Moisture was measured at 2 in. and 18 in. from the edge of the sheet. The measurements were made with a handheld gamma backscatter gauge.



10. Three more cylinders were treated, bringing the total number of cylinders treated to eight. Sheet moisture was measured at 2 in. and 21 in. from the edge for 43-g/m² newsprint (left) and 48.8-g/m² newsprint (right) (1124 m/min and 1126 m/min, respectively).

Figure 8 shows this moisture profile for the dryer section before treatment. As the sheet moves through the dryer section, the difference in moisture content becomes larger between the two positions 16 in. apart. As a result, the sheet has overdried edges as it exits the dryer.

Figure 9 shows the moisture profiles at 2 in. and 21 in. from the edge after five drying cylinders have been treated with thermal barrier coating. There is much less difference between the two curves. The edge does begin to overdry, however, in the last drying section where the cylinders are not treated.

After three additional cylinders have been coated, the results are nearly perfect. **Figure 10** shows the moisture profiles at 2 in. and at 21 in. in for two different basis weights. For both products, the moisture content at 2 in. closely matches the moisture content at 21 in. as the paper exits the dryer. Paper from this machine no longer has overdried edges.

ADVANTAGES AND BENEFITS

The thermal barrier coating can be applied without opening the dryer can manholes, as some other solutions require. The coating can be monitored visually at all times. There is no risk of detachment under normal conditions. The coating provides a permanent solution, yet it can be removed or modified if necessary.

This new technique has no moving parts or control system, it requires no water or steam supply, and it takes no maintenance. Rather than masking the problem or correcting it after it occurs, this solution actually prevents the formation of overdried edges. The basis weight and moisture profile coming out of the press section no longer have to be adjusted at the edges to compensate for overdrying. The part of the showering required to add moisture to the web at the edges can be eliminated.

It has been estimated that the elimination of overdried edges can result in annual benefits totaling up to $1,000,000 per year based on the savings associated with the reduced number of breaks, the increased trim width, and other factors. The cost of coating the cylinder ends can be recouped in a couple of months. **TJ**

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Received for review May 28, 1998.
Accepted Sept. 21, 1998.

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THE PLASMA SPRAYING PROCESS

Plasma is an ionized gas that can be generated by passing electrical current between two electrodes. In the plasma spraying process, a nontransferred torch (i.e., a torch that houses both the anode and the cathode) is used to generate a jet of plasma. The plasma temperature can exceed 10,000 K, and the jet has a velocity of roughly 100–200 m/s. The plasma-forming gas is usually pure argon or a mixture of argon and hydrogen. The arc current, the distance between the torch and the surface being coated, and the composition of the plasma-forming gas are the most important parameters used to control the quality of the coating.

The application of the coating begins when metered quantities of a powder are introduced into the plasma jet. The jet entrains the particles, melts them, and accelerates the molten droplets toward the surface. When the molten droplets hit the surface, they splat and freeze rapidly because the surface remains relatively cold throughout the process. The coating is formed as one splat freezes on top of another.

Both porous and dense coatings can be formed by plasma spraying. The process is extremely versatile. Almost any material that has a liquid phase, including all metals and most ceramics, can be plasma sprayed into a coating. The composition of the final coating is the same as that of the powder.