

Strategies for economical alternatives for wax replacement in packaging

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ABSTRACT: We report studies of the incorporation or blending of various pigments for waterproofing linerboard, along with changes in relevant physical properties. We observed the impregnation of polymer/pigment blends to increase strength properties substantially, as explained by the increase of modulus in a composite matrix. We also made observations of surface flame treatment and curtain coating, which can lower the coating basis weight required to attain a required level of water resistance. We also looked at the potential for electrospinning of nanofiber membranes to supplant conventional coating technologies.

Application: These results can be used for cost-effective process optimization strategies for the production of water-resistant linerboard.

BACKGROUND

Wax-coated paperboard boxes are used extensively for the transport of produce and food products, primarily from point of production to market. Because of the difficulty of recycling, many waxed containers have been replaced by plastic packaging, threatening a major volume of containerboard production that approaches as much as 50% at some box plants. Grocery retail chains now demand the total elimination of waxed containers that are non-recyclable, thus forcing the corrugated container industry to develop economically viable alternatives.

Moreover, the recently decreased supply of OCC in North America, due to exports of OCC to Asia, drives the need for a larger supply of recyclable OCC. The replacement of waxed containers by recyclable alternative water-resistant containers could potentially add an additional 4 millions tons per year of OCC to the market. Aqueous polymeric alternatives for wax coatings have existed commercially for decades, but have had limited acceptance and application in the industry, primarily

because of their relative cost compared to wax.

We targeted wax-alternative investigations at IPST to provide an objective body of evidence about their introduction to the industry. Specifically, the goal was to evaluate the comparative performance of wax-alternative technologies compared to curtain-coated waxed boxes. The results from a previously reported initial study [1] demonstrated the capabilities of newly available wax-alternative technology and the challenges to be overcome with it.

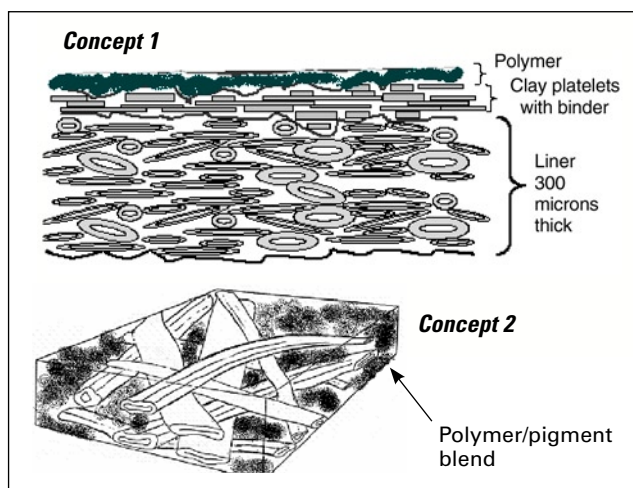
More recently, various scenarios using clay pigments to reduce costs of polymer coatings were explored and reported [2]. The characteristics of kaolin clay were exploited to form either a base coating followed by a polymer top coat or to incorporate the clay in a base coating to replace more expensive polymer.

SUBSTITUTING PIGMENT FOR WAX

The use of pigment as an economical substitute for petroleum derived polymer or wax follows two concepts illustrated in **Fig. 1**.

In Concept 1 (top), a standard clay-based coating is applied to resist the penetration of the aqueous polymer coating. Concept 1 investigations have been reported previously [2]. Concept 2 proposes to achieve waterproofing of the fibers through replacement of the air-void volume with a suitable polymer, using an impregnation process.

In summary, using a clay base coat on linerboard will produce two simultaneous economic dividends: 1) the amount of polymer in the top coat for a targeted water resistance can be reduced substantially and 2) the combination of a clay base coat with a polymer top coat increases the compression strength of linerboard, allowing a 20% decrease in the basis weight. This latter observation is explained by the modulus of clay being higher than those of paper or polymer. The laboratory study showed that the combination of a clay coating with a polymer top coat results in water resistance comparable to a curtain-coat wax coating and is more economical in terms of material costs.



1. Schematic of the 2 concepts of using polymer pigment combinations for waterproofing or enhancing the strength of paper.

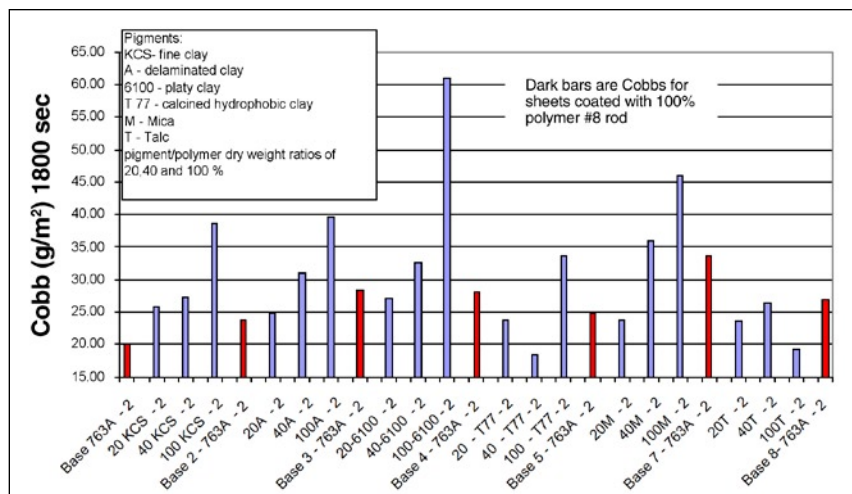
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Bench-top draw-down coating observations using blends

Our investigations included bench top experiments using an automated wire rod draw-down coater and various pigment polymer blends. We obtained various pigments in dry form from commercial suppliers: experimental platy clay, XP6100; a standard delaminated clay, "Astraplate;" a fine No. 2 clay, KCS®; a hydrophobic calcined kaolin, Translink® 77; delaminated mica, Alsibronz® 39; and a delaminated talc. These pigments were blended in various weight ratios ranging from 1/5:1 to 1:1 with a commercial aqueous acrylic dispersion, 763-A, intended specifically for corrugated wax replacement.

We blended pigments with high shear mixing to form well-suspended dispersions of pigments apparently free of entrained air, and applied with an automated rod drawdown coater followed by IR heat lamp drying. The coatings were all applied using a #8 wire rod and an Industry Tech automated drawdown coater with a commercial 205 g/m² kraft/OCC linerboard resting on a resilient elastomeric pad to avoid pooling of coating. This arrangement results in a coating that typically has a dry basis weight of 12 g/m². Before each series of pigmented blended colors, a measurement for comparison was made, using an unblended polymer coating, given the variability of the base sheet and the laboratory drawdown coating process. The water resistance results summarized in **Fig. 2** indicate that introduction of kaolin clay as a blend into a polymer aqueous dispersion generally reduce its water resistance.

The best water-resistance values for polymer/pigment blends shown in Fig. 2 are obtained when talc "T" or Translink® 77 ("T77") is blended with the polymer. The effect of blending talc with the polymer increases the 30-minute Cobb water resistance of the polymer from 30 to 10 g/m² when the talc is blended in equal weight ratio with polymer [2]. Water resistance is improved (lower Cobb value) and the cost of coating is substantially reduced when a com-



2. Water resistance measured by Cobb (TAPPI method T - 441) 30 minute water exposure using coatings of aqueous polymer (red bars) and various polymer/pigment blends.

paratively inexpensive pigment displaces the polymer. In this case, replacement of the polymer with hydrophobic pigment in a coating formulation lowers the cost of the coating by about 60%.

Polymer/pigment impregnation

Concept 2, shown in Fig. 1, is inspired by the observation that the CD tensile stiffness of linerboard is increased by 50% when the linerboard is impregnated with wax, easily achieved simply by dipping linerboard in molten wax or using a wax cascading process on board for containers meant to transport water-chilled produce. Replacing molten wax with an aqueous polymer dispersion that does not easily penetrate into the sheet, requires a pressure gradient to drive it into the sheet structure. Penetration of coating into a sheet matrix is proportional to the pressure gradient required to overcome the resistance to flow presented by the matrix tortuosity or porosity, and is formulated by D'Arcy's law. Accordingly, impregnation trials were performed at the pilot plant in Western Michigan University, Kalamazoo, on a Vits Impregnator.

Trials initially used a 220 g/m² kraft linerboard, followed by a 127 g/m² I green liquor process medium. The effects of pigment inclusion were investigated using impregnation formulations that were various prepared slurries of

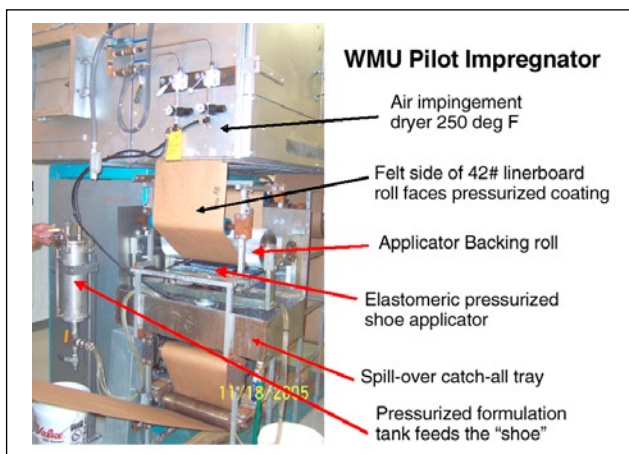
platy, delaminated, and fine clays blended in various proportions with Acronal® 4787X. Acronal is a commonly available 50%-by-dry-weight aqueous co-polymer dispersion of styrene and butyl acrylate with a glass transition temperature of 23° C. Another formulation consisted simply of the Acronal dispersion without any pigment. A list of the formulations for the Concept 2 impregnation trial is shown in **Table I**. "A" is 1:1 platy clay/polymer blend, "B" 1:1 delaminated/polymer, "C" 1:1 fine clay/polymer, "D", "E" and "F" are equivalent blends but with dry weight clay/polymer ratios changed to 1:2. "100%" formulation has no clay.

An impregnator is a shoe press with a pressurized delivery system (**Fig. 3**). To impregnate the sheet, the coating is put under pressure, 10-100 psi, and is forced into the sheet as it passes through the shoe nip. Controlled penetration depths of 20%-80% are typical and have produced commercial benefits to corrugated board manufacturers seeking strength and stiffness improvements, while leaving one side unaffected for bonding to medium [3]. Both coating reservoir and shoe pressure are controlled to alter the depth of coating penetration. A minimum shoe pressure is required to prevent leakage from the shoe as the coating pressure is raised.

Depth of penetration of the coatings is governed by the coating reservoir pressure, ultimately limited by the sheet

Formulation Name	Clay: polymer dry weight ratio	Clay type
A	1:1	Platy
B	1:1	Delaminated
C	1:1	Fine
D	1:2	Platy
E	1:2	Delaminated
F	1:2	Fine
100 %	0:1	No clay

1. Summary of the formulations used in the Impregnation trials of Concept 2.



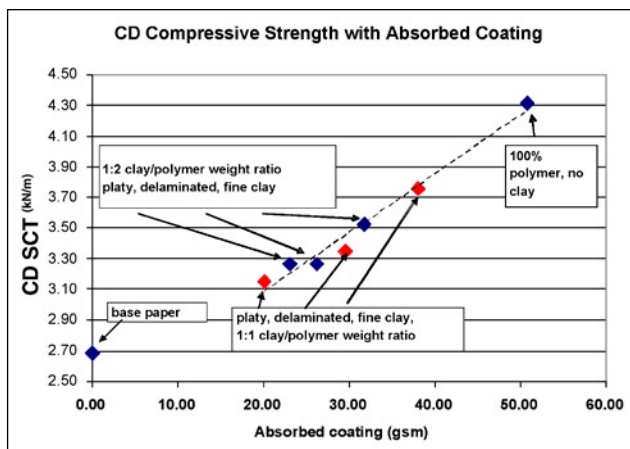
3. Photograph of the pilot impregnator.

tensile strength required to endure being pulled through the pressurized nip. An anilox roll behind the sheet on the other side of the coating applicator enables displaced air to escape through the backside of the sheet. The felt side of the sheet was made to face the pressurized coating since coating absorption is dependent on sheet porosity.

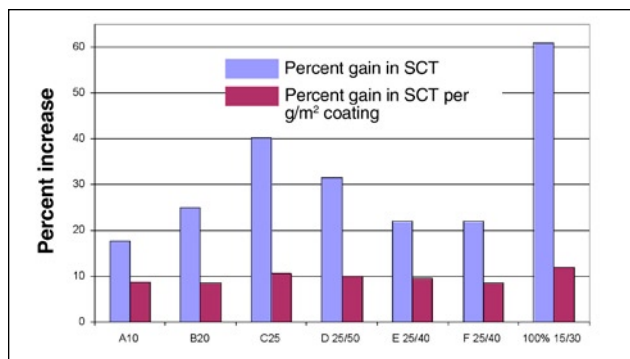
We adjusted both shoe and coating reservoir pressures to achieve maximum absorption of coating into the substrate in the current experiments. Physical properties of the linerboard and medium indicate substantial increase of strength properties proportional to the amounts of absorption of coating into the sheet.

Optimum coating absorption was obtained using corrugating medium, compared to previous results using linerboard, which is denser. Kaolin clay/polymer blends were used in solid weight ratio of pigment to polymer of 1:2 and 1:1, the pigments were a fine clay, delaminated clay and a super platy clay [2]. Results regarding compressive strength (SCT – short span compression) and coating pick-up for the case of the medium substrate are shown in **Fig. 4**. The untreated base paper measured a CD SCT (kN/m) of 2.7 kN/m.

We emphasize the CD SCT as the primary strength property of interest since the board edgewise compressive strength ECT and the stacking strength of corrugated containers is dependent on the medium or linerboard CD SCT. This may be seen in the Whitsitt formulation for ECT [4] or the McKee equation [5] for BCT. Figure 4 shows that platy clay inhibits



4. Short span compression strength and coating pick-up for medium.



5. Percent gains in short span compression strength from impregnation of medium. "A" is 1:1 platy clay/polymer blend, "B" 1:1 delaminated/polymer, "C" 1:1 fine clay/polymer, "D", "E" and "F" are equivalent blends but with dry weight clay/polymer ratios changed to 1:2. "100%" formulation has no clay.

coating absorption, compared to the other clays. Coating absorption is as much as 28% of the total weight of the medium with no clay present. Our analysis of the percentage gain in compression strength per gram of absorbed coating shown in **Fig. 5** indicates no particular advantage from the inclusion of clay toward increases in compression strength, but there is nonetheless a reduction in cost by the replacement of polymer by pigment into the void volume of the sheet structure.

Replacing the polymer with a higher modulus substance such as clay by a volume ratio as much as 1:3 polymer to clay, as in the case of formulations A, B and C, the percentage of gain in compressive strength per unit of absorbed mass should be greater than that of the polymer alone. Compressive strength is expected to be increased as a result of the summation of the moduli E_i weighted by the respective volume fractions α_i of the $i = n$ components of the composite matrix resulting from the impregnation process, simply stated as:

$$E_{eq} = \sum_i^n \alpha_i E_i \quad \sum_i^n \alpha_i = 1 \quad (1)$$

where E_{eq} is the equivalent elastic modulus of the impregnated

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ed matrix. For the ideal case of a polymer matrix E_p consisting of no air-void volume, a pigment of modulus E_{cl} and critical pigment volume concentration (CPVC) being taken as the pigment volume fraction α_c

$$E_c \cong E_{cl}\alpha_c + E_p(1 - \alpha_c) \quad (2)$$

Equation (2) is the basis for the high modulus of many reinforced composite materials such as glass-fiber epoxy matrices. Accordingly, if a paper fiber structure of modulus E_f and void volume α_f should become impregnated with composite material of modulus E_c its equivalent modulus can become:

$$E_{eq} = E_f\alpha_f + E_c(1 - \alpha_f) \quad (3)$$

which upon using (2) is rewritten as:

$$E_{eq} = E_f\alpha_f + E_{cl}\alpha_c(1 - \alpha_c) + E_p(1 - \alpha_c)(1 - \alpha_f) \quad (4)$$

For simplicity, assume that the air-void volume in a bulky sheet such as medium is $\approx 1/2$ and, similarly, the critical pigment volume of kaolin clay to be also $1/2$, so that $\alpha_f = \alpha_c$, then equation 5 can be approximated as:

$$E_{eq} \approx \frac{E_f}{2} + \frac{E_{cl} + E_p}{4} \quad (5)$$

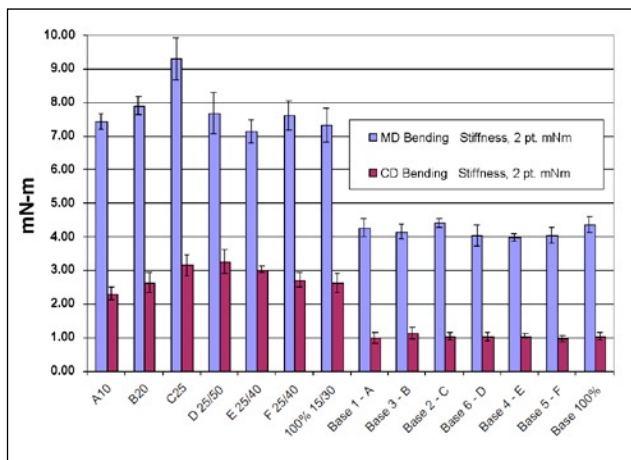
The CD modulus of typical virgin kraft linerboard is 2010 MPa. The modulus of clay platelets from atomic force microscopy measurement is reported to be about 6 GPa [6] and measurements of thin films of acrylic binder polymers indicate a modulus of 210 MPa. Therefore in the idealized case, assuming 100 % impregnation and no air void volume in the polymer or fiber network, the potential increase in modulus E_{eq}/E_f is 30%.

The hypothesized effect of increased modulus with pigment inclusion is supported by observations of two point bending stiffness D shown in **Fig. 6** since for a beam of thickness t per unit width we can expect:

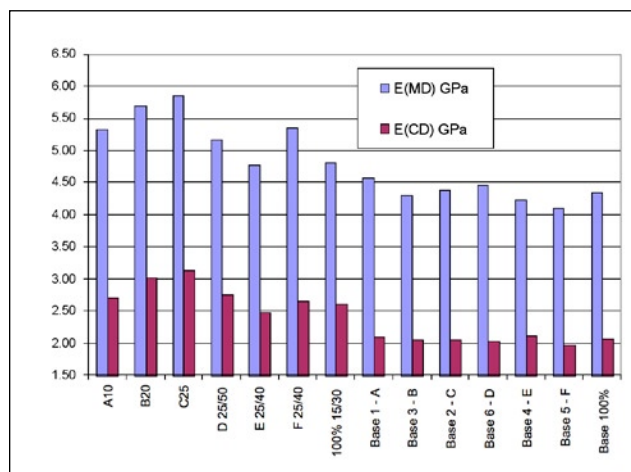
$$D = \frac{E_{eq}t^3}{12} \quad (6)$$

The bending stiffness increases with the inclusion of polymers into the sheet matrix, especially when clay is combined with the polymer. The impregnation process causes the paper to become wet and swell irreversibly, increasing the caliper by an average of 2.4%, which would increase the bending stiffness by only 7.2 %. Therefore, the remaining increase in stiffness is attributable to the pigment and polymer penetration into the sheet structure.

Identical plots show 20%-25% increases in in-plane modulus measured by ultrasonic wave propagation [7] corroborates the preferential increase of modulus by the inclusion of pig-



6. Observations of two-point bending stiffness of increased modulus with pigment inclusion.



7. Summary of measurements of MD and CD modulus of the impregnated medium sample set by ultrasonic methods using the IPST robotic station.

ment, particularly in the case of formulation C, which is a fine clay/polymer blend of equal weights. As shown in **Fig. 7**, the CD modulus is increased by 54% for the case of formulation C over its corresponding base paper value.

Results for formulation C deserve mention, since in this case the color pick-up into the sheet is 38 g/m² compared to 50 g/m² for the unblended polymer. The presence of pigment inhibits penetration of color into the sheet. However, the increase in bending stiffness, ultrasonically measured in-plane stiffnesses from the base paper case, is 25% higher for the C formulation, compared to that of the unblended polymer sample dubbed "100% 15/30." Thus the pigment is beneficial in terms of increased stiffness.

The increases in bending stiffness and in-plane stiffness can be ascribed to the contribution of clay in the blend. Thin film sheets were made using the Acronal® co-polymer, and polymer/clay dispersions formulations "D" and "F", "D" containing platy clay and "F" with fine clay in a 2:1 weight ratio with the polymer. We tested these sheets for tensile stiffness using an Instron Model 1142 test frame with its Series IX software and for in-plane elastic moduli using the IPST Robotic Ultrasonic tester. Results of the measurements are shown in **Table II**.

Substrate	Modulus by tensile test (MPa)	Modulus by ultrasonics (MPa)
Copolymer only	414 ± 13	1950
Copolymer and KCS clay	742 ± 42	2970
Copolymer and 6100 clay	856 ± 52	4040
Kraft 205 gsm linerboard MD	5423 ± 13	7660
Kraft 205 gsm linerboard CD	2520 ± 47	3460

II. Measurements of modulus of film slabs made from some of the formulations and linerboard.

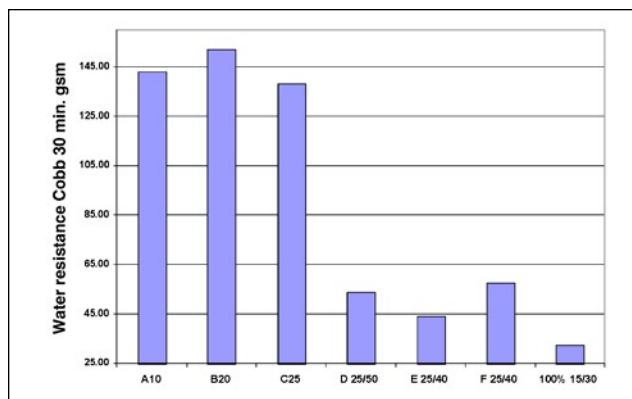
The table indicates, as expected from the theory of composites, that the inclusion of clay increases the modulus of the matrix. The inclusion of the platy clay in the weight ratio of 1:2 with the binder polymer increased the modulus by a factor of two. Our data corroborate recent reports of J. Husband [8], which show that modulus of platy clay coatings to be of the order of 2 GPa compared to fine clay which is about 1 GPa, the results being independent of binder content. In this case, coatings were placed in a centrifuge to remove any entrained air prior to film formation, followed by tensile testing for modulus determination, which resulted in higher observed moduli. The relative increases of the polymer film with clay content in Table II are the same whether measured ultrasonically or mechanically. Results for a virgin kraft linerboard of basis weight 205 g/m² are also shown for comparison.

The lack of a beneficial effect of clay per unit weight absorbed into the sheet, as shown in Fig. 5 for short span compression, may be due to concentrations of clay causing out-of-plane delamination break-up of the fiber composite matrix when in compression, which does not occur when in tension. Nonetheless, the presence of clay can produce some advantages in strength properties, but as shown previously in studies of clay/polymer blends coated on the surface, the presence of clay in the blend will reduce the water resistance, as indicated in Fig. 8.

Performance of HSC boxes with impregnated medium

A box made of impregnated medium may have sufficient strength under wet conditions to satisfy some requirements. It was shown previously [1] in a simulated ice-pack trial, that the medium must be non-wicking if a box is to retain any significant portion of its dry stacking strength after a test duration. If only the linerboard facings are made water resistant, the box will essentially disintegrate when the medium becomes wet. It may be economical therefore, to have boxes constructed from fortified waterproofed medium made by the polymer impregnation process.

We prepared half-slotted container (HSC) boxes with medium impregnated with an unblended polymer (formulation "100%") bonded to commercial virgin kraft 206 g/m² linerboard, bonded using a specially processed primary starch



8. Water resistance for medium impregnated with polymer/clay blends.

(FiberBond®) Stein-Hall adhesive system. Thermosetting resin and cross-linker were added to the adhesive as recommended by the manufacturer. The test boxes were filled with ice and placed in a cold room maintained at 80% RH and 40°F. The HSC box bottoms consisted of glued flaps with a one-inch square opening for melt water to drain away into a tray suspended below the test boxes. The trial boxes were tested for vertical stacking strength (BCT) retention after 72 hours exposure to these wet conditions, representing a typical ice-pack transport scenario.

As shown in Fig. 9, these HSC boxes have a BCT of 3.1 – 3.6 kN. After exposure, these impregnated medium boxes showed an average BCT of 930 ± 140 N, a retention of 25%. By comparison, previous studies [1] showed that if only the linerboard facings are coated with wax or polymer, then BCT retention is only about 12%. Commonly, wax replacement boxes have inside liners polymer coated and medium sized to the extent that it is non-wicking. In these circumstances [1], BCT retention after 72 hours ice-pack exposure is 44% compared to the 66% retention of a typical wax curtain coated box made with wax impregnated medium.

Therefore, if a comparable amount of polymer is impregnated within the medium rather than being distributed as coatings on the linerboard, the BCT will increase by a predicted 12% from the increased compression strength of the impregnated medium, and the box will retain 25% of its stacking strength after prolonged exposure to wet conditions. Polymer coatings on the surface of linerboard do not increase compression strength. Thus a satisfactory alternative for some applications may be to form boxes with impregnated medium rather than to have coatings applied to linerboard facings.

Curtain coating comparison

Curtain coating [9] offers the advantage of non-contact metering. The application of a coating film falling onto the substrate means the coating will conform to the contours of the surface. Coatings applied with a wire rod below 8 g/m² basis weight will often leave fiber crossings near the surface insufficiently coated, which causes pinhole-sized water leaks and failure of the coating as a waterproofing barrier. A conforming coating

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formed by a falling film will, in principle, cover the protruding fibers or fiber crossings uniformly with polymer. Thus, curtain coating by this principle is expected to permit a lower weight of polymer coating to produce water resistance superior to that of a comparable coating applied by a wire rod.

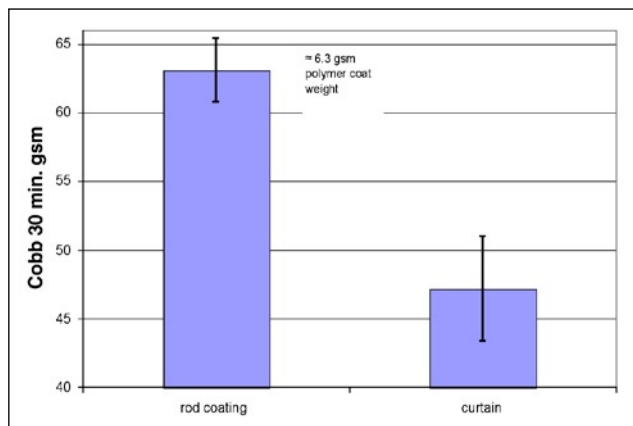
We tested this hypothesis using a slot-head curtain coater at the Western Michigan University's pilot plant facilities in Kalamazoo. We chose parameters to match the falling film speed with the sheet speed and attain a coating of about 6 g/m². We diluted a co-polymer dispersion to 12.5% solids and added a polyacrylamide thickener, Sterocol® BL, at 0.25% wet weight, to enable a stable coating film to fall freely from a 318 micron-wide slot. The linerboard passed under the falling curtain at 152 m/min and was hot-air dried at 177°C, using three independently controlled high velocity air impingement gas dryers.

We prepared dilutions of copolymer for comparison and adjusted viscosity with thickener to produce wire rod drawdown coatings of 6 g/m² basis weight. At these coat weights, the cost of polymer becomes comparable to the cost of a wax coating. Cobb water resistance measurements show an improvement (**Fig. 10**) of 34% in the amount of absorbed water when the same weight of polymer is applied with a falling curtain rather than a wire rod. By comparison, to obtain a similar water resistance using rod coating would require a coat weight of 18 g/m² of the diluted polymer formulation. Thus, for this case, the coat weight is reduced by a factor of 3 when wire rod coating is replaced by a falling curtain film and a similar water resistance is achieved at this reduced coat weight.

Flame surface treatment

Fibers protruding from the surface of linerboard are considered to be a limiting factor for producing water resistance with thin polymer coatings. Surface modification through calendering or pre-coating can lower the basis weight requirement of a polymer coating to attain a certain level of required water resistance. Removal of surface protruding fibers to achieve the same effect has been claimed [10].

We conducted a trial using Herty Foundation pilot plant-prepared DLK linerboard subjected to a commercial stabilized methane flame burner produced by Enercon. The web passed over a water-chilled roll at 152 m/min. A linear flame array consisting of a mesh of orifices extending about 1 inch in the MD, applied a



10. Comparison of the water resistance of rod and curtain coated linerboard with Acronal coat weights of 6 g/m².

calculated energy density of 377 Watts/m²/min achieved by a 10:1 ratio of air-to-methane fed to the burner at the rate of 1,300 L/min, as a recommended typical operating condition. Variations of the fuel mixture rate in the range of 18% above and below 1,300 L/min did not affect the observed results.

Coat weights of rod-applied aqueous polymer were measured for a variety of rod sizes before and after the flame treatment. Flame treatment did not alter the pick-up of coating by the linerboard, as shown in **Fig. 11**.

If a sufficient number of surface fibers protrude through a thin coating surface, surface flame burn-off treatment of these fibers should have a more obvious positive effect on water resistance in the case of lighter coat weights. Both treated and untreated linerboard samples were tested for water resistance for the various coat weights. The results are summarized in **Fig. 12**, where samples were singly coated with various sizes of wire drawdown rod. In some cases, it is not apparent that the flame treatment has positively improved the water resistance. At coat weights of 16 g/m² and larger there is no effect of the flame treatment, as may be expected since at high coat weights the film thickness is sufficient to cover protruding fibers.

We repeated the flame treatment trial using a typical commercial 80/20 virgin/recycle kraft linerboard of 205 g/m² basis weight. In this case, differences in water resistance between untreated and flame treated surfaces are more evident for coat weights on the order of 15 g/m². When coating weights are greater than 15 g/m², the fibers are sufficiently covered and flame treatment does not provide an advantage.



9. Photograph of the simulated end-use ice-pack test for waterproofing performance on the left, on the right, bottom of a box after 72 hours of ice-pack exposure showing wicking along the outside facings.

Electrospinning prospects

Solutions of polymers pumped through a syringe pipette in a high electric field break up into a Taylor cone and provide a suitable combination of conditions of solvent evaporation rate and viscosity to form cobweb-like coatings of fibers of submicron thicknesses [11]. The basic concept of electrospinning is shown in **Fig. 13**.

These webs have a much greater hydrophobicity than equivalent thin films of the same material. A sample obtained from a preliminary commercialization attempt [12] of this principle led to a mea-

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were 74 and 65 g/m² for the two coat weights, respectively.

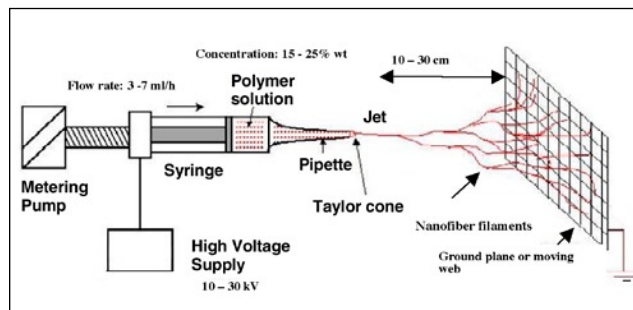
Current developments are overcoming limitations to this technology, such as the flow rate per syringe tip being restricted by physics to be on the order of 50 μ L/min, thus limiting achievable on-line coating weights. This can be overcome somewhat by using a high density plurality of nozzles in a matrix configuration and slower web speeds. The electrohydrodynamic instability works for a limited number of solvent/solute combinations, many of which are not aqueous. Optimization programs include factorial experiments of varying viscosity, surface tension, polymer/solvent choice and concentration, applied potential, ambient humidity, and other factors to produce a filamentary structure without detrimental artifacts so that the hydrophobicity of the coating is maximized.

Another advantage, aside from the high water resistance at ultra-low coat weight, is that the requirement for drying the coating becomes minimal or is eliminated entirely by solvent evaporation from the forming nanofilament. This is an area for future exploration and development. It may eventually supplant many current coating technologies.

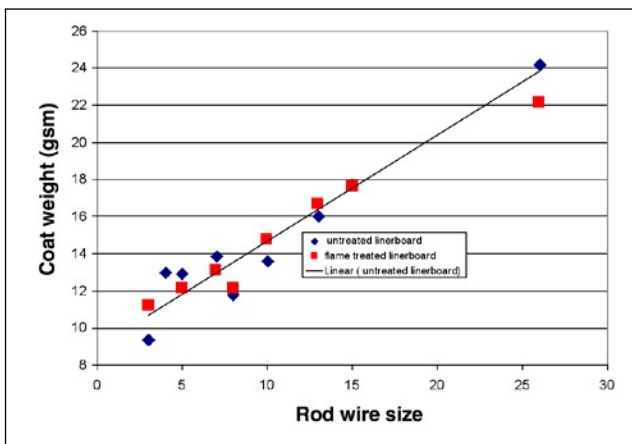
Summary

The waterproofing of corrugated containers for the wet transport applications as required for certain foodstuffs presents challenges for devising cost-effective methods, and the pressure to produce solutions is evident in the advent of increasingly unavailable and expensive paraffin-based waxes traditionally used for impregnations and coating. Demonstrated in this and previously cited related work is that sufficient levels of water resistance (below 25 g/m² 30 minutes Cobb) may be achieved with aqueous polymer coatings applied to linerboard substrates. Material costs of polymer dispersion coatings can be reduced through precoating with a pigment, followed by a polymer overcoat or through blending a suitable hydrophobic pigment with the polymer dispersion. Impregnation of polymer dispersions or polymer/pigment can replace surface coating and has the advantage of substantially increasing the required compressive strength of the impregnated material. Pigments in an impregnated matrix add to the in-plane stiffness but do not appear to contribute to compression strength.

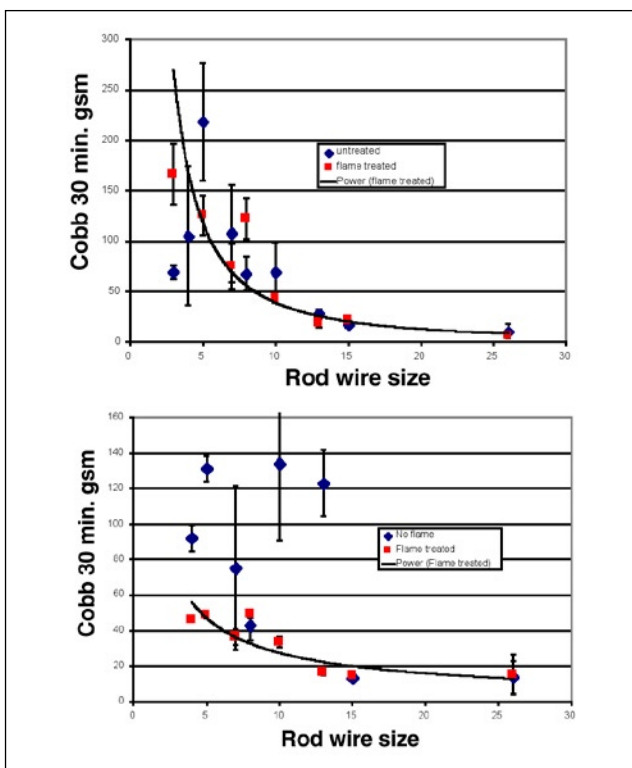
Other cost reducing strategies for the replacement of wax curtain coating technology involve investment in new capital



13. Schematic of the concept of electrospinning with some typical parameters.



11. Coat weight versus wire rod size for untreated and flame treated linerboard.



12. Water resistance versus rod size for untreated and flame treated pilot plant made DLK linerboard (top) and commercial 80/20 virgin recycled commercial linerboard. Error bars represent 95% confidence intervals of 4 or more measurements. The curve represents the best fit through the flame treated case points.

sured 30-minute Cobb of 50 g/m² from an electro-hydrodynamic spinning (EHS) coating only 0.5 g/m² in weight, about 20 times lighter than the solid-film polymer coating required to achieve comparable water resistance.

Another recent trial example [13] applied nanofiber films of poly-acrylonitrile polymer (PAN) on a 205 g/m² linerboard web using a commercial pilot line producing rolls of membranes. Electrospun membranes of 0.3 and 1.1 g/m² were determined gravimetrically by peeling them off from the linerboard substrate once dampened. Superhydrophobicity of such nanofiber films is evidenced by measured water droplet contact angles of 132 degrees. In this case, measured 30-minute Cobb values

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equipment but reduce material requirements. Examples presented in this paper are curtain coating, which has been shown to produce a more effective thin polymer film than can be achieved with a rod coater; and flame surface treatment that may potentially reduce coating requirements through removal of protruding surface fibers of uncalendered linerboard. Recently reintroduced electrospinning technology has the potential to reduce required coat weights by an order of magnitude once the challenge of achieving higher throughput rates and suitable polymer/solvent combinations are developed in future investigations. **TJ**

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LITERATURE CITED

1. Popil, R.E., Schaepe, M., *TAPPI J.*, 4(8):25 (2005).
2. Popil, R.E., *TAPPI J.*, 5(9): 18 (2006).
3. Joyce, M., Joyce, T., "Practicalities of Using an Impregnation (Controlled Penetration) Sizing Method for Improving the Barrier and Strength Properties of Paper and Board," 2003 Internal and Surface Sizing PIRA Conference, Dec. 11-12, Graz, Austria.
4. Whitsitt, W.J., *Tappi J.*, 58(12):163 (1988).
5. McKee, R.C., Gander, J.W., Wachuta, J.R., *Paperboard Packaging* 48(8):149 (1963).
6. Prasad, Kopycinska, M., Rabe, U., Arnold, W., *Geophysical Research Letters*, 29(8):1301 (2002).
7. Waterhouse, J., *Tappi J.*, 77(10):120 (1994).
8. Husband, J.C., Preston, J.S., Gate, L.F., Blair, D., Creaton, P., Factors affecting the printing strength of kaolin-based paper coatings" *Proceedings 2007 TAPPI Coating and Graphics Arts Conference*, Miami.
- Husband, J.C., Preston, J.S., Gate, L.F., Storer, A., Creaton, P., *TAPPI J.*, 5(12):3 (2006).
9. Triantafillopoulos, N., Gron, J., Luostarinen, I., Paloviita, P., *TAPPI J.*, 3(11):6 (2004).
- Trez, M., Fröhlich, U., *TAPPI J.*, 4(11):3 (2005).
10. Ogilvie, M.O., Whatley, P.M., Olvey, M.W., US. Patent 6,113,981. "Process for coating paperboard with a water dispersible polyester polymer."
11. Ramakrishna, S., Fujihara, K., Teo, W-E., Lim, T-C., MA, Z., "An Introduction to Electrospinning and Nanofibers," World Scientific Publishing Co., (2005).
12. Nanostatics LLC., Columbus, Ohio.
13. e-Spin Technologies, Chattanooga, Tennessee.

INSIGHTS FROM THE AUTHORS

This paper is the third in a series intended to provide technological solutions for effective waterproofing wax replacement.

The motivation for the research lies in the opportunities for pursuing existing resources such as kaolin to address the problem of wax replacement for waterproofing corrugated board. We also see other alternative technologies such as electrospinning, surface treatment, and different forms of coating applications that may provide the next leap forward toward economically waterproofing corrugated board to expand its markets and usage.

From the research, we found that some commonly available pigments add strength properties to board when used as a coating layer or impregnated into the sheet structure. A hydrophobic pigment can also displace a proportion of the costly polymer in a waterproofing formulation.

Electrospinning of nanofibers, perhaps even of biodegradable polymers (think of a spider's web with dew drops on it), offers the opportunity to create waterproofing barriers at a fraction of the coat weights required for

currently used polymers. The challenge is to produce the coating at current board production rates and make them durable enough to withstand converting operations.

Paperboard producers can use these findings to devise optimal cost-reduction methods for water-resistant linerboard.



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