Wet-strength performance of corrugated board made with high-performance facings

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Boxes made with high-performance liners have dry compression strength comparable to those made with conventional liners. However, wet-strength tests tell a different story.

Corrugated boxes used to transport produce are customarily exposed to harsh moisture conditions. The most severe is where produce-laden boxes are totally submerged in chilled water to quickly reduce the produce temperature before being top-iced and shipped in refrigerated facilities. Shipping invariably involves stacking and palletizing. In this environment, the corrugated's wet compression characteristics are critical.

Corrugated is saturated with wax to provide the necessary wet strength. Saturation is typically achieved by exposing corrugated to a cascade of molten wax, draining off excess wax, and allowing the box to cool.

Economic and ecological considerations find corrugated manufacturers trying to produce boxes with acceptable edgewise compressive strength test (ECT) results while using less fiber. Producing high-performance (HP) liners by changing refining, improving fiber orientation, and increasing pressing achieves this goal. Corrugated made with HP liners can have the same dry compression strength as corrugated with conventional liners but at 10–20% lower basis weights.

Our ongoing and continuing participation with manufacturers of waxed corrugated boxes indicated that corrugated made with HP liners does not pick up as much wax as corrugated made with conventional liners. We found that though corrugated of both types have the same dry ECT, corrugated made with HP liners have lower wet ECT.

This could have an adverse effect on the actual performance of corrugated exposed to wet conditions. This paper presents the relationship we found between dry and wet ECT, wax pickup, and corrugated types.

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Materials

Corrugated

Table I describes the corrugated we tested. Four sets of two boxes (or boards) each were obtained from different manufacturing plants. Each set was comprised of C-flute corrugated using HP and conventional liners, with a construction that yielded approximately the same dry ECT. The amount of recycled material they contain is probably relatively small. However, we also evaluated corrugated made with conventional liners containing significant amounts of recycled fiber.

All processing and measuring was completed after samples were TAPPI-conditioned (23°C and 50% relative humidity) for a minimum of 24 h.

To simplify and expedite the acquisition of wax pickup data, we usually determined this by weight difference after waxing and the particular corrugated's measured basis weight. **Table II** summarizes the basis weight data.

Saturating wax

All waxing was done with Chevron Saturating Wax 2. Typical properties, based on American Society for Testing and Materials (ASTM) methods, are shown in **Table III.**

Methodology

Wax application

Our pilot wax cascader waxes corrugated boards 76.2 cm high × 25.4 cm wide, or 76.2 cm wide × 58.4 cm high with the flutes vertical. The effect of different cascading conditions (as well as the effect of corrugated type at the same cascading conditions) upon wax pickup can be evaluated. These variables include type of board, nature of the wax, and cascading conditions. Cascading conditions include preheat, waxing (circulation rate, time, and temperature), post-treat (time, temperature, air circulation, and vibration), and cooling (time and air circulation).

Sometimes we waxed a single board type in a cascader run; other times we ran a variety of board types simultaneously. Cascading conditions affect wax pickup, while identical cascading conditions produce different

I. Characteristics of corrugated liners tested

	High-performance liners				Conventional liners			
	Construction, g/m²*			ECT, kN/m	Construction, g/m²*			ECT, kN/m
Plant AI	280	160	280	9.6	340	160	340	9.4
Plant AII	230	160	230	8.1	340	160	200	8.2
Plant B	300	160	300	9.4	340	160	340	9.6
Plant C	220	160	220	8.1	200	160	340	7.1
Plant D	...			...	340	160	200	8.9

*Numbers refer to basis weight of outer liner, medium and inner liner, respectively.

II. Corrugated unit weights

				Basis weight, g/m²		
Plant	Construction, g/m²			Calculated[a]	Measured[b]	
AI	280	160	280	801	815	(6.2)
AI	340	160	340	908	920	(5.4)
AII	230	160	230	693	720	(4.7)
AII	340	160	200	776	802	(4.7)
B	300	160	300	840	850	(12.1)
B	340	160	340	908	912	(8.4)
C	220	160	220	674	681	(2.5)
C	200	160	340	776	799	(7.3)
D	340	160	200	776	816	(11.5)

[a]Assuming 1.45 take-up factor for medium.
[b]Numbers in parentheses represent the standard deviation.

wax pickups with different corrugated types.

In addition, we hand-dipped different corrugated types to establish maximum wax pickup levels.

Wax pickup measurement

For most of the study a unit weight (g/m²) was established for each corrugated type, and the percent wax pickup was established by the weight difference of TAPPI-conditioned samples before and after waxing. This facilitated data acquisition and reduced the amount of solvent needed for determining wax pickup by extraction. All wax pickup data are based on unwaxed TAPPI-conditioned corrugated.

Selected waxed corrugated samples were extracted with chlorothene (1,1,1-trichloroethane), and the residue remaining after evaporation of the solvent was used to calculate wax pickup. (Extraction of the untreated samples indicated only 0.1–0.3% extractables.) **Figure 1** plots data comparing wax pickup obtained by the two methods. Wax pickup by extraction is approximately 2% (relative) greater than wax pickup by weight difference.

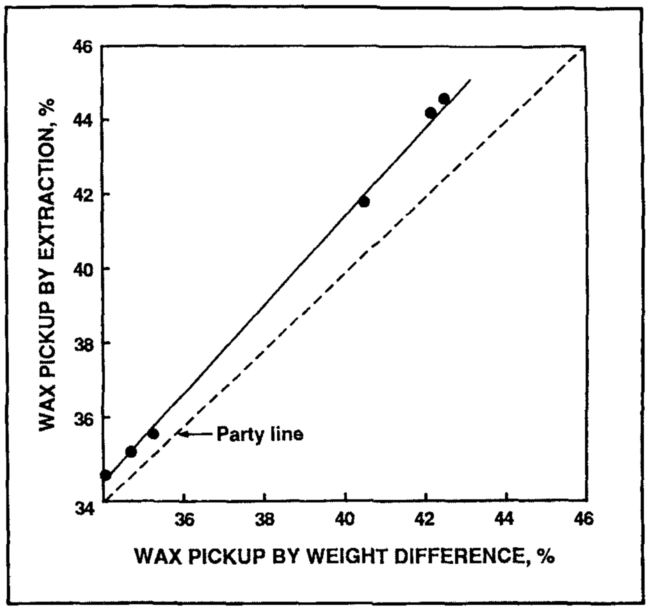
ECT determination

ECT data were obtained on an Instron Model 4501. It has a 0.1905-cm/min (0.075 in./min) crosshead speed to approximate the desired rate of force increase called for by TAPPI Test Method T 811. It also has a spring-loaded specimen holder rather than the standard block holder. All testing was at TAPPI conditions.

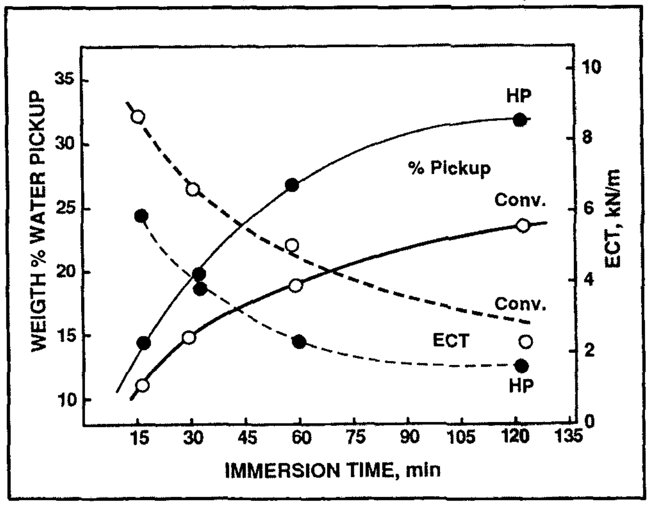
III. Typical physical properties

Property	*ASTM method*	*Typical level*
Melting point, °C (°F)	D 87	60 (140)
Penetration, mm/10	D 1321	
at 25°C (77°F)		9
at 37.8°C (100°F)		21
Viscosity, cp	D 445	
at 100°C (212°F)		4.5
Oil content, mass %	D 721	0.5
Blocking point, °C (°F)	D 1465	115 (239)
Density, g/mL	D 4052	
at 25°C (77°F)		0.92
at 79.4°C (175°F)		0.77
Flash point, COC, °C (°F)	D 92	232 (450)
Auto ignition temp., °C (°F)	D 2155	343 (650)

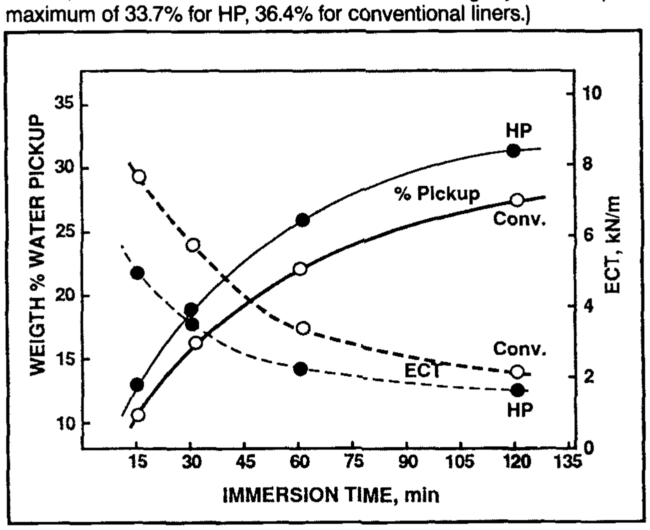
1. Comparison of TAPPI-conditioned corrugated wax pickup by extraction and weight difference



2. Comparison of plant A, set I, corrugated wet compression strength and water pickup (Boxes cascaded under identical conditions to 30.4% for HP, 37.5% for conventional liners. Saturating by hand dip to maximum of 31.7% for HP, 40.0% for conventional liners.)



3. Comparison of plant A, set II, corrugated wet compression strength and water pickup (Boxes cascaded under identical conditions to 32.8% for HP, 33.1% for conventional liners. Saturating by hand dip to maximum of 33.7% for HP, 36.4% for conventional liners.)



Corrugated specimen preparation

Individual untreated and treated (waxed) corrugated specimens were 5.08 cm × 5.08 cm. They were cut with a Billerud cutter and a Lorentzen & Wettre waist-down cutter. Loading edges were paraffin sealed.

Sample testing

Dry untreated and treated ECT data were obtained on the various corrugated types. Wet ECT data were obtained on each treated type following immersion in 23°C water for various lengths of time. Following immersion, the samples were tapped to remove water droplets. They were then weighed to obtain water pickup and quickly tested for ECT. This immersion procedure is recognized as a severe test—even for waxed corrugated.

Discussion

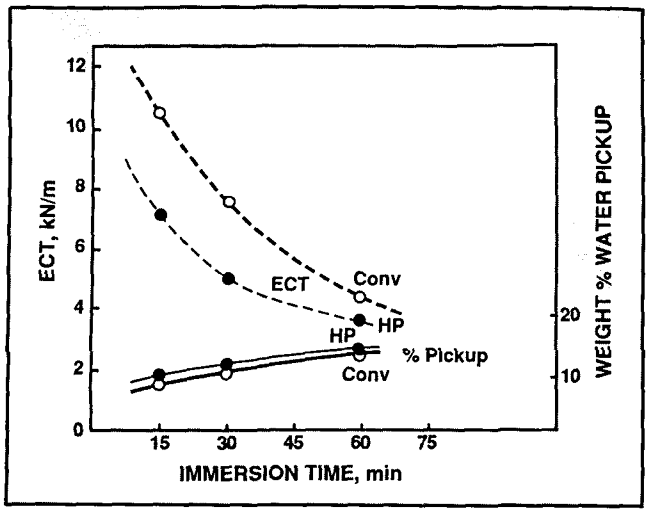
Figures 2-6 summarize the results. In every case, the wet ECT of corrugated made with HP liner is lower than the corresponding corrugated made with conventional liners.

Figures 2 and 3 provide wet strength and water pickup data for immersion times up to 2 h. Immersion times for Figs. 4-6 extend to an hour. While deterioration of wet strength continues beyond an hour, time is saved and sufficient data obtained if immersion time is limited to 1 h.

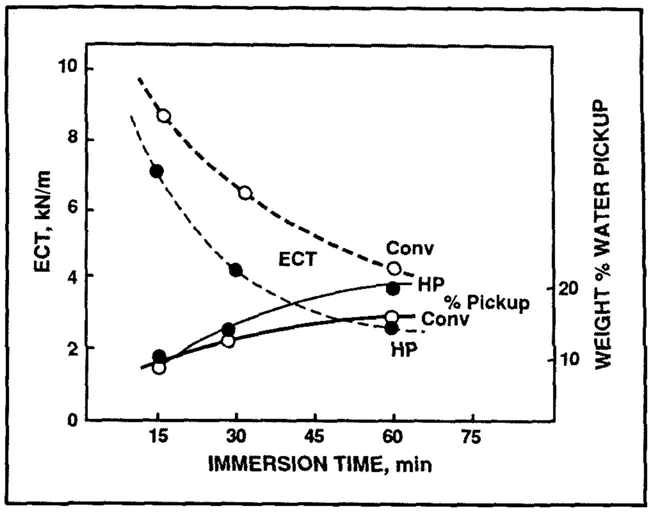
Wax pickup

As indicated, even though the boards were cascaded at identical conditions, wax pickup between corrugated made with HP or conventional liners can vary significant-

4. Comparison of plant B corrugated wet compression strength and water pickup (Boxes cascaded under identical conditions to 28.6% for HP, 29.0% for conventional liners.)



5. Comparison of plant C corrugated wet compression strength and water pickup [Boxes cascaded under identical conditions to 39.6% (by weight difference) and 43.1% (by extraction) for HP, 41.9% for conventional liners.]



ly. There is an apparent interaction between the cascading conditions and the wax pickup capacity of different corrugated types.

We briefly explored the issue of wax pickup capacity by hand-dipping various corrugated specimens. **Table IV** illustrates the effect of the waxing temperature on wax pickup for these corrugated specimens. All other waxing conditions were identical. It illustrates vividly the wax pickup differences observed even among corrugated substrates with the same basis weight.

Components of several corrugated samples were separated as carefully as possible to determine the wax distribution between the mediums and the liners. The wax in the fillets at the medium-liner junctions was arbitrarily assigned to the mediums.

Table V summarizes the results. Obviously there is a significant variation in wax distribution between the corrugated components. We have not yet determined the extent of this variation in corrugated with the same wax pickup.

Wet compressive strength

Figures 2 and 3 illustrate that the wax pickup by cascading closely approximates the maximum wax pickup by hand dipping. For both sets of corrugated from Plant A, the desired equivalent dry strength was obtained for corrugated made with either HP or conventional liners. Figure 2 might be interpreted as manifesting a wax pickup factor, since the corrugated wax pickup with conventional liners was significantly larger than that for the corrugated made with HP liners. However, Fig. 3 shows that even with essentially the same wax pickup the corrugated made with conventional liners demonstrates superior wet strength and less water pickup.

Figure 4 indicates that water pickup is not always a reliable indicator of relative compressive strength. Again, the corrugated with conventional liners has superior wet strength.

6. Comparison of plant C corrugated wet compression strength following waxing by hand dipping (43.6% wax pickup for HP, 43.5% for conventional liners)

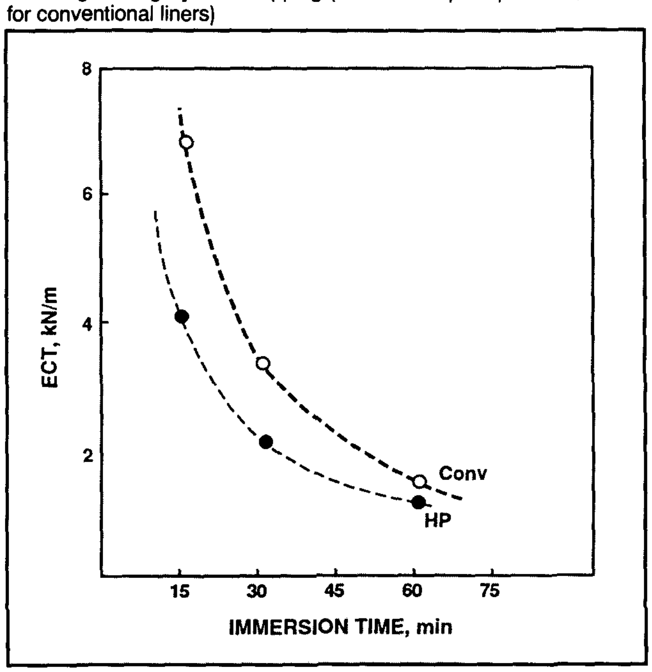


Figure 5 illustrates the superior wet compressive strength of Plant C's corrugated made with conventional liners, even though its dry ECT is significantly less than that of the corrugated made with HP liners. Hand-dipping Plant C's specimens produced the data in Fig. 6. Again, the board made with conventional liners has superior wet strength even at the same wax pickup level.

Conclusions

HP liners provide economic and ecological advantages where dry ECT is the index of acceptability. When wet

V. Wax distribution

Plant	Corrugated construction, g/m²			Total wax pickup, %	Percent of total wax pickup		
					Outer liner	Medium	Inner liner
B	340	160	340	33.2	34.5	28.9	36.6
B	300	160	300	38.2	34.9	33.1	32.0
C	200	160	340	45.5	28.3	26.6	45.1
D	340	160	200	51.9	42.2	35.1	22.7

IV. Temperature effect on wax pickup

Plant	Corrugated construction, g/m²			Mass % wax pickup, Waxing temp., °F	
				180	230
A	340	160	200	35.4	...
C	200	160	340	39.3	44.0
D	340	160	200	48.6	52.7

ECT is the critical index of performance, dry ECT is not a suitable measure.

Normally, HP liners pick up less wax than do conventional liners waxed at the same cascading conditions. However, the performance of HP liners in wet applications is inferior to conventional liners with the same wax pickup.

What might explain this? Is it possible that the explanation resides in the corrugated adhesive binding the structure together? Perhaps the bonding to the fiber is less for HP liners. When immersed in water, the bond is broken more easily, and wet ECT suffers. If this theory is correct, it is possible that improved adhesion and wax pickup would enable full realization of the potential HP liners represent.□

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