Bonding on the corrugator: the energy aspects

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Future corrugator design will need the results of research into the paper properties affecting the bonding process, especially wetting and penetration.

Before discussing what new features are needed on the corrugator of the future, let's analyze the important trends in our industry of the last 15-20 years. The trends point to more automation and more process and quality control, but new designs will react to new market needs such as just-in-time production and product flexibility.

We should also learn more about the mechanisms of the various functions performed on the corrugator. Much work has been done to produce flat board, to reduce warp. Recent machinery developments toward this end are constant web tension, heat supply proportional to web speed, constant glue application, automatic splicers, an automated dry end, and even automatic grade change. In the late '70s, the fingerless single-facer conquered the market for new equipment, going a long way toward the reduction of the high-low effect.

In this paper, we will focus on the bonding process. Research concerning better glueability (wettability, surface roughness, and pressure and capillary penetration), especially in Europe, showed the essential influences of paper, glue, and machine on the bonding process.

Paper: its fiber consistency and surface structure

Figures 1 and 2 show that fiber composition and surface structure, i.e., paper consistency, have the greatest influence on glueability. Sufficient gluing is almost always obtained with kraft liner and semichemical fluting (medium). This is far from true for recycled papers, whose fiber composition is very different and whose glueability is much more problematic because of the proportion of short fibers.

The measured values for glueability of common papers are shown in **Table I**.

Absorptivity can be displayed even more clearly by means of a newly developed measuring device—Bristow's apparatus (**Fig. 3**).

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Wetting

The glue applied on the paper needs a certain wetting time before the actual penetration takes place. The wetting time is proportional to the paper roughness factor, which correlates well to the roughness measured by the Bendtsen smoothness test.

For kraft liners, the wetting time is approximately 0.1 s, and it can increase to 0.4 s for recycled fiber liners (**Fig. 4**).

Penetration

Pressure penetration is important in the single-face glue line. Under pressure, solids and water migrate together into the paper pores. The most important criteria are the amount of pressure, the average pore radius, and the glue viscosity. The measured value for paper for this is the air permeability. According to the Bendtsen test, it should be at least 400-500 mL/min.

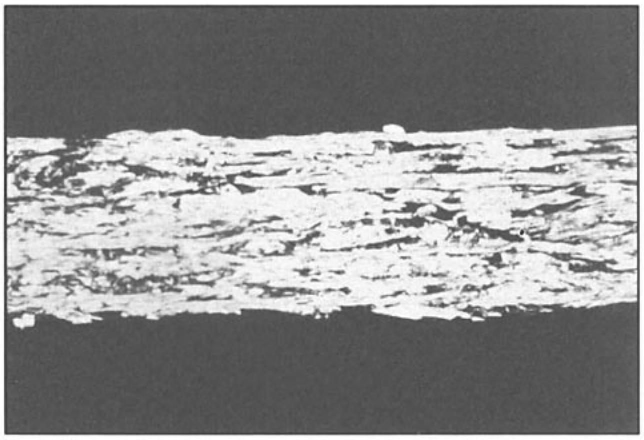
Capillary penetration occurs on each side of the flute tip line in the medium and over the full glue line area on the double-face glue line. In the case of capillary penetration, the water penetrates mainly into the paper fibers and pores as liquid and steam, because the large starch granules are less mobile than the smaller water molecules and cannot penetrate into the small pores. Moreover, the viscosity of the water reduces considerably as the temperature increases. Paper with higher moisture content provides more favorable conditions for capillary penetration (**Fig. 5**). Dense papers with small pores inhibit capillary penetration.

We learned from grinding samples that both gelatinized and ungelatinized starch penetrated up to 25 in. deep. Up to 50 in., only gelatinized starch and up to 100 in. only water-soluble starch could be detected in traces. Below 100 in., no starch at all could be detected (**Fig. 6**).

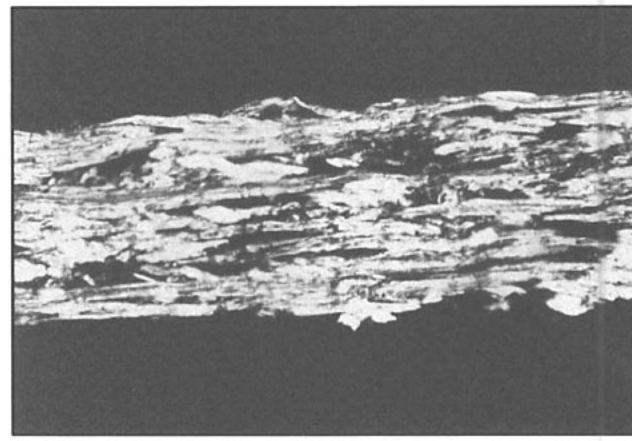
Values concerning paper that need to be controlled and which can be influenced are:

- Surface roughness of the inner side (Bendtsen smoothness)
- Air permeability (Bendtsen porosity, questionable for double-ply papers)

1. Microscopic slice sections of paper (sodium bicarbonate kraft liner)



2. Microscopic slice sections of paper (semichemical fluting)



I. Standard test values for gluing characteristics of different papers

	Dimension	*Semichemical fluting*	*Recycled fluting*	*Kraft*	*Duplex*	*Schrenz*
Surface roughness		OS 1500-2900	1600-2500	1200-2000	1500	2150
Acc. to Bendtsen	mL/min	SS 1800-3000		...	1900	2400
Porosity						
Acc. to Bendtsen	mL/min	300-900	160-600	400-900	...	400-500
Acc. to Gurley	s/100 mL	240-400	75-300	...	...	...
Base moisture	%	7-9	7-9	7-9	7-9	7-9
Variation of moisture profile	%	± 1.5	± 1.5	± 1.5	± 1.5	± 1.5
Drop test Pph 12	s	OS 9.0-30	15-55	50-80	15-30	15-30
	s	SS 7.5-30	11-60	...		
Cobb, inside 10 s	g/m²	100	...	20-35	150-200	100-200
2 s	g/m²	40-130	40-130	40-130	40-130	40-130
Dennison wax pick, resistance to pick test	g/m²	> 16				

- Paper moisture (basic moisture and moisture profile over the working width)
- Water absorption (Cobb or drop test).

These values may later be defined even better by means of the Bristow device.

Glue application, gelling, and drying of glue film

The most important influences for gluing are glue composition, starch concentration, glue viscosity, and quantity of glue applied.

Figures 7 and 8 clearly show the water that helps to transport carrier starch and smaller starch grains into the paper pores.

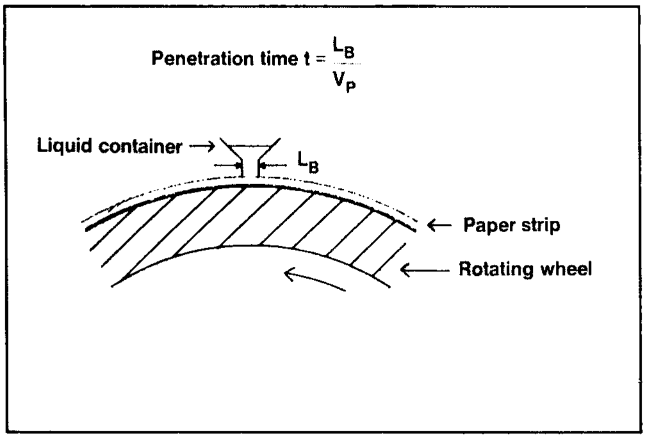
The starch concentration strongly influences the quantity of water that evaporates. Too high a concentration strongly diminishes penetration, too low a concentration increases the energy requirement to dry the glue film. For high-speed corrugators, starch solids concentrations of 23–27% are field proven (**Table II**).

Also, considerable success can be achieved in reducing the necessary drying heat and in obtaining an even sheet when glues with additives to delay penetration are used, particularly for porous, more absorbent papers.

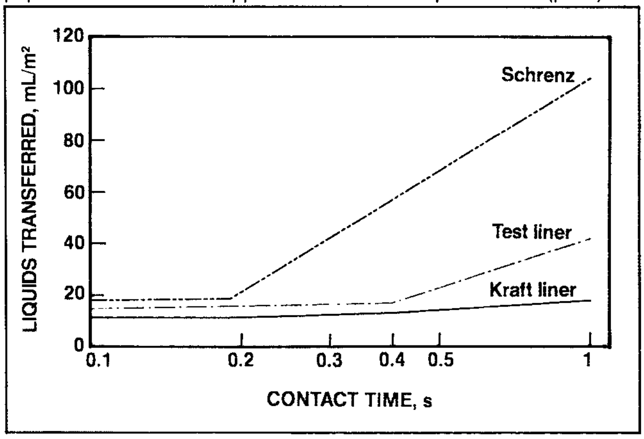
The glue viscosity is important for penetration of the glue into the paper pores. To reduce viscosity, starches with linear molecule chains (i.e., starches with high amylose content) can be used to avoid the reduction of starch concentration.

According to our experience, an even and minimum glue application is guaranteed at vicositities of 55–60 s, measured according to Steinhall.

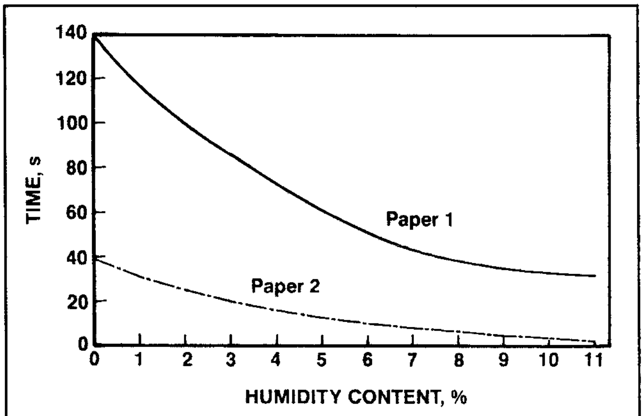
3. Measuring device according to Bristow



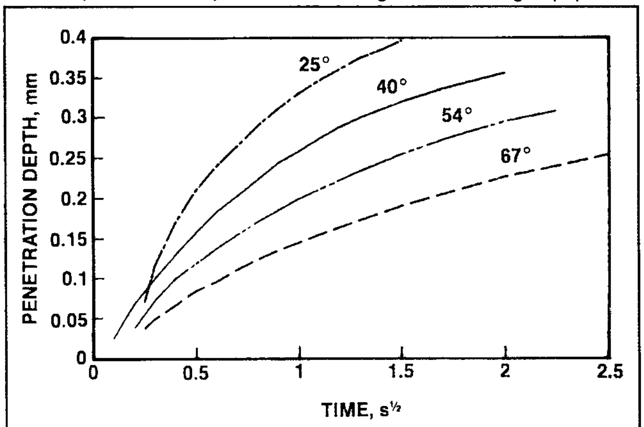
4. Wetting and penetration quantity as a function of time for different papers with the Bristow apparatus. Reference liquid is water (pH 7).



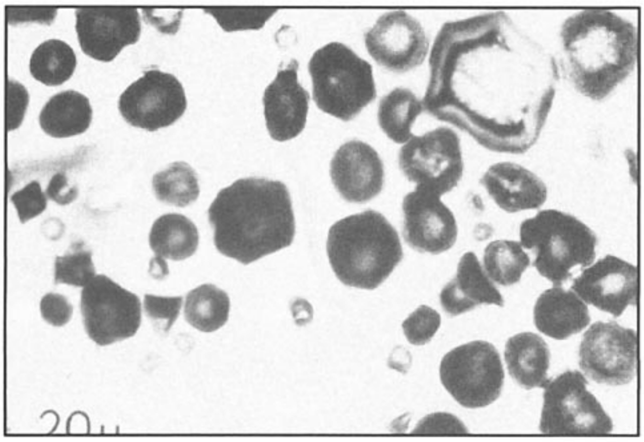
5. Penetration time as a function of moisture content (drop test)



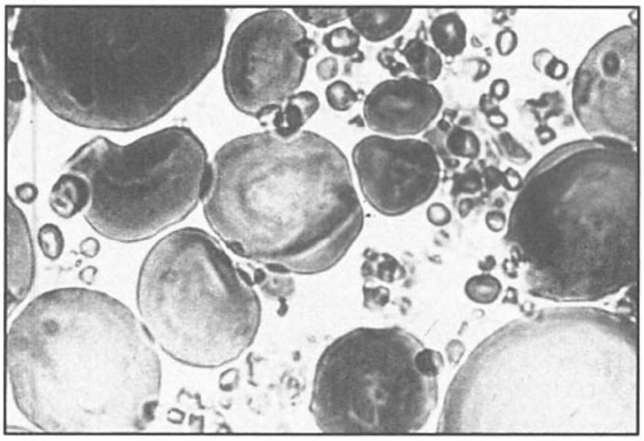
6. Glue penetration depth for different degrees of beating of paper



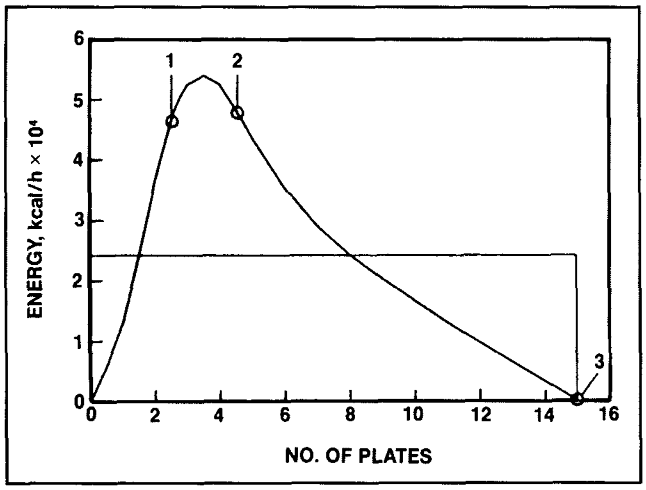
7. Microscope photo of a glue produced according to the Steinhall principle



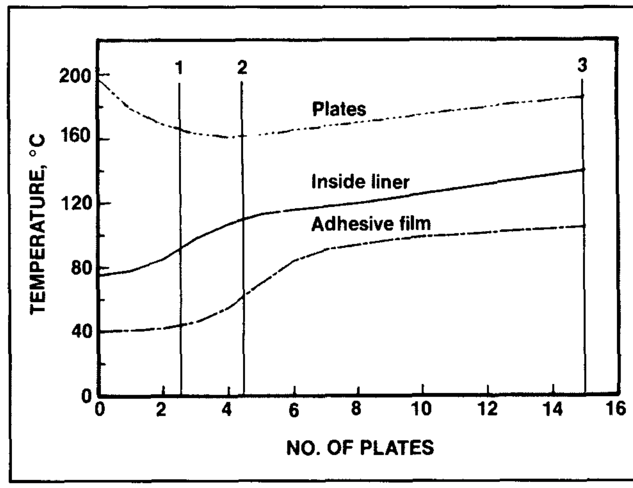
8. Microscope photo of a glue produced according to the no-carrier principle



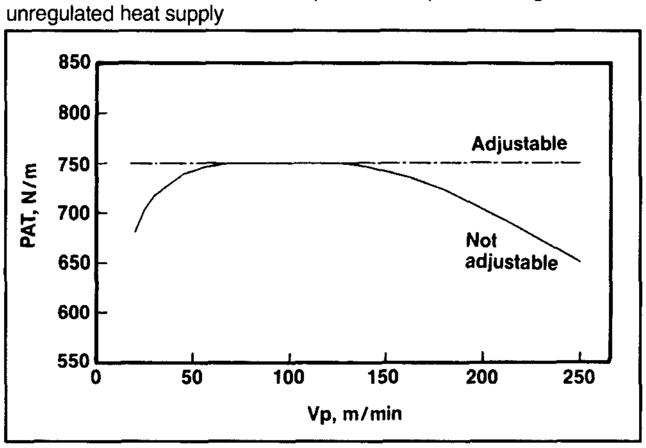
12. Heat flow as a function of number of plates (single-wall board). D.F. liner = 150-g/m² test liner, ≅ 5.5% moisture. Fluting = AP 112 g/m², ≅ 6% moisture, absolutely dry starch ≅ 5 g/m², ≅ 20% solids content. Vp = 150 m/min = 9-m constant length of heating section. The distance between: 0 and 1 = heat-up phase; 1-2 = evaporation phase; 2-3 = regulating phase (heat supply).



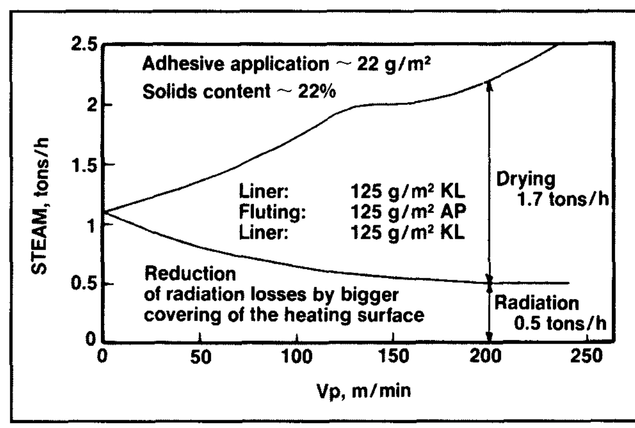
13. Temperature of inside liner of glue film and of hot plates. The distance between: 0 and 1 = heat-up phase; 1-2 = evaporation phase; 2-3 = regulating phase (heat supply).



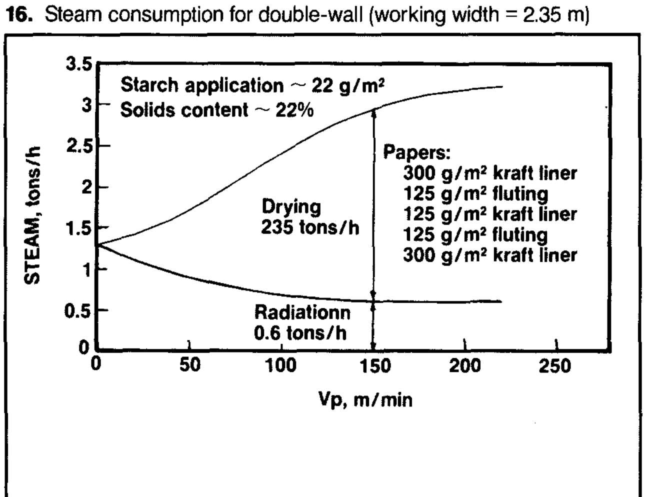
14. PAT values as a function of production speed for regulated and unregulated heat supply



15. Steam consumption for B-flute (working width = 2.35 m)



16. Steam consumption for double-wall (working width = 2.35 m)



Bond strength and test values

The PAT value shows the bond strength of the corrugated board structure (**Fig. 14**).

In the case of unregulated heat supply, the values are not adequate at low speeds. Since the paper temperature (110-120°C) is too high, brittle bonding results.

The PAT values also are low at high speeds because of too-low paper temperatures (80-90°C), visible as a white glue line.

Good design dictates that the preheating and heating surfaces can be regulated over the entire speed range in a way that the paper temperature neither exceeds nor falls below the optimum of 100°C.

Total heating power as a function of production speed

In **Figures 15 and 16**, the necessary heat quantity is expressed in tons of steam per hour as a function of production speed. The necessary thermal energy supply is composed of radiation heat lost and effective drying heat. The quantity of radiation heat diminishes with increasing speed since the available heating surfaces are better utilized (**Table V**).

In corrugated board manufacture, only about 24% of the total energy is needed to dry the glue film, even for single-wall board. Double-wall board needs only 20% of the total heat quantity/m². The remaining 76–80% of the total energy is used for heating fluting and liner (**Table VI**).

Conclusion

Knowledge of the mechanisms and energy requirements of the bonding process has allowed a better design of new corrugators. Further, this understanding should prove helpful in the modernization of existing corrugators and the improvement of their operating efficiency and productivity.□

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