Gluing corrugating medium and linerboard together on the corrugator

E. Daub
Research scientist, R&D Dept. of Feldmühle AG, Mill Uetersen, Federal Republic of Germany

U. Höke
Chief engineer, R&D Dept. of Jagenberg AG, Düsseldorf, Federal Republic of Germany

L. Göttsching
Head of the Institut für Paperfabrikation, Technical University of Darmstadt, Federal Republic of Germany

ABSTRACT *The aim of gluing corrugating medium to linerboard is to achieve a sufficient pin adhesion strength in the corrugated board. Glueability is related to the interaction between paper and glue under the influence of the amount of glue applied, heat, joining pressure, and web speed (especially as web speed determines open and closed times). Glueability can be viewed as the ability of paper to act with the glue to develop the adhesion forces supporting the strength characteristics required. How do the process parameters influence the structural strength of single-faced board and the optimal conditions for attaining maximum pin adhesion strength? How do paper properties affect glueability?*

KEYWORDS
Corrugated boards
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Gluing
Linerboard
Strength

Joining corrugated medium and linerboard by gluing is an essential part in the production of corrugated board. The purpose of gluing is to achieve sufficient structural strength in the corrugated board. The structural strength is affected by process parameters, by machine characteristics, by the properties of paper and glue, and by heat, as illustrated in **Fig. 1**.

Glueability is the ability of paper to anchor and to permit setting of the glue, which is determined by the glue's setting mechanism. For starch glue, the setting mechanism is gelatinization, which requires heat and water. The main parameters of the gluing process are the amount of glue applied (or "spread"), the joining pressure, heat, and the open time and closed time as determined by web speed.

The main differences between the single facer and double backer are in open time, closed time, and joining pressure. Here, we will look at the effect of spread and heat on the structural strength—as measured by pin adhesion strength—of single-faced corrugated board.

Experimental equipment

Trials have been performed with a semitechnical fingerless single facer made by BHS (Bayerische Hutten und Salzwerke in Weierhammer, Federal Republic of Germany). Depicted in **Fig. 2**, this machine works like a commercial corrugator but with a paper web width of 50 mm and a speed of at least 100 m/min. Higher speeds up to 300 m/min are attainable for the purpose of evaluating the corrugating system.

Because the web is narrow, a conventional two-roll glue application system could not be used, so an injection shoe (*1*) on the application roll is used to apply the glue reliably. The injection shoe guarantees an exact, reproducible film thickness simply by precise metering of the flow volume through control of the pump. The principle of this glue applicator system is shown in **Fig. 3**.

Gluing has been performed with a ready-to-use Stein-Hall starch glue (VC 46) based on corn and supplied by Maizena CPC (today Cerestar Company). The main features of the glue are: 24% solids content, 60°C gelatinization temperature, and a viscosity of 35 s measured at 27°C with a Stein-Hall cup.

Ten corrugating media and eight linerboards have been studied. Two of the corrugating media were made from semichemical pulp (NSSC, or neutral sulfite semichemical), two of the linerboards were kraft liner, but the rest were made from recycled fiber. The various corrugating media have been combined with the same kraft liner, and the various linerboards were glued to the same fluting. The corrugating media and linerboards have been heated in three different modes—low, medium, and high preheating. Low preheating means no wrapping, medium preheating means quarter wrapping, and high preheating means half wrapping both preheaters at the same time.

Controlling spread

The amount of glue applied has been controlled by metering the film thickness on the applicator roll. We have measured the actual amount of glue applied by two different methods. In one method, the spread is measured by determining the difference between the glue delivered by the metering pump and the glue scraped off after application (Fig. 3). This difference is then related to the area of combined board produced. In the second method, the spread is measured by means of a chemical tracer, $LiCl_2$, added to the glue slurry.

Under these procedures, the application of glue is directly proportional to the film thickness. **Figure 4** shows mean values based on trials with ten different corrugating media. As a rule of thumb, 1 g/m² of glue applied is equal to a film thickness of 25 μm for a typical C-flute profile independent of speed and speed ratio between the applicator roll and the lower corrugator roll. **Figure 5** shows that the amount of glue applied per 100 μm of film thickness depends on the roughness of the corrugating medium.

Minimal amount of glue required

The minimal amount of glue required for a sufficient pin adhesion strength is affected by the cavities to be filled on the surfaces of corrugating medium and linerboard. This amount depends on the roughness and can be assessed by the roughness coefficient determined by the short time absorption test (*2*), with a starch solution as test liquid:

$$M_{min} = C_K \rho A_K (K_{r,M} + K_{r,L}) \approx 2 C_K \rho A_K K_r \approx (K_{r,M} + K_{r,L})/2 \quad (1)$$

where

M_{min} = minimum amount of glue required, g/m²

C_K = solids content of the glue (here, 0.24 g/g), g/g

ρ = density of the glue (here, 1.10 g/cm³), g/cm³

A_K = ratio of the glue line area to the linerboard area

$K_{r,M}$ = roughness coefficient of corrugating medium, mL/m²

$K_{r,L}$ = roughness coefficient of linerboard, mL/m²

K_r = mean value of $K_{r,M}$ and $K_{r,L}$, mL/m²

The value for the ratio of the glue line area to the linerboard area can be found by:

$$A_K = n_g\, b/len \quad (2)$$

where

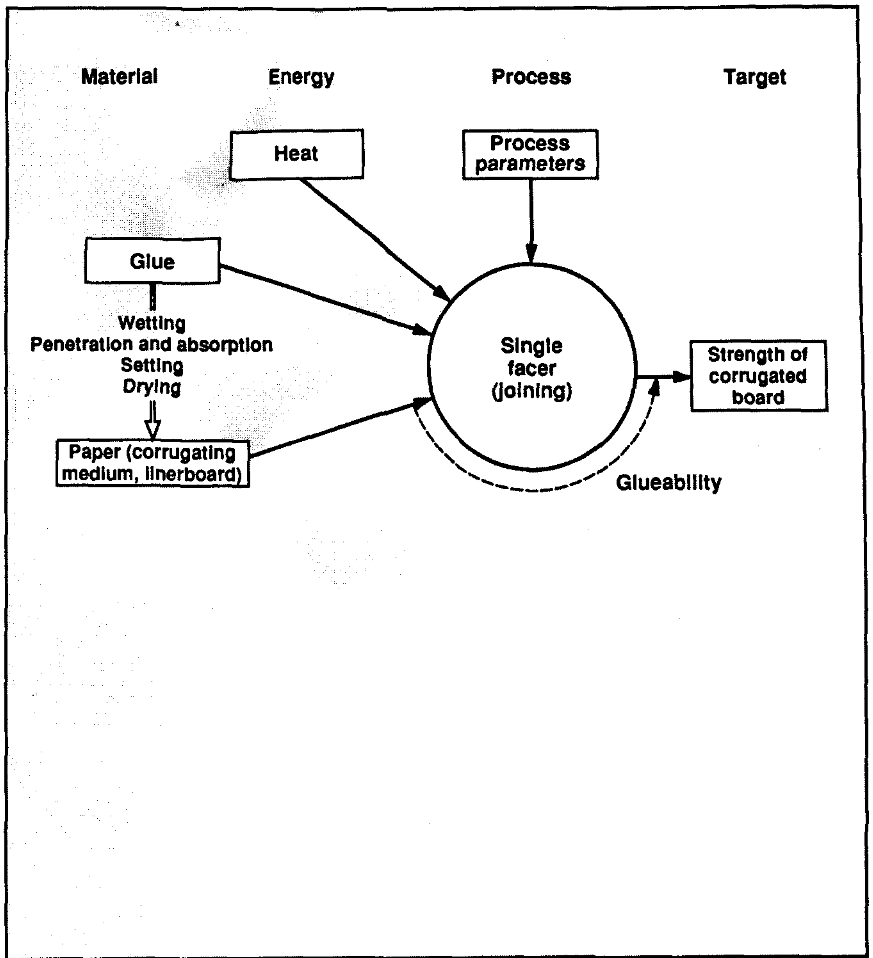
n_g = number of glue lines per running meter (here, 128 for C-flute)

len = length (here, 1 m), m

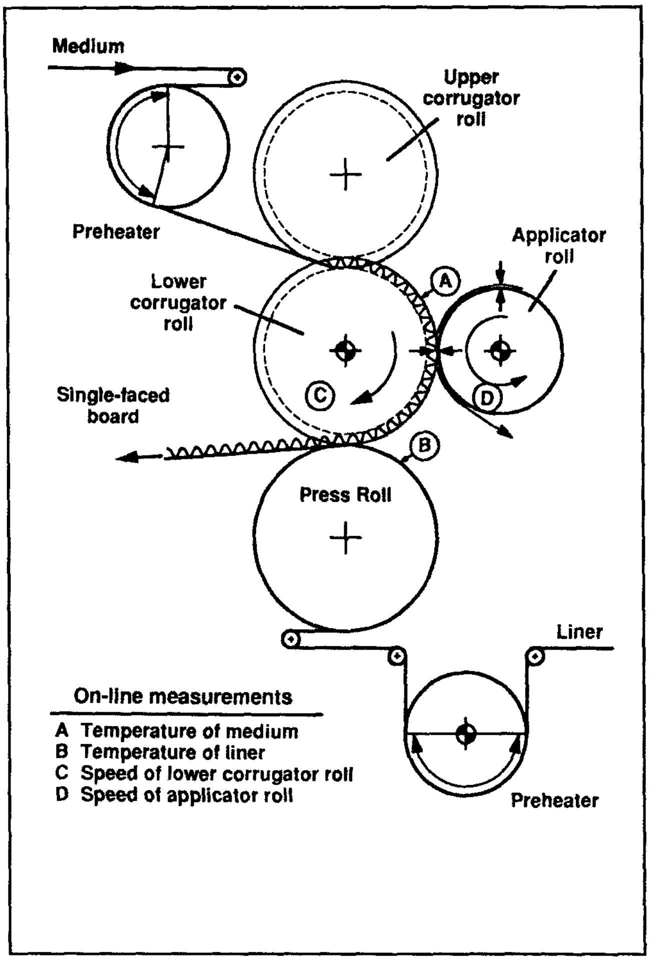
b = breadth of a glue line (here, 1.5 mm), mm.

The roughness coefficient of the corrugating media and linerboards covered ranges between 15 and 30 mL/m² for starch as test liquid. Based on these figures, the M_{min} amounts are between 1.6 and 3.2 g/m² (0.3–0.7 lb/1000 ft²). We found that the pin

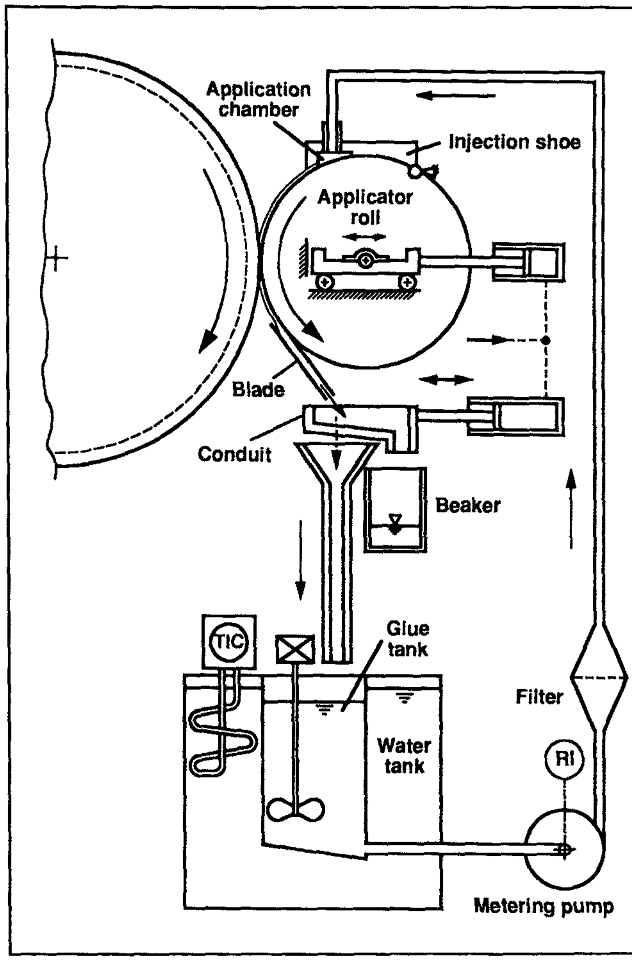
1. Principle of gluing in a single facer



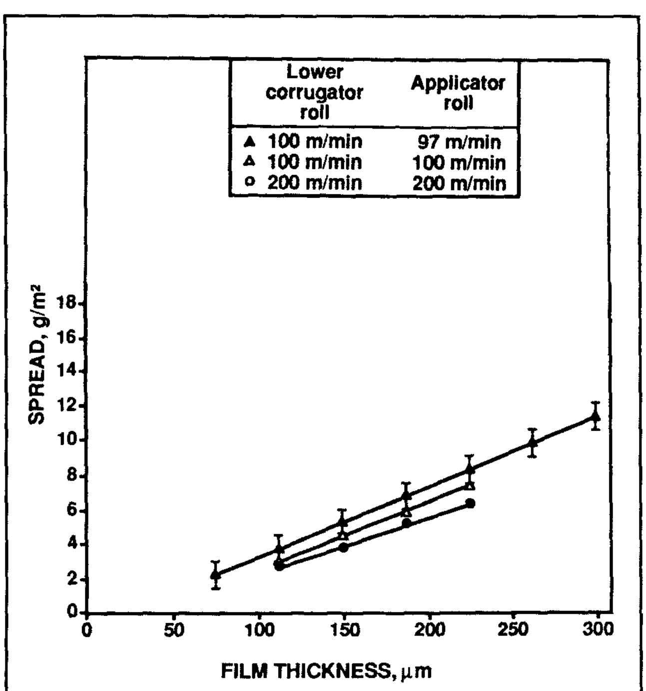
2. Scheme of the pilot fingerless single facer



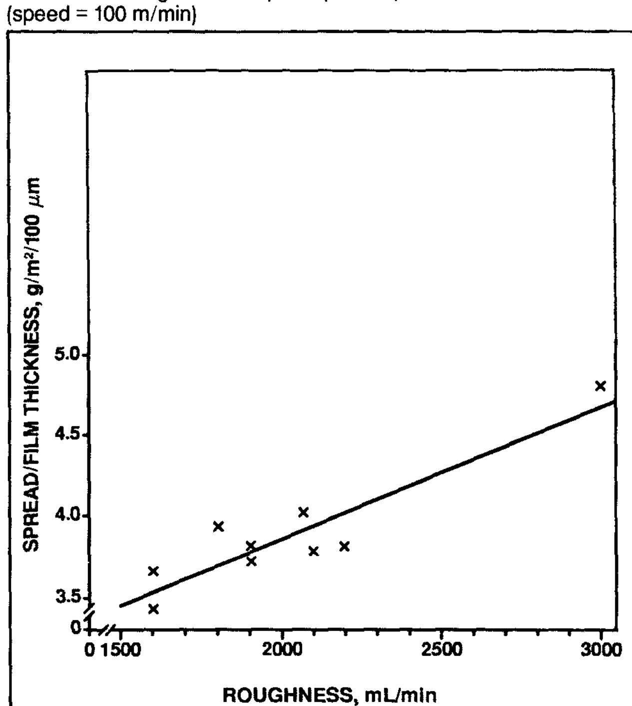
3. Application of glue in the fingerless single facer. TIC = temperature indicator control. R = revolution indicator.



4. Spread vs. film thickness at different speeds



5. Bendtsen roughness vs. spread per 100 μm of film thickness offered (speed = 100 m/min)



adhesion strength of the corrugated board is indeed minimal if glue is applied in these quantities. Below a spread of 2 g/m^2 (0.4 lb/1000 ft^2), the corrugating medium and linerboard do not adhere.

Flat crush resistance and hardness value

The trials have unearthed no significant effect of spread and heat on the flat crush resistance. According to our findings, the flat crush resistance is mainly determined by the flute geometry, the quality of conversion, and by the flat crush strength of the corrugating medium (CMT value).

Things are different with the hardness value, where an effect of heat and spread has been found. The hardness value is defined as the point of the first irreversible deformation of the flute in the stress-strain diagram of the flat crush test.

To demonstrate a general trend, we have plotted in **Fig. 6** the results of trials with ten different media in relation to the hardness value at a spread of 6.6 g/m^2 (1.35 lb/1000 ft^2) and medium preheating (points of reference = 100%). The hardness value is increased by spread and heat. At medium preheating and at a spread of 6.6 g/m^2, a hardness is attained that is not increased by applying more glue. At high preheating above a spread of 7 g/m^2, the hardness improves. The difference between maximum attainable and minimal hardness amounts to 30%, within the limits studied.

The improvement of the hardness value with increasing spread is explained by the supporting effect of the glue on the flanks of the flutes. The heat favors the gelatinization, which promotes the adhesion between glue and paper. Too much heat makes the glue brittle and hard, which also favors the hardness value.

Ring edge crush test

The ring edge crush test characterizes the crush resistance of single-face board formed into a ring of 160 mm in diameter and a free span of 16 mm. This test simulates the edge crush test and is performed like the ring crush test.

The results of the ring edge crush test have also been plotted in relation to the strength value of 6.6-g/m^2 spread and medium preheating (points of reference = 100%). **Figure 7** shows the relative mean values of the ring edge crush test for corrugating medium depending on spread at three different preheating conditions. Essentially the same results as with the corrugating media have been found with the linerboards.

Figure 7 indicates that the values for the ring edge crush test are improved by spread and heat. No significant difference exists between medium and high preheating. The difference between low and medium preheating amounts to approximately 10% on the average. With the linerboards at spreads above 4 g/m^2, the difference between low and medium preheating is more significant. The results indicate that at approximately 6-g/m^2 spread and with medium preheating, a strength is attained that cannot be increased by more spread and heat.

Pin adhesion strength

The pin adhesion strength has been evaluated by the pin adhesion test performed according to the European Federation of Corrugated Board Manufacturers Standard No. 11. The pin adhesion test has the disadvantage that at good gluing the pin adhesion strength cannot exceed the internal bonding strength of the components liners and corrugating medium. Correlations between the pin adhesion and ring edge crush tests have been found, with correlation coefficients ranging between 0.7 and 0.9. No correlation has been detected between pin adhesion test results and hardness values.

The pin adhesion test values have also been compared relative to 6.6-g/m^2 spread and medium preheating. **Figure 8** shows these relative pin adhesion test values at different spreads depending on the surface temperature of the corrugating medium measured directly before the glue was applied (Fig. 3).

At the low spreads in Fig. 8A, the relative pin adhesion test values at 3.7-g/m^2 spread are generally higher than those at 2.2-g/m^2 spread, which does not exceed 90%. (Again, the point of reference is taken as 100% at 6.6 g/m^2 spread.) The values scatter, but they indicate an optimum temperature at which the relative pin adhesion test attains its maximum. At 2.2-g/m^2 spread, this optimum temperature is about 90°C; at 3.7-g/m^2 spread, it is about 95°C. At 2.2-g/m^2 spread and temperatures above 90°C, brittle bonding occurs.

The variations and the low pin adhesion test values have two causes. One cause is that small amounts of glue can gelatinize and dry extensively before the corrugated medium comes into contact with the linerboard, which causes brittle bonding. The other reason is that the amount of glue is not sufficient to fill the cavities on the surface of rough papers.

Figure 8B demonstrates that at medium spread (5.1 and 6.6 g/m^2), the relative pin adhesion values reach their maximum at 100°C. The pin adhesion strength does not depend only on spread, but also on the ratio between spread and heat. There must be enough heat available for the gelatinization of the starch, but the glue should not be overheated.

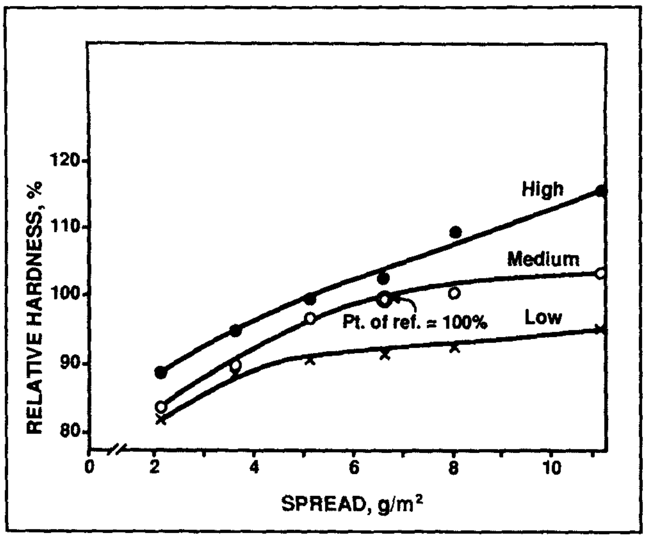
At high spreads (8.2 and 11.0 g/m^2), there is a linear relationship between pin adhesion test and the surface temperature of the corrugating medium, as Fig. 8C shows, because it takes more heat for the larger amount of glue to gel. Below 90°C, the starch does not gel, and white glue lines occur.

At low and medium spreads, no relationship could be detected between pin adhesion test values and the surface temperature of the linerboard measured just before its joining with the corrugated medium. At high spreads, however, the pin adhesion test value increases with the surface temperature of the linerboard in a way similar to that shown in Fig. 8C.

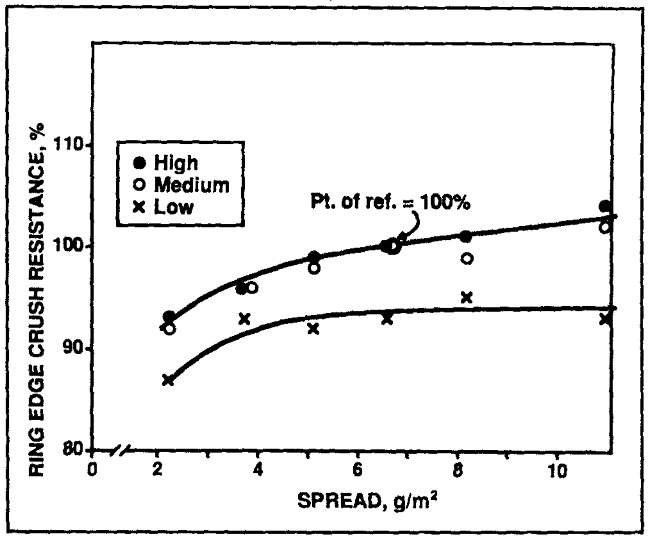
The explanation for these findings is that the surface temperature of the corrugating medium exerts a stronger influence on the gelatinization of the glue than the temperature of the linerboard because the corrugated medium has the first contact with the glue. The corrugating medium has to gelatinize a small portion of the glue without drying it before joining with the linerboard, in order to effect the green bond. At higher spread, the additional heat from the linerboard is more significant.

From these results, we conclude that optimal conditions for maximum

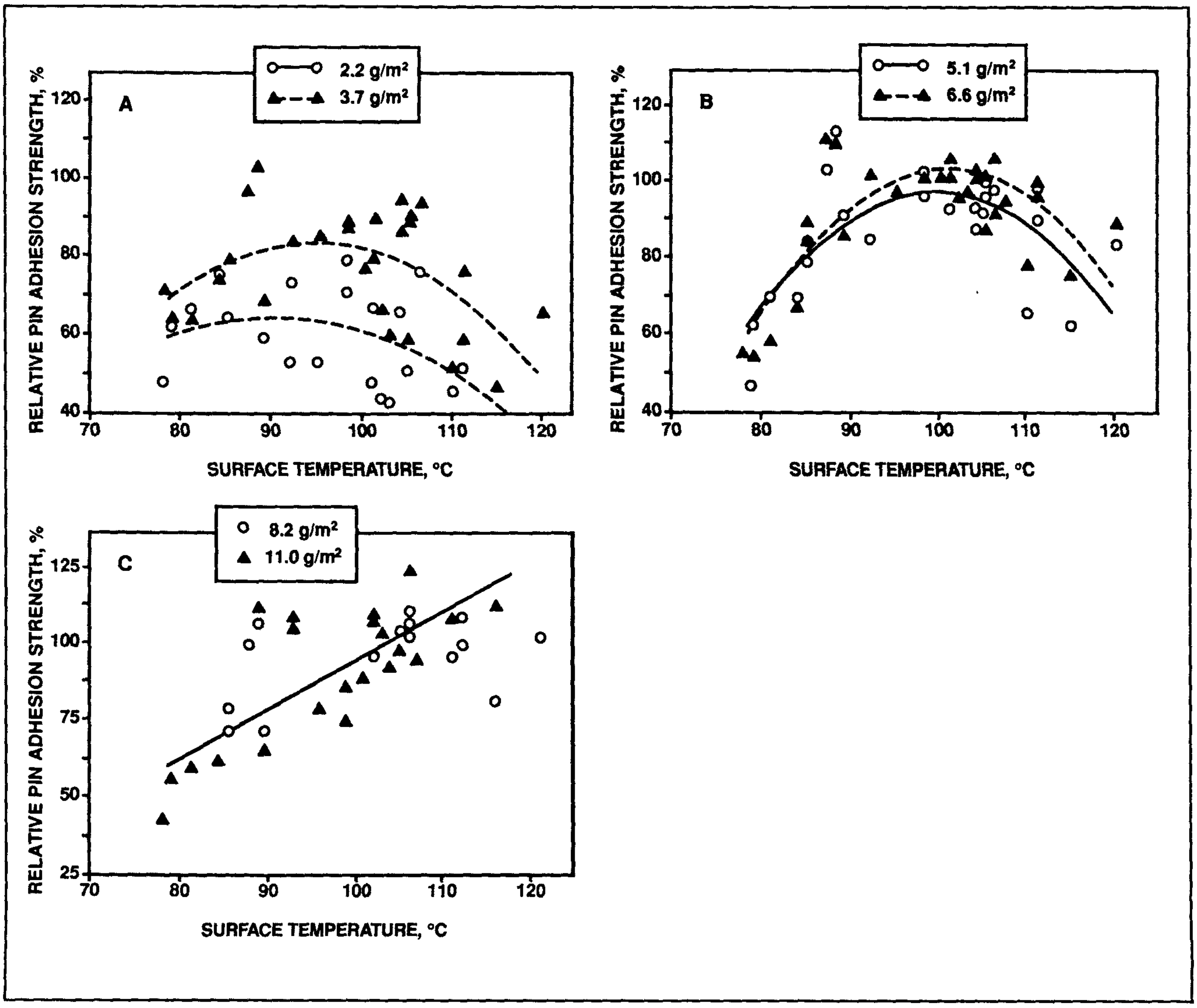
6. Spread vs. relative hardness at low, medium, and high preheating of corrugating medium and linerboard (speed = 100 m/min)



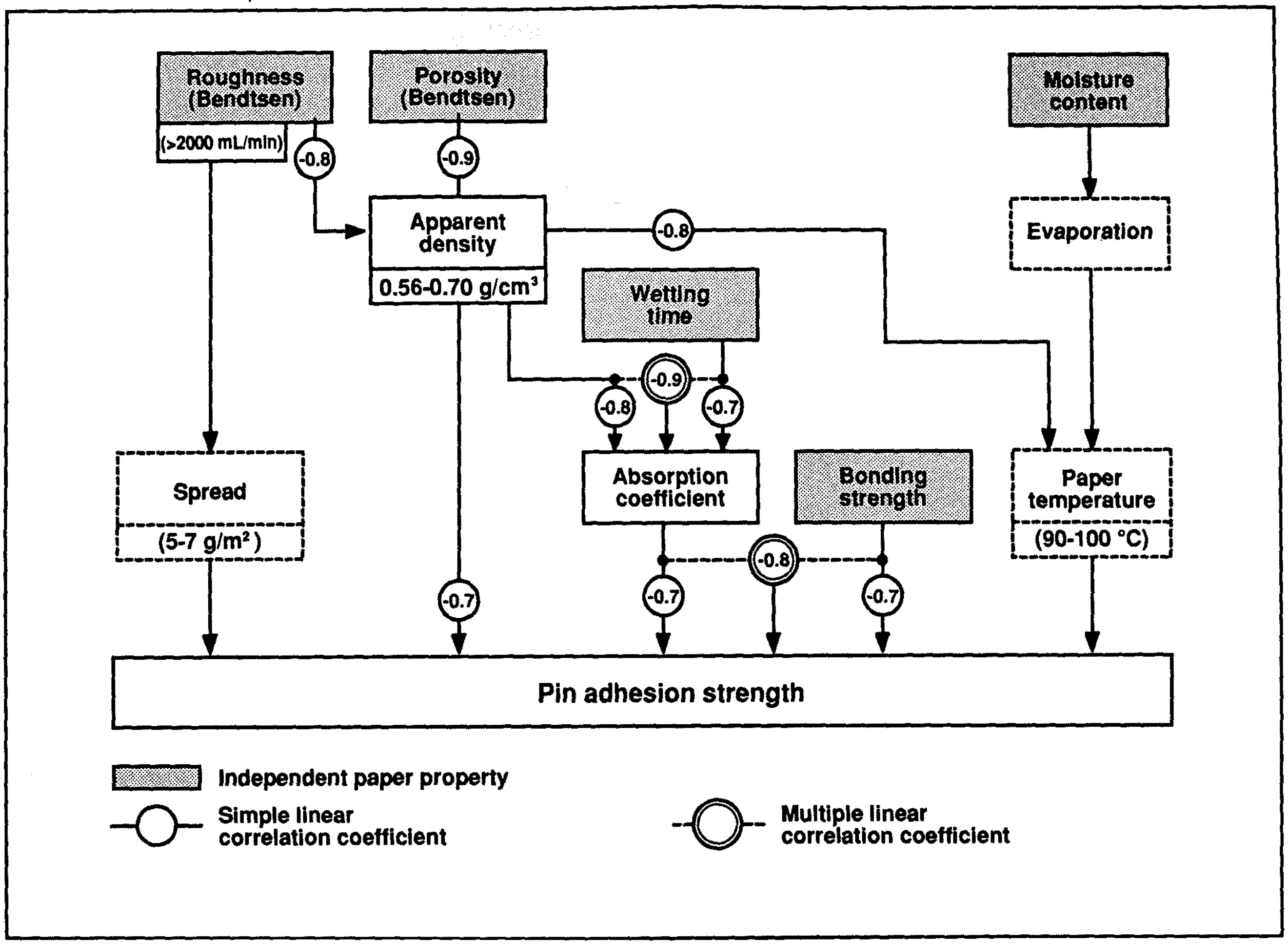
7. Spread vs. the relative ring edge crush resistance of single-faced board at low, medium, and high preheating of corrugating medium and linerboard (speed = 100 m/min)



8. Relative pin adhesion strength vs. surface temperature of the corrugating medium just before glue is applied at (A) low, (B) medium, and (C) high spreads



9. Correlation between paper characteristics and pin adhesion strength (spread between 5 and 7 g/m² and paper surface temperatures between 90°C and 100°C)

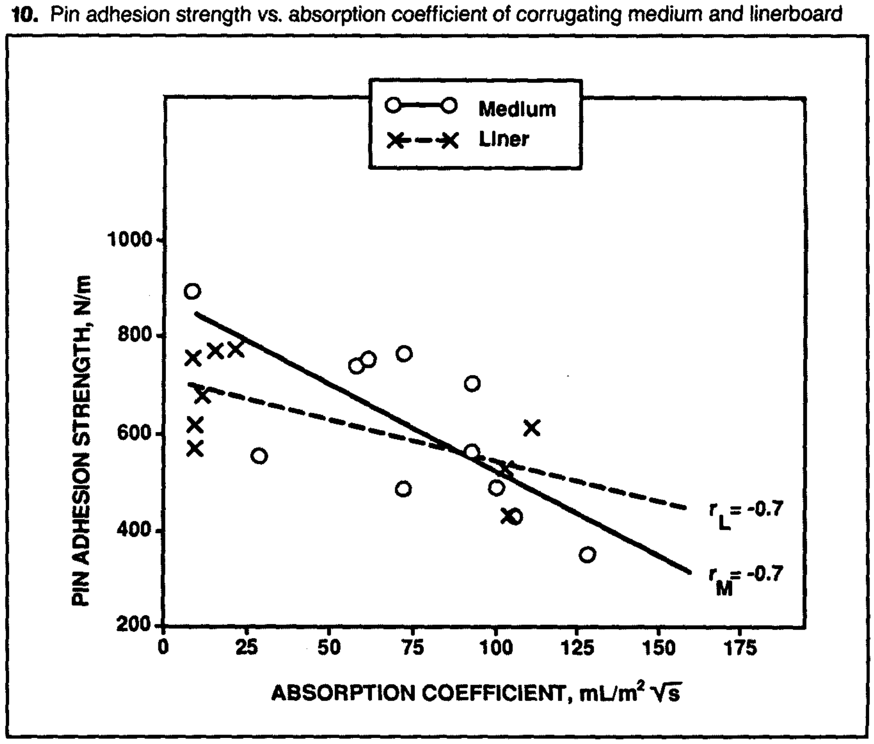


pin adhesion strength are attained at spreads between 5 and 7 g/m² (1.0–1.4 lb/1000 ft²) and at a surface temperature of the corrugated medium of 100°C, measured right before the glue is applied. The temperature of the linerboard should be in the same range. However, applying more glue does not increase the pin adhesion strength further.

Glueability

The paper properties which probably affect the glueability are basis weight, apparent density, moisture content, porosity, absorbency, thermal conductivity, surface energy, and roughness (*3*). The absorbency behavior of paper is different for glue and water. Looking at it in another way, it also depends on the capillary forces and external pressure (*4*). As to glueability, the absorption of water of pH 7 due to capillary forces is relevant. Most paper properties are interrelat-

10. Pin adhesion strength vs. absorption coefficient of corrugating medium and linerboard



ed, so our discussion can be focussed on a few independent properties.

Figure 9 depicts the way paper properties interrelate and the correlation between paper properties and pin adhesion strength. To ensure a fair comparison between the linerboards and corrugating media, we have considered only the pin adhesion strength that had been achieved under optimal conditions—i.e., medium preheating and 6.6-g/m^2 spread. The pin adhesion strength is best explained in a multiple correlation analysis, with the absorption coefficient and bonding strength of the papers having a multiple correlation coefficient of 0.8. The absorption coefficient has been measured by the short time absorption test with water of pH 7. The absorption of water has a negative effect on bonding because it disturbs the gelatinization process, which requires water and heat. The internal bonding strength of paper affects the pin adhesion strength at good gluing. Therefore, this bonding strength has to be taken into account.

Figure 10 shows that lower pin adhesion strength is indeed obtained at higher absorption coefficients. This trend becomes more evident for the corrugating media because they had been glued with a kraft liner that is less absorbent. On the other hand, the linerboards had been joined with an absorbent fluting, which blurred the influence of the linerboards.

The apparent density correlates with the pin adhesion strength at densities higher than 0.56 g/cm^3 (Fig. 9). The surface temperature of linerboards and media heated solely in the single facer without the preheaters correlates with apparent density (Fig. 2). Therefore, the correlation between apparent density and pin adhesion strength is explained by an effective heat transfer from the rolls to the paper. For media, this is important because in a fingerless single facer, less cold air is sucked through a dense medium, which results in less cooling and thus promotes gelatinization. At apparent densities below 0.56 g/cm^3, the lowest temperatures have been measured both on the liner and on the corrugating medium surfaces, but the pin adhesion strength is higher than expected. The reason is that the roughness in this low-density range exceeds 2000 mL/min (Bendtsen), and this improves the anchoring of the glue in the paper surface. This is confirmed by the linear relationship between roughness and adhesion strength in this high roughness range.

Even though surface temperature and apparent density correlate, we may not assume that there is a direct relationship between density and thermal conductivity. The heating of paper is a complex process involving thermal conduction, evaporation and condensation effects, and the drying of paper. If paper is heated on a metallic surface with the temperature below 100°C, little moisture evaporates. Heat is transferred to the colder surface mainly by thermal conduction. The thermal conductivity is essentially independent of apparent density in the range up to 0.9 g/cm^3 (*5*) and amounts to approximately 0.8 W/(m•°K).

Quite different mechanisms take effect if the temperature of the metallic surface is considerably above 100°C. Where the surface is 170°C, evaporation takes place in the paper layer immediately adjacent to the contact surface. A considerable portion of the energy supplied is converted to steam, which moves to the relatively colder layers. In doing so, it partially condenses and returns the energy to the paper. This cyclic evaporation and condensation is an effective means of heat transfer (*6*), and this explains why the thermal conductivity does not decrease although moisture is evaporated.

As long as the nonheated surface does not exceed 100°C, the thermal conductivity remains at the constant 0.8 W/(m•°K). When the temperature rises about 100°C, the thermal conductivity decreases dramatically (*7*) because steam cannot condense, and its energy is lost to the surroundings. Therefore, at a constant basis weight, the surface temperature of the corrugating medium that is optimal for gluing at 100°C can easily be controlled by the contact time of the medium with the preheater and corrugating rolls.

The moisture content is more crucial in determining the surface temperature of the paper. Trials have been conducted at the Institut für Papierfabrikation (*7*) using a preheater with a surface temperature of 170°C. These trials have shown that the moisture content decreases linearly to approximately 2.5% moisture. In this linear range, the surface temperature of the paper cannot surpass a limit that is distinctly below the temperature of the preheater (*8*). A certain amount of energy is lost to the surroundings. This amount ranges between 25% and 40% of the energy transferred and is smaller, the denser the paper. The increase in surface temperature with apparent density is explained by the reduction in the losses of heat energy to the surroundings. The losses are greater with greater moisture content of the paper. If the moisture drops below 2.5%, the rate of evaporation diminishes dramatically. Now the surface temperature can approach the temperature of the preheater; however, the temperature rises slowly because the thermal conductivity has decreased.

To evaluate the effect of moisture, gluing trials have been performed with two papers in which the moisture content at the edge of the paper machine was intentionally raised by a steam spray to 11% in one case and overdried to 5% in the other. In the experimental single facer, the paper with 11% moisture has reached a lower surface temperature than the reference papers with 7% moisture, and the paper with 5% moisture has attained a higher surface temperature glued under the same conditions. The pin adhesion strength correlates with the surface temperatures of the paper in the single facer. This experiment demonstrates why the moisture content should be in the range of 6% to 7%. Too much moisture hinders the heating, while a low moisture content facilitates overheating. Because the porosity correlates well with the apparent density, the relationships for density are inversely valid for porosity. This means that porosity does not promote pin adhesion strength.

Conclusions

Gluing trials were conducted using a semitechnical single facer. These trials showed that the maximum pin adhesion strength of corrugated board, its maximum hardness, and the maximum ring edge crush strength of single-faced linerboard are achieved at glue applications of 5–7 g/m^2 and at a surface temperature of the corrugated medium of 100°C measured just before the glue is applied.

The pin adhesion strength is affected by the absorption coefficient and the bonding strength of paper. Highly absorbent paper will produce a corrugated board with a lower pin adhesion strength than less absorbent paper. The moisture content affects the heating of the paper. More heat is transferred via dense paper than via porous paper. Roughness only increases pin adhesion strength if it exceeds 2000 mL/min (Bendtsen).□

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