The Influence of Pin Adhesion Strength on Edge Crush and Box Compression Strength

M. Schaepe

April 2000

Submitted to Corrugating International
The Institute of Paper Science and Technology is an independent graduate school, research organization, and information center for science and technology mainly concerned with manufacture and uses of pulp, paper, paperboard, and other forest products and byproducts. Established in 1929 as the Institute of Paper Chemistry, the Institute provides research and information services to the wood, fiber, and allied industries in a unique partnership between education and business. The Institute is supported by 52 North American companies. The purpose of the Institute is fulfilled through four missions, which are:

- to provide multidisciplinary graduate education to students who advance the science and technology of the industry and who rise into leadership positions within the industry;
- to conduct and foster research that creates knowledge to satisfy the technological needs of the industry;
- to provide the information, expertise, and interactive learning that enables customers to improve job knowledge and business performance;
- to aggressively seek out technological opportunities and facilitate the transfer and implementation of those technologies in collaboration with industry partners.

ACCREDITATION

The Institute of Paper Science and Technology is accredited by the Commission on Colleges of the Southern Association of Colleges and Schools to award the Master of Science and Doctor of Philosophy degrees.

NOTICE AND DISCLAIMER

The Institute of Paper Science and Technology (IPST) has provided a high standard of professional service and has put forth its best efforts within the time and funds available for this project. The information and conclusions are advisory and are intended only for internal use by any company who may receive this report. Each company must decide for itself the best approach to solving any problems it may have and how, or whether, this reported information should be considered in its approach.

IPST does not recommend particular products, procedures, materials, or service. These are included only in the interest of completeness within a laboratory context and budgetary constraint. Actual products, materials, and services used may differ and are peculiar to the operations of each company.

In no event shall IPST or its employees and agents have any obligation or liability for damages including, but not limited to, consequential damages arising out of or in connection with any company's use of or inability to use the reported information. IPST provides no warranty or guaranty of results.

The Institute of Paper Science and Technology assures equal opportunity to all qualified persons without regard to race, color, religion, sex, national origin, age, disability, marital status, or Vietnam era veterans status in the admission to, participation in, treatment of, or employment in the programs and activities which the Institute operates.
THE INFLUENCE OF PIN ADHESION STRENGTH ON EDGE CRUSH AND BOX COMPRESSION STRENGTH

Michael Schaepe
Institute of Paper Science and Technology
500 10th St, NW, Atlanta, GA 30318

Introduction

Field data have, on occasion, appeared to indicate that a significant relationship exists between pin adhesion strength and edge crush strength (ECT) and box compression strength (BCT). The field data are derived from tests performed on production boxes. In these cases, pin adhesion cannot be considered an independent variable. The consequence is that cause and effect cannot be established. In other words, although pin adhesion, ECT, and BCT values may be low, it cannot be said that low compression strength was due to poor pin adhesion.

This article will investigate historical information regarding the relationship between pin adhesion and ECT and BCT. Further, recent data generated at the Institute of Paper Science and Technology regarding this relationship will be presented, and special circumstances that may influence this relationship will be explored.

Terminology

It is first necessary to discuss terminology. Pin adhesion is the strength of the adhesive bond that holds the board facings to the corrugated medium. For C-flute board, the pin adhesion test sample is 2 inches in the flute direction and 6 inches long. Pin adhesion is measured by placing 13 pins through the flutes. Six alternating pins are driven downward while the other pins remain stationary. The force that is required to separate the linerboard from the medium is measured. In this manner 12 glue lines or 24 inches of glue line are tested. The force that is required to separate the facing from the medium is divided by 2 to generate pin adhesion strength in units of pounds force per foot (lbf/ft). Figure 1 presents a partial view of the pin adhesion test with 6 of 13 pins visible. The arrangement of pins in this view is for selective pin adhesion where one facing, either the single-face or double-back linerboard, is separated from the medium.

Edge crush test (ECT) is a column test for a combined-board sample. The sample is typically 2 inches high by 2 inches wide; however, there are several edge crush test methods, and sample size may vary. Sample dimensions can also vary based on flute size. Figure 2 shows the sample configuration and direction of applied force. ECT is the compression strength of the sample reported as pounds force per inch. It is an important test for predicting box performance.
Pin Adhesion

Figure 1: Selective pin adhesion test sample with 6 of 13 pins shown. Pins move downward as shown while alternating pins remain fixed. The bottom linerboard is separated from medium.

ECT

Figure 2: Edge crush test

Box compression test (BCT) is a measure of the compressive strength of a full box. As indicated in Figure 3, the top-to-bottom test is performed with the load applied from the top. For reference, ECT and pin adhesion samples are outlined on the front of the box,
which in this case has a front panel dimension of approximately 24 inches wide by 15 inches high.

![Figure 3: Top-to-bottom box compression test. ECT and pin adhesion sample orientation indicated.](image)

Historical Data

In 1989, Whitsitt, Smith and Hall (1) conducted experiments exploring the relationship between high-speed corrugator runnability and bonding. The emphasis of this work was on the effects of medium and corrugating conditions on combined board quality. A regression analysis was performed using several terms including pin adhesion. A simplification of the resulting equation concentrating only on the pin adhesion term is:

$$\text{ECT (lbf/in)} = 0.02 \times \text{Pin Adhesion (lbf/ft)} + \text{other terms}$$

This equation indicates that for a 10-lbf/ft change in pin adhesion strength, only a 0.2-lbf/in change in ECT would be expected.
In 1993, Batelka and Smith (2) studied the effect of box plant variables on ECT. The regression analysis for this work involved several different terms but included pin adhesion. The resulting equation with only the pin adhesion term emphasized is:

\[
\text{ECT (lb/in)} = 0.15 \times \text{Pin Adhesion (lb/ft)} + \text{other terms}
\]

Here, a slightly more significant relationship was found between pin adhesion and ECT. For a 10-lbf/ft change in pin adhesion strength, a 1.5-lbf/in change in ECT would be expected.

In both studies, a relationship was found between pin adhesion strength and ECT. The relationship was, however, small. Next, the effect of pin adhesion strength change is applied to specific ECT and BCT cases.

Application

Pin adhesion strength of 50-lbf/ft is often considered to be a low limit at box plants, whereas, 60-lbf/ft is typically recognized as good pin adhesion strength. Let us see what happens to ECT strength if pin adhesion strength drops from 60-lbf/ft to 50-lbf/ft while all other factors are held constant. In the Whitsitt, Smith and Hall equation, a combined board sample having an initial ECT strength of 40-lbf/in would drop only 0.2-lbf/in to 39.8-lbf/in. In the Batelka and Smith equation the loss would be 1.5-lbf/in with the resulting ECT strength of 38.5-lbf/in.

The lower limit of pin adhesion strength in a commercial corrugating operation is approximately 30 lbf/ft. Below this level delamination is likely. The Whitsitt, Smith and Hall equation would predict a final ECT strength of 39.4 lbf/in if the pin adhesion strength were to fall from 60-lbf/ft to 30-lbf/ft. This is a loss of only 0.6-lbf/in. The Batelka and Smith equation would predict a somewhat larger 4.5-lbf/in loss in ECT and result in a final ECT strength of 35.5-lbf/in. Figure 4 shows these relationships.

<table>
<thead>
<tr>
<th>Pin Adhesion</th>
<th>ECT Whitsitt/et.al</th>
<th>ECT Batelka/Smith</th>
<th>BCT Whitsitt/et.al</th>
<th>BCT Batelka/Smith</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 lbf/ft</td>
<td>40 lbf/in</td>
<td>40 lbf/in</td>
<td>800 lbf</td>
<td>800 lbf</td>
</tr>
<tr>
<td>50 lbf/ft</td>
<td>39.8 lbf/in</td>
<td>38.5 lbf/in</td>
<td>797 lbf</td>
<td>791 lbf</td>
</tr>
<tr>
<td>30 lbf/ft</td>
<td>39.4 lbf/in</td>
<td>35.5 lbf/in</td>
<td>778 lbf</td>
<td>733 lbf</td>
</tr>
</tbody>
</table>

Figure 4: The effect of pin adhesion loss on ECT and BCT. Shown are the predicted ECT and BCT losses for 10-lbf/ft and 30-lbf/ft reductions in pin adhesion strength based on two studies cited.
What would be the predicted outcome of comparable pin adhesion losses on box compression strength? According to the work of McKee, Gander and Wachuta (3), the expected BCT loss from a 10% reduction in ECT would be 7.5%. Using this relationship, a box with an initial strength of 800-lbf would lose 3-lbf for a 10-lbf/ft loss in pin adhesion strength and 9-lbf for a 30-lbf/ft pin adhesion loss according to the Whitsitt, Smith and Hall equation. The resulting box strengths would be 797-lbf and 791-lbf force, respectively. With the Batelka and Smith equation, the loss would be somewhat larger with 22-lbf and 67-lbf losses. The resulting box strengths would be 778-lbf and 733-lbf. This information is presented in Figure 4.

Recent Studies

Over the past several years, studies conducted at the Institute of Paper Science and Technology have added to the information available to address the relationship between pin adhesion strength and ECT and BCT. In one study, samples were collected at several corrugating speeds for different adhesives and two paper grade combinations. All other factors were held constant. These experiments were conducted at regular intervals over a three-year period. Another experiment involved a broad range of paper grades at several corrugating speeds. All other conditions remained constant. The Institute’s pilot single-facer corrugator was used in these experiments. Single-face board was combined using a static platen press. Results from these experiments are presented in the following charts.

![ECT and Pin Adhesion vs Speed](image)

**Figure 5: Summary of corrugating trials conducted at IPST**
It is widely accepted that pin adhesion will decrease as corrugator speed increases. Figure 5 summarizes data generated from adhesive studies conducted from 1994 through 1996 at IPST. Different adhesives and board combinations produced different curves, but in all cases, pin adhesion decreased as speed increased. Also displayed on Figure 5 are ECT results. Notice, that as speed increases and pin adhesion strength decreases, a corresponding trend does not appear for ECT. The curves for ECT remained flat as corrugator speed increased. To place pin adhesion and ECT on the same graph, pin adhesion was expressed as lbf. ECT was reported in lbf/in.

The next set of three graphs (Figures 6 through 8) show the relationship between pin adhesion and ECT at 300, 500, and 700 fpm. Since only limited information was available at 900 fpm, these data were not displayed. Data for 1994 and 1996 produced the same trends and, therefore, only 1996 data are provided here. In none of the three graphs does a statistically significant trend arise. In at least one case, ECT appeared to increase as pin adhesion decreased.

The data on Figures 6 through 8 are combined to create Figure 9. A trend-line based on linear regression is included. Although a positive slope is indicated, the statistical
confidence of this line is weak with $R^2 = 0.18$. Still, from these data, the regression analysis provides the following equation:

$$\text{ECT (lbf/in) } = 0.125 \times \text{Pin Adhesion (lbf/ft)} + \text{constant}$$

This equation tells us that for a 10-lbf/ft change in pin adhesion strength, a 1.25-lbf/in change in ECT would be expected. If the initial ECT strength of combined board is 40-lbf/in and pin adhesion strength is 60-lbf/ft, and the pin adhesion strength dropped to 50- and 30-lbf/ft, respectively, then ECT strength would drop to 38.8- and 36.2-lbf/in. If the initial box compression strength were 800-lbf and the pin adhesion strength decreased as described, the resulting box strengths would be 782-lbf and 746-lbf.

For experiments in 1998, linerboard grades were varied. Four linerboard grades, 26#, 35#, 42#, and 55#, were used. The medium basis weight for these trials was 26#. Figure 10 plots pin adhesion and ECT versus corrugator speed. The solid symbols represent pin adhesion. Here, as in previous experiments, pin adhesion strength decreased as corrugator speed increased. The heavier the board weight the greater the decrease in pin adhesion strength. The open symbols on the graph represent ECT strength. Three different symbols appear. Triangle symbols represent 55#, circular symbols represent 26#, and square symbols represent 35# and 42# boards. No obvious trend appears for this ECT data. Two traces appear to have positive slopes while the others are noisy but overall flat.

This data is then plotted in Figure 11 as ECT versus pin adhesion. The 35# and 42# linerboard follow the same general trend reported for the 1994 and 1996 data. The 26#
and 55# board results appear anomalous, but with only three data points each, no reliable conclusion can be reached regarding these grades.

Figure 11: ECT-Pin Adhesion relationship for four linerboard grades

Figure 12: BCT-Pin Adhesion relationship for four linerboard grades
RSC containers with partial flaps were constructed from the board generated in these experiments. The containers were 12”x7”x8” and within McKee box parameters (3). BCT was performed on these boxes and the results are reported on Figure 12. BCT results for the 26# and 35# boxes do not show a compression strength change as pin adhesion strength changes. But, as combined board weight increases, pin adhesion plays a larger role in box performance. As board weight increases, compression strength and bending stiffness also increase. It can be expected, based on the increase in these properties, that the normal force on the glue line would be greater. As the pin adhesion strength decreases, bending and shear forces on the glue line can exceed adhesive strength and cause box failure at lower compression strength.

Conclusions

It has been shown from recent experiments and historical studies that the influence of pin adhesion strength on edge crush and box compression strength is minimal. For a 10-lbf/ft change in pin adhesion strength a 0.2-lbf/in to 1.5-lbf/in change in ECT may occur; for a 30-lbf/ft change in pin adhesion a 0.6-lbf/in to 4.5-lbf/in change in ECT can be expected. This level of ECT loss is below the threshold of detection or statistical significance when considering commercial box plant operations. Therefore, it can be concluded that pin adhesion strength does not significantly impact the compressive performance of boxes.

It has also been shown, however, that there are exceptions to this rule. Basis weight can impact the relationship between pin adhesion and box performance. Heavy weight linerboards, due to increased bending and shear stresses on the glue line, may decrease box strength to a greater degree than grades of 42# or less.

Intermittent glue application, glue line skip, can magnify the effects of pin adhesion loss on ECT and BCT (4). A 0.1-inch glue skip can cause a 4% loss in ECT, and a 0.4-inch skip can cause a 17% ECT loss (5). Furthermore, the combined effects of glue line skip and heavy board weight would have an even greater impact on compression performance.

There are still other factors that may influence the relationship between pin adhesion and compression strength. These include mismatched board components, asymmetric box construction and brittle bond, all of which may cause a greater than expected change in compression strength due to changes in pin adhesion. Unless these special circumstances exist, however, it would not be wise to ascribe compression strength losses to pin adhesion.
Literature Cited


(2) Batelka and Smith, The Effects of Box Plant Variables on the Edge Crush Test of Corrugated Board, Final Report to the Containerboard and Kraft Paper Group, API, 1993.

