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

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THE INFLUENCE OF PIN ADHESION STRENGTH ON EDGE CRUSH AND BOX COMPRESSION STRENGTH

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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.

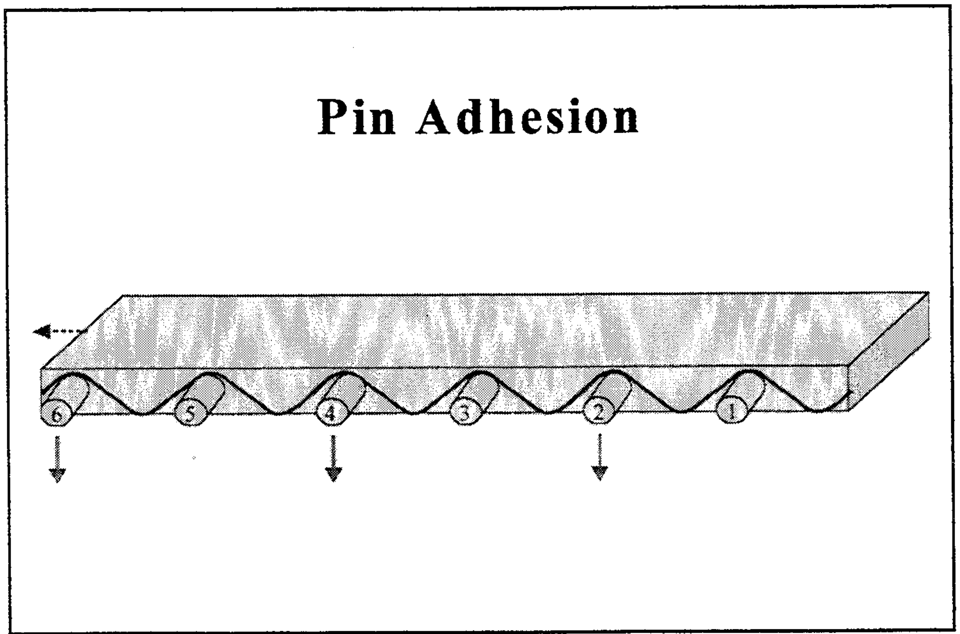

Figure 1: Selective pin adhesion test sample with 6 of 13 pins shown. Pins move downward as shown while alternating pins remain fixed. The bottom linerboard is separated from medium.

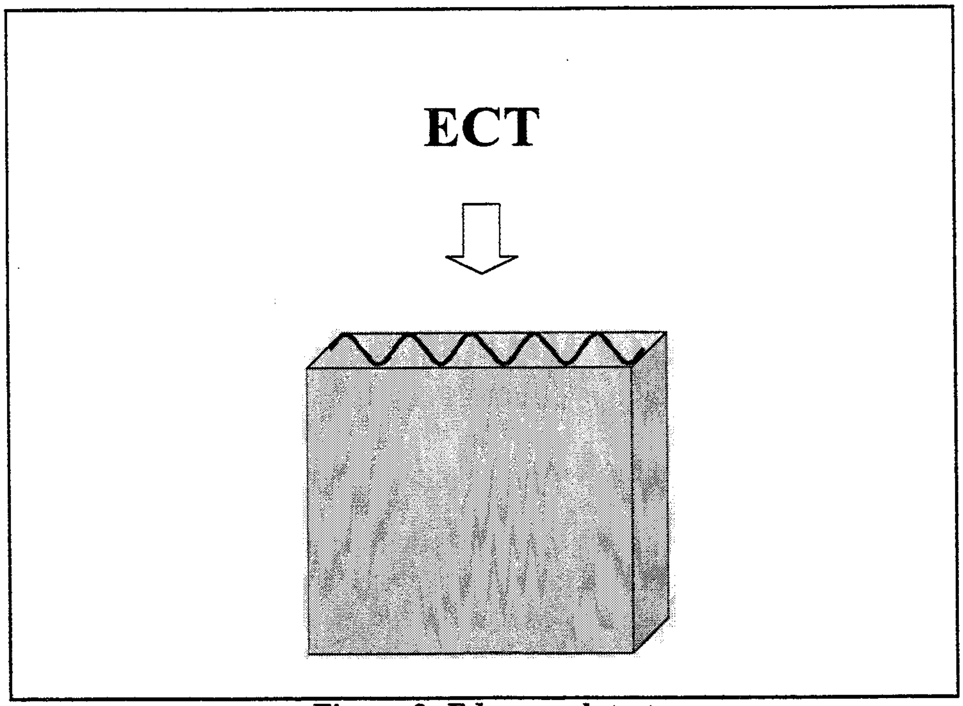

Figure 2: Edge crush test

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.

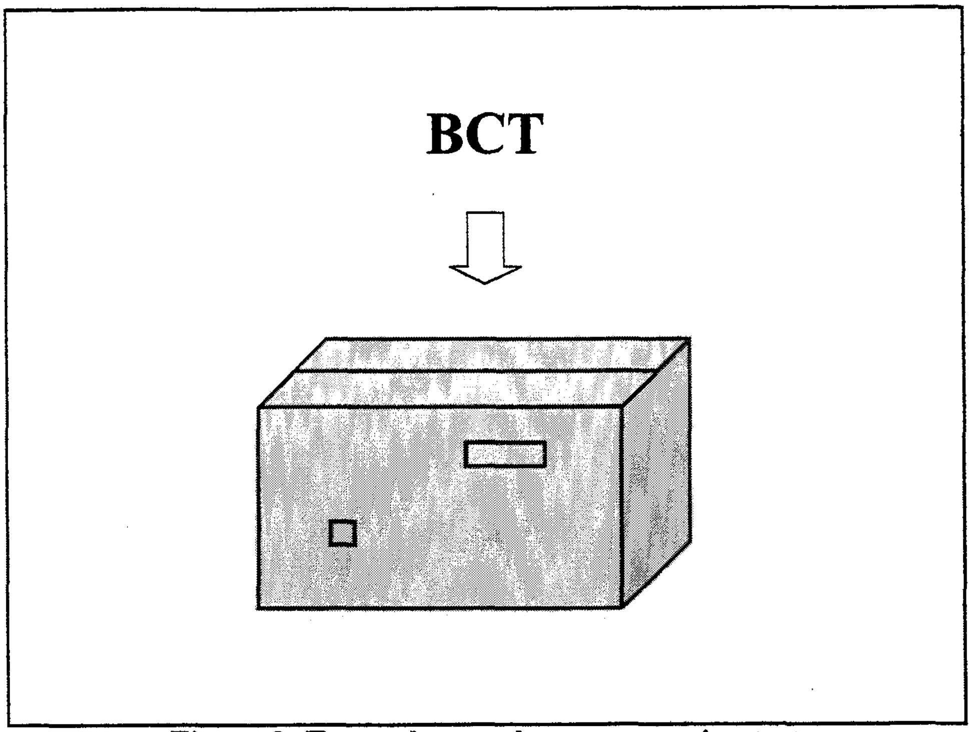

Figure 3: Top-to-bottom box compression test.
ECT and pin adhesion sample orientation indicated.

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:

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

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:

$$\text{ECT (lbf/in)} = 0.15 * \text{Pin Adhesion (lbf/ft)} + \text{other terms}$$

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.

<u>Application</u>

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.

Effect of Pin Adhesion Loss on ECT

Pin Adhesion	ECT Whitsitt/et.al.	ECT Batelka/Smith
60 lbf/ft	40 lbf/in	40 lbf/in
↓ 50	↓ 39.8	↓ 38.5
↓ 30	↓ 39.4	↓ 35.5

Effect of Pin Adhesion Loss on BCT

Pin Adhesion	BCT Whitsitt/et.al.	BCT Batelka/Smith
60 lbf/ft	800 lbf	800 lbf
↓ 50	↓ 797	↓ 778
↓ 30	↓ 791	↓ 733

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.

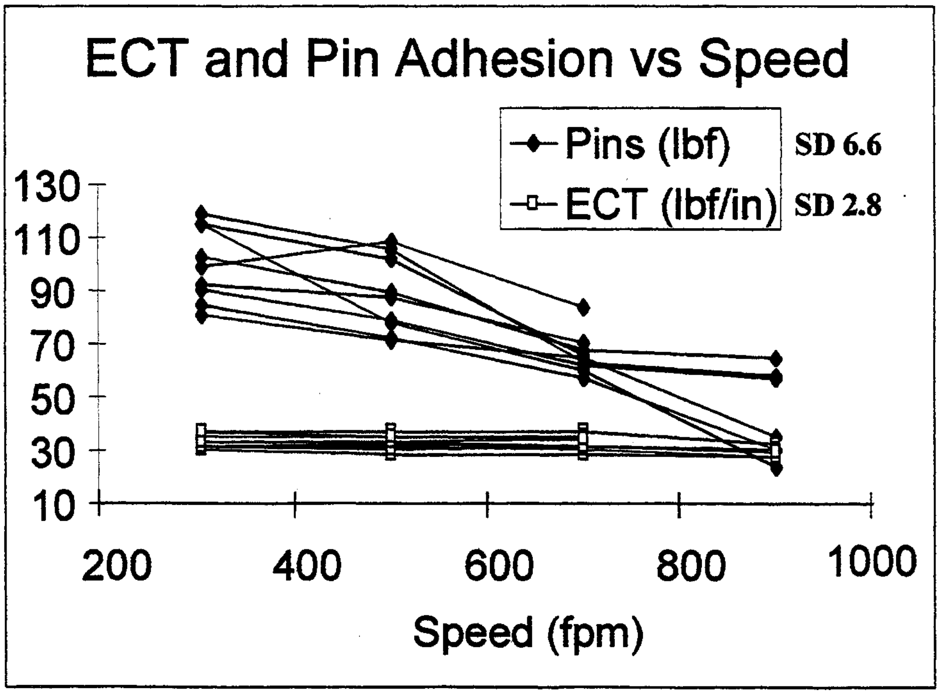

Figure 5: Summary of corrugating trials conducted at IPST

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.

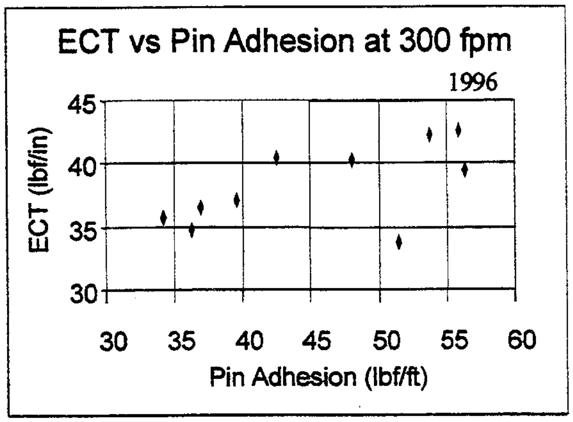

Figure 6

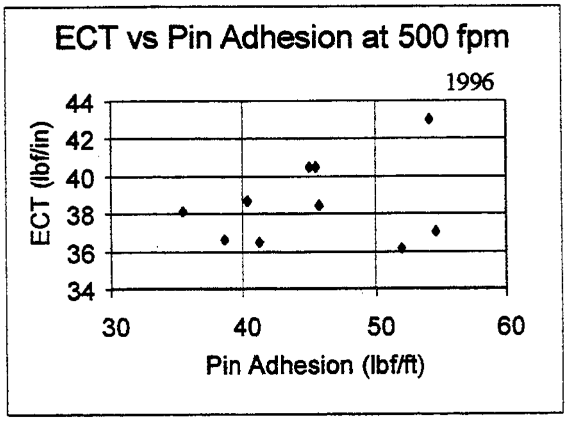

Figure 7

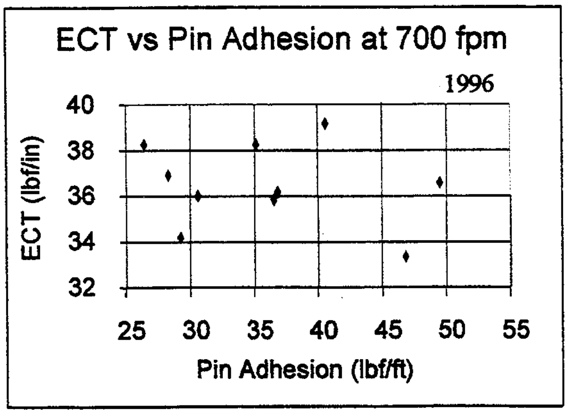

Figure 8

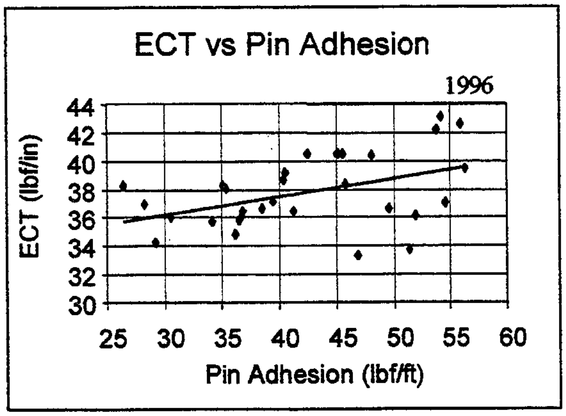

Figure 9

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:

$$ECT\ (lbf/in) = 0.125 * Pin\ Adhesion\ (lbf/ft) + constant$$

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.

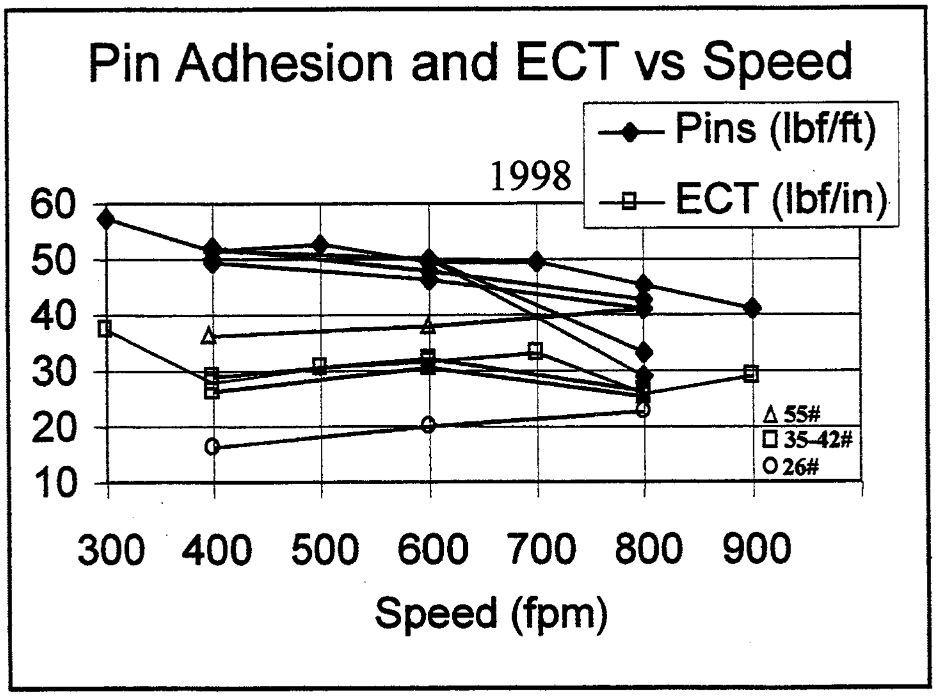

Figure 10: IPST corrugating trials using four linerboard grades

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.

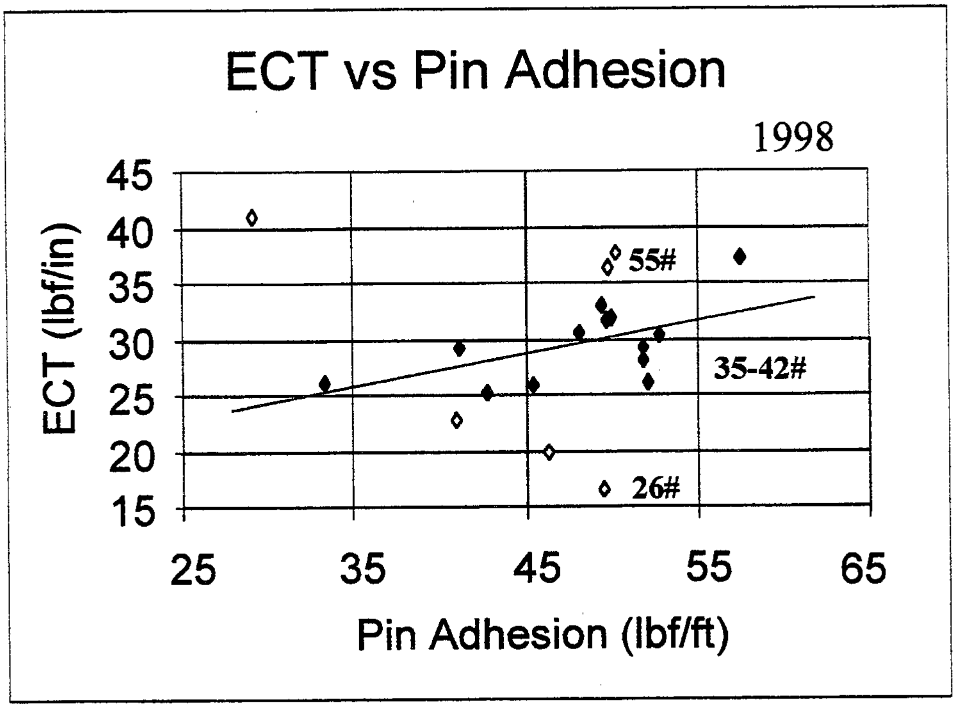

Figure 11: ECT-Pin Adhesion relationship for four linerboard grades

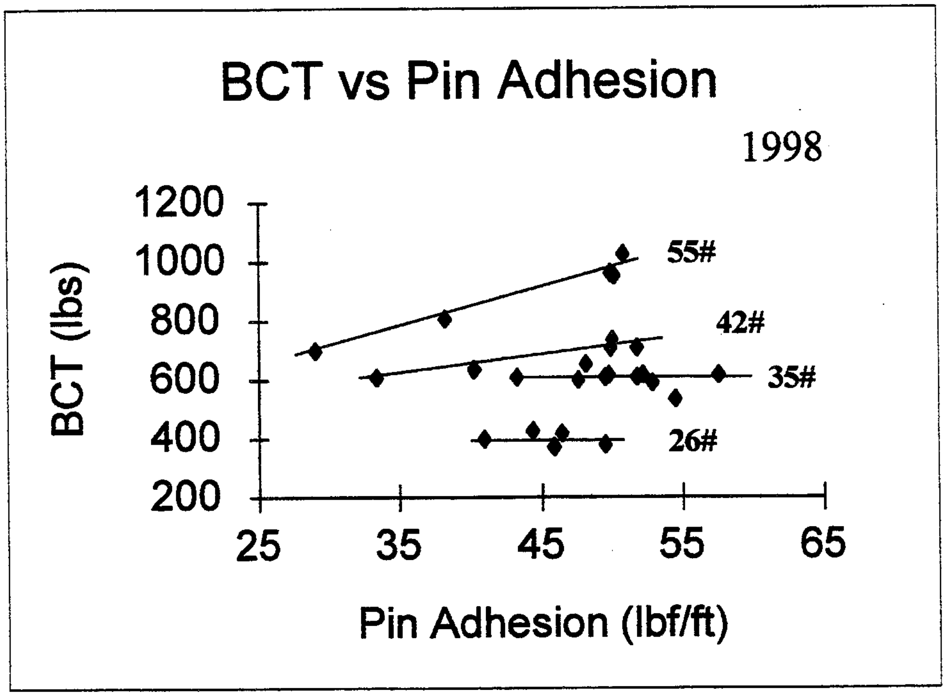

Figure 12: BCT-Pin Adhesion relationship for four linerboard grades

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 roll 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.

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