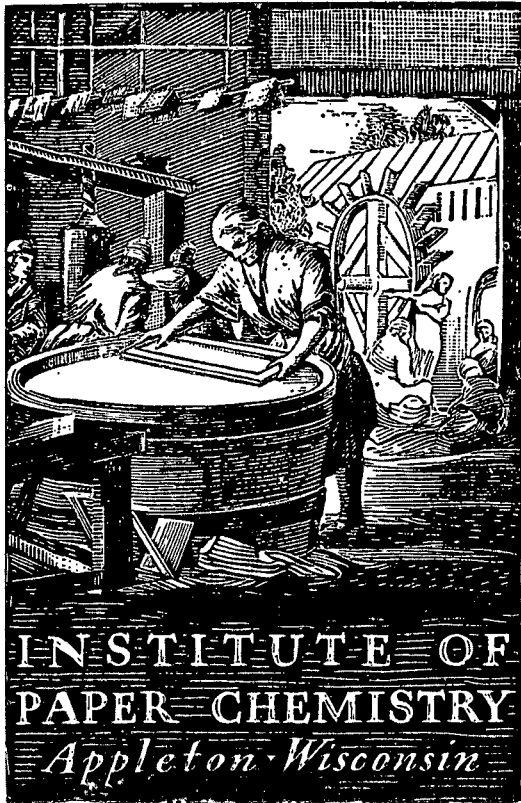


M. LORENZ

GENERAL



**STUDY OF THE EFFECT OF DIFFERENT SCORING
TECHNIQUES AND SCORING PROFILES ON BOX
COMPRESSION PERFORMANCE**

Project 2695-19

**A Summary Report
to**

**FOURDRINIER KRAFT BOARD GROUP
of The
AMERICAN PAPER INSTITUTE**

October 19, 1977

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

The score lines required to convert corrugated board into boxes play a critical role in the box making process. Improper scoring can cause numerous problems in the box plant or at the user level. Some of these are cracked liners, flaps that do not stay glued in place, and poor box compression performance. Even the outward appearance of the finished box is partially dependent upon the scoring process.

The scoring wheels used in the scoring process have changed very little during the last few years. A patent was issued several years ago describing new scoring wheel profiles and the theory behind their design. It was decided to obtain a set of these wheels and compare them to the common industry standard profiles and also to some additional scoring wheel combinations that could be set up from the current types of scoring wheels found in a typical box plant.

The profiles evaluated were as follows:

For flap scores:

Standard 3-point flap score

Inverted 3-point flap score

V vs. V flap score

Majewski Patent flap score

Notched flap score

For panel scores:

Standard V vs. flat steel

V vs. flat polyurethane
Mejewski Patent 90° cross-direction profile
Mejewski Patent 180° cross-direction profile

Furthermore, it was decided to vary the scoring wheel set-up parameters of clearance and offset in order to better understand their effects on the scoring process.

An optimum scoreline should possess the following qualities:

1. The fold should be uniform along the scored line.
2. There should be no cutting of the liners during scoring and no cracking of the liners during folding.
3. Box performance should be maximized.
4. Folding torque should be minimized.

Based on these criteria, the evaluation of the scoring profiles was made by comparing the results of box compression tests (top load for flap scores and end load for panel scores), scoreline folding torque tests, and scoreline cracking tests. The tests were conducted on five different combined board series.

These results were obtained:

1. Flap score profiles

No single combination of profile, clearance and off-set proved to be superior to all others over the full range of the five board samples. Table I shows the results of the top load compression tests as a composite of the four single wall board constructions and the double wall board construction.

TABLE I
SUMMARY OF BOX TOP LOAD COMPRESSION TESTS

Profile	Clearance	Offset	Single Wall Composite of Four Board Series		Double Wall Series	
			% of Standard Top Load	% of Standard Deflection	% of Standard Top Load	% of Standard Deflection
Standard 3-point	Standard	0	--	--	--	--
Standard 3-point	-0.010"	0	-2.8	+5.5	+0.8	+8.3 ^a
Standard 3-point	+0.010"	0	-1.9	-0.3	+2.0	-4.5
Inverted 3-point	Standard	0	-7.6 ^a	+11.9 ^a	+5.2 ^a	-14.7 ^a
V vs. V	Standard	0	+2.9 ^a	-18.5 ^a	+13.3 ^a	-21.9 ^a
V vs. V	-0.010"	0	+4.2 ^a	-15.9 ^a	+26.5 ^a	-17.4 ^a
V vs. V	+0.010"	0	+3.3 ^a	-12.1 ^a	+26.3 ^a	-18.1 ^a
Majewski Patent	-0.010"	0.010"	+6.8 ^a	-6.7 ^a	+26.7 ^a	-23.7 ^a
Majewski Patent	-0.005"	0.010"	+8.7 ^a	-5.9 ^a	+21.2 ^a	-23.3 ^a

^aPercentage difference considered significant at the 0.05 level.

In general, the V vs. V profile and Majewski Patent flap score profile produced boxes of slightly higher top load strength and correspondingly lower deflection than the boxes produced with the 3-point flap score. Both the V vs. V profile and the Majewski Patent flap score profile are narrower than the standard 3-point profile and crush a smaller area of the corrugated board during the scoring process. A more sharply defined scoreline results from this narrower scoring pattern. The expected results from the more sharply defined scorelines are higher than standard top load strengths and lower than standard deflections. Therefore, the test results agree with theory.

The V vs. V scorelines produce the higher box top load compression results at the expense of much higher folding torque requirements. The single wall composite averages for the conditions shown in Table I indicate that the folding torque requirements for the V vs. V scorelines are 56.8 to 99.2% higher than the folding torque requirements for the standard 3-point flap scorelines.

The Majewski Patent flap scorelines require only slightly more folding torque than the standard 3-point flap scorelines. However, the Majewski Patent profiles have a much higher tendency to cause cracking of the single face liner during the scoring process than either the 3-point flap score profile or the V vs. V profile.

Finally, the 3-point flap score profile proved to be relatively insensitive to clearance variations while the results of the other profiles evaluated were more variable as the scoring wheel clearances were changed.

2. Panel score profiles

There was less difference between panel score profiles tested than existed between the flap score profiles tested. Table II summarizes the end load compression test results.

As in the case of the flap score profiles, no one single panel score set-up combination proved to be superior to all other combinations when all five board samples were considered. The Majewski Patent profiles (both 90° and 180° cross direction) exhibited slightly higher than standard box end load strengths but offered no advantage in reducing deflections. The Majewski Patent profiles also required from 24.9 to 51.0% lower than standard folding torque when considering the single wall composited averages. As in the case of the flap score profiles, the Majewski Patent profiles had a higher than standard tendency to produce cracking in the liners during the scoring process.

The V vs. flat polyurethane profile produced results very similar to the V vs. flat steel profile for all tests and all combined board series.

3. General

Isolated cases of specific conditions of nonstandard profile, clearance and offset produced very substantial increases in box performance for some of the combined board grades. However, the lack of uniformity in this improvement over all of the board grades for a given combination of profile, clearance and offset indicates that a large amount of experimental work would be required in order to find the

TABLE II
SUMMARY OF BOX END LOAD COMPRESSION TESTS

Profile	Clearance	Offset	Single Wall Composite of Four Board Series		Double Wall Series	
			% of Standard End Load	% of Standard Deflection	% of Standard End Load	% of Standard Deflection
V vs. flat steel	Standard	0	--	--	--	--
V vs. flat steel	-0.005"	0	3.0 ^a	+11.6 ^a	-5.3 ^a	+0.5
V vs. flat poly	Standard	0	-0.1	+2.3	-4.0	+0.5
V vs. flat poly	-0.005"	0	+2.1	+7.5 ^a	-11.0 ^a	-1.0
Majewski 90° C.D.	+0.025"	0	+4.4 ^a	+1.7	-3.5	+6.9
Majewski 90° C.D.	Standard	0.1"	+1.6	-0.8	+0.5	+3.8
Majewski 90° C.D.	-0.005"	0.1"	+5.0 ^a	+6.0 ^a	-9.4 ^a	+2.5
Majewski 180° C.D.	Standard	0	+2.5	+6.4 ^a	+1.3	+5.3
Majewski 180° C.D.	-0.005"	0	+3.8 ^a	0	-7.6 ^a	-0.3

^aPercentage difference considered significant at the 0.05 level.

optimum set-up for each combined board to be scored. It is possible that the effort spent to optimize a particular set-up may be justified for a long production run or in order to solve a specific problem.

The Majewski Patent profiles are very complex in shape and much work could be done in altering their geometry for further attempts at finding universally better flap and/or panel score profiles.

INTRODUCTION

The process of scoring corrugated board plays an important role in the manufacture of corrugated boxes. The scoring wheels act to reduce the stiffness of the corrugated board to allow the board to be folded along the scoring line. Improper scoring can cause cutting of the single face liner at the time of scoring, cracking of the double face liner at the time of folding, or an overall reduction in box performance after the box is filled and sealed.

It is generally known that a rectangular tube consisting of four vertical walls made from corrugated board will have a top load compression strength about 25% greater than a box made of the same size and material, but having top and bottom flaps. In addition, the results of box compression tests for maximum load and deflection are highly variable and the majority of this variability is attributed to the presence and nature of the scorelines. Thus, the existence of scorelines and flaps has an important effect on corrugated box performance. The scorelines also have an effect on other box converting operations since the forces needed to fold the corrugated board for making the manufacturer's joint and seal the flaps are functions of the effectiveness of the scoring process. Ultimately, the outward appearance of a finished box is a direct result of the quality of the scores made on the corrugated board.

There has been very little work published lately regarding the effect of different scoring profiles or conditions on box manufacture or box properties. However, interest has been generated in this subject recently. This is in part due to the granting of a patent for scoring wheels that promises increased box compression performance, lower folding torque requirements, reduced liner cracking and better finished appearance (1). This interest resulted in the funding for

this project which was undertaken to study the effects of various scoring profiles and conditions on box compression performance and scoreline folding properties.

This report presents the results of flap scoreline effects on box top load compression, panel scoreline effects on box end load compression, and a relative comparison of scoreline folding torques and cracking tendencies for various flap and panel scoring conditions on five different grades of combined board.

FLAP SCORE PROFILES EVALUATED

STANDARD THREE POINT FLAP SCORE

The standard 3-point flap score is the one most widely used by industry for producing the machine direction scorelines needed for box top and bottom flaps. It consists of a wheel with a single blunt ridge to score the single face liner mated to a wheel with a double blunt ridge to score the double face liner. A drawing of the profile is shown in Fig. 1, along with some of the critical dimensions obtained from the wheels used for this project.

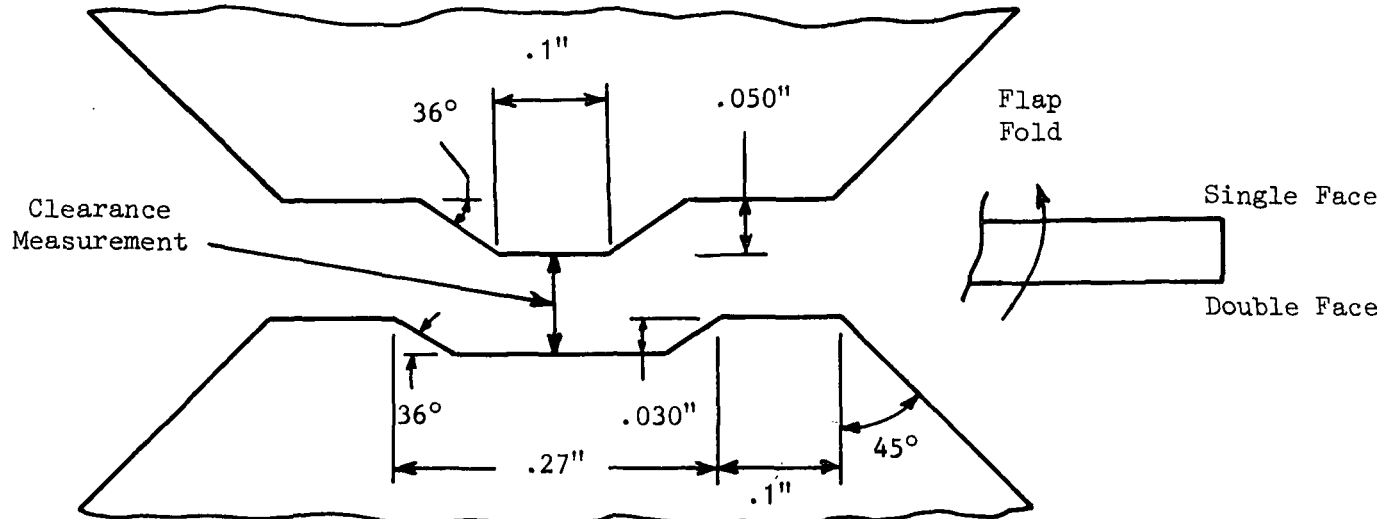


Figure 1. Drawing of Standard 3-Point Flap Score

The clearance of this profile is defined as the distance between the peak of the ridge on the single face wheel and the valley between the ridges on the double face wheel (Fig. 1). The profile is symmetrical and no offset is allowable because of the possibility of interference between the ridges of the opposing wheels. Clearance must be measured indirectly or by dimensional wires inserted into the clearance space between the wheels. The indirect method of clearance measurement is discussed in the report in a special section under "Test Procedures."

In normal scoring operations at the Institute, this profile is used with a clearance equal to the sum of the component calipers (single face and double face liner plus medium) plus 0.005 inch (noted as t+5 for convenience). This condition of scoring was considered as the standard flap score and used as the basis of comparison for all other flap scores. This scoring condition was also used as the flap score for all the boxes made with different panel scores in the evaluation of the panel score profiles.

In addition to the standard clearance condition of t+5, this profile was also run at 0.010 inch wider gap setting (t+15) and at 0.010 inch narrower gap setting (t-5) for all board series tested. One board series was also run at a 0.020 inch wider gap setting than standard (t+25).

INVERTED THREE POINT FLAP SCORE

The inverted 3-point flap score was made using the same wheels as the standard 3-point flap score except that the position of the wheels relative to the liners was reversed. The single face liner was scored by the wheel with two ridges while the double faced liner was scored by the wheel with the single ridge. The wheel clearance of t+5 (sum of component calipers plus 0.005 inch) of the standard scoring condition was the only one evaluated.

V vs. V FLAP SCORE

The wheels for the V vs. V flap score profile were obtained from the normal panel score profile of V vs. flat wheel. Two of the V-shaped wheels from that profile were set opposite each other as shown in Fig. 2.

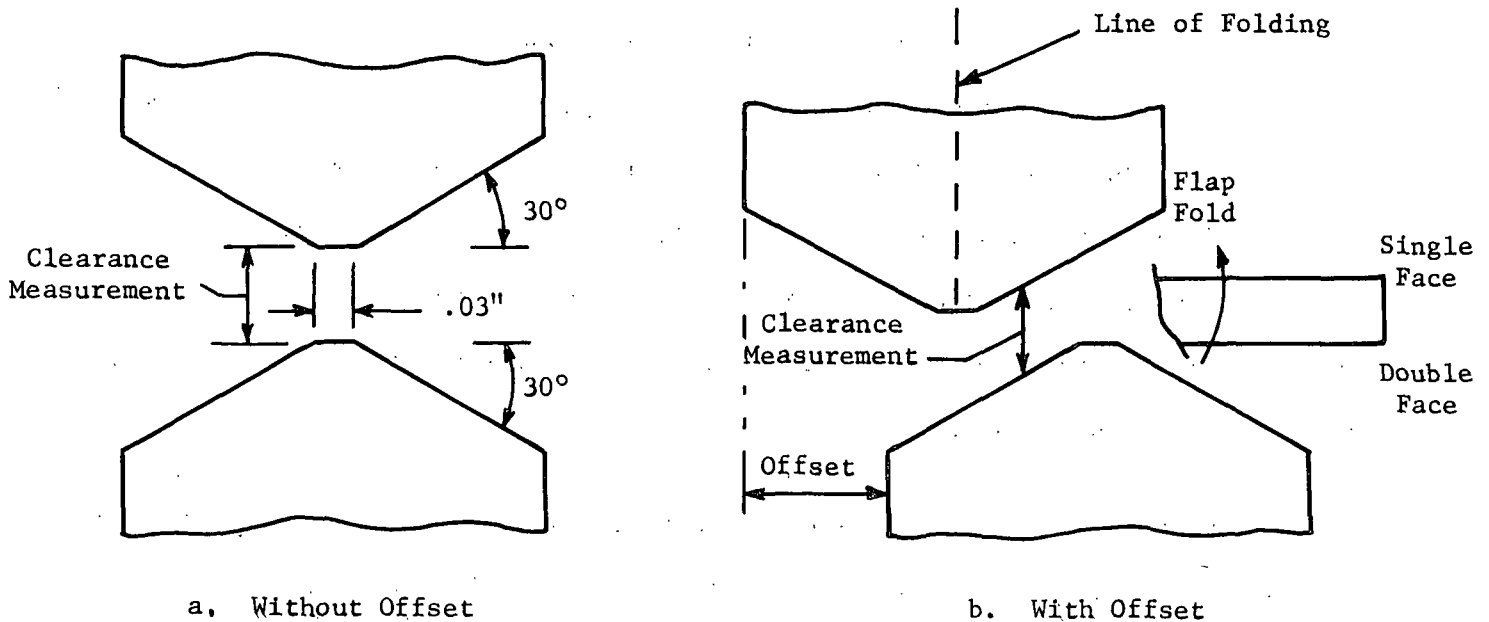


Figure 2. Drawing of V vs. V Flap Score

In the case of zero offset (Fig. 2a), with the wheels directly opposed, the clearance was measured between the wheel diameters using feeler gages. The wheels were run at three levels of clearance in this configuration, $t+5$, $t-5$, and $t+15$.

An offset of 0.12 inch was also selected for evaluation after some simple scoring and folding experiments using the V vs. V profiles. The wheel contacting the double face liner was offset in the direction of the flap (toward the outside of the blank) by the specified amount as shown in Fig. 2b. The actual offset measurement was done by using the faces of the scoring wheels as reference points. The offset of the wheels made direct measurement of wheel clearance impossible and the indirect method had to be used. Only the standard clearance of $t+5$ was used for this combination of profile and offset.

MAJEWSKI PATENT FLAP SCORE (MACHINE DIRECTION)

The United States patent number 3,746,593, issued to Majewski, contains profile descriptions for both flap and panel scores (1). The flap score profile, also referred to as the machine direction profile in the patent, is shown in Fig. 3.

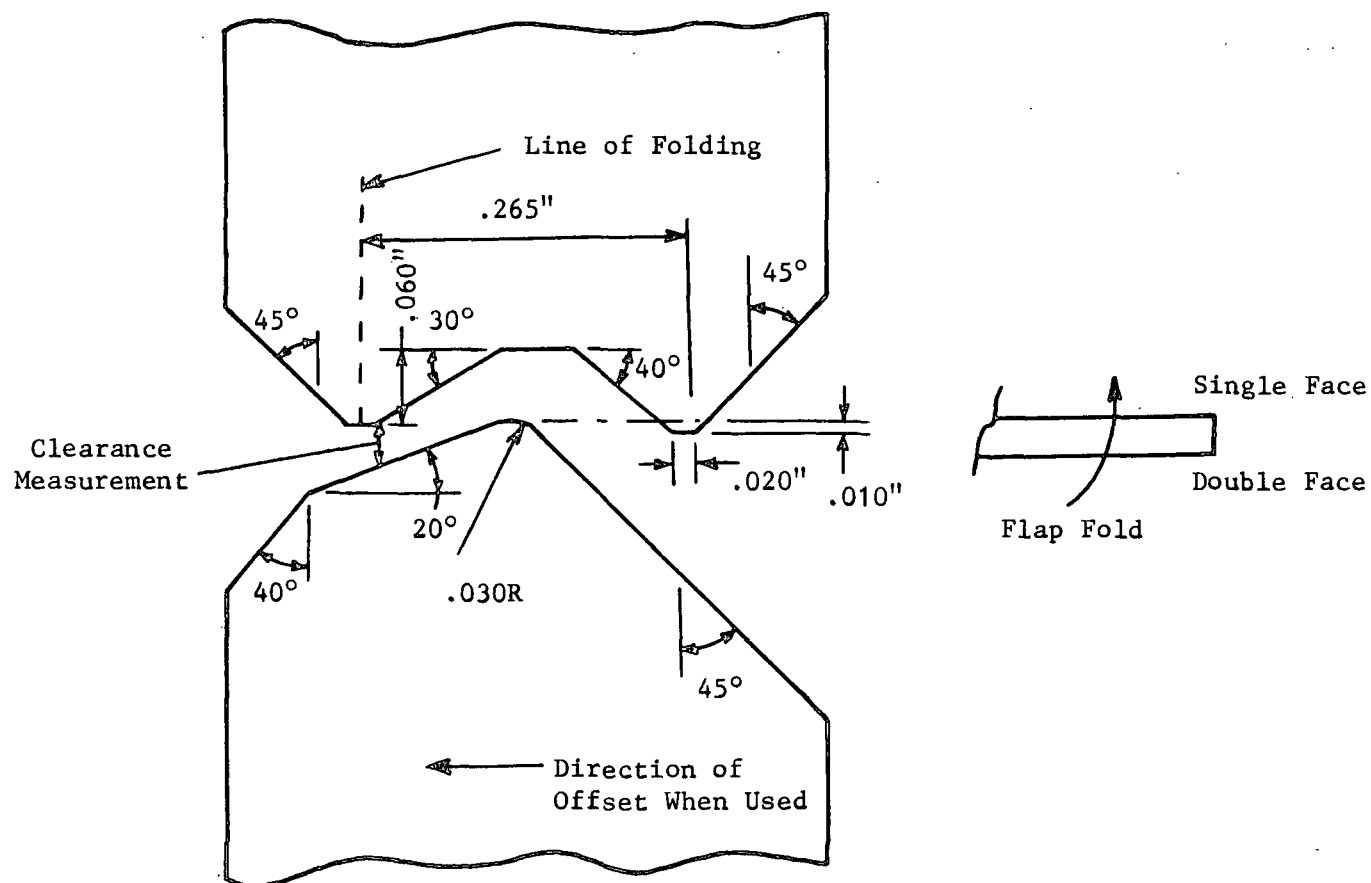


Figure 3. Majewski Patent Flap Score Profile

Referring to Fig. 3, the profile is basically an inverted 3-point style with special geometry on all of the ridges of both wheels. The shape is unsymmetrical in nature. As shown in the drawing, the primary folding takes place at

the left-hand peak of the upper wheel. The right-hand peak of that same wheel creates a secondary crease in the single face liner which, in theory, reduces the stiffness of the structure and allows a hinge to be formed without causing bulging of the inner liner. At the same time, the outer liner tensile stress is believed to be reduced. The net effect, as explained by the Majewski Patent, is to create a narrow zone within which the combined board deformation can take place without causing rolled box edges or bulging box walls. The incentive for this approach is derived from earlier published work that found that box compression strength is increased as the width of the area deformed during scoring decreases (2).

It should be noted that the ridge for the secondary score on the wheel contacting the single face liner is actually of a larger diameter than the ridge for the primary score. The primary score, however, tends to form properly because of the unsymmetrical nature of the lower wheel and its closer proximity to the primary ridge.

The actual dimensions for the manufacture of the wheels were obtained from the Australian Paper Manufacturers Limited, the assignee of the patent. The patent does not contain sufficient dimensions for the manufacture of any profiles. The profiles used were originally developed for B-flute board, but APM believes them to be suitable for use on C-flute as well. No commercial application of these patented profiles has been made on C-flute board to date.

Figure 4 shows a representation of the scoreline after being folded through 90° for flap formation.

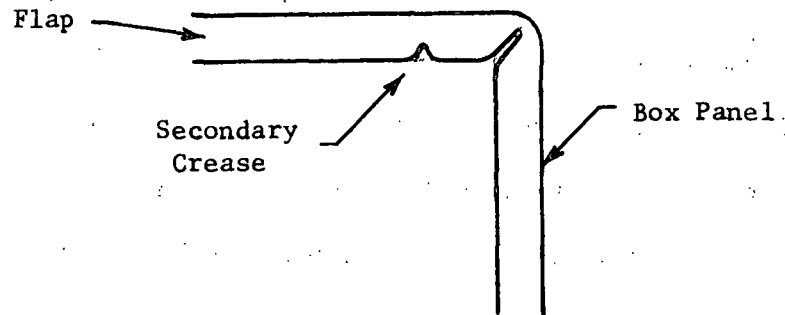


Figure 4. Representation of Flap Relationship to Box After Being Folded Thru 90° with Majewski Patent Flap Score Profile

The first scoring trials with these wheels were conducted at zero offset and with the standard clearance of $t+5$. The clearance was measured indirectly. After only a few samples, it became apparent that some adjustments in clearance and offset would have to be made. The primary and secondary scores were to approximately the same degree and the folding of the board was highly erratic. Folds occurred partially on the primary score and partially on the secondary score yielding uneven boxes. Only two board grades were evaluated at this condition.

An attempt was made to reduce the clearance by 0.010 inch to the $t-5$ condition. This caused a sharper distinction between the primary and secondary scorelines, but also caused single face liner cracking in the area between the scorelines. Only the double wall sample could be run at this reduced clearance with no offset.

An offset of 0.005 inch was next tried with the reduced clearance of $t-5$. The wheel contacting the double face liner was moved along the scorer axis toward the ridge for the primary score on the single face wheel causing more distinction between the primary and secondary scores. This alleviated the single

face liner cracking slightly. However, after allowing the box blanks to sit overnight to allow the manufacturer's joint glue to cure, the resulting box flaps did not fold as well as expected due to some recovery of the single face liner scores during the idle period. It was only possible to evaluate one grade of combined board under these conditions as the others would not make up properly into boxes. An offset of 0.010 inch was found to be necessary in combination with the t-5 clearance in order to make good quality boxes. Since the Majewski Patent flap score wheels appeared to be more sensitive to clearance than the other flap score profiles evaluated, an intermediate condition of t+0 clearance was used with the 0.010 inch offset previously found to be effective.

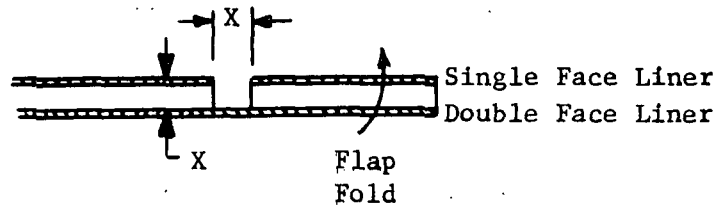
No offset was required for the double wall board grade which performed well at all clearances with zero offset. A larger clearance of t+15 was tried with the double wall board (also at zero offset) for comparison purposes to the larger clearances used with the other profiles.

NOTCHED FLAP SCORE

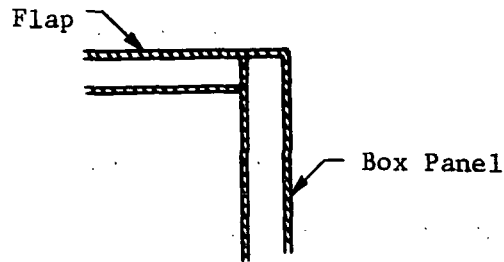
The notched flap score was formed by cutting through the single face liner and medium with saw blades and leaving only the double face liner. This is shown in Fig. 5.

The cuts were made using multiple circular saw blades stacked with shims to produce the correct width. Boxes were then made up in normal fashion with full sized flaps.

Only one board grade was used for this trial because of the complexity of the set-up needed to achieve proper results.



Before Folding



After Folding

Figure 5. Notched Flap Score

PANEL SCORE PROFILES EVALUATED

STANDARD V vs. FLAT STEEL PANEL SCORE

The panel score profile chosen as the standard for this project was the V vs. flat steel. This profile is shown in Fig. 6. Clearance measurements were made directly. The standard clearance was chosen as the sum of the component calipers (single face and double face liner plus medium) plus 0.005 inch. This is the same value that was used as the standard clearance for the flap score profiles. One additional reduced clearance setting of the sum of the component calipers minus 0.005 inch ($t-5$) was also used for evaluation.

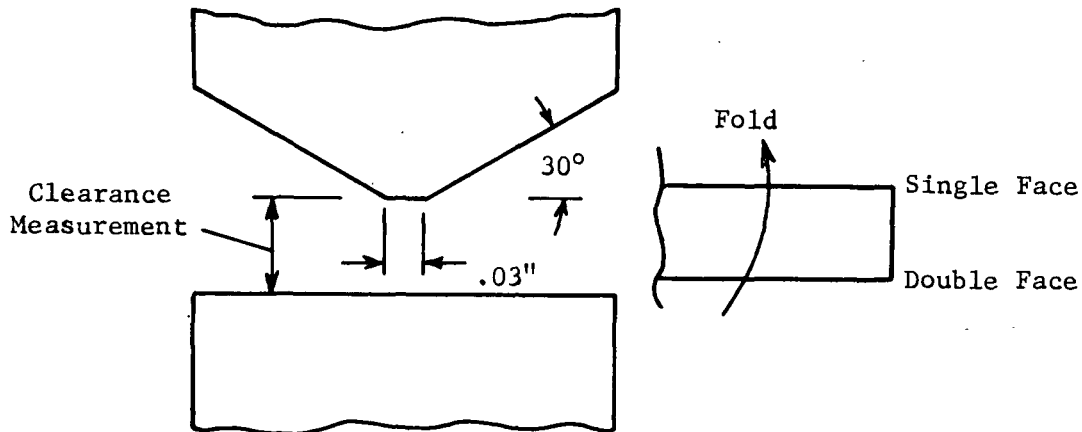


Figure 6. V vs. Flat Steel Panel Score

The V vs. flat steel profile at the $t+5$ clearance was used as the panel score for all the boxes made with different flap scores in the evaluation of the flap score profiles. This clearance value had to be increased by 0.090 inch for panel scoring of the A/B double wall board in order to avoid single face liner cracking.

V VS. FLAT POLYURETHANE SCORE

The V vs. flat polyurethane profile is basically the same as the V vs. flat steel profile except that the diameter of the flat wheel is covered with a ring of polyurethane to provide for some deflection during the scoring process. This deflection tends to provide a slight increase in the clearance between the wheels at the time of scoring and reduce the severity of the scoring process on the double face liner.

Test runs for the V vs. flat polyurethane wheels were made at the same clearance conditions as were the runs for the V vs. flat steel wheels, t+5 (standard) and t-5.

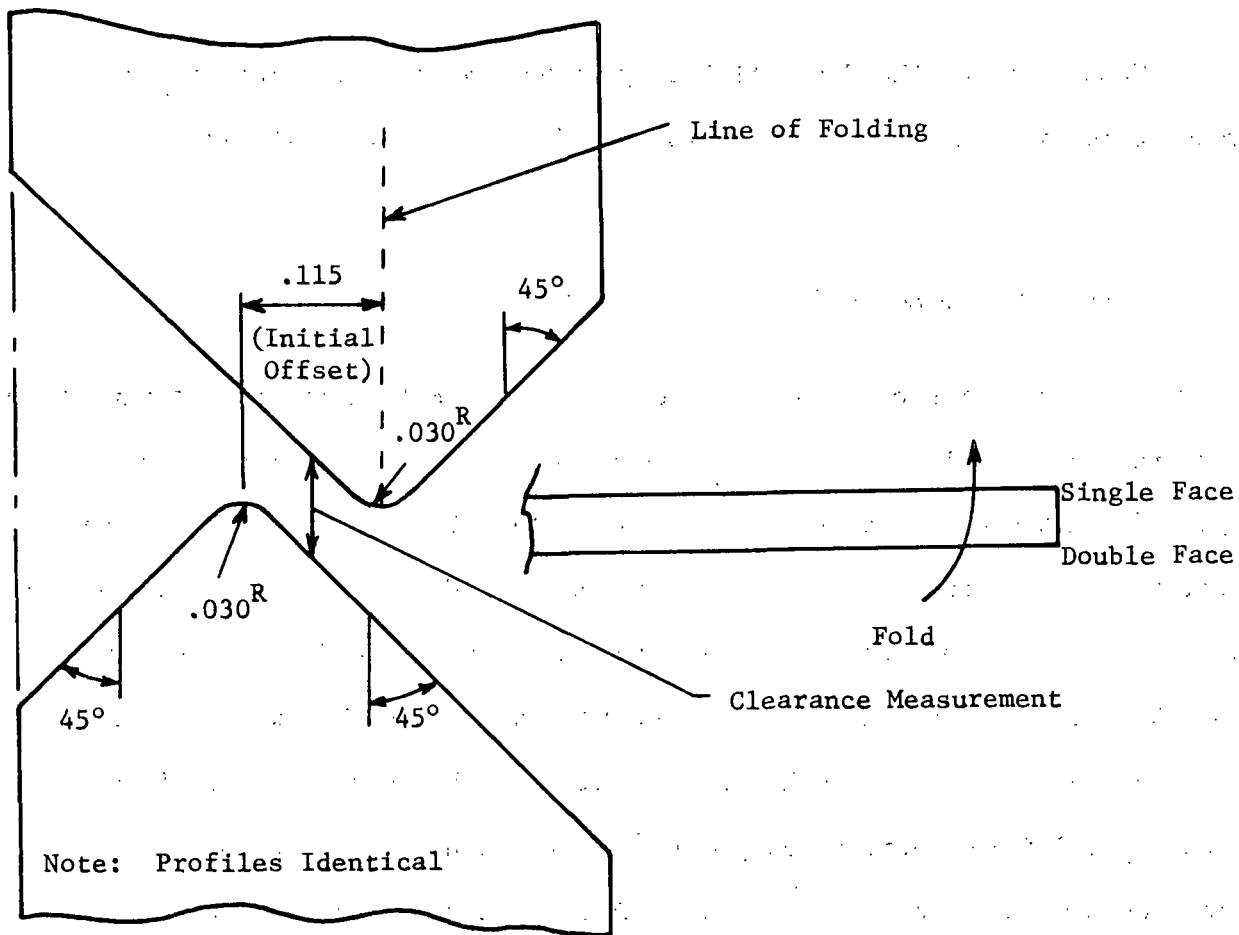
MAJEWSKI PATENT 90° CROSS-DIRECTION PROFILE SCORE

The patent issued to Majewski contains information for the design of two panel score profiles (1). One of these is designed for the folding of panels through 90° and the other for the folding of panels through 180°. In box manufacture, two of the panel scores are folded through 180° when the manufacturer's joint is made, while the other two panel scores are not folded until the box is set up, at which time they are only folded 90°. Therefore, Majewski theorized that optimum box performance could be obtained through the use of two different profiles. The 90° cross-direction profile is the result of an attempt to keep the score damaged area to a minimum for each fold required in the fabrication of boxes.

The patent also states, however, that the 90° cross-direction profile can be used for the 180° folds at a slightly reduced performance level. In this

project, all four panel scores for the end load compression test boxes were made from the same scoring profile.

The 90° cross-direction profile appears in Fig. 7. It is basically a V vs. V type profile with an initial offset. Note that the terminology for this report considers the initial offset (shown as 0.115 inch in Fig. 6) as the condition of zero offset. The clearance measurements were made indirectly.



(Shown at zero offset)

Figure 7. Majewski Patent 90° Cross-Direction Profile

Preliminary trials indicated that an unusually large clearance of $t+30$ (sum of component calipers plus 0.030 inch) was needed to prevent scoreline cracking when the zero offset condition (shown in Fig. 7) was used. A complete test series on all board grades was made with this set-up.

Additional trials also indicated that an offset of 0.100 inch produced by moving the wheels away from each other to increase the distance between the flanks of the V's would allow the standard clearance of $t+5$ to be used. Complete test series were run at both the $t+5$ and the $t-5$ clearance conditions for this offset.

MAJEWSKI PATENT 180° CROSS-DIRECTION PROFILE SCORE

The Majewski Patent 180° cross-direction profile is of the V vs. V type, similar to the 90° cross-direction profile. However, the V of the wheel scoring the single face side of the corrugated sheet is opposed by a relatively flat portion of the diameter of the wheel scoring the double face side of the sheet. This is shown in Fig. 8. In addition to this departure from the basic V vs. V concept, the V of the wheel scoring the single face sheet (upper wheel in Fig. 8) has one flank which recedes from the peak of the V at a shallow (10°) angle creating a zone of scoring. This zone of scoring acts on a larger area of the corrugated board than the V vs. V shape of the 90° cross-direction profile providing for the additional deflection needed to accommodate the 180° fold. At the same time, box performance is expected to be reduced below the level of the boxes made from the 90° cross-direction profile because of the wider scorelines.

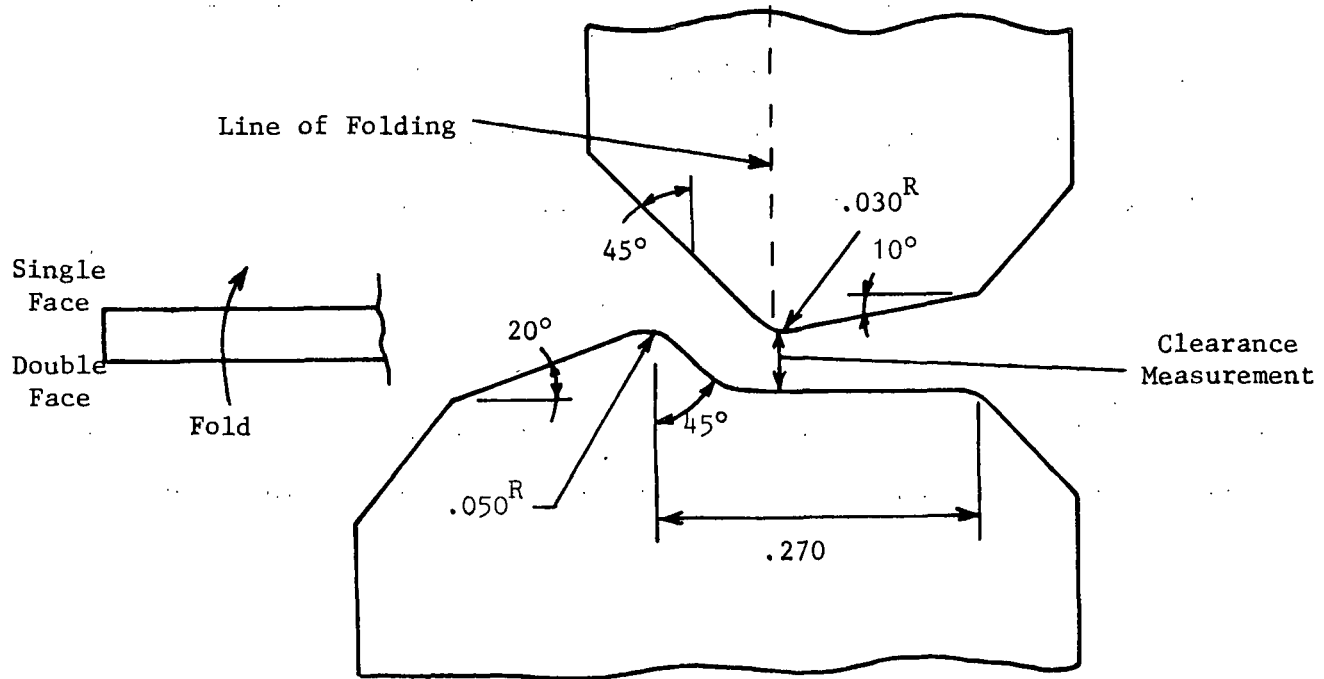


Figure 8. Majewski Patent 180° Cross-Direction Profile

It was decided to use the Majewski Patent 180° cross-direction profile with no offset (i.e., as shown in Fig. 8) at the two clearance levels of $t+5$ and $t-5$. Clearances were measured indirectly.

TEST PROCEDURES

MATERIAL

Five different grades of combined board were selected as the base material for this project. Four of these were C-flute construction of different bursting strength test levels, while the fifth grade was of A/B double wall construction. Selected properties of the five grades are listed in Table III.

TABLE III
SELECTED TEST MATERIAL PROPERTIES

Code No.	Flute Construction	Nominal Bursting Strength, psi	Basis Weight, lb/m ft ²	Combined Board Caliper, pt	Sum of Component Calipers, pt	Flat Crush, psi
917	C	350	221	187	59	35.8
918	A/B	350	210	307	55	--
919	C	275	179	178	49	39.3
920	C	200	124	163	35	40.3
921	C	200	125	162	35	38.0

Two grades of C-flute 200 lb bursting strength were requested from the supplier at two different levels of flat crush. Their flat crush values, however, were only about 6% apart, and it is doubtful that this difference had any effect on the results.

CONDITIONING

All samples of combined board, except for the low relative humidity test samples, were preconditioned for 24 hours at 23°C and less than 35% RH. They were then conditioned for at least 48 hours at 50 ± 2% RH and 23 ± 1.0°C.

before being scored and fabricated into boxes. The samples for low RH testing were conditioned for 24 hours at 23°C and less than 20% RH before being scored and tested.

SCORING METHOD

All scoring was done on a Langston four bar slitter scorer located in the conditioned space (23 ± 1.0°C and 50 ± 2% RH). The scoring wheel shaft speed was set at 96-98 rpm. All scoring wheels had diameters about 8-5/8 inches for a surface running speed of about 210-220 ft/min. Previous work at the Institute has shown the scoring speeds of 200-600 ft/min can be used with no affect on panel scoreline foldability or box performance. (3).

The parallelism of the scoring roll shafts was checked and found to be off by about 0.0008 inch/ft of distance along the shafts. For the 73 inches of separation between the extreme outward wheels of the panel score set-ups, this represented a potential difference in clearance settings of about 0.005 inch. In order to compensate for this, the actual diameters of the scoring wheel sets were checked and recorded (scoring wheels are manufactured in matched pairs). At scoring set-up time, these diameter measurements were used to place the largest diameter wheel sets at the end of the slitter-scorer where the shafts were furthest apart and the smallest diameter wheel sets at the opposite end of the scorer shafts. This effectively reduced the clearance errors that would have resulted from the combination of machine condition and different wheel diameters caused by manufacturing tolerances.

INDIRECT METHOD FOR MEASURING SCORING WHEEL CLEARANCE

As mentioned in the discussion of the various scoring profiles, most scoring wheel clearance measurements had to be made by an indirect method since the profiles did not allow direct insertion of feeler gages between the wheels.

The method used for this measurement is shown in Fig. 9. The scoring wheels were set longitudinally on the shafts of the slitter-scorer and the upper and lower shafts were brought together until the wheels touched, resulting in zero clearance. The spacer block and parallel-sliding measuring tool shown in the photograph were inserted between the slitter-scorer shafts. This insertion was done at the midpoint along the length of the slitter-scorer shafts in order to reduce the out-of-parallelism effects discussed in the previous section. The parallel-sliding tool was expanded until it became a tight fit in the space between the two shafts. A micrometer reading of the height of the parallel-sliding tool was taken and recorded as the zero clearance measurement. From this point, each clearance setting was calculated as a desired micrometer reading. The shafts of the slitter-scorer were separated and adjusted until the micrometer reading taken by the method just described was identical to the desired micrometer reading for the proper clearance.

This method was repeated for the set-up of each scoring profile requiring indirect measurement.

BOX COMPRESSION TESTS

All boxes made for this project were of standard RSC construction in a 20 x 16 x 16 inch size. Proper allowances for the scoring dimensions for the box blanks were made according to the grade of the combined board. The manufacturer's joint had a 1-1/4 inch tab attached to the end panel and glued to the inside of a side panel for all single wall constructions. The double wall grade had a special 2 inch tab on an end panel that was glued to the outside of the side panel.

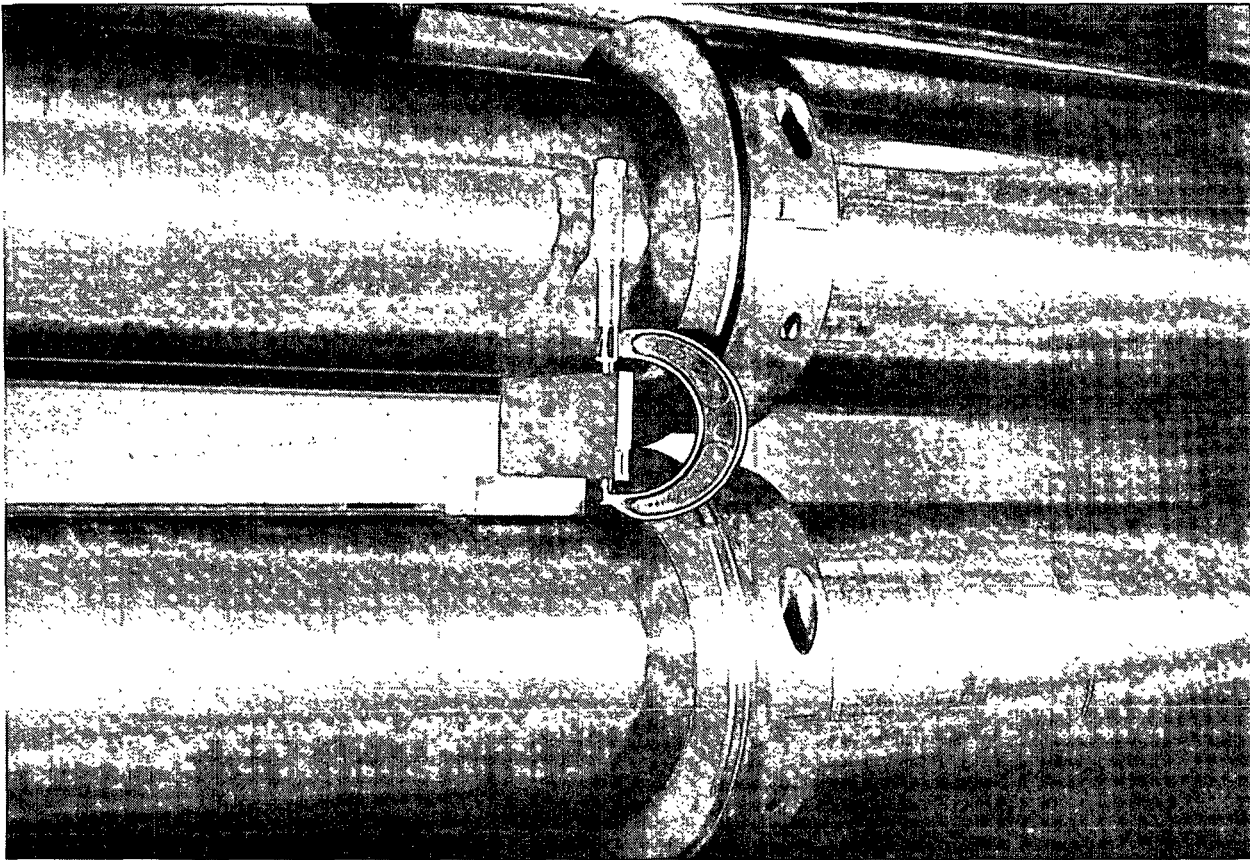


Figure 9. Indirect Method for Measuring Scoring Wheel Clearance

Boxes for top load compression testing were made with a stapled bottom and glued top. Boxes for end load compression testing were made with a glued top and bottom.

Ten boxes were tested for each set-up combination of profile, clearance and offset. The compression testing was conducted on a Baldwin-Southwark Universal Tester and an output graph of load vs. deflection was obtained for each box.

FOLDING TORQUE TESTS

The folding torque tests were conducted on a special fixture developed at The Institute of Paper Chemistry. The fixture, as modified for this project,

is shown in Fig. 10. The fixture provides for the clamping of the specimen of scored combined board in a horizontal position beneath a rotating lever arm. Positioning guides are part of the clamp to insure that the specimen scoreline is at the pivot point of the arm. As a tensile force is applied to the vertical steel strip, the lever arm is caused to rotate forcing the combined board to fold at its scoreline. Figure 10 shows this lever arm in a partially-rotated position.

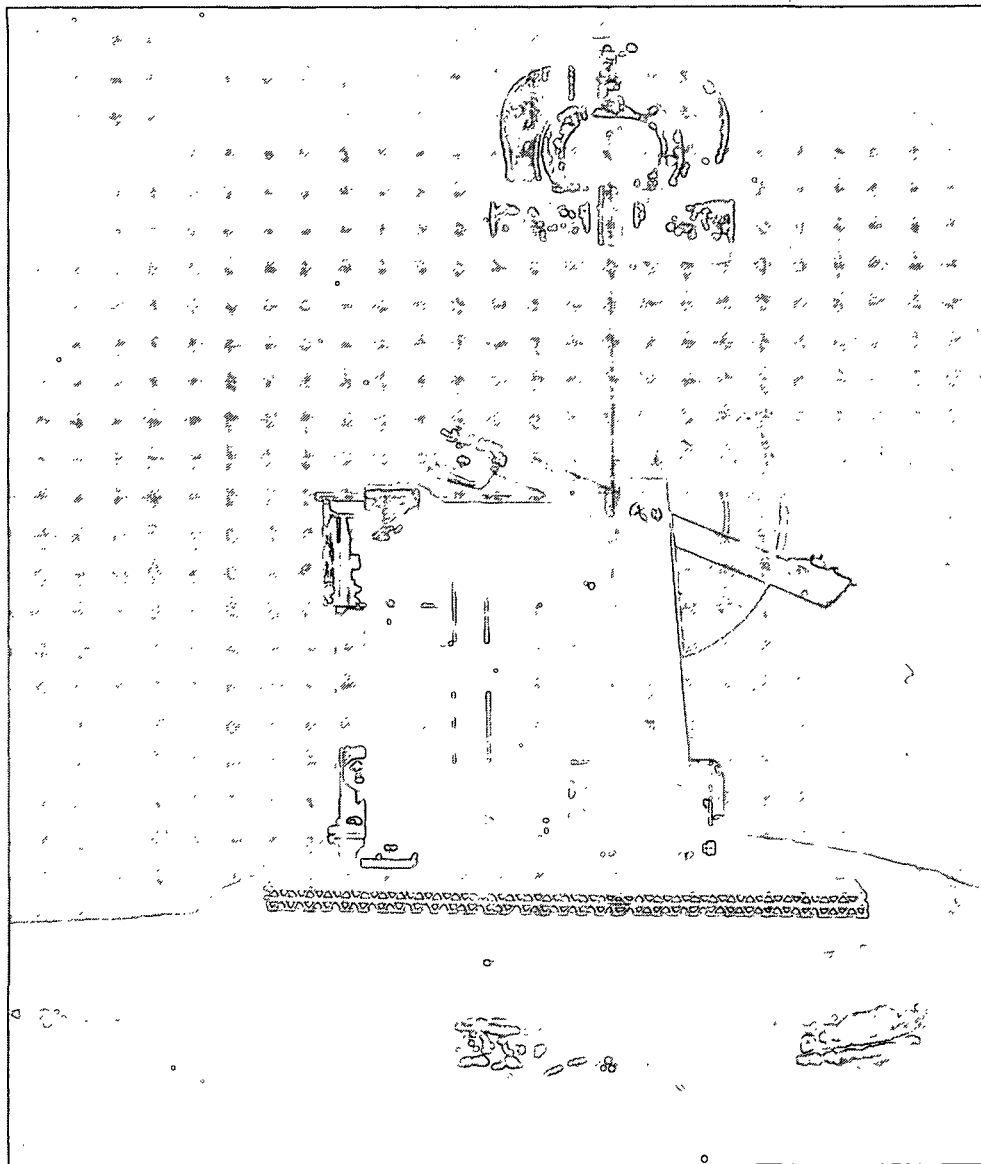


Figure 10. Folding Torque Test Fixture

The test for this part of the project consisted of two parts. In the first part, a tensile load was applied to the vertical steel strip, as just described, by the cross arm of a Baldwin-Southwark Universal Tester. During this process, a reading of maximum tensile force was obtained from the machine instrumentation. This was later converted to a torque reading of inch-pounds per inch of scoreline. After the maximum force reading was obtained, the tensile force on the steel strip was maintained until the lever arm rotated through 90°. This rotation was signaled when the lever arm contacted a limit switch. At the time of limit switch contact, the tensile force applied to the steel strip was released allowing the lever arm to return to a horizontal position. After a period of 30 seconds from the time of contact of the limit switch, as measured by an electric timer, a reading was taken of the angle of return of the specimen from the 90° position by the use of the protractor attached to the fixture. A high angle of return, therefore, indicated the presence of a high amount of restoring energy in the folded score and a less effective scoreline. The 30 second delay period was selected from several trials as a time after which very little recovery motion occurred.

The test, made in this manner, provided for a direct measurement of the torque required to fold the board initially and an indirect method of comparing (within a board series) the amount of restoring energy available in the scoreline after the fold.

Specimens for the test were cut from scored box blanks for all scores except the notched flap score. The specimen cutting was done on a circular table saw to insure accuracy of size, squareness of edges and proper positioning of the scoreline with respect to the ends of the specimen. Five specimens were tested for each set-up condition of profile, clearance and offset.

SCORELINE CRACKING TESTS

Scoreline cracking tests were conducted on the smallest clearance setting for each flap and panel score profile except the notched flap score.

Combined board was conditioned at 23°C and less than 20% RH as described previously. For scoring, the board samples were brought into the main laboratory (23 ± 1°C, 50 ± 2% RH) immediately before scoring and then returned to the low relative humidity atmosphere. After being in the low RH atmosphere for 24 hours after scoring, the samples were folded on the scorelines..

Flap scored samples were folded out 90° (toward the double face liner) and then in 90° and returned to a flat condition. Panel scored samples were folded toward the single face liner through 180° and returned to a flat condition.

Specimens were examined immediately after scoring and again after folding for evidences of liner cracking. Eight specimens were tested for each flap and panel score profile evaluated.

DISCUSSION OF RESULTS

FLAP SCORE PROFILES

Table IV shows the maximum load and deflection results of the box top load compression tests for the various conditions of scoring profile, clearance, offset and combined board series. The individual board series results are shown separately along with a composite calculation of all of the single wall results. Percent differences between the results of the tests for each condition and the results of the tests at the standard condition are tabulated within each board series and for the single wall composite.

In looking at the maximum load results for the top load compression test, it can be seen that very little significant difference exists (within each board series) between any of the tests run with the 3-point flap score wheels. This is true for all board grades. In only one case, that of the 3-point flap score at t-5 clearance for the #920 (C-200) board, was there a top load strength significantly below (8.4%) the standard top load strength. Although the differences between the top load results at different clearance settings were not significant, the 3-point flap score at the standard t+5 clearance generally produced top load compression strengths about 1-3% higher than the same flap score at either smaller or larger clearances. The analysis of the deflections for these same boxes concurs that very little significant difference exists between any of the boxes made with different clearance settings on the 3-point flap score wheels. The isolated cases where significant differences did exist were of such a nature that the deflections of the boxes made with the nonstandard clearances were always greater than the deflections of the boxes made with the standard clearance for the same board grade.

TABLE IV
BOX TOP LOAD COMPRESSION RESULTS

Lot No.	Flap Score	Clearance	#920 C-200	#921 C-200	#919 C-275	#917 C-350	Single Wall Composite	#918 A/B Dbl. Wall	% Diff.	Maximum Loads, lb		% Diff.
										Offset ^a	% Diff. ^b	
1	3 point	t + 5	892	861	1466	1711	1232	1391	--	--	1466	--
2	3 point	t - 5	816	845	1455	1676	1198	1402	-8.4 ^c	-2.0	1455	+0.8
3	3 point	t + 15	880	876	1388	1692	1209	1419	-1.3	-1.1	1388	+2.0
3A	3 point	t + 25	0	860	0	0	0	0	0	0	0	0
4	Inverted 3 pt.	t + 5	806	812	1304	1630	1138	1464	-9.5 ^c	-4.8 ^c	1304	+5.2 ^c
5	V vs. V	t + 5	916	899	1466	1793	1268	1577	+2.7	+4.8 ^c	1466	+13.3 ^c
6	V vs. V	t - 5	874	918	1482	1864	1284	1760	-2.0	+9.0 ^c	1482	+26.5 ^c
7	V vs. V	t + 15	902	914	1470	1808	1274	1756	+1.2	+5.6 ^c	1470	+26.3 ^c
8	V vs. V	t + 5	862	858	1444	1818	1245	1653	-3.4	+6.2 ^c	1444	+18.8 ^c
16	Maj. flap	t + 5	0	882	0	0	0	0	0	0	0	+16.6 ^c
17	Maj. flap	t - 5	0.010 ^d	934	1456	1918	1317 ^a	1762	+7.5 ^c	+12.1 ^c	1456	+26.7 ^c
18	Maj. flap	t	0.010 ^e	974	1529	1904	1340 ^c	1686	+6.7 ^c	+11.3 ^c	1529	+21.2 ^c
18A	Maj. flap	t + 15	0	0	0	0	0	0	0	0	0	+17.2 ^c
27	Notch	--	929	0	0	0	0	0	+4.2	--	0	--
Deflections, inches												
1	3 point	t + 5	0.53	0.53	0.78	0.68	0.63	1.08	--	--	0.78	--
2	3 point	t - 5	0.51	0.52	0.83	0.81	0.67	1.17	-4.9	+20.1 ^c	0.83	+8.3 ^c
3	3 point	t + 15	0.53	0.55	0.66	0.77	0.63	1.04	-0.4	+14.5	0.66	-4.5
3A	3 point	t + 25	0	0.60	0	0	0	0	0	0	0	0
4	Inverted 3 pt.	t + 5	0.61	0.59	0.87	0.75	0.71	0.92	+14.4 ^c	+10.7 ^c	0.87	-14.7 ^c
5	V vs. V	t + 5	0.49	0.48	0.54	0.55	0.51	0.85	-8.1 ^c	-18.8 ^c	0.54	-21.9 ^c
6	V vs. V	t - 5	0.51	0.52	0.57	0.53	0.53	0.90	-2.1	-22.2 ^c	0.57	-17.4 ^c
7	V vs. V	t + 15	0.68	0.50	0.52	0.51	0.55	0.89	+28.3 ^c	-24.4 ^c	0.52	-18.1 ^c
8	V vs. V	t + 5	0.43	0.42	0.46	0.58	0.47	0.77	-19.3 ^c	-14.5 ^c	0.46	-28.7 ^c
16	Maj. flap	t + 5	0	0.92	0	0	0	0.80	0	0	0	-26.7 ^c
17	Maj. flap	t - 5	0.010 ^d	0.70	0.57	0.62	0.59 ^d	0.83	-10.9 ^c	-9.0 ^c	0.57	-23.7 ^c
18	Maj. flap	t	0.010 ^e	0.71	0.58	0.61	0.59 ^c	0.83	-11.0 ^c	-9.9 ^c	0.58	-23.3 ^c
18A	Maj. flap	t + 15	0	0.82	0	0	0	0.77	0	0	0	-29.0 ^c
27	Notch	--	0.32	0	0	0	0	0	-40.1 ^c	--	0	--

^aMeasurement of clearance and offset conditions dependent upon the type of profile being used as discussed in the description of the profiles.
Clearance = t (sum of liners and medium calipers) + or - N (number of thousandths of an inch). Offset is measured from an established reference.
^bBased on the values of Lot #1 as reference.
^cSignificant at the 0.05 level.
^dLot #920-17 was made at 0.005" offset. Lot #918-17 was made at 0 offset.
^eLot #920-18 was made at 0.020" offset. Lot #918-18 was made at 0 offset.
Note: All boxes were made with a standard panel score consisting of V vs. flat steel at a clearance of t + 5 (see Lot #31) except for Group #918 (A/B double wall) where the clearance was t + 95.
Each value is the average of 10 determinations.

The inverted 3-point flap scored top load test boxes had strengths significantly lower than the standard 3-point flap scored boxes for all single wall constructions. Reductions in top load strength varied from 4.8% for the C-350 series to 11% for the C-275 series. The corresponding deflections for these boxes were all significantly larger than the deflections of the boxes made with the standard condition. Boxes made from the A/B double wall construction with the inverted 3-point flap score, on the other hand, exhibited a significant 5.2% increase in strength over the boxes made with the standard flap score. They also exhibited a correspondingly 14.7% lower deflection than the boxes made with the standard profile and clearance in the double wall series.

Boxes made from the V vs. V flap score profile at zero offset tested significantly better in top load compression than did the standard boxes for two of the single wall board series (#921, C-200 and #917, C-350) and for the double wall board series. These significant increases for the two single wall board series mentioned were high enough to cause the single wall composite averages to also show values significantly higher than the standard composite average. The highest gain of 4.2% above the standard composite average was obtained at the lowest clearance setting tried. This was also true in the case of the double wall construction where the minimum clearance setting for the V vs. V profile at no offset produced the highest box top load compression strength. However, 80% of the double wall blanks scored at this low clearance setting exhibited small single face liner cracks after scoring.

The box top load deflections for those boxes made with the V vs. V flap score at zero offset were generally significantly lower than the top load deflection of the standard box for all five of the board series. These results

agree with the theory that narrower scorelines, such as the V vs. V wheels produce, will result in higher box top load compression strengths and less box deflection.

The top load test results of the boxes made from the V vs. V flap scores with the 0.12 inch offset were not significantly different from the standard test results for any board series except the C-350 series and the double wall series. For both of these series, the top load results were significantly higher than the standard top load results. Since these increases above standard values occurred only in the higher board calipers, there is indication that the offset used was too great to be effective for the lower caliper boards. This caused the fold lines for the boxes made from those boards to become less defined and resulted in poorer box compression performance. The deflections for the boxes made from the V vs. V profile with the 0.12 inch offset were generally the smallest of all of the deflections recorded for any of the other flap score profiles.

A discussion of the difficulties involved in finding the proper clearance and offset conditions for the Majewski Patent flap score profiles was given in the section describing the Majewski profile theory and geometry. At the zero offset condition, all of the scorelines for the single wall board constructions tended to fold erratically on either or both of the primary and secondary creases. As a result, only one single wall series (#921, C-200) was evaluated. The box top load for that series was not significantly different from the standard top load, but the deflection was 73.4% greater than standard due to the extra rolling of the scoreline allowed by the double crease.

Boxes made from the Majewski Patent flap score wheels with an offset at the time of scoring generally showed significantly higher top load strengths than did the standard boxes. In only one board series (#919, C-275) was there no significant difference between the boxes made from the Majewski Patent scores and the standard 3-point score. The single wall composite averages showed the Majewski Patent flap score results to be 6.8% higher than the standard score results for the t-5 clearance and 8.7% higher than the standard score results for the t clearance. The deflections for the boxes made from the single wall grades followed the same pattern as the loads but were not as consistent. One board series (#921, C-200) exhibited 31.3% greater deflection than the standard boxes for the Majewski Patent flap score at 0.010 inch offset and t-5 clearance and 34.2% greater deflection than standard at the t clearance. At the other extreme, the #919, C-275 series exhibited 27.7 and 26.1% reductions in deflection below the standard boxes for the same t-5 and t clearances, respectively.

The double wall construction performed differently for the Majewski Patent flap scores than did the single wall constructions in that all trials could be run at zero offset. This difference could be partially explained by the combined board caliper difference between the double wall and single wall constructions but may also have been due to the difference in flute shapes. The single wall constructions were made with C-flute while the double wall construction was made with A- and B-flutes. The A-flute side of the board was used as the inside of the box. The boxes in the double wall construction made with the Majewski Patent flap score wheels generally exhibited 16-26% greater top load strength and 23-29% less deflection than did the boxes made with the standard 3-point flap score wheels. The highest top load carrying capacity for the double wall series was registered with the Majewski Patent flap scored

boxes at the smallest wheel clearance setting. Also, percentage changes in box top load strength recorded for a 0.005 inch change in clearance setting of the Majewski Patent wheels were equivalent to the percentage changes recorded for a 0.010 inch change in the clearance of the standard 3-point flap score wheels. This indicates that the Majewski Patent flap score wheels are much more sensitive to clearance setting.

The notched flap score was evaluated only for the #920, C-200 board series. The boxes tested with this scoreline averaged only 4.2% above the boxes made with the standard scoreline. This is much less than was expected due to the similarity between the boxes made with the notched score and a pure tube shape. The main difference between the box and the tube is the presence of flaps on the box. Since the flaps were left full, it is believed that their overlapping in the completed box caused uneven strains on the vertical box panels and reduced the box performance to a level near that of a standard box. This type of explanation has been previously suggested in published literature (4).

Figure 11 graphically depicts the results of the flap score profile effects on box top load compression as discussed and serves to emphasize the fact that no single profile condition was uniformly better than the others for all board series.

The folding torque and restoring angle test results for the flap score profile tests are shown in Table V. The folding torque requirements of the scorelines made by the 3-point flap score wheels were very sensitive to clearance conditions. The scorelines made at the t-5 clearance required 27.8% less torque for the single wall composite average than did the scorelines made at standard clearance. Similarly, the scorelines made at the t+15 clearance

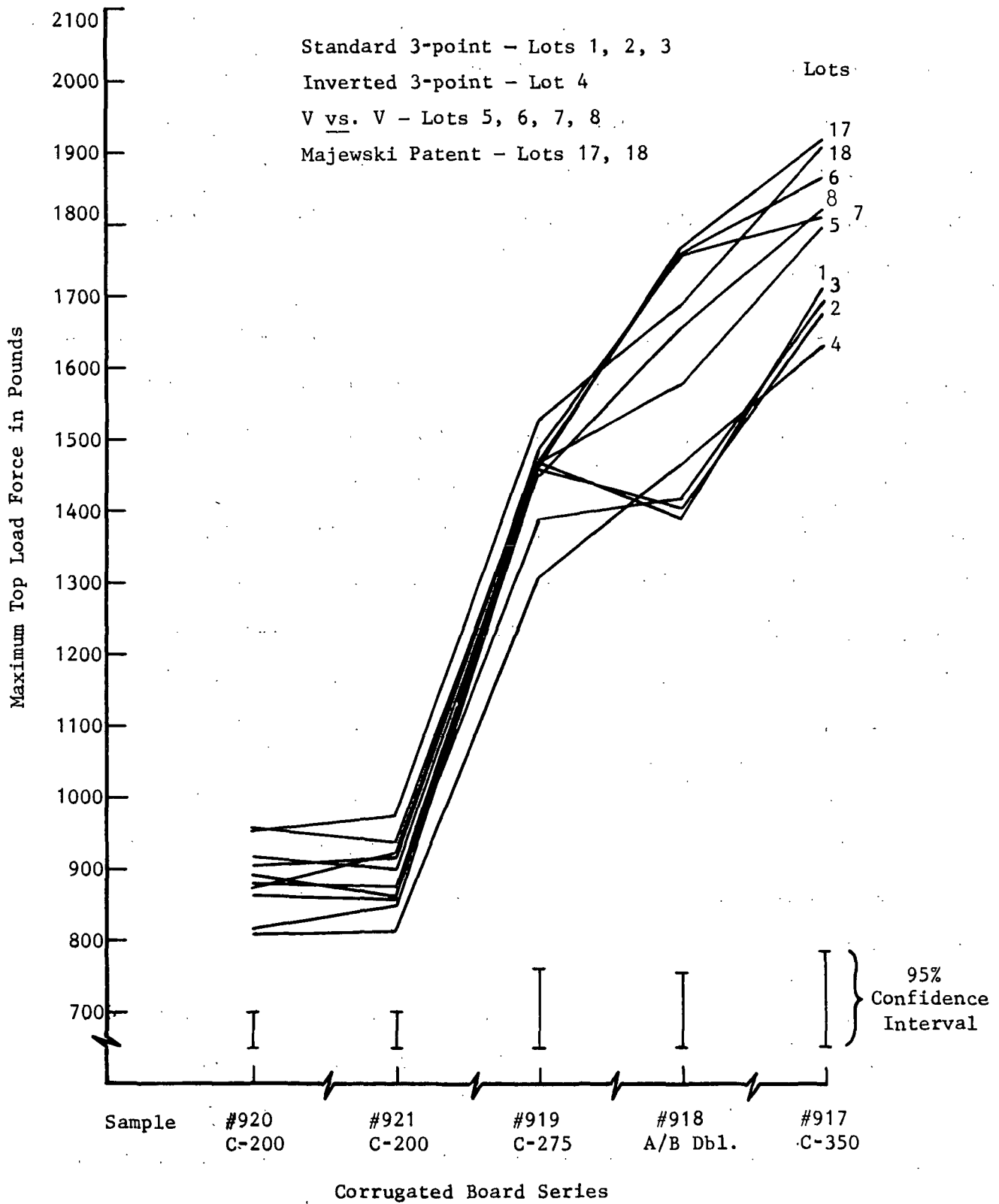


Figure 11. Flap Score Profile Effect on Box Top Load Compression

TABLE V
FLAP SCORELINE FOLDING TORQUE RESULTS

Lot No.	Flap Score	Clearance ^a	Offset ^a	#920 C-200		#921 C-200		#919 C-275		#917 C-350		Single Wall Composite	#918 A/B Del. Wall		% Diff.
				% Diff. ^b	#920	% Diff. ^b	#921	% Diff. ^b	#919	% Diff. ^b	#917		% Diff. ^b	#918 A/B	
Maximum Torque, in.-lb/in.															
				0.80	0.72	1.01	1.37	1.08	1.80	1.11	1.08	1.08	2.10	2.10	2.10
1	3 point	t + 5	0	-44.7 ^c	0.47	-35.1 ^c	0.84	-16.7 ^c	1.38	-23.7	0.78	1.56	-25.7 ^c	1.56	-25.7 ^c
2	3 point	t - 5	0	+13.5	0.88	+21.2	1.45	+43.3 ^c	2.21	+22.4	1.36	1.96	+25.4 ^c	1.96	-6.6
3	3 point	t + 15	0		0.93	+28.7									
3A	3 point	t + 25	0		0.60	-17.6 ^c									
4	Inverted 3 pt.	t + 5	0	-45.2 ^c	1.17	+61.1 ^c	1.37	+35.8 ^c	2.03	+12.8	1.11	2.55	+21.3 ^c	2.55	+21.3 ^c
5	V vs. V	t + 5	0	+41.3 ^c	1.17	+75.5 ^c	1.96	+96.6 ^c	2.52	+39.7 ^c	1.70	2.76	+56.8 ^c	2.76	+31.7 ^c
6	V vs. V	t - 5	0	+41.8 ^c	1.27	+75.5 ^c	1.96	+93.6 ^c	2.98	+65.0	1.83	2.60	+69.2 ^c	2.60	+23.6 ^c
7	V vs. V	t + 15	0	+81.7 ^c	1.47	+102.6 ^c	2.42	+139.2 ^c	3.30	+83.2 ^c	2.16	2.89	+99.2 ^c	2.89	+37.5 ^c
8	V vs. V	t + 5	0.12"	+59.1 ^c	1.20	+65.4 ^c	2.16	+109.1 ^c	2.68	+48.8 ^c	1.82	2.78	+67.6 ^c	2.78	+32.5 ^c
16	MaJ. flap	t + 5	0	-32.7 ^c	0.68	-5.9			1.65	-8.7	1.01 ^d	2.08	-1.0	2.08	-1.0
17	MaJ. flap	t - 5	0.010" ^d	-3.4	0.67	-6.9	1.19	+17.5 ^c	2.01	+11.3	1.26 ^e	1.88	-10.6 ^c	1.88	-10.6 ^c
18	MaJ. flap	t + 5	0.010" ^e		0.82	+13.3	1.44	+42.6 ^c	2.01	+11.3	1.26 ^e	2.07	-1.4	2.07	-1.4
18A	MaJ. flap	t + 15	0		0.86	+19.2			2.01	+11.3	1.26 ^e	2.25	+16.2 ^c	2.25	+7.0
Angle of Restoration, deg. f															
1	3 point	t + 5	0		67.6	65.4	65.4	65.4	65.4	67.1	67.1	71.8	67.1	71.8	67.1
2	3 point	t - 5	0	+1.4	70.8	+4.7	65.2	-0.3	64.0	-2.1	67.7	69.2	+1.0	69.2	-3.6
3	3 point	t + 15	0	-0.3	73.4	+8.6	64.8	-0.9	59.2	-9.5 ^c	66.8	68.6	-0.4	68.6	-4.5 ^c
3A	3 point	t + 25	0		74.0	+9.5									
4	Inverted 3 pt.	t + 5	0	+5.4	74.4	+10.1	67.4	+3.1	67.2	+2.8	70.7	75.8	+5.4 ^c	75.8	+5.6 ^c
5	V vs. V	t + 5	0	+2.6	70.8	+4.7	68.8	+5.2 ^c	67.2	+2.8	69.6	65.0	+3.8 ^c	65.0	-9.5 ^c
6	V vs. V	t - 5	0	+5.1	69.6	+3.0	67.0	+2.4	67.6	+3.4	69.4	61.8	+3.5 ^c	61.8	-13.9 ^c
7	V vs. V	t + 15	0	+1.7	69.0	+2.1	65.8	+0.6	65.4	0	67.8	60.4	+1.1	60.4	-15.9 ^c
8	V vs. V	t + 5	0.12"	-5.1	67.0	-0.9	67.6	+3.4 ^c	66.8	+2.1	67.0	66.0	-0.2	66.0	-8.1 ^c
16	MaJ. flap	t + 5	0	+7.1	72.8	+7.1	68.6	+4.9 ^c	66.8	+2.1	72.0 ^d	68.8	+7.3 ^c	68.8	-5.3
17	MaJ. flap	t - 5	0.010" ^d	+8.3	76.8	+13.6	67.6	+3.4 ^c	67.0	+2.4	70.4 ^e	68.2	+4.8 ^c	68.2	-5.0
18	MaJ. flap	t + 5	0.010" ^e	+5.7	72.8	+7.7	67.6		67.0	+2.4	70.4 ^e	68.2	+4.8 ^c	68.2	-5.0
18A	MaJ. flap	t + 15	0		72.4	+7.1			67.0	+2.4	70.4 ^e	68.0	+4.8 ^c	68.0	-5.3

^aMeasurement of clearance and offset conditions dependent upon the type of profile being used as discussed in the description of the profiles.
Clearance = t (sum of liners and medium calipers) + or - N (number of thousandths of an inch). Offset is measured from an established reference.

^bBased on the values of Lot #1 as reference.

^cSignificant at the 0.05 level.

^dLot #920-17 was made at 0.005" offset. Lot #918-17 was made at 0 offset.

^eLot #920-18 was made at 0.020" offset. Lot #918-18 was made at 0 offset.

^fAngle of restoration is measured from the vertical release point after folding scoreline thru 90°. Higher angular values indicate more restoration and less efficient scoring.

Note: All boxes were made with a standard panel score consisting of V vs. flat steel at a clearance of t + 5 (see Lot #31).

Clearance for #918 (A/B double wall) was 0.090" greater than the listed clearance for all lot numbers.

Each value is the average of 5 determinations.

required 25.4% more torque for the single wall composite average than did the scorelines at standard clearance. The restoring angles for the scores made with the 3-point flap score wheels did not generally show any significant difference based on clearance differences.

The inverted 3-point flap scorelines generally required less folding torque than the standard scoreline for the lower caliper boards and more folding torque than the standard for the higher caliper boards. Their angle of restoration was always higher than the standard indicating that more restoring energy was present after folding.

The V vs. V flap scorelines generally required significantly more folding torque than did the standard scorelines. This requirement seemed about the same for the t-5 and t+5 clearances but increased substantially as the clearance increased to t+15. The restoration angles for these scorelines averaged slightly more than the standard restoration angles at the t+5 and t-5 clearances (3.8 and 3.5%, respectively, for the single wall composites). The V vs. V scorelines for the double wall board, on the other hand, showed restoration angle reductions of up to 15.9% below the standard angle of restoration.

The scorelines made by the Majewski Patent flap score wheels were inconsistent in their requirements for folding torque. Generally the scores made at the lowest clearance setting required less folding torque than did the standard scorelines while the scores made at the largest clearance setting required more folding torque than did the standard scorelines. Only some of the differences, however, were significant. The restoration angles of the Majewski Patent flap scorelines were generally higher than the angles of the standard scorelines except for the double wall series.

In the double wall series, the angles of restoration for almost all of the flap score profiles considered were less than the angle of restoration for the standard 3-point flap score profile.

Table VI shows the percentage of specimens exhibiting flap scoreline cracking when scored and later folded under low relative humidity (<20% RH) conditions. Eight specimens were evaluated for the minimum clearance condition of each of the four flap score profile and offset combinations listed. As can be seen from the table, only the Majewski Patent flap score wheels consistently cracked the single face liner during the scoring process at the low humidity condition.

PANEL SCORE PROFILES

Table VII shows the maximum load and deflection results of the box end load compression tests for the various conditions of scoring profile, clearance, offset and combined board series. The individual board series results are shown separately along with a composite calculation of all the single wall results. Percent differences between the results of the tests for each condition and the results of the tests at the standard conditions are tabulated within each board series and for the single wall composite.

The standard panel score profile, V vs. flat steel was tested at two clearances. The standard clearance of t+5 was used along with a reduced clearance of t-5. There were only two board series that showed a significant difference between the end load test results of the V vs. flat steel wheels at the two clearances. The #920, C-200 series boxes at the t-5 clearance showed a 12% higher end load strength than the boxes at the t+5 clearance. The #918, A/B

TABLE VI
EVALUATION OF FLAP SCORELINE CRACKING

Sample	Board Series	Lot No.	Flap Score	Clear- ance	Offset	% of Scorelines Cracked ^a			
						After Scoring		After Folding	
						S.F. Liner	D.F. Liner	S.F. Liner	D.F. Liner
920	C-200	2	3 point	t-5	0	0	0	0	
921	C-200	2	3 point	t-5	0	0	0	0	
919	C-275	2	3 point	t-5	0	0	0	0	
917	C-350	2	3 point	t-5	0	0	62	12	
918	A/B	2	3 point	t-5	0	0	0	0	
920	C-200	6	V vs. V	t-5	0	0	0	0	
921	C-200	6	V vs. V	t-5	0	0	0	0	
919	C-275	6	V vs. V	t-5	0	0	0	0	
917	C-350	6	V vs. V	t-5	0	0	0	0	
918	A/B	6	V vs. V	t-5	0	0	12	0	
920	C-200	8	V vs. V	t+5	0.12"	0	0	0	0
921	C-200	8	V vs. V	t+5	0.12"	0	0	0	0
919	C-275	8	V vs. V	t+5	0.12"	0	0	25	0
917	C-350	8	V vs. V	t+5	0.12"	0	0	12	0
918	A/B	8	V vs. V	t+5	0.12"	0	0	0	0
920	C-200	17	Majewski Patent	t-5	0.010"	100	0	--	0
921	C-200	17	Majewski Patent	t-5	0.010"	100	0	--	0
919	C-275	17	Majewski Patent	t-5	0.010"	75	0	--	0
917	C-350	17	Majewski Patent	t-5	0.010"	0	0	62	0
918	A/B	17	Majewski Patent	t-5	0.010"	100	88	--	--

^a Each percentage represents the number of specimens exhibiting cracking out of a total of eight specimens per sample.

TABLE VII
BOX END LOAD COMPRESSION RESULTS

Lot No.	Panel Score	Clearance ^a	Offset ^a	#920 C-200	% Diff. ^b	#921 C-200	% Diff. ^b	#919 C-275	% Diff. ^b	#917 C-350	% Diff. ^b	Single Wall Composite	% Diff. ^b	#918 A/B Dbl. Wall	% Diff. ^b
31	V vs. flat stl.	t + 5	--	770	--	859	--	1504	--	1943	--	1269	--	1250	--
32	V vs. flat stl.	t - 5	--	863	+12.0 ^c	872	+1.0	1519	+1.0	1976	+1.7	1307	+3.0 ^c	1184.	-5.3 ^c
33	V vs. flat poly.	t + 5	--	758	-1.7 ^c	874	-3.1	1458	-3.1	1980	+1.9	1267	-0.1	1200	-4.0 ^c
34	V vs. flat poly.	t - 5	--	862	+11.9 ^c	834	-2.9	1462	-2.8	2023	+4.1	1295	+2.1 ^c	1112	-11.0 ^c
35	Maj. 90°	t + 30	0	858	+11.4 ^c	832	-3.2	1523	+1.3	2086	+7.3 ^c	1325	+4.4 ^c	1206	-3.5
37	Maj. 90°	t + 5	0.1"	844	+9.5 ^c	826	-3.8	1526	+1.2 ^c	1964	+1.1 ^c	1290	+1.6 ^c	1256	+0.5 ^c
38	Maj. 90°	t - 5	0.1"	750	-2.6	862	+0.4	1644	+9.4	2073	+6.7 ^c	1333	+5.0 ^c	1132	-9.4 ^c
42	Maj. 180°	t + 5	0	742	-3.7 ^c	904	+5.2	1600	+6.5	1956	+0.7	1301	+2.5	1266	+1.3 ^c
43	Maj. 180°	t - 5	0	842	+9.3 ^c	896	+4.3	1476	-1.8	2056	+5.8 ^c	1318	+3.8 ^c	1154	-7.6 ^c
<u>Deflections, inches</u>															
31	V vs. flat stl.	t + 5	--	0.30	--	0.32	--	0.44	--	0.40	--	0.36	--	0.39	--
32	V vs. flat stl.	t - 5	--	0.41	+34.7 ^c	0.38	+20.5 ^c	0.42	-6.1	0.42	+6.6	0.41	+11.6 ^c	0.40	+0.5
33	V vs. flat poly.	t + 5	--	0.33	+9.2 ^c	0.34	+8.2	0.41	-7.7	0.41	+3.3	0.37	+2.3 ^c	0.40	+0.5
34	V vs. flat poly.	t - 5	--	0.40	+32.0 ^c	0.34	+7.9	0.39	-11.3	0.43	+9.6	0.39	+7.5 ^c	0.39	-1.0
35	Maj. 90°	t + 30	0	0.32	+5.9	0.33	+5.4	0.41	-8.1	0.42	+6.6	0.37	+1.7	0.42	+6.9
37	Maj. 90°	t + 5	0.1"	0.31	+2.3	0.31	-1.6	0.42	-5.4	0.41	+2.8	0.36	+0.8	0.41	+3.8
38	Maj. 90°	t - 5	0.1"	0.35	+14.9 ^c	0.35	+10.7 ^c	0.40	-9.3	0.45	+12.6 ^c	0.39	+6.0 ^c	0.40	+2.5
42	Maj. 180°	t + 5	0	0.35	+14.9 ^c	0.37	+17.7 ^c	0.44	-1.8	0.40	0	0.39	+6.4 ^c	0.41	+5.3
43	Maj. 180°	t - 5	0	0.34	+11.6 ^c	0.34	+5.7	0.39	-12.4	0.40	+0.5	0.36	0	0.39	-0.3

^aMeasurement of clearance and offset conditions dependent upon the type of profile being used as discussed in the description of the profiles.
Clearance = t (sum of lines and medium caliper) + or - N (number of thousandths of an inch). Offset is measured from an established reference.

^bBased on the value of Lot #31 as reference.

^cSignificant at the 0.05 level.

Note: All boxes were made with a standard flap score consisting of 3 point wheels at a clearance of t + 5 (see Lot #1).
Clearance for #918 (A/B double wall) was 0.090" greater than the listed clearance for all lot numbers.
Each value is the average of 10 determinations.

double wall boxes made at the t-5 clearance showed a 5.3% lower top load strength than the double wall boxes made at the t+5 clearance. Looking at the deflection measurements for the boxes made with the V vs. flat steel wheels, both of the C-200 board series groups showed significantly more end deflection for the boxes made from the reduced clearance (t-5) condition. In the other series, there were no significant differences between the deflections recorded for boxes at the standard and reduced clearances.

The V vs. flat polyurethane wheels produced boxes with end load strength and deflection properties nearly equivalent to the V vs. flat steel wheels. This was true for both the t+5 and t-5 clearance settings.

It should be noted that the A/B double wall board, in addition to requiring an extra 0.090 inch clearance above the normal clearance for all settings had to be conditioned at high relative humidity (>80% RH) before scoring in order to eliminate single face liner cracks on the A-flute portion. This was found to be necessary for all profiles and was a function of the liner properties rather than the scoring process.

The Majewski Patent 90° cross-direction profile end load results at zero offset and a large t+30 clearance were significantly higher for two of the single wall board series, #920, C-200 and #919, C-350. The deflections, however, for all of the boxes made with the Majewski Patent 90° cross-direction wheels at the zero offset did not differ significantly from the deflection of the boxes made from the standard wheels. There was also some small single face liner cracking on several of the blanks from all of the board series at this scoring condition.

Boxes made from the Majewski Patent 90° cross-direction wheels at the 0.1 inch offset and the t+5 clearance did not differ significantly from boxes made with the standard V vs. flat steel wheel at the t+5 clearance for either end load strength or deflection. When the clearance for the Majewski Patent 90° cross-direction wheels was reduced to t-5, then significant increases in end load strength above the standard boxes occurred for both the #919, C-275 series (9.4%) and the #917, C-350 series (6.7%). Also at this t-5 clearance, the end load deflections for boxes of three of the four single wall board series were significantly higher than for the standard boxes. The double wall construction boxes, on the other hand, exhibited a significant 9.4% lower than standard end load strength when made from blanks scored with the Majewski Patent 90° cross-direction wheels. Some slight cracking of the double face liner was noted on specimens of the C-275 and C-350 series boards.

The Majewski Patent 180° cross-direction wheels at the t+5 clearance produced boxes with end load strengths that did not differ significantly from the end load strengths of the standard boxes for any of the board series. The deflections of the boxes made from these same scoring conditions for the #920 and #919 (C-200) series boards were significantly higher than the deflections of the boxes made from the standard scoring conditions.

Boxes from two of the single wall constructions scored with the Majewski Patent 180° cross-direction wheels at the t-5 clearance exhibited end load strengths significantly higher than the standard boxes. Boxes made from the double wall board scored with the Majewski Patent 180° cross-direction wheels at the t-5 clearance exhibited a significant 7.6% lower than standard end load compression strength. The end load deflections for boxes made with the Majewski Patent 180°

cross-direction wheels were generally not significantly different from the end load deflections of the standard boxes.

Figure 12 graphically shows the results of the panel score profile effects on box end load compression as discussed. By comparison with Fig. 11, it can be seen that the panel score profile changes affected box end load compression even less than flap score profile changes affected box top load compression.

Table VIII shows the folding torque and restoring angle test results for the various panel score profile, offset and clearance conditions evaluated.

The V vs. flat steel scorelines at the reduced t-5 clearance required less torque to fold than did the V vs. flat steel scorelines at the standard t+5 clearance. However, there were no significant differences in the angles of restoration between the scorelines at the two clearance levels.

The V vs. flat polyurethane scorelines made at the t+5 clearance level generally required less torque to fold than did the V vs. flat steel scorelines at the t+5 clearance level. For the composite of the single wall constructions, this reduction in required torque was a significant 17.7%. The double wall construction evaluated under the same conditions required 8.2% less torque to fold than did the double wall standard scoreline. There were very little differences in the angles of restoration of the V vs. polyurethane and the V vs. steel wheels at any clearance level.

The scorelines made from the V vs. polyurethane panel score wheels at the t-5 clearance level also exhibited lower folding torques than did the standard scorelines. However, the results of the folding torque tests on these

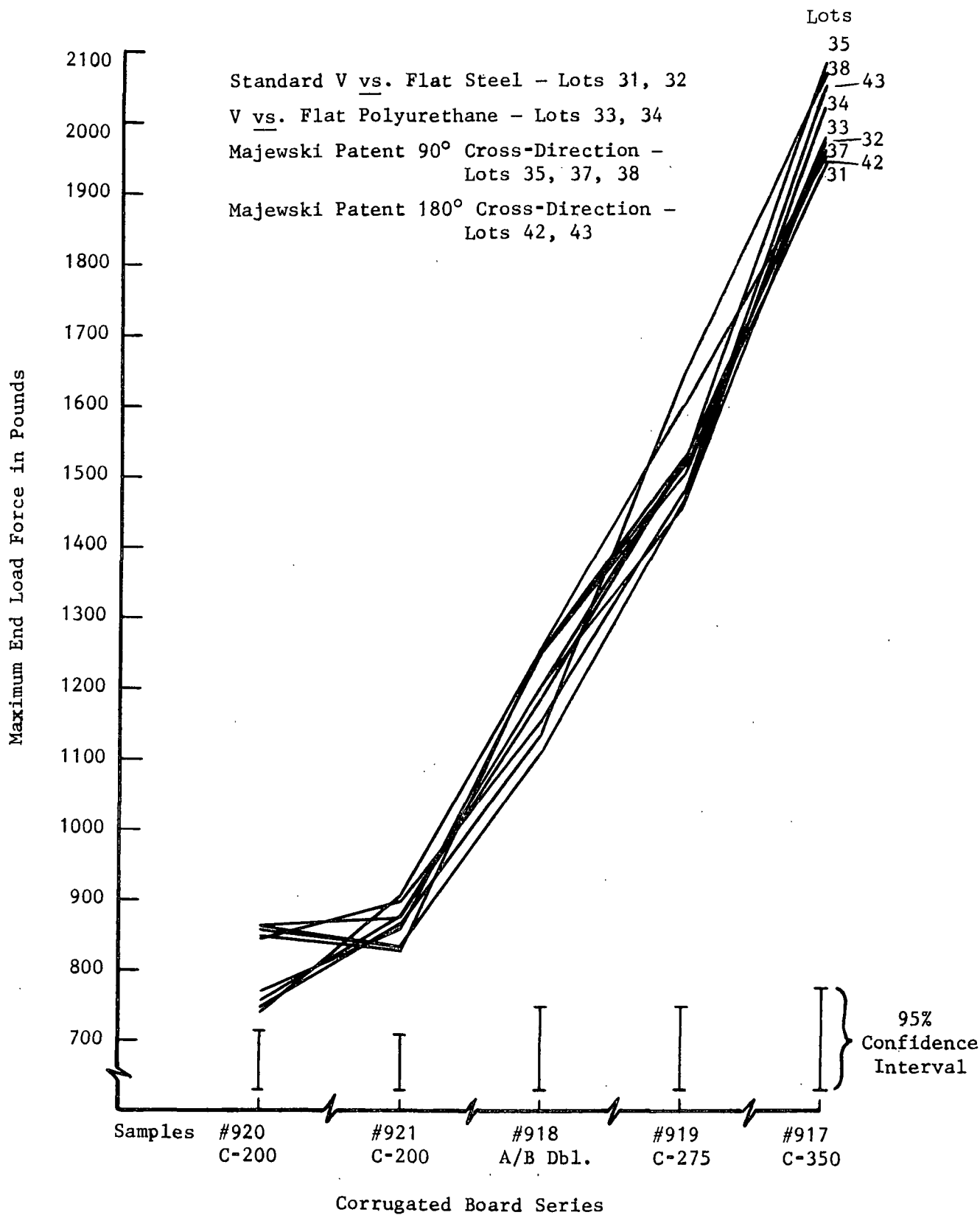


Figure 12. Panel Score Profile Effect on Box End Load Compression

TABLE VIII
PANEL SCORELINE FOLDING TORQUE RESULTS

Lot No.	Panel Score	Clear- ance ^a	Offset ^a	#920 C-200		#921 C-200		#919 C-275		#917 C-350		Single Wall Composite		#918 A/B Dbl. Wall	
				% Diff.	% b	% Diff.	% b	% Diff.	% b	% Diff.	% b	% Diff.	% b	% Diff.	% b
31	V vs. flat steel	t + 5	--	0.63	--	0.81	1.37	1.48	1.07	2.39	1.07	2.39	--	2.39	--
32	V vs. flat steel	t - 5	--	0.62	-1.9	0.52	-36.0 ^c	1.38	0.81	2.19	0.81	2.19	-24.6 ^c	2.19	-8.5 ^c
33	V vs. flat poly.	t + 5	--	0.72	+14.7 ^c	0.72	-11.8	1.17	0.88	2.20	0.88	2.20	-17.7 ^c	2.20	-8.2
34	V vs. flat poly.	t - 5	--	0.72	+15.4 ^c	0.80	-1.4	1.38	0.98	2.70	0.98	2.70	-8.1	2.70	+12.7 ^c
35	Maj. Patent 90°	t + 30	0	0.31	-50.9 ^c	0.32	-60.6 ^c	1.02	0.58	2.05	0.58	2.05	-45.7 ^c	2.05	-14.3 ^c
37	Maj. Patent 90°	t + 5	0.1"	0.37	-40.1 ^c	0.30	-63.0 ^c	1.02	0.60	2.07	0.60	2.07	-44.1 ^c	2.07	-13.7 ^c
38	Maj. Patent 90°	t - 5	0.1"	0.28	-55.2 ^c	0.31	-62.1 ^c	1.05	0.60	2.07	0.60	2.07	-51.0 ^c	2.07	-26.5 ^c
42	Maj. Patent 180°	t + 5	0	0.46	-27.0 ^c	0.52	-36.5 ^c	1.35	0.80	1.94	0.80	1.94	-24.9 ^c	1.94	-19.0 ^c
43	Maj. Patent 180°	t - 5	0	0.40	-35.5 ^c	0.43	-47.4 ^c	1.18	0.74	1.92	0.74	1.92	-30.6 ^c	1.92	-19.6 ^c

Maximum Torque, in.-lb/in.

Angle of Restoration, degrees^d

^aMeasurement of clearance and offset conditions dependent upon the type of profile being used as discussed in the description of the profiles.
Clearance = t (sum of liners and medium caliper) + or - N (number of thousandths of an inch). Offset is measured from an established reference.

^bBased on the value of Lot #31 as reference.

^cSignificant at the 0.05 level.

^dAngle of restoration is measured from the vertical release point after folding scoreline thru 90°. Higher angular values indicate more restoration and less efficient scoring.

Note: All boxes were made with a standard flap score consisting of 3-point wheels at a clearance of t+5 (see Lot #1).
Each value is the average of 5 determinations.
Clearance for #918 - A/B double wall was 0.090" greater than the listed clearance for all lot numbers.

scorelines were not as low or as consistent among all of the combined board grades as the test results of the V vs. polyurethane wheels at the t+5 clearance.

All of the Majewski Patent 90° cross-direction scoreline samples exhibited folding torque requirements consistently lower than the standard scoreline folding torques for all of the five board series. The restoration angles of these scorelines were not significantly different from the restoration angles of the standard scorelines except for the double wall board series. For the double wall board series, the angles of restoration of the Majewski Patent 90° cross-direction scorelines were significantly higher than the restoration angle of the standard scoreline.

All of the Majewski Patent 180° cross-direction scoreline samples also exhibited folding torque requirements significantly lower than the standard scoreline folding torques. As with the Majewski Patent 90° cross-direction wheels, the 180° cross-direction wheels produced scorelines requiring the least torque to fold when operated at the lowest clearance setting. The angles of restoration for the Majewski Patent 180° cross-direction scorelines at the t+5 clearance were slightly higher than the standard scoreline angle of restoration. For the single wall composite average, this value for the angle of restoration was a significant 4.1% above the standard angle of restoration. The angles of restoration of the Majewski Patent 180° cross-direction scoreline at the t-5 clearance were generally not significantly different from the standard angles of restoration.

Table IX shows the percentage of specimens exhibiting panel scoreline cracking when scored and later folded under low relative humidity (<20% RH) conditions. Eight specimens were evaluated at the minimum clearance condition of each of the four panel score profile combinations listed in the table. There

TABLE IX

EVALUATION OF PANEL SCORELINE CRACKING

Sample	Board Series	Lot No.	Panel Score	Clear- ance	Offset	% of Scorelines Cracked ^a			
						After Scoring		After Folding	
						S.F. Liner	D.F. Liner	S.F. Liner	D.F. Liner
920	C-200	32	V vs. steel	t-5	--	0	0	0	0
921	C-200	32	V vs. steel	t-5	--	0	0	0	0
919	C-275	32	V vs. steel	t-5	--	0	0	0	88
917	C-350	32	V vs. steel	t-5	--	0	0	0	100
918	A/B	32	V vs. steel	t-5+90 ^b	--	0	0	0	0
920	C-200	34	V vs. poly.	t-5	--	0	0	0	0
921	C-200	34	V vs. poly.	t-5	--	0	0	0	0
919	C-275	34	V vs. poly.	t-5	--	0	0	0	100
917	C-350	34	V vs. poly.	t-5	--	0	0	0	100
918	A/B	34	V vs. poly.	t-5+90 ^b	--	0	0	0	0
920	C-200	38	Majewski 90° C.D.	t-5	0.1"	0	0	0	0
921	C-200	38	Majewski 90° C.D.	t-5	0.1"	0	25	0	25
919	C-275	38	Majewski 90° C.D.	t-5	0.1"	0	0	0	88
917	C-350	38	Majewski 90° C.D.	t-5	0.1"	0	0	0	100
918	A/B	38	Majewski 90° C.D.	t-5+90 ^b	0.1"	0	0	0	0
920	C-200	43	Majewski 180° C.D.	t-5	0	25	50	25	50
921	C-200	43	Majewski 180° C.D.	t-5	0	12	100	12	--
919	C-275	43	Majewski 180° C.D.	t-5	0	0	100	0	--
917	C-350	43	Majewski 180° C.D.	t-5	0	0	38	0	100
918	A/B	43	Majewski 180° C.D.	t-5+90 ^b	0	0	0	0	0

^a Each percentage represents the number of specimens exhibiting cracking out of a total of eight specimens per sample.

^b Clearance factor of +90 refers to the additional clearance used for A/B double wall throughout the project to prevent cracking.

was a noticeable tendency for the board series with the heavy weight liners to crack after folding regardless of the score profile used. The Majewski Patent 90° cross-direction profile caused some cracking of the double face liner on one sample (#921, C-200) during scoring. The Majewski Patent 180° cross-direction profile caused considerable double face liner cracking during the scoring process in all board series except for the double wall construction and even caused some single face liner cracking in the scoring of the samples made from the lighter liner weight.

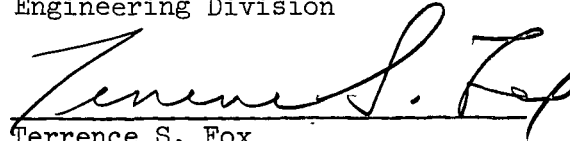
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