THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

ECT/COMPONENT RELATIONSHIPS

Project 3511

Report Two

A Progress Report

to

FOURDRINIER KRAFT BOARD GROUP

of the

AMERICAN PAPER INSTITUTE

and

FIBRE BOX ASSOCIATION

February 18, 1983

THE INSTITUTE OF PAPER CHEMISTRY

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INTRODUCTION

At the request of the Ad Hoc Rule 41 Committee, work has been carried out in two areas to further development of the proposed alternate to Rule 41/Item 222. First, a simple working formula, based on currently available data, has been developed to relate combined board ECT values to medium and liner ring crush (RC) values. This formula, and estimates of the scatter in ECT values, have been used to estimate the average liner ring crush values required to satisfy the proposed alternate rule. Secondly, specifications for the test procedure and equipment used to obtain the ECT data presented in Progress Report One, Project 3511, September 10, 1982, have been prepared. Three commercial instruments capable of meeting these specifications have been identified. Finally, the relationships between ring crush and STFI compressive strength measurements, and between ECT and estimated STFI component data, have been presented.

ECT - RING CRUSH RELATIONSHIPS

DATA SOURCES

As a basis for establishing a working ECT/RC relationship, data were solicited from industry sources by the Ad Hoc Rule 41 Committee. Only a few data sets were submitted; these were augmented by data available within the Institute that were of a comparable nature. The complete data collection is summarized in Tables I and II. Note that there are not enough data to establish a relationship for double wall, to include the 150 lb grade in the single wall analysis, or to distinguish the effect of flute size. Note, also, that the data are concentrated in the central grades. Some of the ring crush data were submitted as the composite RC sum, L+DM, thus making it impossible to separate medium and liner contributions to ECT. Finally, because these data are derived from only a few sources, they may show less scatter than is characteristic of the industry as a whole. If so, component strength requirements estimated from these data will be too low to satisfy the specified ECT values at the desired level of confidence.

All of the data used in this analysis are shown in Fig. 1 as ECT versus L+DM, both in lbs/in. Our task was to find a simple working relationship to represent this data set. In this report the composite RC is signified by L+DM where L is the sum of the liner RC values, M is the medium RC and D is the draw factor. The B-and C-flute draw factors used were 1.36 and 1.42 respectively.

TABLE I
ECT/COMPONENT DATA BY SOURCE

SOURCE CODE	NO. OF LOTS: SINGLE WALL B-FLUTE	C-FLUTE	TOTAL	DOUBLE-WALL[a]
A	--	87	87	3
B	1	13	14	1
C	17	33	50	15
D	--	58	58	--
E	5	25	30	--
TOTAL	23	216	239	19

[a] Twelve BC and seven AB or AC combinations.

TABLE II
SINGLE-WALL DATA BY SOURCE AND SERIES

SOURCE CODE	NO. OF LOTS: 125 Series	150 Series	175 Series	200 Series	275 Series	350 Series	TOTAL
A	--	--	23	32	25	7	87
B	1	--	5	3	5	--	14
C	5	3	6	22	10	4	50
D	7	--	8	22	11	10	58
E	6	--	7	8	9	--	30
TOTAL	19	3	49	87	60	21	239

BACKGROUND

Over the years, many relationships between ECT values and component properties have been developed. These have become progressively more complex as the models have been refined to take into account all of the important structural and component characteristics. The model by Urbanik, et al, is a good example. Such relationships are of great value for research and development purposes, and may ultimately find a role in everyday business. For present purposes, however, such models are too complicated for practical use, and the detail they contain is far overshadowed by the scatter in the data we are trying to represent.

FORMULA DEVELOPMENT

Analysis of the data in Fig. 1 shows that the ECT/L+DM relationship is curved, so much so that a single straight line formula does not fit the data in a satisfactory fashion. An appropriate nonlinear relationship would describe the data better than a straight line, but would be too cumbersome for everyday use. To preserve simplicity, we have chosen to divide the grade range into two parts, and fit each with a straight line formula.

For current single wall grades through 200 psi, the formula is

$$ECT = 0.80\,(L+DM) + 12$$

This formula is intended for use with the new ECT grades through 32 lbs/in. The fitting constants were obtained by regression of the data for current grades of 125, 175, and 200 psi. Equal weighting was assigned to each grade to avoid

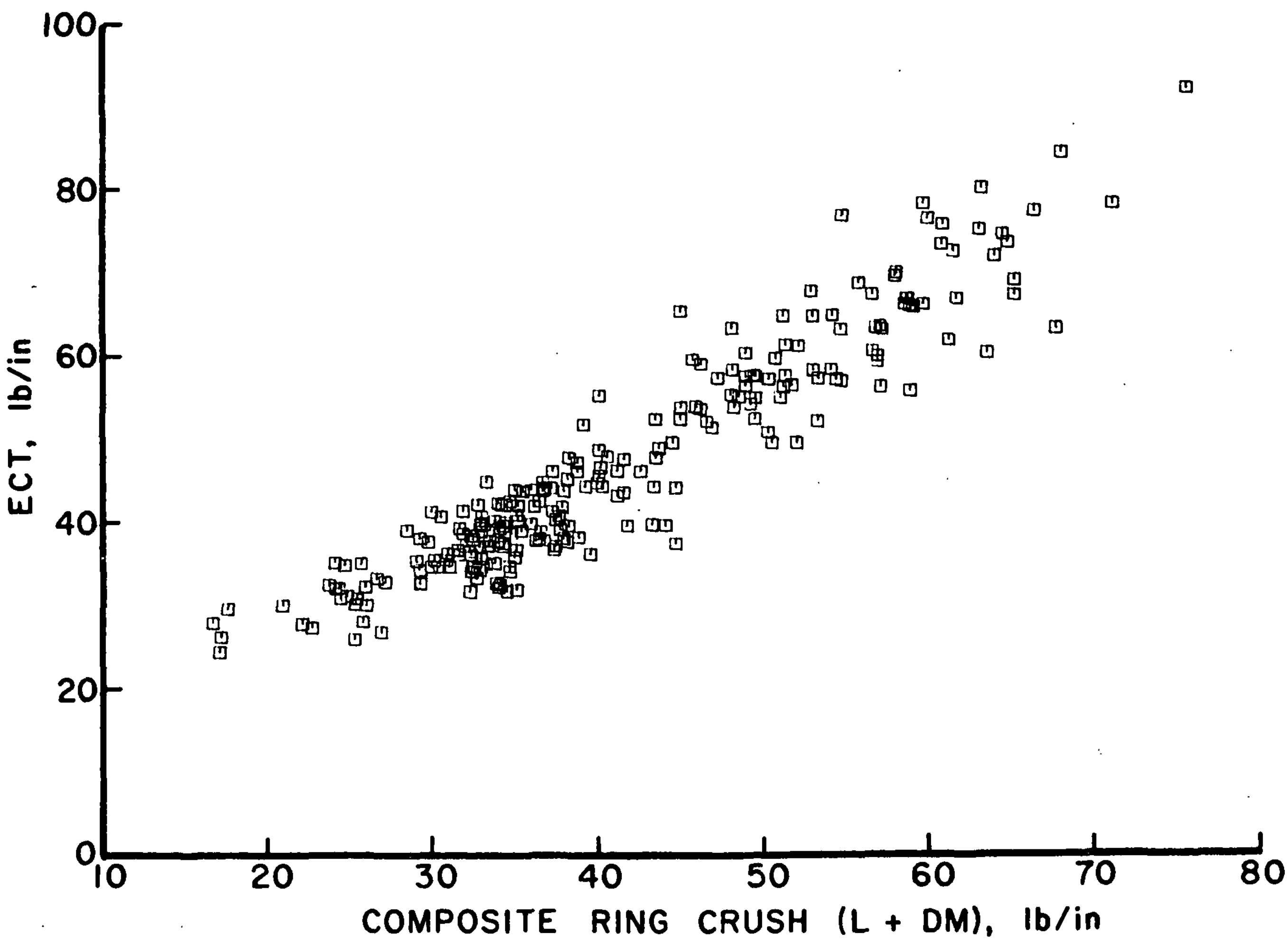


Figure 1: Data Set for Determining ECT/L+DM Relationship

domination by the large numbers of data in the central grade range. Both ECT and L+DM are in lbs/in.

For current single wall grades of 250 psi and above, the formula is

$$ECT = 1.27 (L+DM) - 6.0$$

This formula is intended for use with new ECT grades of 38 lbs/in and above. The fitting constants were obtained by regression of the data for the current grades of 200, 275, and 350 psi with each grade weighted equally. Both ECT and L+DM are in lbs/psi.

These formulae, shown by the solid lines through the data in Fig. 2, represent "average" relationships based on very limited data. Even these data are widely scattered about the formula line with a standard deviation of about 10%. Also shown in Fig. 2 are the lower 5 and 10% rejection lines for the relationship. For example, at a given ring crush level, no more than 5% of the observed ECT values should fall below the 5% rejection line. Fig. 2 indicates that the rejection lines are in good agreement with the data. Fig. 3 shows the formula line with the grade average ECT and L+DM values from this study superimposed. The 5 and 10% rejection lines are also included.

COMPONENT RING CRUSH REQUIREMENTS

Fig. 4 shows the new ECT grade specifications superimposed on the 10% rejection line. These intersection points can be used to estimate the average composite ring crush value necessary to meet the grade requirements. For

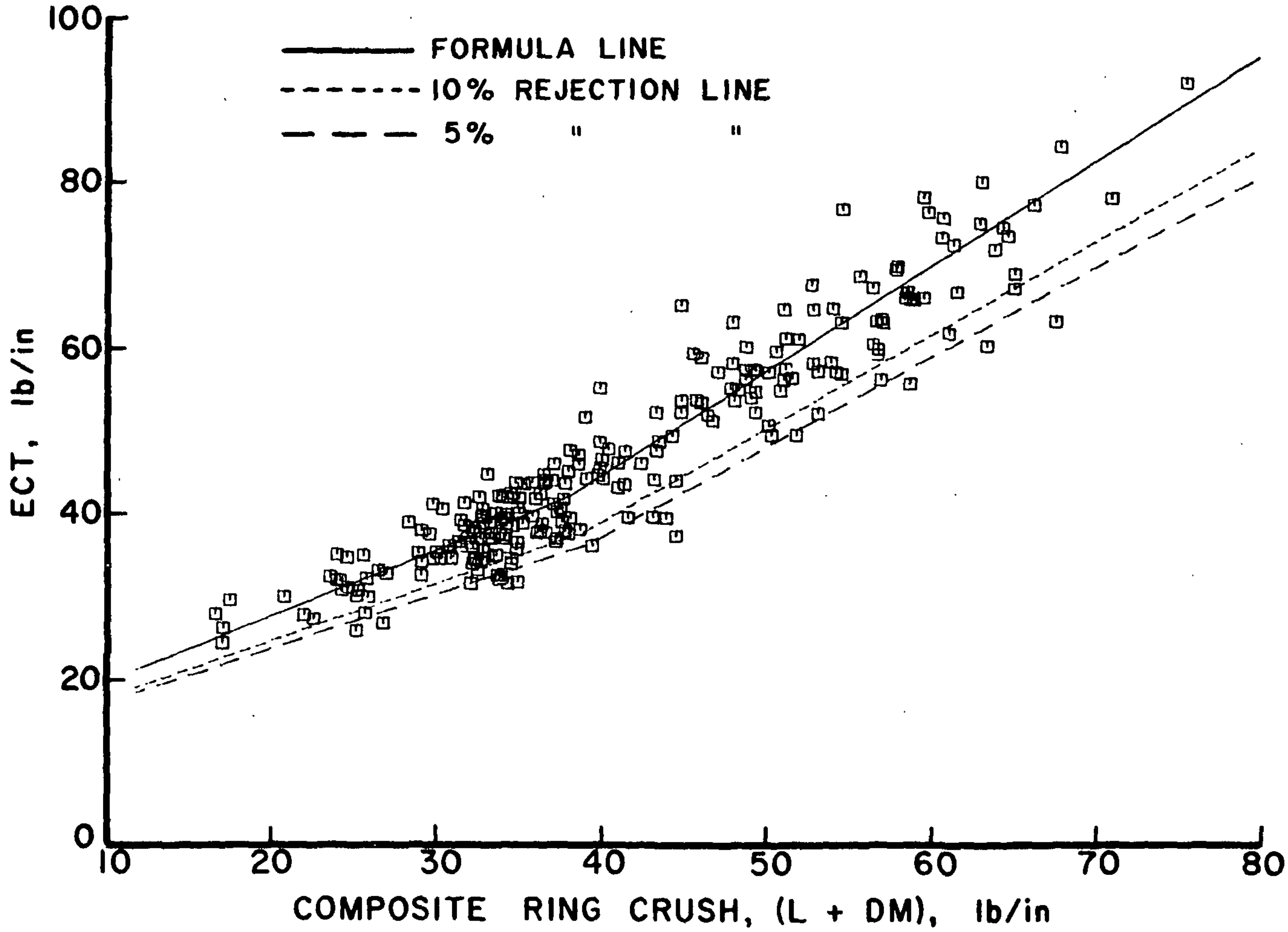
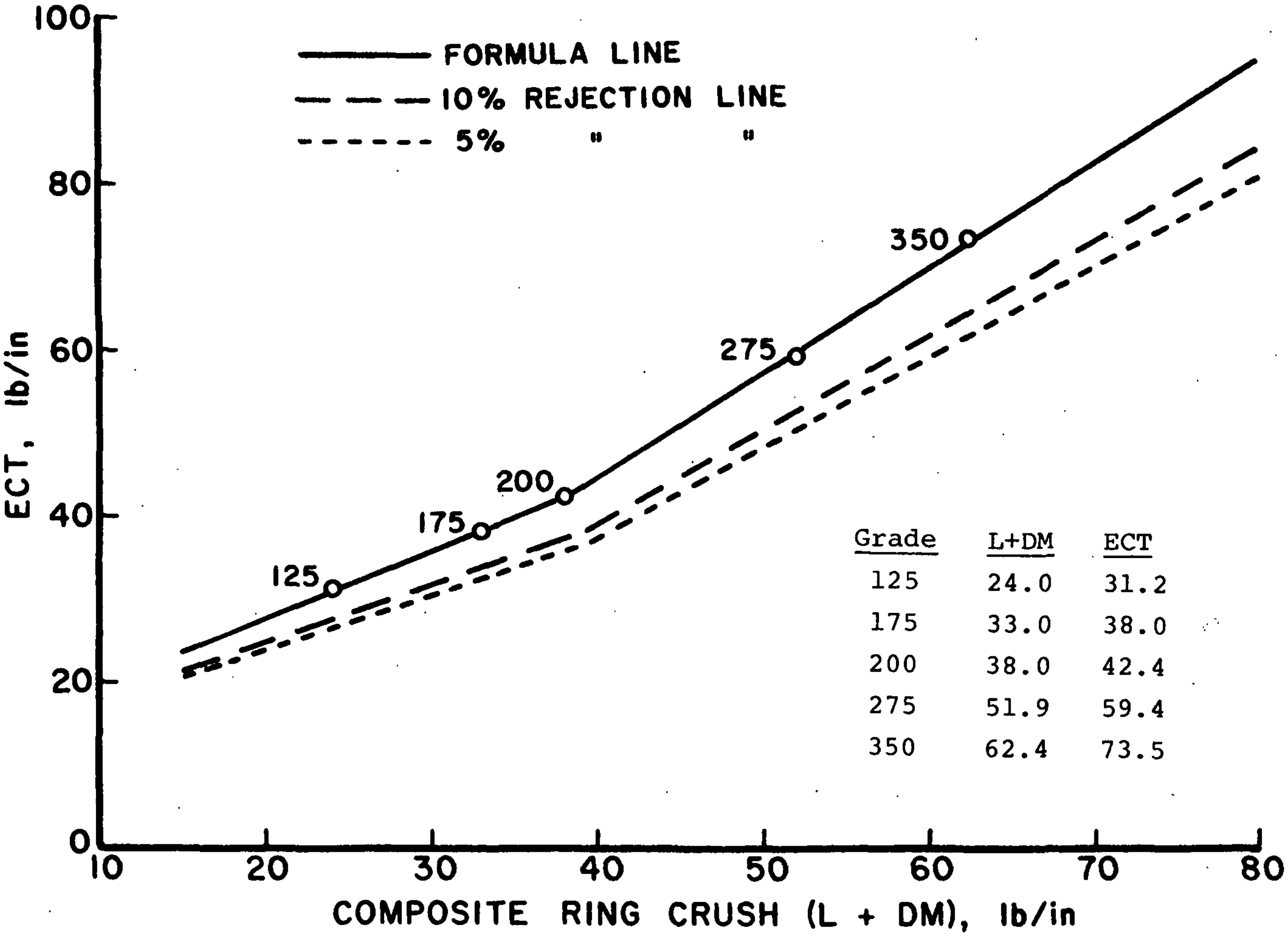


Figure 2: "Average" Relationship of ECT to Composite Ring Crush with 5 and 10% Rejection Lines Reflecting Variability



Grade	L+DM	ECT
125	24.0	31.2
175	33.0	38.0
200	38.0	42.4
275	51.9	59.4
350	62.4	73.5

Figure 3: "Average" ECT/Ring Crush Relationship and 5 and 10% Rejection Lines Lines with Grade Averages Superimposed

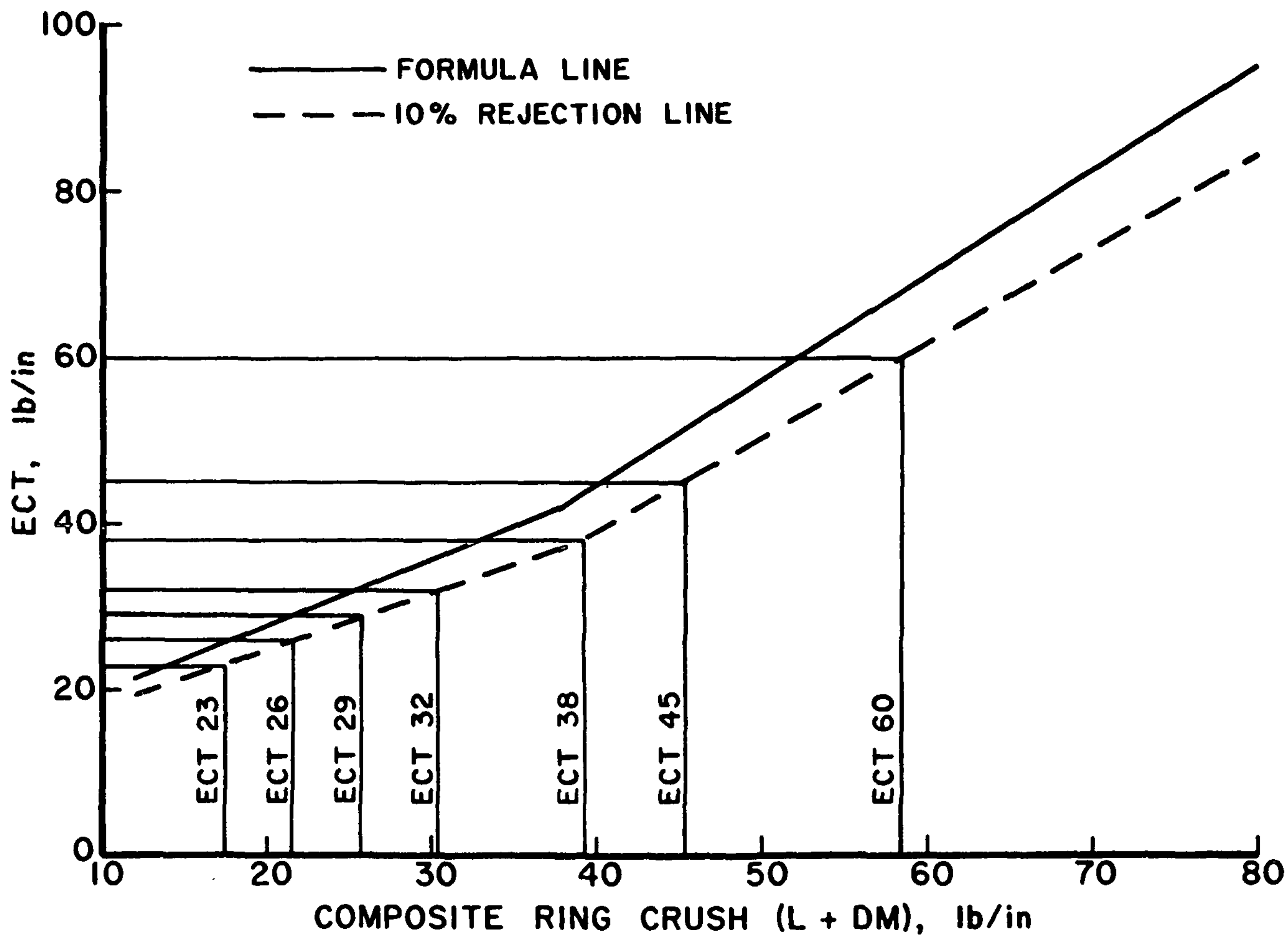


Figure 4: Composite Ring Crush Target Levels
Based on 10% Rejection Line

example, to obtain the new 32 lb/in grade level (current 200 series), an average composite ring crush of 30.2 lb/in would be needed to exceed the grade minimum 90% of the time. Fig. 5 shows the corresponding results using the 5% rejection line. The average composite ring crush values needed to achieve the specified ECT grade levels are summarized in Table III for all the new grade designations. Corresponding average liner ring crush values (assuming average medium ring crush of 5.5 lb/in) are also tabulated. The differences in the average liner ring crush estimates between the 10% and 5% rejection levels range from about 13% for the 23 grade to about 5% for the 60 grade.

Typically, mill production will need to be adjusted so that the average ring crush values are at or above these levels. In this sense, these values can be interpreted as mill production targets. However, each mill will need to use its own experience to set production specifications to satisfy the ECT requirements. These projections of ring crush are based on the variability present in the data in Tables I and II. As such, they are intended only to be illustrative, and should not be used in any other context without proper precautions or qualifications. Moreover, this average relationship may deviate substantially from that for a specific mill and box plant. Nevertheless, the data are useful in pointing to the approximate requirements for component ring crush.

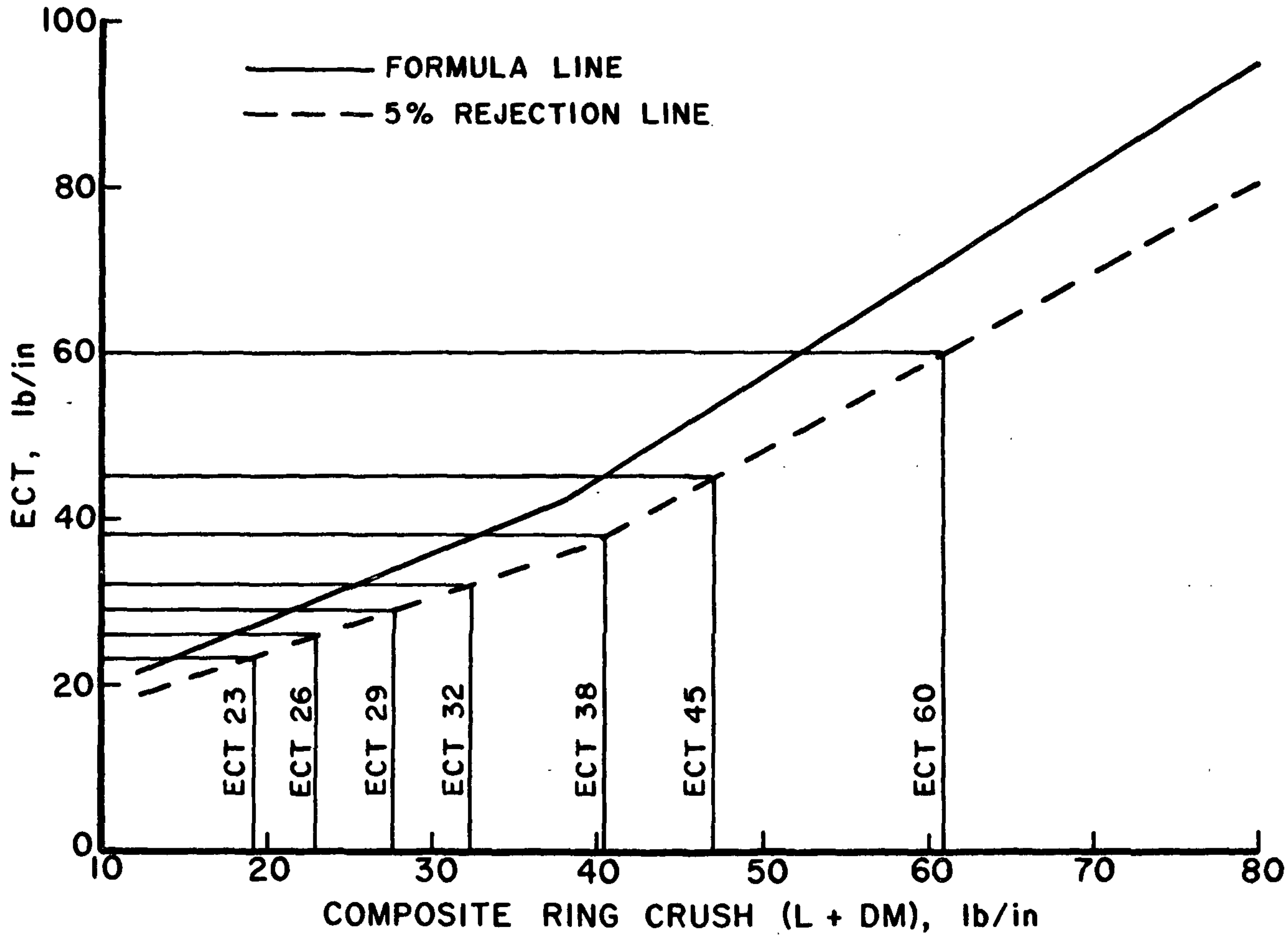


Figure 5: Composite Ring Crush Target Levels
Based on 5% Rejection Line

TABLE III
ESTIMATED AVERAGE (TARGET) COMPOSITE AND LINER RING CRUSH VALUES
CORRESPONDING TO 10% AND 5% REJECTION LIMITS

		10% Limits		5% Limits	
Current Grade Reference	New ECT Reference lb/in	Average Composite Ring Crush lb/in	Average Liner* Ring Crush lb/in	Average Composite Ring Crush lb/in	Average Liner* Ring Crush lb/in
125	23	17.2	4.7	18.4	5.3
150	26	21.5	6.9	23.0	7.6
175	29	25.9	9.0	27.5	9.9
200	32	30.2	11.2	32.1	12.1
250 (new)	38	39.0	15.6	40.5	16.3
275	45	45.2	18.7	46.9	19.6
350	60	58.4	25.3	60.8	26.5

*Assumed average medium ring crush = 5.5 lb/in; D = 1.42.

VARIABILITY IN ECT

The scatter in ECT values directly affects the location of the rejection lines and, hence, the estimates of required composite or liner ring crush. This scatter is dependent on several sources of variability, including component variability, conversion quality, and between laboratory testing differences.

The industry round-robins show that the between laboratory variability is about 10% in the case of both ECT and ring crush. Thus, large differences in ECT or ring crush can occur merely because of test instrumentation, maintenance, and calibration. In the case of this study, the data came from five "well controlled" laboratories, so testing differences are probably not as great as would occur in a wider industry sampling.

More consistent control of production processes and test instrumentation would make it possible to reduce compressive strength requirements. The economic significance of such reductions is self-evident with even a few percentage points being important.

To illustrate, we examined the effects of a 25% reduction in ECT variability on estimated ring crush requirements. This seems achievable via more consistent conversion quality control, better instrumentation and/or reduced component variability. Fig. 6 shows required average L+DM values for current and reduced ECT variability for the lower grades. Fig. 7 shows similar data for the upper grades. The resulting average composite and liner ring crush values are compared in Table IV. For example, for the 32 lb/in ECT grade (current 200 series) the reduced variability would result in about a 6-7% reduction in the average liner ring crush required to satisfy the grade requirement. While seemingly buried in present variability, even a 6-7% reduction in target requirements could result in large savings.

TESTING AND INSTRUMENTATION

TEST METHOD

For the box survey results presented in Report One, Project 3511, ECT values were measured with an Instron rigid platen test instrument. It is anticipated that the industry will move toward rigid platen systems for the measurement of compressive strength. Accordingly, we were asked to prepare specifications to describe the equipment and test procedures used in that survey. These are included in preliminary form in Appendix A in the format of a TAPPI method.

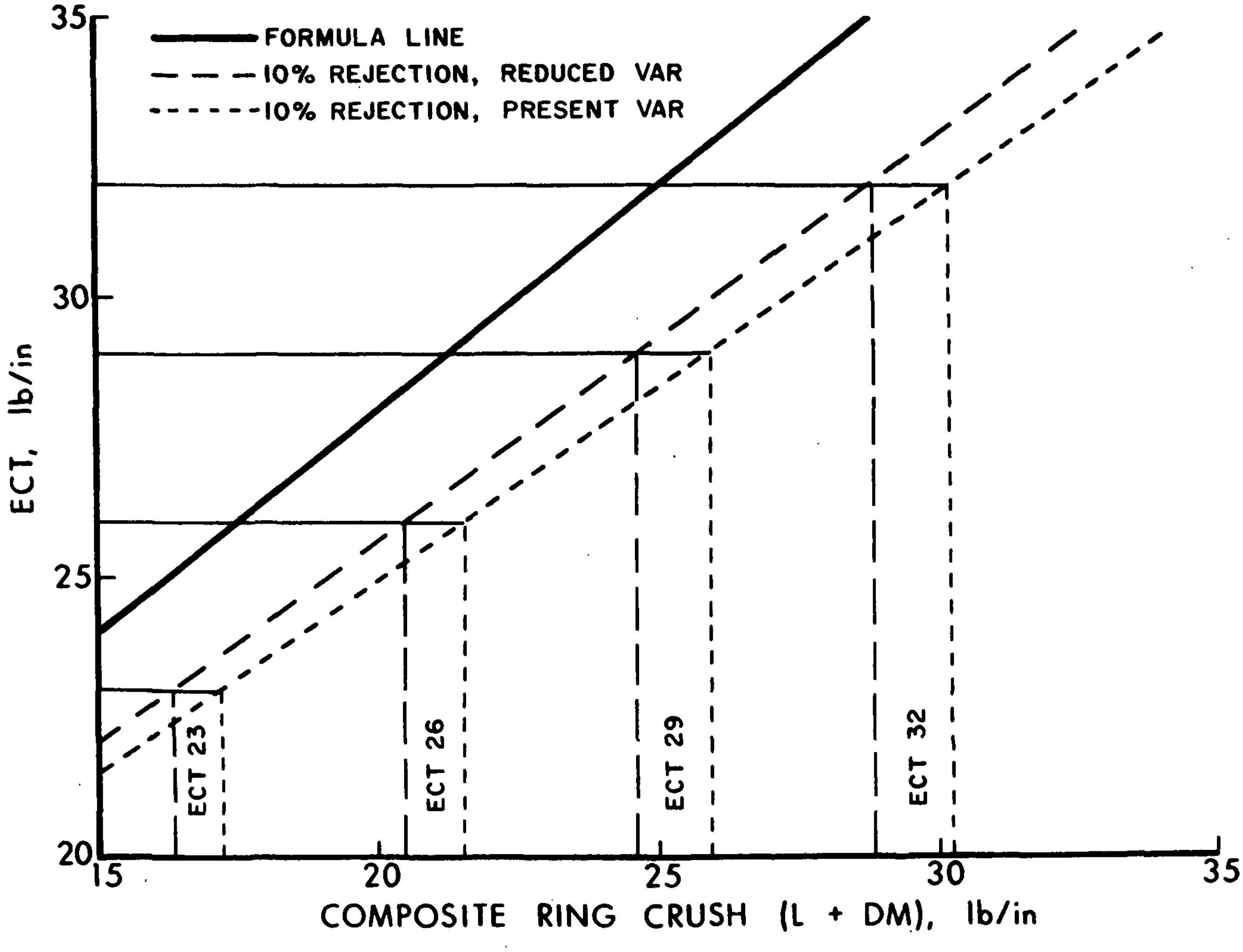


Figure 6: Estimated Ring Crush Savings for Lower Grades
Achievable via 25% Reduction in Variability

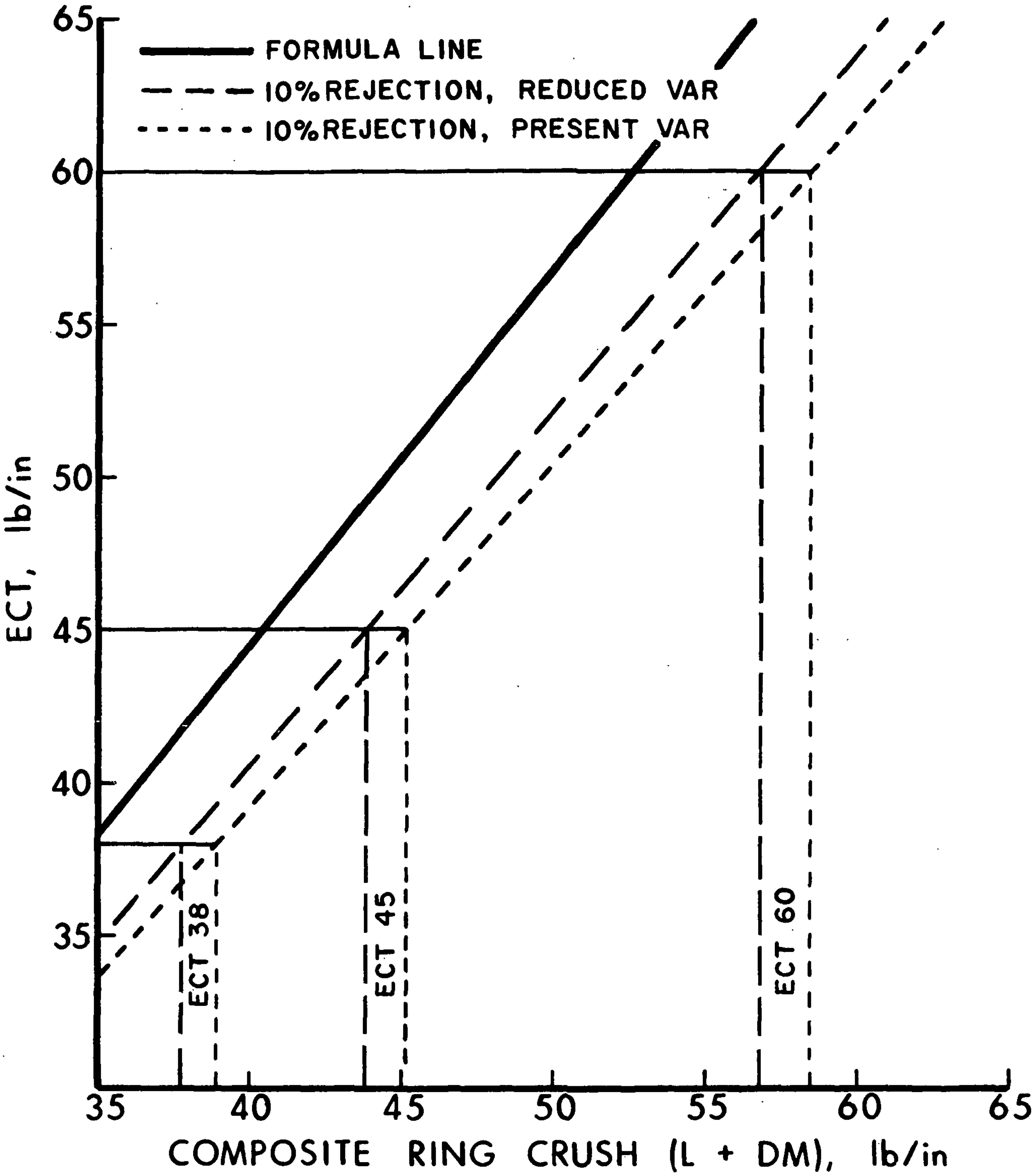


Figure 7: Estimated Ring Crush Savings for Higher Grades
Achievable via 25% Reduction in Variability

TABLE IV
EFFECT OF 25% REDUCTION IN VARIABILITY ON 10% LIMITS
FOR REQUIRED COMPOSITE AND LINER RING CRUSH

		Present Data		Assumed 25% Reduction of Variability	
Current Grade Reference	New ECT Reference lb/in	Average Composite Ring Crush lb/in	Average Liner* Ring Crush lb/in	Average Composite Ring Crush lb/in	Average Liner* Ring Crush lb/in
125	23	17.2	4.7	16.3	4.2
150	26	21.5	6.9	20.4	6.3
175	29	25.9	9.0	24.6	8.4
200	32	30.2	11.2	28.8	10.5
250 (new)	38	39.0	15.6	37.8	15.0
275	45	45.2	18.7	43.8	18.0
350	60	58.4	25.3	56.7	24.4

* Assumed average medium ring crush = 5.5 lb/in; D = 1.42.

ECT TEST INSTRUMENTS

To date, we have identified three test systems that should be compatible with the preliminary specifications. These are:

1. Certain late model Instron equipment
2. TMI Series 400 Crush Tester
3. L & W Model Code 506

There may also be a Japanese unit that is suitable, but our efforts to get specific information about it were unsuccessful.

STFI STRIP COMPRESSION TESTER

In implementing a rule based, in part, on compressive strengths, it will be necessary to have proper instrumentation for measuring both ECT values and component compressive strengths. Some aspects of the ECT measurement requirement are addressed in the proposed TAPPI method, included in this report as Appendix A. For component compressive strengths, ring crush measurements based on the H & D tester have been most commonly used. Although simple in concept, the H & D tester requires careful attention to produce good results. Collaborative reference data show that, in practice, the ring crush test is subject to wide variability between laboratories. Also, for the low basis weights, the ring crush test tends to reflect the buckling failure load rather than a true crush or compressive failure. For these reasons, it is worthwhile to explore alternative component compressive strength testers.

In earlier work for FKBG, the Institute studied the relationship between compressive strength as measured on the STFI strip compression tester (STFI compressive strength) and as measured by several other instruments, including the regular ring crush test (ring crush). Many liner and medium samples from numerous mills were included in the evaluation. Figure 8 shows the grade average STFI data plotted versus the grade average ring crush data. A nonlinear regression line has been fitted to these points and is also shown in the figure. The fit is good.

The regression relationship shown by the line in Fig. 8 exhibits significant curvature for the lightweight grades. This is believed to be a reflection of buckling in the ring crush tests for the lower basis weight (thin) samples. Buckling reduces the failure loads and, hence, shifts the data points to the left on the ring crush scale.

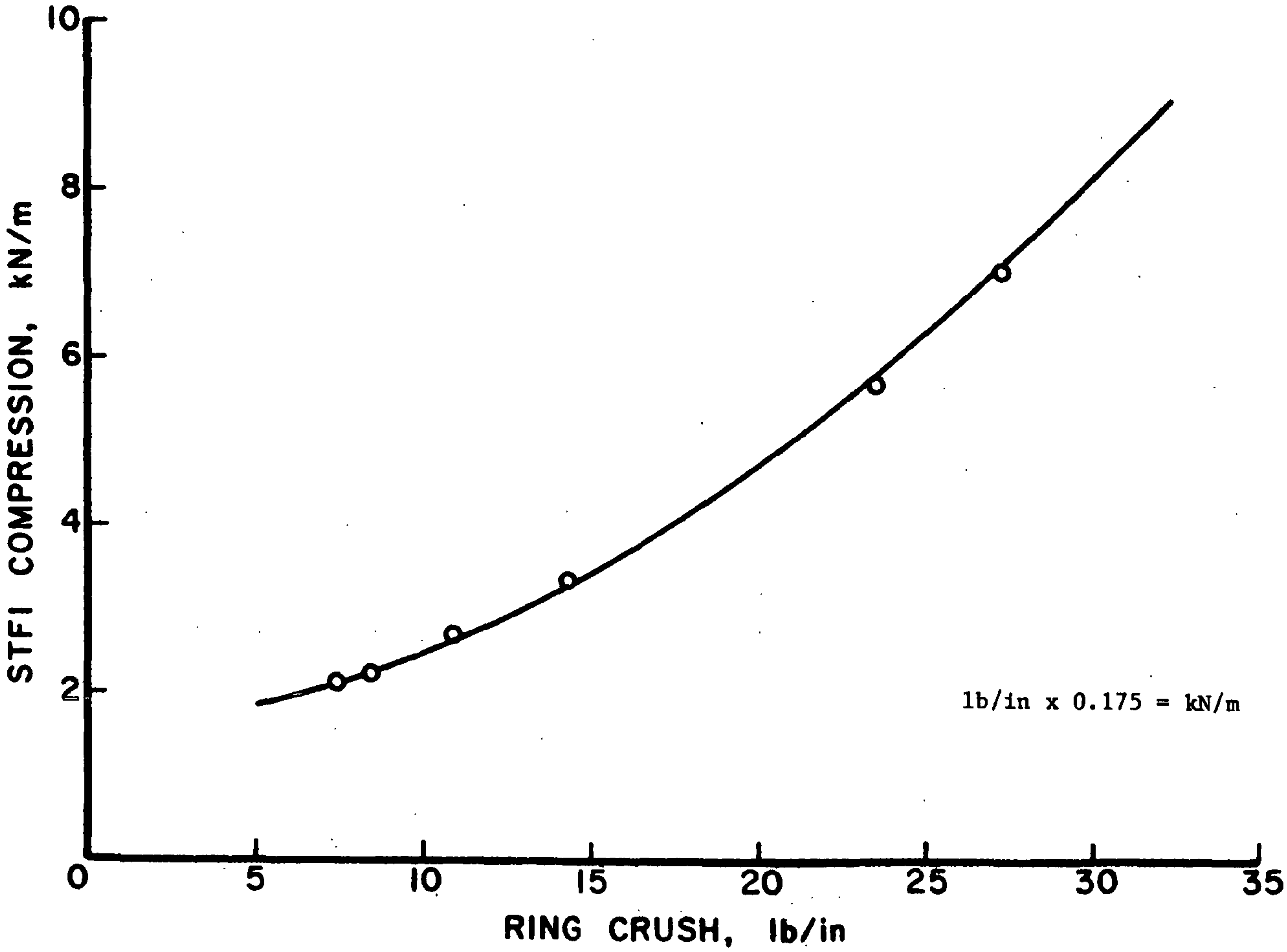


Figure 8: Relationships Between STFI Compression Values
and Regular Ring Crush Values

All of the ring crush data submitted for this study (Tables I & II) were converted to the equivalent STFI value by using the relationship represented in Fig. 8. The corresponding ECT values were then plotted against composite STFI compressive strength to yield the point diagram shown in Fig. 9. A straight line was fitted to these data by linear regression methods, with equal weighting assigned to all grades. This is shown as the solid line in Fig. 9. The corresponding 5 and 10% rejection lines are also shown as labeled.

When ECT is related to composite STFI compressive strength, as in Fig. 9, the result is a straight line passing very close to the origin. Again, this is believed to result from the measurement of true compressive strength by the STFI, as opposed to buckling which occurs in ring tests on light grades. For completeness, the formula and rejection lines, and the grade average data values are shown in Fig. 10 without the individual data points. By using the STFI data, a single relationship has been derived, which fits all grades.

One word of caution about the use of these data for <u>any</u> quantitative purpose: The STFI tester has undergone some recent design modifications which may cause future results to differ slightly from those shown here. The intent of this presentation is to show the potential advantages of such an instrument in simplifying interrelationships. The simplicity of the device as a test instrument is already known.

Lorentzen and Wettre, of Sweden, is now planning to market a new version of the STFI strip compression tester. This new tester will include means for automatically measuring sample moisture content as it measures compressive strength, and for adjusting the latter to a standard moisture content condition. With this moisture measurement and strength correction package, it will be possible

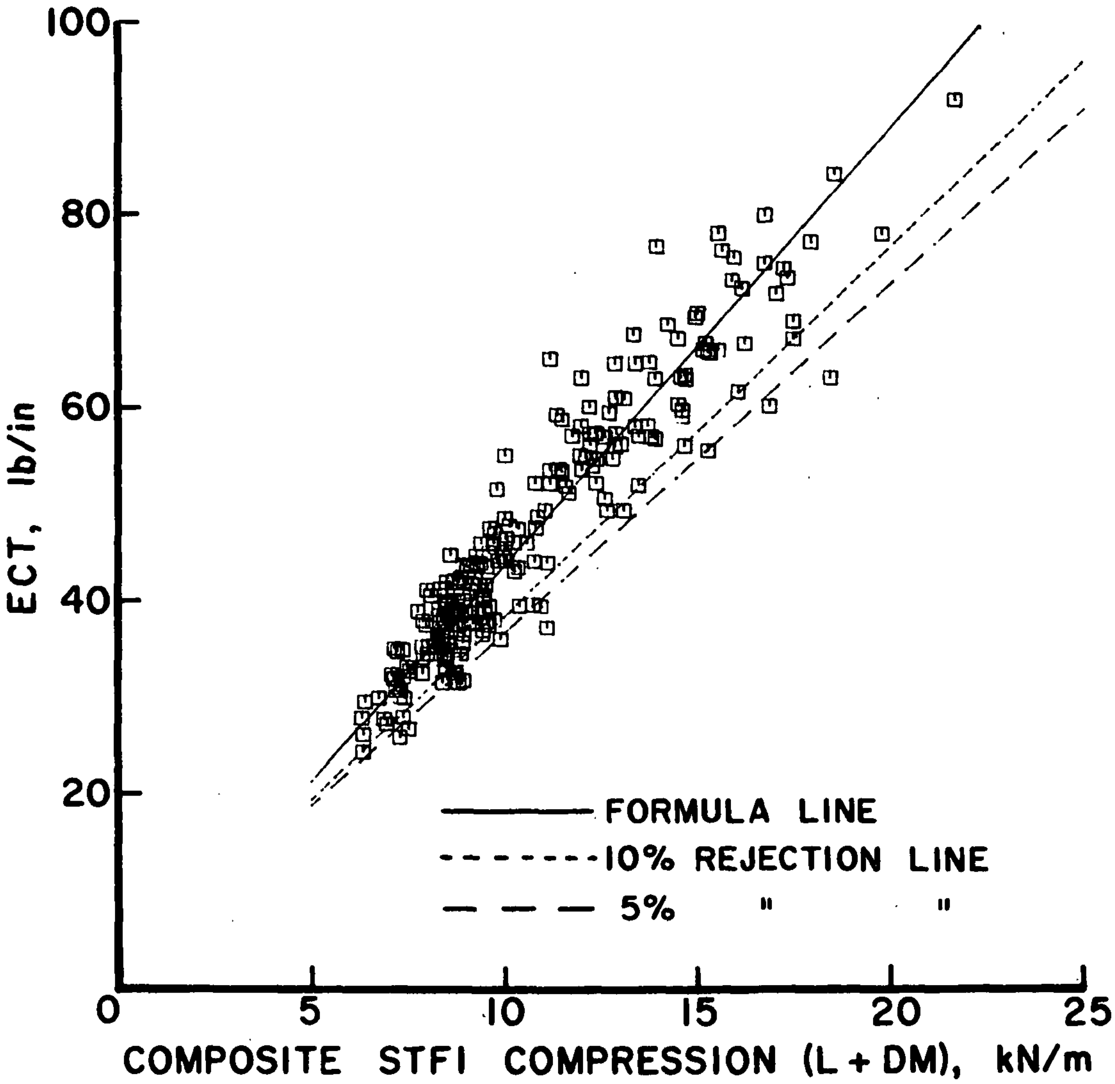


Figure 9: Relationship Between ECT Values and STFI Compression Values Estimated from Ring Crush Values

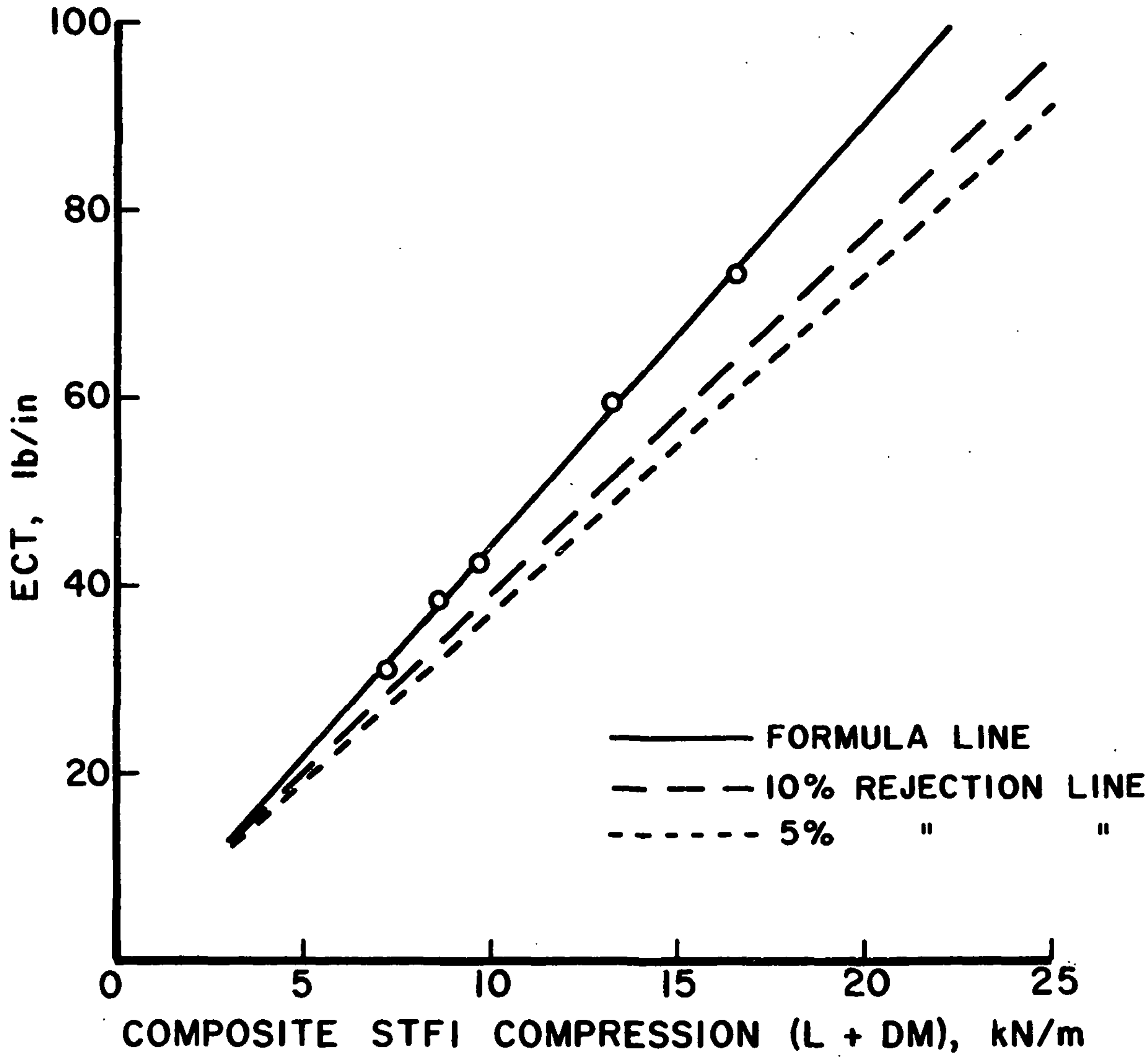


Figure 10: Formula and Rejection Lines Based on STFI Component Compression Values

to use the instrument on unconditioned samples with results very close to those that would be obtained from conditioned samples. This capability will make machine-side testing much faster and simpler, and the results will be much better than those typically obtained on unconditioned or poorly conditioned samples. The STFI tester, so modified, may thus become a valuable quality control tool for compressive strength. A brochure describing this new version of the instrument is included as Appendix B. Commercial availability of the instrument is expected in June, 1983; the first prototype should be on display at the 1983 TAPPI Annaul Meeting.

P R O P O S E D

APPENDIX A

EDGEWISE COMPRESSIVE STRENGTH OF CORRUGATED FIBERBOARD

(Rigid Support Method)

1. SCOPE

This method describes a procedure for determining the edgewise compressive strength, parallel to the flutes, of a short column of single-, double-, or triple-wall corrugated fiberboard. In this method, the specimen rests on a rigid support and is tested at a constant rate of deformation. Tappi Method T 811 describes a procedure in which the specimen rests on a non-rigid support and is tested at a constant rate of loading.

2. SIGNIFICANCE

Research has shown that the edgewise compressive strength of specimens with flutes vertical, in combination with the flexural stiffness of the combined board, relates to the top-to-bottom compressive strength of vertically fluted corrugated fiberboard shipping containers(1). This method may be used for comparing the edgewise compressive strength of different lots of similar combined boards or for comparing different material combinations(2,3).

3. APPARATUS

3.1 Compression testing machine having the following:

3.1.1 An upper and lower platen, one rigidly supported and the other driven. Each platen shall have a working area of at least 100 sq cm. The platens are required to have not more than 0.050 mm lateral relative movement, and the rigidly supported platen not more than 0.050 mm vertical movement, within a load range of 0 to 2500 N. The surfaces of the platens are required to be smooth, flat, and to remain parallel to each other within one part in 5000 throughout the test.

3.1.2 A means for moving the driven platen to achieve an initial platen separation of at least 6.0 cm. Within a range of platen separation of 0 to 6.0 cm., and within a load range of 0 to 2500 N, the speed of the driven platen shall be controllable at 10 $\pm$ 0.2 mm per minute. (Note: for convenience, the test machine should be capable of rapid return and automatic, settable positioning).

3.1.3 A capacity of at least 2500 N.

3.1.4 A means for measuring and indicating the maximum load sustained by the test specimen within 2.5 N.

3.2 Metal guide blocks (Fig. 1). Two are required to align the specimen vertically in the testing machine.

4. SAMPLING AND TEST SPECIMENS

4.1 From each test unit of a sample, obtained in accordance with T 400, accurately cut with a sharp, no set (hollow-ground or taper-ground is desirable) saw blade 10 representative specimens. Cut the specimens to a width of 51 ± 0.8 mm (2.00 ± 0.031 inch), and to a height of 32 ± 1.6 mm (1.25 ± 0.062 inch) for B-flute, 38 ± 1.6 mm (1.50 ± 0.062 inch) for C-flute, and 51 ± 1.6 mm (2.00 ± 0.062 inch) for A-flute and for double- and triple-wall board. The width edges shall be parallel to each other and perpendicular to the axis of the flutes (Fig. 2). Ensure that the saw blade is 90° to the table supporting the specimen.

4.2 Dip each loading edge (long edge) in molten paraffin (approx. melting point 52°C) to a depth of 6 mm (1/4 inch) and hold there until the absorbed paraffin, as determined visually, begins to migrate above the 6 mm dipped zone. Normally, a 3 sec. dip in molten paraffin at a temperature of 69-74°C is satisfactory. If excessively rapid migration is encountered, reduce the temperature of the molten paraffin. Immediately after dipping, momentarily blot the loading edges of the specimen on paper toweling preheated on a hot plate maintained at 77-82°C.

Note 1: The following alternative procedure for impregnating the loading edges of specimens with paraffin is permissible. Place the loading edges on a paraffin saturated pad, such as paper toweling, heated on a hot plate maintained at 77-82°C until the paraffin impregnates the specimen to the desired 6 mm depth. Generally this method is slower than the dipping method, and therefore permits better control of the depth of paraffin penetration for specimens in which paraffin migration is rapid.

5. CONDITIONING

Precondition and condition the prepared specimens in an atmosphere in accordance with Tappi Method T 402.

6. PROCEDURE

6.1 Perform all tests in the conditioned atmosphere.

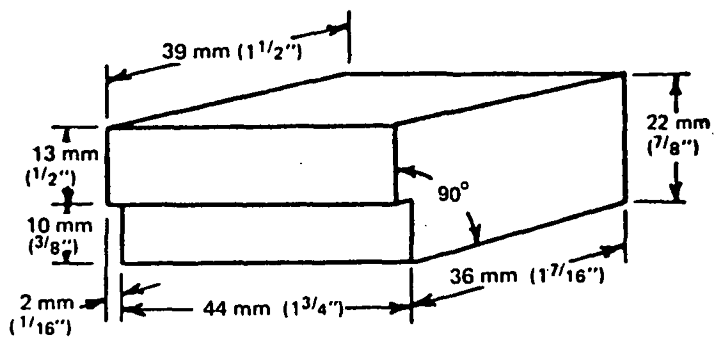


Fig. 1. Metal Guide Block

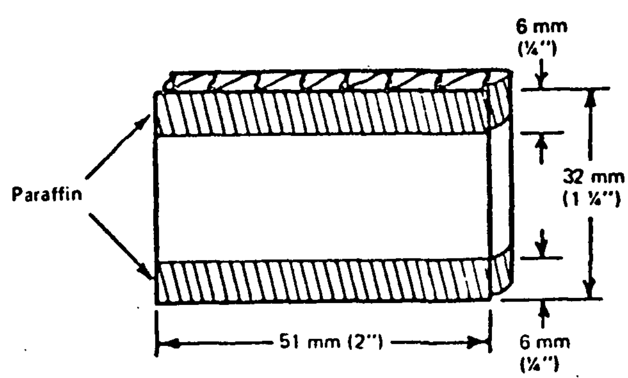


Fig. 2. Edgewise Test Specimen

6.2 Measure and record the width (nominal 51 mm) dimension of each specimen to the nearest 0.5 mm (1/16 inch).

6.3 Center the specimen on the bottom platen. Place a guide block on each side of the specimen, centrally located relative to it, so that the flutes are held perpendicular to the platen. Place the blocks largest face up, with the offset ends adjacent to, and in contact with, the specimen between the paraffined areas.

6.4 Activate the loading mechanism to close the driven platen on the specimen at a speed of 10 mm per minute. Continue the platen motion until the specimen fails, removing both guide blocks when the load on the specimen is between 20 and 69 N (5 and 15 lbs).

6.5 Record the maximum load and whether or not the specimen exhibited a valid failure (see Note 2).

Note 2: Valid tests are required to have the failure of the specimen occur by crushing in the region between the paraffin reinforcement zones. Failures by bending are not valid.

7. REPORT

7.1 For each test unit report:

7.1.1 The average maximum load per unit width for valid tests in kN/m (lb per 2-inch width x 0.08756 = kN/m) and, if desired, in lb/inch.

7.1.2 The standard deviation of valid tests.

7.1.3 The number of valid test specimens.

7.1.4 A description of material tested.

7.1.5 A statement that the test was conducted in accordance with this procedure, or a description of any deviations.

8. PRECISION

8.1 Repeatability (within a laboratory) = 4.2%

8.2 Reproducibility and comparability = not known in accordance with the definitions of these terms in T1206.

8.3 Repeatability was determined using test results from one laboratory for 271 samples ranging from 125-lb single-wall to 350-lb double-wall board.

REFERENCES

1. McKee, R. C., et al., "Compression Strength Formula for Corrugated Boxes", Paperboard Packaging 48:149 (August 1963).

2. Maltenfort, G. G., "Compression Strength of Corrugated", Paperboard Packaging 48:160 (August 1963).

3. Moody, R. C., "Edgewise Compressive Strength of Corrugated Fibreboard as Determined by Local Instability", U.S. Forest Service Research Paper FPL 46 (December 1965).

STFI Compression Strength Tester

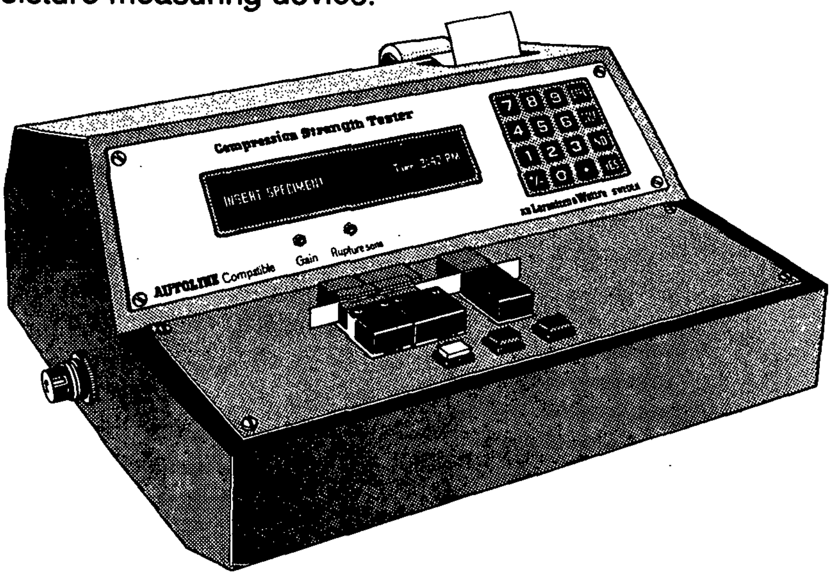
with moisture correction

CODE 53M

AUTOLINE Compatible

For measuring the compression strength in paper and board in the grammage range 100–400 g/m². The values measured are recalculated to standardized moisture content by means of a built-in microcomputer and a moisture measuring device.

This tester has been developed at the Swedish Forest Products Research Laboratory in Stockholm. The device and method for moisture correction was developed at the Institute of Paper Chemistry in Appleton, Wis.



This is a superior method which uses a microcomputerized precision instrument for providing an accurate measure of the compression strength at standardized moisture in one operation. Highly automated measurement and calculation according to preselected programs minimizes the risk of human errors.

Compression strength
Definition: The maximum compression force per unit width that a test piece of paper or board can support until the onset of failure in a compression test.

SI unit	N/m.
Recommended multiple unit	kN/m.

Compression index
Definition: The compression strength divided by the grammage.

SI unit	Nm/kg.
Recommended multiple unit	kNm/kg.

Specification

The unit includes a microcomputer which collects, stores and processes data. The compression strength measured is recalculated to standardized moisture according to a preselected program, depending on the grammage and quality of the test piece. Test results are presented on an alphanumeric printer. Conversational mode of operation with the computer (questions and answers) is presented on an alphanumeric display. Input data are entered via a keyboard.

- Memory capacity max 64 kBytes.
- Display max 40 positions, alphanumeric. Character height 5 mm.
- Printer max 20 positions, strip width 70 mm.
- Keyboard with digits 0–9, exponent, comma character, minus sign, information YES/NO, and five function keys.
- Rugged design permits use of the instrument in the papermachine environment.

We reserve the right to make changes in design.

AB Lorentzen & Wettre

Box 4 - S-163 93 SPÅNGA-STOCKHOLM, Sweden
Tel/Phone 08-752 01 60, telex 12999 WETTRE S
Besök/Visitors: Viderögatan 2, Kista

- Moisture measurement based on the conductivity of the test piece.
- Measuring range 300 N corresponding to 20 kN/m.
- Load cell 500 N, calibrated to 300 N.
- Adjustable clamping force.
- Strip width 15 mm.
- Strip length 120 mm minimum.
- Free span 0.7 mm.
- Presentation of corrected and uncorrected compression strength, test piece moisture content, correction program code, time and date of measurement, sample grammage, mean value and standard deviation of data measured and calculated.
- Dimensions: 0.5x0.5x0.3 m.

Connections

Power supply 110 V, 1-phase, 60 Hz, 100 W.
Instrument air min. 600 kPa.

Operation

Before performing a test series, the grammage of the sample and the program code suitable for the quality are entered via the keyboard. A test piece is placed vertically on its longest edge in the open pneumatic clamps (one pair for the force measurement and one pair for the moisture measurement). The work cycle is started, the clamps close and the motor-powered clamp compresses the test piece against the fixed clamp. Simultaneously the moisture content is measured. The force value obtained at "rupture" is retained. The compression strength is presented on the display and is printed out on the operator's command. The clamps release automatically after rupture and return to the open position. Work cycle 4–10 s. After finishing a test series, the date and time, sample grammage, program code and statistical data are automatically printed out.

Options

Asynchronous serial output 20 mA current loop for connection to printer or computer.
Analog signal output 0–10 V with automatic recorder start, suitable for the graphic recorder PM 8202, modified by L&W.
Other power supplies.

ORDERING DATA

Code No.
Voltage
Frequency

SHIPPING DATA

Net weight	24 kg
Gross weight	33 kg
Approx volume	0.3 m^3