THE RELATION BETWEEN EDGEWISE COMPRESSION STRENGTH AND THE DEGREE OF THE ANGLE PERPENDICULAR TO THE COMPRESSIVE FORCE OF CORRUGATED FIBREBOARD

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JAMES FRANCIS BORG

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ABSTRACT

THE RELATION BETWEEN EDGEWISE COMPRESSION STRENGTH AND THE DEGREE OF THE ANGLE PERPENDICULAR TO THE COMPRESSIVE FORCE OF CORRUGATED FIBREBOARD

By

James Francis Borg

This study was undertaken to determine what, if any, differences exist in edgewise compression strength of corrugated fibreboard, when the angle of the score, perpendicular to the compressive force, is varied from unscored, 180 degrees, through the angles of 135, 90, 45, and 30 degrees. From this data a ratio or ratios of length to width (L/W) for maximum compressive or stacking strength was determined. Samples of B-flute, 200-lb. test corrugated fibreboard, twelve inches square were compressed, with the height remaining constant and the distance from the score varying one inch from the edge, perpendicular to the direction of the compressive load, to a maximum of six inches from that edge. This was repeated for all angles tested. A ratio of the length to width (L/W) of between 1.20 and 1.40 and a 90 degree angle was found to be the combination that gave the greatest compressive strength.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

In the corrugated fibreboard industry, today, the Mullen Burst Test is used, almost exclusively, to specify the strength of corrugated board. Although the real strength and protective qualities of corrugated board may vary widely for the same test of board, the Mullen Burst Test is still used because of transportation tariff regulations, its ingrained nature in the industry and because the Burst Test is "quick and easy." The opinion that the burst strength of corrugated board is unsatisfactory as a test method and is only very indirectly related to the service strength of the end use of corrugated board, the box, is widely held.[1]

If the standard by which corrugated board is rated, today, is so ineffective, then what should the industry use as a standard in rating and specifying corrugated board? In the last ten to fifteen years many notable authorities of the corrugated industry, including McKee, Gander,

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[1]Robert George Bjornseth, "The Top to Bottom Compression Strength of a Corrugated Container as a Function of Flute Size and Relative Humidity Determined by Dead Load" (unpublished M.S. thesis, Michigan State University, 1959).

Wachuta; Maltenfort; and Kellicut and Landt, have come out in favor of using top-to-bottom compression tests as a truer means of identifying corrugated fibreboard quality and strength in actual use situations. "The top-to-bottom resistance of corrugated boxes is a true test, well correlated to properties of practical importance."[2] According to McKee, Gander, and Wachuta of the Institute of Paper Chemistry, "Compression strength of a corrugated box is of importance both as a partial indication of its warehouse stacking performance and as an overall measure of the quality of the fibreboard materials and conversion efficiency."[3]

This concept of compression strength is much more in line with the actual use of corrugated fibreboard and containers, rather than the Mullen Burst Test. One of the first objections raised when one discusses the replacement of the Mullen Burst Test is that any test that replaces it must be as easy to perform and the results of the board quality must be ready quickly. Probably the most serious limitation of the box compression test is that it is generally not capable of distinguishing between the several factors which contribute to box strength. In the event of

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[2]Oivend Langaard, "Optimation of Corrugated Board Construction with Regard to Compression Resistance of Boxes," International Paper Board Industry (November, 1968).

[3]R. C. McKee, J. W. Gander, and J. R. Wachuta, "The Why and How of Measuring Flexural Stiffness of Corrugated Board," Paperboard Packaging (December, 1962).

inadequate box strength, for example, it may not be apparent whether the fault lies with the component liners or corrugating medium, or the manufacture of the corrugated board, or the conversion operations. Closely allied with this lack of sensitivity to individual factors is the obvious shortcoming that the box test is so remote, in both time and location, from the manufacture of the paperboard and corrugated board, as to be of only limited value in the quality control operations of the mill and corrugating plant.[4]

Although the box compression strength test relates much more closely with the containers actual potential, the objections raised are valid from the manufacture's standpoint. The introduction of the "edgewise compression test" was and still is a property of major interest and overcomes the objections of the box compression test.

By edgewise compression, reference is made to the direction of the applied load, that is, parallel to the plane of the liners, in contrast to the flat-crush test where the compression is flat-wise. McKee et al. attribute the current interest in this property of combined board to the facts that (a) box compression strength is dependent to a large degree on the edgewise compression, (b) edgewise compression strength may reflect certain fabrication effects of corrugating, as well as the strength of the basic

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R. C. McKee, J. W. Ganer, J. R. Wachuta, "Edgewise Compressive Strength of Corrugated Fibreboard," Paperboard Packaging (November, 1961), pp. 70-76.

materials and therefore is a realistic measure of one of the qualities of corrugated board which govern top-load compression, and (c) from a research standpoint, study of combined board strength is a first step in a chain of relationships linking box compression performance to fibre properties.[5] Oivend Langaard, of the Billeruds Aktiebolag, Säffle, Sweden, writes on this subject ". . . the edge crush test is a theoretically sound method of assessing the quality of corrugated board and should be highly recommended for use instead of its bursting strength."[6]

F.E.F.C.O., Federation Europienne de Cartons Ondules, (European Corrugated Manufactures Association) in 1968 Published F.E.F.C.O. Testing Method No. 8, "Determination of the Edgewise Crush Resistance of Corrugated Board," which gives the exact test procedure and defines the apparatus used to determine edgewise crush resistance of corrugated fibreboard.[7] Reference can also be found from the Forest Products Laboratory, of the U.S. Forest Service

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[5] R. C. McKee, J. W. Gander, J. R. Wachuta, "Compression Strength Formula for Corrugated Boxes," Paperboard Packaging (August, 1963), pp. 149-159.

[6] Langaard, op. cit.

[7] F.E.F.C.O., "Determination of the Edgewise Crush Resistance of Corrugated Fibreboard," F.E.F.C.O. Testing Method No. 8 (November, 1968).

at Madison,[8,9] and from the Institute of Paper Chemistry at Appleton, Wisconsin.

In the study to be presented, the author used the procedures of F.E.F.C.O. Testing Method No. 8, previously mentioned, with two minor exceptions.

This study was conducted with the objective of determining what, if any, differences exist in edgewise compression of corrugated fibreboard, when the angle of the score was varied from an unscored, 180 degree, sample through the angles of 135, 90, 45, and 30 degrees, perpendicular to the compressive load. From the data collected, an optimum compressive strength ratio of the length to width (L/W) was also found. The study was not made to give any specific figures, in pounds per linear inch, although these figures do appear in the Tables of Chapter III.

For this study, B-flute, 200-lb. test board was used, because Moody, of the Forest Products Laboratory, had found that B-flute corrugated fibreboard was both theoretically and experimentally, to be higher in edgewise compressive strength than either A- or C-flutes.[10]

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[8]R. C. Moody, "Edgewise Compressive Strength of Corrugated Fibreboard as Determined by Local Instability," U.S. Forest Service Research Paper, FPL-46, December, 1965.

[9]R. C. Moody and J. W. Konning, Jr., "Effect of Loading Rate on the Edgewise Compressive Strength of Corrugated Fibreboard," U.S. Forest Service Research Note, FPL-0121, April, 1966.

[10]Moody, op. cit.

CHAPTER II

EXPERIMENTAL PROCEDURE

Design of Study

The objective of this study was to determine the differences that exist in edgewise compression of corrugated board, when the angle of the score is varied from an unscored, 180 degrees, sample through the angles of 135, 90, 45, and 30 degrees, perpendicular to the compressive load. From this data a ratio or ratios of length to width (L/W) for maximum compressive or stacking strength, could be determined.

The study adhered to F.E.F.C.O. Testing Method No. 8, "Determination of Edgewise Crush Resistance of Corrugated Board," in all aspects, except for the size of the specimen and the speed of the platens. The size of the specimen was changed to a board size of 12 inches by 12 inches, which was felt would represent a corrugated box more realistically, than the 25cm. by 100cm. specimen suggested by the test method. The speed of the platens was changed from 12.5mm. per minute to two inches per minute to accelerate the testing, because of the numerous samples involved.

Preparation

All board used in the study was of the same lot and was conditioned according to TAPPI Standard T402-m-49 (Temperature = 73±3.5 degrees F; Relative Humidity = 50±2% and for not less than 24 hours). The corrugated board used was B-flute, 200-lb. test.

To assure straight and parallel edges, perpendicular to the flute direction and facings of the board, a jig was constructed, as shown in the appendix. An Exacto Knife was used to make the final cuts on the board, along the edges to be compressed. The blade for the knife was changed after each group of eighteen specimens.

Two guide fixtures were also cut from 3/4 inch marine plywood, to fit the platens of the compression table, with 1/8 inch grooves cut at angles of 90, 45, and 30 degrees. These fixtures were aligned and clamped to the platens by means of C-clamps.

Apparatus

The compression test machine or table used was a Baldwin-Emery SR-4 (Model FGT) with the attached Baldwin Microformer Stress-Strain Recorder (Model MA1E).

Test Method

As previously mentioned all corrugated fibreboard used was conditioned prior to cutting and testing. All testing was done under controlled conditions of 73±3.5 degrees F and 50±2% relative humidity.

Samples, 14 inches by 12 inches, were cut from flat 96 inches by 48 inches pieces of board. The samples were then cut to the test size of 12 inches by 12 inches, by use of the jig mentioned above. All edges of the specimens used were parallel and square, with the board itself free from converting marks and damage. All samples were scored on a S&S Corrugated Paper Machinery Co. box making table.

For each group of specimens 18 samples were used, to give a statistical base of 90 per cent (±5%) accuracy.

All data was recorded on graph paper by the attached recorder.

Compression Test

For each group of specimens, with the exception of the unscored, 180 degree group, the samples were scored at 1, 2, 3, 4, 5, and 6 inches from the edge parallel to the direction of the fluting. This made samples of 1"x11"x12", 2"x10"x12", 3"x9"x12", 4"x8"x12" and so on to a maximum of 6"x6"x12" (See Figure 1). This was done for each angle of 135, 90, and 45 degrees, making a total of 108 specimens per angle. For the 30 degree angle only the 6"x6"x12" series of samples were used, as explained in Chapter III.

For the right angle or 90 degree group, an additional series of samples, 1"x1"x12", 2"x2"x12", 3"x3"x12", and so on to a maximum of 8"x8"x12" were also tested to complete the data on the 90 degree angle.

As mentioned previously, the apparatus used for the compression tests was a Baldwin-Emery SR-4 Testing

A" x B" x C"

D = ANGLE

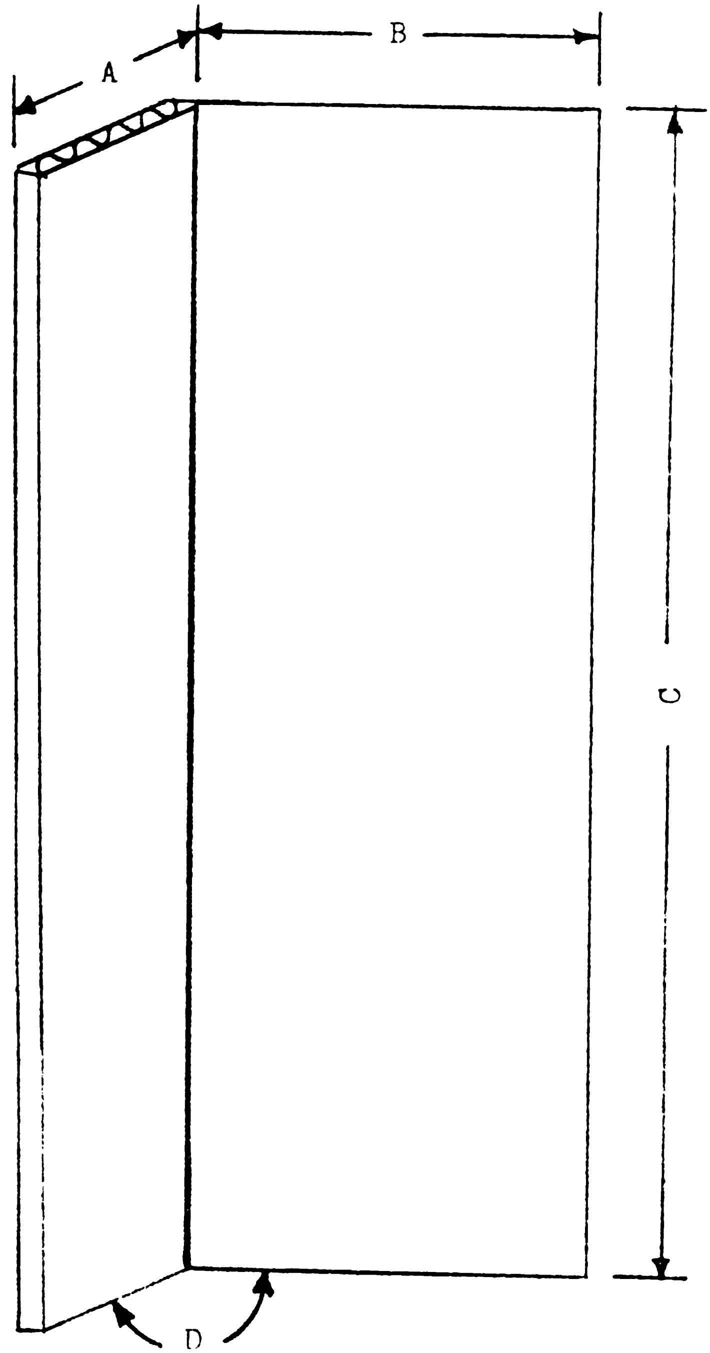

Figure 1.--Configuration of Test Specimen.

Machine and attached recorder, are shown in Figures 2 and 3.

The tests were run in five series, with each series containing 108 samples, with the exception of the unscored 12"x12" group and the 30 degree group, which contained 18 samples, as explained in Chapter III.

The machine settings used for these tests, are as follows:

Load Range . . . . 1000 lbs.
Platen Speed . . . . 2.00 in/min.
Recorder Range . . . . Full Range
Recorder Magification . . . . 1 to 3

The samples were placed in the holding fixtures and aligned, so they were perpendicular to the direction of loading. The recording pen was then zeroed and the compression test commenced. The machine was manually operated and was shut down when compression had reached the board's failure point, with the recorder pen travelling back to the zero point. The sample was then removed, the maximum compression having been noted and recorded on the graph.

The test procedure just described was performed on all samples. By using this procedure and recording the maximum compression force, in pounds per linear inch, for the different configurations, of the same board area, height remaining constant, it was possible to formulate a series of strength ratios based on the angle and the linear length of the board, as it extended from the score.

The results, as shown in Chapter III, indicate there is a considerable variation between angles and configurations

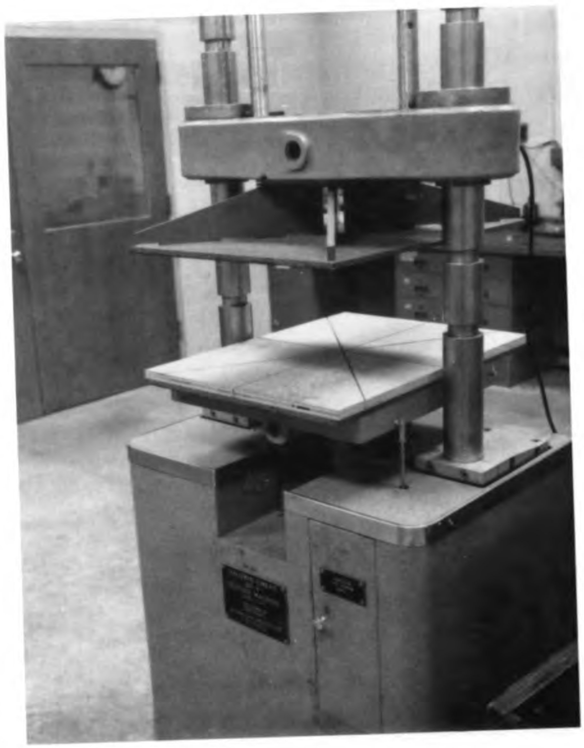

Figure 2.--Baldwin-Emery SR-4 Testing Machine Model FGT.

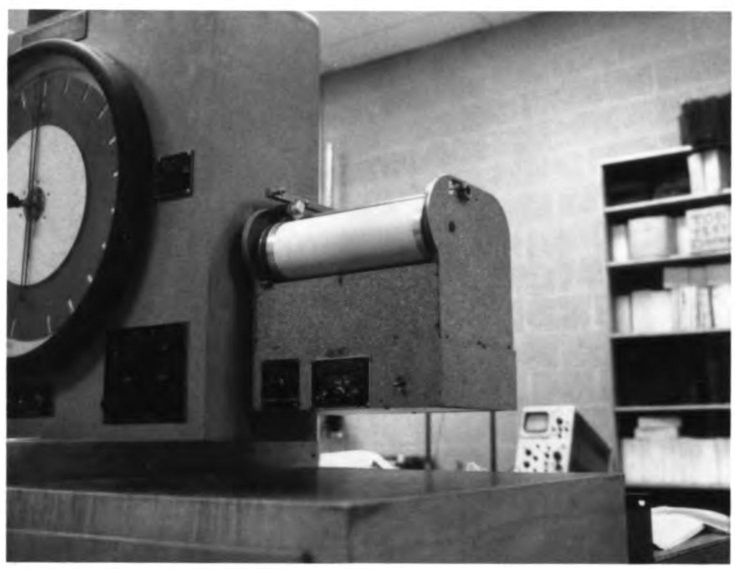

Figure 3.--Baldwin Microformer Stress-Strain Recorder Model MA1E.

of length. There is also a leveling off point in the compression strength, for all angles and configurations, from which added board or extra length is extraneous and adds no compression strength.

CHAPTER III

ANALYSIS OF DATA

In Tables 1 through 5 the analysis of the data is given by recording the average of the specimens run and the high and the low of the group. Table 4 records the results of samples run with a 90 degree angle, 12 inches in height, but with increasing linear inches in the ratio of 1:1. The first sample is 1"x1"x12" and the size increases to a sample size of 8"x8"x12". This extra data was gathered to complete the information for the 90 degree angle, which was found to be the angle that gave the greatest compression strength.

Analysis of Test Results

The data from this study suggests a general pattern for all the angles tested, that is, the compression strength increases, then peaks and remains relatively constant. This can be clearly seen in Figure 4, where the four graphs have the same general shape. The compression strength of the samples tested increased in a linear fashion (see Figure 5), then leveled off. A slight increase in compression strength after this point may be noted, due to the additional

TABLE 1.--180 Degrees, Unscored, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

12"x12"	Average 51	
	High	60
	Low	40

TABLE 2.--135 Degrees, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

1"x11"x12"	Average 114	
	High	150
	Low	90
2"x10"x12"	Average 170	
	High	180
	Low	150
3"x9"x12"	Average 194	
	High	220
	Low	175
4"x8"x12"	Average 209	
	High	230
	Low	180
5"x7"x12"	Average 200	
	High	230
	Low	170
6"x6"x12"	Average 218	
	High	235
	Low	170

TABLE 3.--90 Degree, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

1"x11"x12"	Average 134	
	High	160
	Low	100
2"x10"x12"	Average 192	
	High	210
	Low	170
3"x9"x12"	Average 210	
	High	225
	Low	190
4"x8"x12"	Average 218	
	High	245
	Low	185
5"x7"x12"	Average 224	
	High	260
	Low	190
6"x6"x12"	Average 222	
	High	250
	Low	195

TABLE 4.--90 Degrees, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

Size			
1"x1"x12"	Average 57.5		
	High	. . . .	70
	Low	. . . .	45
2"x2"x12"	Average 124		
	High	. . . .	135
	Low	. . . .	110
3"x3"x12"	Average 153		
	High	. . . .	160
	Low	. . . .	140
4"x4"x12"	Average 181		
	High	. . . .	195
	Low	. . . .	165
5"x5"x12"	Average 210		
	High	. . . .	230
	Low	. . . .	190
6"x6"x12"	Average 222		
	High	. . . .	250
	Low	. . . .	195
7"x7"x12"	Average 211		
	High	. . . .	225
	Low	. . . .	200
8"x8"x12"	Average 225		
	High	. . . .	230
	Low	. . . .	220

TABLE 5.--45 Degrees, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

1"x11"x12"	Average 114		
	High	140	
	Low	95	
2"x10"x12"	Average 158		
	High	185	
	Low	130	
3"x9"x12"	Average 165		
	High	225	
	Low	140	
4"x8"x12"	Average 173		
	High	185	
	Low	160	
5"x7"x12"	Average 179		
	High	225	
	Low	140	
6"x6"x12"	Average 187		
	High	225	
	Low	160	

TABLE 6.[1]--30 Degrees, B-Flute, 200-lb. Test (Maximum Compression, Pounds per Inch).

6"x6"x12"	Average 142	
	High	165
	Low	130

[1]See explanation in analysis text.

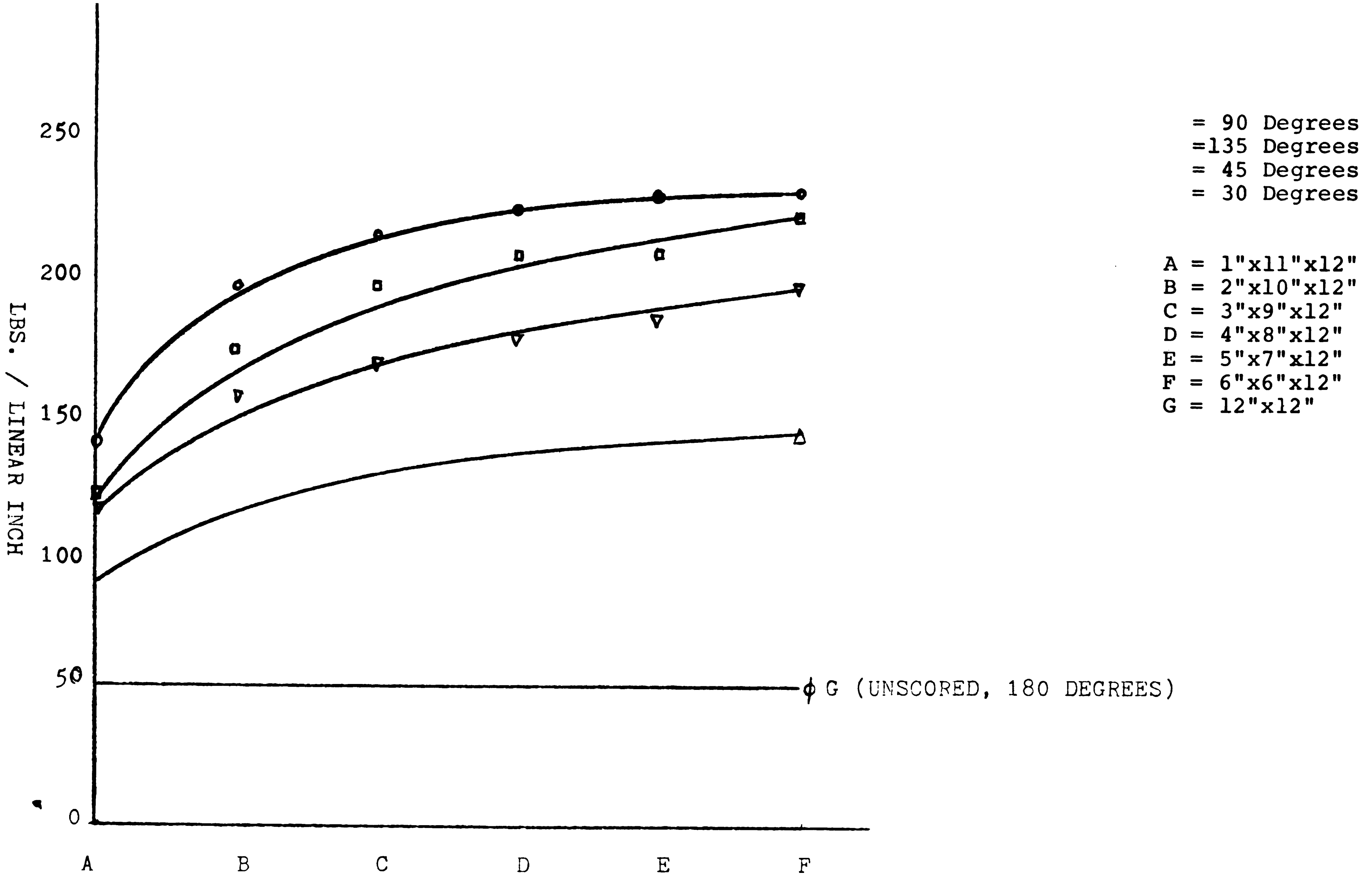

Figure 4.--Graph of 90, 135, 45, 30, and 180 Degrees Results.

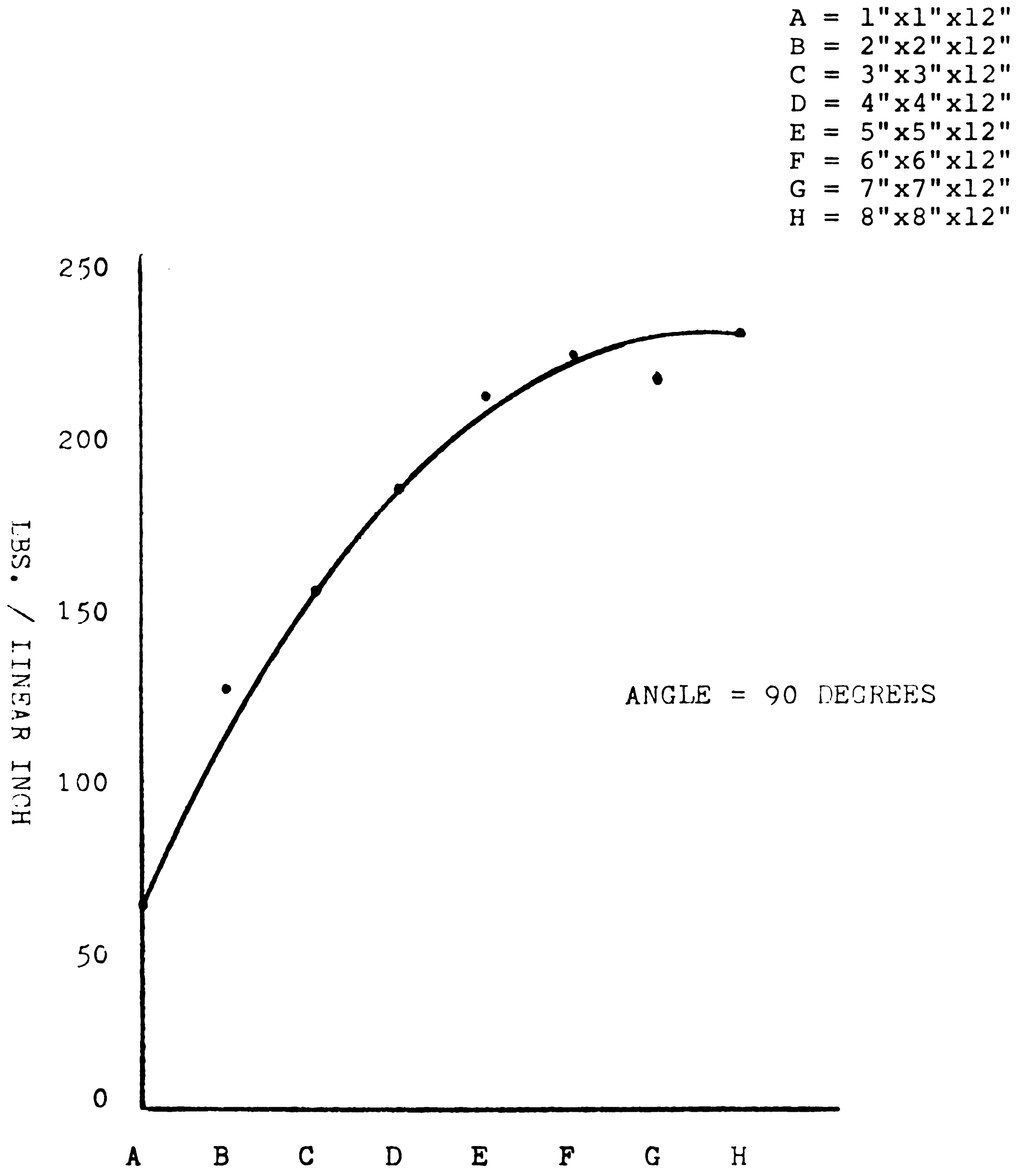

Figure 5.--Graph of Additional 90 Degrees Results.

material present and not to any inherent strength capacity of the board.

The 90 degree or right angle gave the greatest compressive strength, followed by the 135 degree, 45 degree, and 30 degree angles. The 30 degree angle was only tested at the 6"x6"x12" configuration, because it had become apparent that the 90 degree angle was the optimum and only a one to one ratio in the 30 degree angle was needed to complete the information.

In this study it was determined that the greatest compression strength occurred when the ratio of length to width (L/W) was between 1.20 and 1.40. With a L/W ratio of 1.00 (6"x6"x12"), it was found that a leveling off of the compression strength commenced. The findings of this study agree most favorably to one of S. S. Mirasol, Jr.,[11] who found that a length to width ratio (L/W) of between 1.25 and 1.50 gave the highest compression strength in corrugated boxes. He also found as the L/W ratio increased to 2.00 the compression strength dropped considerably from the L/W ratio of 1.00 or a square. Keep in mind that the Mirasol study was concerned with complete corrugated boxes, while this study dealt with scored pieces of corrugated board, yet the findings of both studies concur quite closely.

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[11]Salustiano S. Mirasol, Jr., "Evaluation of Some Existing Empirical Equations for Top-to-Bottom Compression Strength of Corrugated Fibreboard Boxes" (unpublished M.S. thesis, Michigan State University, 1966).

At the same time this study was being conducted, another study[12] was being made on varying column heights of corrugated board. The column height was varied from 12 inches, the same height as used in this study, to 24 inches, with an 18 inch intermediary, using B-flute, 200-lbs. test board. The results of this study gave further correlation to the results found herein and also found that the Rankine Formula, the typical formula for short columns, can be used to predict the edgewise compressive strength for interior corrugated packing pieces.

[12]Tani, "Compressive Strength of Corrugated Board Columns" (unpublished study for the School of Packaging, Michigan State University, 1972).

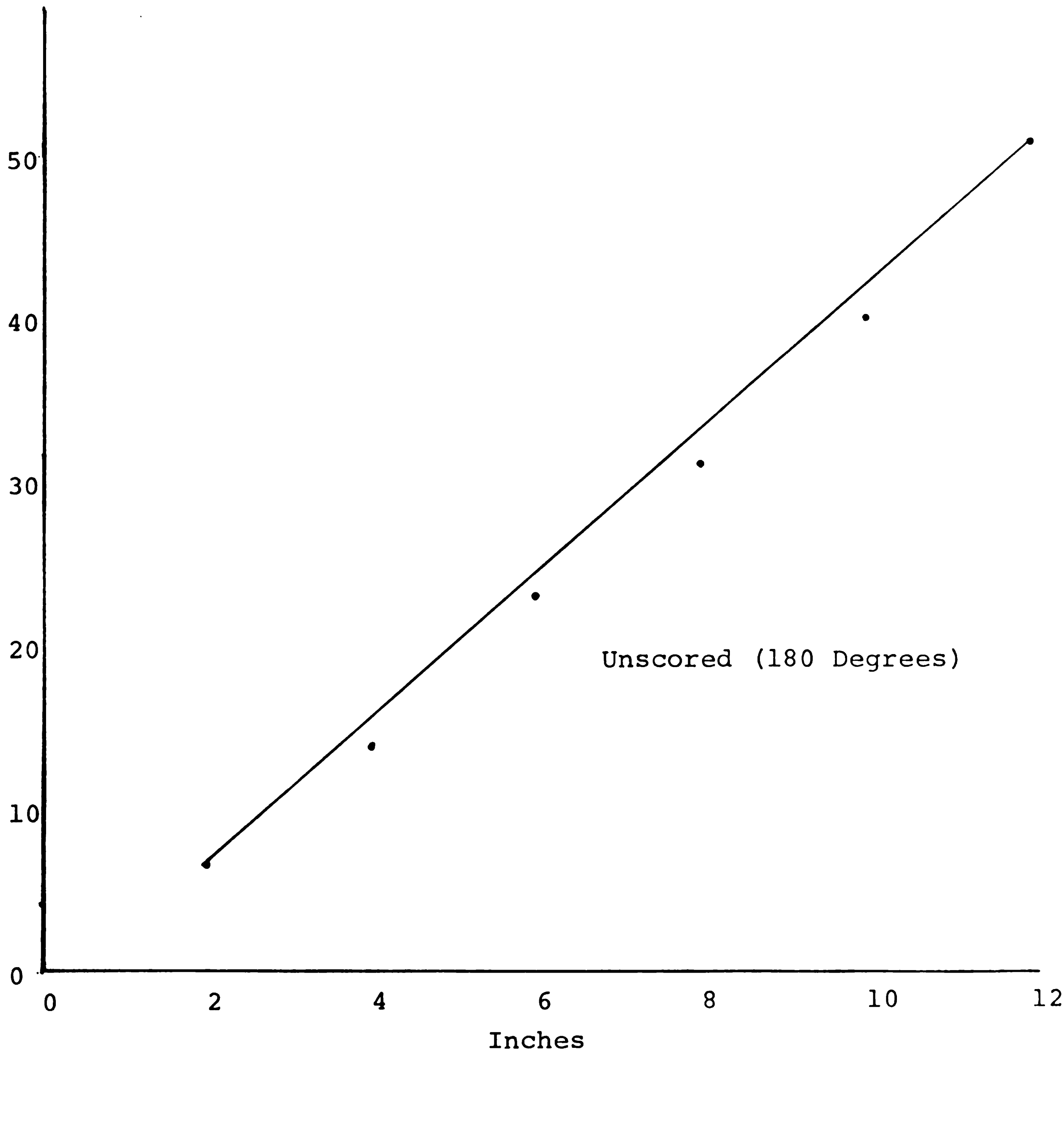

Figure 6.--Unscored (180 Degrees).

CHAPTER IV

CONCLUSIONS

From this study and others related to the compressive capacity of corrugated fibreboard, it can be stated that the maximum compression strength occurs when the angle of the score is 90 degrees and the length to width (L/W) ratio is between 1.20 and 1.50. This information can be applied to the design of interior packing, such as partitions, dividers and corner protectors and to the corrugated case itself. In a time when all are concerned with ecology and the preservation of our natural resources, the utmost should be done to stop the over use of needless packaging materials through efficient package design.

As a final comment, the author acknowledges the limited depth of this study, due to time requirements, but it is hoped that this work may be a basis from which further studies can be conducted, so a sound test and specification system may be set up to replace the outdated and inadequate Mullen Burst Test.

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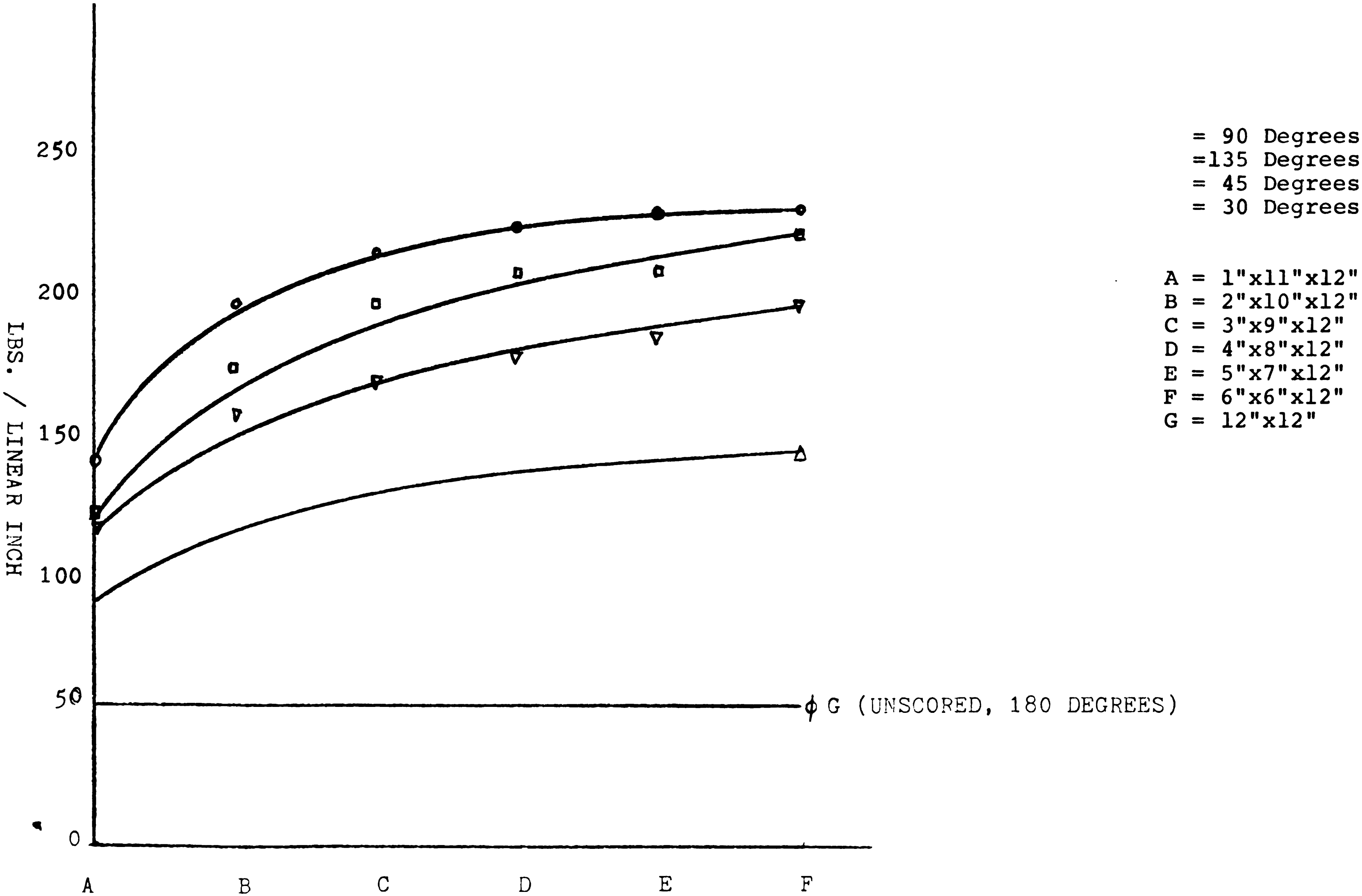
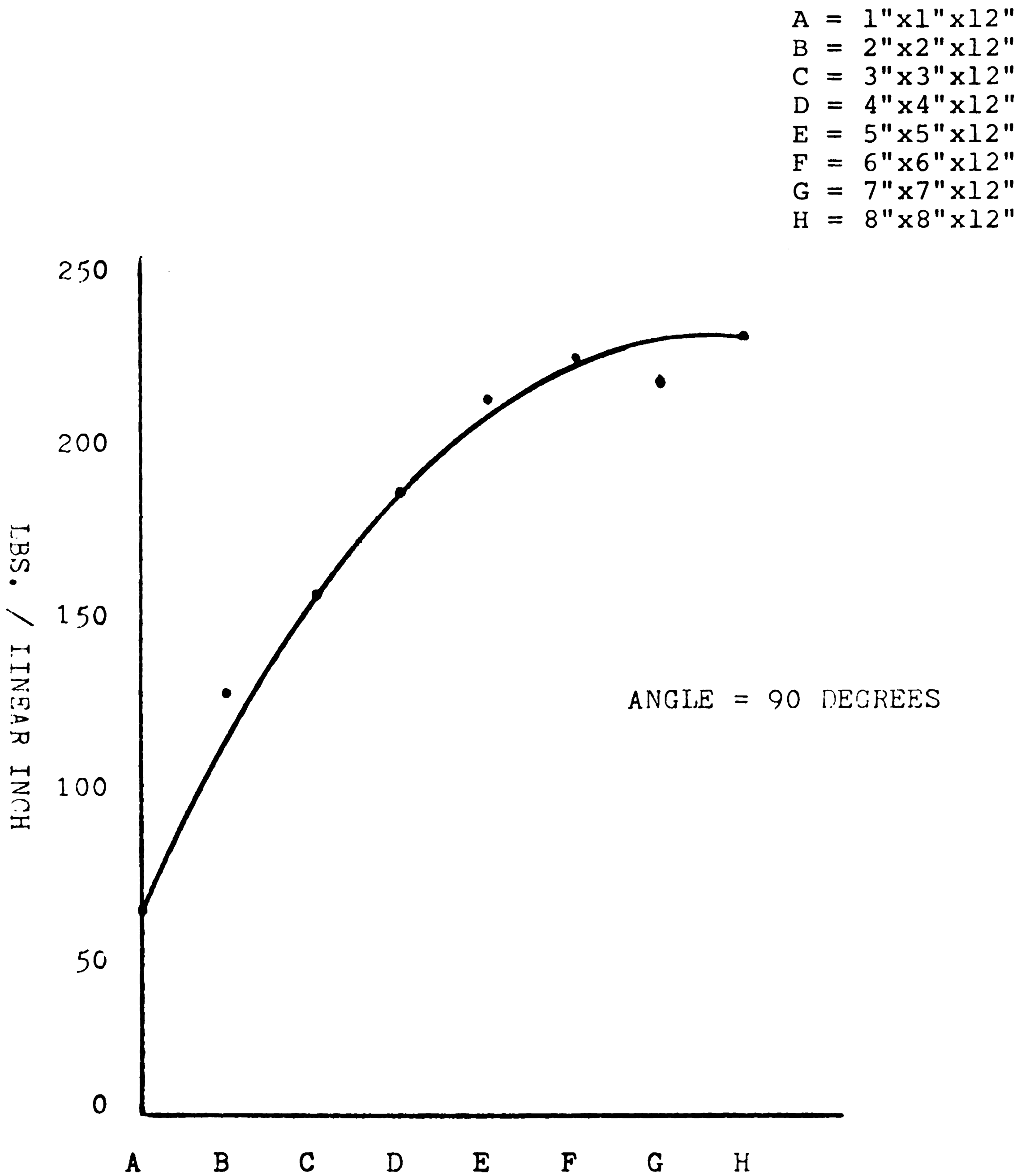


Figure 4.--Graph of 90, 135, 45, 30, and 180 Degrees Results.



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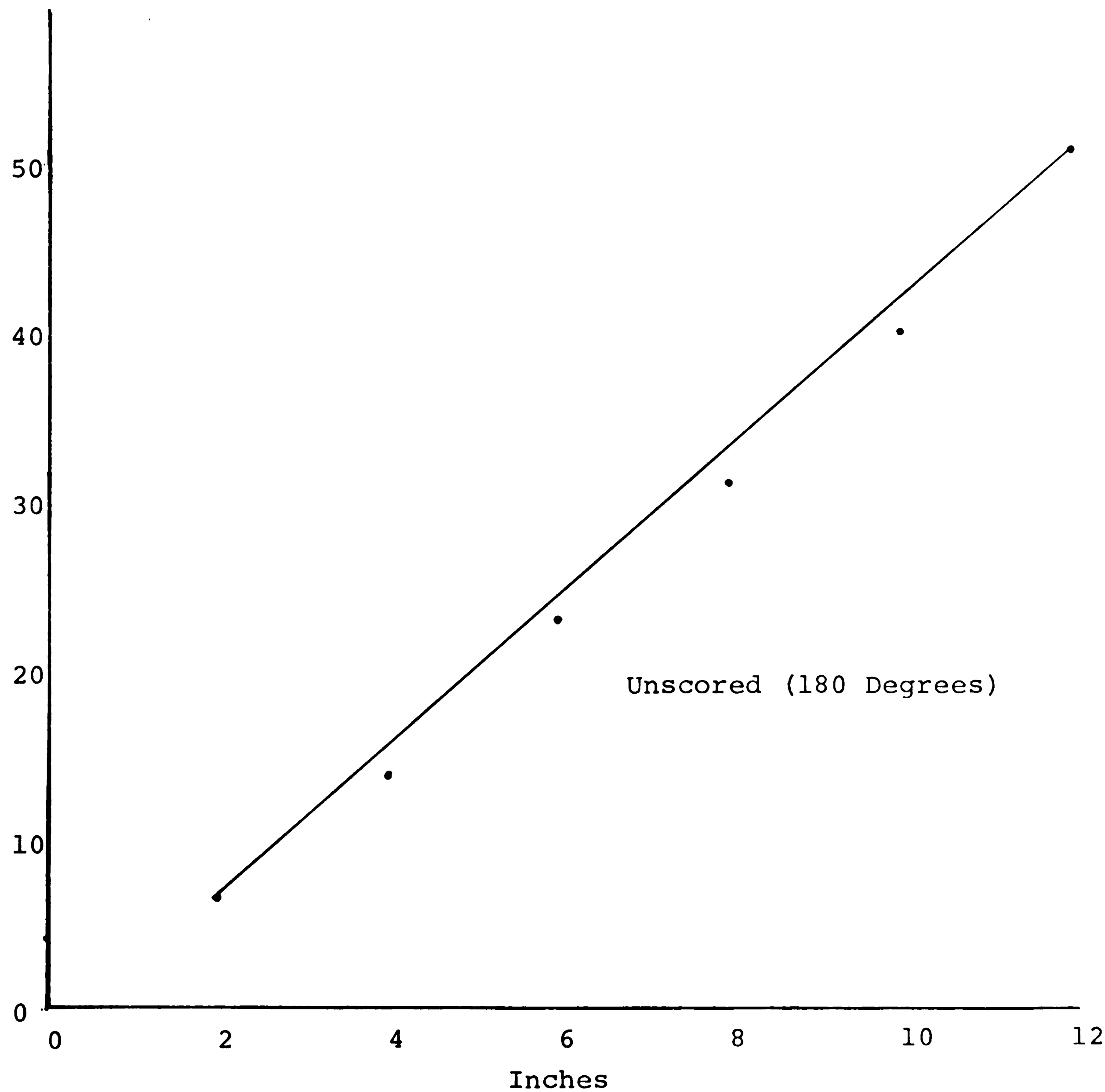

Figure 6.--Unscored (180 Degrees).

CHAPTER IV

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APPENDIX

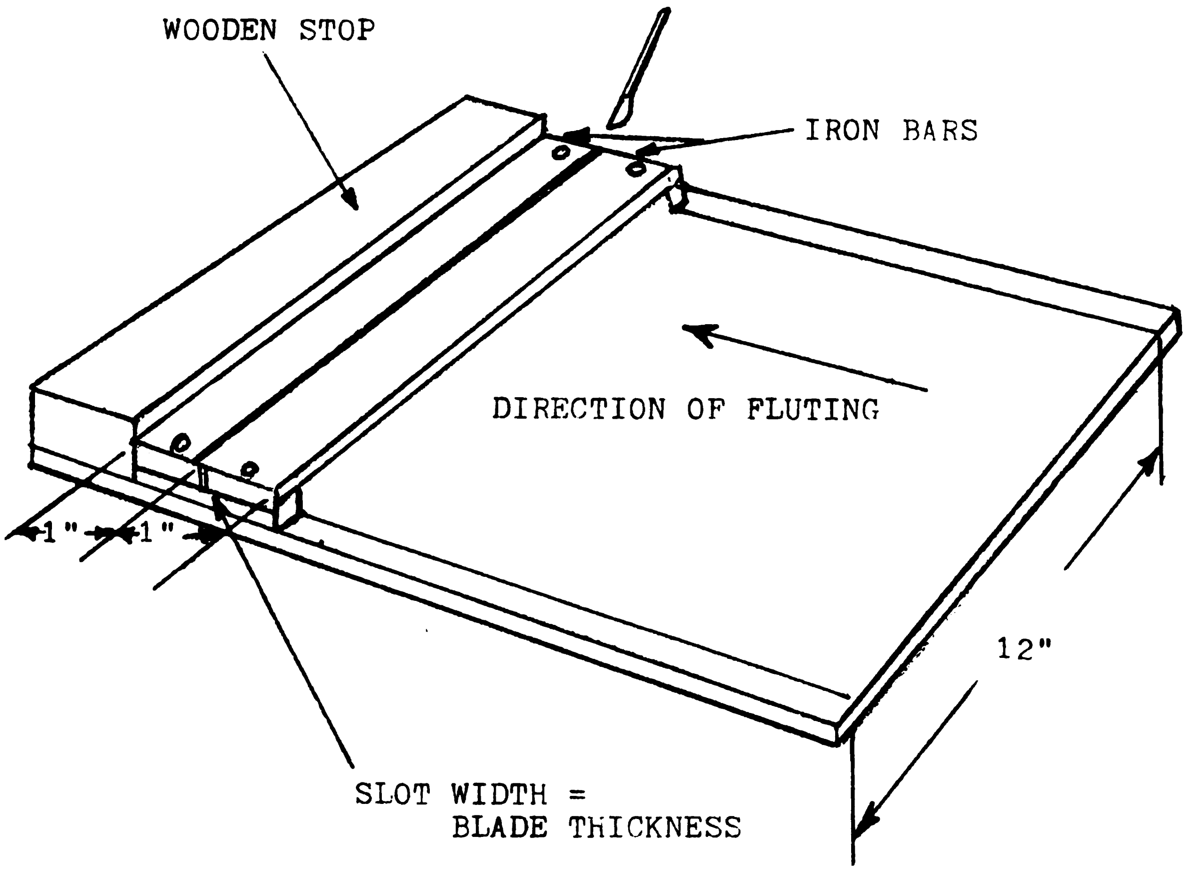

Figure 7.--Jig for Preparing Samples.