GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT INITIATION

Date: January 17, 1972

Project Title: Research on Improved Cotton Carpet Backing Fabrics

Project No: E-27-610

Principal Investigator Prof. W. C. Boteler

Sponsor: Cotton, Inc., Raleigh, N. C.

Agreement Period: From January 1, 1972 Until November 30, 1972

Type Agreement: Contract No. 71-544

Amount: $50,000.00

Reports Required: Monthly Progress Reports; Quarterly Technical Reports; Annual Report (if extended beyond one year); Final Report

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Assigned to: School of Textile Engineering

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RA-3 (6-71)

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GEORGIA INSTITUTE OF TECHNOLOGY

OFFICE OF RESEARCH ADMINISTRATION

RESEARCH PROJECT TERMINATION

Date: May 31, 1973

Project Title Research on Improved Cotton Carpet Backing Fabrics

Project No: E-27-610

Principal Investigator: Prof. W. C. Boteler

Sponsor: Cotton, Inc.; Raleigh, N.C.

Effective Termination Date: November 30, 1972 (Contr. Expiration)

Clearance of Accounting Charges: Final billing completed

Grant/Contract Closeout Actions Remaining: NONE

Assigned to: School of Textile Engineering

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RA-4 (6-71)

GEORGIA INSTITUTE OF TECHNOLOGY
A. FRENCH TEXTILE SCHOOL
ATLANTA, GEORGIA 30332

February 11, 1972

Mr. R. B. Cleaver
Research Manager
Cotton, Inc.
3901 Barrett Drive
Raleigh, North Carolina 27609

SUBJECT: Contract No. 71-544, Georgia Tech Project No. E-27-610
Monthly Letter Report for January

Dear Sir:

Project personnel presently consist of Professor Ralph Lathem, Professor Gerald Fletcher, and graduate research assistants Frank Ko and James Satterfield. Professor Lathem will advise and assist in the area of yarn manufacturing and Professor Fletcher will advise and assist in the weaving of fabrics.

A search for literature pertinent to the problem has been completed. The few articles which related specifically to cotton carpet backing were concerned with sheeting and canvases, which are still used in the chenille and custom tufting industries.

The bibliography will be included in the first quarterly report.

There is little information available on the required filling strength for broadloom carpets. However, there is a rule of thumb which indicates from experience that filling strength after tufting should be at least 50 pounds per inch.

Since there are no data available on the strength of cotton fabrics due to tufting, a fabric was designed to provide some basic data. Since the 5/32 inch needle spacing is most commonly used, and 7 stitches per inch is a widely used stitch count, a 13 x 14 fabric will be made to provide basic strength loss data. The initial fabric will be made from 2.5 count singles yarns in both warp and filling. This fabric will weigh 7.2 Oz./Yd.^{2} and while the filling strength may be marginal, the resulting data will be useful in planning more refined fabrics.

To facilitate the weaving of the base data fabrics, 140 pounds of yarn made from nominal 1 inch fiber were obtained from a commercial spinner. This yarn is being wound on a loom beam by a commercial weaver in the interest of time. However, subsequent yarns and loom beams will be prepared at Georgia Tech.

It is anticipated that the base fabric will be available sometime in February for tufting and subsequent evaluation.

Respectfully submitted,

Winston C. Boteler
Project Director

WCB/lmb

APPROVED:

James L. Taylor
Director
A. French Textile School

GEORGIA INSTITUTE OF TECHNOLOGY
A. FRENCH TEXTILE SCHOOL
ATLANTA, GEORGIA 30332

June 23, 1972

Mr. R. B. Cleaver
Research Manager
Cotton, Inc.
3901 Barrett Drive
Raleigh, North Carolina 27609

Subject: Contract No. 71-544, Georgia Tech
Project No. E-27-610
Monthly Letter Report for April

Dear Sir:

The P-3, P-4 and P-5 fabrics were completed, evaluated, and tufted during the month. The P-3, 14 x 14, roving x yarn fabric had a breaking strength of 104.7 in the warp direction and 119.5 lbs. in the filling direction. Fabric weight was 8.2 oz./yd.^{2}. The strength retention after fine gauge tufting was 93% for the warp and 67% for the filling. The P-4, 13 x 12, fabric, with 2.1 hank roving warp and 2.1 c.c. yarn filling, weighed 6.4 oz./yd.^{2} and had breaking strengths of 94.2 and 56.4 lbs. in warp and filling directions, respectively. Strength retention after tufting was 97% in the warp direction and 88% in the filling direction. The P-5 fabric, with 2.1 hank roving in both warp and filling directions, weighed 6.73 oz./yd.^{2}. Fabric breaking strength was 94.2 lbs. for the warp and 82.7 lbs. for the filling. The strength retention after tufting was 94% in the warp direction and 77% in the filling direction.

The conclusion was drawn from the preliminary studies that the roving fabrics are easily woven and that the all roving backings have better tuftability than yarn fabrics.

The original objectives of the project require the optimum performance fabric to have the greatest tuftability at the lowest cost. From previous experience, it is known that successful dyeing, latexing, and backing of a fabric can be best accomplished with fabrics having high strength retention after tufting. The absolute strength after tufting is important because the fabric must withstand the tensile forces in the filling direction due to shrinkage on the tenter frame during drying after dyeing and during the latex curing process.

An experiment was designed in which the factors are needle gauge, fabric construction, and yarn linear density. Twelve fabrics will be required for this phase of the project. Twisting of the rovings required for these fabrics is in progress.

Respectfully submitted.

Winston C. Boteler
Associate Professor

WCB/lmb

APPROVED:

James L. Taylor
Director
A. French Textile School

GEORGIA INSTITUTE OF TECHNOLOGY
A. FRENCH TEXTILE SCHOOL
ATLANTA, GEORGIA 30332

June 26, 1972

Mr. R. B. Cleaver
Research Manager
Cotton, Inc.
3901 Barrett Drive
Raleigh, North Carolina 27609

Subject: Contract No. 71-544, Georgia Tech
Project No. E-27-610
Monthly Letter Report for May

Dear Sir:

Wet strength and shrinkage tests were made to determine the importance of these parameters. The P-2-T-A tufted fabric was processed through a mock dyeing operation. The sample was held at 200° F for two hours and rotated in a laboratory dye beck. The additives included 1% Igepon-73 and 2% glacial acetic acid, but without any dye. The fabric was hung for one hour, partially dried by two passes through a squeeze roll, then evaluated for strength and dimensional change. There was no significant change in length and approximately a 2% shrinkage in the filling direction. The low filling shrinkage, compared to approximately 10% for the untufted fabric, is attributed to the restrictive influence of the nylon face yarns. The partially dried fabric, moisture content 41%, was evaluated for breaking strength. The wet fabric had a 40% increase in warp strength and a 49% increase in filling strength compared to the dry fabric.

Manufacture of the quantities of 2.1, 2.3, and 2.5 hank twisted rovings required for the experimental fabrics was completed during the month. Three of the 12 fabrics in the experimental program were also completed during the month, although they were not evaluated.

Respectfully submitted,

Winston C. Boteler
Associate Professor

WCB/bbr

APPROVED:

James L. Taylor
Director
A. French Textile School

GEORGIA INSTITUTE OF TECHNOLOGY
A. FRENCH TEXTILE SCHOOL
ATLANTA, GEORGIA 30332

September 25, 1972

Mr. R. B. Cleaver
Research Manager
Cotton, Inc.
3901 Barnett Drive
Raleigh, North Carolina 27609

Subject: Contract No. 71-544, Georgia Tech Project No. E-27-610
Monthly Letter Report for July

Dear Sir:

Fabrics 14, 24, and 34 were completed during July. All of the remaining ten fabrics were tufted on machine "A" and the remaining four fabrics were tufted on machine "B".

Tensile strength evaluations were completed on all the untufted fabrics. The tensile tests were delayed due to the failure and subsequent replacement of the jaw clamps on the Instron tester.

The computer program was completed during the month and as soon as the data are complete, the prepared data cards will be punched.

Respectfully submitted,

Winston C. Boteler
Associate Professor

WCB/lb

APPROVED:

W. Denney Freeston, Jr.
Director
School of Textile Engineering

A. French Textile School
Georgia Institute of Technology
Atlanta, Georgia

Quarterly Report No. 1
Cooperative Agreement No. 71-544
Research Project No. E-27-610

Research on Improved Cotton Carpet Backing Fabrics

Prepared for:

Cotton, Inc.

Respectfully Submitted

Winston C. Boteler
Associate Professor

APPROVED:

James L. Taylor
Director
A. French Textile School

June 15, 1972

Quarterly Report No. 1, Project No. E-27-610

I Introduction

This report covers the work accomplished on the investigation of improved cotton carpet backing fabrics during the first quarter of 1972. Much of the quarter's work was involved in the weaving and evaluation of fabrics to be used as preliminary standards.

II Literature Search

A search was made of the literature back to 1950 with little success. A number of articles were located which described the cotton fabrics used in tufting. However, the fabrics referred to were either relatively heavy canvases or light weight closely-woven fabrics used in the bedspread industry. In all, some 74 articles were located which related to cotton fabrics, but none described specifically any technical information related to broadloom tufted fabrics as used today.

III Experimental Program

The experimental program has been planned as follows:

A. Preliminary Studies (February - April)

It is anticipated that information obtained during the preliminary studies will permit the design of an experiment which will lead to the optimum fabric. The objectives of the preliminary experiments are to explore the possibility of using roving instead of yarn to form the fabric and to select the variables and determine the ranges and areas of exploration.

B. Collection of Data (May - August)

Extensive experimentation will be conducted according to the experimental design selected. This experimentation will include the manufacture of rovings, sizing of warp yarns, weaving of fabrics, tufting at two needle gauges, characterization of roving and fabrics, and the plotting of data.

C. Results, Analysis, and Conclusion (September - November)

Based on the experimental results, the best prediction equations will be developed using a stepwise regression analysis. The type of backing which has the optimum tuftability with respect to cost will be determined, and the conclusions and recommendations will be submitted in a final report.

IV Progress to Date

The purpose of these experiments was to establish a base level from which to design a set of experimental fabrics. A series of 5 fabrics was planned for the preliminary experiments as follows:

Code*	Weave	Ends x Picks	Warp	Filling
P-1	Plain	14 x 12	Yarn	Yarn
P-2	Plain	14 x 14	Roving	Yarn
P-3	Plain	14 x 14	Roving	Roving
P-4	Plain	13 x 12	Roving	Yarn
P-5	Plain	13 x 12	Roving	Roving

*The suffix T will be added to denote tufted fabrics, such as P-1-T. The tufted fabrics will be denoted by adding suffix A for fine gauge tufting (5/64 in.) and B for medium gauge tufting (7 needles/in.).

A nominal 1 inch staple length cotton was used for the preliminary experiments. Specifications for the yarn and hard twist roving were as follows:

Yarn Count	=	2.5 Cotton Count
Roving Count	=	2.1 HANK
Yarn Twist	=	5 Turns Per Inch
Roving Twist	=	5 Turns Per Inch

An attempt was made to weave the fabrics without sizing the warp yarns, however, due to excessive warp yarn breakage, the experiment was unsuccessful. The warps were then sized on a Callaway Model 50 slasher with 3 oz./lb. concentration of Hercules CMC size. After several trials, it was determined that a yarn speed of 5 feet per minute, cylinder speed of 3 rpm, and average temperature of 200^{o}F were the optimum operating parameters.

The unsized yarn and roving were tested according to ASTM Method D-2256-69, with the following results.

	Yarn	Roving
Linear Density	2.5 c.c.	2.1 HANK
Twist	5 T.P.I.	5 T.P.I.
Breaking Strength (lbs.)	5.1	8.9
C.V. %	12.3	11.4
Elongation, %	10.6	8.6
C. V. %	7.6	29.4

The gauge length was 10 inch; chart speed was 10 in./min.; head speed was 10 in./min.; and 30 observations were made on each set of samples.

The strength of the warp was increased as shown by the test data for the sized warp yarns: breaking strength, 5.3 lbs., C. V. 13.2%. After sizing, the warp was set up in a Draper X-2 loom and the fabrics woven according to the following specifications.

Loom:	Draper X-2
Fabric Width:	36 Inches
Reed Width:	44.75 Inches
Ends x Picks/inch:	14 x 12 Finished
Loom Speed:	190 Picks/Min.

The actual weight of the 14 x 12 P-1 fabric, which was woven with yarn in both warp and filling, was 5.44 oz./yd.^{2}. The fabric was evaluated for strength with grab break tests on an Instron testing machine. The test specifications were as follows.

Type of Test:	Grab Break
Conditions:	70°F, 65% R.H.
Full Scale Load:	100 lbs.
Gauge Length:	3 Inches
Jaw Speed:	1 in./min.
Chart Speed:	10 in./min.
Fabric Dimension:	4 in. x 8 in.
Number of Observations:	5 Warp, 5 Filling

The number of observations was a preliminary selection to determine the coefficient of variation and to determine the total number of observations required to produce statistically valid results.

The following data resulted from the preliminary Instron tensile test for the P-1 fabric.

	WARPWISE				FILLINGWISE			
	Strength	Crimp%	Yarn Elong. %	Total Elong.	Strength	Crimp%	Yarn Elong. %	Total Elong.
$\overline{X}$	82.4	4.38	7.93	12.31	49.5	9.48	12.92	22.4
	5.43	0.72	0.48	1.63	4.58	0.41	0.83	0.88
%C.V.	7	16	12	13	9	4	6	4
Max.	90.0	5.3	9.6	14.9	55	10.2	13.8	23.1
Min.	80.5	3.53	7.06	10.83	44.5	9.2	11.6	20.9
Range	9.5	1.8	2.5	4.1	10.5	1.0	2.2	2.2

Assuming a 4% error, with the above mean values, standard deviations, and coefficients of variation, according to ASTM D-2264, 20 observations would be required for a 95% probability level.

The rovings were sized and woven in the same way as were the yarns. The roving strength did not increase significantly after sizing, 7.1 lbs. vs. 7.0 lbs., but the weaveability did improve considerably.

The specifications and properties of the P-2 fabric are listed below.

A. Physical Properties

Fabric Construction:	14 x 14, plain
Weight/Square Yard:	7.11 oz.
Warp:	2.1 HANK, Hard Twisted Roving
Filling:	2.5 c.c. Yarn
Twist:	Yarn, 5 T.P.I.

B. Mechanical Properties

1. Warpwise

a. Average Breaking Strength: 95.8 lbs., 12.6%C.V.

b. Crimp: 7.3%, C.V. 24.7%

c. Yarn Elongation: 9.5%, C.V. 14.7%

d. Fabric Elongation: 17.0%, C.V. 16.7%

2. Fillingwise

a. Average Breaking Strength: 64.8 lbs., C.V. 6.9%

b. Crimp: 8.9%, C.V. 17.8%

c. Yarn Elongation: 12.8%, C.V. 6.8%

d. Fabric Elongation: 21.7%, C.V. 8.2%

The P-2 fabric is slightly stronger than the P-1 fabric in both warp and filling. The warp strength increase is due to the greater strength of the roving, while the additional 2 picks/inch provides additional strength in the filling direction.

The two fabrics were tufted on the fine gauge machine (5/64 in. needle spacing) at 11 stitches per inch with 2600 denier nylon bulked continuous filament yarn. The fabric mechanical properties after tufting are listed below.

A. Fabric: P-1-T-A 14 x 12 Yarn x Yarn

Warpwise Mechanical Properties

1. Average Breaking Strength: 75.3 lbs., C.V. 5.7%

2. Crimp: 9.6%, C.V. 12.0%

3. Yarn Elongation: 9.6%, C.V. 8.1%

4. Fabric Elongation: 16.7%, C.V. 7.7%

A. French Textile School
Georgia Institute of Technology
Atlanta, Georgia

Quarterly Report No. 2
Cooperative Agreement No. 71-544
Georgia Tech Research Project No. E-27-610

Research on Improved Cotton Carpet Backing Fabrics

Prepared for:

Cotton, Inc.

Respectfully submitted

Winston C. Boteler
Associate Professor

APPROVED:

W. Denney Freeston, Jr.
Director
A. French Textile School

Quarterly Report No. 2 - Project No. E-27-610

I. Introduction

This report covers the work accomplished on the investigation of improved cotton carpet backing fibers during the second quarter of 1972. All but three of the 12 fabrics to be evaluated in the experimental program were completed during this period.

II. Experimental Program

Based on the result of the experimental fabrics evaluated in Phase I, the following experiment was planned.

FACTORS	LEVELS	MEASURED		LEVELS		CODE			
Needle Gauge	2	13/in.		7/in.		A		B	
Fabric Construction	4	14x14	13x13	13x12	12x12	1	2	3	4
Filling Linear Density* (Hank)	3	2.1	2.3	2.5		10	20	30	

*The warp rovings will be kept constant at 2.1. The warp yarn size may be varied later after optimum filling size is determined.

The total number of tufted fabrics to be evaluated is 24.

The experimental design matrix for the tufted fabrics is as follows:

11A	21A	31A
11B	21B	31B
12A	22B	32B
12B	22B	32B
13A	23A	33A
13B	23B	33B
14A	24A	34A
14B	24B	34B

The responses will be:

(1) Breaking Strength
(2) Elongation
(3) Strength Retention

The data will be analyzed using the stepwise multiple linear regression technique - BMDO2R program on the Univac 1108 computer - and the polynomial regression technique - BMDO5R on the Univac 1108. A canonical analysis may be used to determine the response surface if necessary. The presentation of results will include the best regression equation, the multiple correlation coefficients and correlation matrix, the standard error of estimate, and analysis of variance table, and a plot of the residues versus the input variables. A cost prediction equation will be developed using real production costs from industry and the LaGrange multiplier method will be used to determine the optimum combination of factors with respect to cost.

The description of fabric constructions and codes for the second phase of the study are listed in Table I.

A number of tufting yarns were used during the first phase of the study and are listed below.

FIBER		DENIER	COTTON COUNT
Nylon B.C.F.	(1	1300	4.09
	(2	2600	2.1
	(3	3700	1.4
Nylon-Polyester Spun		4850	1.1
Acrylic (brown)		3600	1.48
Acrylic (white)		4622	1.14
Cotton		5595	0.95/2 ply

TABLE I

UNTUFTED FABRIC NO.	CODE UNTUFTED FABRIC	CODE TUFTED FABRIC	FABRIC CONSTRUCTION ENDS x PICKS	ROVING LINEAR DENSITY WARP	ROVING LINEAR DENSITY FILLING	CALCULATED FABRIC WEIGHT OZ./YD.^{2}
1	11	11A 11B	14 x 14	2.1	2.1	8.24
2	12	12A 12B	13 x 13	2.1	2.1	7.36
3	13	13A 13B	13 x 12	2.1	2.1	6.72
4	14	14A 14B	12 x 12	2.1	2.1	6.35
5	21	21A 21B	14 x 14	2.1	2.3	7.74
6	22	22A 22B	13 x 13	2.1	2.3	7.20
7	23	23A 23B	13 x 12	2.1	2.3	6.64
8	24	24A 24B	12 x 12	2.1	2.3	5.97
9	31	31A 31B	14 x 14	2.1	2.5	7.00
10	32	32A 32B	13 x 13	2.1	2.5	6.56
11	33	33A 33B	13 x 12	2.1	2.5	6.16
12	34	34A 34B	12 x 12	2.1	2.5	5.80

All yarns listed could be used on machine B (7 needles/inch), however yarns heavier than 1.48 cotton counts did not tuft well on machine A (12.8 needles/inch) due to numerous broken yarns.

Nine of the twelve fabrics have been completed. The three fabrics remaining to be woven are 14, 24, and 34. These fabrics will be completed before the end of July. Eight of the twelve "B" tufted fabrics have been tufted and two of the twelve "A" tufted fabrics have been completed. Failure of a part on the 5/64 inch delayed the tufting of the remaining ten fabrics, but it is estimated that they will be completed during July.

The 2.1 and 2.3 hank rovings were evaluated in June and the results are tabulated below.

	2.3 H.R.	2.5 H.R.
Breaking Strength	7.50	6.58
Elongation, %	9.53	8.76
Standard Deviation	0.70	0.59
% C. V. (strength)	9.37	9.01

These rovings were twisted to five turns per inch.

III. Future Plans

It is anticipated that all the fabrics will be completed during July and that all tufting and fabric evaluation will be completed during August.

School of Textile Engineering
Georgia Institute of Technology
Atlanta, Georgia

Quarterly Report No. 3
Cooperative Agreement No. 71-544
Research Project No. E-27-610

Research on Improved Cotton Carpet Backing Fabrics

Prepared for:

Cotton, Inc.

Respectfully submitted,

Winston C. Boteler
Principal Investigator

APPROVED:

W. Denney Freeston, Jr.
Director
School of Textile Engineering

Quarterly Report No. 3, Project No. E-27-610

I Introduction

This report covers the work accomplished during the third quarter of 1972. The collection of tensile and elongation data was completed for all of the experimental fabrics. The computer statistical analyses of these data were completed during the reporting period.

II Experimental Program

a. Statistical Analysis

Analysis of all the tensile test curves was completed during July and August, as well as calculation of the average strength and elongation, coefficient of variation, and strength retention after tufting. During the month of September the collected data were keypunched onto computer cards for statistical analysis.

A stepwise regression analysis was made on the UNIVAC 1108 computer at the Computer Center of the Georgia Institute of Technology. The program used was a Biomedical Computer Program "BMDO2R" which was prepared by personnel at UCLA (Dixon, W. J., Biomedical Computer Programs, University of California Press, Berkeley, 1971). Tufted fabric strength, elongation, and strength retention were investigated with respect to machine gauge (mc), construction (c), filling linear density (D), and interaction of construction and linear density (CD). The results are shown on Table I.

The needle spacing does not have a significant effect on warpwise strength. There is a strong influence due to fabric construction and filling linear density interaction of the two variables; fabric construction has a greater effect on the tufted fabric warpwise strength

TABLE I

STEPWISE REGRESSION RESULTS

	Description	Regression Equation	Multiple Correction Coefficient	% Variation Explained	95% Confidence Limit	Level of Significance
1.	Warpwise Strength	WS = 16.41+0.25+18.23D	0.83	69.5	±12.2	≫ 95%
2.	Fillingwise Strength	FS = 136.77-9.97NC+0.08C -43.79D+0.09D	0.90	80.4	±10.4	≫ 95%
3.	Warpwise Elongation	WE = 23.05-1.48MC+0.01C -6.48D+0.03CD	0.67	61.4	± 3.00	> 95%
4.	Fillingwise Elongation	FE = 22.38-3.17MC+1.78D	0.67	44.6	± 5.7	> 95%
5.	Warpwise Strength Retention	WSR = 54.4+0.53+34.19D -0.1CD	0.81	65.9	± 8.9	> 95%
6.	Fillingwise Strength	FSR = 49.72-0.96MC+0.13C +25.24D	0.73	54.0	±12.5	> 95%

than filling linear density. The tufted fabric warpwise strength increases with the increase of ends and picks per inch and the filling linear density.

The tufted fabric fillingwise strength is affected significantly by changes in machine needle spacing. As expected, the closer needle spacing causes more damage to the filling yarns. The most significant factor affecting tufted fabric fillingwise strength is the ends and picks per inch.

The filling linear density also affects the filling strength significantly. As the filling hank number increases, the fillingwise strength decreases.

The combination of variables listed in the hypothetical model accounts for 61% of the variation of warpwise elongation due to the responses. The ends and picks per inch affect tufted fabric warpwise elongation significantly. The warpwise elongation of the tufted fabrics increases as ends and picks per inch increase. The needle spacing affects the warpwise elongation of the tufted fabric. Fabrics tufted on the machine with closer needle spacing have lower elongations. Filling linear density and fabric construction -linear density interaction affect warpwise elongation, but only to a minor degree. An increase in the filling hank number causes a decrease in warpwise elongation. Only 45% of the fillingwise elongation is accounted for by the assumed computer model. Of all the variables, only needle spacing has a significant effect on fillingwise elongation. Fabrics tufted on the finer gauge machine have lower filling elongations. The filling linear density, fabric construction and linear density-construction interaction do not have a significant effect on the fillingwise elongation.

Strength retention of the fabric after tufting is of highest importance. In jute backed carpets and unlubricated woven polypropylene carpets, the loss of filling strength after tufting is a serious processing problem. Generally, cotton backing fabrics have a much higher strength retention due to the relatively low modulus of the yarns and the relatively high breaking elongation of the cotton fibers. In the series of fabrics which was investigated, loss of strength after tufting is not a significant problem. On the average, strength retention values up to 84% were obtained in the fillingwise direction. Regardless of the insignificant strength loss, the effect of each of the variables can be examined based on the data from the explored experimental region.

The loss of strength in the warpwise direction is insignificant. This is due primarily to the needle configuration. Since the needle eye is parallel to the filling direction of the fabric as it passes through the tufting machine, the needle is relatively thin in the warpwise direction and thick in the fillingwise direction. Thus, the needle pushes aside the warp yarns, but many filling yarns are pierced or cut. The number of ends and picks has the greatest influence on the warpwise strength retention. With a lower number of ends and picks per inch, a fabric tends to have higher warpwise strength retention. Filling linear density has a significant effect on warpwise strength retention. The strength retention increases with a decrease of filling linear density. In other words, a higher level of strength retention in the warp direction results if a smaller filling yarn is used. This increases the ability of the warp yarns to move away from the needle during fabric penetration.

As anticipated, fillingwise strength retention is lower than warpwise strength retention. There are no standards regarding minimum tufted fabric filling strength. However, values in the range of 50 to 60 pounds per inch have been suggested as standards by various groups. Many tufters have found that a filling strength of 50 lbs/in. is necessary to insure that the fabric will not split on the tenter frame during the secondary backing or foaming process. Needle spacing is the dominant factor for fillingwise strength retention. As the needles are moved closer together, the fabric damage is increased. Ends and picks per inch and filling linear density affect fillingwise strength retention at about the same level, but do not affect the strength as significantly as does needle spacing. A decrease in ends and picks per inch would increase the fillingwise strength retention. Fillings of higher hank roving number (finer roving) tend to increase the strength retention. The interaction of construction and linear density does not have a significant effect on strength.

Linear correlation analyses of the tensile properties were made with respect to weight per unit area of fabric, ends and picks per inch, and yarn linear density. The simple correlation equations relating the tensile properties and weight per unit area are shown on Table II,

TABLE II.

Tensile Properties Versus Weight Per Unit Area of Fabric

Response	Regression Equation	Correlation Coefficient	95% Confidence Limit
Untufted Warpwise Strength	UWS = 8.35W-42.21	0.71	±6.11
Untufted Fillingwise Strength	UFS = 17.07W-25.25	0.93	±4.94
Warpwise Strength Regention A Machine	WSRA = -5.19W+137.14	-0.64	±4.83
Warpwise Strength Retention B Machine	WSRB = -5.24W+136.07	-0.72	±3.69
Fillingwise Strength Retention A Machine	FSRA = -6.84W+126.73	-0.89	±2.59
Fillingwise Strength Retention B Machine	FSRB = -2.19W+104.10	-0.22	±7.13
Untufted Fabric Warpwise Elongation	UWE = 2.09W+0.90	0.80	±1.20
Untufted Fabric Fillingwise Elongation	UFE = -0.5W+21.62	-0.20	±1.53
Tufted Fabric Warpwise Elongation A Machine	TWEA = 2.43W+0.77	0.96	±0.52
Tufted Fabric Warpwise Elongation B Machine	TFEB = 0.34W+23.58	0.11	±2.19

As expected, the strength of untufted fabrics increases as the fabric weight per unit area increases. The rate of increase in the fillingwise direction is faster than that in the warp direction. Both warpwise and fillingwise strength retentions, except for the fillingwise strength after tufting with the wide gauge machine (B), showed strong negative correlations with fabric weight per unit area. The strength retentions decrease significantly with increases in fabric weight. Untufted fabric warp elongation shows a high correlation with fabric weight, while the fillingwise elongation shows no significant change with change in fabric weight. Of the tufted fabrics, only the warpwise elongation for the fine gauge tufted fabric had a significant correlation with fabric weight, showing an increase in elongation with increased fabric weight.

The linear regression equations for the relationship between tensile properties and ends x picks per inch are shown on Table III. In general, the strength of the untufted fabric decreases as the ends x picks per inch of fabric increases. The rate of the strength decrease is faster in the filling direction. For the balanced fabric, warpwise strength is higher than fillingwise strength. These strength losses are attributed to the additional bending and consequent yarn elongation.

The relationships between the tensile properties and yarn linear density are listed in Table IV. The warpwise strength increases as the filling hank roving increases, while the fillingwise strength decreases with an increase in filling hank roving.

TABLE III

Tensile Properties Versus Ends x Picks Per Inch

Response	Regression Equation	Correlation Coefficient	95% Confidence Limit
Untufted Fabric Warp Strength	UWS = -6.70C+115.9	-0.91	± 7.13
Untufted Fabric Fillingwise Strength	UFS = -8.49C+112.31	-0.74	±18.07
Warpwise Strength Retention (A)	WSRA = -2.96C+107.05	-0.59	±10.16
Warpwise Strength Retention (B)	WSRB = -4.76C+101.20	-0.65	± 8.07
Fillingwise Strength Retention (A)	FSRA = -3.68C+81.55	-0.62	± 8.91
Fillingwise Strength Retention (B)	FSRB = -7.08C+98.63	-0.73	± 9.99
Untufted Fabric Warpwise Elongation	UWE = -1.02C+17.88	-0.60	± 3.20
Untufted Fabric Fillingwise Elongation	UFE = -0.21C+19.54	-0.15	± 3.08
Tufted Fabric Warpwise Elongation (A)	TWEA = -1.40C+20.83	-0.88	± 0.83
Tufted Fabric Warpwise Elongation (B)	TWEB = -0.95C+21.11	-0.47	± 4.22
Tufted Fabric Fillingwise Elongation (A)	TFEA = -0.19C+27.59	-0.10	± 4.16
Tufted Fabric Fillingwise Elongation (B)	TFEB = -0.71C+27.69	-0.38	± 4.07

TABLE IV
Tensile Properties Versus Yarn Linear Density

Response	Regression Equation	Correlation Coefficient	95% Confidence Limit
Untufted Fabric Warpwise Strength	UWS = -4.20D+102.26	0.42	±3.63
Untufted Fabric Fillingwise Strength	UFS = -13.57D+134.29	-0.68	±2.29
Warpwise Strength Retention (A)	WSRA = 4.04D+96.54	0.31	±3.52
Warpwise Strength Retention (B)	WSRB = 11.14D+85.82	0.72	±3.32
Fillingwise Strength Retention (A)	FSRA = -2.36D+84.46	-0.22	±4.08
Fillingwise Strength Retention (B)	FSRB = -4.96D+100.21	-0.42	±3.49
Untufted Fabric Warpwise Elongation	UWE = -2.79D+23.06	-0.82	±2.29
Untufted Fabric Fillingwise Elongation	UFE = -0.36D+19.5	-0.15	±3.08

III Future Plans

It is anticipated that the cost data will be completed during November. A stepwise regression analysis will be made which will include cost as a variable. It is expected that these data will indicate which fabric has the highest strength retention at the lowest cost.

FINAL REPORT

RESEARCH ON IMPROVED COTTON CARPET BACKING FABRICS

by

Winston C. Boteler

Frank Ko

Georgia Tech Project No. E-27-610
Cotton, Inc. Contract No. 71-544

Prepared for

Cotton, Inc.
Raleigh, N. C.

January 1, 1972 to November 30, 1972

School of Textile Engineering
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ABSTRACT

A series of light weight cotton carpet backing fabrics was developed and evaluated. The properties of the resulting tufted fabrics indicated that suitable competitive backing fabrics could be manufactured if the fiber price remains at a reasonable level. The strength retention characteristics of the fabrics make their use for fine gauge tufting particularly attractive.

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ACKNOWLEDGEMENTS

Appreciation is expressed to Cotton, Inc., Raleigh, North Carolina, for its support of this work. The cooperation and advice of Mr. Robert Cleaver was most gracious and greatly appreciated. Special thanks are due Mr. Frank Ko for his valuable assistance in tufting and evaluating the fabrics and for his expertise in the computer analysis of the data. Messrs. Howard Dotson and John Smith made the fabrics under difficult conditions and contributed greatly to the project.

I. Introduction

The objective of the project was to develop cotton carpet backing fabrics which would be competitive, particularly in fine gauge carpets. Synthetic fabrics have taken more than 50% of the primary backing market, due to a number of factors. The synthetic backings are relatively cheap, currently ranging from 17 to 26 cents per square yard. The relative inertness of the synthetic fabrics to biological degradation and dimensional change due to moisture have made possible the indoor-outdoor type carpets. However, a premium must be paid to insure that the backing is colored the same as the face yarns. This is presently accomplished in two ways: by using solution-dyed polypropylene backing and by needle punching a nylon fiber web onto the fabric face. Jute fabrics are either dyed prior to tufting or dyed in a separate bath after the face yarn has been dyed.

Cotton has the natural advantage of good yarn rupture elongation which made it desirable as a backing fabric during the early days of tufting. However, the early fabrics were relatively heavy and costly with respect to jute. Jute has the advantage of a higher modulus of elasticity, but the low rupture elongation causes a high strength loss when tufted at close needle spacings.

II. Summary and Recommendations

A number of fabrics were manufactured in the weights and constructions which previous experience indicated would be likely to meet the requirements of an economical fabric with suitable physical properties. Evaluation of data from the preliminary tufted fabrics yielded sufficient information to permit the design of a controlled experiment using one size warp yarn and three different filling yarns. Twelve fabrics were woven and tufted at both fine and medium gauge needle spacings. The fabric weights ranged from 5.80 oz/yd^2 to 8.24 oz/yd^2.

The manufacturing costs were calculated using an 8 loom set-up as part of a larger cotton fabric mill. The costs were based on a fiber price of 30 cents per pound and a fabric width of 144 inches. The calculated labor costs ranged from 3.7 to 4.4 cents per pound, while the materials costs ranged from 16 to 19 cents per pound. The optimum fabric, selected on the basis of minimum total cost and maximum fillingwise strength retention, was a 13 x 13 fabric, with a 2.1 hank roving warp and 2.5 filling, weighing 6.56 ounces per square yard. The estimated manufacturing cost of the fabric is 20.6 cents per yard. The machinery requirements and cost break-down are summarized in Table I and described in detail in Section VI of the report. A larger manufacturing scale would result in somewhat lower manufacturing costs. No comparable fabrics are listed on the commodity market. However, comparison with a recent selling price for 36-inch 20 x 12, 23 yds/lb, tobacco cloth permits some evaluation of the large scale manufacturing costs. The selling price of 5.26 cents per yard for the tobacco cloth included 1.3 cents per yard for fiber at 30 cents per pound. Thus, the production cost plus margin amount to only 4 cents per yard. Some additional economy would be effected by weaving a wider fabric, so that the large scale manufacturing cost for carpet backing should be no greater than the calculated range.

COST AND SUMMARY OF MACHINES REQUIRED

Warp/Filling Hank	2.1/2.1				2.1/2.3				2.1/2.5			
Construction	14x14	13x13	13x12	12x12	14x14	13x13	13x12	12x12	14x14	13x13	13x12	12x12
Number of Looms	8	8	8	8	8	8	8	8	8	8	8	8
Number of Slashers	0.29	0.29	0.31	0.29	0.29	0.29	0.31	0.29	0.29	0.29	0.31	0.29
Number of Warpers	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Number of Winders Spindles	35	35	37	35	36	36	39	36	35	35	39	35
Number of Spinning Spindles	737	737	768	737	736	736	797	736	734	734	795	734
Number of Drawing (Del)	4.06	4.07	4.24	4.07	3.7	3.9	4.2	3.9	3.7	3.8	4.1	3.8
Number of Cards	7.5	7.5	7.8	7.5	7.1	7.2	7.7	7.2	6.9	6.9	7.5	7.2
Total Lbs/Wk (120 hr)	44717	44735	46715	44756	42893	42910	46487	42931	41360	41378	44826	41399
(Payroll: \$3120/wk) Labor Cost \$/lb.	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070	0.070
Material Total Cost(30¢/lb),\$	13415.1	13420.4	14014.5	13426.8	12867.9	12873.	13946.1	12879.3	12408.	12413.4	13447.8	12419.7
Lb/yd of Fabric	2.56	2.38	2.29	2.19	2.45	2.28	2.20	2.10	2.37	2.20	2.13	2.03
Labor Cost \$/running yd.	0.18	0.17	0.15	0.19	0.18	0.17	0.15	0.19	0.18	0.17	0.15	0.19
Material Cost (30¢/lb), \$/yd	0.77	0.71	0.69	0.80	0.74	0.68	0.66	0.78	0.71	0.66	0.64	0.76
Material & Labor Cost, \$/yd	0.95	0.88	0.84	0.99	0.91	0.85	0.81	0.97	0.89	0.82	0.79	0.95
(Fabric Width 144") Fabric Weight, lb/sq.yd.	0.64	0.59	0.57	0.55	0.61	0.57	0.55	0.53	0.59	0.55	0.53	0.51
Fabric Weight, oz/sq.yd.	7.7	7.1	6.9	6.6	7.4	6.8	6.6	6.3	7.1	6.6	6.4	6.1
Labor Cost/sq.yd., \$	0.045	0.041	0.038	0.038	0.045	0.041	0.037	0.038	0.045	0.041	0.037	0.038
Material Cost/sq.yd., \$	0.19	0.18	0.17	0.16	0.18	0.17	0.17	0.16	0.18	0.16	0.16	0.15
Material & Labor Cost/sq.yd.,\$	0.24	0.22	0.21	0.20	0.23	0.21	0.20	0.20	0.22	0.21	0.20	0.19

The experimental fabric constructions are listed in Table II. A summary of the fillingwise fabric breaking strengths are listed in Table III. The "A" fabrics were tufted at 13 needles per inch and 10 stitches per inch, while the"B" fabrics were tufted at 7 needles per inch and 7 stitches per inch. The A and B tufting levels represent "contract" and "residential" type carpets, respectively. It can be seen from Table III that the untufted fabric strength decreases as fabric weight decreases, while the strength retention increases. The result is that strength after tufting is almost as high for the light weight 2.5 hank roving filling fabrics as for the heavier 2.1 H.R. filling fabrics. The optimum fabric was selected on the basis of strength retention for the "A", or fine gauge, fabric, since this needle spacing represents the most critical tufting condition in industry. Tables IV and V list the warpwise strength properties and elongations, respectively. It will be noted on Table IV that some warpwise strength retentions are more than 100%. This is due to the very few broken warp yarns and the additional inter-fiber friction produced by the insertion of the face yarn. The level of elongations shown on Figure V indicates the reason for the relatively high fillingwise strength retentions. The filling yarns are sufficiently elastic to avoid the tufting needles most of the time.

It is recommended that additional experiments be conducted to determine the behavior of these fabrics after tufting, backing, and finishing into complete carpets. In addition, some 12 foot broad loom fabrics should be woven, tufted, and backed, so that the completed carpets can be evaluated.

TABLE II

EXPERIMENTAL FABRIC CONSTRUCTIONS

No.	Fabric Code	Ends x Picks/in.	Filling Linear Density Hank	Fabric Weight oz/yd^2
1	11	14 x 14	2.1	8.24
2	12	13 x 13	2.1	7.36
3	13	13 x 12	2.1	6.72
4	14	12 x 12	2.1	6.35
5	21	14 x 14	2.3	7.74
6	22	13 x 13	2.3	7.20
7	23	13 x 12	2.3	6.64
8	24	12 x 12	2.3	5.97
9	31	14 x 14	2.5	7.00
10	32	13 x 13	2.5	6.56
11	33	13 x 12	2.5	6.16
12	34	12 x 12	2.5	5.80

Note: The warp linear density for all the fabrics is 2.1 hank roving.

All fabrics are plain weave.

TABLE III

SUMMARY OF FABRIC STRENGTH - FILLINGWISE

Code	Untufted Fabric Lbs. Breaking Strength	Tufted Fabric A Breaking Strength	Tufted Fabric A Strength Retention (%)	Tufted Fabric B Breaking Strength	Tufted Fabric B Strength Retention (%)
11	179.52	79.9	67	93.97	79
12	100.68	81.35	81	95.93	95
13	82.69	65.15	79	63.89	77
14	89.70	75.38	84	81.05	90
21	109.54	83.55	76	93.38	85
22_1	93.72	69.07	74	86.45	92
22_2	98.78	71.58	72	88.75	90
23	85.58	66.38	78	82.93	97
24	84.94	71.88	85	74.13	88
31	92.38	75.23	81	84.05	91
32	85.50	72.78	85	81.88	96
33	74.30	63.45	85	73.55	99
34	74.30	64.00	86	60.08	81

TABLE IV

SUMMARY OF FABRIC STRENGTH - WARPWISE

Code	Untufted Fabric Lbs. Breaking Strength	Tufted Fabric A Breaking Strength	Tufted Fabric A Strength Retention (%)	Tufted Fabric B Breaking Strength	Tufted Fabric B Strength Retention (%)
11	107.67	97.02	93	96.07	92
12	98.45	100.13	102	93.55	95
13	94.16	91.78	97	88.28	94
14	89.71	93.35	104	90.20	101
21	114.24	111.73	98	109.88	96
22_1	102.72	96.60	94	103.58	101
22_2	98.35	101.45	103	102.45	104
23	96.05	100.58	105	98.93	103
24	91.10	100.93	111	92.98	102
31	113.07	105.10	93	118.35	105
32	97.85	105.95	108	101.15	103
33	101.10	98.95	98	102.25	101
34	86.73	93.80	108	96.5	111

TABLE V

FABRIC ELONGATION

Code	Warpwise Elongation (%)			Fillingwise Elongation (%)		
	Untufted Fabric	Tufted Fabric		Untufted Fabric	Tufted Fabric	
		A	B		A	B
11	20.34	19.94	21.01	19.40	21.59	25.58
12	16.47	18.87	15.98	14.86	26.56	23.89
13	14.53	16.85	13.45	17.58	18.72	24.46
14	14.33	16.03	19.55	19.56	23.21	25.57
21	17.36	20.16	21.92	21.29	22.95	27.69
22_1	13.53	19.25	18.88	18.94	22.79	26.34
22_2	16.73	17.82	18.19	20.41	24.75	26.99
23	16.18	16.05	19.63	19.11	20.10	24.52
24	13.94	15.46	18.91	19.13	22.88	24.51
31	14.70	17.92	20.20	20.03	21.93	26.20
32	14.08	16.91	20.50	19.89	22.39	32.05
33	15.07	15.97	18.24	19.32	19.23	24.94
34	13.36	14.62	16.49	19.20	23.08	25.03

III. Preliminary Study

The objective of the preliminary study was to get a general idea of the tuftability of cotton fabrics and to establish limits for a more detailed investigation. Relatively short and cheap fibers were used, and both yarn and hard twist rovings were examined as candidate warp and filling materials. The preliminary fabrics were woven as shown in the following table.

Fabric	Construction	Warp and Filling	
1	14 x 12	Yarn	Yarn
2	14 x 14	Roving	Yarn
3	13 x 12	Roving	Yarn
4	14 x 14	Roving	Roving
5	13 x 12	Roving	Roving

The yarns were 2.5 cotton count with 5 turns per inch of twist, while the rovings were 2.1 cotton count, also with 5 turns per inch of twist. The fabrics were tufted at both 13 needles per inch and 7 needles per inch gauges. It was found that the 2.1 hard twist roving was considerably stronger than the 2.5 C.C. yarn: 8.91 lbs. compared to 5.06 lbs. A preliminary tensile test on five samples indicated that, according to ASTM Designation D2264, 20 warp and filling specimens would be required to produce a 95% significance level.

The warp yarns were sized on a Callaway Model 50 slasher with 3 oz/lb of CMC. The slasher was operated at 3 rpm, giving a yarn speed of 5 feet per minute at an average temperature of 200°F.

The fabrics were woven on a Draper X-2 loom at a speed of 190 picks per minute.

The preliminary experiments indicated that all the roving fabrics were superior to the yarn fabrics as carpet backings.

IV. Design of the Experiment

According to the main objective of the project, the experiment was designed to determine the lowest cost fabric with the highest tuftability.

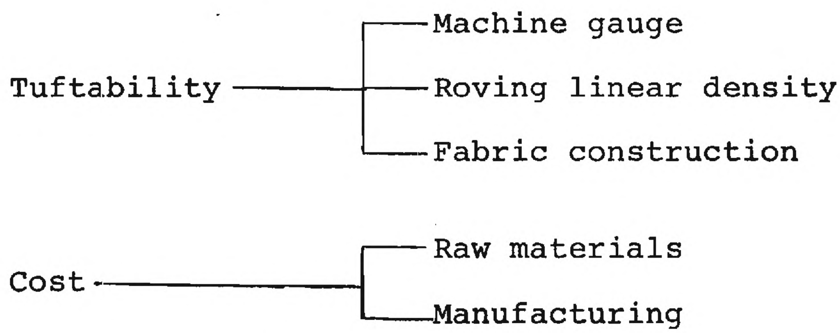
Factors affecting each can be listed as follows:

1) Tuftability (in terms of strength retention)

T = f (Machine gauge, roving linear density, fabric construction)

2) Cost C = g (Raw material, processing)

where raw materials, roving linear density and fabric structure are inter-related, as illustrated in the following diagram.



Therefore, the following experiment was developed.

Experimental Design

Factors	Levels	Measured Values				Code
Needle Gauge (Needles/in.)	2	13 n/in.	7 n/in.			A B
Fabric Construction	4	14x14	13x13	13x12	12x12	1 2 3 4
Filling Linear Density (Hank Roving)	3	2.1	2.3	2.5		10 20 30

Warp rovings were the same, 2.1 H.R., for all fabrics.

Total number of experiments = 24

Design Matrix for Tufted Fabrics =

11A	21A	31A
11B	21B	31B
12A	22A	32A
12B	22B	32B
13A	23A	33A
13B	23B	33B
14A	24A	34A
14B	24B	34B

The responses were (1) breaking strength,(2) elongation, and (3) strength retention.

The variables of interest, region of exploration, and specific experimental levels were determined in the preliminary study. Since the selected region was based on experimental data, it was quite likely a near optimum region prior to investigation.

When several factors are involved in an experimental study, a factorial design is one of the most efficient ways of generating the required information. A two-factor, three-level (3^2 factorial) experiment was planned. The two factors are fabric construction and filling yarn linear density. All the fabrics were tufted on two different machines with different needle spacings (5/32 in. and 5/64 in.). The introduction of the machine variable suggests that there were two different blocks of data. A dummy variable, representing the machine, was inserted into the experimental design.

The coded and measured levels of the variables are listed in the following table.

Factors	Levels*	Coded and Measured Value +1	0	-1	Units	Code Name
x_1 Tufting Machine	2	A**	B		---	MC
x_2 Fabric Construction	3	14x14	13x13	12x12	Ends x Picks per inch	C
x_3 Filling Linear Density	3	2.5	2.3	2.1	Hank	D

* +1 = High Level, 0 = Center, -1 = Low Level

**A = 5/64 Gauge, B = 5/32 Gauge

The design matrix in terms of coded values is as follows:

Experiment Number	Code Name	Block	x_1	x_2	x_3
1	11	A	1	1	-1
2	34	A	1	-1	1
3	31	A	1	1	1
4	14	A	1	-1	-1
5	21	A	1	1	0
6	24	A	1	-1	0
7	32	A	1	0	1
8	12	A	1	0	-1
9	22-1	A	1	0	0
10*	22-2	A	1	0	0
11	11	B	0	1	-1
12	34	B	0	-1	1
13	31	B	0	1	1
14	14	B	0	-1	-1
15	21	B	0	1	0
16	24	B	0	-1	0
17	32	B	0	0	1
18	12	B	0	0	-1
19	22-1	B	0	0	0
20	22-2	B	0	0	0

*An additional observation at the center of the design to check the experimental error.

From past experience it has been noted that the tensile response of a tufted fabric can be sufficiently described as a linear function of the backing structural properties. Therefore, a model was assumed to represent the fabric, where the true response "Y" is determined by the following equation:

$$Y = B_o + B_1X_1 + B_2X_2 + B_3X_3 + B_{23}X_2X_3 + E \quad (1)$$

Where B_o = Constant Term

B_i and B_{ij} = coefficients of ith and ijth variable

X_1 = Machine Taype 1 = 5/64, 0 = 5/32

X_2 = Fabric Construction

X_3 = Filling Yarn Linear Density

X_2X_3 = Interaction between Fabric Construction and Filling Linear Density

E = Random Error Term

Y = Tensile Response of a Fabric, such as Absolute Strength, Elongation, and Strength Retention

The coefficients in Equation 1 were estimated by the method of least squares. Then the estimates of the coefficients were used to write the estimated response function, as follows;

$$\hat{Y} = b_o + b_1x_1 + b_2x_2 + b_3x_3 + b_{23}x_2x_3 \quad (2)$$

Where b_i and b_{ij} are estimated coefficients

x_1, x_2, x_3 and x_2x_3 are the variables listed above

$\hat{Y}$ = Estimated Response

The specific program used to compute the data for this study on the Georgia Tech Univac 1108 Computer was the BMD 02R Stepwise Regression, compiled by UCLA. The program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. The variable added is the one which produces the greatest reduction in the error sum of squares.

The added variable is also that variable which has the highest partial correlation with the dependent variable partialed on the variables which were added previously. Also, the added variable would have the highest F-value. Variables can be forced into the regression equation by setting a low F-value of inclusion.

In addition to the standard output which would be obtainable by a routine regression analysis, this program gives the following additional information:

1) Mean and standard deviation of the variables
2) Covariance and correlation matrix
3) List of residuals and plots of residuals versus the input variables
4) Summary table

The correlation matrix shows not only the partial correlation between independent and dependent variables, but also the inter-relationships between the independent variables. The list of residuals indicates how close the predicted response is to the observed response, or experimental response. The residual is also an indication of the amount of experimental data which the regression equation has not been able to explain. An examination of the plots of residuals versus the dependent and independent variables helps to pinpoint the unexplained variables. The residuals can also serve as a means of verifying our assumptions about the error. (The usual assumptions are that the errors are independent, have a zero mean constant variance, and are normally distributed.)

V. Collection of Data

The 24 tufted fabrics were tested on the Instron tensile test machine to determine the relationship between load and elongation and to determine the breaking strength and elongation. The resulting data were plotted against the fabric variables and the data plots are included as Figures 1 through 32 in Appendix I.

The production data used to calculate the manufacturing costs were developed by assuming a set of 8 looms running 120 hours per week. The resulting production data are listed below.

Construction	14x14	13x13	13x12	12x12
Total Warp lbs/wk	24,474	24,763	26,828	24,785
Total Filling 2.1 Hank	24,019	24,019	24,019	24,019
Total Filling 2.3 Hank	21,931	21,930	23,758	21,930
Total Filling 2.5 Hank	20,176	20,176	21,856	20,176
2.1/2.1 Total lbs. Warp & Filling	44,717	44,735	46,715	44,756
2.1/2.3 Total lbs.	42,893	42,910	46,487	42,431
2.1/2.5 Total lbs.	41,360	41,378	44,826	41,399
Machines Required, 2.1/2.1				
Slashers	0.29	0.29	0.31	0.29
Warpers	0.05	0.05	0.05	0.05
Winder	35	35	37	35
Spindles	737	737	768	737
Drawing Frames	4.06	4.07	4.24	4.07
Cards	7.5	7.5	7.8	7.5

	14x14	13x13	13x12	12x12
2.1/2.3				
Slashers	0.29	0.29	0.31	0.29
Warper	0.05	0.05	0.05	0.05
Winder	36	36	39	36
Spindle	736	736	797	736
Drawing	3.7	3.9	4.2	3.9
Cards	7.1	7.2	7.7	7.2
2.1/2.5				
Slasher	0.29	0.29	0.31	0.29
Warper	0.05	0.05	0.05	0.05
Winder	35	35	39	35
Spindles	734	734	795	734
Drawing	3.7	3.8	4.1	3.8
Cards	6.9	6.9	7.5	7.2

The labor costs in Table I are based on the following labor requirements.

Weavers	2
Slasher	1
Winder	1
Spinners	2
Carding	2
Drawing	2
Open & Cleaning	

Total = 8 laborers at average $3.25/hour
Total Payroll = $3120

VI. Analysis and Discussion of Results

The summary of the regression data is shown on Table VI. The computer print-outs are included as Appendix II to this report.

TABLE VI

SUMMARY OF STEPWISE REGRESSION ANALYSIS

Description	Regression Equation	Multiple Correlation Coefficient	% Variation Explained	95% Confidence Limit	Level of Significance
1) Warpwise Strength	WS = 16.41 + 0.25C + 18.23D	0.83	69.5	±12.2	>>95%
2) Fillingwise Strength	FS = 136.77 - 9.97MC + 0.08C -43.79D + 0.09CD	0.90	80.4	±10.4	>>99%
3) Warpwise Elongation	WE = 23.05 - 1.48MC + 0.01C -6.48D + 0.03CD	0.78	61.4	±3.0	>95%
4) Fillingwise Elongation	FE = 22.38 - 3.17MC + 1.78D	0.67	44.6	±5.7	>95%
5) Warpwise Strength Retention	WSR = 54.37 + 0.53C + 34.19D -0.1CD	0.81	65.9	±8.9	>95%
6) Fillingwise Strength Retention	FSR = 49.72 - 9.96MC + 0.13C + 25.24D - 0.1CD	0.73	54.0	±12.5	>95%

Note: MC = Machine Gauge
C = Construction (Ends x Picks/inch)
D = Filling Linear Density in Hank
CD = C and D Interaction

The data summary gives a general idea of the relative contribution of all the variables entered into the regression equations. The square of the multiple correlation coefficient indicates how much of the response variation has been explained. The increases in the square of multiple correlation (RSQ) and the "F" value are the indicators of the relative significance of each entered variable. The sign of the estimated coefficient indicates the relationship between each variable and the corresponding response. A negative coefficient implies that the response increases with a decrease of the corresponding variable.

a. Warpwise Strength

The relationships between warpwise fabric strength and the fabric variables are detailed on Printout I in Appendix II. In general, warpwise strength is higher than fillingwise strength. Needle spacing was not a significant factor in warpwise strength.

Fabric construction and filling linear density show a strong influence on warpwise strength at the beginning of Printout I. But as soon as the individual factors are entered into the regression equation the interaction effect becomes insignificant. (This is indicated by the analysis of variance table in Printout I.) This indicates that the early sign of importance in the regression was due primarily to the individual factors, fabric construction and filling linear density. To verify this deduction, an additional analysis was made by entering only fabric construction and filling linear density, as shown on Printout II.

A multiple regression correlation coefficient of 0.834 was obtained, which indicates that 69.5% of the response variation was contributed by the two variables. This can be compared with the results in Printout I, which show that the three variables, namely, fabric construction, filling linear density, and fabric construction-filling linear density interaction, contribute 69.6% of the response variation. Considering the difference in the RSQ's* and the fact that the interaction effect vanished at the end in Printout I, it can be concluded that only fabric construction and filling linear density are significant to the response. Of the two, fabric construction has more effect than filling wise linear density on tufted fabric warpwise strength. Tufted fabric warpwise strength increases with an increase in ends x picks per inch and filling linear density.

b. Fillingwise Strength

The effect of needle spacing on tufted fabric fillingwise strength is significant, and as expected, the 5/64 inch fine gauge machine caused more backing damage and produced weaker fabrics. The machine type contributes 24.9% of the response variation out of a total of 80.36% variation due to all variables, as shown on Printout III. The most significant factor affecting tufted fabric fillingwise strength is the number of ends x picks per inch, which contributes 31% of the total response. Filling linear density also affects the fillingwise strength significantly, accounting for 22% of the response variation. As the filling hank increases, fillingwise strength decreases. The interaction of ends x picks per inch

*RSQ = Square of Multiple Correlation Coefficient. RSQ = 0.8 means that 80% of the variation has been explained.

and filling linear density has a positive effect on filling strength, but it is a minor effect.

c. Warpwise Elongation

The combination of all the variables as proposed in the hypothetical model accounts for 61.39% of the response variation, as shown on Printout IV, which indicates that almost 40% of the variation remains unexplained. There may be some fiber translation which was not included in the model.

Ends x picks per inch have a significant effect on tufted fabric warpwise elongation, accounting for 36.7% of the response variation. Warpwise elongation increases as ends x picks per inch increases. Machine type contributes 17.6% of the response variation. Fabrics tufted on the fine gauge machine have lower elongations. The effect of fabric construction and filling linear density-fabric construction interaction is positive but not significant. An increase in filling hank number causes a decrease in warpwise elongation.

d. Fillingwise Elongation

Printout V shows that the hypothetical model explains only 45% of the response variation. Of all the variables, only machine type has a highly significant effect on the fillingwise elongation. It accounts for 43.26% of the response variation. The negative effect shown in the correlation indicates that fabrics tufted at fine gauge have lower elongations. Filling linear density has a positive effect, but not a significant one. Fabric construction and the interaction do not have a significant effect on fillingwise elongation.

e. Warpwise Fabric Strength Retention

There is no significant strength loss for the fabrics in the experimental region. An examination of the multiple correlation coefficient from Printout VI indicates that about 66% of the response variation has been explained. Ends x picks per inch have the greatest influence on the warpwise strength retention. Fabrics tend to have higher warpwise strength retentions as the ends x picks per inch are decreased. About 35% of the total response variation is explained by this variable. Filling linear density also has a significant effect on warpwise strength retention. It accounts for about 26% of the response variation. The warpwise strength retention increases with an increase in filling linear density (hank number). In other words, a higher level of strength retention can be achieved in the warp direction if a smaller size filling yarn is used. Interaction of the above factors is of only minor significance, and needle spacing is not a significant factor.

f. Fillingwise Strength Retention

As anticipated, fillingwise strength retention is lower than warpwise strength retention. The average fillingwise strength retention for fabrics in this study was 84%. As shown on Printout VII, machine type, or needle spacing, is the dominant factor in fillingwise strength retention, accounting for 41% of the response variation. The fabric tufted strength decreases as needle spacing decreases. Ends x picks per inch and fillingwise linear density affect fillingwise strength retention at about the same level, but are not as significant as needle spacing. A decrease of ends x picks per inch causes an increase in fillingwise strength retention, and a finer filling roving with respect to the warp produces an increase in strength retention.

In summation, for warpwise strength retention, the fabric should have a high ends x picks per inch while keeping the hank number as low as possible. For maximum filling strength retention, the fabric should have a low ends x picks per inch and finer filling (higher hank number).

APPENDIX I

FABRIC DATA PLOTS

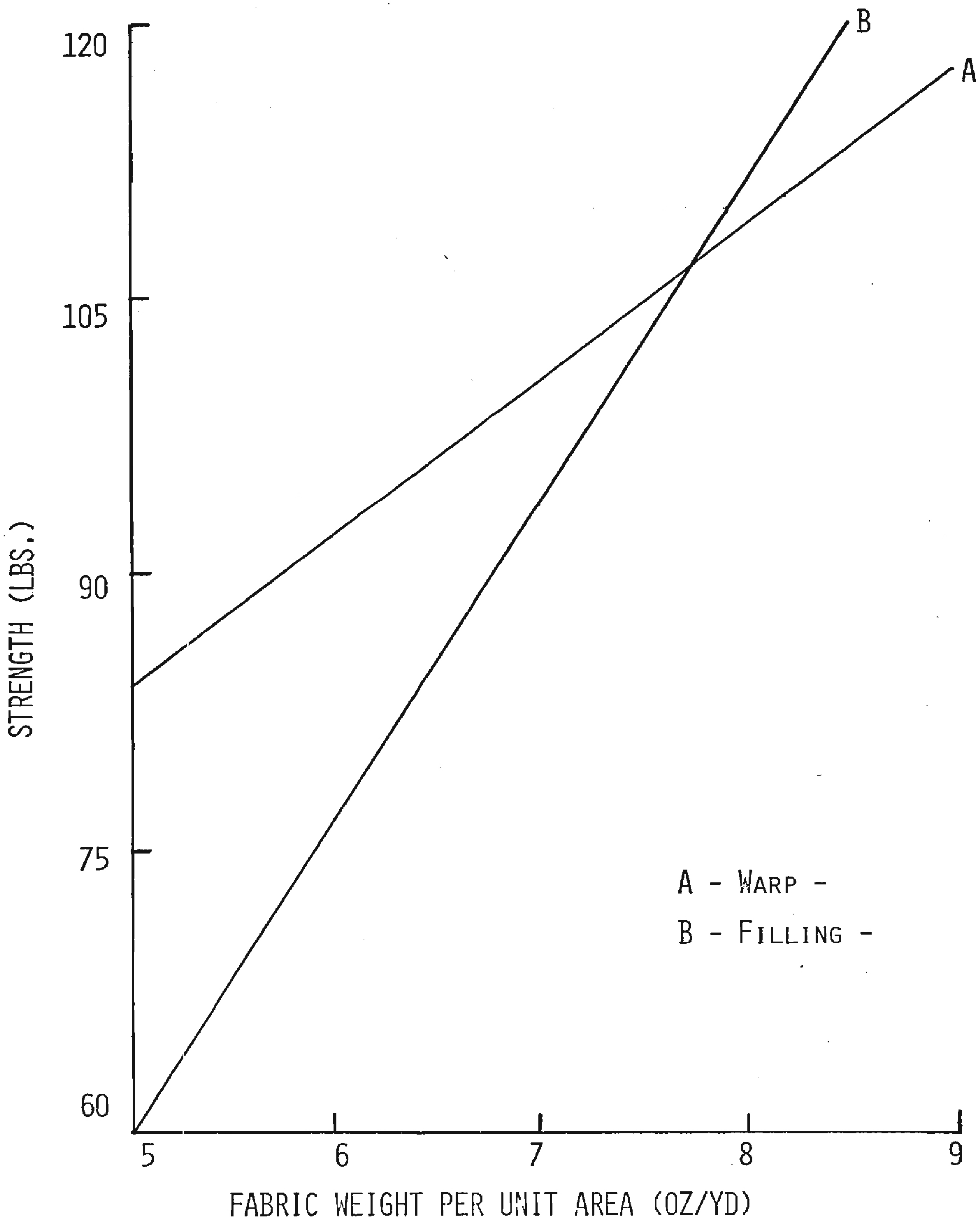


Figure 1. The Effect of Fabric Weight per Unit Area on Fabric Strength.

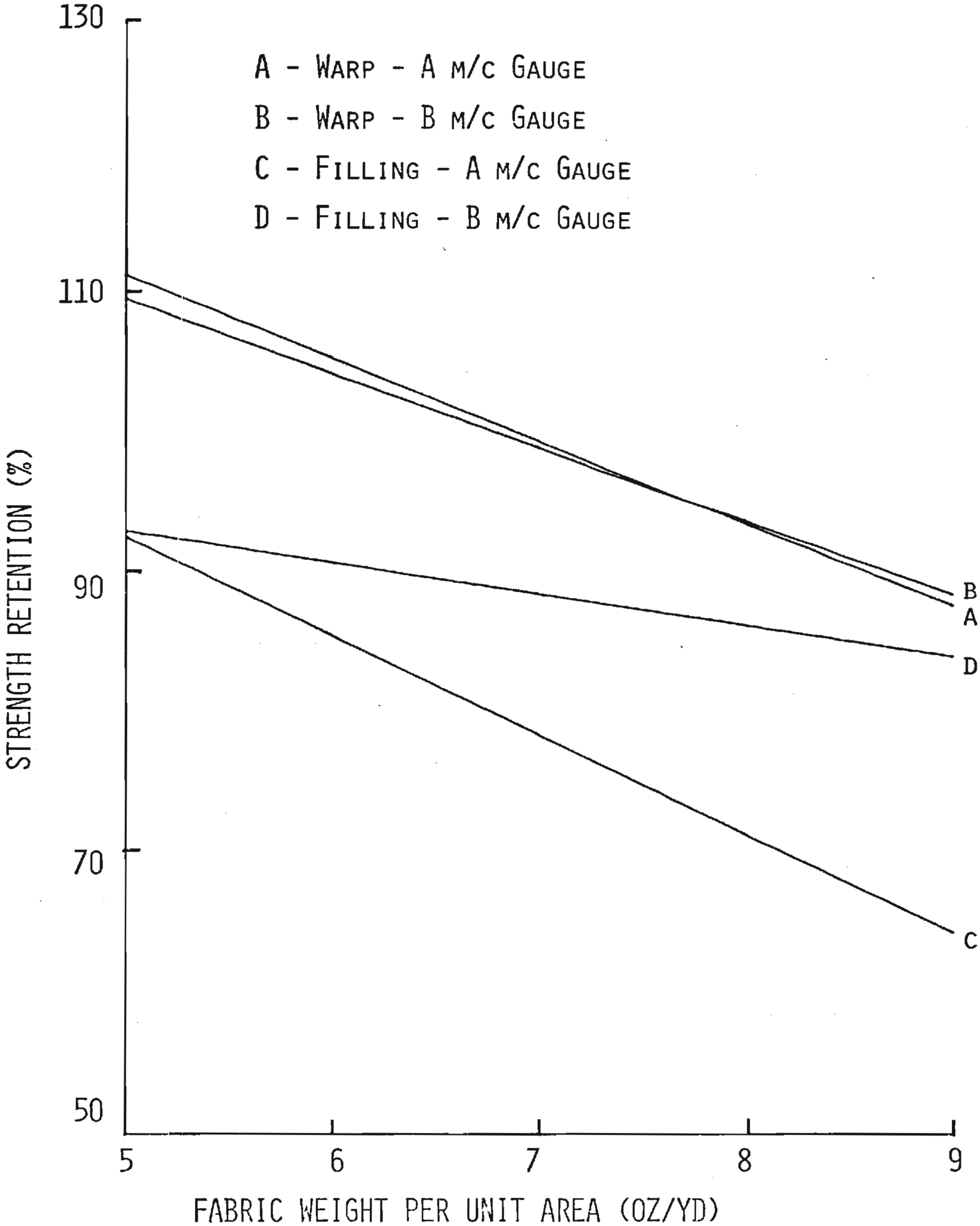


Figure 2. The Effect of Fabric Weight per Unit Area on Fabric Strength Retention.

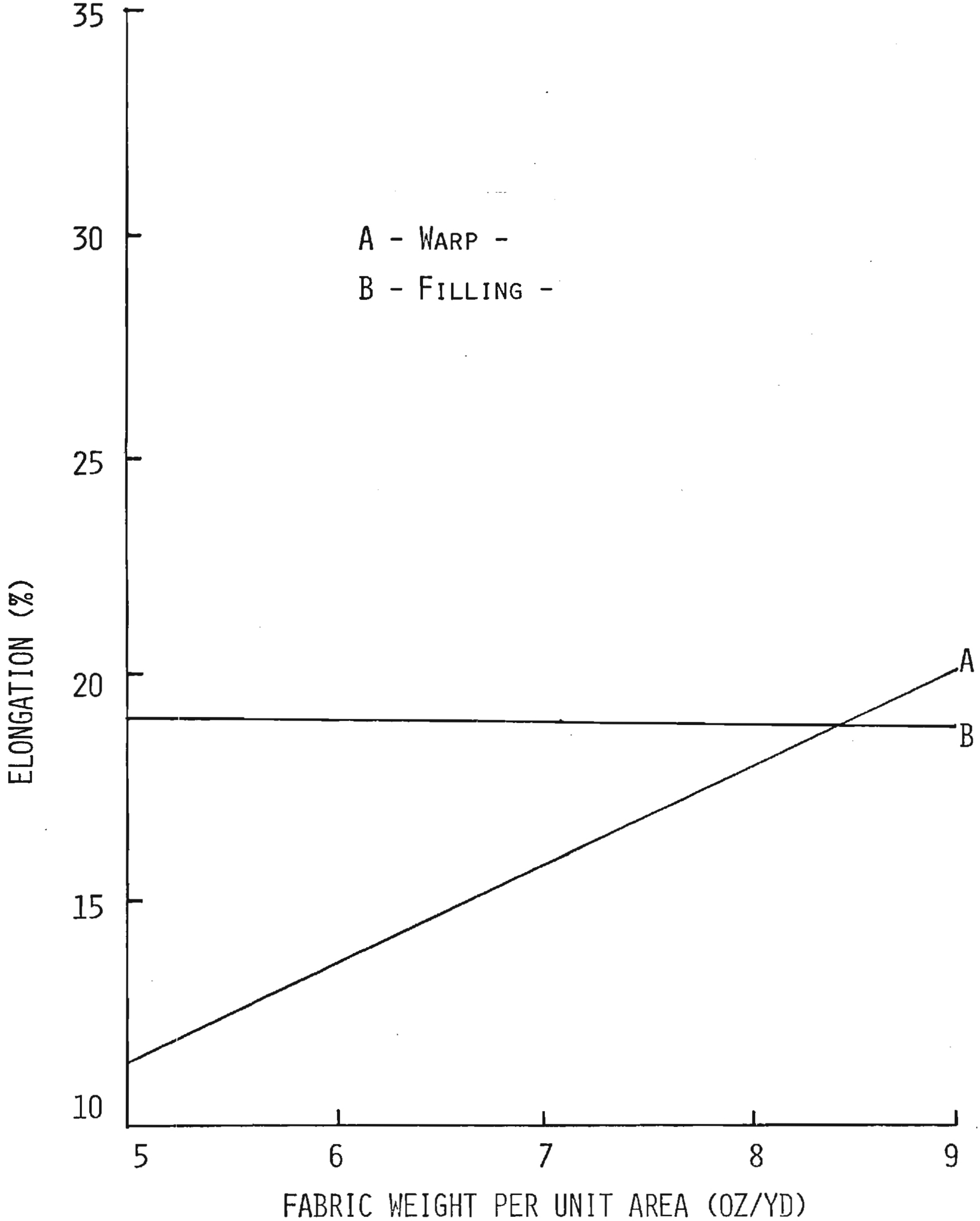


Figure 3. The Effect of Fabric Weight per Unit Area on Untufted Fabric Elongation.

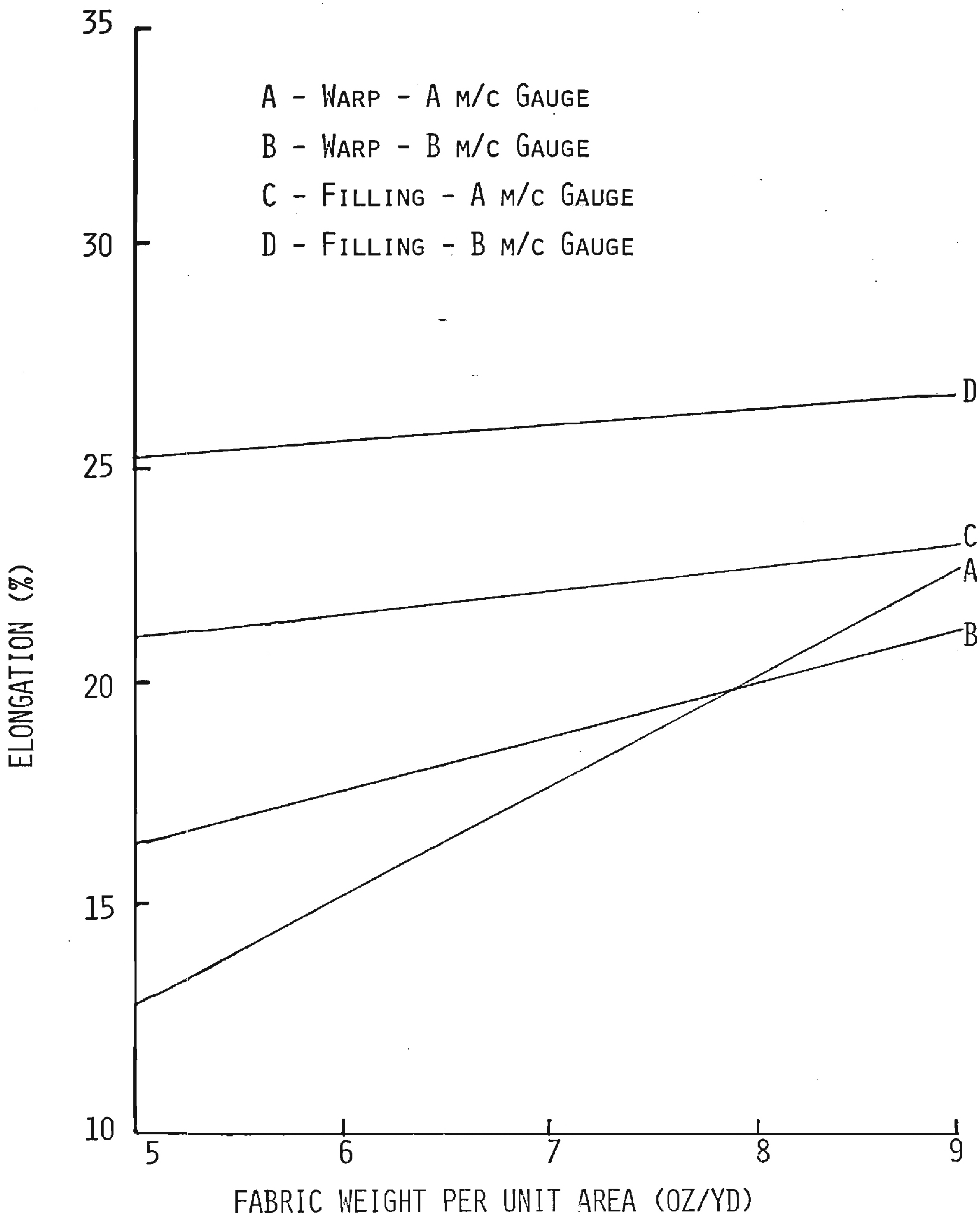


Figure 4. The Effect of Fabric Weight per Unit Area on Tufted Fabric Elongation.

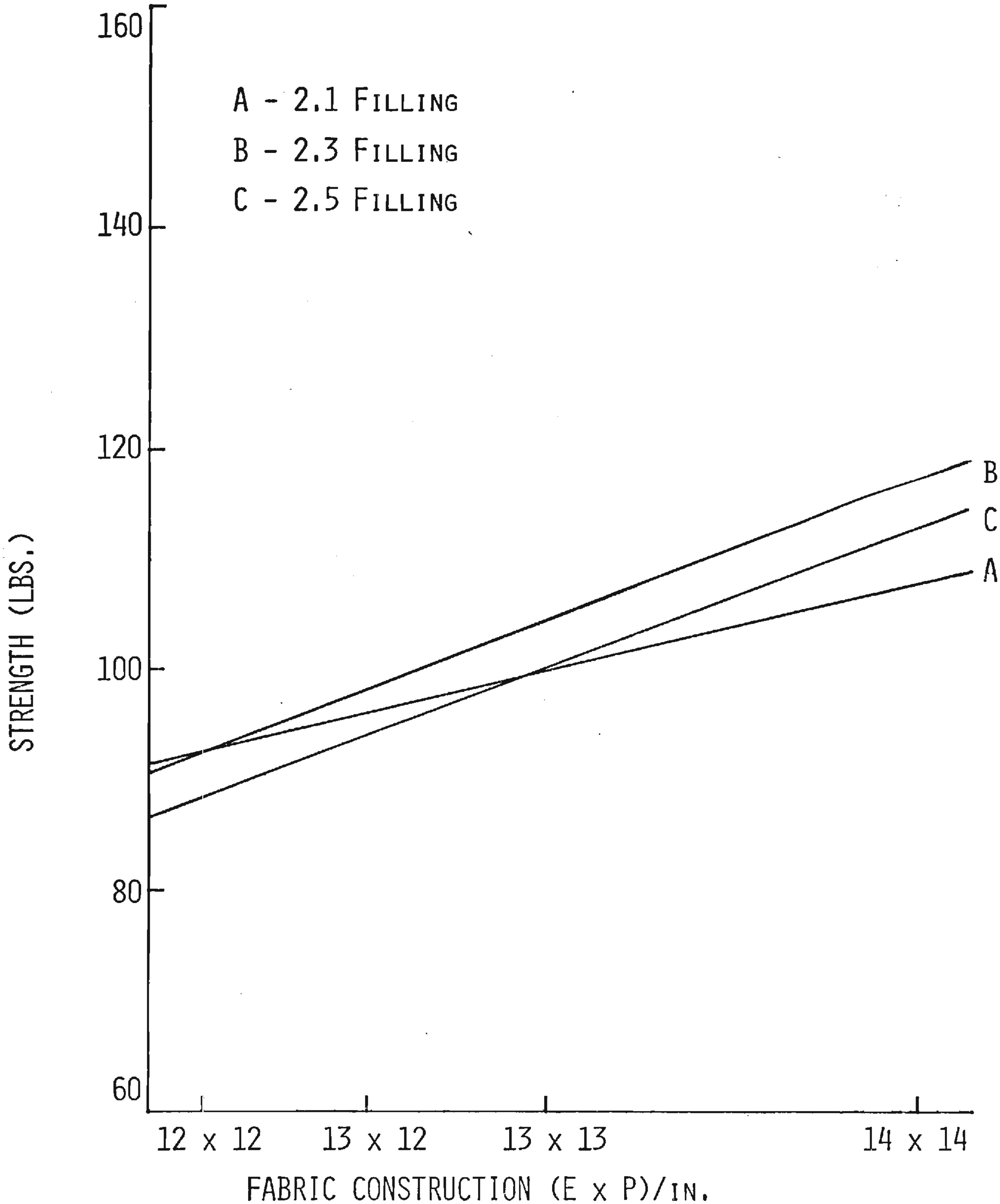


Figure 5. The Effect of Fabric Construction on Warpwise Fabric Strength.

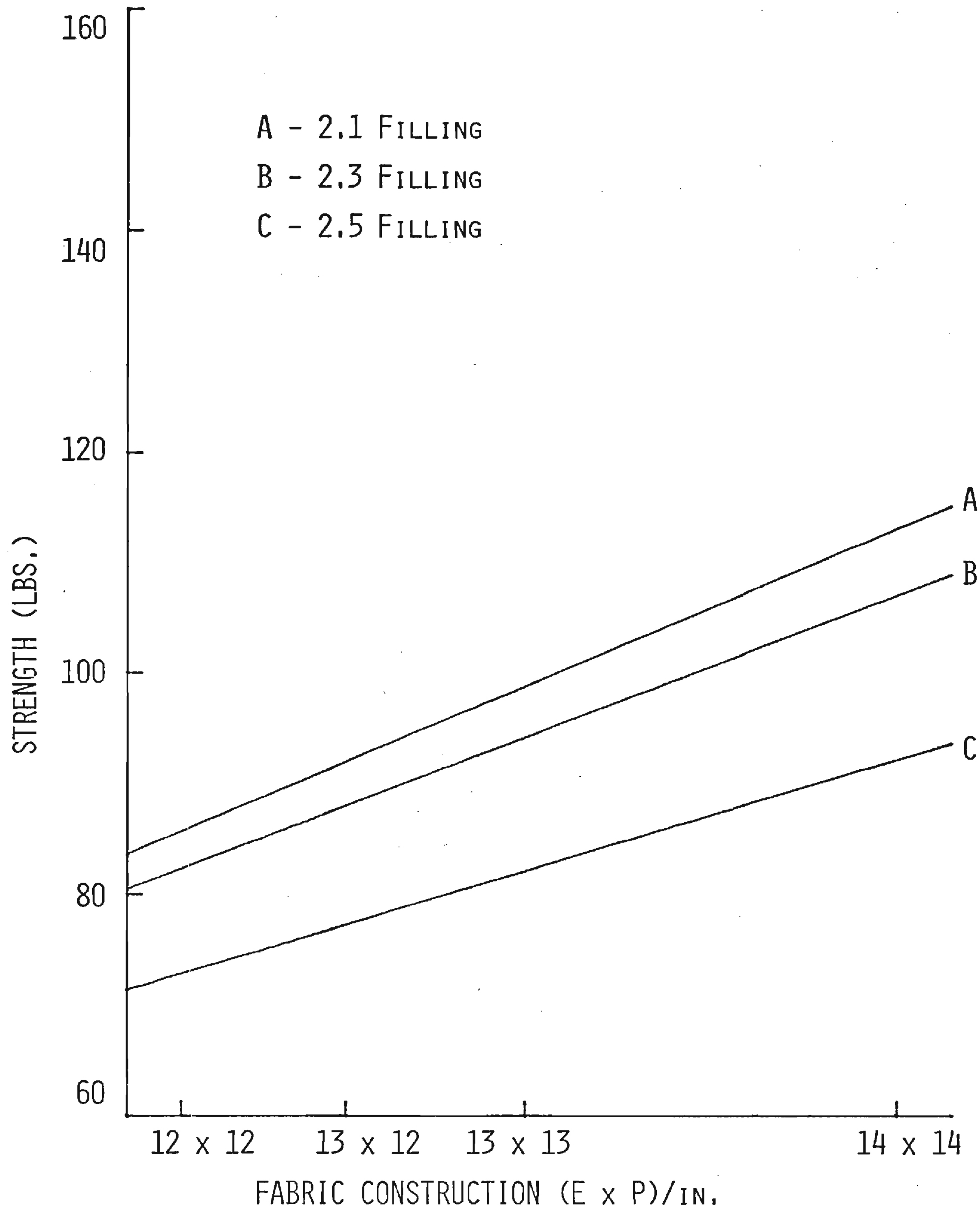


Figure 6. The Effect of Fabric Construction on Fillingwise Fabric Strength.

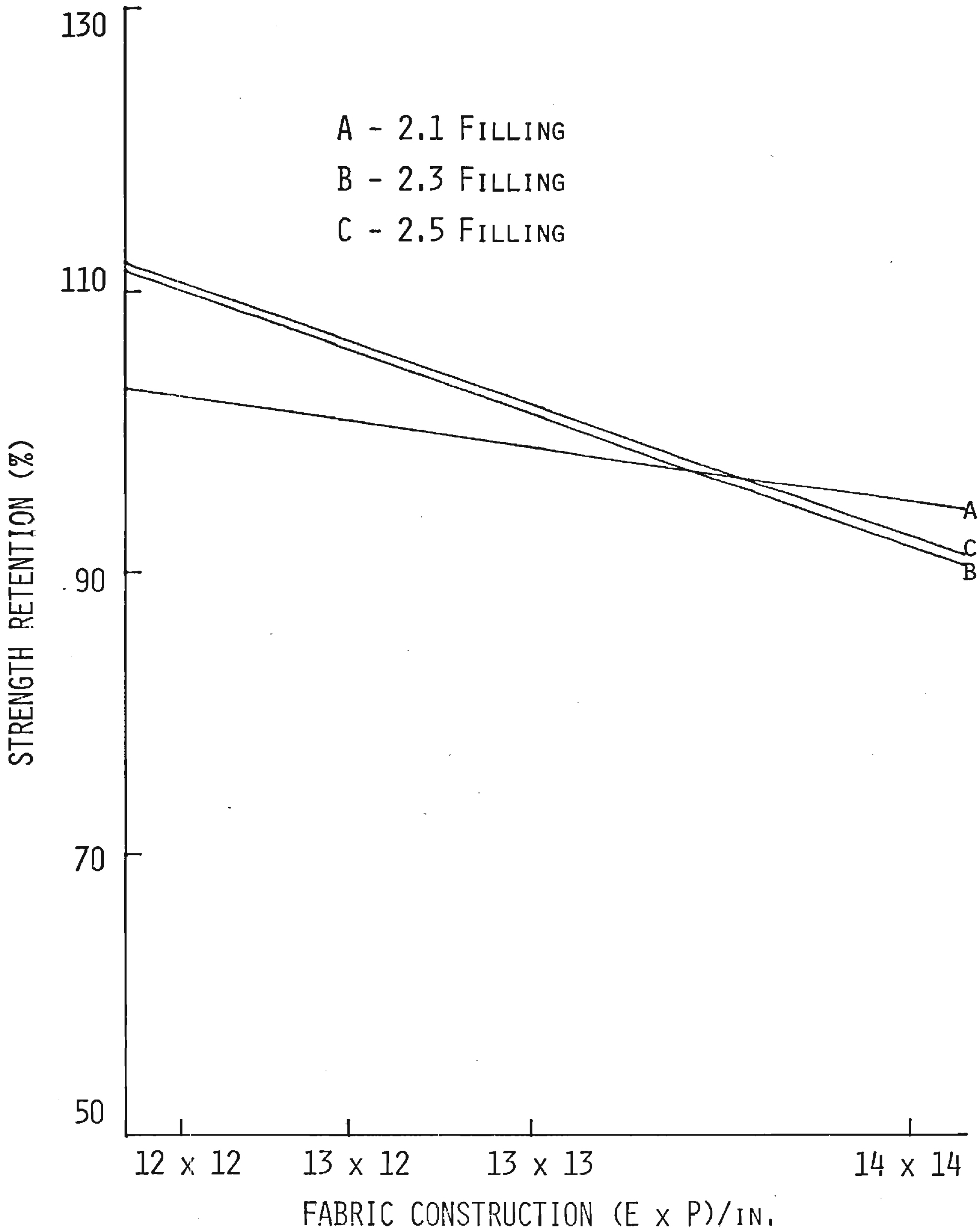


Figure 7. The Effect of Fabric Construction on Warpwise Fabric Strength Retention - A M/C Gauge.

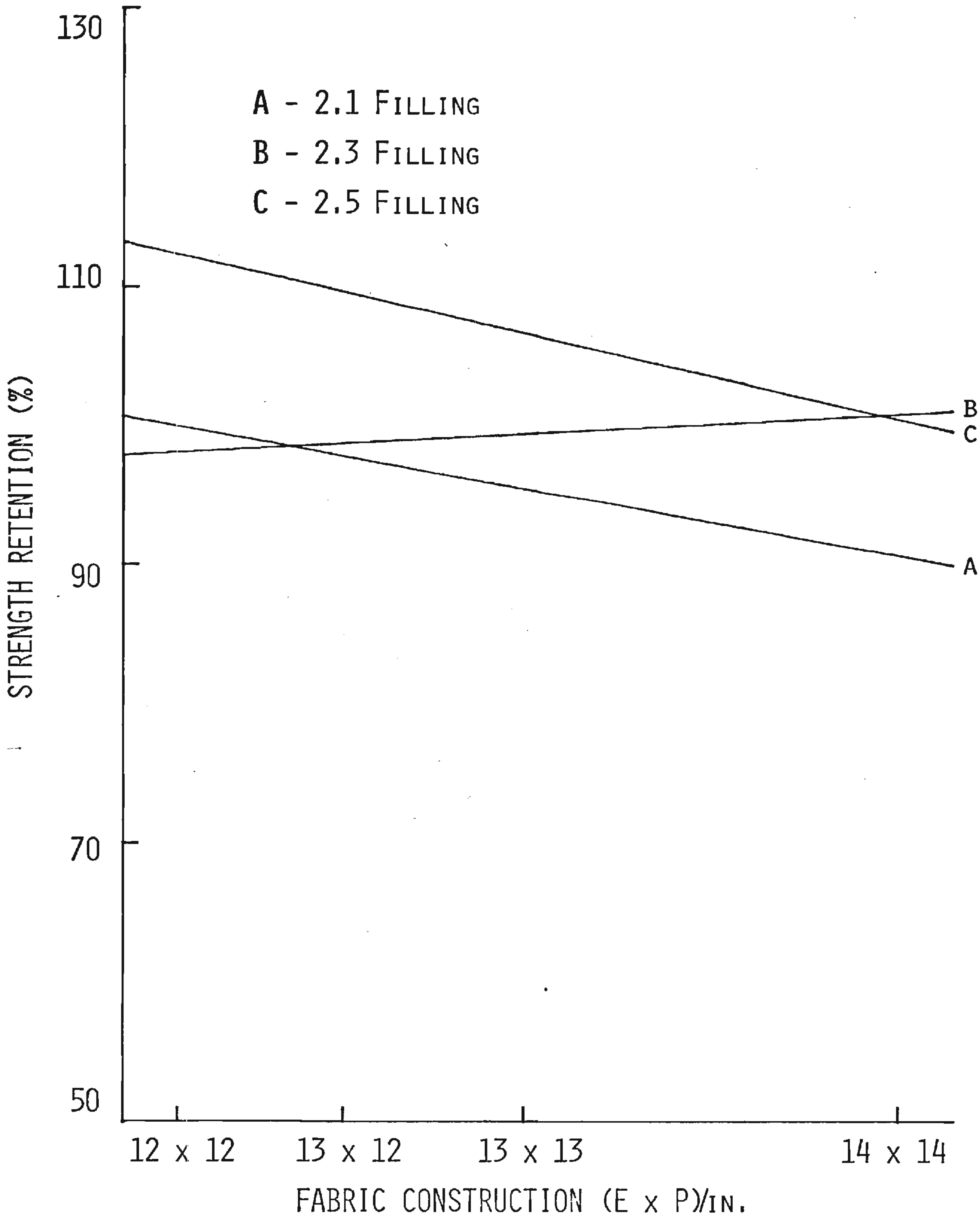


Figure 8. The Effect of Fabric Construction on Warpwise Fabric Strength Retention - B M/C Gauge.

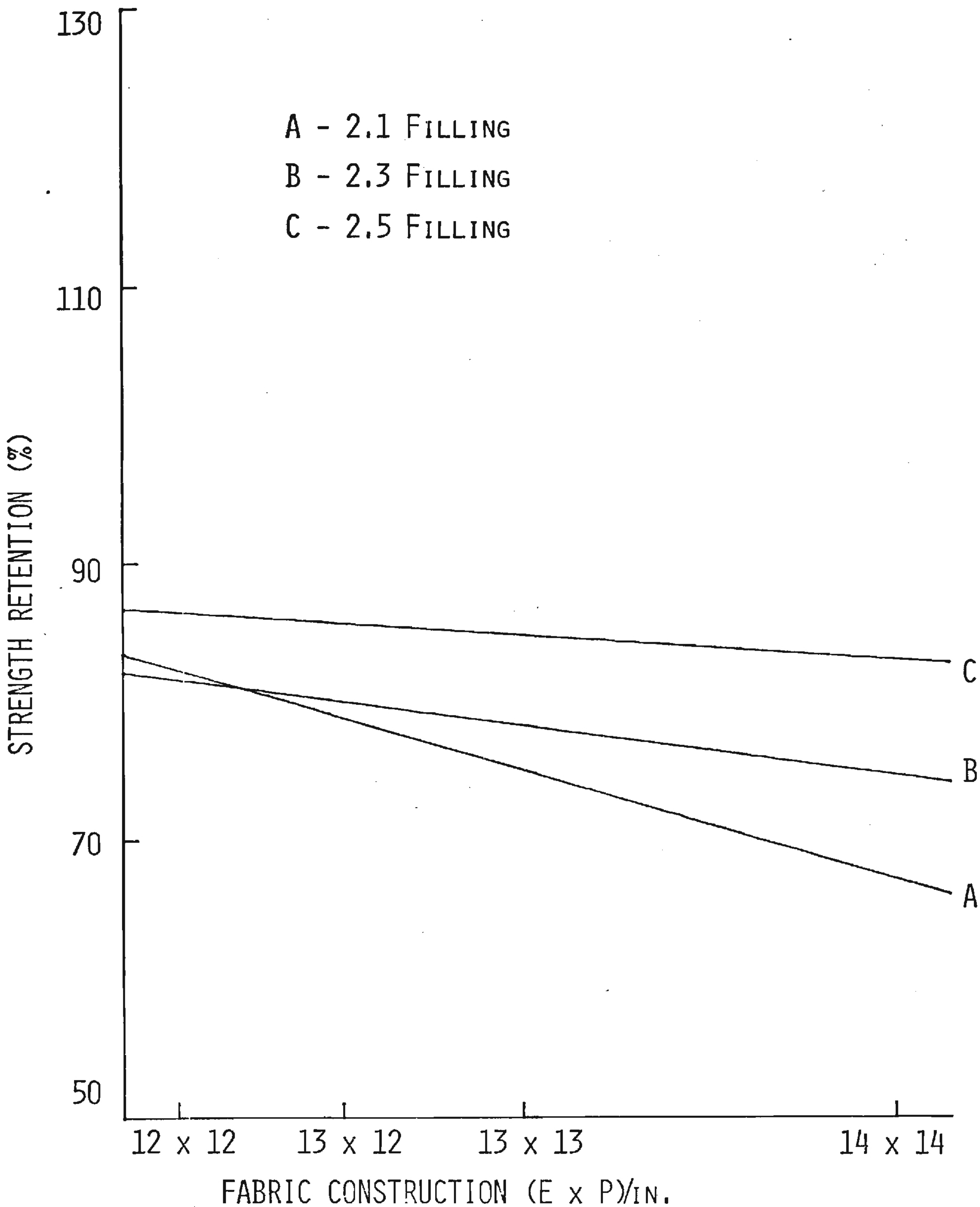


Figure 9. The Effect of Fabric Construction on Fillingwise Fabric Strength Retention - A M/C Gauge.

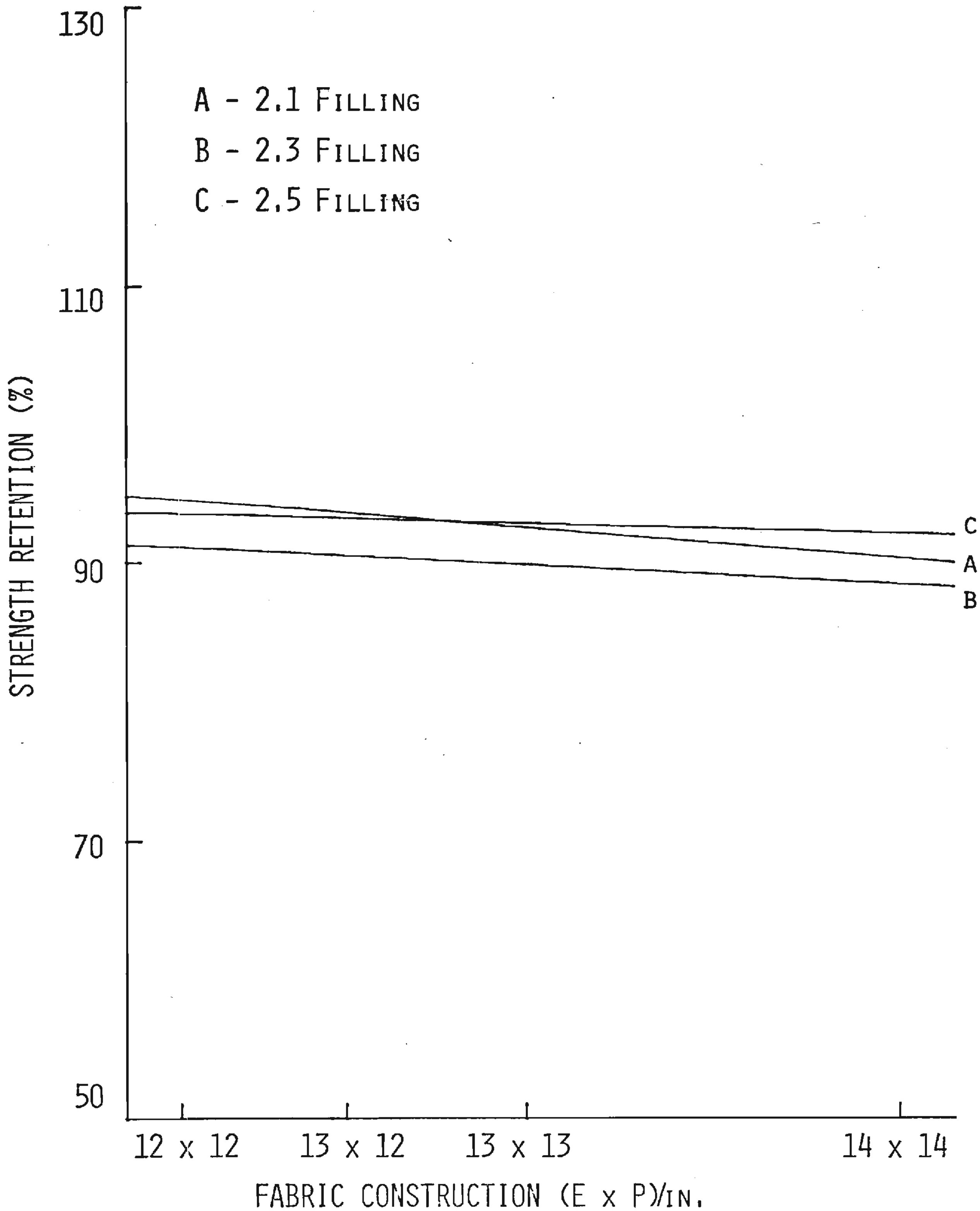


Figure 10. The Effect of Fabric Construction on Fillingwise Fabric Strength Retention - B M/C Gauge.

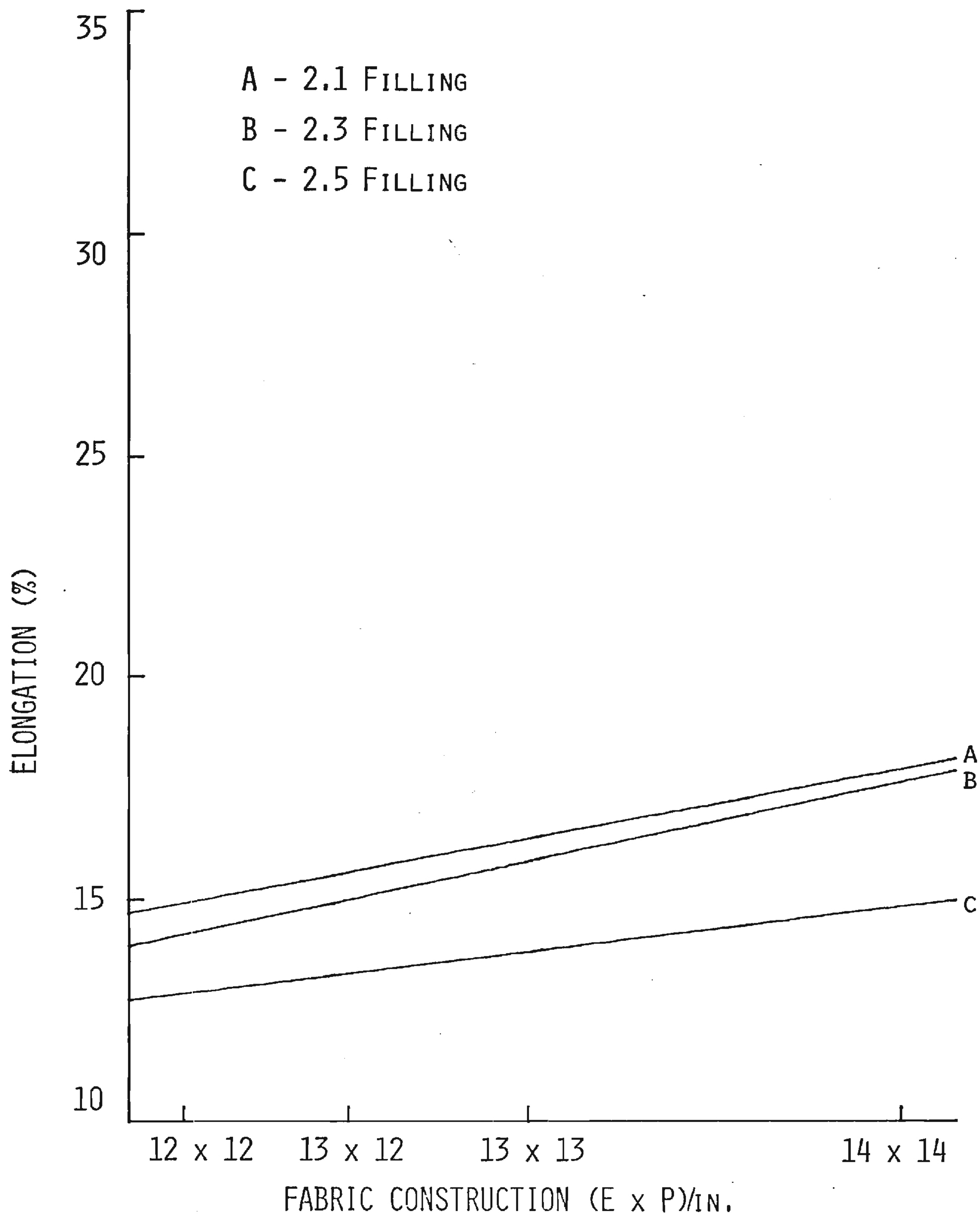


Figure 11. The Effect of Fabric Construction on Warpwise Untufted Fabric Elongation.

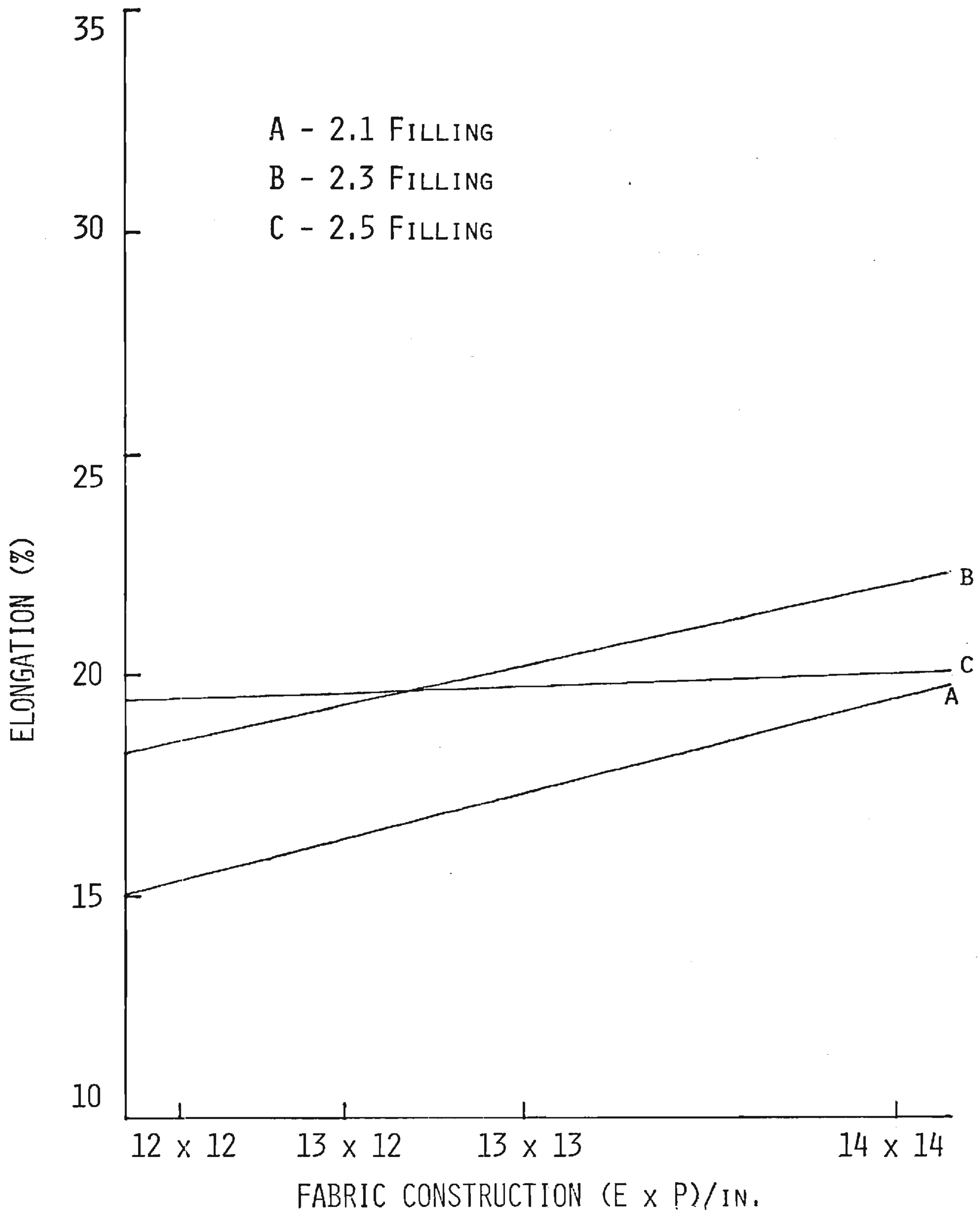


Figure 12. The Effect of Fabric Construction on Fillingwise Untufted Fabric Elongation.

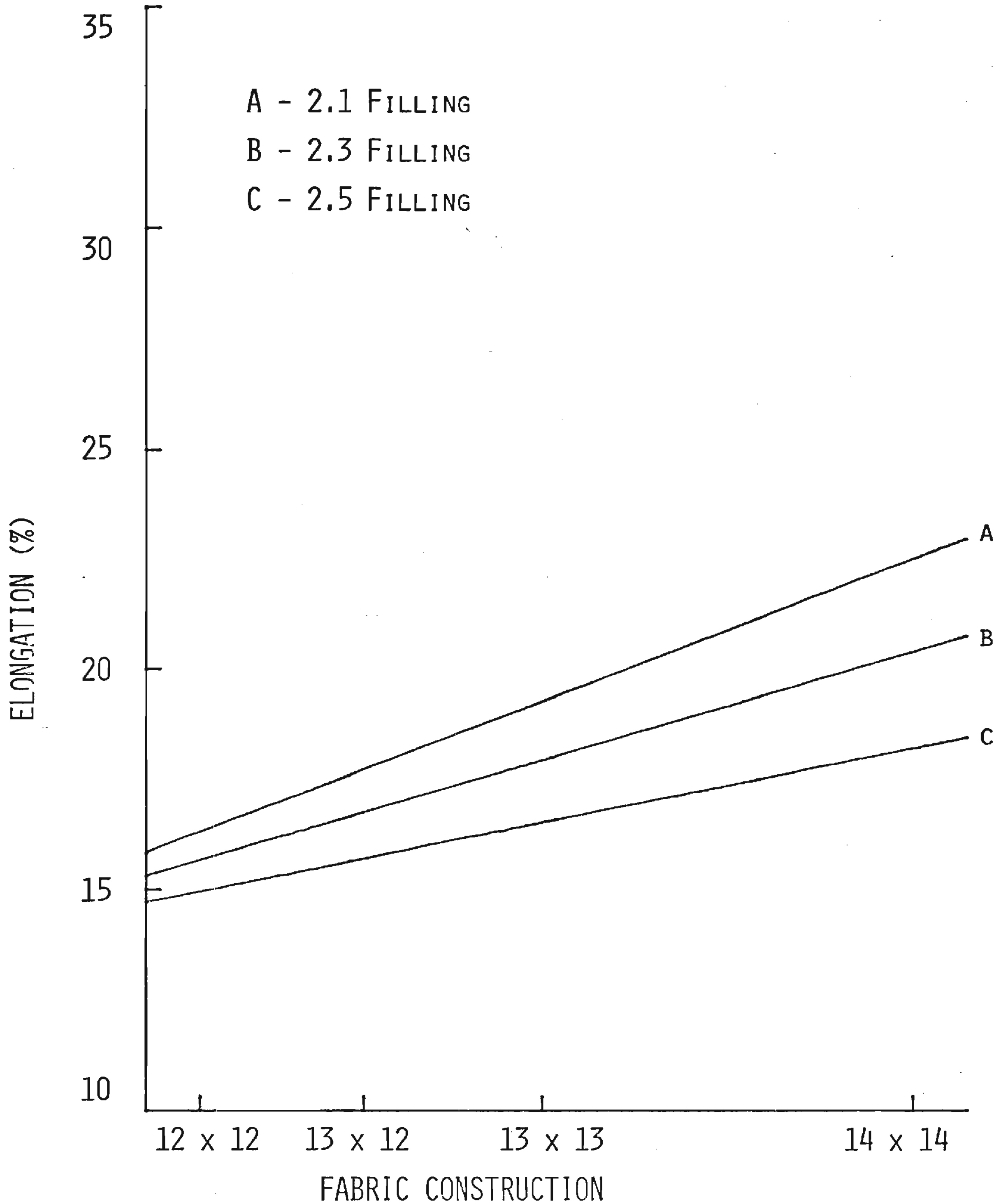


Figure 13. The Effect of Fabric Construction on Warpwise Tufted Fabric Elongation - A M/C Gauge.

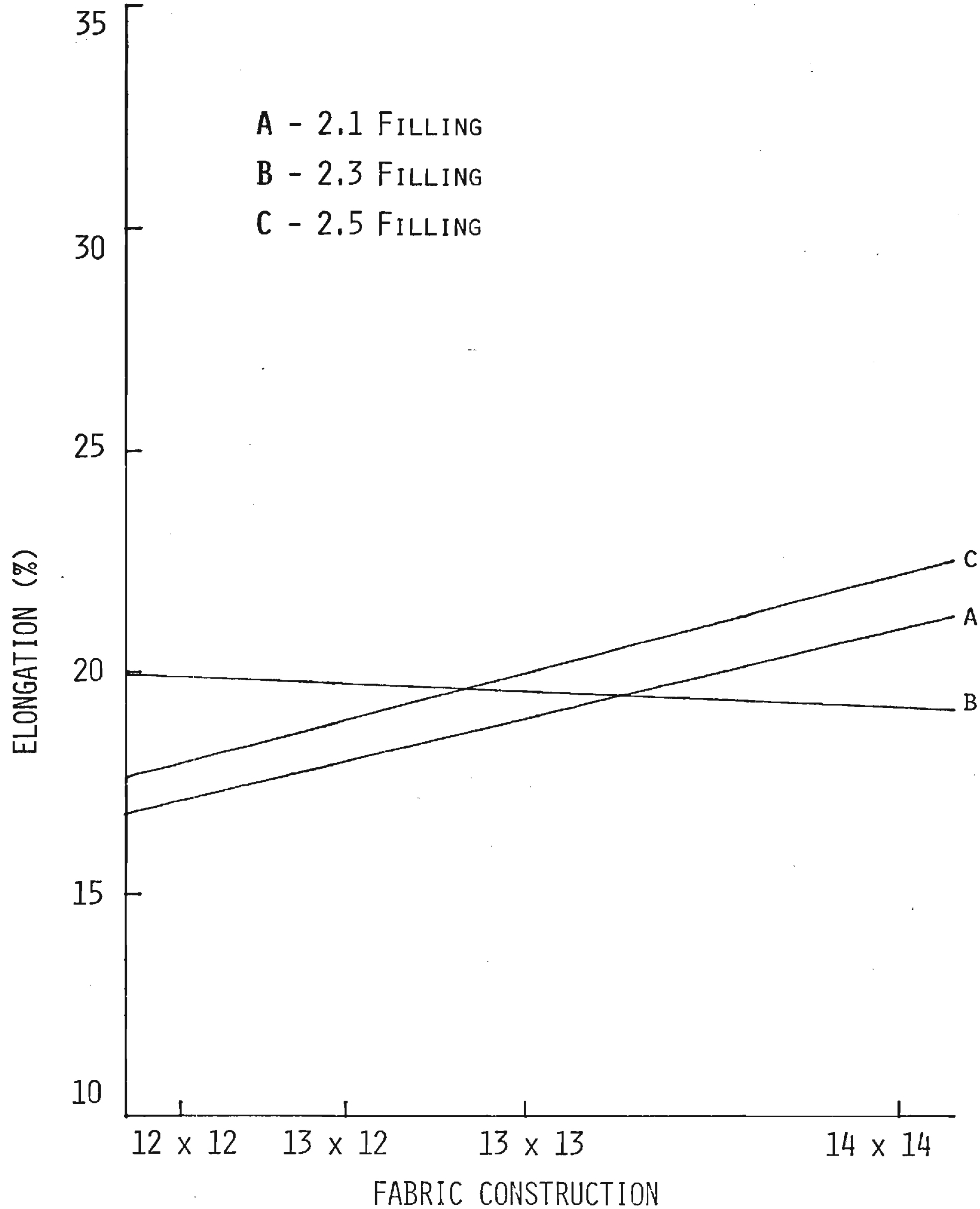


Figure 14. The Effect of Fabric Construction on Warpwise Tufted Fabric Elongation - B M/C Gauge.

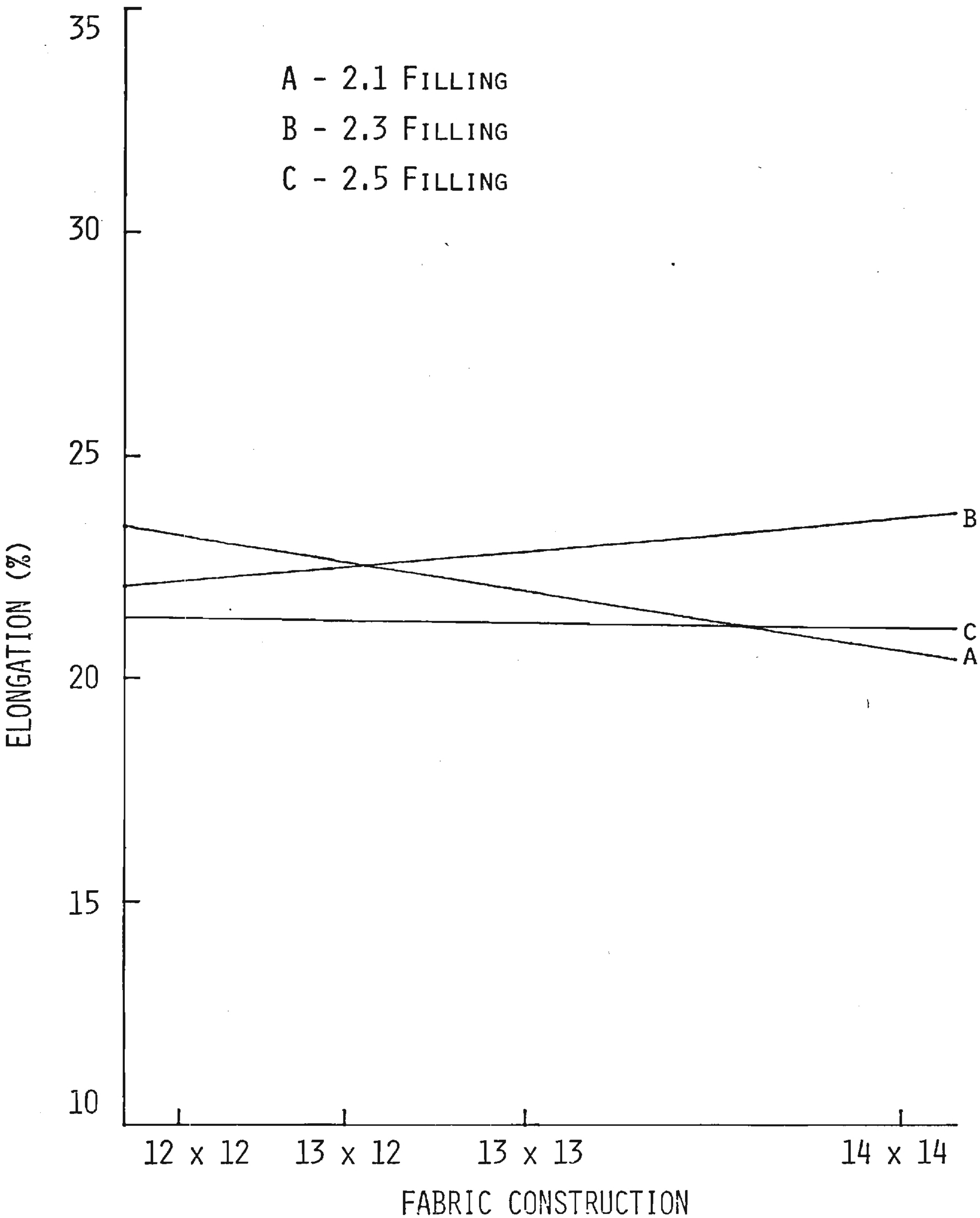


Figure 15. The Effect of Fabric Construction on Fillingwise Tufted Fabric Elongation - A M/C Gauge.

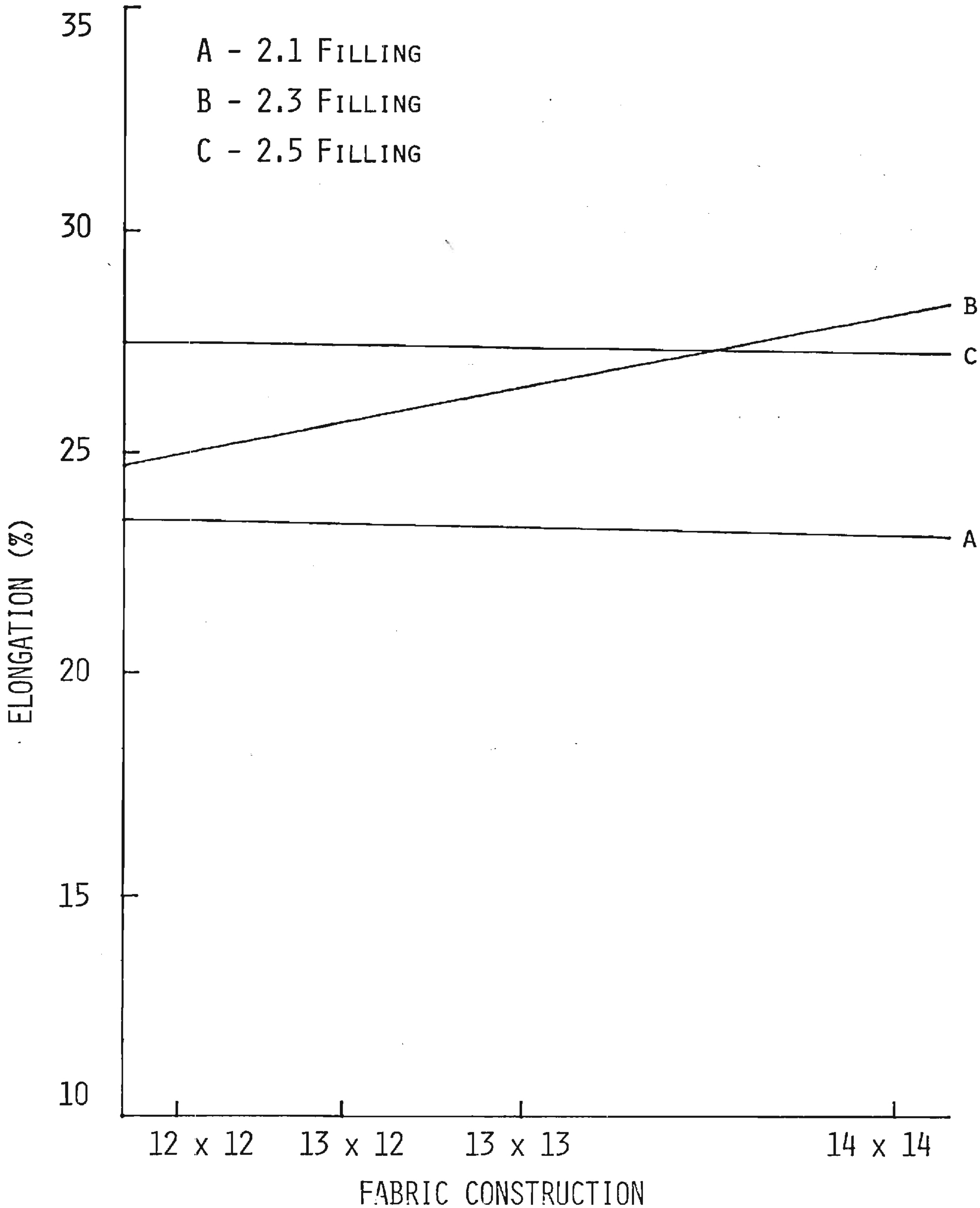


Figure 16. The Effect of Fabric Construction on Fillingwise Tufted Fabric Elongation - B M/C Gauge.

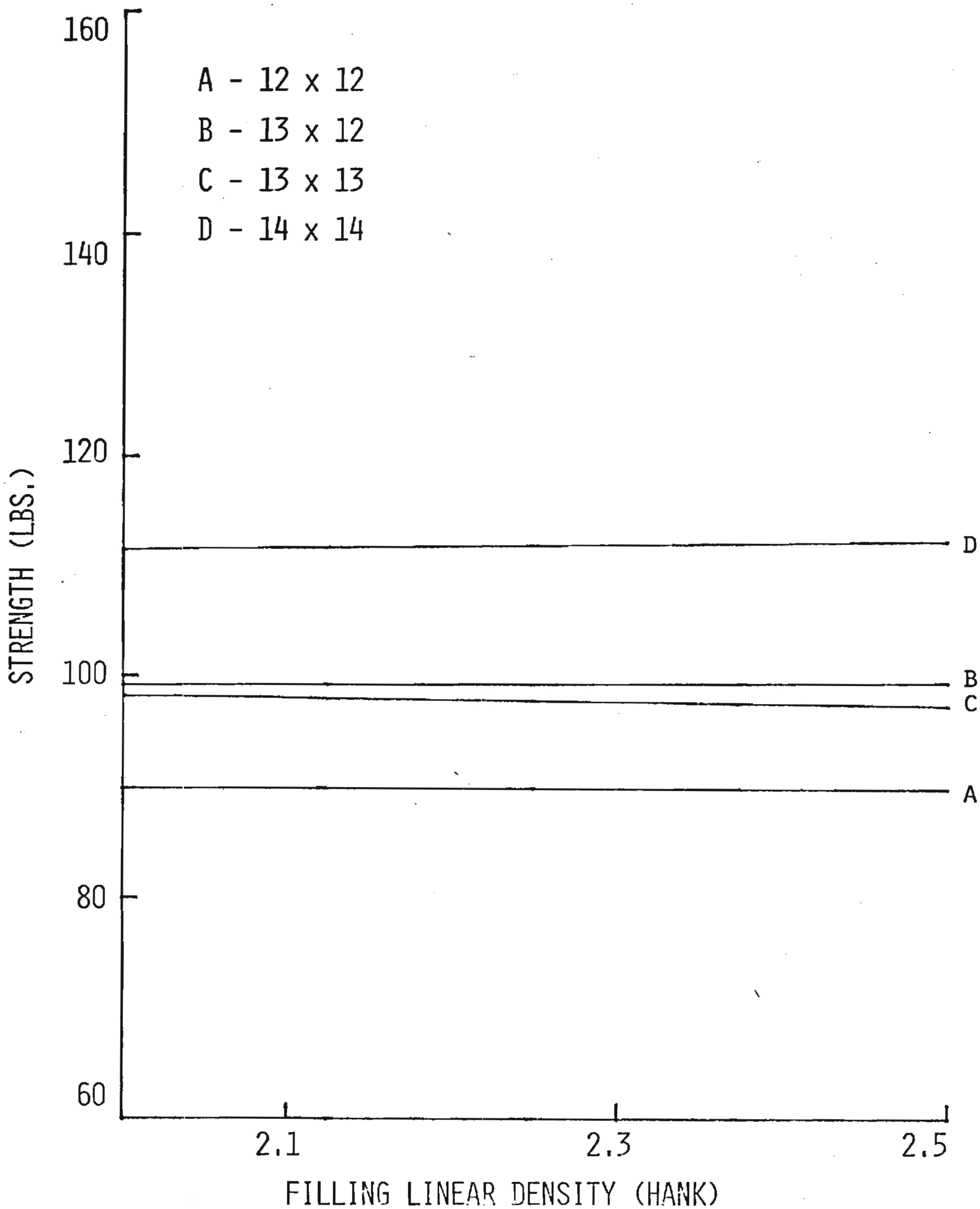


Figure 17. The Effect of Filling Linear Density on Warpwise Fabric Strength.

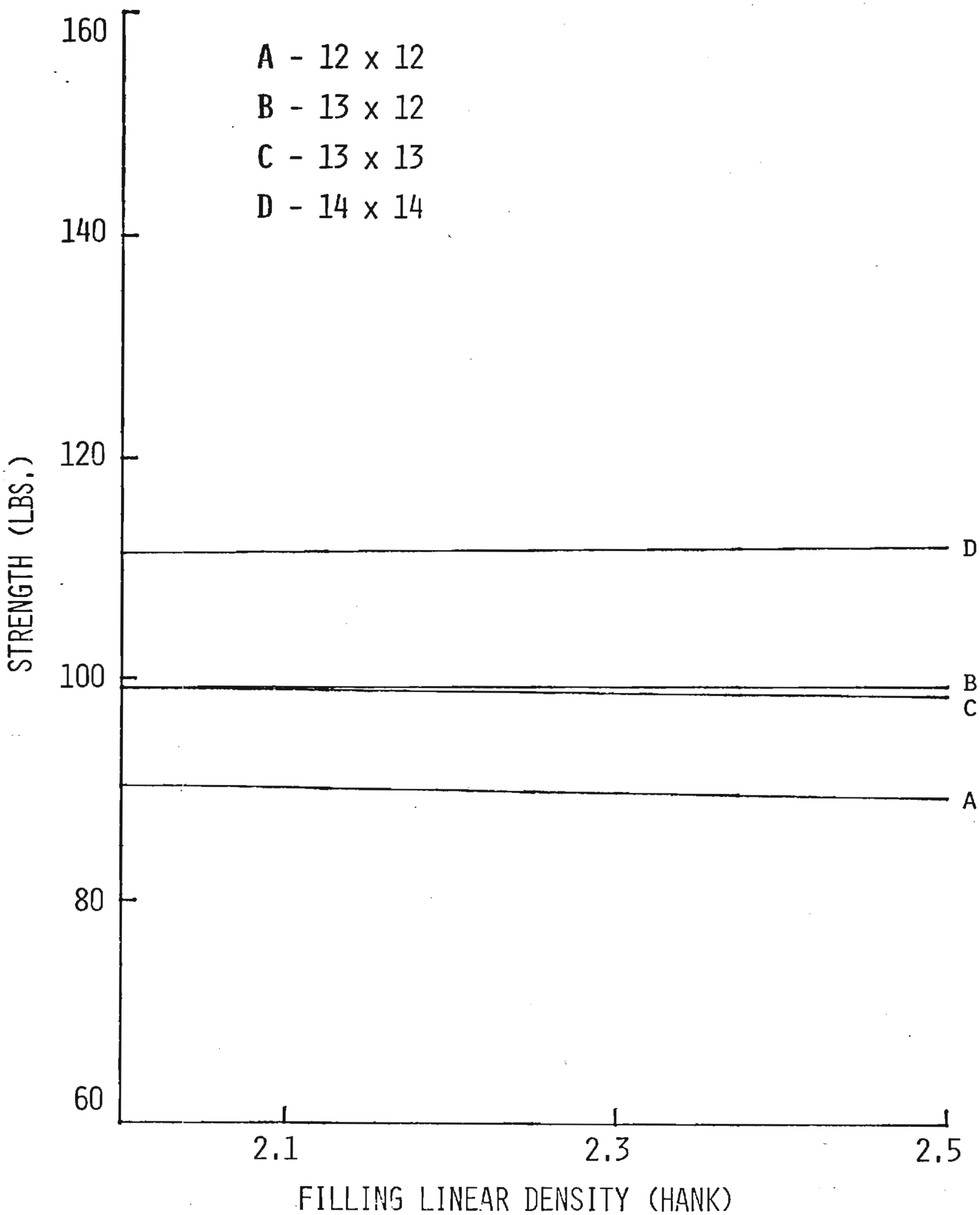


Figure 18. The Effect of Filling Linear Density on Fillingwise Fabric Strength.

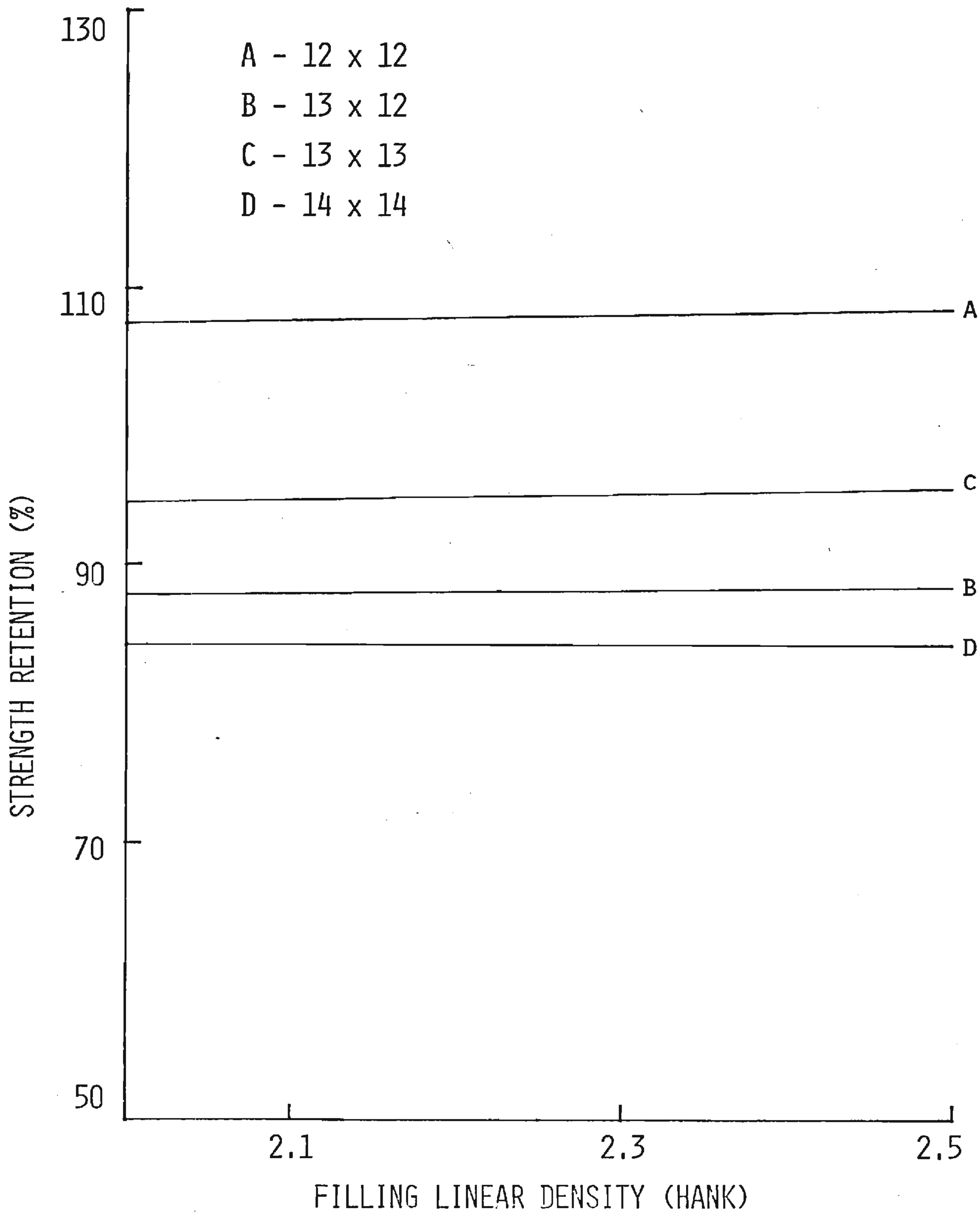


Figure 19. The Effect of Filling Linear Density on Warpwise Fabric Strength Retention - A M/C Gauge.

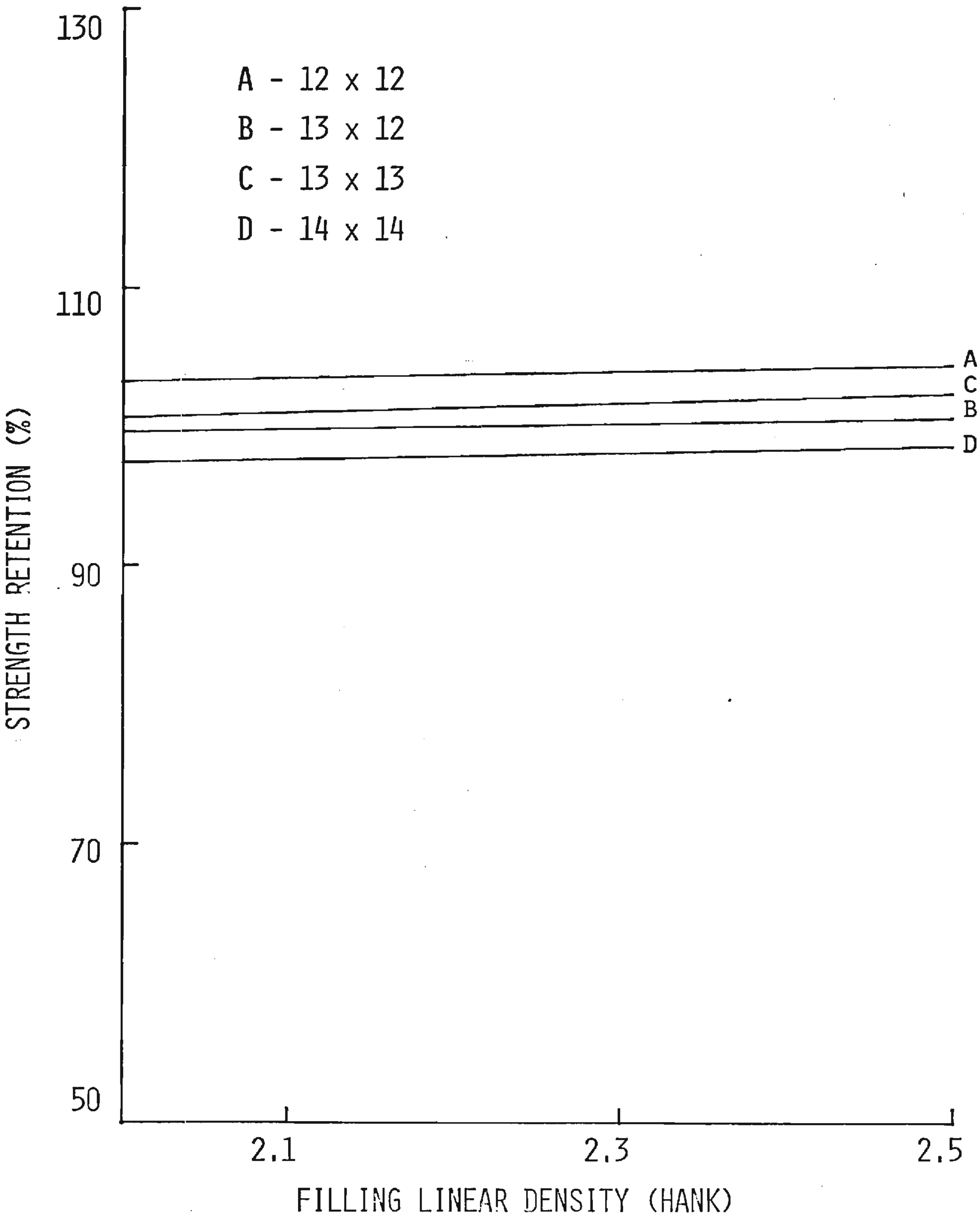


Figure 20. The Effect of Filling Linear Density on Warpwise Fabric Strength Retention - B M/C Gauge.

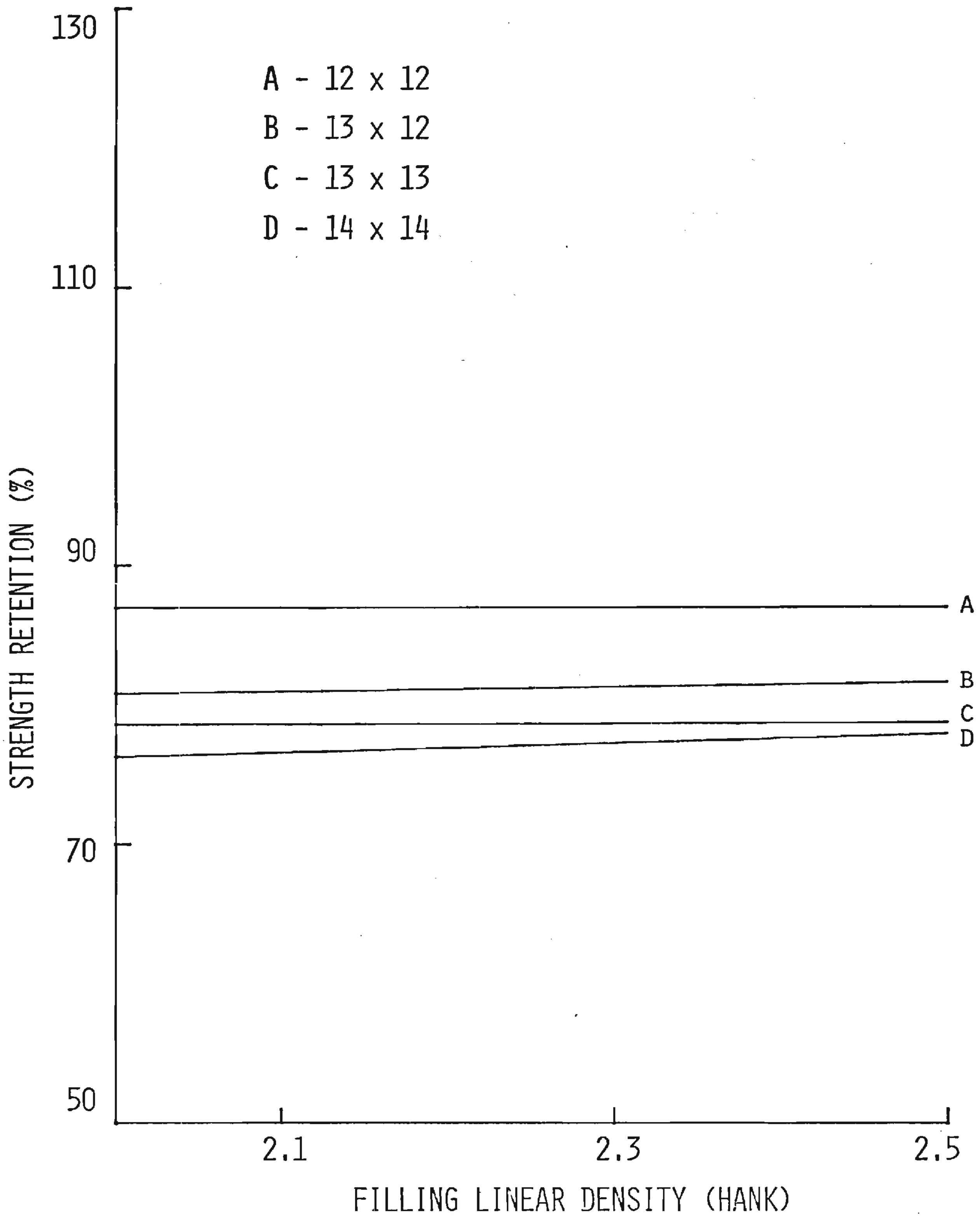


Figure 21. The Effect of Filling Linear Density on Fillingwise Fabric Strength Retention - A M/C Gauge.

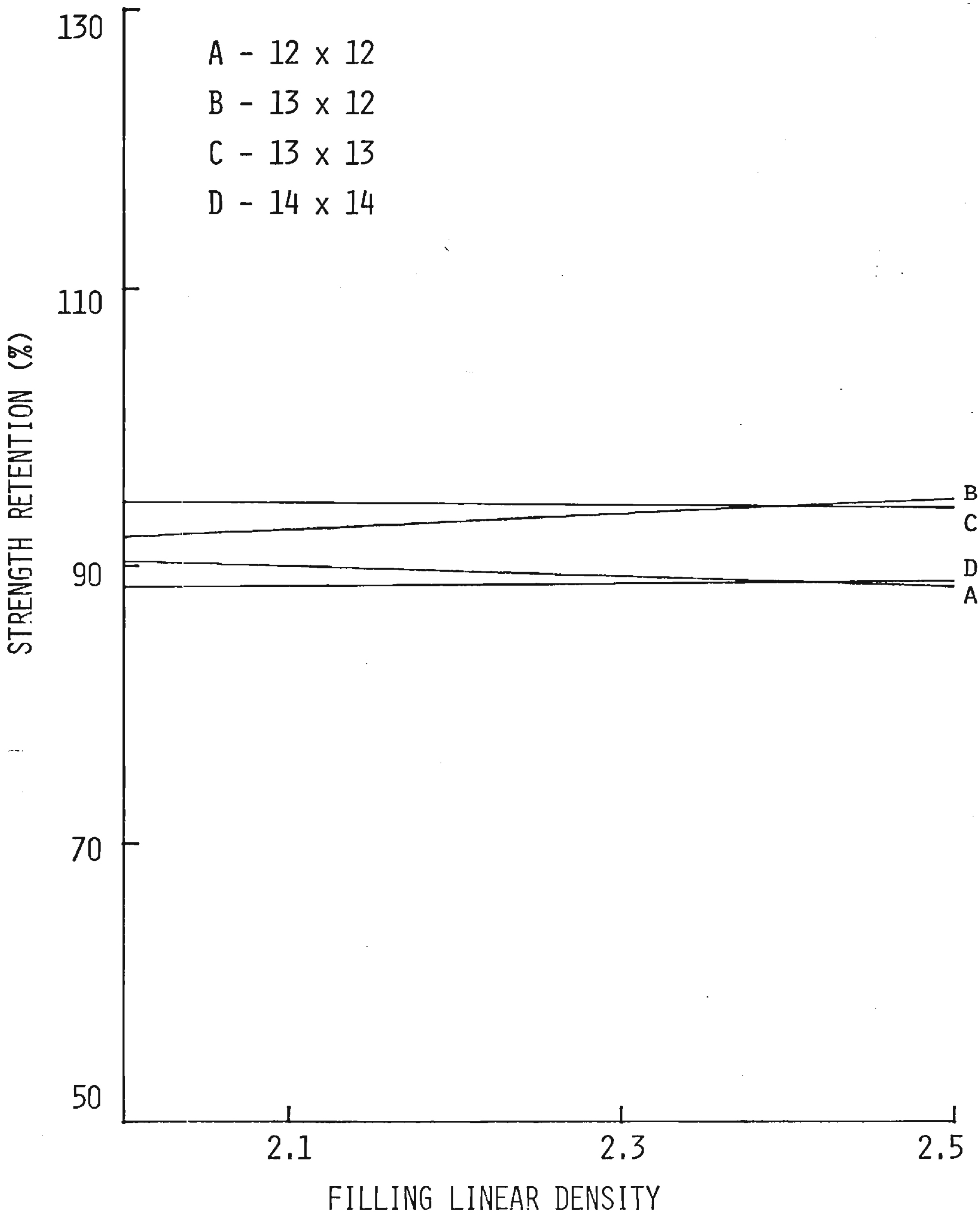


Figure 22. The Effect of Filling Linear Density on Fillingwise Fabric Strength Retention - B M/C Gauge.

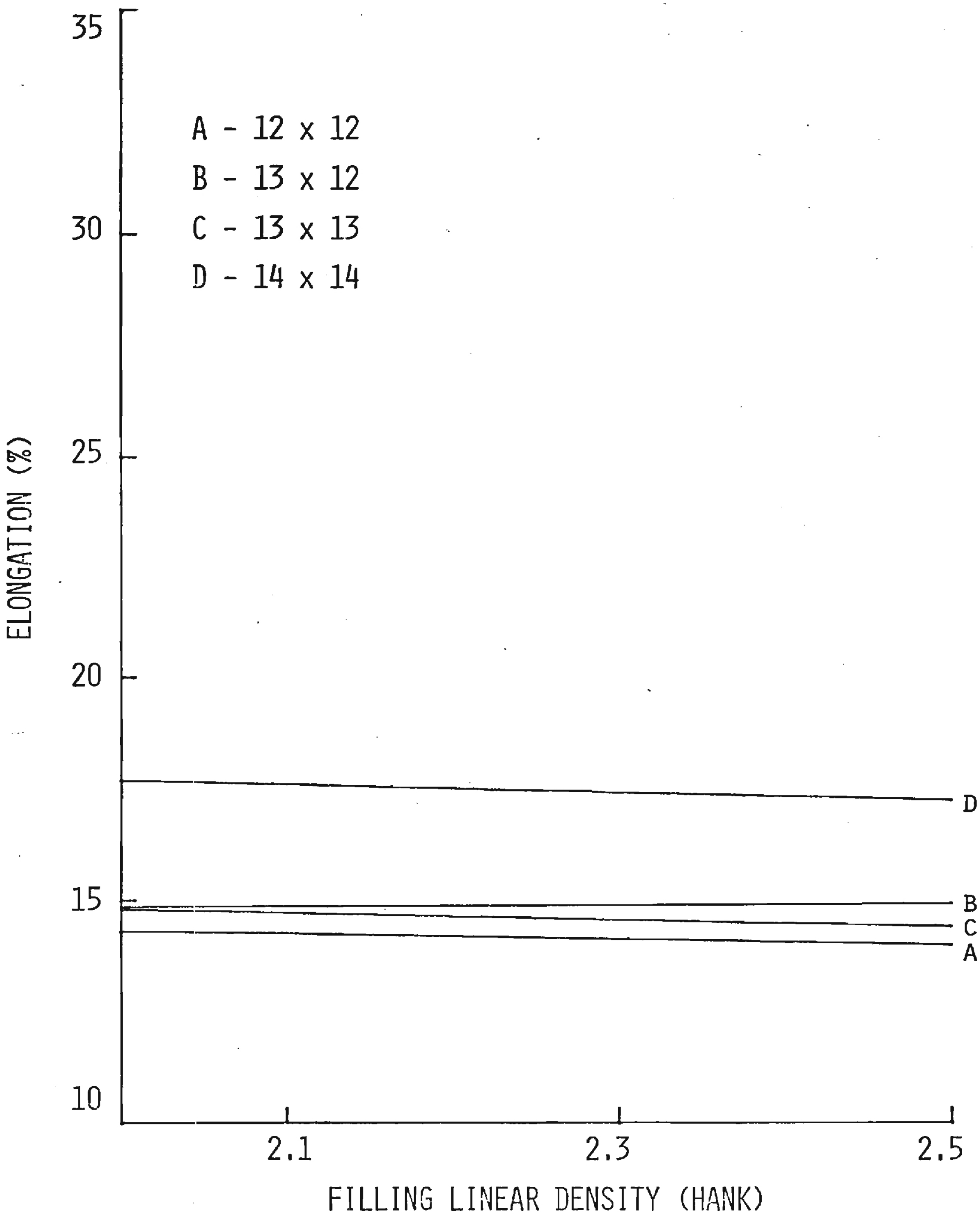


Figure 23. The Effect of Filling Linear Density on Warpwise Untufted Fabric Elongation.

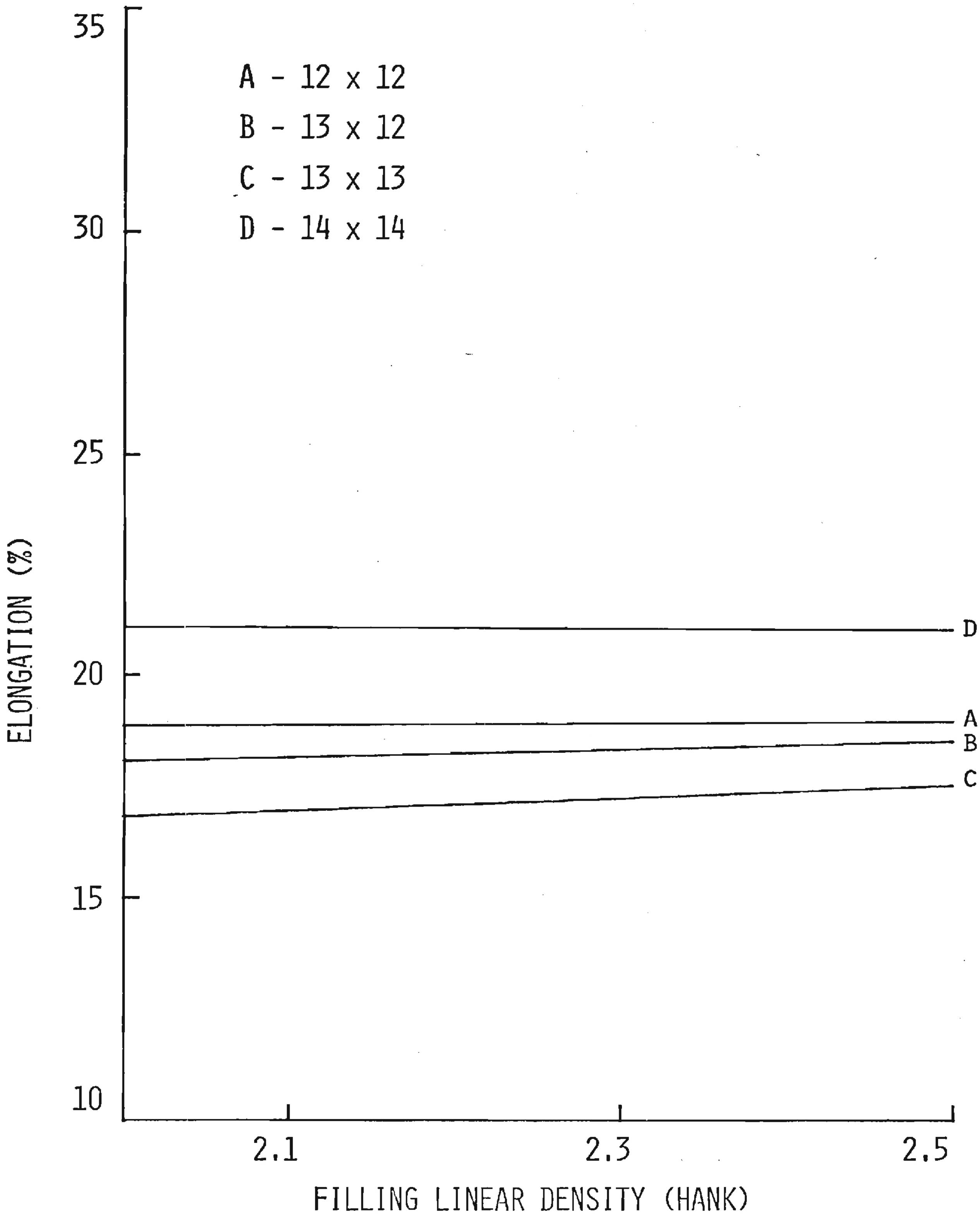


Figure 24. The Effect of Filling Linear Density on Fillingwise Untufted Fabric Elongation.

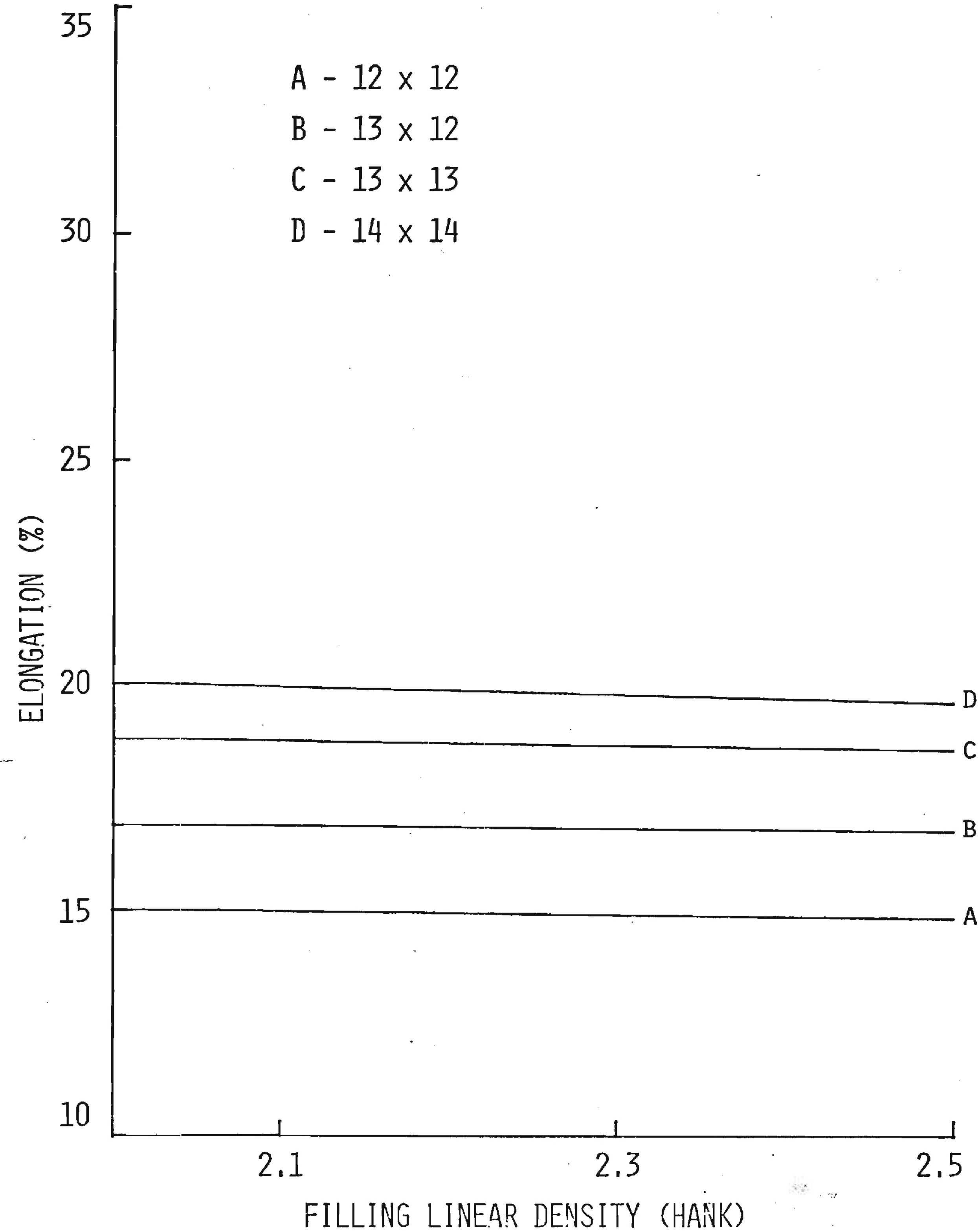


Figure 25. The Effect of Filling Linear Density on Warpwise Tufted Fabric Elongation - A M/C Gauge.

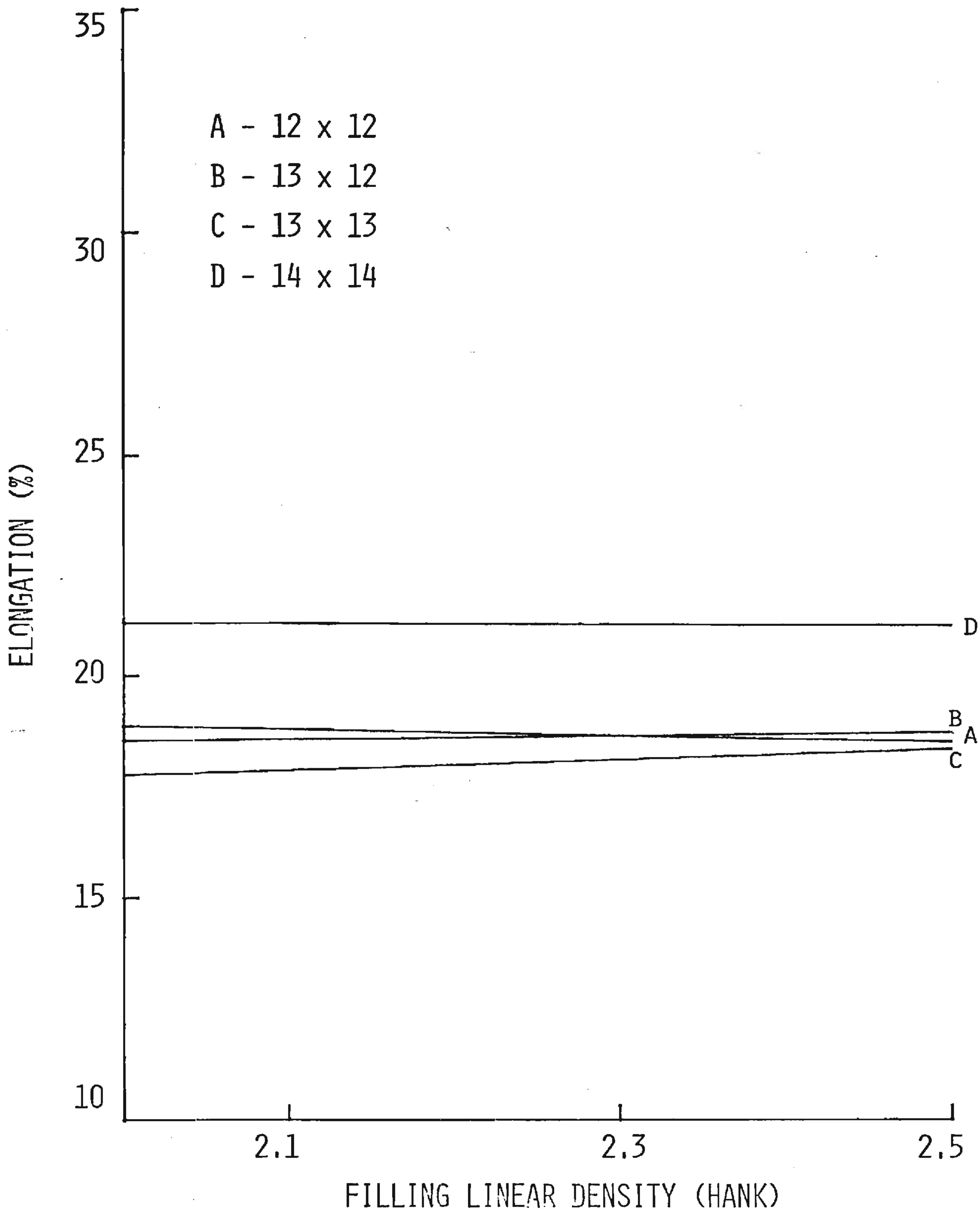


Figure 26. The Effect of Filling Linear Density on Warpwise Tufted Fabric Elongation - B M/C Gauge.

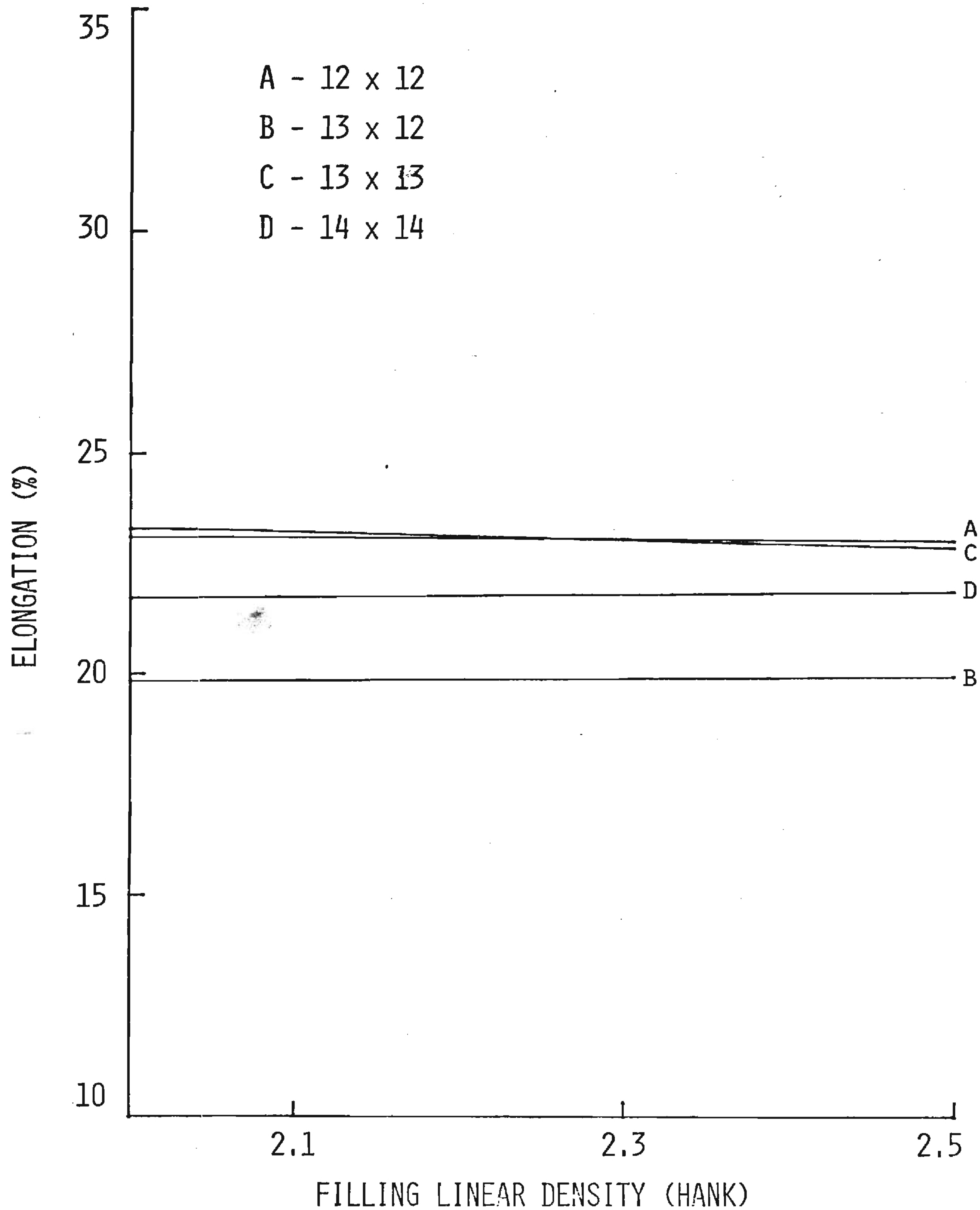


Figure 27. The Effect of Filling Linear Density on Fillingwise Tufted Fabric Elongation - A M/C Gauge.

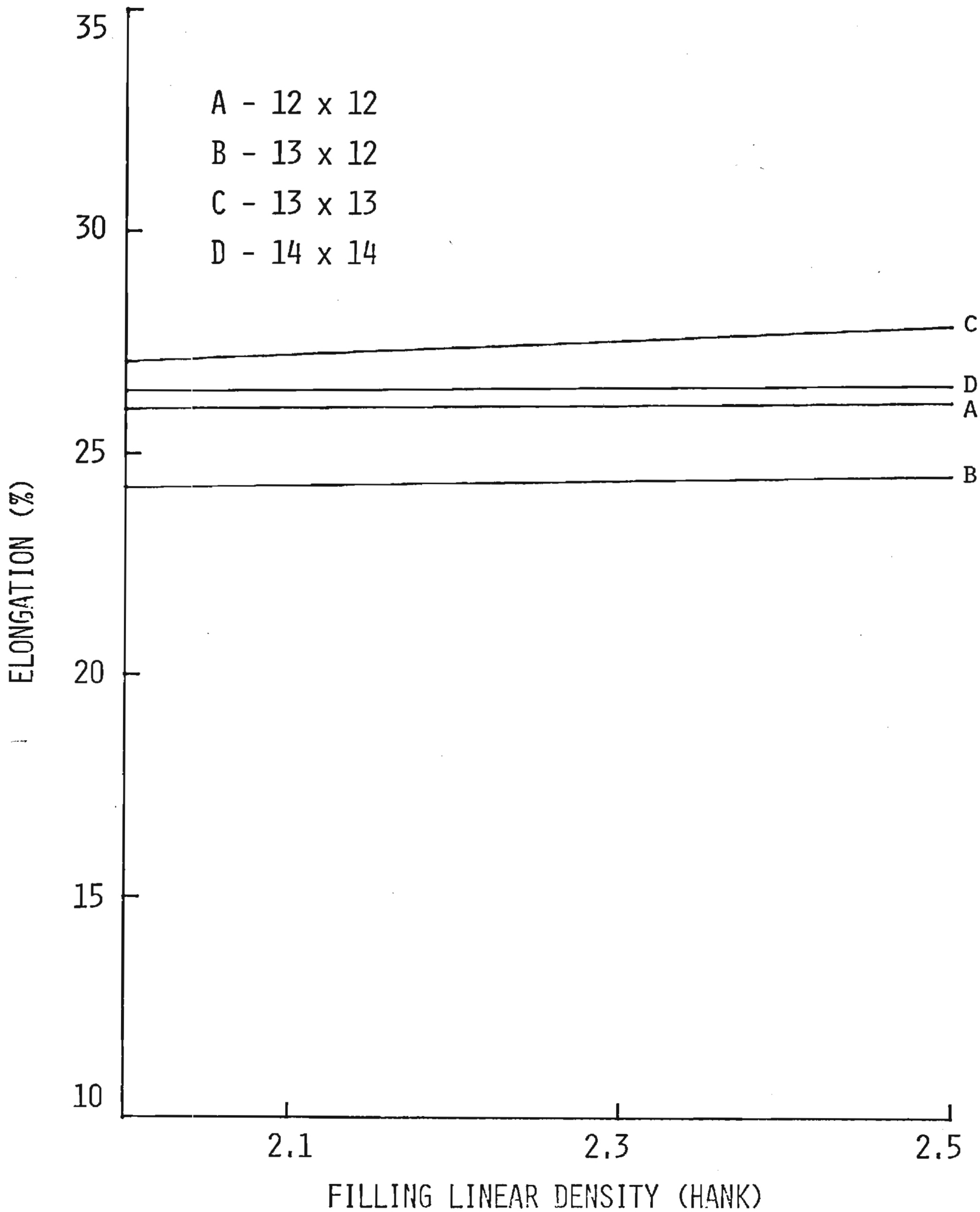


Figure 28. The Effect of Filling Linear Density on Fillingwise Tufted Fabric Elongation - B M/C Gauge.

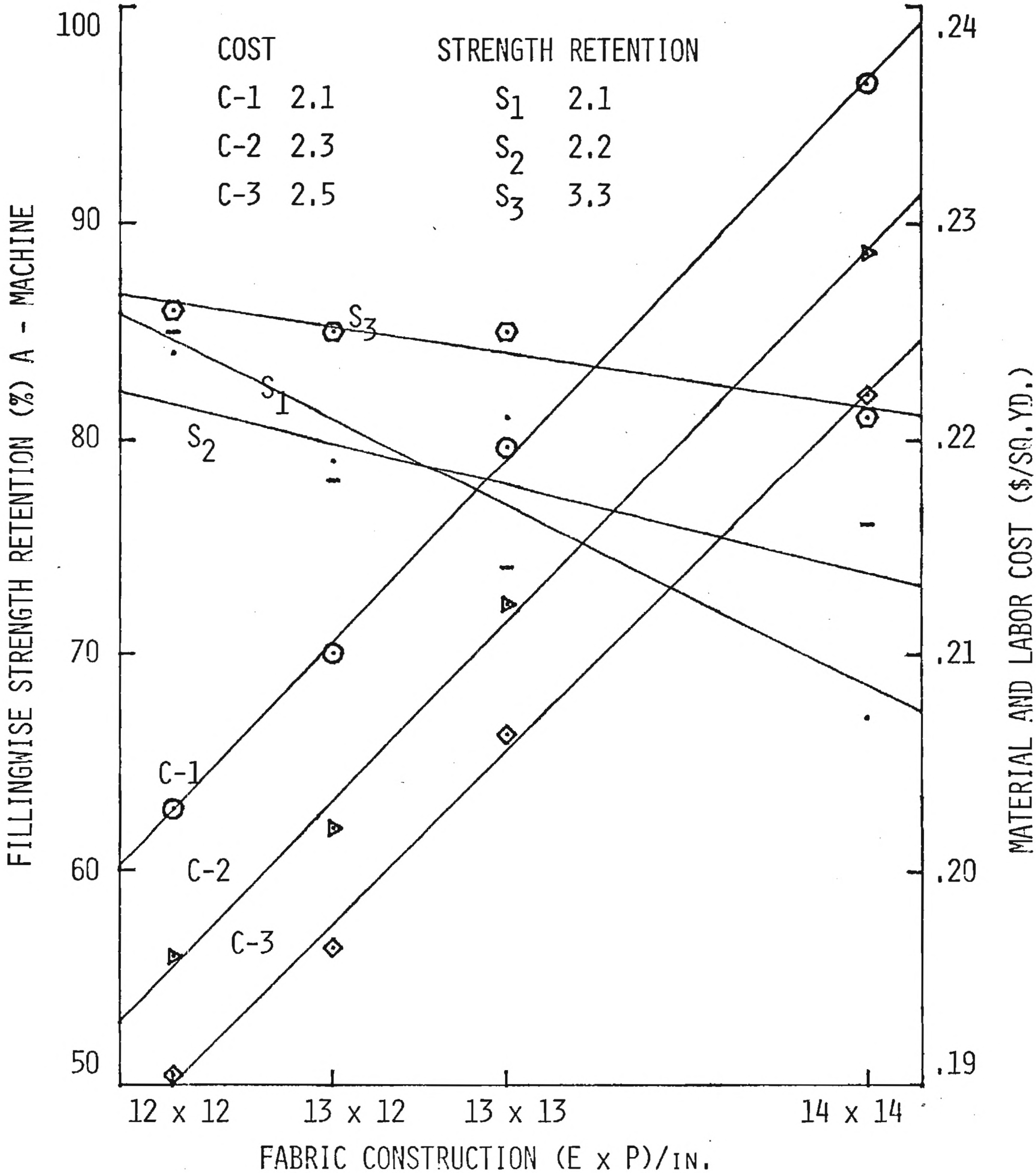


Figure 29. Relationship of the Cost of Fabric to Fillingwise Strength Retention (A - Machine).

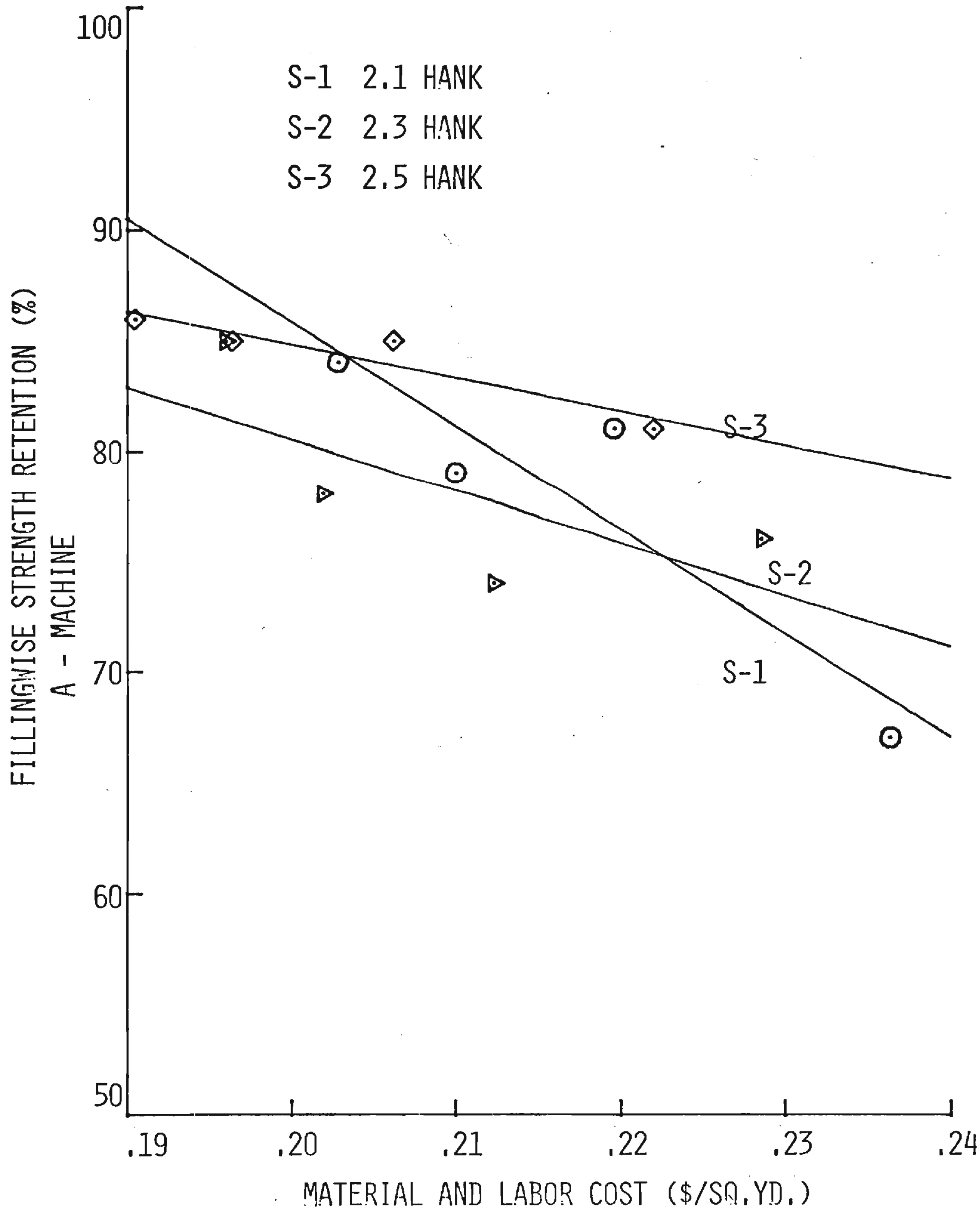


Figure 30. Direct Relationship of Cost to Fillingwise Strength Retention (A - Machine).

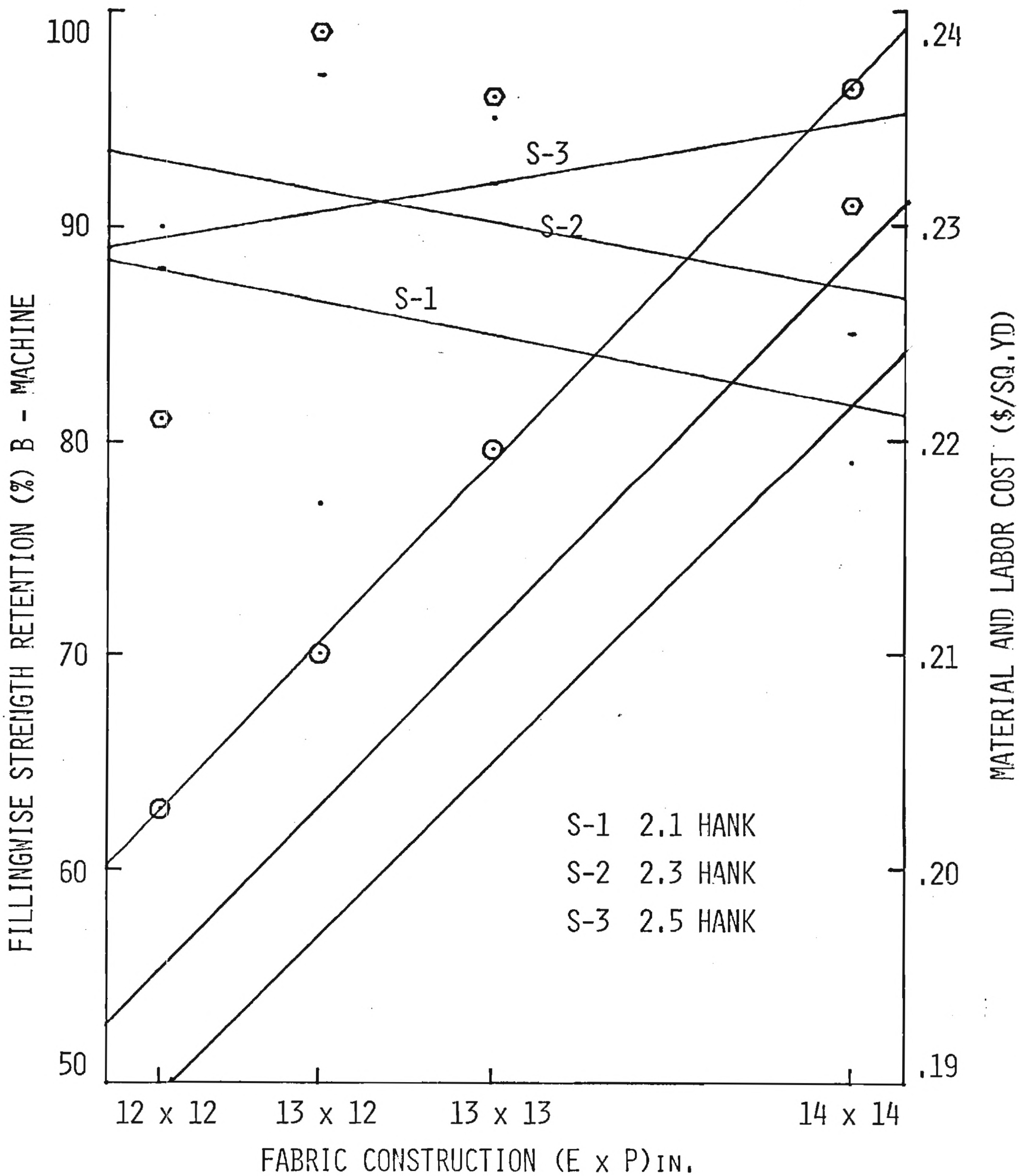


Figure 31. The Relationship of the Cost of Fabric to Fillingwise Strength Retention (B - Machine).

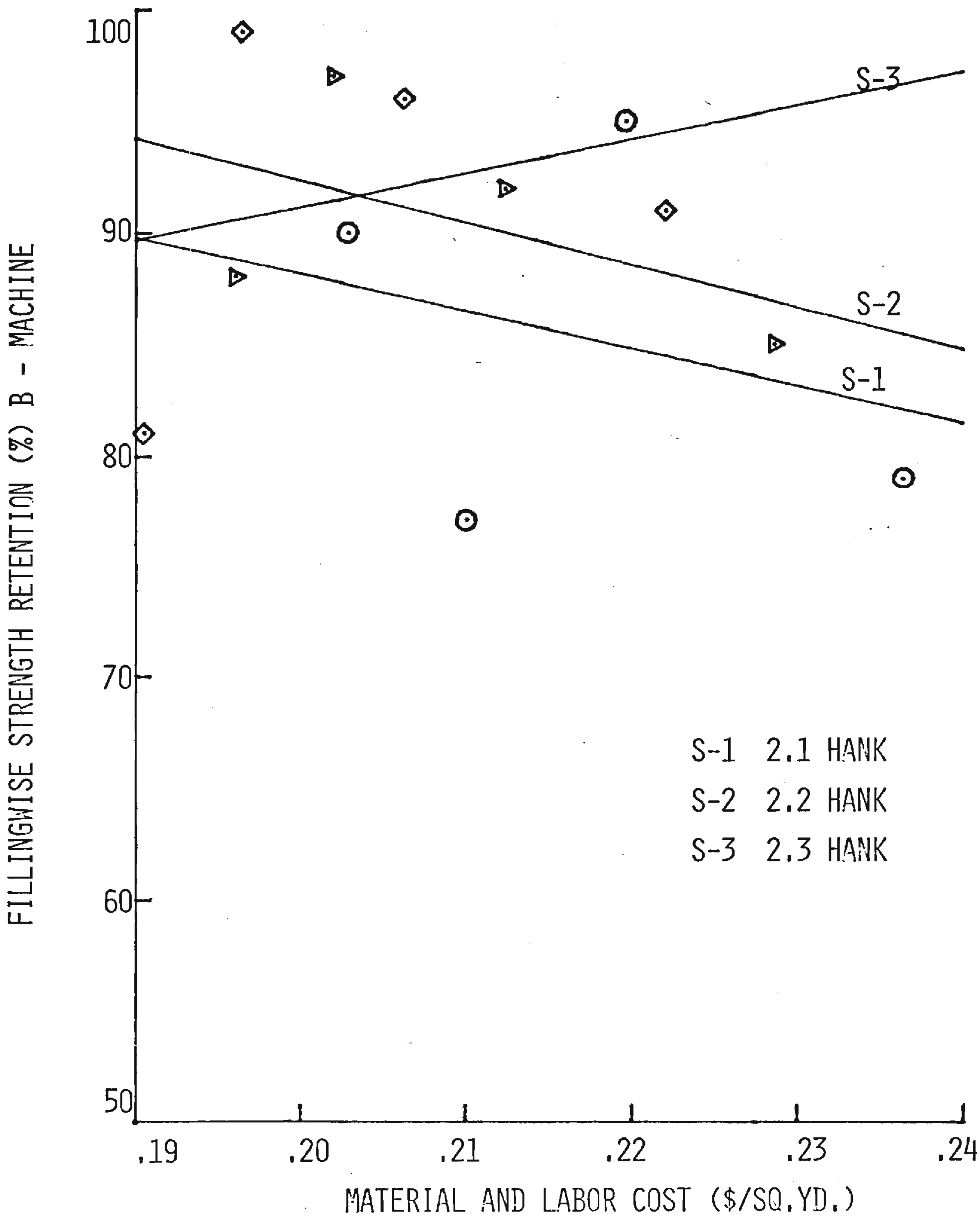


Figure 32. Direct Relationship of Cost to Fillingwise Strength Retention (B - Machine).

APPENDIX II

COMPUTER PRINTOUTS

PRINTOUT I

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TWS
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
SE	1	.50000	.51299
C	2	165.25000	19.71340
D	3	2.30000	.15894
CD	4	390.07998	54.75877
TWS	5	100.53050	7.13917

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	.711	-.000	-.000	.036
2		388.618	.204	951.978	102.644
3			.025	4.296	.532
4				2998.522	318.219
5					50.968

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.070	-.000	-.000	.010
2		1.000	.091	0.892	.799 ✓
3			1.000	.492	.469
4				1.000	.814 ✓
5					1.000

```
SUB-PROBLEM    1
 DEPENDENT VARIABLE                 5
 MAXIMUM NUMBER OF STEPS           10
 F-LEVEL FOR INCLUSION        .010000
 F-LEVEL FOR DELETION         .005000
 TOLERANCE LEVEL              .001000


  STEP NUMBER    1
  VARIABLE ENTERED     4

  MULTIPLE R                 .8140
  STD. ERROR OF EST.        4.2605

  ANALYSIS OF VARIANCE
                              DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
              REGRESSION       1         641.649        641.649       35.348
              RESIDUAL        18         326.738         18.152

               VARIABLES IN EQUATION                 .             VARIABLES NOT IN EQUATION
    VARIABLE        COEFFICIENT  STD. ERROR  F TO REMOVE .    VARIABLE     PARTIAL CORR.     TOLERANCE     F TO ENTER
                                                     .
   (CONSTANT         59.14120 )                          .
  CD       4           .10613      .01785     35.3484 .    MC       1          .01670          1.0000         .0047
                                                     .    C        2          .04190          .2223          .0299
                                                     .    D        3          .13424          .7575          .3120


  STEP NUMBER    2
  VARIABLE ENTERED     3

  MULTIPLE R                 .8177
  STD. ERROR OF EST.        4.3444

  ANALYSIS OF VARIANCE
                              DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
              REGRESSION       2         647.537        323.769       17.155
              RESIDUAL        17         320.850         18.874

               VARIABLES IN EQUATION                 .             VARIABLES NOT IN EQUATION
    VARIABLE        COEFFICIENT  STD. ERROR  F TO REMOVE .    VARIABLE     PARTIAL CORR.     TOLERANCE     F TO ENTER
                                                     .
   (CONSTANT         52.12939 )                          .
  D        3          4.02425     7.20485       .3120 .    MC       1          .01595          1.0000         .0045
  CD       4           .10037      .02091     23.0357 .    C        2          .29489          .0664         1.4134
```

STEP NUMBER 3
VARIABLE ENTERED 2

MULTIPLE R .8340
STD. ERROR OF EST. 4.2925

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	673.579	224.526	12.186
RESIDUAL	16	294.809	18.426	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION				
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		19.30545)							
C	2	.23945	.19384	1.4134	MC	1	-.06595	.9257	.0655
D	3	16.90955	13.02359	1.7018					
CD	4	.00868	.07935	.0118					

STEP NUMBER 4
VARIABLE ENTERED 1

MULTIPLE R .8348
STD. ERROR OF EST. 4.4236

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	674.861	168.715	8.622
RESIDUAL	15	293.526	19.568	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION	PARTIAL CORR.	TOLERANCE	F TO ENTER
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		17.50475)						
MC	1	-.52033	2.05620	.0655				
C	2	.24494	.20763	1.3917				
D	3	17.80477	13.79411	1.6660				
CD	4	.00291	.08532	.0012				

STEP NUMBER 5
VARIABLE REMOVED 4

MULTIPLE R .8348

STD. ERROR OF EST. 4.2833

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	674.838	224.946	12.261
RESIDUAL	16	293.549	18.347	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION				
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		16.53697)							
MC	1	-.54485	1.92034	.0805	CD	4	.00881	.0472	.0012
C	2	.25180	.05018	25.1801					
D	3	18.22145	6.20816	8.6147					

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

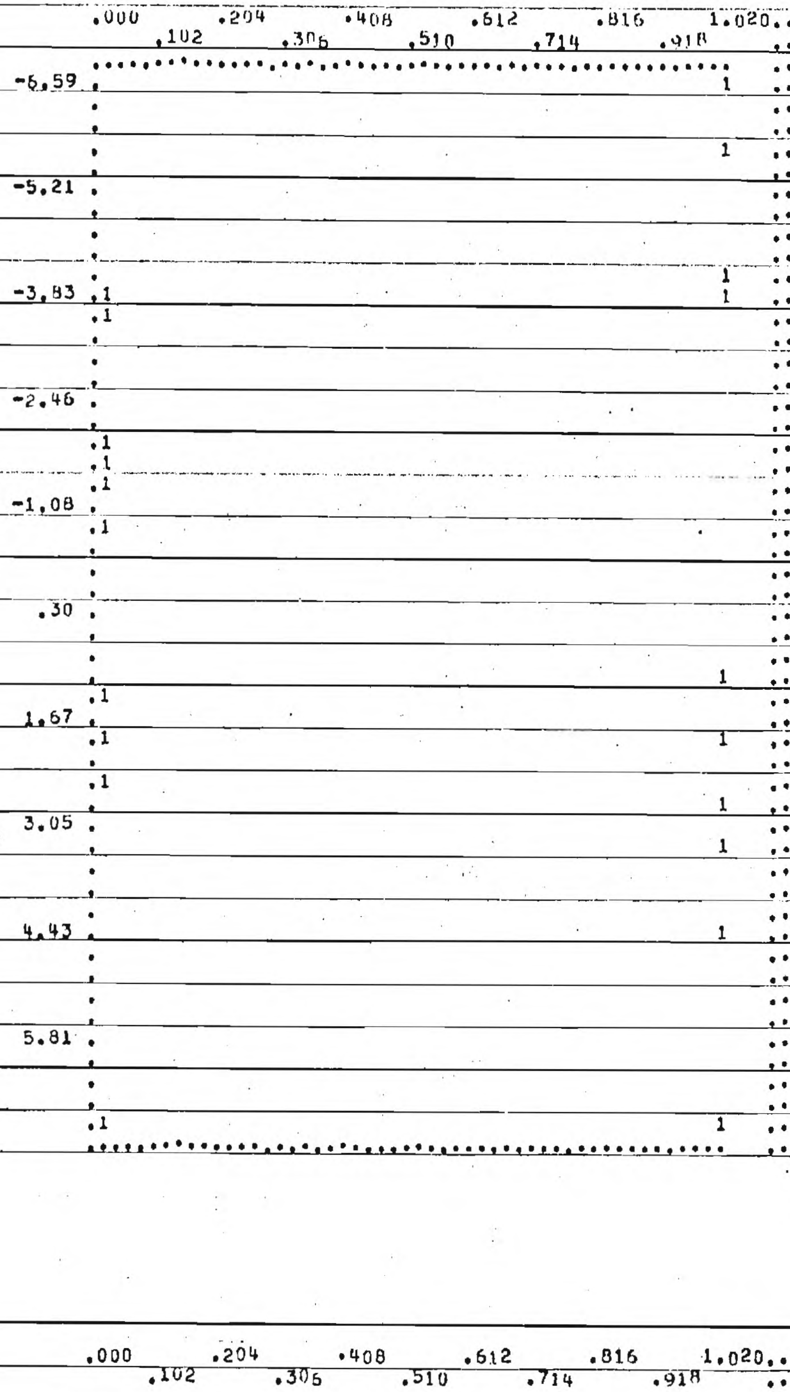
SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED		VARIABLE REMOVED		MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	CD	4			.8140	.6626	.6626	35.3484	1
2	D	3			.8177	.6687	.0061	.3120	2
3	C	2			.8340	.6956	.0269	1.4134	3
4	MC	1			.8348	.6969	.0013	.0655	4
5			CD	4	.8348	.6969	-.0000	.0012	3

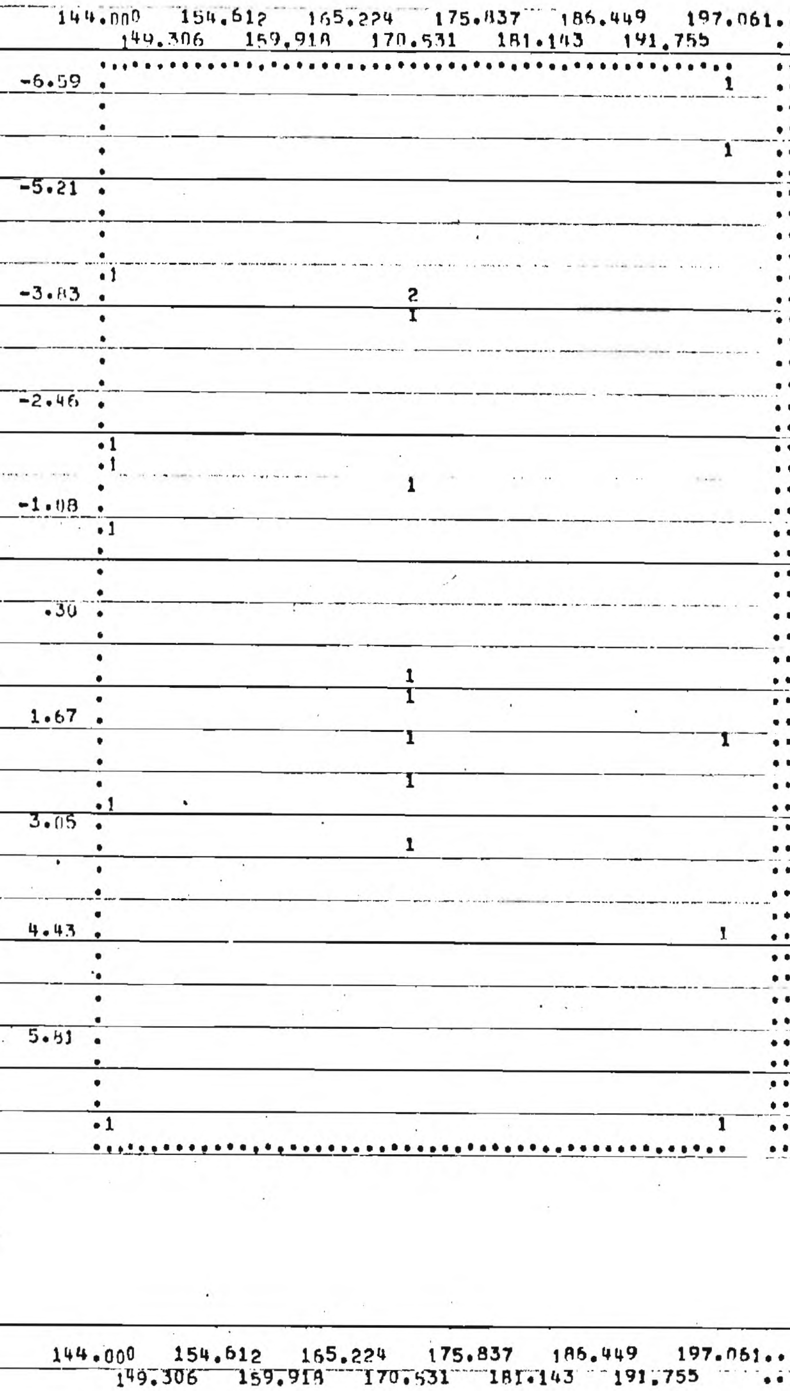
LIST OF RESIDUALS

CASE	RESIDUAL
1	-5.79769
2	2.83426
3	4.47660
4	6.76997
5	1.85079
6	3.31937
7	-3.85492
8	.99508
9	-6.56911
10	-4.00432
11	-1.28548
12	-1.84917
13	6.90746
14	-.86059
15	2.08175
16	-1.72488
17	-3.49406
18	-3.80548
19	2.58023
20	1.45023

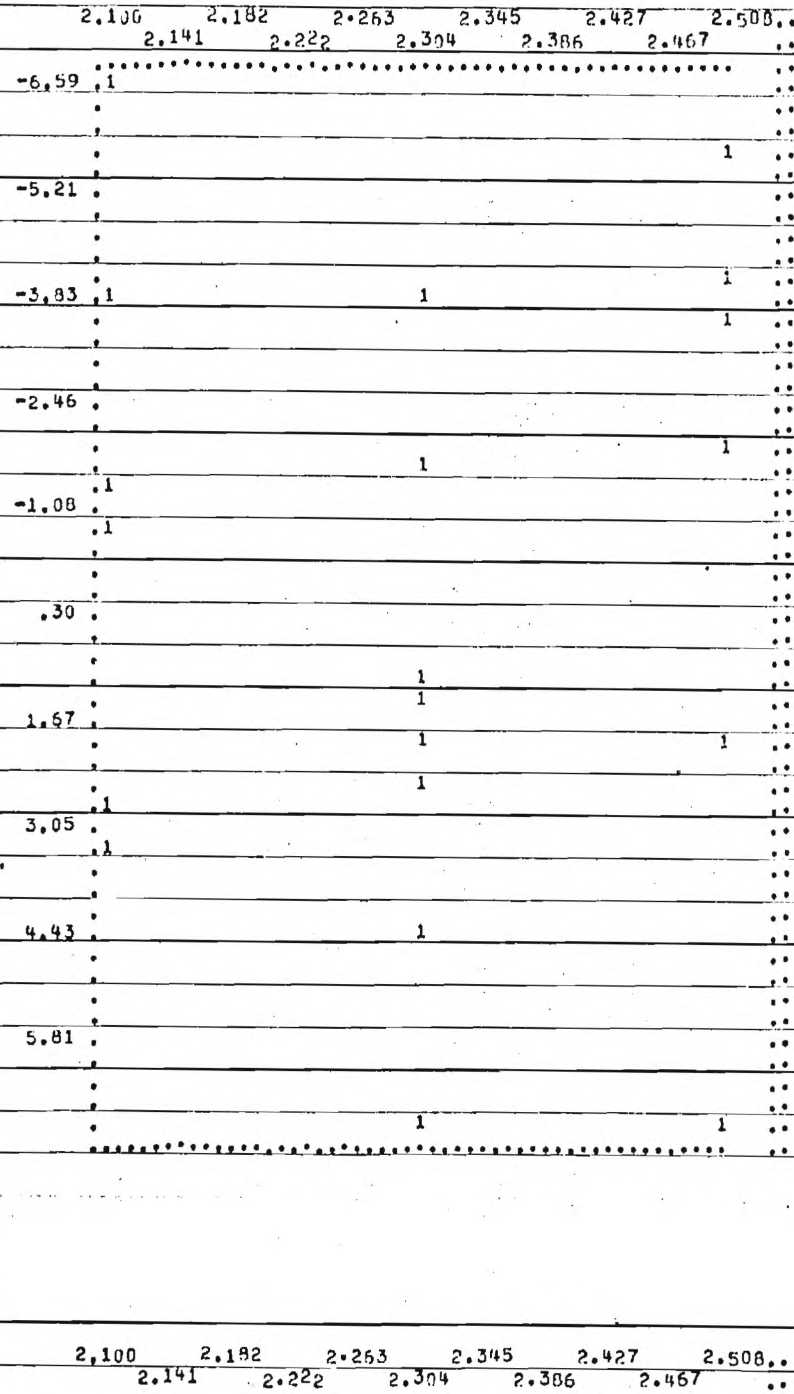
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)



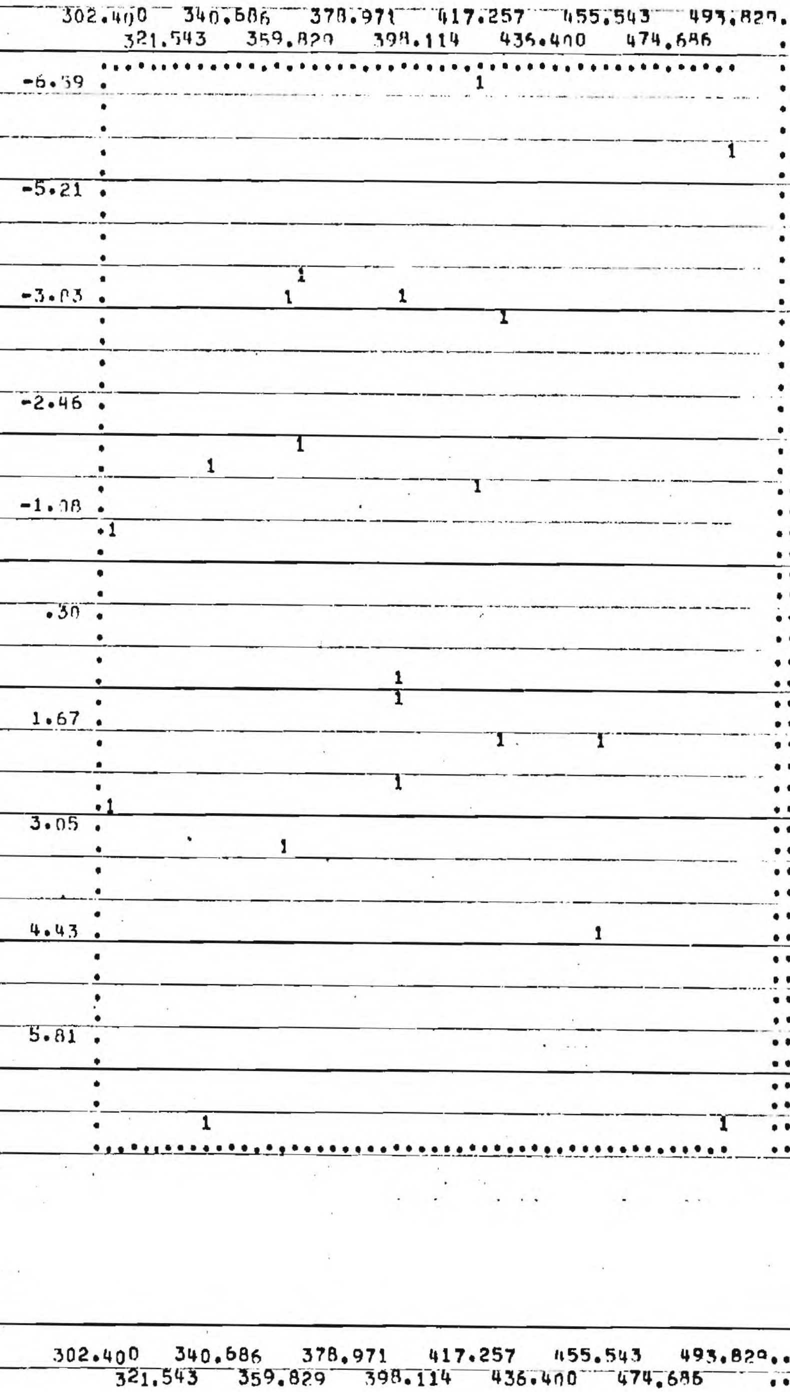
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)



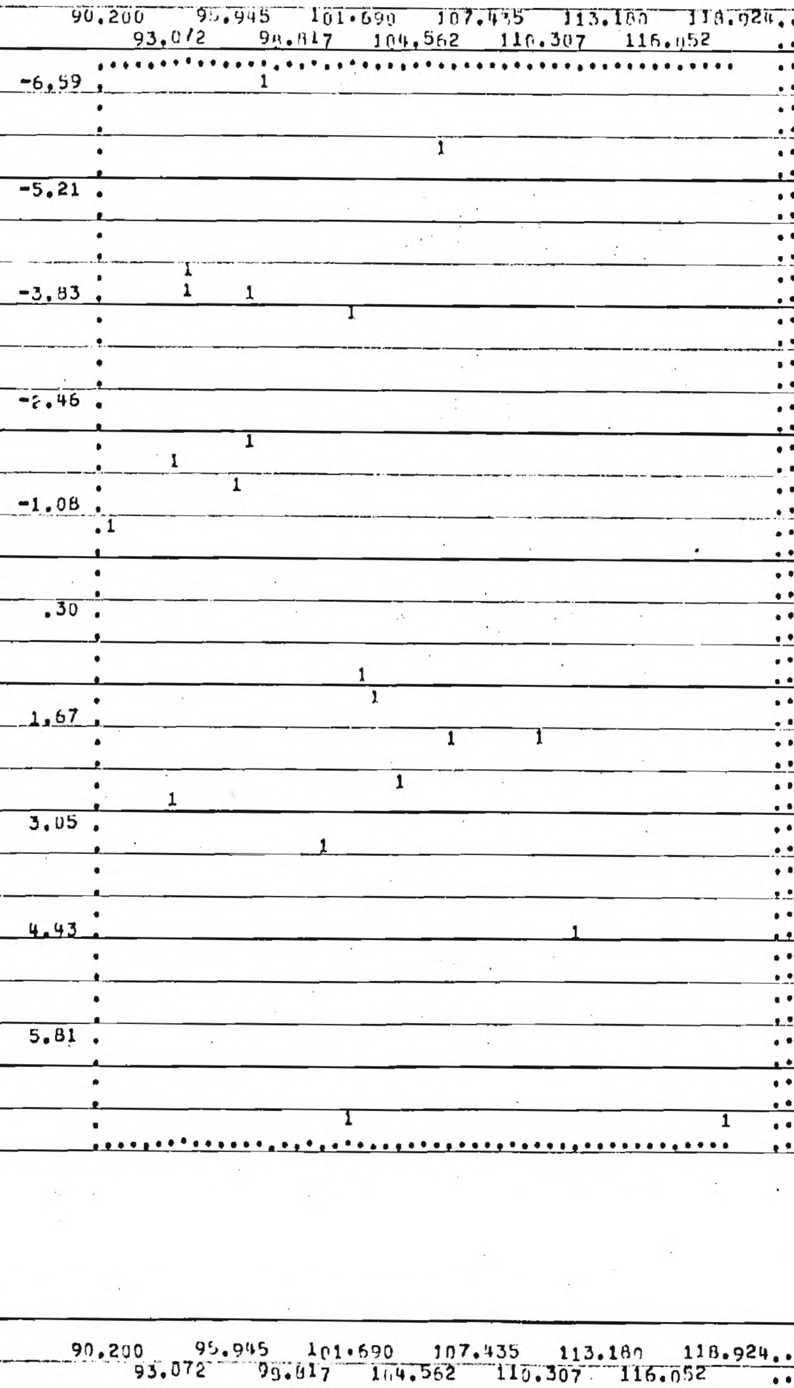
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)



PRINTOUT II

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TWS
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	3
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	3
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
C	1	168.25000	19.71340
D	2	2.30000	.15894
TWS	3	100.53850	7.13917

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3
1	388.618	.284	102.644
2		.025	.532
3			50.968

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE TWS
NUMBER OF CASES 20
NUMBER OF ORIGINAL VARIABLES 3
NUMBER OF VARIABLES ADDED 0
TOTAL NUMBER OF VARIABLES 3
NUMBER OF SUB-PROBLEMS 1

VARIABLE		MEAN	STANDARD DEVIATION
C	1	168.25000	19.71340
D	2	2.30000	.15894
TWS	3	100.53850	7.13917

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3
1	388.618	.284	102.644
2		.025	.532
3			50.968

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3
1	1.000	.091	.729
2		1.000	.469
3			1.000

SUB-PROBLEM 1

DEPENDENT VARIABLE	3
MAXIMUM NUMBER OF STEPS	6
F-LEVEL FOR INCLUSION	.010000
F-LEVEL FOR DELETION	.005000
TOLERANCE LEVEL	.001000

STEP NUMBER 1
VARIABLE ENTERED 1

MULTIPLE R	.7293
STD. ERROR OF EST.	5.0182

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	515.107	515.107	20.455
RESIDUAL	18	453.281	25.182	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION			
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		56.09940)						
C	1	.26413	.05840	20.4551	D 2	.59087	.9918	9.1190

STEP NUMBER 2
VARIABLE ENTERED 2

MULTIPLE R	.8339
STD. ERROR OF EST.	4.1659

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	673.361	336.681	19.400
RESIDUAL	17	295.026	17.354	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION			
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		16.40755)						
C	1	.25079	.04868	26.5401				
D	2	18.23275	6.03781	9.1190				

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	C	1	.7293	.5319	.5319	20.4551	1
2	D	2	.8339	.6953	.1634	9.1190	2

LIST OF RESIDUALS

CASE	RESIDUAL
1	-6.04450
2	2.53974
3	4.23205
4	6.47319
5	1.57686
6	3.04996
7	-4.12659
8	.72341
9	-6.83140
10	-4.30336
11	-1.01004
12	-1.60336
13	7.20550
14	-.61026
15	2.38205
16	-1.47681
17	-3.22314
18	-3.53004
19	2.85341
20	1.72341

PRINTOUT III

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TFS
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
MC	1	.50000	.51299
C	2	166.75000	18.60072
D	3	2.30000	.15894
CD	4	390.07999	54.75877
TFS	5	79.21950	9.75810

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	1.500	-.000	-.000	-2.499
2		345.987	-.032	794.210	85.018
3			.025	4.286	-.732
4				2998.522	141.918
5					95.221

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.157	-.000	-.000	-.499 ✓
2		1.000	-.011	.780	.468 ✓
3			1.000	.492	-.472 ✓
4				1.000	.266
5					1.000

SUB-PROBLM 1
DEPENDENT VARIABLE 5
MAXIMUM NUMBER OF STEPS 10
F-LEVEL FOR INCLUSION .010000
F-LEVEL FOR DELETION .005000
TOLERANCE LEVEL .001000

STEP NUMBER 1
VARIABLE ENTERED 1

MULTIPLE R .4992
STD. ERROR OF EST. 8.6872

ANALYSIS OF VARIANCE

	DF.	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	450.776	450.776	5.973
RESIDUAL	18	1358.415	75.467	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		83.96700)		
MC	1	-9.49501	3.88503	5.9731

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
C	2	.63906	.9753	11.7355
D	3	-.54482	1.0000	7.1762
CD	4	.30651	1.0000	1.7627

STEP NUMBER 2
VARIABLE ENTERED 2

MULTIPLE R .7455
STD. ERROR OF EST. 6.8755

ANALYSIS OF VARIANCE

	DF.	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	1005.549	502.775	10.636
RESIDUAL	17	803.641	47.273	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		35.75403)		
MC	1	-11.17172	3.11354	12.8745
C	2	.29416	.08587	11.7355

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
D	3	-.69939	.9999	15.3201
CD	4	-.41962	.3766	3.4195

STEP NUMBER 3
VARIABLE ENTERED 3

MULTIPLE R .8792
STD. ERROR OF EST. 5.0655

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	1398.647	466.216	18.170
RESIDUAL	16	410.544	25.659	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		102.01682)		
MC	1	-11.15646	2.29387	23.6546
C	2	.29148	.06327	21.2266
D	3	-28.61904	7.31181	15.3201

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
CD	4	.36689	.1255	2.3332

STEP NUMBER 4
VARIABLE ENTERED 4

MULTIPLE R .8965
STD. ERROR OF EST. 4.8668

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	1453.909	363.477	15.346
RESIDUAL	15	355.281	23.685	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		136.77431)		
MC	1	-9.96912	2.33695	18.1976
C	2	.08310	.14930	.3104
D	3	-43.79298	12.16693	12.9553
CD	4	.08790	.05755	2.3332

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

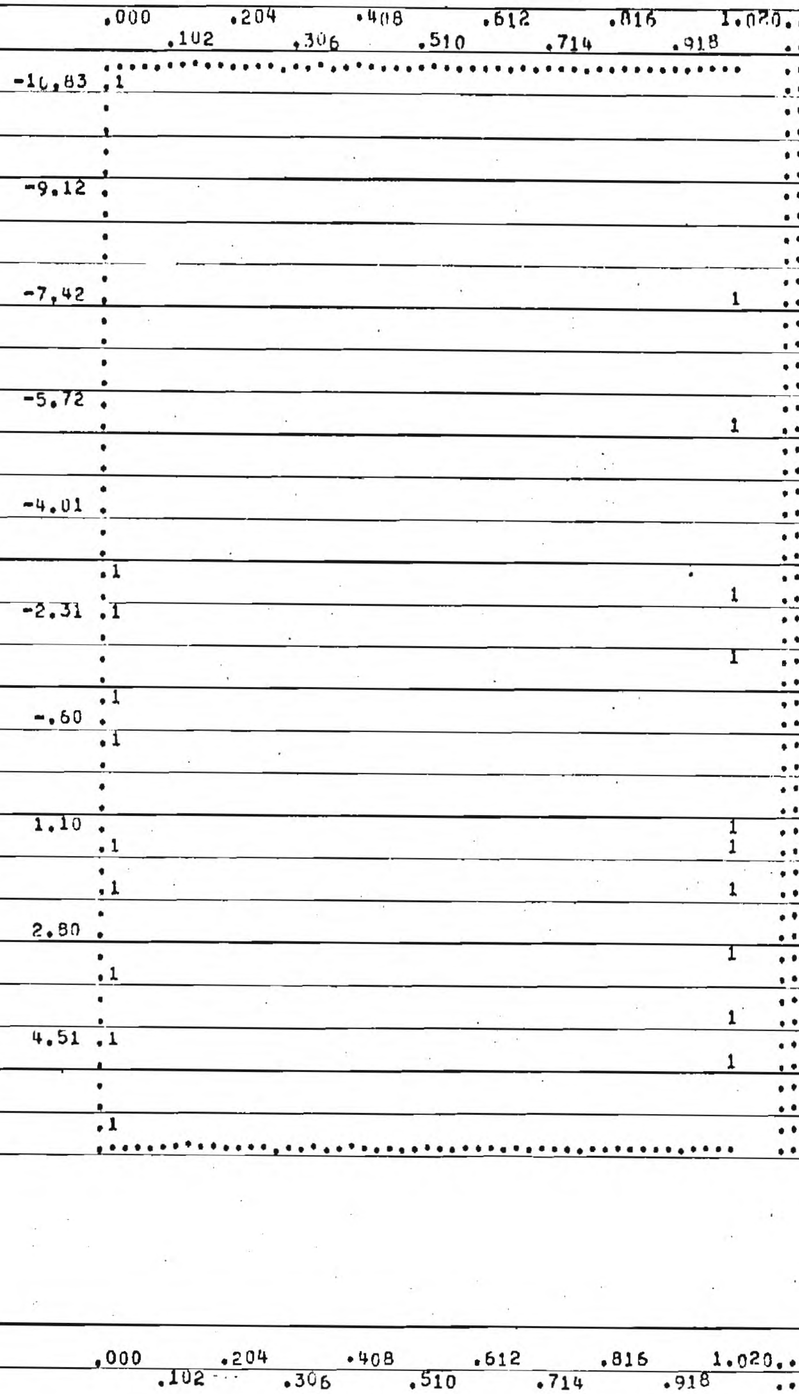
SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	MULTIPLE RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	MC 1		.4992	.2492	.2492	5.9731	1
2	C 2		.7455	.5558	.3066	11.7355	2
3	D 3		.8792	.7731	.2173	15.3201	3
4	CD 4		.8965	.8036	.0305	2.3332	4

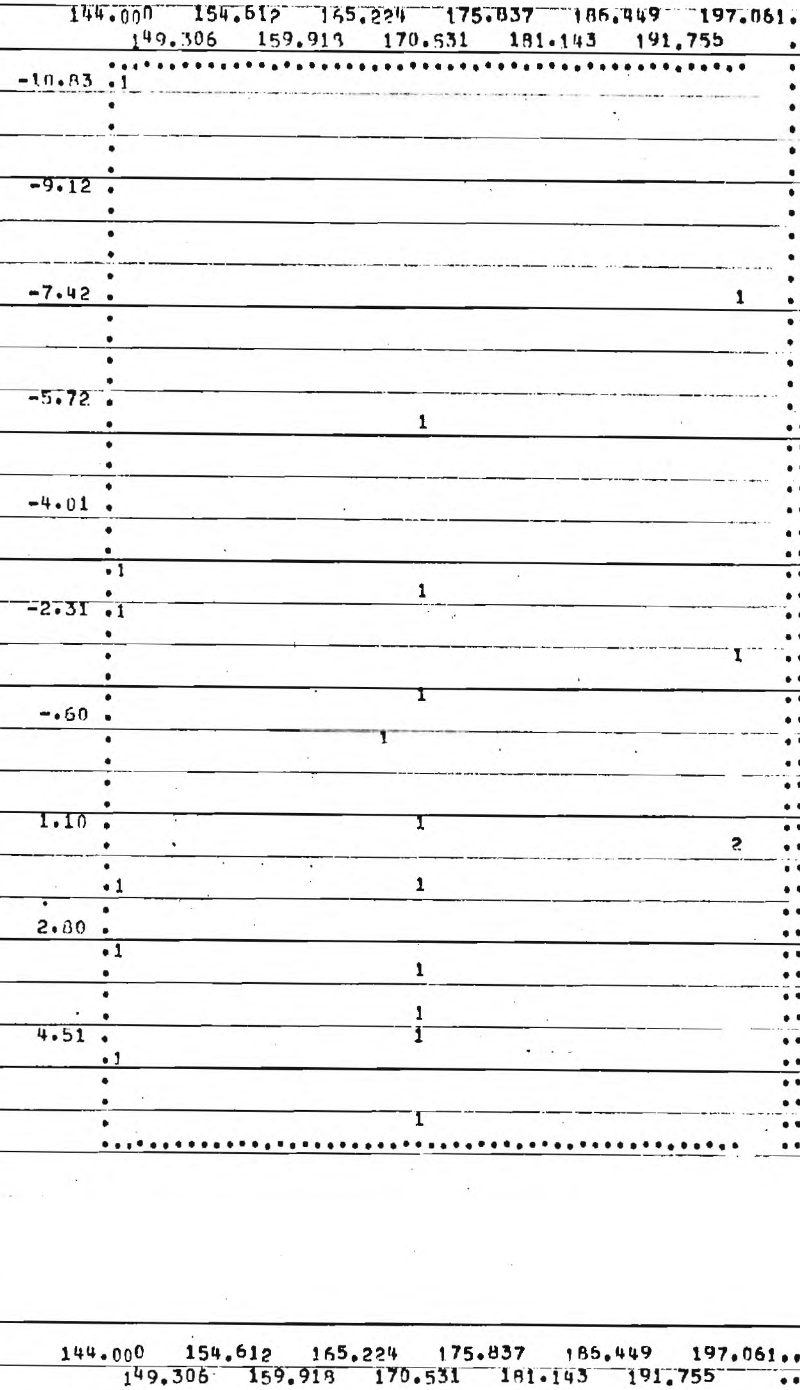
LIST OF RESIDUALS

CASE	RESIDUAL
1	-7.41907
2	3.05997
3	-1.46217
4	1.98576
5	1.54938
6	4.71287
7	4.26583
8	1.26161
9	-5.23078
10	-2.72079
11	-1.07139
12	-10.82015
13	-.11595
14	-2.31336
15	1.40576
16	-3.00626
17	3.39770
18	5.87249
19	2.18010
20	4.48010

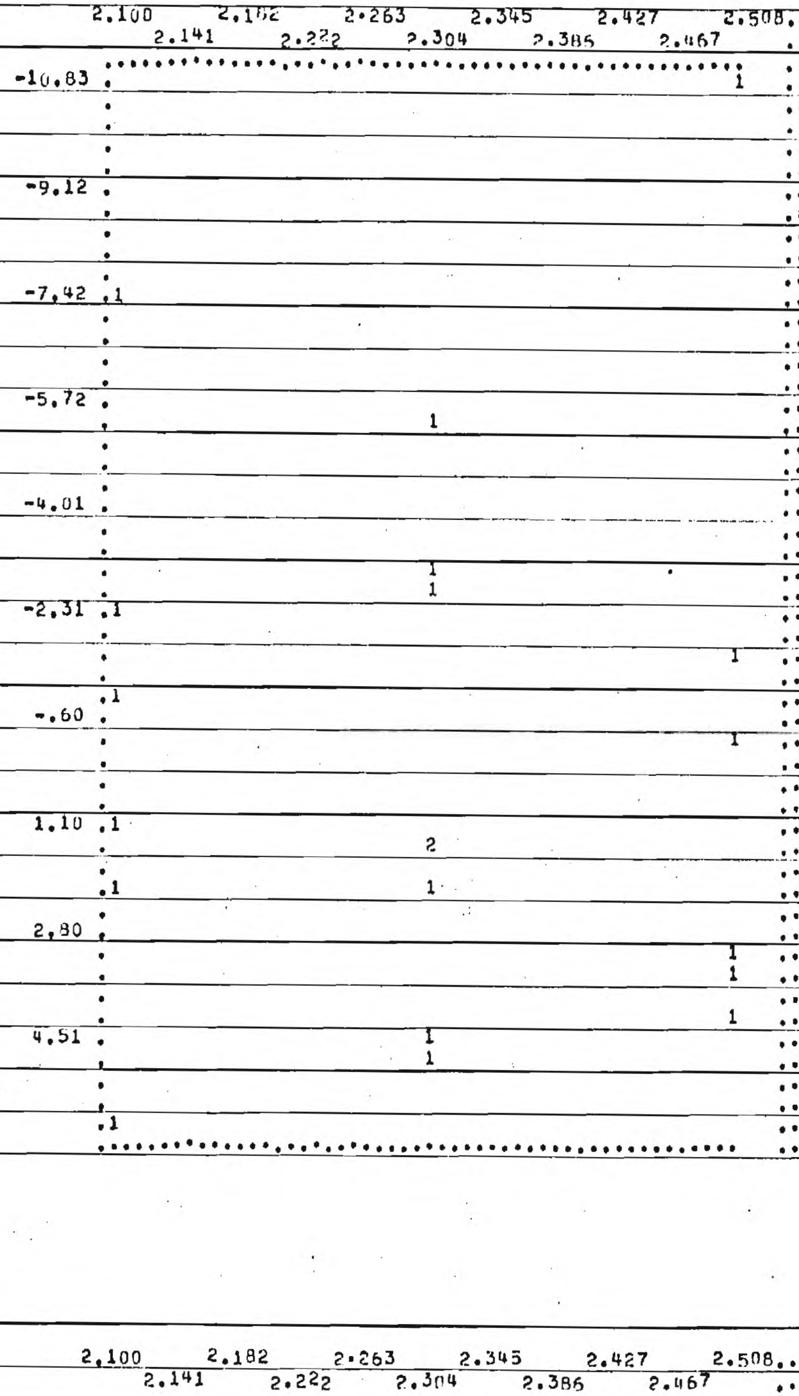
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)



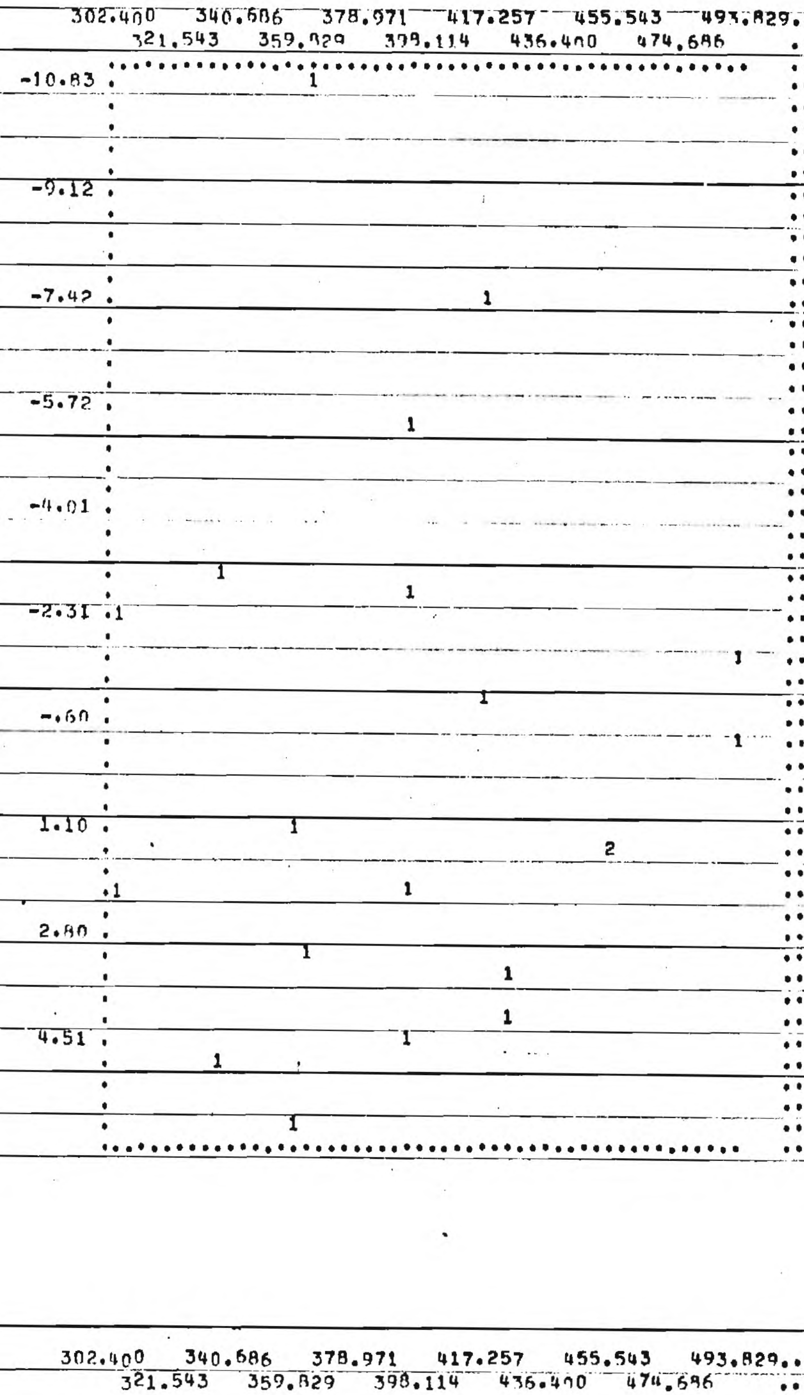
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)



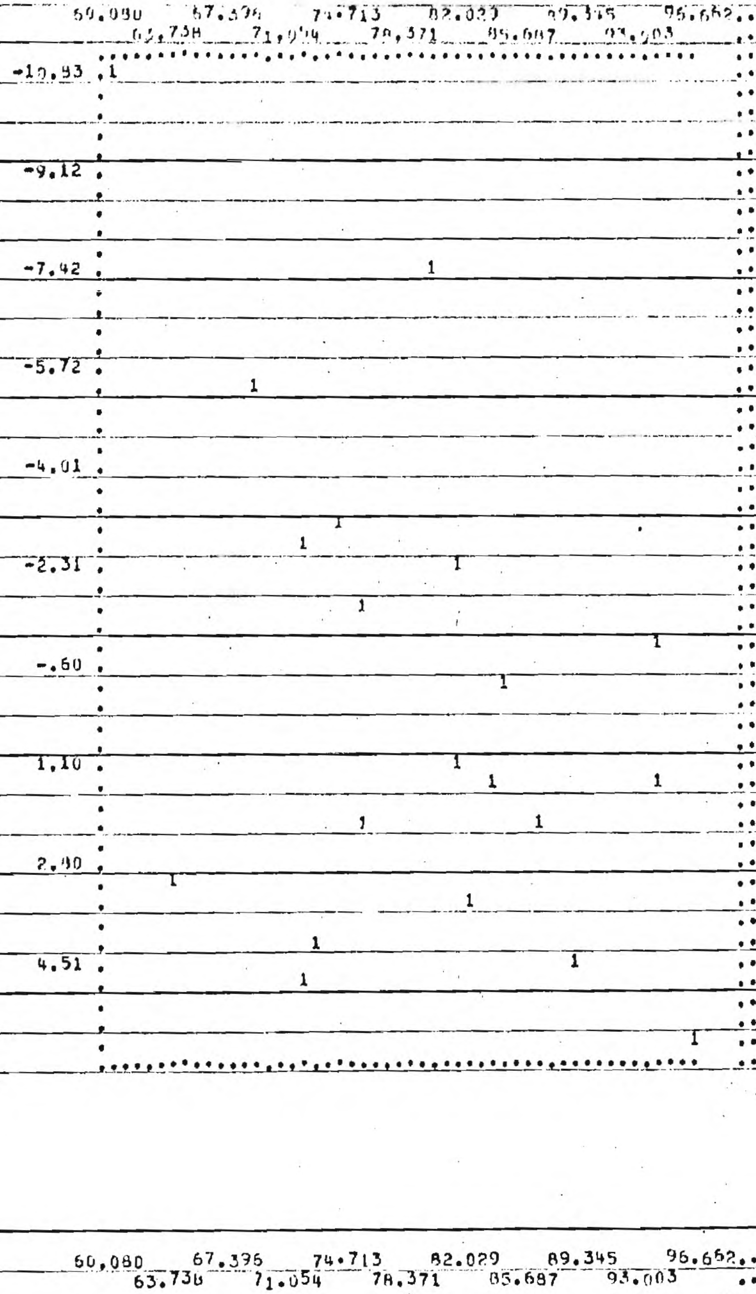
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)



FINISH CARD ENCOUNTERED
PROGRAM TERMINATED

PRINTOUT IV

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TWE
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
MC	1	.50000	.51299
C	2	168.25000	19.71340
D	3	2.30000	.15894
CD	4	390.07998	54.75877
TWE	5	18.43050	1.99926

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	.711	-.000	-.000	-.386
2		388.618	.284	951.978	23.881
3			.025	4.286	-.050
4				2998.522	55.297
5					3.997

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.070	-.000	-.000	-.376
2		1.000	.091	.882	.606
3			1.000	.492	-.157
4				1.000	.505
5					1.000

SUB-PROBLM 1
DEPENDENT VARIABLE 5
MAXIMUM NUMBER OF STEPS 10
F-LEVEL FOR INCLUSION .010000
F-LEVEL FOR DELETION .005000
TOLERANCE LEVEL .001000

STEP NUMBER 1
VARIABLE ENTERED 2

MULTIPLE R .6059
STD. ERROR OF EST. 1.6340

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	27.882	27.882	10.443
RESIDUAL	18	48.061	2.670	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		8.09141)		
C	2	.06145	.01902	10.4426

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
MC	1	-.52734	.9951	6.5487
D	3	-.26757	.9918	1.3109
CD	4	-.07801	.2223	.1041

STEP NUMBER 2
VARIABLE ENTERED 1

MULTIPLE R .7370
STD. ERROR OF EST. 1.4286

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	41.248	20.624	10.105
RESIDUAL	17	34.696	2.041	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		8.40672)		
MC	1	-1.63901	.64048	6.5487
C	2	.06445	.01667	14.9524

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
D	3	-.31890	.9917	1.8114
CD	4	-.17511	.2184	.5061

STEP NUMBER 3
VARIABLE ENTERED 3

MULTIPLE R .7679
STD. ERROR OF EST. 1.3957

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	44.776	14.925	7.662
RESIDUAL	16	31.167	1.948	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		14.33464)		
MC	1	-1.64441	.62573	6.9063
C	2	.06645	.01635	16.5162
D	3	-2.72255	2.02289	1.8114

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
CD	4	.24345	.0472	.9451

STEP NUMBER 4
VARIABLE ENTERED 4

MULTIPLE R .7835
STD. ERROR OF EST. 1.3981

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	46.624	11.656	5.963
RESIDUAL	15	29.320	1.955	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		23.05032)		
MC	1	-1.47762	.64987	5.1699
C	2	.00467	.06562	.0051
D	3	-6.47512	4.35966	2.2059
CD	4	.02621	.02696	.9451

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

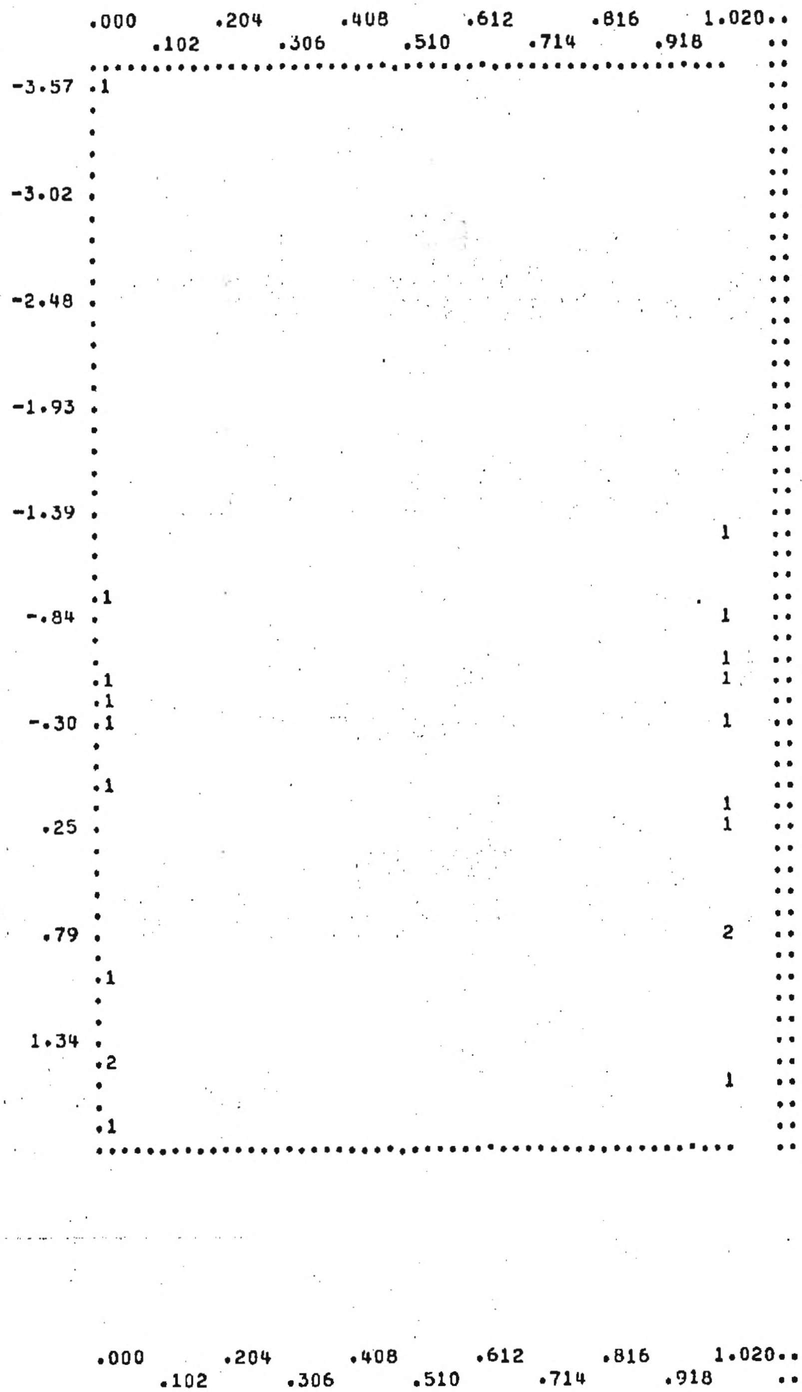
SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	C	2	.6059	.3671	.3671	10.4426	1
2	MC	1	.7370	.5431	.1760	6.5487	2
3	D	3	.7679	.5896	.0465	1.8114	3
4	CD	4	.7835	.6139	.0243	.9451	4

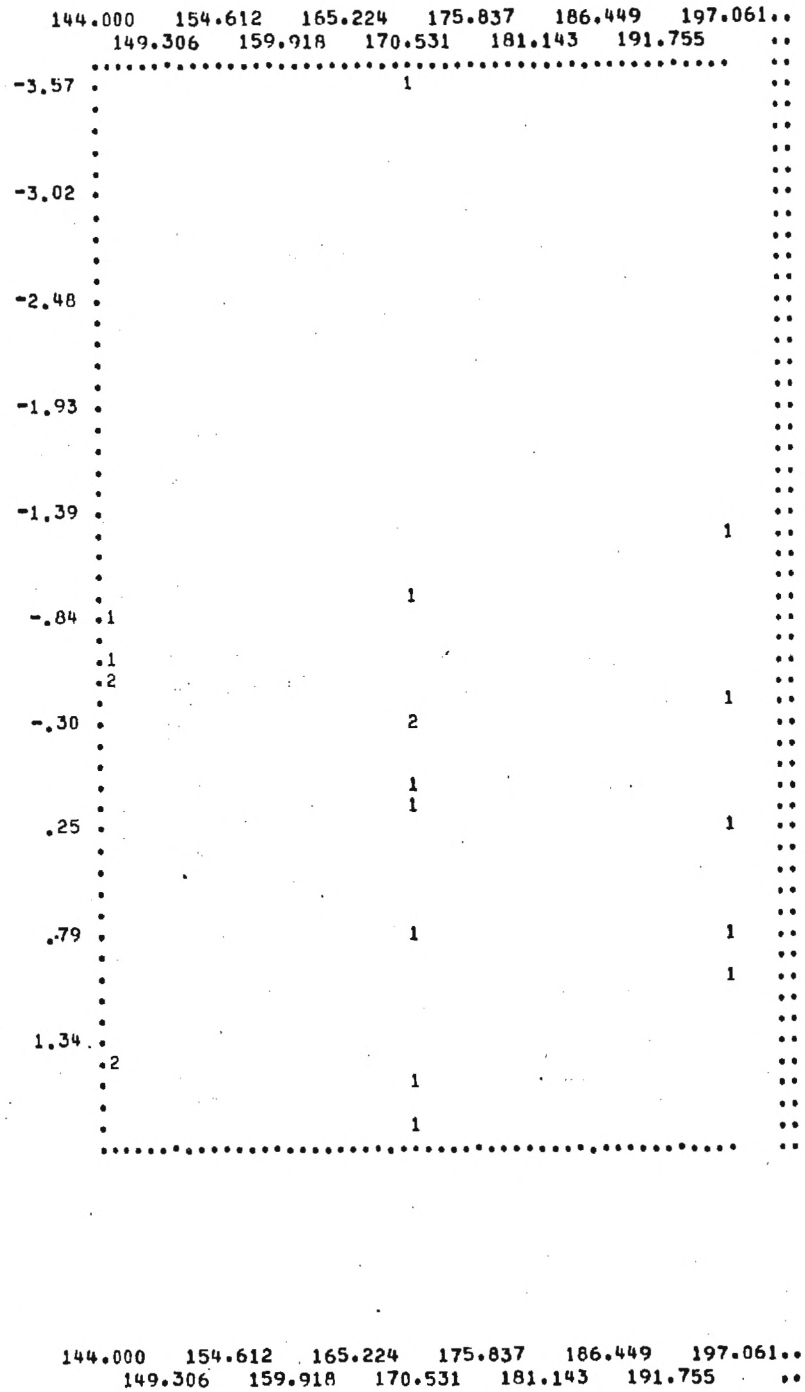
LIST OF RESIDUALS

CASE	RESIDUAL
1	.25946
2	-.87481
3	-1.22561
4	-.54498
5	.74692
6	-.57489
7	-.34000
8	.80196
9	1.59098
10	.16098
11	-.02195
12	-.48243
13	-.42323
14	1.49740
15	1.02930
16	1.39748
17	1.77237
18	-3.56566
19	-.25664
20	-.94664

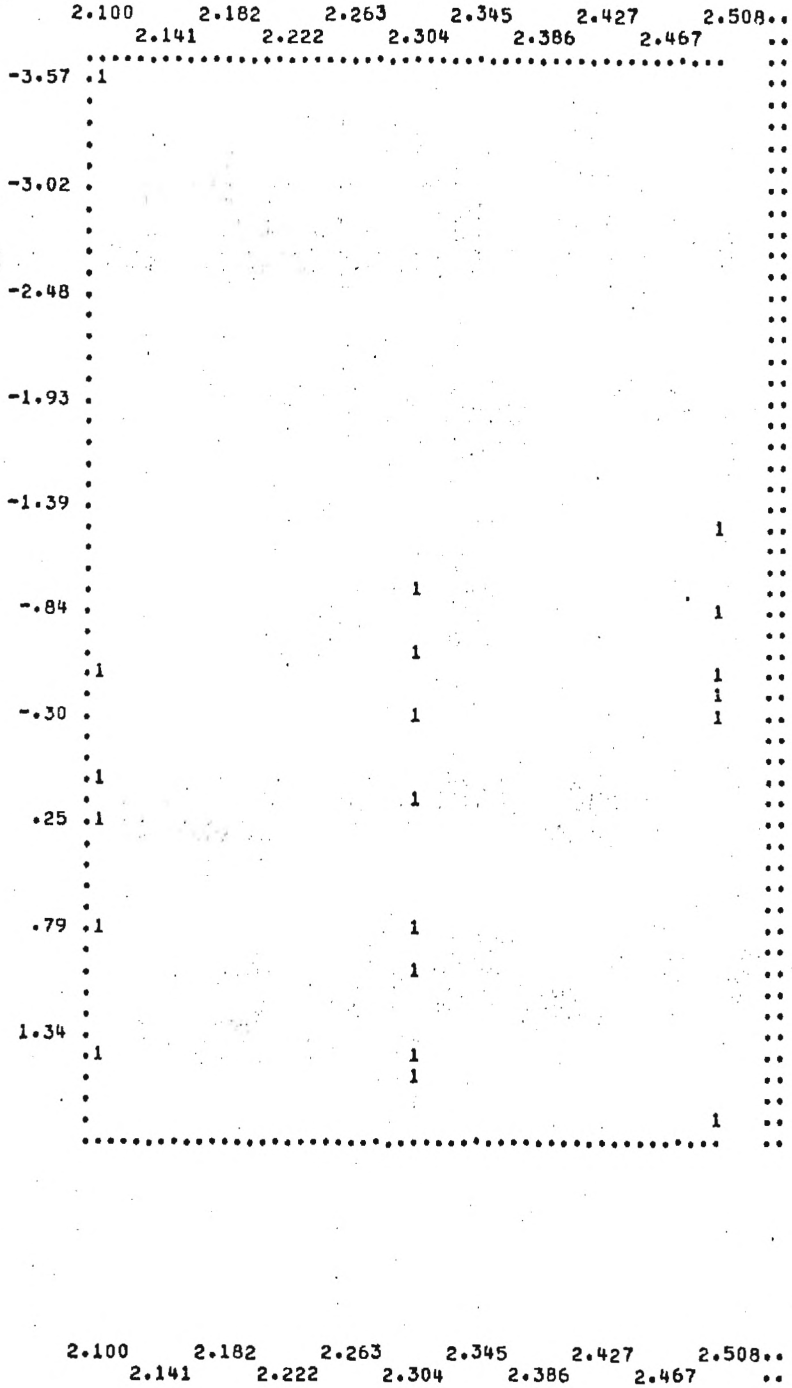
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)



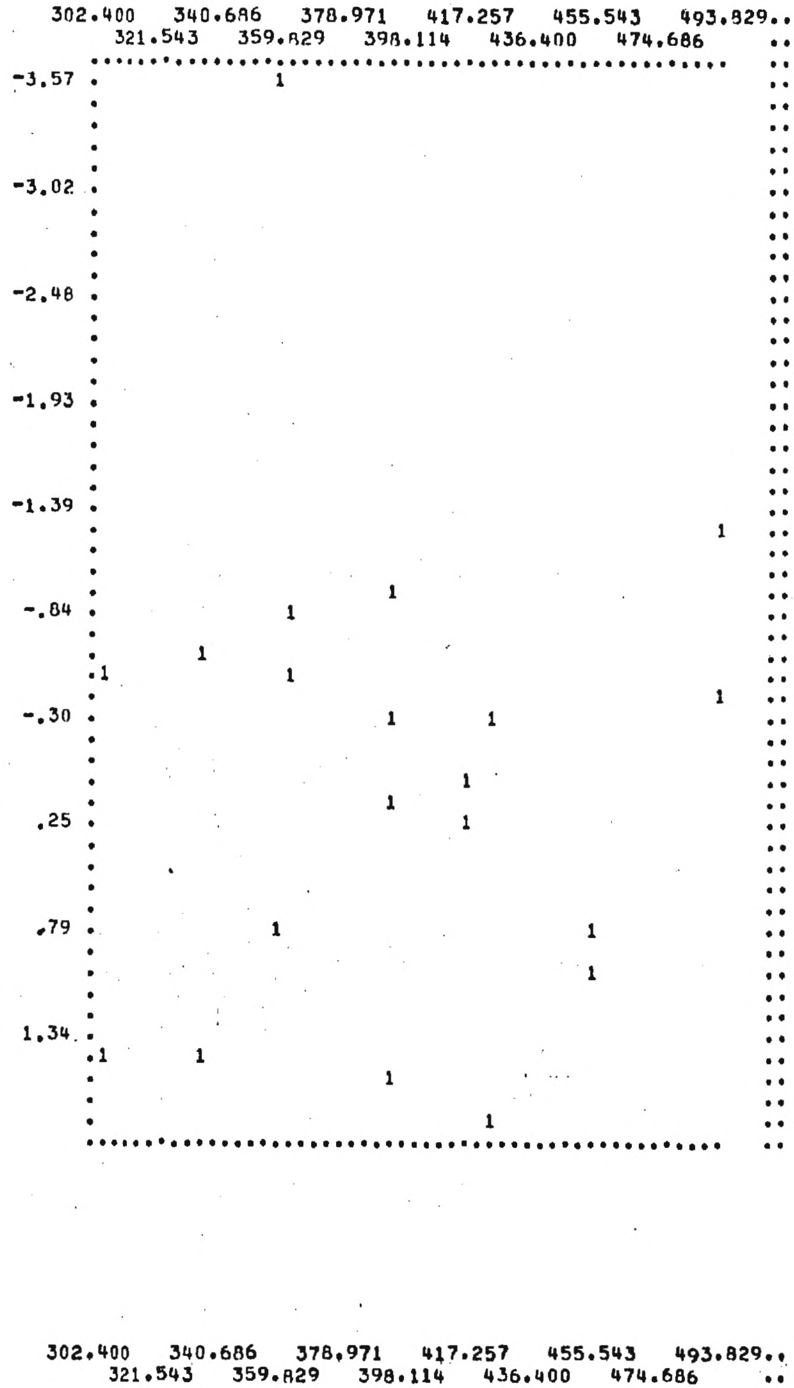
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)



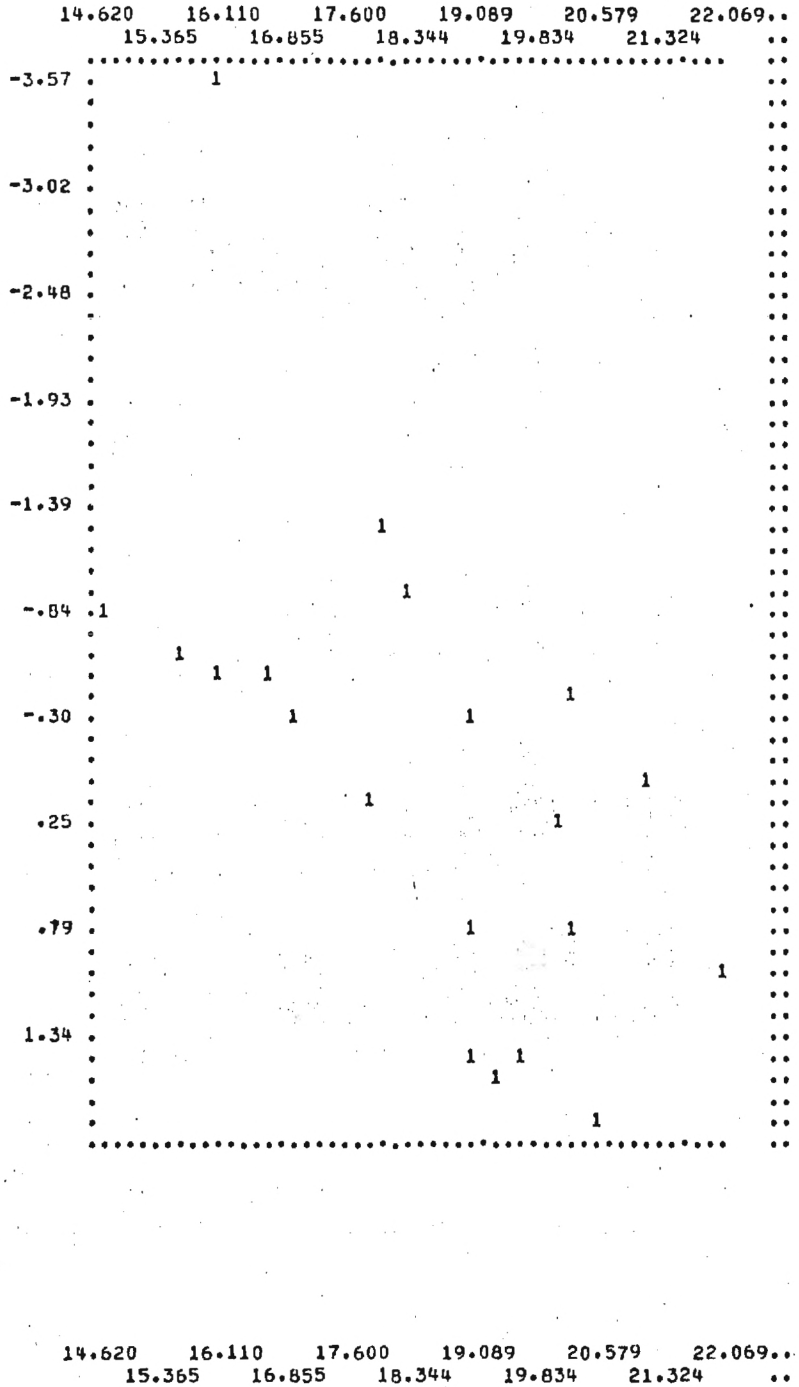
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)



PRINTOUT V

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TFE
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
MC	1	.50000	.51299
C	2	168.25000	19.71340
D	3	2.30000	.15894
CD	4	390.07998	54.75877
TFE	5	24.79900	2.47400

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	.711	-.000	-.000	-.835
2		388.618	.284	951.978	.774
3			.025	4.286	.045
4				2998.522	12.396
5					6.121

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.070	-.000	-.000	-.658
2		1.000	.091	.882	.016
3			1.000	.492	.115
4				1.000	.091
5					1.000

```
SUB-PROBLM     1
  DEPENDENT VARIABLE            5
  MAXIMUM NUMBER OF STEPS       10
  F-LEVEL FOR INCLUSION      .010000
  F-LEVEL FOR DELETION       .005000
  TOLERANCE LEVEL            .001000


   STEP NUMBER    1
   VARIABLE ENTERED    1

   MULTIPLE R               .6577
   STD. ERROR OF EST.      1.9146

   ANALYSIS OF VARIANCE
                        DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
           REGRESSION    1         50.308          50.308      13.723
           RESIDUAL     18         65.985           3.666

                 VARIABLES IN EQUATION              .              VARIABLES NOT IN EQUATION
                                                    .
    VARIABLE     COEFFICIENT  STD. ERROR  F TO REMOVE .  VARIABLE   PARTIAL CORR.   TOLERANCE   F TO ENTER
                                                    .
   (CONSTANT       26.38500 )                       .
  MC       1       -3.17200     .85625    13.7234   .  C     2        .08262         .9951      .1168
                                                    .  D     3        .15210        1.0000      .4026
                                                    .  CD    4        .12147        1.0000      .2546


   STEP NUMBER    2
   VARIABLE ENTERED    3

   MULTIPLE R               .6676
   STD. ERROR OF EST.      1.9472

   ANALYSIS OF VARIANCE
                        DF    SUM OF SQUARES    MEAN SQUARE    F RATIO
           REGRESSION    2         51.834          25.917       6.835
           RESIDUAL     17         64.459           3.792

                 VARIABLES IN EQUATION              .              VARIABLES NOT IN EQUATION
                                                    .
    VARIABLE     COEFFICIENT  STD. ERROR  F TO REMOVE .  VARIABLE   PARTIAL CORR.   TOLERANCE   F TO ENTER
                                                    .
   (CONSTANT       22.28337 )                       .
  MC       1       -3.17200     .87083    13.2679   .  C     2        .06989          .9868      .0785
  D        3        1.78332    2.81058      .4026   .  CD    4        .05413          .7575      .0470
```

STEP NUMBER 3
VARIABLE ENTERED 2

MULTIPLE R .6696
STD. ERROR OF EST. 2.0022

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	52.149	17.383	4.336
RESIDUAL	16	64.144	4.009	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		21.35638)		
MC	1	-3.18975	.89767	12.6264
C	2	.00657	.02346	.0785
D	3	1.70937	2.90202	.3470

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
CD	4	-.05439	.0472	.0445

STEP NUMBER 4
VARIABLE ENTERED 4

MULTIPLE R .6709
STD. ERROR OF EST. 2.0649

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	52.339	13.085	3.069
RESIDUAL	15	63.954	4.264	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		18.56282)		
MC	1	-3.24321	.95979	11.4182
C	2	.02637	.09692	.0741
D	3	2.91214	6.43879	.2046
CD	4	-.00840	.03982	.0445

VARIABLES NOT IN EQUATION

VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

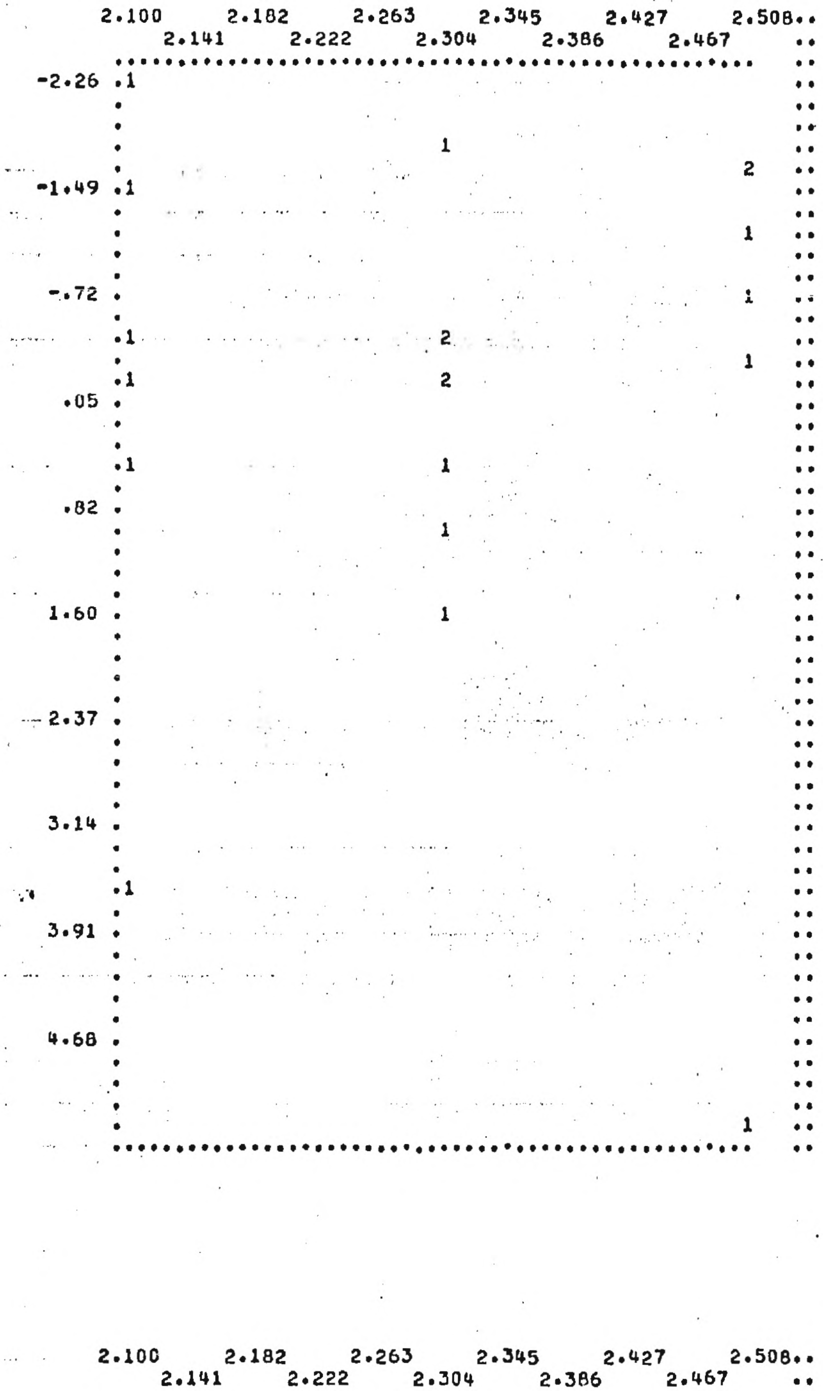
SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	MC	1	.6577	.4326	.4326	13.7234	1
2	D	3	.6676	.4457	.0131	.4026	2
3	C	2	.6696	.4484	.0027	.0785	3
4	CD	4	.6709	.4501	.0016	.0445	4

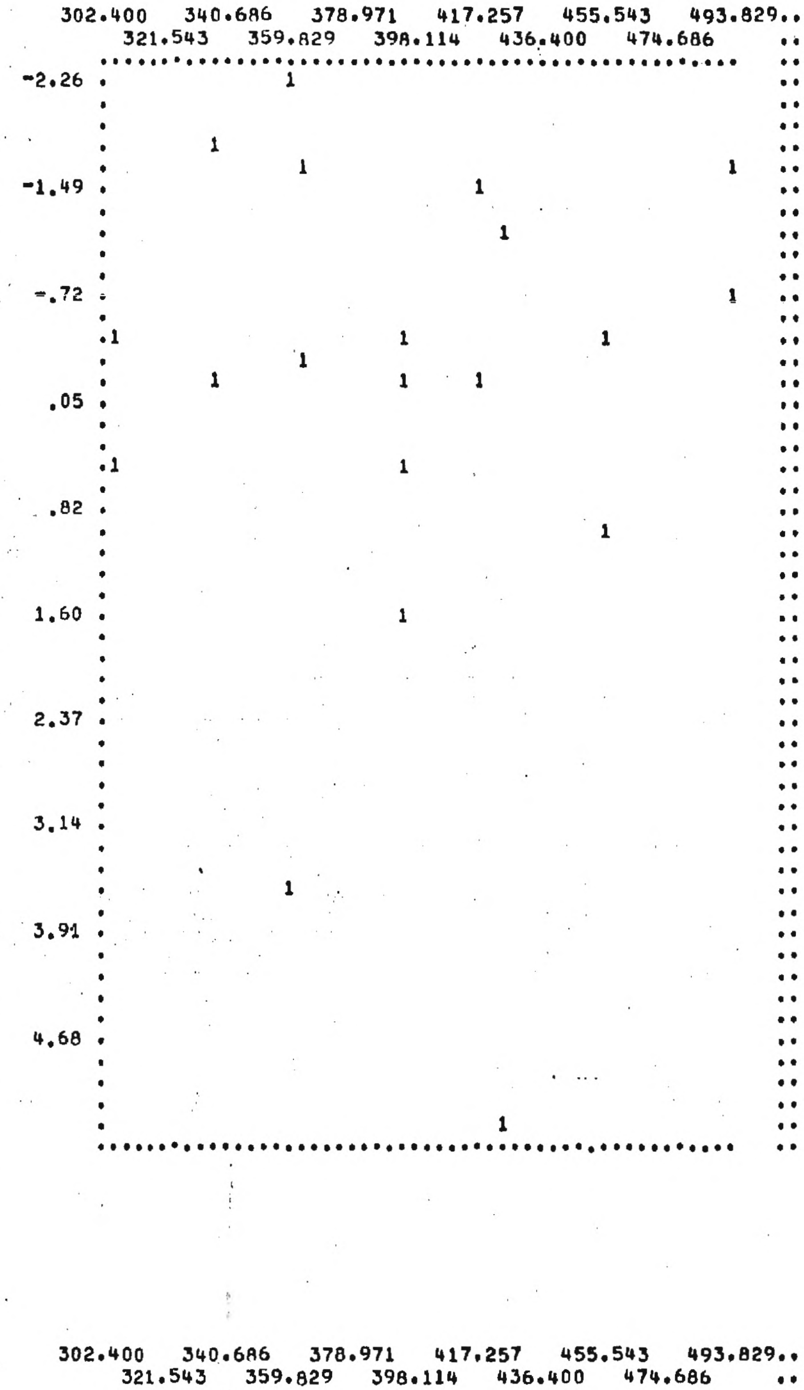
LIST OF RESIDUALS

CASE	RESIDUAL
1	-1.55601
2	-.29300
3	-1.72216
4	.51790
5	-.44908
6	-.15255
7	-1.11721
8	3.64968
9	-.41877
10	1.54123
11	-.09715
12	-1.58621
13	-.69537
14	-.36531
15	1.04771
16	-1.76576
17	5.29958
18	-2.26353
19	-.11198
20	.53802

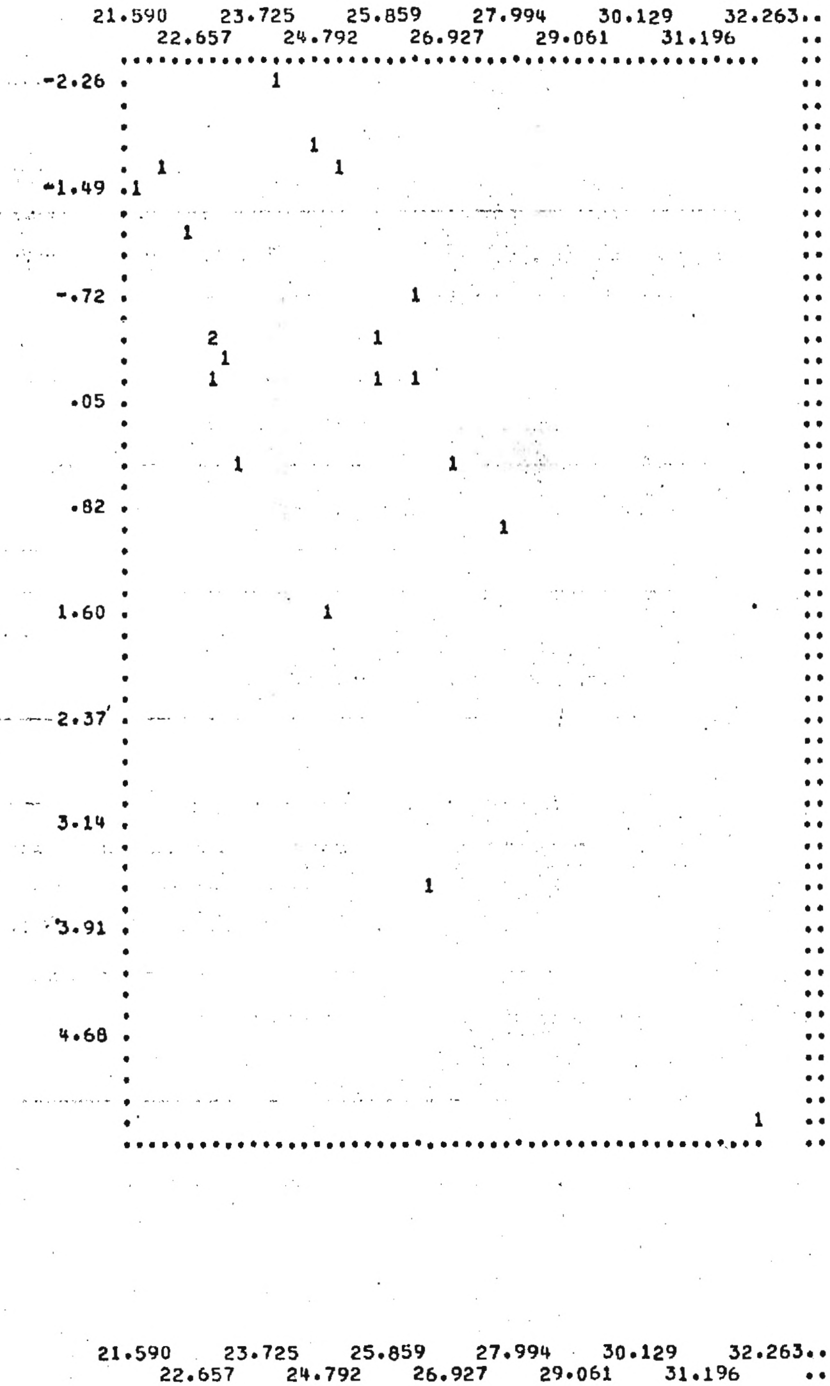
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)

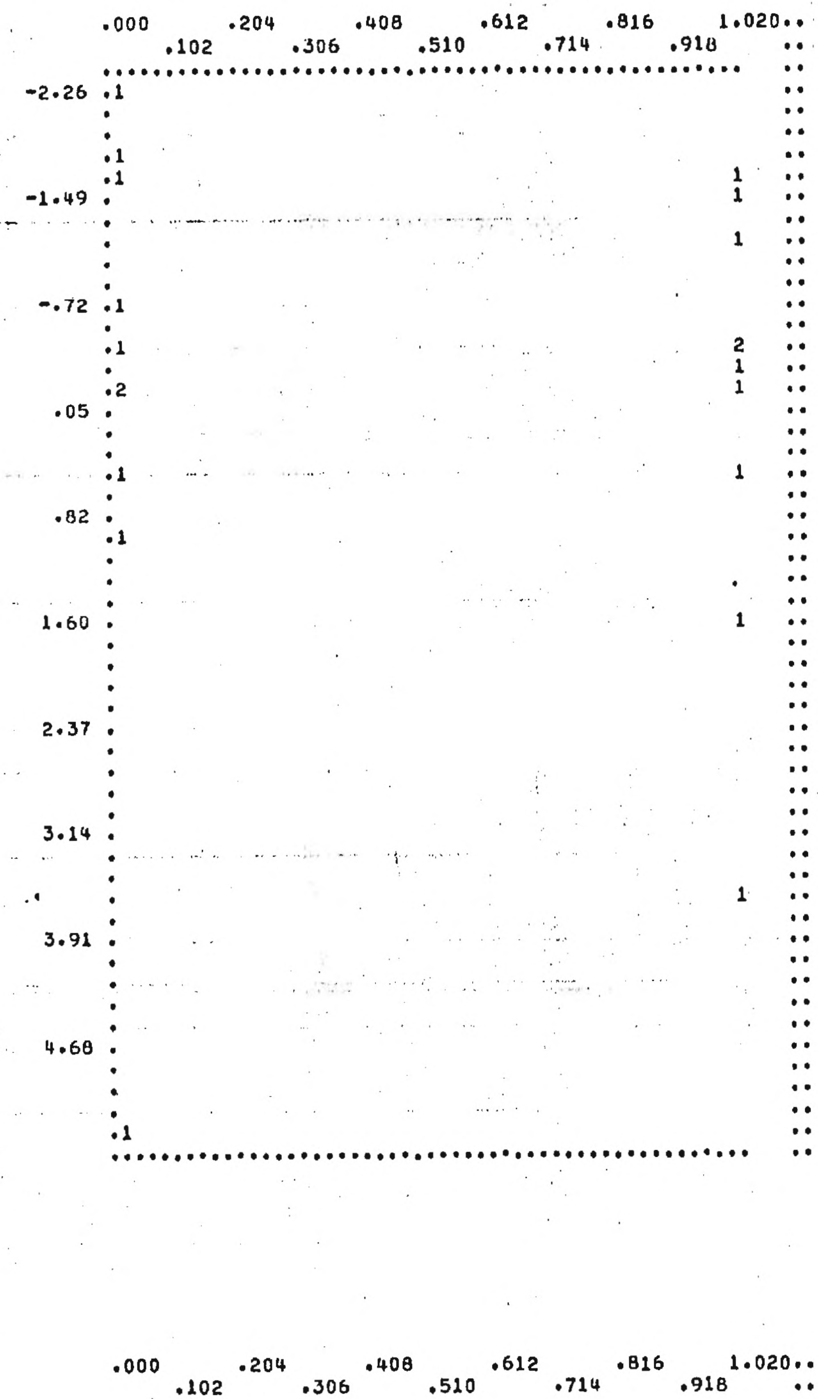


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)

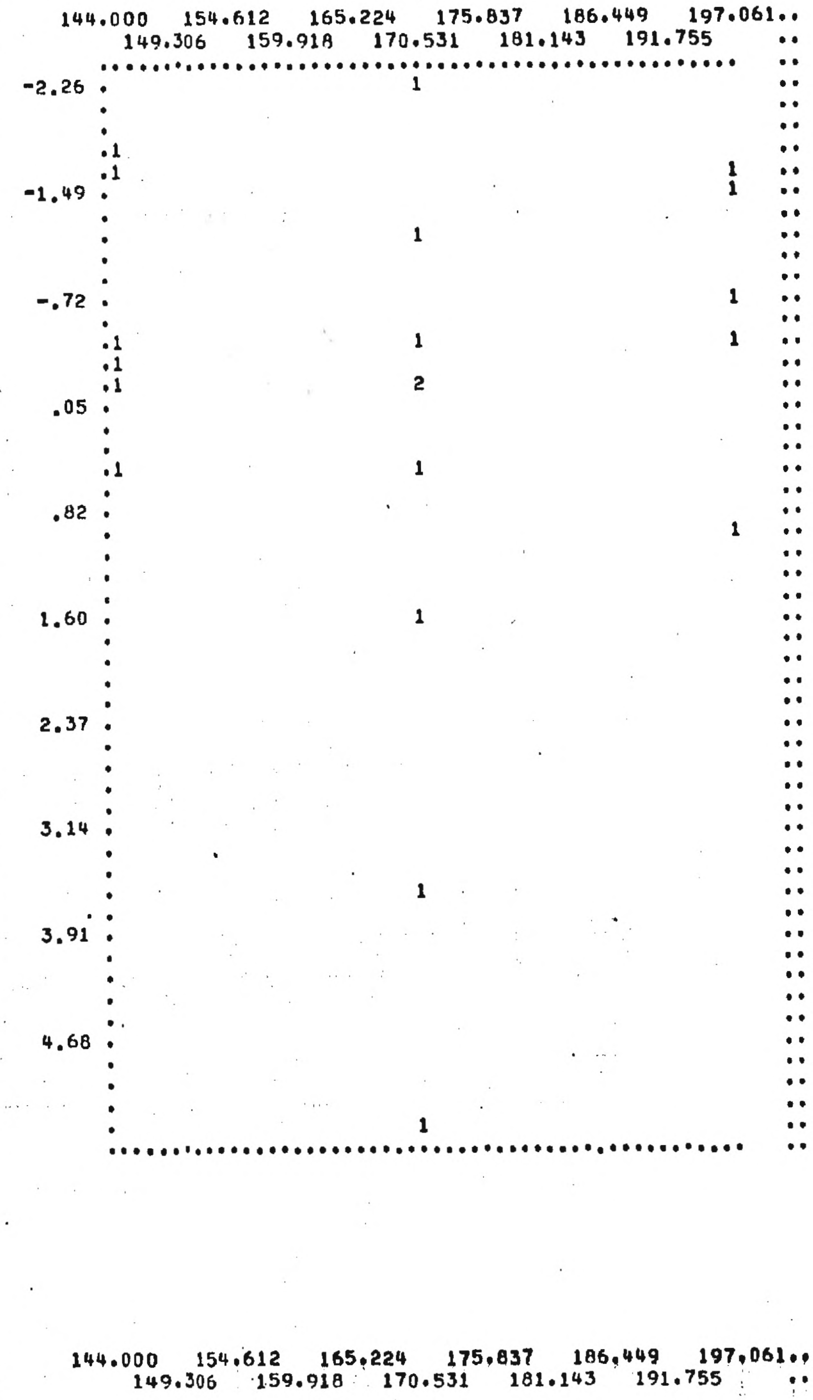


FINISH CARD ENCOUNTERED
PROGRAM TERMINATED

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)



PRINTOUT VI

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TWSR
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
MC	1	.50000	.51299
C	2	168.25000	19.71340
D	3	2.30000	.15894
CD	4	390.07998	54.75877
TWSR	5	101.20000	5.93473

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	.711	-.000	-.000	.105
2		388.618	.284	951.978	-69.053
3			.025	4.286	.432
4				2998.522	-115.943
5					35.221

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.070	-.000	-.000	.035
2		1.000	.091	.882	-.590
3			1.000	.492	.458
4				1.000	-.357
5					1.000

```
SUB-PROBLM     1
 DEPENDENT VARIABLE             5
 MAXIMUM NUMBER OF STEPS       10
 F-LEVEL FOR INCLUSION     .010000
 F-LEVEL FOR DELETION      .005000
 TOLERANCE LEVEL           .001000


  STEP NUMBER     1
  VARIABLE ENTERED     2

  MULTIPLE R             .5902
  STD. ERROR OF EST.    4.9220

  ANALYSIS OF VARIANCE
                          DF     SUM OF SQUARES    MEAN SQUARE    F RATIO
          REGRESSION       1        233.126          233.126       9.623
          RESIDUAL        18        436.073           24.226

                 VARIABLES IN EQUATION              .                 VARIABLES NOT IN EQUATION
  VARIABLE       COEFFICIENT  STD. ERROR  F TO REMOVE .    VARIABLE     PARTIAL CORR.    TOLERANCE    F TO ENTER
                                                       .
  (CONSTANT       131.09595 )                          .
  C       2         -.17769      .05728      9.6229    .    MC      1       .09444         .9951        .1530
                                                       .    D       3       .63572         .9918      11.5301
                                                       .    CD      4       .43023         .2223       3.8614


  STEP NUMBER     2
  VARIABLE ENTERED     3

  MULTIPLE R             .7821
  STD. ERROR OF EST.    3.9096

  ANALYSIS OF VARIANCE
                          DF     SUM OF SQUARES    MEAN SQUARE    F RATIO
          REGRESSION       2        409.360          204.680      13.391
          RESIDUAL        17        259.839           15.285

                 VARIABLES IN EQUATION              .                 VARIABLES NOT IN EQUATION
  VARIABLE       COEFFICIENT  STD. ERROR  F TO REMOVE .    VARIABLE     PARTIAL CORR.    TOLERANCE    F TO ENTER
                                                       .
  (CONSTANT        89.21007 )                          .
  C       2         -.19176      .04569     17.6175    .    MC      1       .12763         .9950        .2649
  D       3        19.24059     5.66632     11.5301    .    CD      4      -.34784         .0507       2.2024
```

STEP NUMBER 3
VARIABLE ENTERED 4

MULTIPLE R .8116
STD. ERROR OF EST. 3.7782

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	440.800	146.933	10.293
RESIDUAL	16	228.400	14.275	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION				
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		54.37216)							
C	2	.05282	.17062	.0958	MC	1	.03958	.9257	.0235
D	3	34.18605	11.46326	8.8937					
CD	4	-.10430	.07028	2.2024					

STEP NUMBER 4
VARIABLE ENTERED 1

MULTIPLE R .8119
STD. ERROR OF EST. 3.8991

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	441.157	110.289	7.255
RESIDUAL	15	228.042	15.203	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION			
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		55.32345)						
MC	1	.27806	1.81238	.0235				
C	2	.04516	.18301	.0609				
D	3	33.75538	12.15942	7.7078				
CD	4	-.10126	.07520	1.8131				

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

SUMMARY TABLE

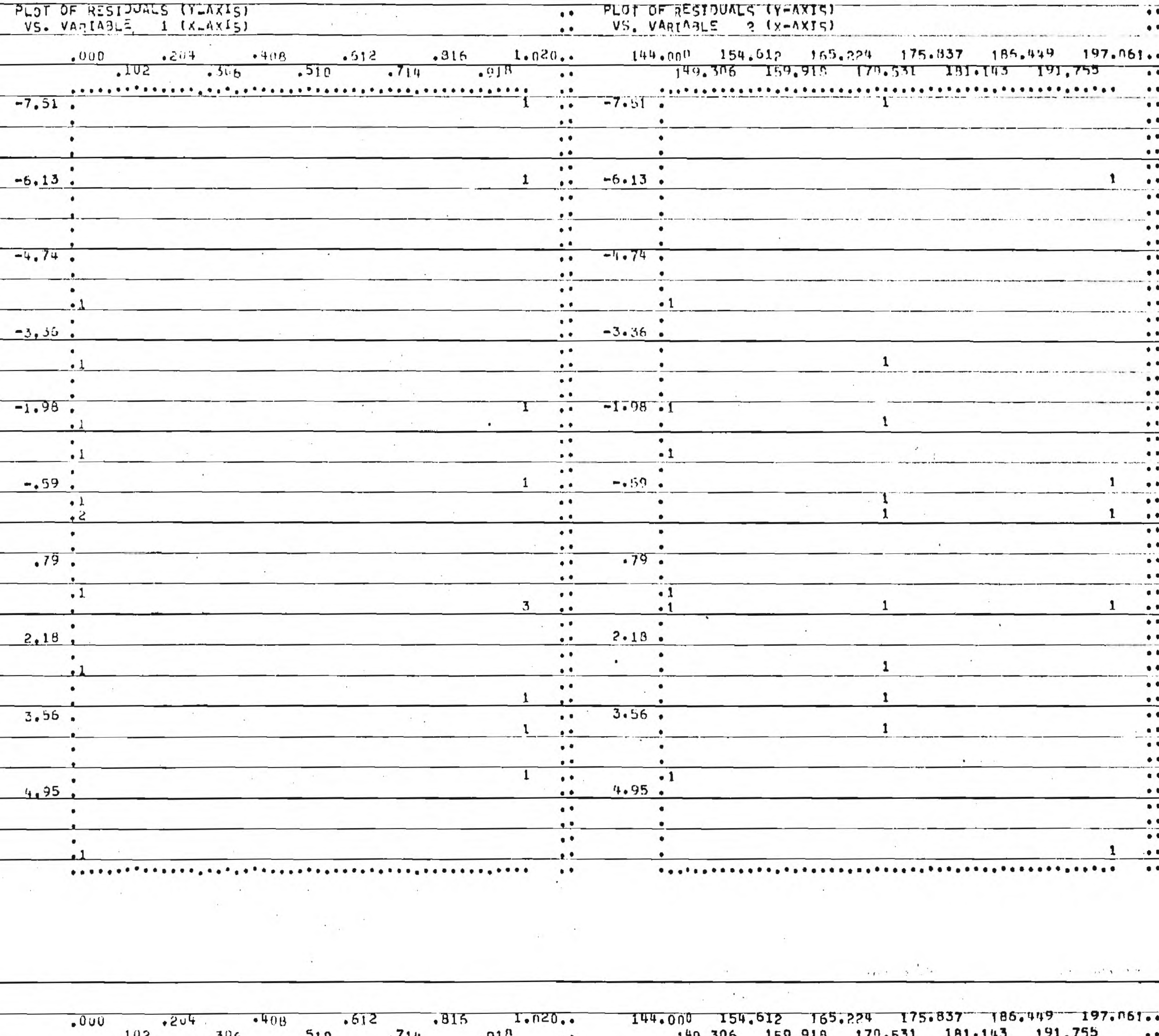
MULTIPLE INCREASE F VALUE TO NUMBER OF INDEPENDENT

SUMMARY TABLE

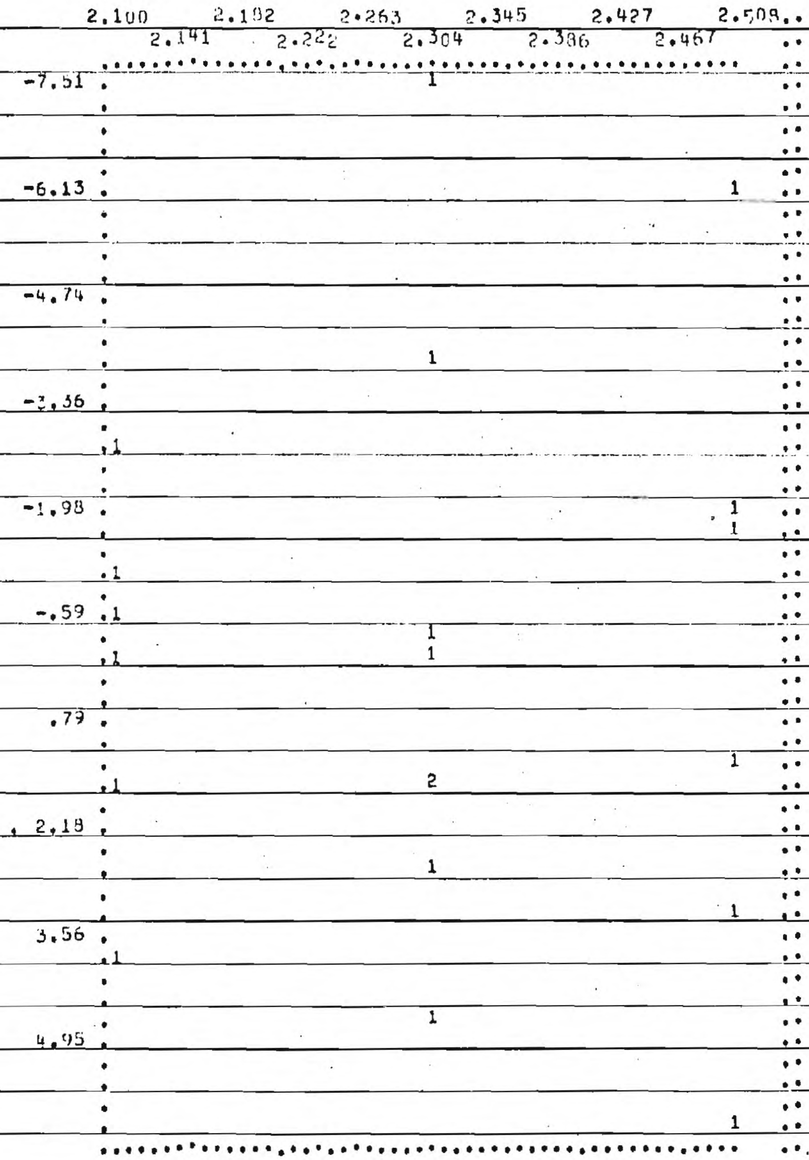
STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	MULTIPLE RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	C	2	.5902	.3484	.3484	9.6229	1
2	D	3	.7821	.6117	.2634	11.5301	2
3	CD	4	.8116	.6587	.0470	2.2024	3
4	MC	1	.8119	.6592	.0005	.0235	4

LIST OF RESIDUALS

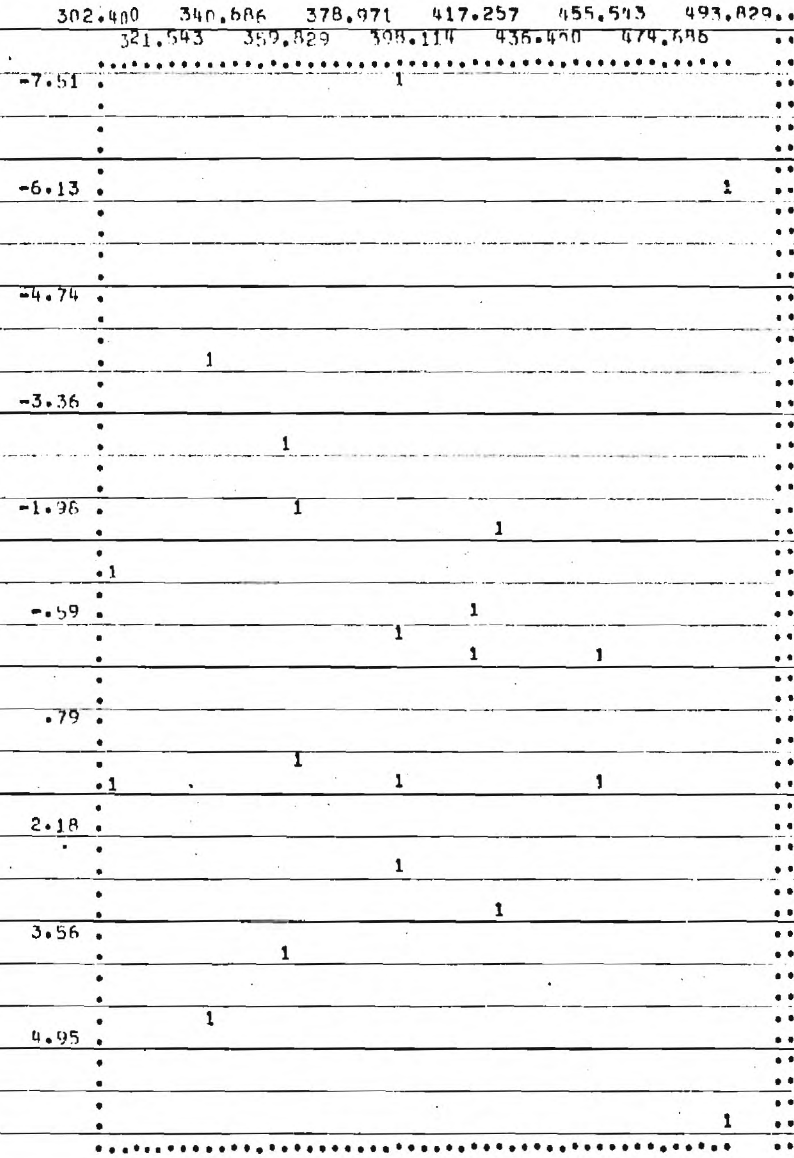
CASE	RESIDUAL
1	-.66220
2	-2.04070
3	-6.22570
4	1.62897
5	1.55605
6	4.79413
7	3.15992
8	3.01591
9	-7.51264
10	1.48736
11	-.15469
12	1.23735
13	6.05235
14	-1.09298
15	-.16590
16	-3.92781
17	-1.56313
18	-2.90604
19	-.25458
20	2.76542


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)
.000 .204 .408 .612 .816 1.020
.102 .306 .510 .714 .918
-7.51
-6.13
-4.74
-3.36
-1.98
-.59
.79
2.18
3.56
4.95
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)
144.000 154.612 165.224 175.837 186.449 197.061
149.306 159.918 170.531 181.143 191.755
-7.51
-6.13
-4.74
-3.36
-1.98
-.59
.79
2.18
3.56
4.95
.000 .204 .408 .612 .816 1.020
.102 .306 .510 .714 .918
144.000 154.612 165.224 175.837 186.449 197.061
149.306 159.918 170.531 181.143 191.755

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)

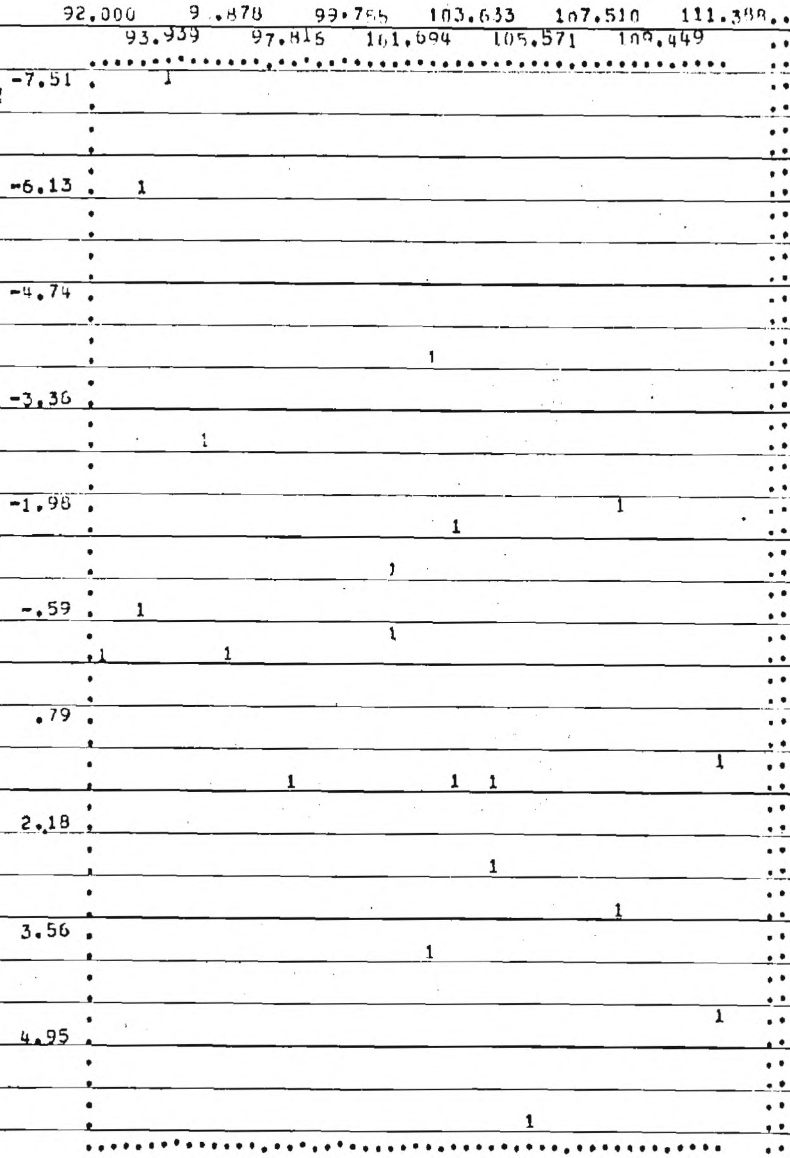


PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)



2.100 2.182 2.263 2.345 2.427 2.508 .. 302.400 340.686 378.971 417.257 455.543 493.829 ..

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)



92.000 95.878 99.755 103.633 107.510 111.388
93.939 97.816 101.694 105.571 109.449

PRINTOUT VII

VII

BMD02R - STEPWISE REGRESSION - VERSION OF SEPTEMBER 1, 1972
GEORGIA TECH PROGRAM LIBRARY

PROBLEM CODE	TFSR
NUMBER OF CASES	20
NUMBER OF ORIGINAL VARIABLES	5
NUMBER OF VARIABLES ADDED	0
TOTAL NUMBER OF VARIABLES	5
NUMBER OF SUB-PROBLEMS	1

VARIABLE		MEAN	STANDARD DEVIATION
MC	1	.50000	.51299
C	2	168.25000	19.71340
D	3	2.30000	.15894
CD	4	390.07998	54.76877
TFSR	5	83.90000	7.68388

COVARIANCE MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	.263	.711	-.000	-.000	-2.526
2		388.618	.284	951.978	-41.658
3			.025	4.286	.253
4				2998.522	-59.902
5					59.042

CORRELATION MATRIX

VARIABLE NUMBER	1	2	3	4	5
1	1.000	.070	-.000	-.000	-.641
2		1.000	.091	.882	-.275
3			1.000	.492	.207
4				1.000	-.142
5					1.000

SUB-PROBLM 1
DEPENDENT VARIABLE 5
MAXIMUM NUMBER OF STEPS 10
F-LEVEL FOR INCLUSION .010000
F-LEVEL FOR DELETION .005000
TOLERANCE LEVEL .001000

STEP NUMBER 1
VARIABLE ENTERED 1

MULTIPLE R .6409
STD. ERROR OF EST. 6.0599

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	1	460.800	460.800	12.548
RESIDUAL	18	660.999	36.722	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		88.70000)		
MC	1	-9.60000	2.71006	12.5483

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
C	2	-.30035	.9951	1.6856
D	3	.26948	1.0000	1.3312
CD	4	-.18547	1.0000	.6056

STEP NUMBER 2
VARIABLE ENTERED 2

MULTIPLE R .6811
STD. ERROR OF EST. 5.9477

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	2	520.429	260.215	7.356
RESIDUAL	17	601.370	35.375	

VARIABLES IN EQUATION

VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE
(CONSTANT		103.73563)		
MC	1	-9.35676	2.66647	12.3134
C	2	-.09009	.06939	1.6856

VARIABLES NOT IN EQUATION

VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
D	3	.31245	.9917	1.7309
CD	4	.17961	.2184	.5333

02

STEP NUMBER 3
VARIABLE ENTERED 3

MULTIPLE R .7185
STD. ERROR OF EST. 5.8238

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	3	579.137	193.046	5.692
RESIDUAL	16	542.663	33.916	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION				
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE		PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		79.55570)							
MC	1	-9.33473	2.61098	12.7819	CD	4	-.21978	.0472	.7613
C	2	-.09825	.06823	2.0738					
D	3	11.10529	8.44080	1.7309					

STEP NUMBER 4
VARIABLE ENTERED 4

MULTIPLE R .7346
STD. ERROR OF EST. 5.8677

ANALYSIS OF VARIANCE

	DF	SUM OF SQUARES	MEAN SQUARE	F RATIO
REGRESSION	4	605.349	151.337	4.395
RESIDUAL	15	516.451	34.430	

VARIABLES IN EQUATION					VARIABLES NOT IN EQUATION			
VARIABLE		COEFFICIENT	STD. ERROR	F TO REMOVE	VARIABLE	PARTIAL CORR.	TOLERANCE	F TO ENTER
(CONSTANT		46.72464)						
MC	1	-9.95300	2.72744	13.3435				
C	2	.13445	.27541	.2383				
D	3	25.24079	18.29718	1.9030				
CD	4	-.03874	.11317	.7613				

F-LEVEL INSUFFICIENT FOR FURTHER COMPUTATION

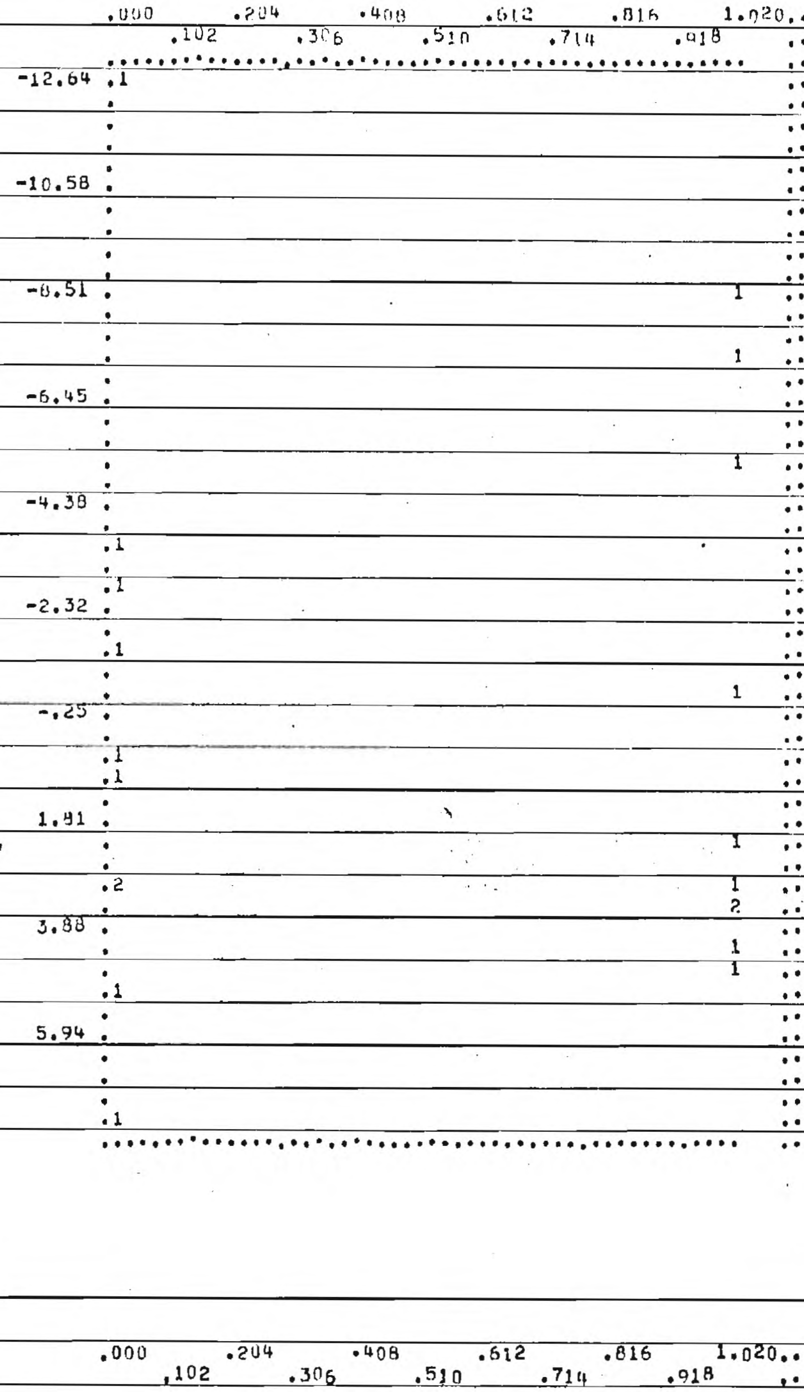
SUMMARY TABLE

STEP NUMBER	VARIABLE ENTERED	VARIABLE REMOVED	MULTIPLE R	RSQ	INCREASE IN RSQ	F VALUE TO ENTER OR REMOVE	NUMBER OF INDEPENDENT VARIABLES INCLUDED
1	MC	1	.6409	.4108	.4108	12.5483	1
2	C	2	.6811	.4639	.0532	1.6856	2
3	D	3	.7185	.5163	.0523	1.7309	3
4	CD	4	.7346	.5396	.0234	.7613	4

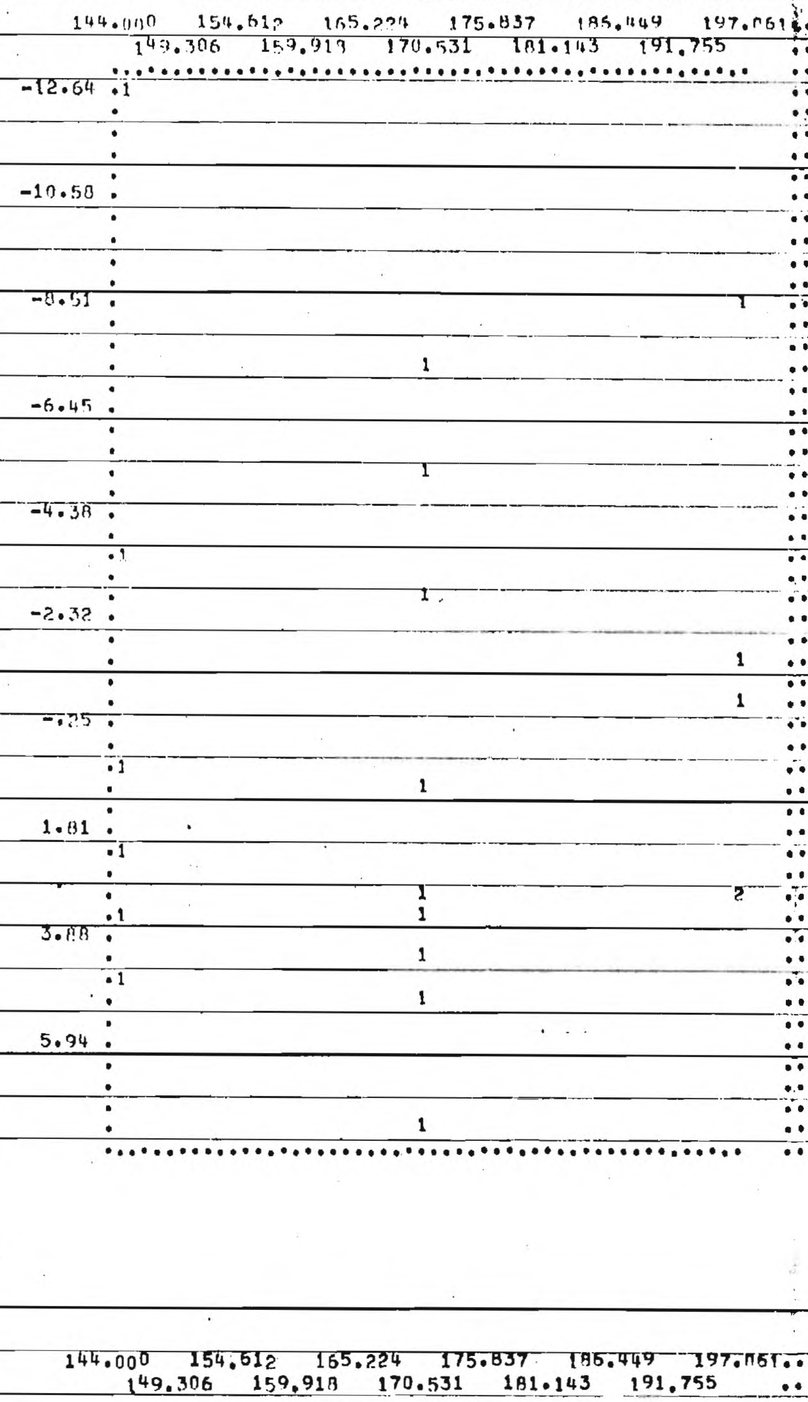
LIST OF RESIDUALS

CASE	RESIDUAL
1	-8.47628
2	2.32348
3	3.16882
4	4.73223
5	-.65373
6	3.52796
7	4.13374
8	3.55505
9	-5.15560
10	-7.15560
11	-2.80924
12	-12.63952
13	3.20582
14	.76923
15	-1.61673
16	-3.43515
17	5.17074
18	7.59206
19	2.88140
20	.88140

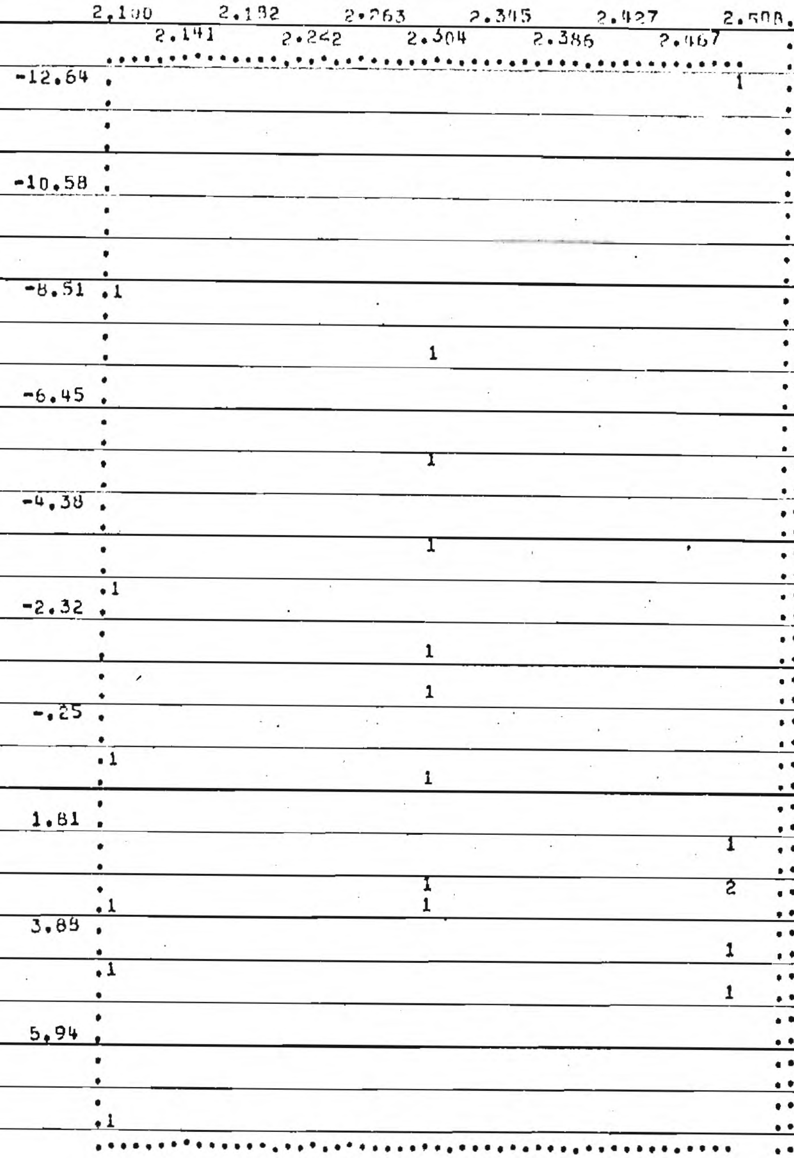
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 1 (X-AXIS)



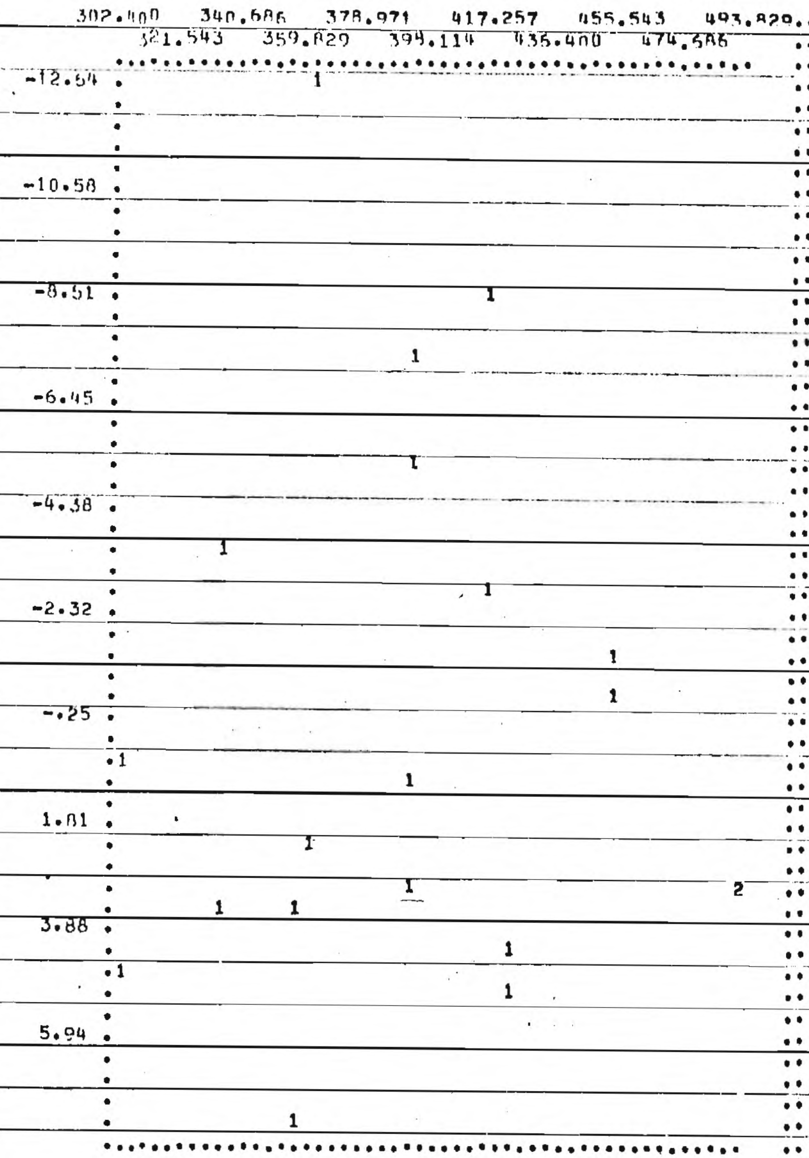
PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 2 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 3 (X-AXIS)



PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 4 (X-AXIS)



2.100 2.182 2.263 2.345 2.427 2.508
2.141 2.222 2.304 2.386 2.467

302.400 340.686 378.971 417.257 455.543 493.829
321.543 359.829 398.114 436.400 474.686

PLOT OF RESIDUALS (Y-AXIS)
VS. VARIABLE 5 (X-AXIS)