THE RELATIONSHIP BETWEEN THE FABRIC CONSTRUCTION AND THE TUFTABILITY OF JUTE CARPET BACKING FABRICS

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By

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Approved:

Date approved by Chairman:

DEDICATED

To my loving and understanding wife, Cap

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SUMMARY

The effect of fabric construction on the tuftability of jute carpet backing fabrics has been studied statistically.

Weave factors were established for fabrics of different construction. It was concluded that there is a significant correlation between weave factor and tuftability. Crimp ratio was found to be the most significant factor affecting the tuftability of the jute carpet backing fabric while yarn linear density was found to be of secondary importance.

Prediction equations based on the 34 fabrics studied were calculated by the multiple linear regression method. With these equations, the tuftability of the jute carpet backing fabrics can be predicted by knowing only the construction of the fabric.

Suggestions have also been given for future research.

CHAPTER I

INTRODUCTION

Statement of the Problem

Along with the growth of the tufted carpet industry, the utilization of woven jute fabrics for carpet backing has increased despite the introduction of synthetic backings. The major reason for this has been the relatively low cost of the jute fabrics and their superior physical properties such as strength, weight, and thickness.

In order to open a wider marketing area or at least maintain the existing marketing power, tufted carpet manufacturers show great interest in the fine gauge tufting area, such as 5/64 inch gauge. Problems arise when the tufting needle density or tuft density increases. The increase in needle density causes the deflection of warp yarns which not only decreases machine efficiency but also results in an irregular spacing of tufts which affects the pattern definition of the carpet. A more serious problem resulting from the increase in needle density is the tremendous loss of strength, especially in the filling direction, after the fabric has been tufted. The loss in strength greatly degrades the functional properties of the tufted carpet in process and in use.

In order to gain an insight into these problems, the effects of jute carpet backing fabric construction are investigated in this study.

Review of the Literature

Since the development of the tufting machine some twenty years ago, tufted carpets have become a popular subject of study, but only a few of these studies are quantitative while even fewer are theoretical.

In the early stage of the tufted carpet industry, much attention was placed on the tufted yarn. Sturley et al. (1) studied the physical properties of tufted carpets with different types of tufted yarn in terms of the resilience and wear-life of the carpet.

Dunlop (2), (3) did a detailed study of the yarn tension that developed during tufting and analyzed the data statistically. Among his investigations, he found the backing material did not affect the needle-force-yarn-tension significantly.

Cusick et al. (4) did a series of studies to evaluate the performance of tufted carpets in terms of pile compaction during use and stress-strain performance. The effect of fiber content, pile weight, and pile construction were studied. Some effects such as the resilience of the backing were mentioned, but no detailed analysis was done.

Hersh et al. (5) did a theoretical study of the mechanics of the deformation of loop-pile carpets. In this study, they were able to construct a mathematical model describing the mechanism of loop deformation with which the strain level in the fibers in a deformed carpet could be predicted.

More recently attention has been shifted to the improvement of carpet backing fabrics especially in the jute carpet backing industry in order to optimize the functional properties and expand the styling features of the tufted carpet.

Burr et al. (6) brought attention to the growth in the application of the jute fiber. They made economic and laboratory studies to account for its growing popularity. The reasons given for the popularity of jute fibers were their relatively low cost and their suitability for carpet backing materials. In their laboratory evaluations, physical properties of tufted carpets with jute backing were compared with the physical properties of tufted carpets having several types of synthetic backings. Jute backing was found to be superior to the synthetic backings. Carpets made on primary backings of jute were found to have better processibility.

An outline of the evolutionary process of carpet backing fabrics was given by Rhodes (7). His outline not only gives the historical background of carpet backing fabrics but also the characteristics of the two major types of backing--jute and synthetics. A detailed comparison was made between jute and synthetic backings. Trend and developmental guide lines were also given for the two types of backing.

In a report of the development of a new carpet backing fabric, Shealy and Lauterbach (8) described the importance of the backing fabric for a tufted carpet. They also pointed out that there was a loss of strength when the tuft density increased. This was considered to be the result of damage to yarn in the backing fabric by the needle penetration.

In a recent study, Bates (9) found that an increase in the number of stitches per inch resulted in a decrease of breaking strength and elongation of the tufted fabric. He found also that the size of tufting yarn had no significant effect on the strength of the tufted fabric. A large variation existed in the test results.

Other topics being studied are the effect of the needle shape and the density of stitches on the strength of the tufted fabric.

In a study by Boteler and Kim (10), it was found that yarn elongation had a great effect on the tensile properties of tufted carpets. The filling strength retention, which was the main concern, was found to increase as the filling yarn elongation increased.

Objective and Method of Attack

The primary purpose of this study was to establish weave factors based on the fabric geometry and determine whether or not there is any correlation between the weave factors and tuftability. The second objective was to investigate the effect of other structural variables such as crimp and yarn linear density on tuftability and finally reduce the experimental results to quantitative relationships with statistical methods.

First the structures of available jute carpet backing fabrics were analyzed. Weave factors were then calculated for each fabric. After the relationship between the weaving and tufting performance had been examined statistically, prediction equations were established by the regression analysis method.

CHAPTER II

BASIC PRINCIPLE OF THE STUDY

According to the literature examined, little attention has been given to the effect of geometrical construction of the backing fabric on the performance of the tufted carpet despite a growing interest in the study of carpet backing fabrics.

The study of fabric geometry is not an unfamiliar subject. Since Peirce's study, fabric structure has been studied extensively and related to numerous end-use performances of fabrics and materials with the fabric as a component part. Therefore, a similar attempt is believed to be applicable to tufted fabrics.

In the last chapter, it was stated that the strength degradation after a fabric has been tufted is a big problem in carpet manufacturing. When the stitch density is increased, strength degradation becomes more severe especially in the filling direction. Obviously, this loss in strength is proportional to the amount of yarn damage which is caused by the needle penetration. The relatively significant strength degradation in the filling direction is caused mainly by the shape of the needle, in which the broad side of the needle is perpendicular to the filling yarn. So the position of the fabric components (warp and filling yarns) relative to the tufting needle at the moment of penetration and after penetration is of importance. Therefore, the geometry of the fabric and the freedom of movement of the components are critical factors affecting the functional properties of the carpets. Fabric geometry can be expressed in terms of threads per inch, crimps, and yarn linear density; and the mobility of the fabric components is controlled by the tightness of the fabric structure or the type of weave.

In order to describe the influence of fabric geometry on the functional properties of the tufted carpet more effectively, an attempt was made to establish some scaleless parameters expressing the joint contribution of threads per inch and the intensity of interlacing to the tuftability of the carpet backing fabric.

The first parameter is the weave factor, W_f. The weave factor for a particular fabric can be defined as follows:

$$W_f = \frac{\text{Ends/inch X Picks/inch}}{W_m}$$

where W_m is the weave multiplier which can be defined as follows:

$$W_m = \frac{\text{Total Number of Threads per Weave Repeat}}{\text{Total Number of Interlacings per Weave Repeat}}$$

The weave multiplier is an empirically derived parameter for a particular weave type. A low value of the weave multiplier indicates a tightly constructed fabric while a high value indicates a loose fabric. The weave multiplier so derived for each type of fabric is shown in Table 10 of the Appendix.

The second parameter is crimp. Crimp is determined mainly by the number of picks per inch and the yarn linear density. As Peirce (11), (12) pointed out, the tightness of fabric structure cannot be determined without crimp data. Two fabrics might have the same weave density and yarn linear density. The change in crimp, resulting from different mechanical and chemical finishing treatments, would cause a substantial difference in the tightness of the fabric structure. Therefore, crimp is not only a major factor in fabric extensibility but also an important factor in the mobility of fabric components.

For the sake of simplicity, the crimp of both warp and filling yarns is expressed in a single value called crimp ratio. Crimp ratio, C, is defined as follows:

$$C = \frac{\text{Warp Crimp \%}}{\text{Filling Crimp \%}}$$

C > 1 indicates a higher warp crimp relative to the filling crimp while C < 1 indicates a higher filling crimp relative to the warp crimp, and C = 1 indicates that the warp crimp and filling crimp are equal. This ratio expresses the relative contribution of warp and filling crimps to the tightness of the fabric and also their relative effect on the tensile properties of the fabric.

The yarn size is a critical factor in crimp. A constant which shows the relative yarn size is the yarn linear density ratio, L, which is formed as follows:

$$L = \frac{\text{Warp Yarn Linear Density (Tex)}}{\text{Filling Yarn Linear Density (Tex)}}$$

$L > 1$ indicates a larger warp yarn size relative to the filling yarn size while $L < 1$ indicates a larger filling yarn size relative to the warp yarn size, and $L = 1$ means that the warp yarn size and filling yarn size are equal.

The geometrical factors that influence the functional properties have been examined and described in terms independent of scale such as weave factor, crimp ratio and yarn linear density ratio.

The functional property of primary interest is the tuftability of the backing fabric for carpets. This tuftability can be used as an indication of how easily and how well the backing fabric can be tufted into a carpet. The breaking strength and elongation were chosen as the quantitative expressions for the tuftability. Good retention of tensile properties after the fabric has been tufted indicates good tuftability.

Non-uniformity is a known property of jute fabrics. As Bates (9) pointed out in his study, this variation caused difficulties in the interpretation of experimental results. If the properties of fabrics having different geometrical constructions could be expressed in the same units, then the fabric properties could be compared on the same basis. Then, a more logical relationship could be established between tuftability and the jute backing fabric geometry. To do this the breaking strength can be normalized by the method proposed by Hearle and Cusick (13).

The equation for calculating the normalized strength follows:

$$\text{Normalized Fabric Strength in g-wt/Tex} = \frac{\text{(Breaking Strength) g-wt}}{\begin{matrix}\text{Weight per} \\ \text{Unit Area} \\ \text{of Fabric} \\ \text{in g/m}^2\end{matrix} \times \begin{matrix}\text{Test} \\ \text{Specimen} \\ \text{Width} \\ \text{in mm}\end{matrix}}$$

After the dependent variable (tuftability in terms of fabric tenacity and elongation) and the independent variables (weave factor, crimp ratio and linear density ratio) have been defined, some functional form can then be assumed as follows:

$$Y = f(X_1, X_2, \ldots X_k)$$

where

Y = dependent variable

$X_1, X_2, \ldots X_k$ are independent variables

In this study, a linear relationship was assumed. First simple linear equations were obtained in the following form:

$$Y = A_0 + A_1X_1$$

$$Y = B_0 + B_1X_2$$

$$\ldots$$

$$Y = N_0 + N_1X_k$$

where A_0, A_1, B_0, B_1, ... N_0, N_1 are estimated coefficients to demonstrate the nature of the relationship between the dependent variable and each independent variable.

Then the proper independent variables were selected to form a multiple linear equation of the following form from which the dependent variable can be predicted:

$$Y = C_0 + C_1X_1 + C_2X_2 + \ldots + C_kX_k$$

where C_0, C_1, C_2, ... C_k are estimated coefficients

After applying the regression technique to obtain the prediction equations, a quantitative relationship between tuftability and the fabric geometry was established.

CHAPTER III

EXPERIMENTAL PROCEDURES

Introduction

Thirty-Four jute carpet backing fabrics of various construction were studied. The construction of each backing fabric was analyzed. The tufted fabrics were prepared in the tufting laboratory of the Textile Engineering Department of the Georgia Institute of Technology. All the tufted fabrics being studied were tufted at 5/64 inch gauge with ten stitches per inch under standard conditions ($70^{o}F$, 65 percent R.H.). Both untufted and tufted fabrics were tested on the Instron Tensile Tester.

Analysis of the Backing Fabrics

The fabrics were analyzed using the conventional method. The procedures are as follows:

(1) Cut square samples (4 inches by 4 inches) from each of the 34 backing fabrics.

(2) Determine the weave type.

(3) Count the ends and picks per inch. (Take the average of ten counts).

(4) Count the ends and picks per weave repeat.

(5) Weigh the specimen and calculate the weight per unit area in grams per square meter.

(6) Count the total number of warp yarns and filling yarns in

the specimen.

(7) Weigh the warp and filling yarn separately.

The fabric analysis results are given in Table 1.

(8) Calculate the yarn linear density using the following equation:

$$\begin{pmatrix}\text{Warp or Filling}\\ \text{Yarn Linear Density}\end{pmatrix} \text{ in Tex} = \frac{\begin{pmatrix}\text{Weight of Warp or Filling}\\ \text{Yarn in Kg}\end{pmatrix}}{\begin{pmatrix}\text{Number of}\\ \text{Warp or Filling}\\ \text{Yarns}\end{pmatrix} \times \begin{pmatrix}\text{Length}\\ \text{of Each}\\ \text{Yarn in}\\ \text{m}\end{pmatrix}}$$

The calculated values of yarn linear density are shown in Table 2.

(9) Calculate the crimp percentage.

Three methods were used to obtain the crimp data, and the crimp ratios obtained from these methods were compared. The three methods were:

(a) Hand Method--Yarn from the fabric: In this method warp and filling yarns are taken from the square specimen of known dimensions and one end of a yarn is fixed on either the top of a ruler or a scaled sheet of paper. Then the yarn is extended to a straight form and the length read from the scale. Let L_1 represent the length of the specimen and L_2 be the length of the individual yarn in straight form. The crimp percentage then can be calculated as:

$$\text{Crimp \%} = \frac{L_2 - L_1}{L_1} \times 100$$

Table 1. Fabric Analysis Results

Fabric	Weave Type	Ends/Inch	Picks/Inch	Ends/ Repeat	Picks/ Repeat	Weight Per Unit Area (Grams/ Square Meter)	Weave Multiplier Wm	Weave Factor Wf
1	Plain	13	13	2	2	280.2625	1	169
2	Plain	13	13	2	2	273.2681	1	169
3	Plain	13	13	2	2	324.5762	1	169
4	Plain	15	13	2	2	310.0498	1	195
5	Plain	13	13	2	2	295.3272	1	169
6	Plain	13	13	2	2	319.4894	1	169
7	Plain	13	13	2	2	323.4024	1	169
8	Plain	15	13	2	2	335.7769	1	195
9	Plain	13	13	2	2	306.5279	1	169
10	Plain	13	13	2	2	314.9896	1	169
11	Plain	13	13	2	2	337.4888	1	169
12	Plain	15	13	2	2	341.5974	1	195
13	Plain	13	13	2	2	304.8649	1	169
14	Plain	13	13	2	2	323.0111	1	169
15	2/2 Herringbone	14	14	4	4	287.3546	2	98

Table 1. Fabric Analysis Results (continued)

Fabric	Weave Type	Ends/Inch	Picks/Inch	Ends/ Repeat	Picks/ Repeat	Weight Per Unit Area (Grams/ Square Meter)	Weave Multiplier Wm	Weave Factor W_f
16	2/2 Herringbone	15	14	4	4	302.8596	2	105
17	3/1 Broken Twill	14	14	4	4	261.0892	2	98
18	3/1 Broken Twill	15	14	4	4	259.9642	2	105
19	Four Harness Sateen	13	20	4	4	295.1316	2	130
20	Four Harness Sateen	15	20	4	4	353.8253	2	150
21	Double Weft Plain	13	20	2	4	293.1751	1.5	173
22	Double Weft Plain	15	20	2	4	323.9697	1.5	200
23	Plain	12	13	2	2	238.5899	1	156
24	Plain	13	13	2	2	248.3233	1	169
25	Plain	13	13	2	2	247.1494	1	169
26	Plain	14	13	2	2	273.5616	1	182
27	Plain	12	14	2	2	225.3056	1	168
28	Plain	12	14	2	2	229.7859	1	168
29	2/1 Twill	13	13	3	3	245.0658	1.5	113

Table I. Fabric Analysis Results (continued)

Fabric	Weave Type	Ends/Inch	Picks/Inch	Ends/ Repeat	Picks/ Repeat	Weight Per Unit Area (Grams/ Square Meter)	Weave Multiplier Wm	Weave Factor W_f
30	2/1 Twill	13	13	3	3	280.3603	1.5	113
31	2/1 Twill	13	13	3	3	258.7415	1.5	113
32	2/1 Twill	13	13	3	3	241.5246	1.5	113
33	2/1 Twill	12	14	3	3	223.9165	1.5	112
34	2/1 Twill	12	14	3	3	228.3185	1.5	112

Table 2. Yarn Linear Density

Fabric	Warp (Tex)	Filling (Tex)	Ratio (Warp/Filling)
1	272.6	266.6	1.0225
2	263.4	259.6	1.0146
3	273.5	334.7	.8171
4	242.9	279.8	.8681
5	255.8	317.7	.8052
6	268.0	346.5	.7734
7	238.8	371.1	.6435
8	236.7	363.5	.6512
9	262.3	333.7	.7860
10	254.5	350.6	.7256
11	251.0	373.0	.6729
12	237.2	371.1	.6392
13	252.2	324.7	.7767
14	229.3	383.1	.5985
15	237.6	263.1	.9031
16	231.7	263.3	.8800
17	221.0	242.0	.9132
18	209.9	228.3	.9194
19	249.2	205.0	1.2156
20	221.2	271.4	.8150
21	243.8	206.7	1.1795

Table 2. Yarn Linear Density (continued)

Fabric	Warp (Tex)	Filling (Tex)	Ratio (Warp/Filling)
22	221.7	237.1	.9325
23	204.7	248.9	.8224
24	221.3	251.1	.8813
25	213.6	271.4	.7870
26	220.5	328.0	.6723
27	198.6	228.5	.8691
28	202.1	243.7	.8293
29	220.8	250.7	.8807
30	282.2	235.9	1.1963
31	205.0	284.1	.7216
32	213.9	242.8	.8810
33	214.1	212.9	1.0056
34	210.8	215.9	.9764

The Dead Load Method uses the same principle and has been described (14).

(b) Load-Elongation Method--Yarn from fabric: Yarns from the fabric are tested in the Instron Tensile Tester. Detailed procedures are given in the Federal Test Method Standard No. 191, Method 4112 (14).

(c) Load-Elongation Method--Fabric: The crimp data can be obtained from the fabric stress-strain curve which is shown in Figure 1 and can be calculated with the following equation:

$$\text{Crimp \%} = \frac{\text{Jaw Speed X OC*}}{\text{Chart Speed X Gauge Length}} \text{ X } 100$$

In order to see if the crimp ratios obtained from the three methods were significantly different from each other, the crimp ratios were compared by using the One-Way-Analysis of Variance Method. It was found that there were no significant differences at a five percent significance level. The analysis of variance table is shown in Table 11 of the Appendix.

The Hand Method is not very scientific, but it is considered adequate for normal inspection work, and it is a quick way to determine crimp.

The Yarn Load-Elongation Method, which was the second method described, is a more accurate method but more time consuming.

The Fabric Load-Elongation Method, the third method described, seemed to be the most efficient method used in this study since other

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* See Figure 1.

data such as the elongation and the breaking strength of the fabric can be obtained in addition to the crimp data. Thus the data obtained from this method were selected for this study.

The crimp data obtained from these three methods are listed in Table 3.

Stress-Strain Properties of the Fabrics

Untufted and tufted fabrics were tested on the Instron Tensile Tester at standard testing conditions. The tensile test results for untufted and tufted fabrics are shown in Tables 4 and 5 respectively. All the data listed in both tables are the average values of ten or more observations depending upon the calculated sample size for each sample according to the ASTM Designation: D2264-64T (15). Each specimen was 4 inches by 8 inches. Untufted and tufted fabrics were tested in both warp and filling directions. Typical stress-strain curves of untufted and tufted fabrics in the filling direction can be seen in Figure 1.

Table 3. Crimp and Crimp Ratio Determined by Different Methods

Fabric	Yarn From Fabric Hand-Method % Warp	Yarn From Fabric Hand-Method % Filling	Crimp Ratio Warp/Filling	Yarn From Fabric Load-Elongation Method % Warp	Yarn From Fabric Load-Elongation Method % Filling	Crimp Ratio Warp/Filling	Fabric Load-Elongation Method % Warp	Fabric Load-Elongation Method % Filling	Crimp Ratio Warp/Filling
1	6.65	6.65	1	9.57	8.86	1.0806	3.7	3.1	1.1935
2	5.65	6.20	0.9113	8.40	7.66	1.0970	4.0	3.5	1.1429
3	6.30	10.15	0.6207	7.09	22.71	0.3119	2.4	7.8	0.3077
4	4.10	24.85	0.165	5.80	64.57	0.0898	3.3	24.4	0.1352
5	5.90	4.75	1.2421	8.97	7.31	1.2266	4.3	3.5	1.2286
6	6.90	5.25	1.3143	11.20	7.66	1.4627	4.3	3.7	1.1622
7	4.65	10.10	0.4604	7.40	21.94	0.3372	2.9	7.9	0.3671
8	6.90	24.95	0.2766	8.37	61.17	0.1369	3.4	20.1	0.1692
9	6.15	5.65	1.0885	9.06	7.54	1.2008	4.4	3.5	1.2571
10	7.50	5.60	1.3393	10.66	7.49	1.4237	3.9	3.2	1.2188
11	5.85	13.05	0.4483	6.29	30.83	0.2039	2.4	10.0	0.24
12	5.20	30.95	0.168	9.03	63.60	0.1420	3.1	23.0	0.1348
13	6.50	10.35	0.628	4.71	19.63	0.2402	2.7	6.5	0.4154
14	6.35	13.90	0.4568	6.46	27.11	0.2381	2.8	8.2	0.2805
15	4.25	6.60	0.6439	5.49	8.40	0.6531	2.2	4.4	0.5

Table 3. Crimp and Crimp Ratio Determined by Different Methods (continued)

Fabric	Yarn From Fabric Hand-Method % Warp	Filling	Crimp Ratio Warp/Filling	Yarn From Fabric Load-Elongation Method % Warp	Filling	Crimp Ratio Warp/Filling	Fabric Load-Elongation Method % Warp	Filling	Crimp Ratio Warp/Filling
16	4.35	19.95	0.218	5.89	28.07	0.2097	2.2	13.1	0.1679
17	3.30	5.30	0.6226	4.29	7.11	0.6024	1.7	2.8	0.6071
18	4.30	14.00	0.3071	5.65	31.74	0.1782	2.4	9.7	0.2474
19	3.45	6.50	0.5308	3.97	10.63	0.3737	2.3	4.1	0.561
20	4.50	23.40	0.1923	6.63	53.80	0.1232	2.6	16.9	0.1538
21	4.85	4.65	1.043	7.06	7.54	0.9356	3.3	2.6	1.2692
22	5.10	23.60	0.2161	7.31	53.69	0.1362	2.4	18.0	0.1333
23	7.65	5.40	1.4167	13.03	5.06	2.5763	4.0	2.6	1.5385
24	8.10	4.60	1.7609	11.80	7.57	1.5585	3.6	2.9	1.2414
25	3.50	9.00	0.389	5.49	15.89	0.3453	1.4	6.5	0.2154
26	3.45	15.80	0.2184	3.57	32.37	0.1103	1.2	11.8	0.1017
27	3.65	17.15	0.2128	5.03	35.63	0.1411	1.7	12.4	0.1371
28	3.40	20.00	0.1700	2.74	40.14	0.0683	1.7	16.4	0.1027
29	5.80	5.55	1.045	6.57	5.86	1.122	3.7	2.8	1.3214
30	5.65	3.70	1.527	6.77	7.51	0.9011	2.7	3.4	0.7941

Table 3. Crimp and Crimp Ratio Determined by Different Methods (continued)

	Yarn FromFabric Hand-Method %		Crimp Ratio	Yarn From Fabric Load-Elongation Method %		Crimp Ratio	Fabric Load-Elongation Method %		Crimp Ratio
Fabric	Warp	Filling	Warp/Filling	Warp	Filling	Warp/Filling	Warp	Filling	Warp/Filling
31	2.85	8.60	0.3314	3.03	13.54	0.2236	1.3	5.8	0.2241
32	3.60	10.25	0.3512	2.14	24.69	0.0868	1.3	8.0	0.1625
33	6.95	12.15	0.5679	5.65	23.2	0.2438	2.3	10.3	0.2233
34	7.40	12.70	0.5827	5.37	24.37	0.2204	2.7	9.4	0.2872

Table 4. Stress-Strain Properties of Untufted Fabrics

Fabric	Fabric Strength in Lbs. Warpwise	Fabric Strength in Lbs. Fillingwise	Normalized Fabric Strength in g/tex X 10^2 Warpwise	Normalized Fabric Strength in g/tex X 10^2 Fillingwise	Fabric Elongation % Warpwise	Fabric Elongation % Fillingwise
1	94.3	101.6	152.7575	164.5828	7.9	7.5
2	86.9	84.7	144.3732	140.7182	7.8	7.6
3	82.5	79.6	115.3966	111.3403	5.7	15.2
4	91.3	84.9	133.6888	124.3174	5.8	38.7
5	91.5	126.5	140.6609	194.4657	8.5	7.6
6	86.7	114.4	123.2022	162.5644	8.5	7.8
7	79.3	106.9	111.3232	150.0688	6.4	16.3
8	78.9	93.8	106.6798	126.8259	6.3	31.6
9	88.7	147.2	131.3740	218.0187	8.4	8.9
10	86.8	137.5	125.1064	198.1811	9.8	9.3
11	75.6	126.5	101.6994	170.1716	6.1	19.4
12	91.8	124.5	122.0068	165.4667	6.5	38.2
13	93.9	83.7	139.8344	124.6447	5.5	13.2
14	92.5	102.0	130.0110	143.3635	5.2	24.3
15	107.3	76.0	169.5264	120.0746	4.4	7.5
16	97.0	61.9	145.4073	92.7909	4.6	19.9
17	97.0	87.7	168.6703	152.4988	4.1	5.9
18	84.9	66.2	148.2689	115.6113	4.6	14.7
19	106.7	138.8	164.1363	213.5156	6.2	8.1
20	92.5	132.5	118.6885	170.0133	5.2	29.0

Table 4. Stress-Strain Properties of Untufted Fabrics (continued)

Fabric	Fabric Strength in Lbs. Warpwise	Fabric Strength in Lbs. Fillingwise	Normalized Fabric Strength in g/tex X 10^2 Warpwise	Normalized Fabric Strength in g/tex X 10^2 Fillingwise	Fabric Elongation % Warpwise	Fabric Elongation % Fillingwise
21	106.7	136.7	165.2316	211.6885	7.5	6.8
22	88.8	100.7	124.4413	141.1175	5.0	28.0
23	67.9	91.6	129.2033	174.3008	7.7	5.7
24	66.9	85.7	122.3107	156.6820	7.4	6.1
25	73.4	88.4	134.8318	162.3860	4.2	10.6
26	73.0	96.9	121.1500	160.8142	3.5	17.9
27	54.1	71.7	109.0137	144.4784	3.7	19.0
28	63.8	78.0	126.0530	154.1087	3.8	22.7
29	69.3	76.7	128.3827	142.0916	6.2	5.3
30	73.7	79.7	119.3457	129.0618	5.1	6.4
31	75.5	87.2	132.4758	153.0052	3.5	9.1
32	79.6	69.1	149.6262	129.8890	3.2	11.7
33	53.3	63.0	108.0680	127.7451	4.2	14.0
34	55.0	67.6	109.3648	134.4192	4.7	12.5

Table 5. Stress-Strain Properties of Tufted Fabrics

Fabric	Fabric Strength in Lbs. Warpwise	Fillingwise	Normalized Fabric Strength in g/tex X 10^2 Warpwise	Fillingwise	Fabric Elongation % Warpwise	Fillingwise
1	83.4	35.7	135.1005	57.8308	7.8	6.8
2	80.3	31.8	133.4082	52.8316	8.5	7.2
3	72.0	32.8	100.7098	45.8789	7.9	12.4
4	78.3	58.0	114.6532	84.9283	5.4	28.3
5	83.1	35.3	127.7478	54.2659	8.4	6.3
6	76.7	31.8	108.9920	45.1884	8.3	7.3
7	67.4	52.9	100.8548	74.2623	8.3	13.6
8	81.7	62.8	110.4656	84.9111	5.6	23.5
9	81.2	48.4	120.2657	71.6855	8.0	7.5
10	78.8	41.6	113.5758	59.9588	8.7	8.3
11	72.7	53.7	97.7982	72.2388	7.6	16.0
12	79.5	79.3	105.6595	105.3937	6.6	27.0
13	79.5	37.2	118.3901	55.3977	5.6	13.7
14	78.3	58.1	110.0526	81.6610	5.9	22.9
15	95.1	38.3	150.2513	60.5113	6.8	8.7
16	81.5	45.0	122.1721	67.4570	5.6	18.4
17	89.5	38.1	155.6288	66.2509	5.4	7.5
18	73.5	37.2	128.3600	64.9659	6.2	12.9
19	90.0	67.7	138.4467	104.1427	6.4	9.7
20	87.1	75.6	111.7597	97.0038	4.9	23.8

Table 5. Stress-Strain Properties of Tufted Fabrics (continued)

Fabric	Fabric Strength in Lbs.		Normalized Fabric Strength in g/tex X 10^2		Fabric Elongation %	
	Warpwise	Fillingwise	Warpwise	Fillingwise	Warpwise	Fillingwise
21	82.5	61.1	127.7564	94.6172	9.1	6.9
22	84.0	71.0	117.7147	99.4970	6.3	26.9
23	73.6	40.2	140.0495	76.4944	8.6	5.7
24	74.9	37.1	136.9368	67.8285	8.0	6.6
25	70.6	45.2	129.6884	83.0299	6.2	9.7
26	68.7	42.7	114.0138	70.8645	5.4	15.4
27	53.1	41.8	106.9987	84.2287	3.6	17.6
28	61.0	33.8	120.5209	66.7804	3.4	16.4
29	70.5	38.1	130.6057	70.5827	6.5	6.1
30	77.7	37.0	125.8231	59.9158	6.5	6.9
31	68.7	38.2	120.5442	67.0275	4.9	9.3
32	73.1	29.4	137.4079	55.2939	4.4	11.0
33	56.3	37.5	114.1506	76.0328	3.8	12.7
34	59.7	44.3	118.7105	88.0884	3.9	15.2

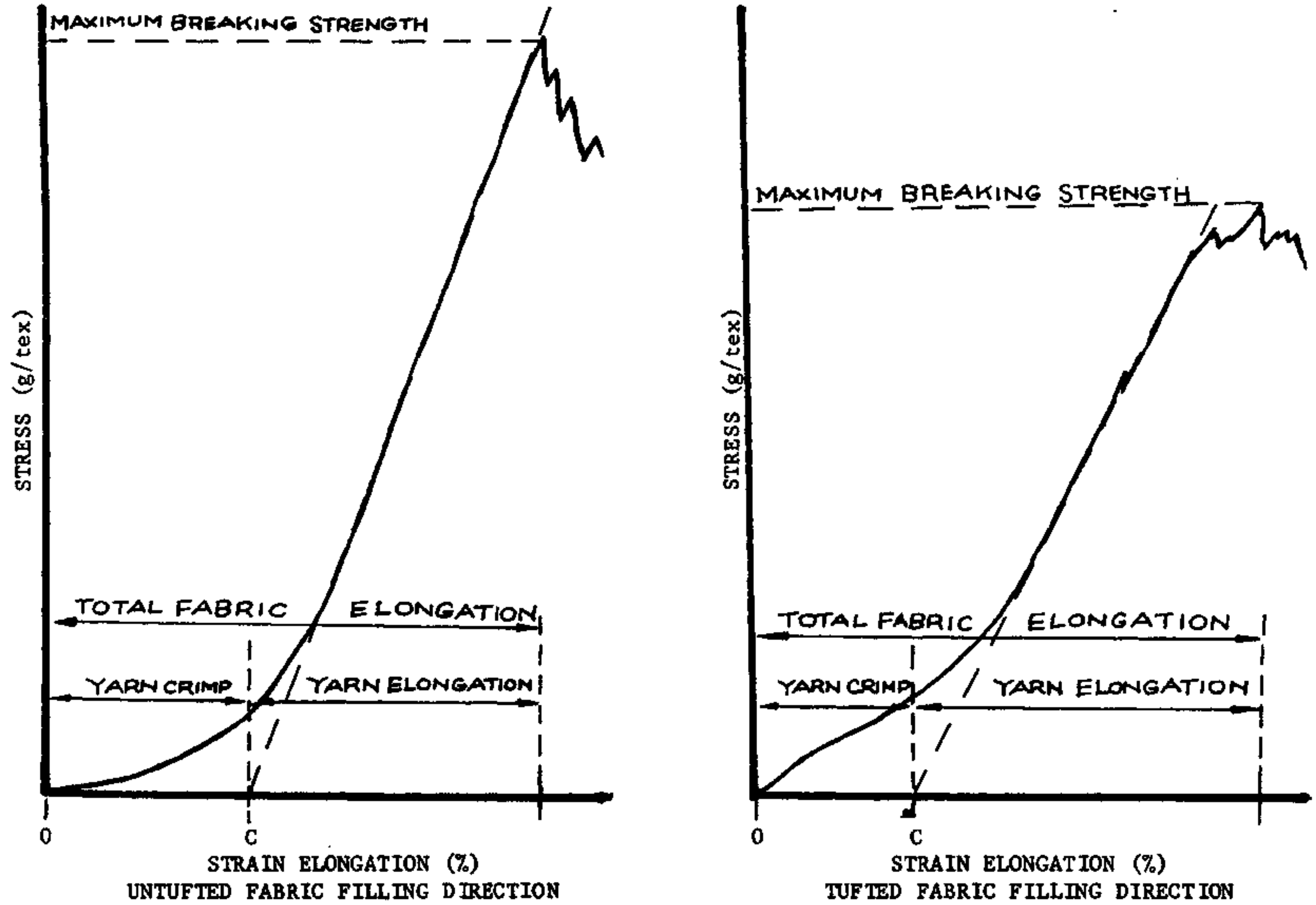

Figure 1. Typical Stress-Strain Curves of Jute Carpet Backing Fabrics

CHAPTER IV

ANALYSIS OF RESULTS AND DISCUSSION

Introduction

Statistical methods were used to analyze the results. A Hewlett-Packard Model 9100 Calculator was used for all the calculations and curve plotting. Simple linear regression was used for the investigation of the relationship between tuftability, that is strength and elongation of the fabrics, and the independent variables such as weave factor and crimp ratio. The correlation coefficients were calculated to determine how much each independent variable contributes to the variation of the dependent variable. Also a significance test was applied to see if the slope of the regression equations differed significantly from zero. All the simple regression equations are shown in Table 6. Besides examining the correlation coefficients and the level of significance of the relationships, the regression curves and the scatter diagrams were examined to establish the graphical relationship between the dependent variable and independent variable. In addition, the tensile properties of the untufted and tufted fabrics were compared. The significance tests used here have been described by Lieberman (16).

The multiple regression method was then used to establish the prediction equations. With these equations not only can the tuftability of a fabric be predicted but the joint effects of the independent variables such as weave factor and crimp ratio can be determined. The multiple correlation coefficients and the 90 percent and 95 percent confidence limits are shown in Table 7, and the methods of calculation are given in Tables 12 and 13 of the Appendix. The multiple regression method has been clearly detailed by Johnson (17). The coefficients of determination are shown in Table 8, and a list of the range of the dependent and independent variables is given in Table 9.

The Effect of the Backing Fabric Construction on Fabric Strength

Effect of the Weave Multiplier, W_m

The regression of the fabric strength on the weave multiplier was found to be more significant in the warp direction at a 99 percent level than in the filling direction, which was only at a 60 percent level.

From the correlation coefficient shown in Table 6, Equations 1-4, we can see that more than 20 percent of the variation of strength in the warp direction was contributed by the weave multiplier.

As illustrated in Figure 2, the warpwise strength increases with the increase of the weave multiplier for both untufted and tufted fabrics, and Figure 3 shows that the untufted fabric fillingwise strength decreases with the increase of the weave multiplier while the tufted fabric fillingwise strength increases with the increase of the weave multiplier.

After the fabric had been tufted, a loss in strength was found in both warp and filling directions. This phenomenon was more severe in the filling direction. As the weave multiplier increases, the strength degradation tends to be slightly higher while in the filling direction the strength degradation becomes less severe.

These results suggest that looser fabric constructions such as the

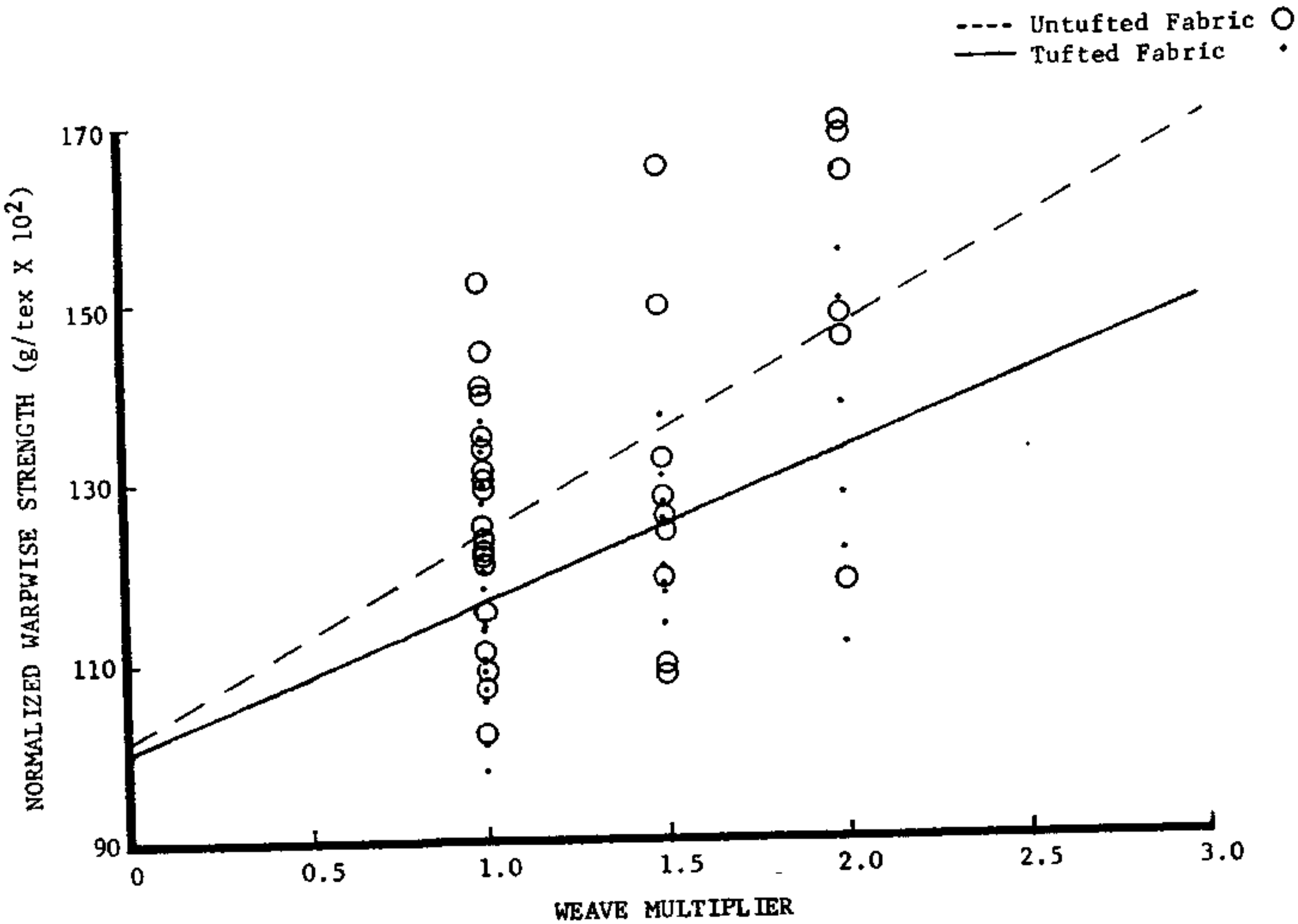

Figure 2. The Effect of Weave Multiplier on Normalized Warpwise Strength

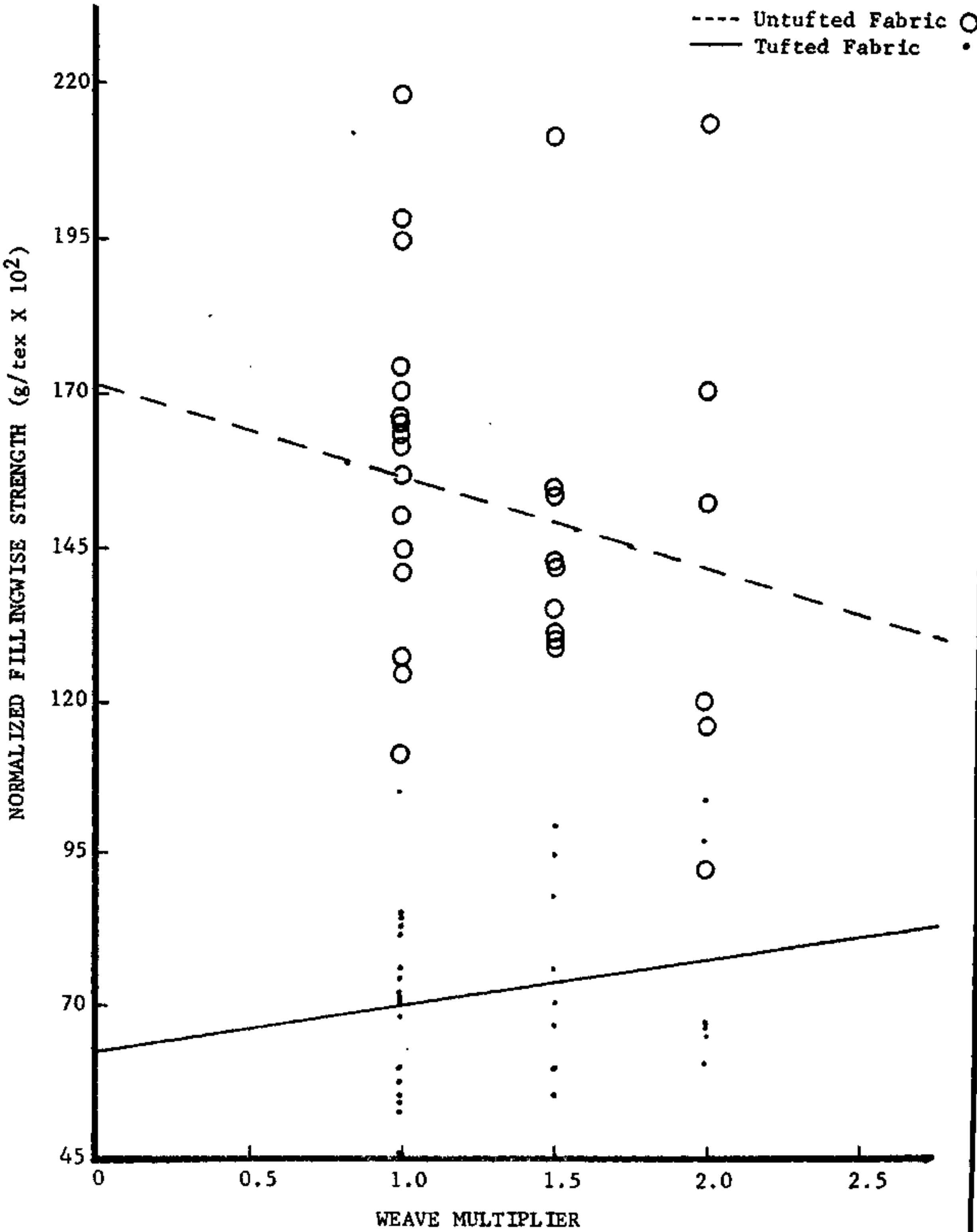

Figure 3. The Effect of Weave Multiplier on Normalized Fillingwise Strength

four harness twills and sateen are preferred if high strength retention is desired. The major reason for higher strength retention in looser structures is that the yarns have more freedom of movement, therefore, less yarn is damaged during the tufting process.

Effect of the Weave Factor, W_f

The effects of the weave factor on strength are shown in Table 6, Equations 5-7 and in Figures 4 and 5.

In general, as expected, the regression of strength on the weave factor is more significant than on the weave multiplier since the weave factor represents the joint effect of the weave multiplier and threads per unit area.

Relatively higher correlation between strength and the weave factor was found in the warp direction. The warpwise strength tends to decrease with the increase of the weave factor for both untufted and tufted fabrics; and in the filling direction, both untufted and tufted fabric strengths increase with the increase of the weave factor. These results generally agree with those in the effect of the weave multiplier. We know that the weave factor is an indication of the density of interlacing of yarns within a fabric or the tightness of the structure. The decrease in warpwise strength may be due to the loss of efficiency of fibers within the yarn because when the frequency of yarn interlacing increases, the degree of fiber bending increases at the same time. Therefore, the contribution of fiber strength to the yarn will decrease and in turn affect the fabric strength.

In the filling direction, the strength of untufted and tufted fabrics increases with the weave factor. This is in contrast to what we

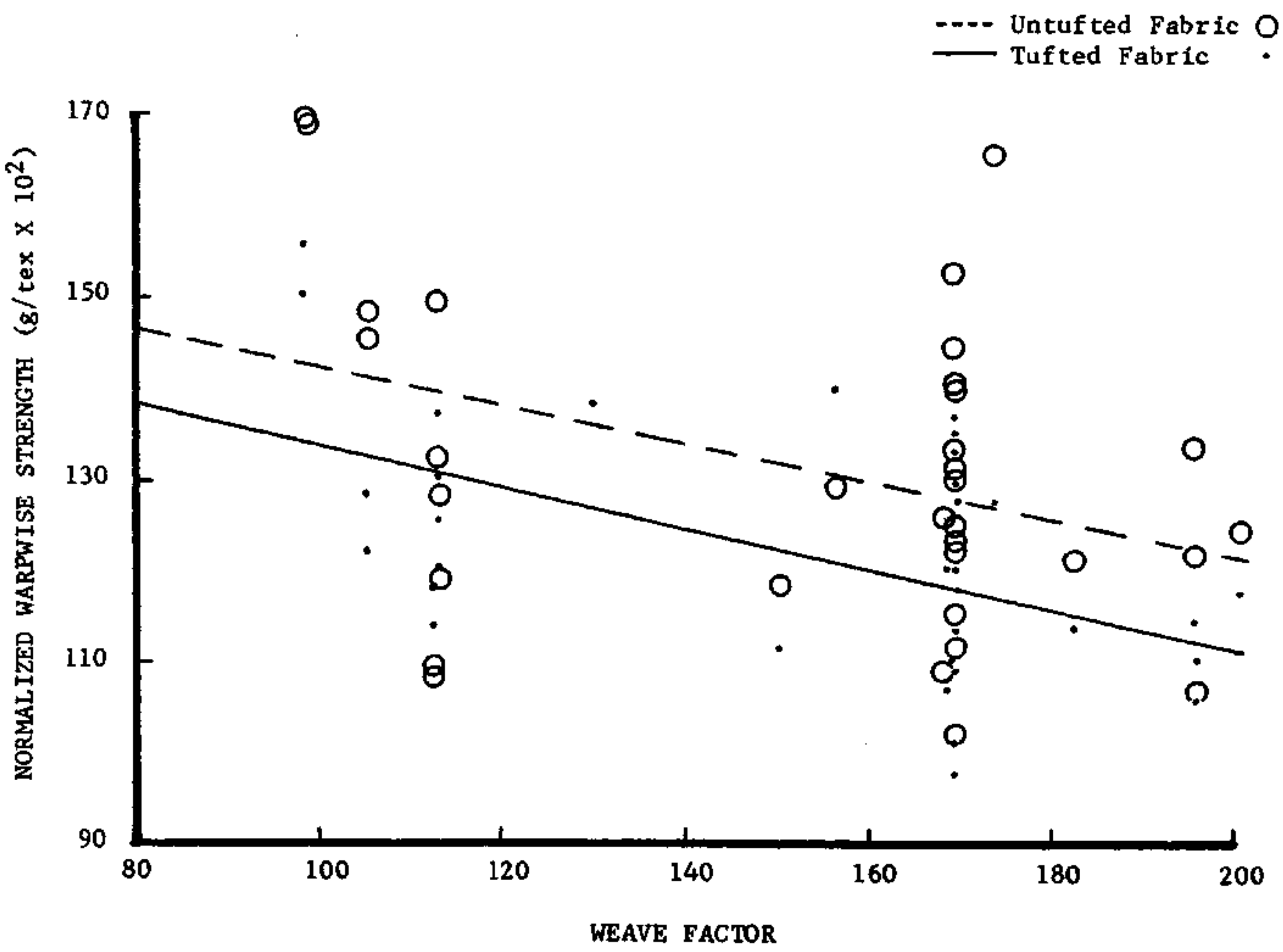

Figure 4. The Effect of Weave Factor on Normalized Warpwise Strength

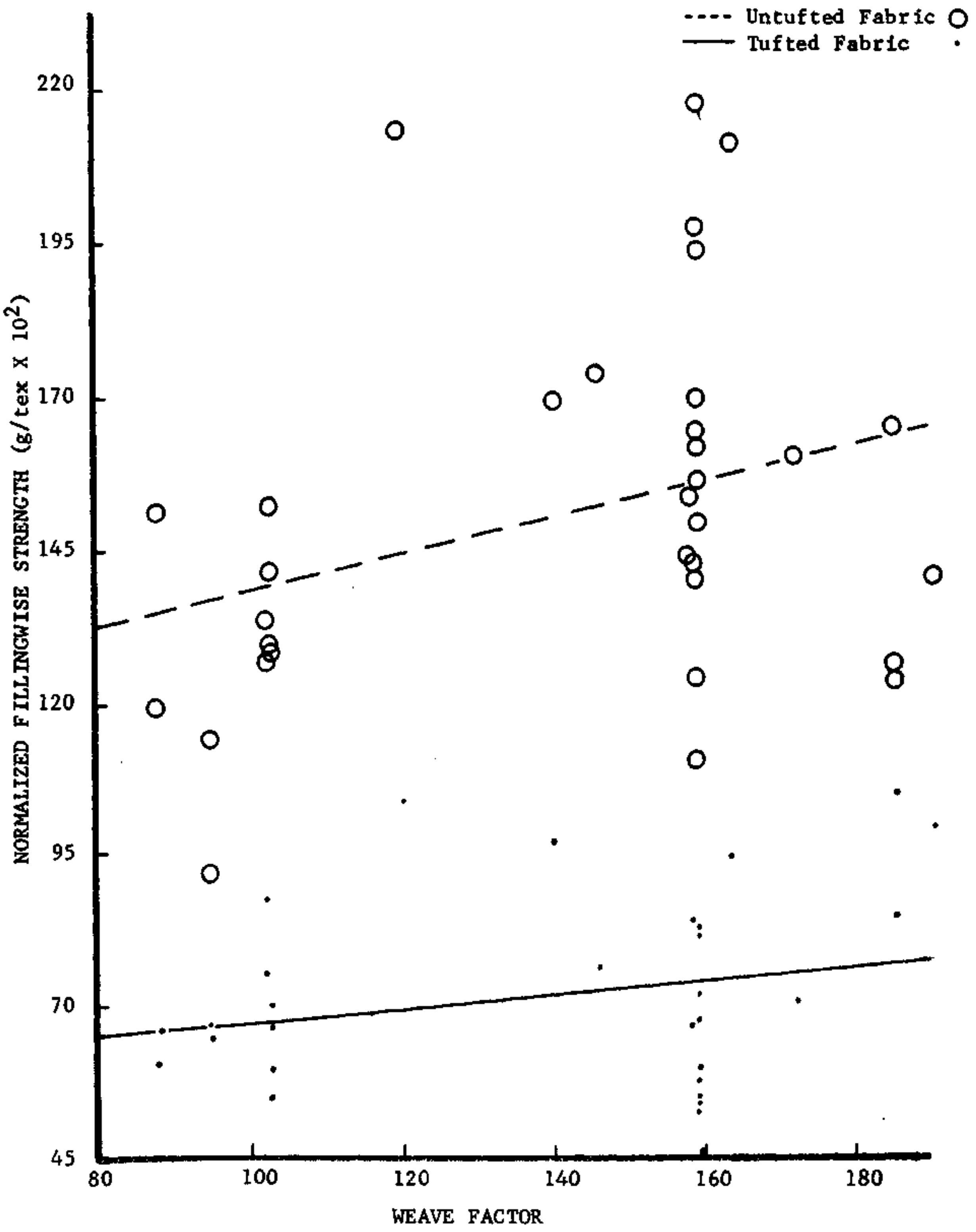

Figure 5. The Effect of Weave Factor on Normalized Fillingwise Strength

observed in the warp direction. This may be due to the relatively larger size of the filling yarns with respect to the size of the warp yarns. This may be seen in Table 4 where 28 of the 34 fabrics used in this study have a higher filling yarn linear density. Therefore, the filling yarns are stronger and the bending of fibers due to the increase of interlacing does not create a significant effect on the fabric strength. On the other hand, the increase in the yarn interlacing may cause an increase in inter-fiber friction which would contribute to the increase of fabric strength.

As to the degradation of strength after the fabric has been tufted, the strength loss in the warp direction is not as great as that in the filling direction. The loss of strength tends to be higher when the construction of the fabric is tighter because when the yarns are packed closer to each other, the possibility of being hit by the needle is greater and therefore, a higher percentage of strength degradation is expected. This effect is less extreme in the warp direction. One reason for this is the shape of the needle. The warp yarns have less chance of being damaged than the filling yarns because the broad side of the needle is parallel to the warp yarn. Another reason for this effect is the addition of tufted yarns in the warp direction. After the failure of the backing fabric structure, the load can still be supported by the tufted yarns.

<u>Effect of the Crimp Ratio, C</u>

The relationship between fabric strength and the crimp ratio was found to be significant at a level higher than 80 percent. This is shown in Table 6, Equations 9 to 12.

From Figures 6 and 7 it can be seen that the warpwise strength

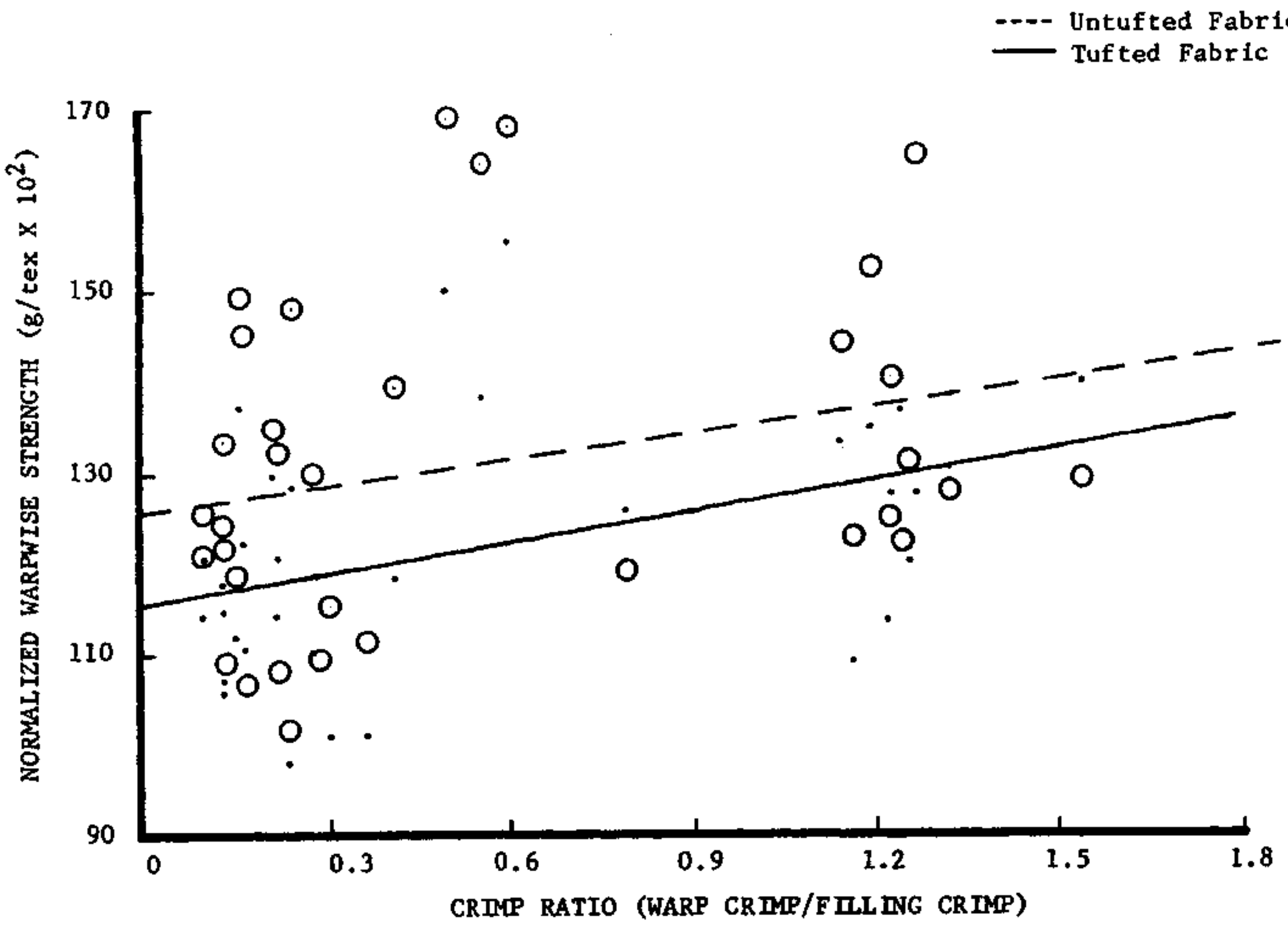

Figure 6. The Effect of Crimp Ratio on Normalized Warpwise Strength

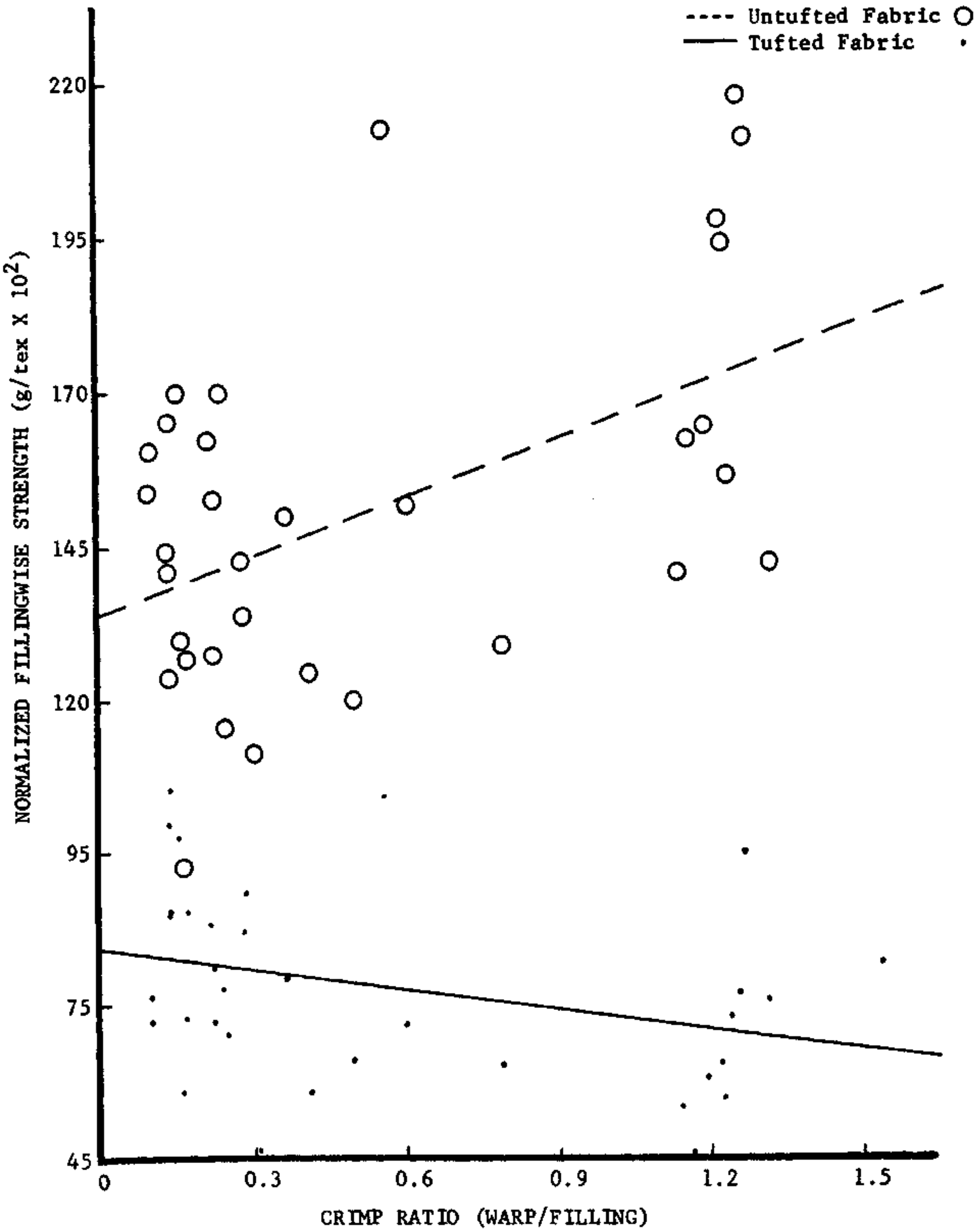

Figure 7. The Effect of Crimp Ratio on Normalized Fillingwise Strength

increases with the increase of the relative crimp level for both untufted and tufted fabrics. In the filling direction, the strength of the untufted fabrics increases with increase of the crimp ratio while for the tufted fabrics, the strength decreases with increase of the crimp ratio. These results imply that the warpwise strength can be increased by increasing the warp yarn crimp for both untufted and tufted fabrics. For an increase in the fillingwise tufted fabric strength, the filling crimp can be increased.

There is a loss of strength in both the warp and filling directions after the fabric has been tufted. As was shown previously, the fillingwise strength retention is poorer than the warpwise strength retention. The loss of fillingwise strength was found to be more significant for fabrics having a high crimp ratio than those with a low crimp ratio. This means an increase of filling crimp could achieve higher filling strength retention. In order to verify this result, the effect of the filling yarn crimp alone on the fillingwise strength was examined. The results are shown in Table 6, Equations 42 and 43 and in Figure 8. The same conclusion was drawn as that given for the effect of crimp ratio. The untufted fabric strength decreases with an increase of filling yarn crimp and the tufted fabric strength tends to increase with an increase of filling yarn crimp. The loss of strength after tufting was found to be reduced for the fabrics with high filling yarn crimp. This agreement of results suggests that crimp ratio is capable of reflecting both the relative effect and the sole effect of warp and filling crimp on the fabric strength.

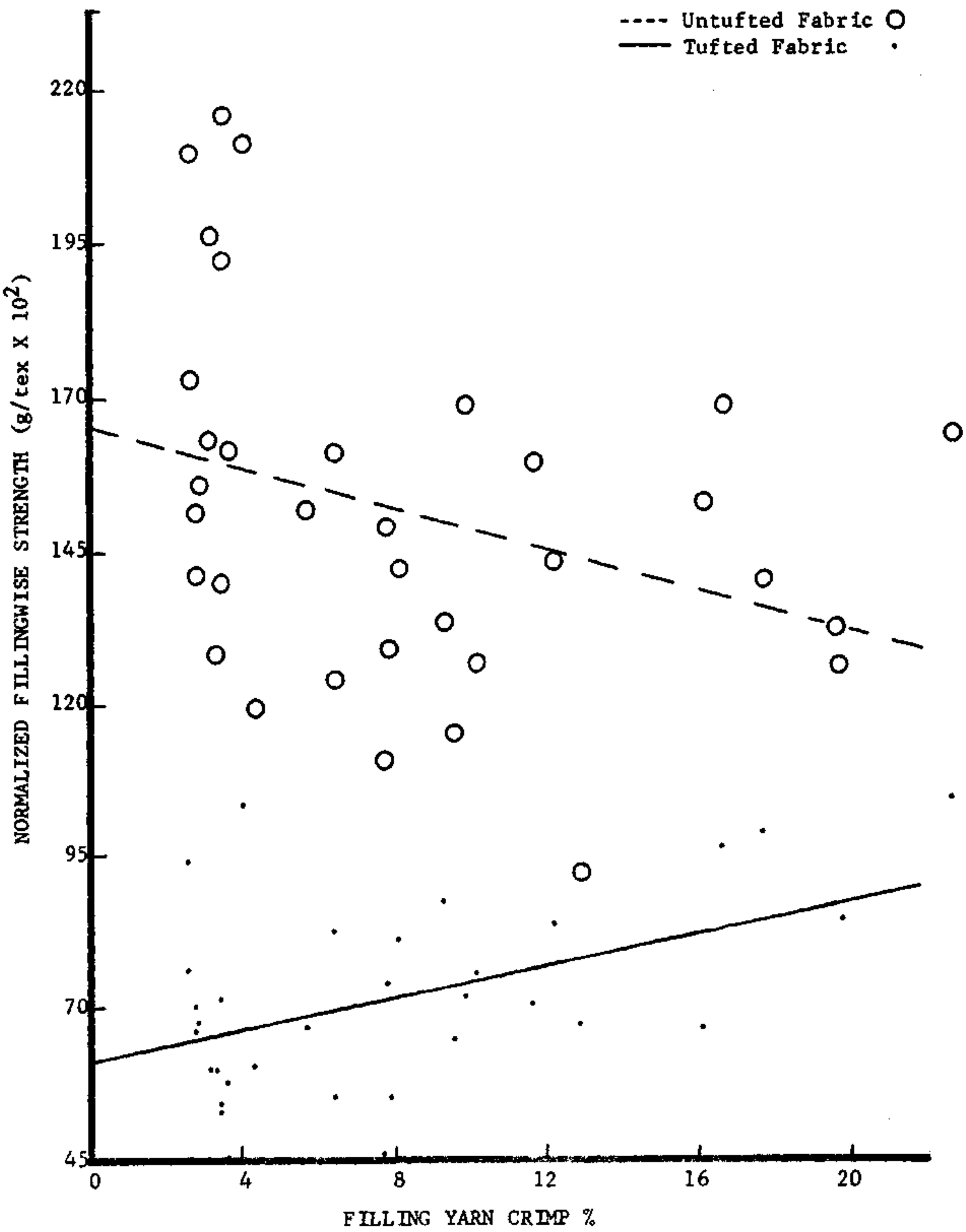

Figure 8. The Effect of Filling Yarn Crimp on Normalized Fillingwise Strength

Effect of the Yarn Linear Density Ratio, L

The relationship of the relative yarn linear density to the warpwise strength is much more significant than with the fillingwise strength. The appropriate significance levels for these relationships and the correlation coefficients are shown in Table 6, Equations 13-16. Their graphical relationships are shown in Figures 9 and 10.

The strength in both warp and filling directions was found to increase simultaneously with the increase of yarn linear density ratio for untufted and tufted fabrics. This means that the warpwise strength tends to increase with an increase of the warp yarn linear density, and the fillingwise strength decreases with an increase of the filling yarn linear density. Since the fabrics being studied are composed of the same raw material and structure, it can be assumed that they have the same fineness. The yarn linear density can therefore be considered as the yarn size. According to these results, warpwise and fillingwise strength of both untufted and tufted fabrics can be increased by increasing the warp yarn size in respect to the filling yarn size.

The loss of strength after tufting was found to be more significant in the filling direction. As the relative yarn size increases, the strength degradation increases only slightly.

The filling yarn tex was plotted against the fillingwise strength in Figure 11. The correlations are not very significant for either untufted or tufted fabric, but it does show that higher strength retention can be achieved with lower filling yarn linear density.

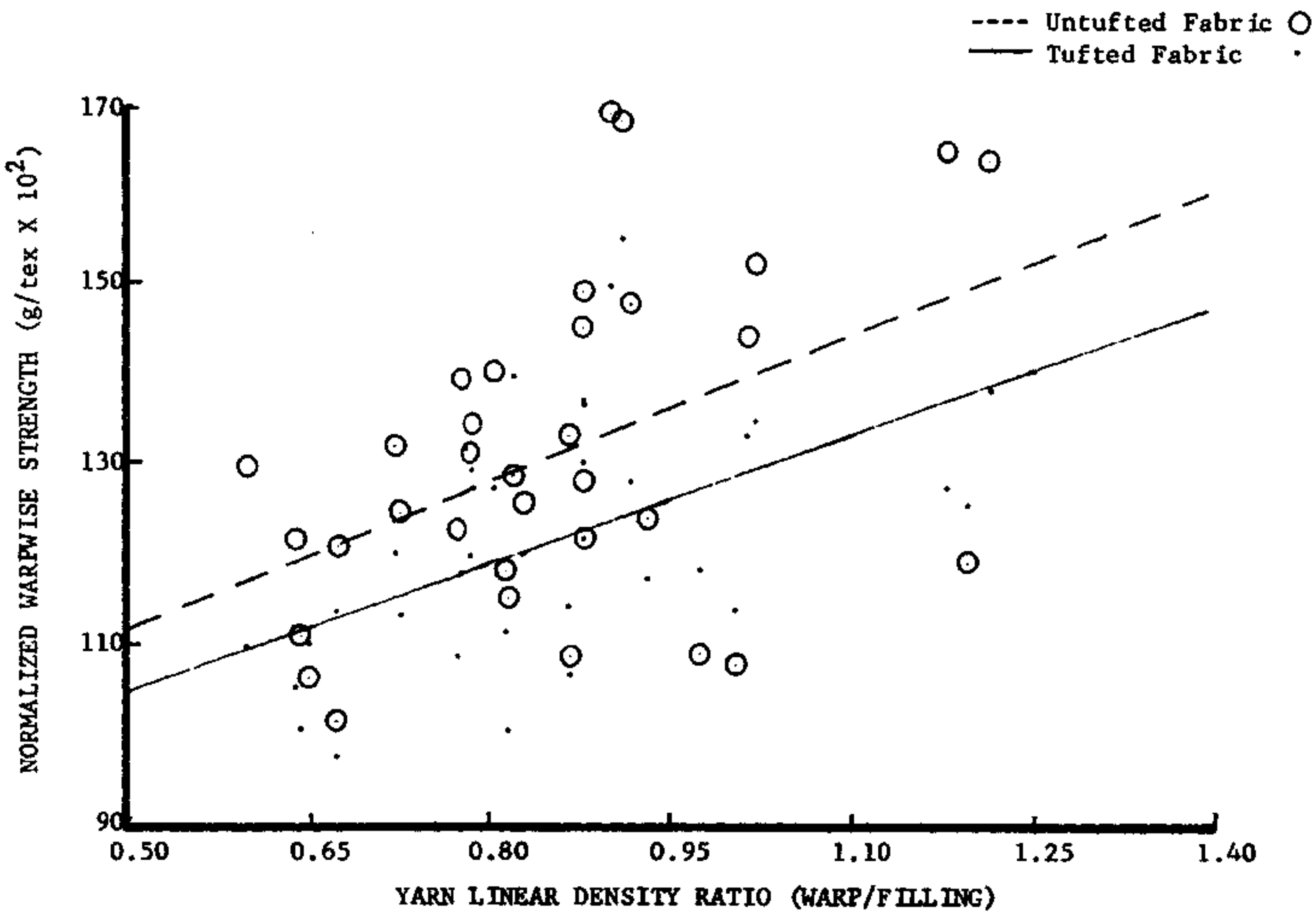

Figure 9. The Effect of Yarn Linear Density Ratio on Normalized Warpwise Strength

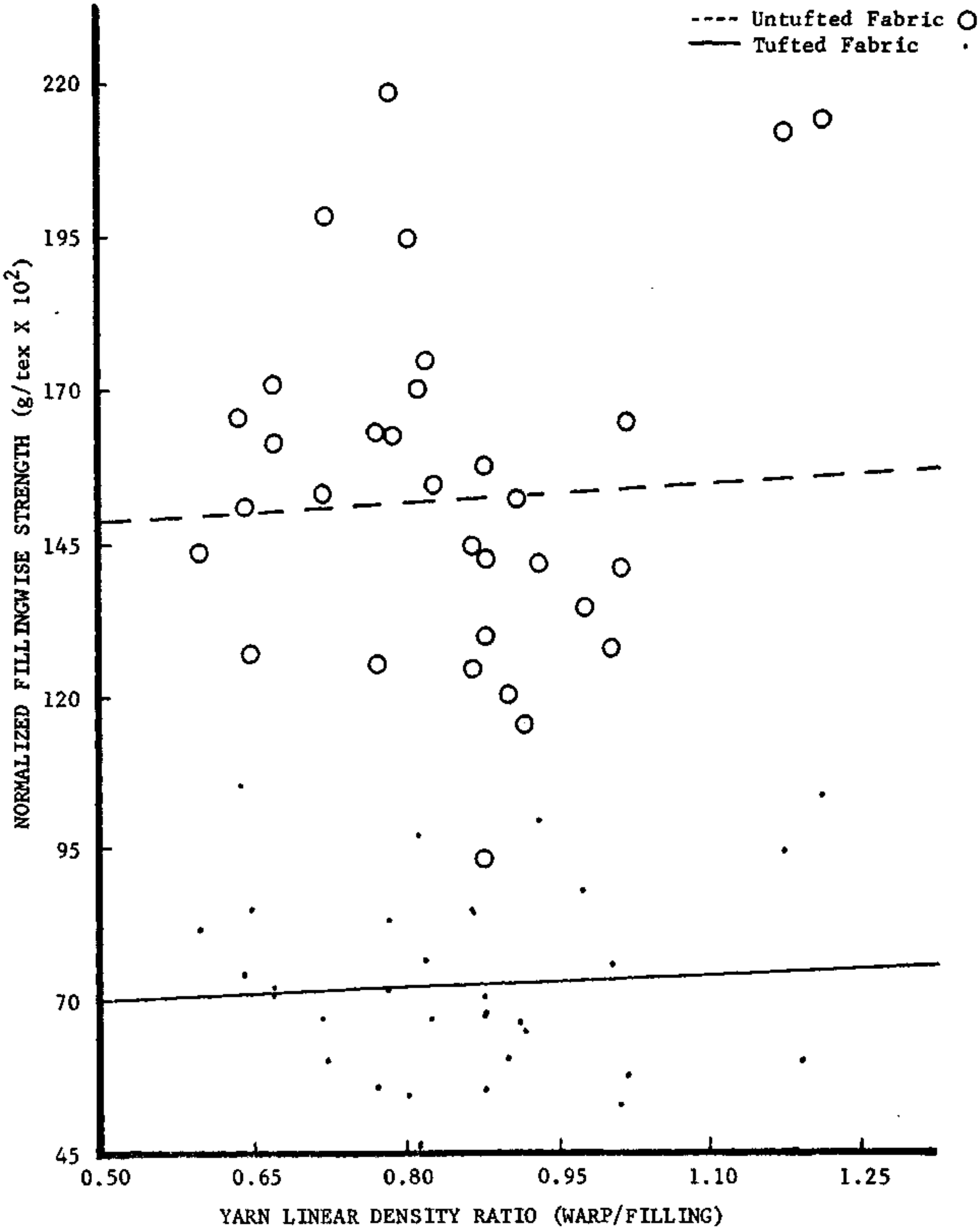

Figure 10. The Effect of Yarn Linear Density Ratio on Normalized Fillingwise Strength

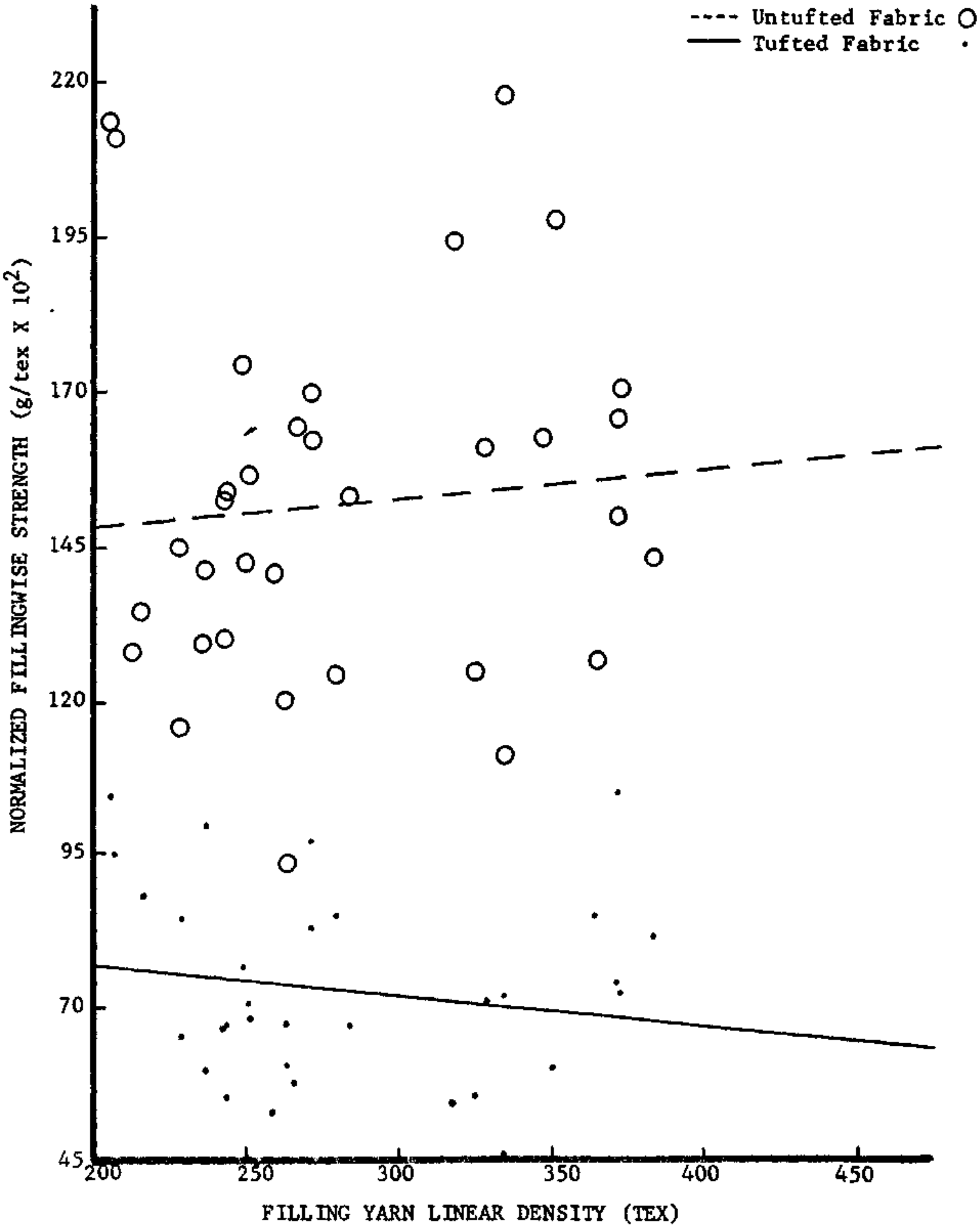

Figure 11. The Effect of Filling Yarn Linear Density on the Normalized Fillingwise Strength

The Effect of the Backing Fabric Construction on Fabric Elongation

Effect of the Weave Multiplier, W_m

There is a significant relationship between elongation and the weave multiplier. This is shown in Table 6, Equations 16 and 17. From the correlation coefficient it can be seen that for the untufted fabric strength about 16 percent of the variation is caused by the weave multiplier while for the tufted fabric strength, only about nine percent of the variation is contributed by the weave multiplier.

As to the fillingwise strength, only slight correlation with the weave multiplier was found, but this does show the trend of their relationship.

From Figures 12 and 13 it can be seen more clearly that both warp and filling elongation of untufted and tufted fabrics decrease as the weave multiplier increases. This means that as the fabric structure becomes looser, the elongation tends to decrease. After the fabric has been tufted there is a loss in elongation in the filling direction. This loss of elongation diminishes as the weave multiplier increases. When the weave multiplier is greater than two there is a gain in elongation. In the warp direction, there is an increase in elongation after the fabric has been tufted, and this increase is more prominent for looser structures. This agrees with the fact that elongation decreases as the number of interlacings decrease since the introduction of additional yarns into the fabric structure makes a tighter fabric structure.

Effect of the Weave Factor, W_f

The relationship of the weave factor to fabric elongation was found

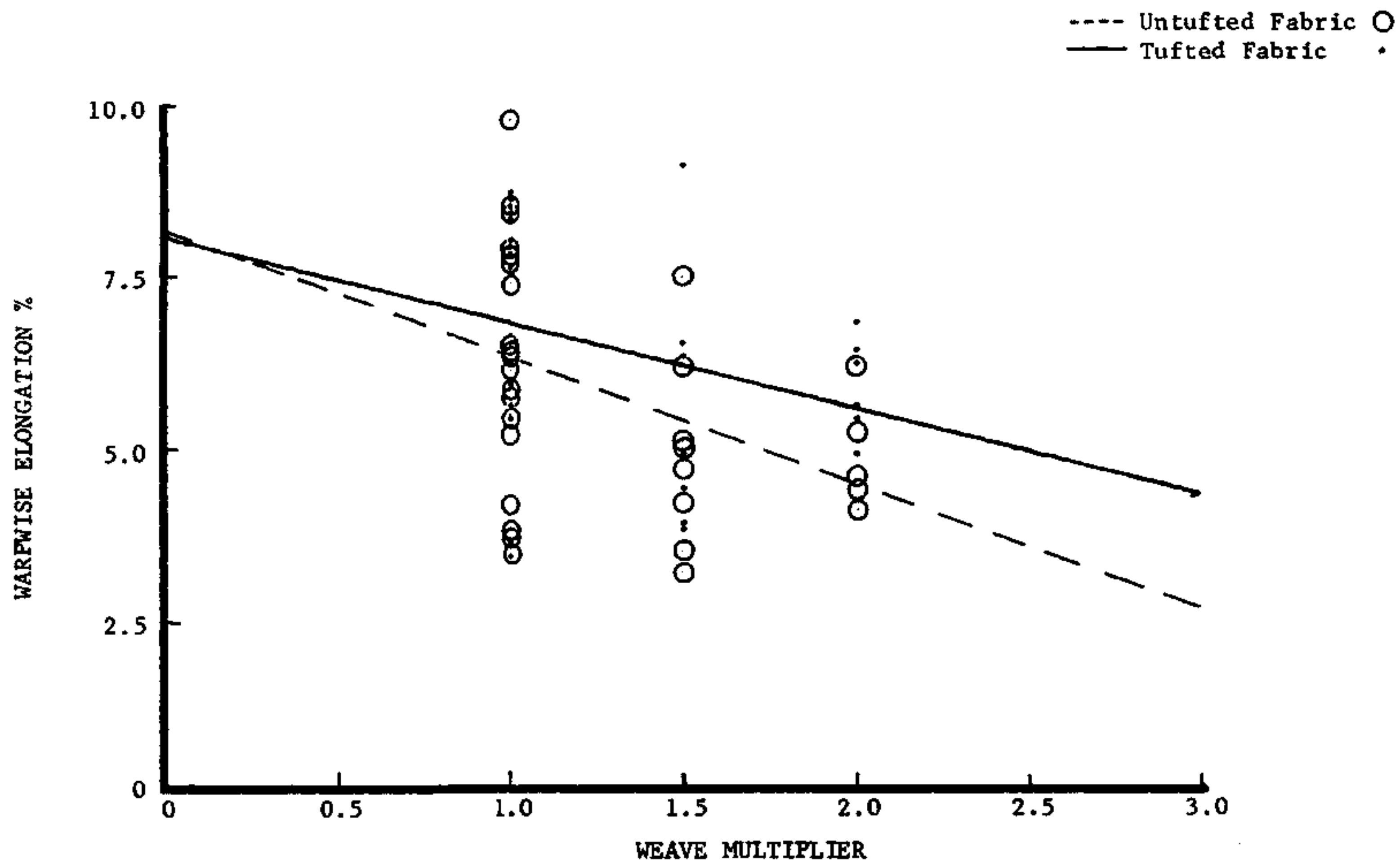

Figure 12. The Effect of Weave Multiplier on Warpwise Elongation

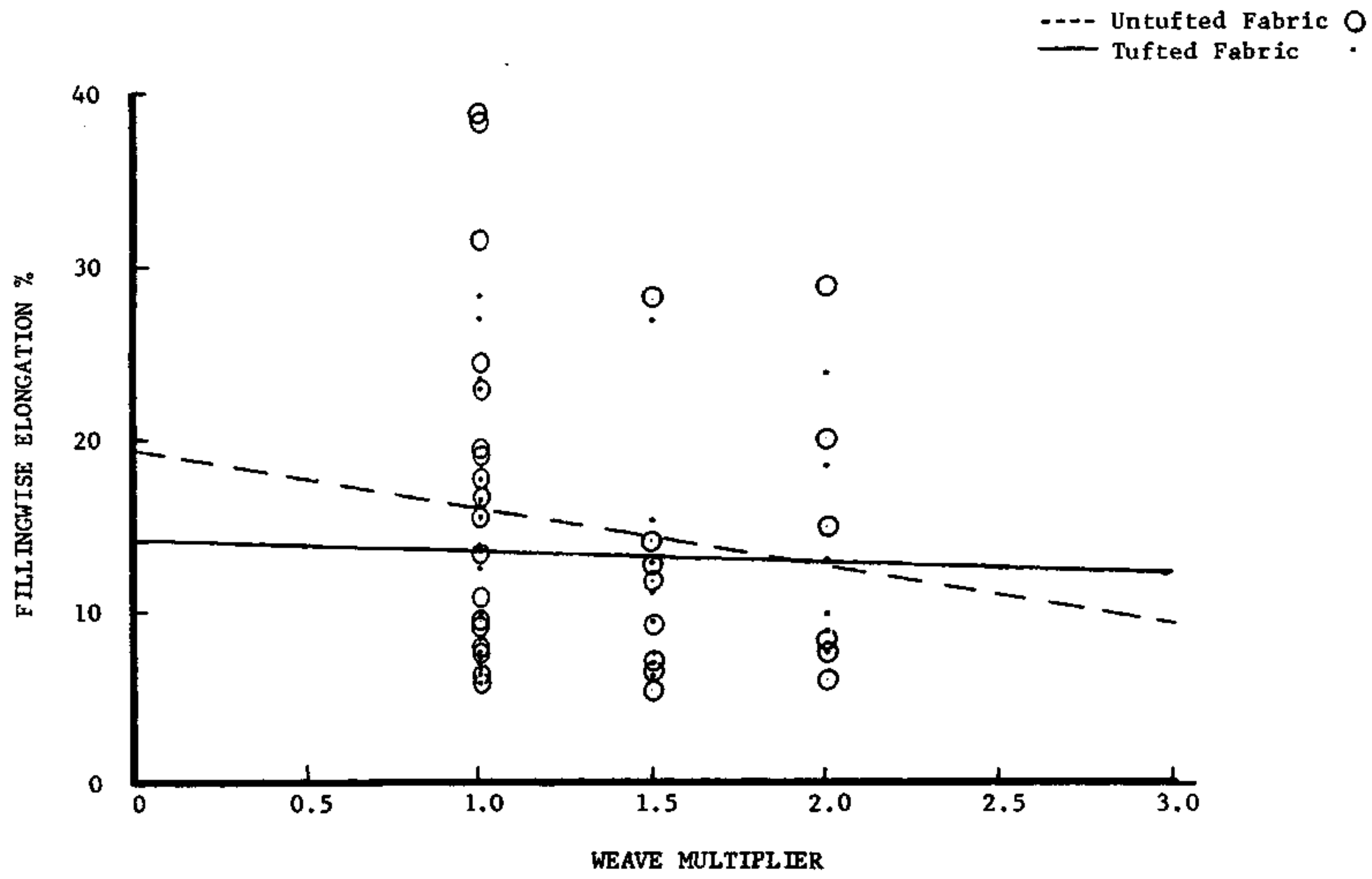

Figure 13. The Effect of Weave Multiplier on Fillingwise Elongation

to be significant at a level higher than 90 percent. On the average, about 15 percent of the variation in fabric elongation is due to the effect of the weave factor.

The regression curves in Figures 14 and 15 show that elongation in both warp and filling directions increases with an increase of the weave factor.

After the fabric has been tufted, both warpwise and fillingwise elongation tend to increase at lower values of weave factor and the increase diminishes at higher values of weave factor. This was shown more significantly in the filling direction. For the values of weave factor lower than 120, which consisted mainly of twill fabrics, there was an increase in elongation after tufting; but for values of weave factor higher than 120, there was a decrease in elongation compared to the untufted fabric.

Effect of the Crimp Ratio, C

The relationship of the crimp ratio to fabric elongation was found to be highly significant as anticipated because a great portion of the total fabric elongation was the result of uncrimping forces.

From the correlation coefficients it can be seen that about 50 percent of the variation in fabric elongation is accounted for by a linear dependence on the relative crimp level of the fabric.

As illustrated in Figures 16 and 17, the warpwise elongation of a fabric increases with an increase of crimp ratio, and the fabric elongation in the filling direction decreases with an increase of the crimp ratio. In other words, elongation increases with the crimp levels since crimp ratio is the ratio of warp crimp divided by the filling crimp. An

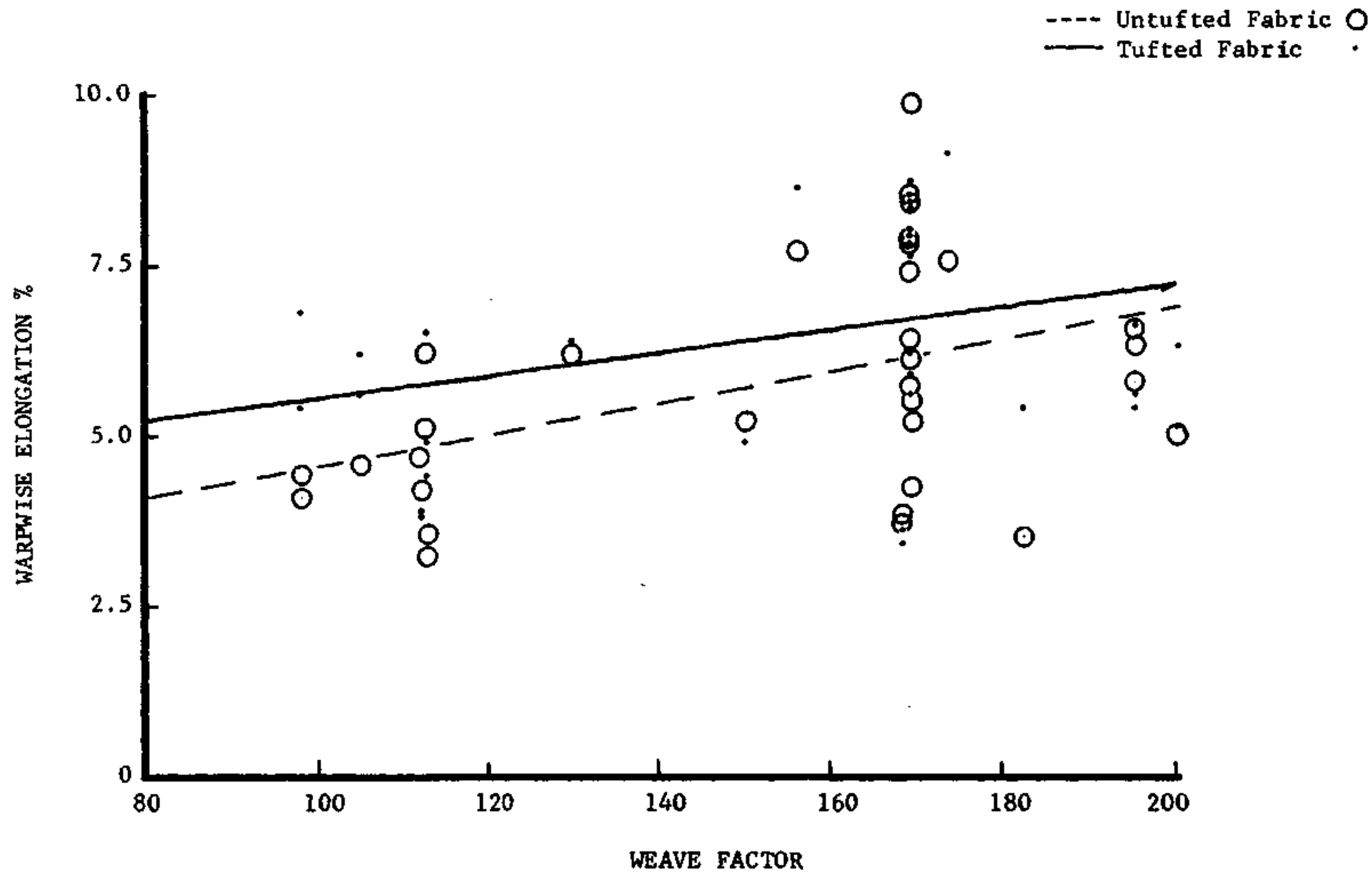

Figure 14. The Effect of Weave Factor on Warpwise Elongation

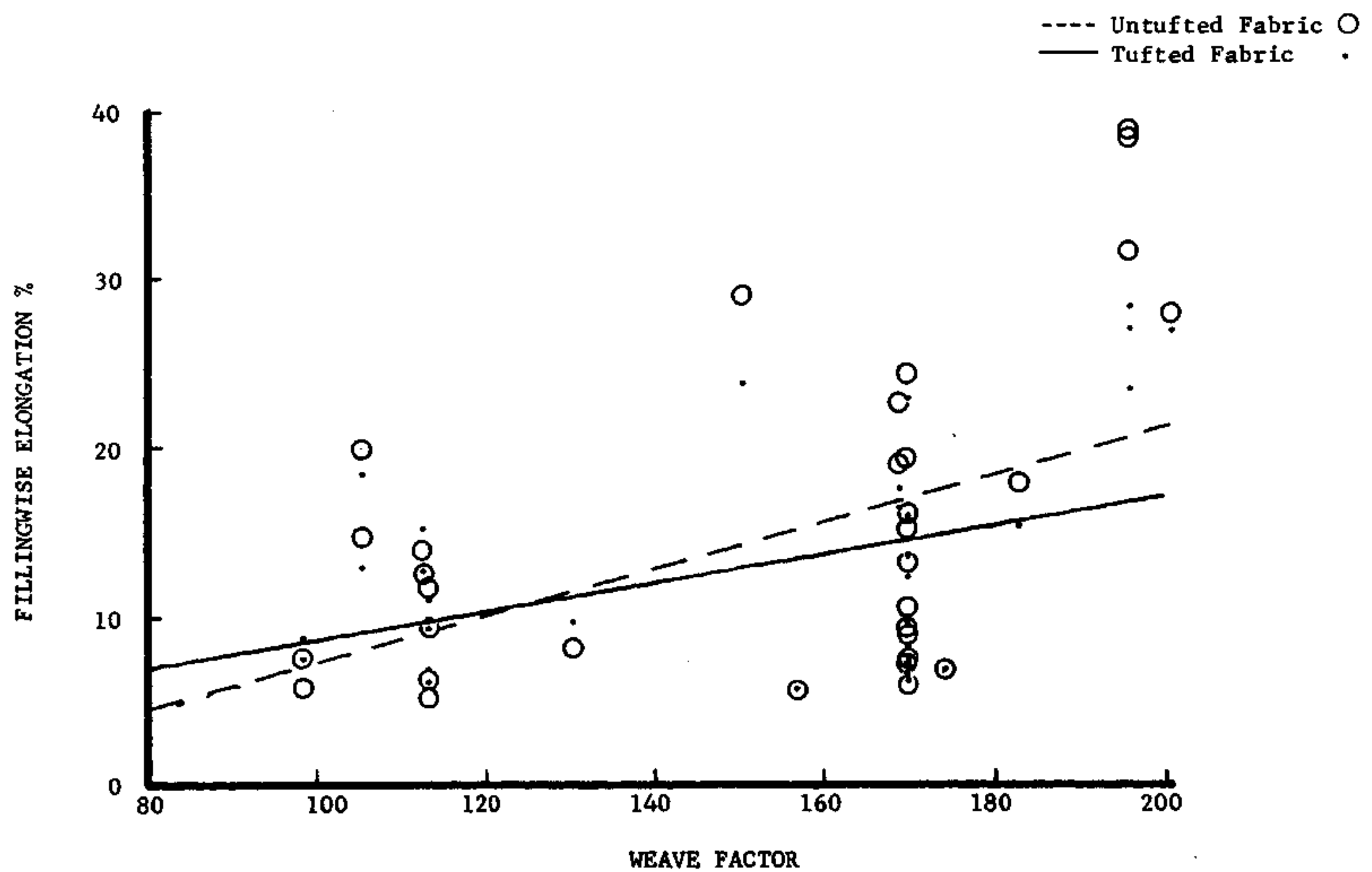

Figure 15. The Effect of Weave Factor on Fillingwise Elongation

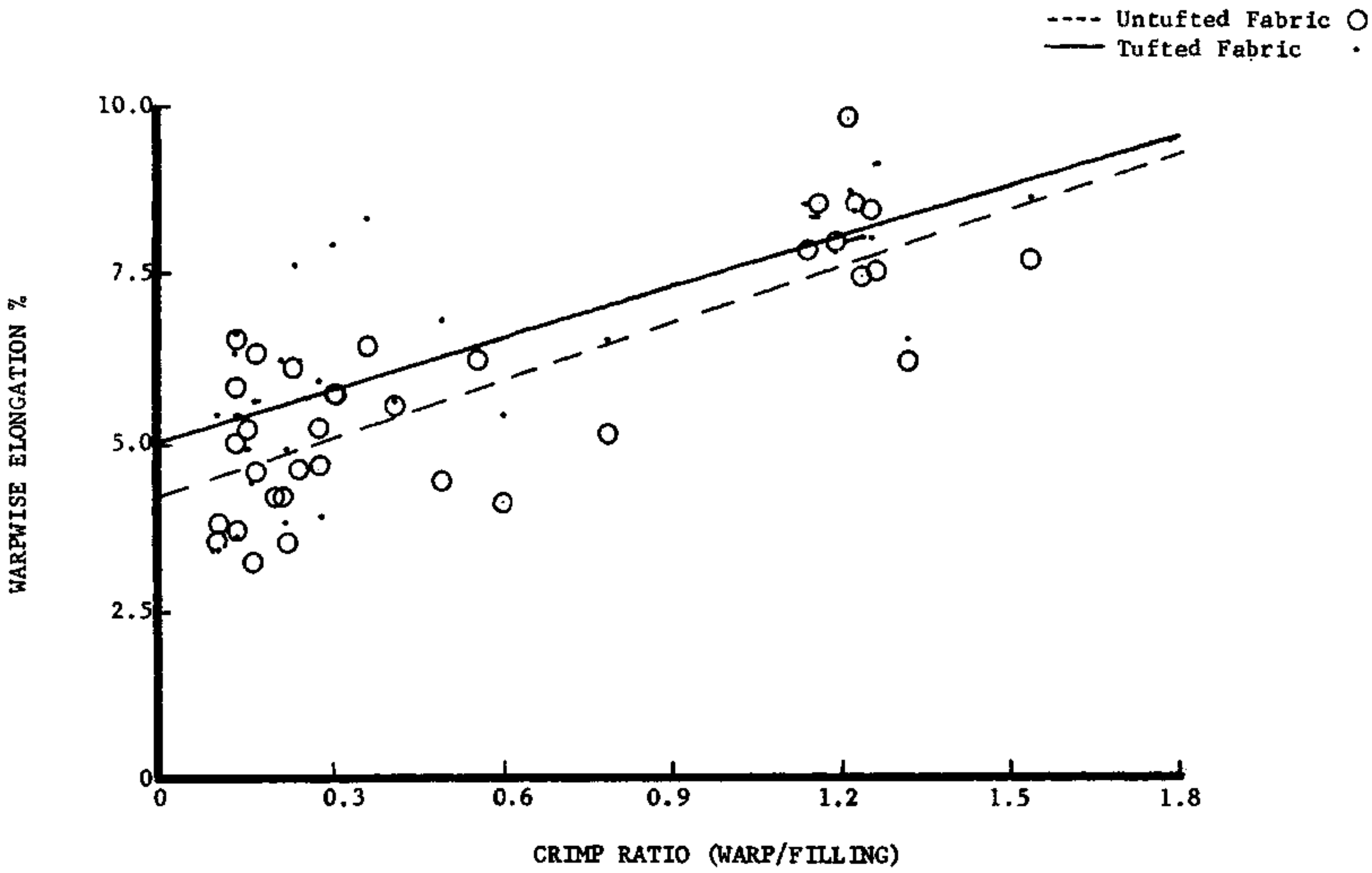

Figure 16. The Effect of Crimp Ratio on Warpwise Elongation

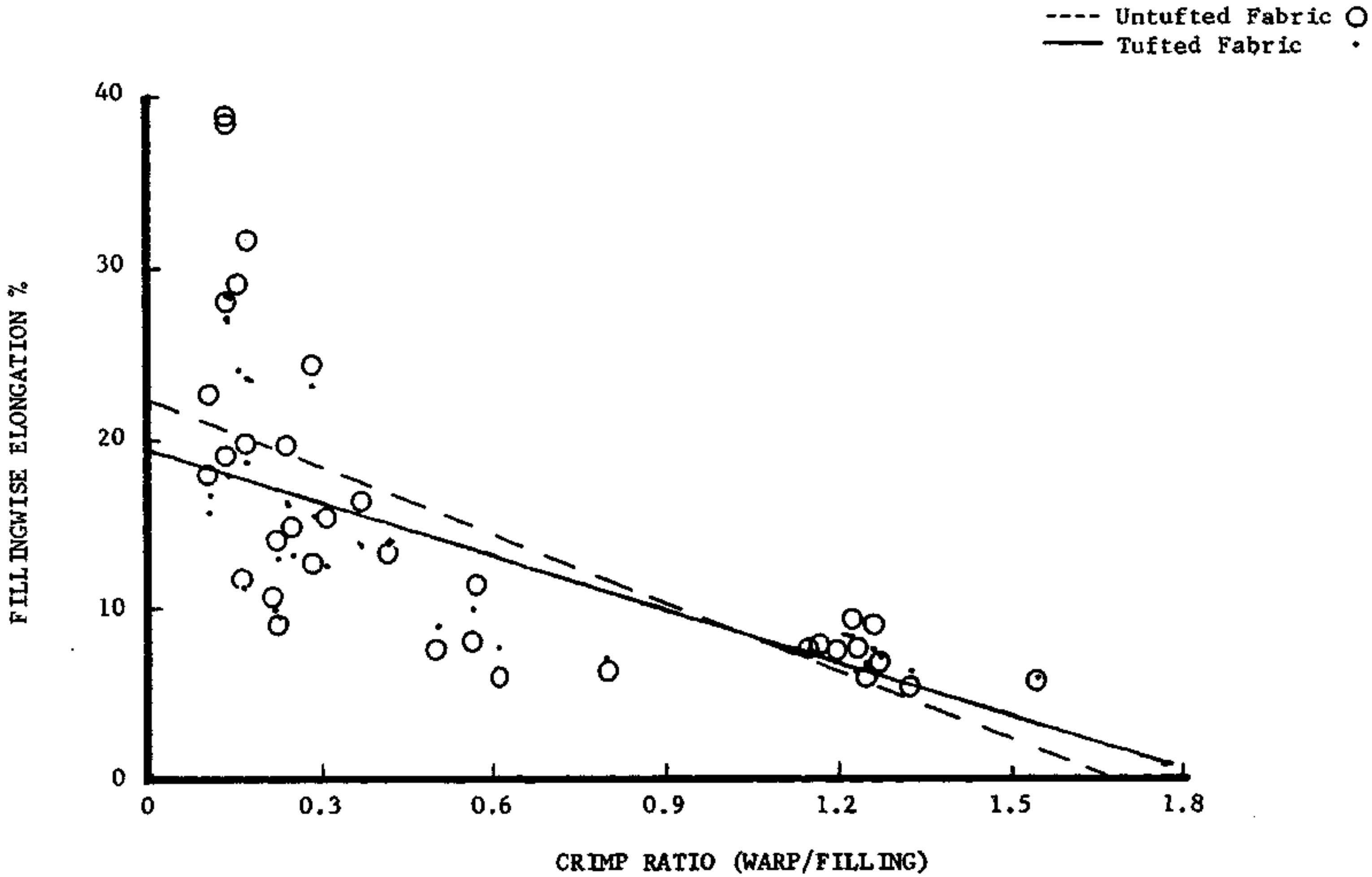

Figure 17. The Effect of Crimp Ratio on Fillingwise Elongation

increase in crimp ratio means an increase in warp crimp while the decrease in crimp ratio means an increase in filling crimp.

There is a slight increase in elongation after the fabric has been tufted. This increase diminishes as the crimp level rises. Figure 18 shows an increase in the crimp level as the weave factor increases or as the frequency of yarn bending increases. As the crimp ratio decreases the gain in the fillingwise elongation diminishes when it reaches the point where the warp and filling crimp levels are equal. This means when the filling crimp is higher than the warp crimp, the loss of elongation tends to be greater after the fabric has been tufted.

Due to the significant effect of the relative crimp level on elongation, the effect of the filling yarn crimp on fabric elongation was examined.

As expected, filling crimp had an almost perfect correlation with the filling elongation for both untufted and tufted fabrics. This can be seen in Table 6, Equations 44 and 45. Figure 19 shows a slight increase in elongation at filling crimp levels below four percent after the fabric has been tufted, while the fillingwise elongation decreases gradually at filling crimp levels above four percent.

It was found that tufted fabric strength depends a great deal on the untufted fabric elongation. As indicated in Figure 20 and Table 6, Equation 39, about one quarter of the variation in the fillingwise strength of the tufted fabrics is accounted for by the linear dependency upon untufted fabric elongation. From Figure 21 and Table 6, Equation 46, it can be seen that the untufted fabric filling yarn elongation has an effect on the tufted fabric similar to that of the fabric elongation.

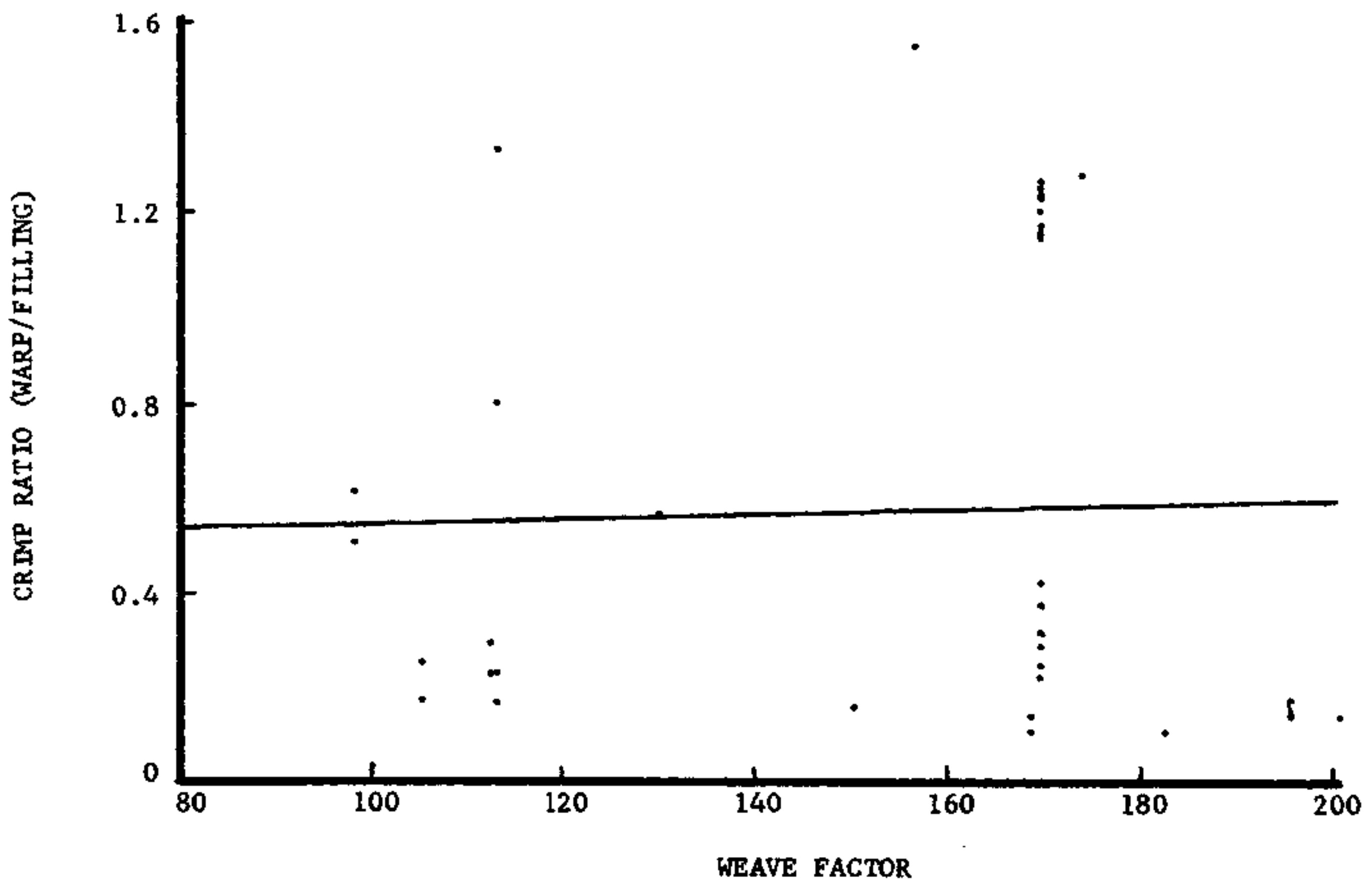

Figure 18. The Relationship of Crimp Ratio to Weave Factor

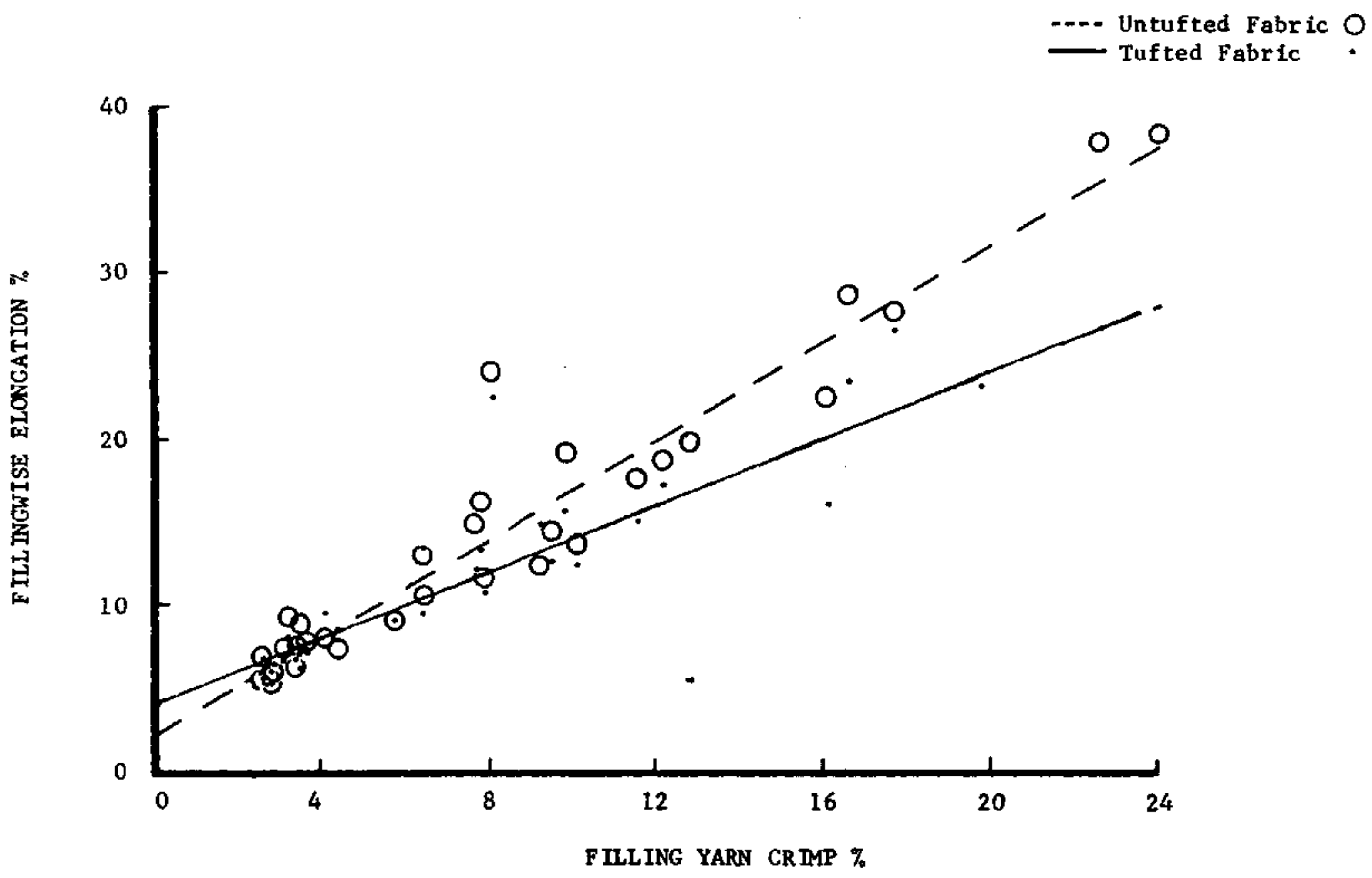

Figure 19. The Effect of Filling Yarn Crimp on Fillingwise Fabric Elongation

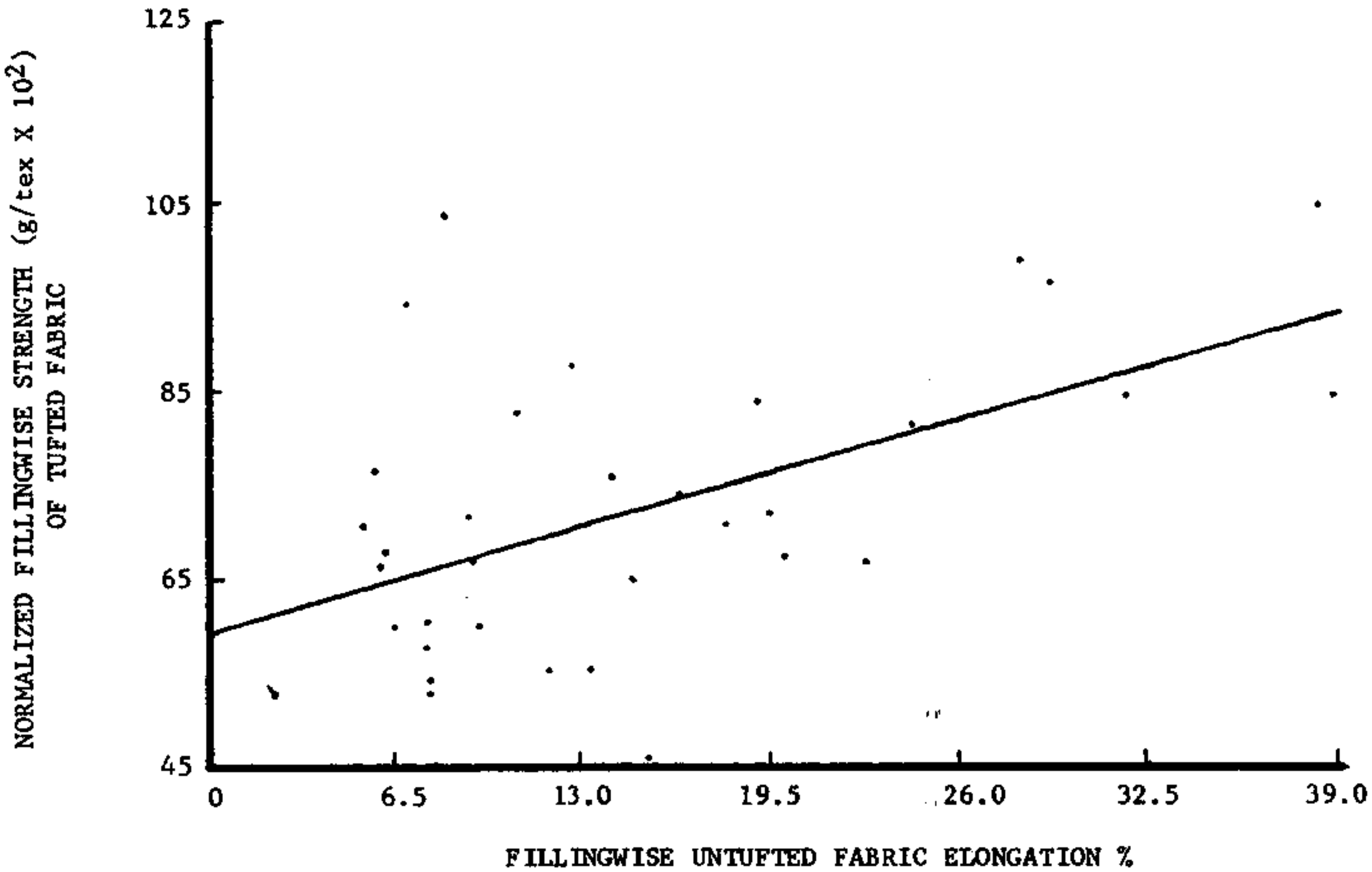

Figure 20. The Effect of Untufted Fillingwise Fabric Elongation on the Normalized Fillingwise Strength of Tufted Fabric

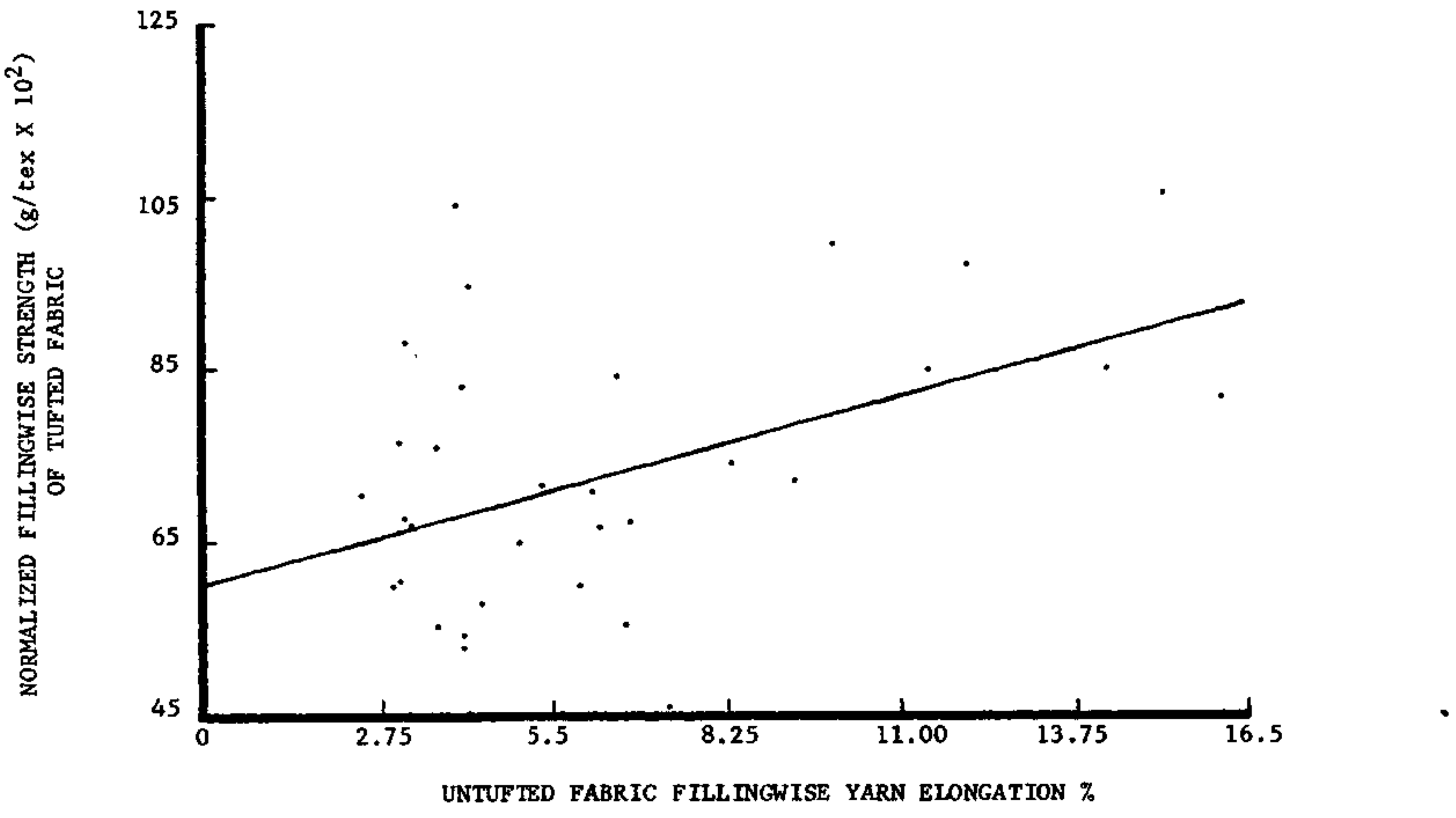

Figure 21. The Effect of Filling Yarn Elongation on the Normalized Fillingwise Strength of Tufted Fabric

Effect of the Yarn Linear Density Ratio, L

The effect of yarn linear density ratio on the warpwise elongation, Figure 22, was found to be insignificant while the relationship between the yarn linear density ratio and the fillingwise elongation was found to be significant at a level higher than 95 percent for both untufted and tufted fabrics. This can be seen in Table 6, Equations 29-32. Figure 23 shows that the fillingwise elongation decreases as the yarn linear density ratio increases. This means that the fillingwise elongation increases as filling yarn linear density increases. After the fabric had been tufted, a gain in fillingwise elongation was found at the region where the yarn linear density ratio, L, was greater than one, while at the region where L was less than one, (meaning the filling yarn was larger than the warp yarn) there was a loss in the fillingwise elongation.

From Figure 24 and Table 6, Equations 37 and 38 it can be seen that the effect of filling yarn linear density alone on fillingwise elongation is fairly significant. Figure 24 illustrates that the loss in elongation after the fabric has been tufted is less significant at low values of yarn linear density. This result agrees with the result obtained for the effect of yarn linear density on fillingwise elongation.

The Effect of the Crimp Ratio on Fillingwise Strength Retention

The significant relationship between elongation and strength as well as the high correlation between crimp and elongation confirms that crimp would affect strength significantly. Previous results show a larger loss of strength in the filling direction after the fabric has been tufted. Therefore, the relationship between the crimp ratio and

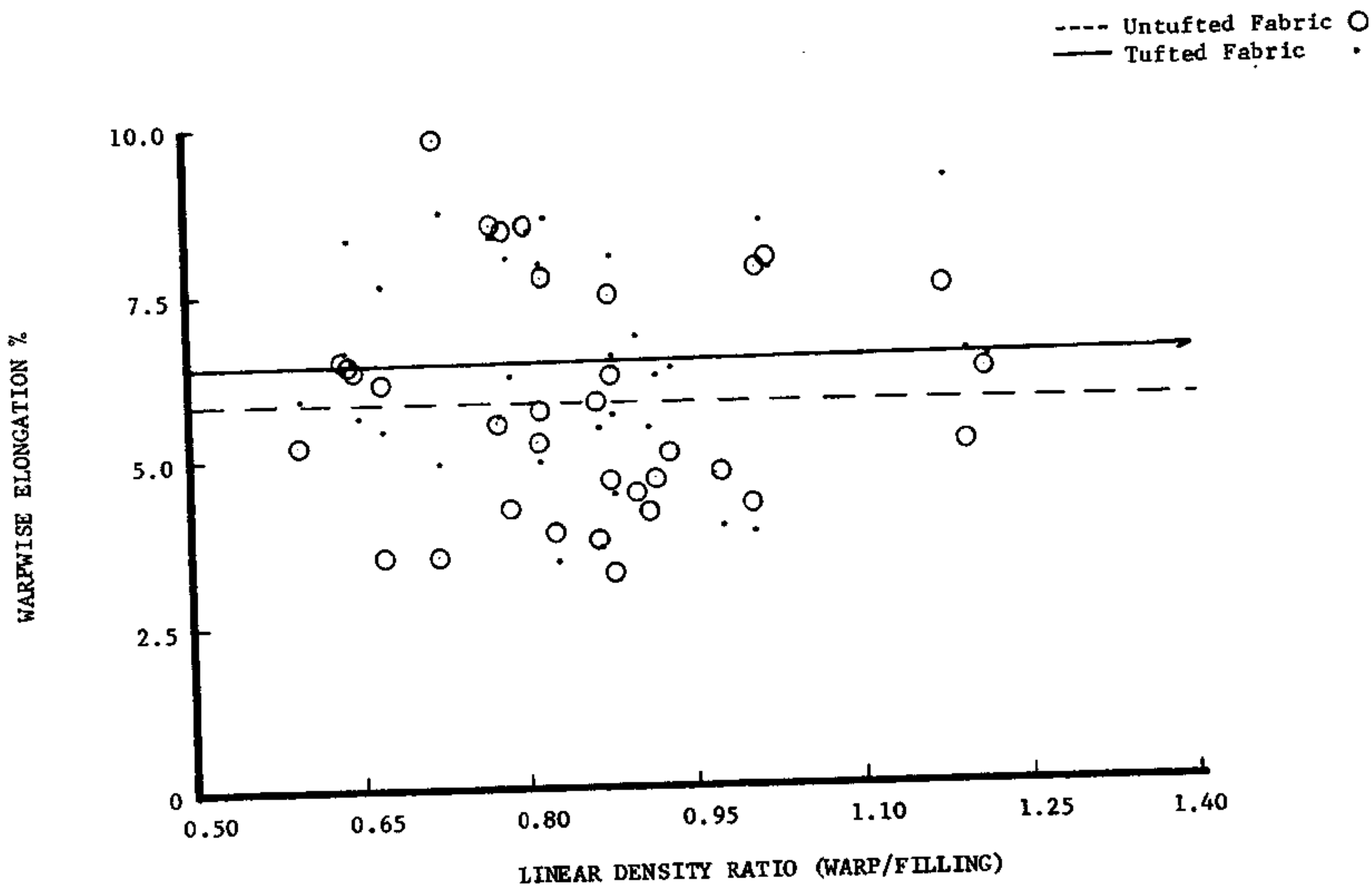

Figure 22. The Effect of Linear Density Ratio on Warpwise Elongation

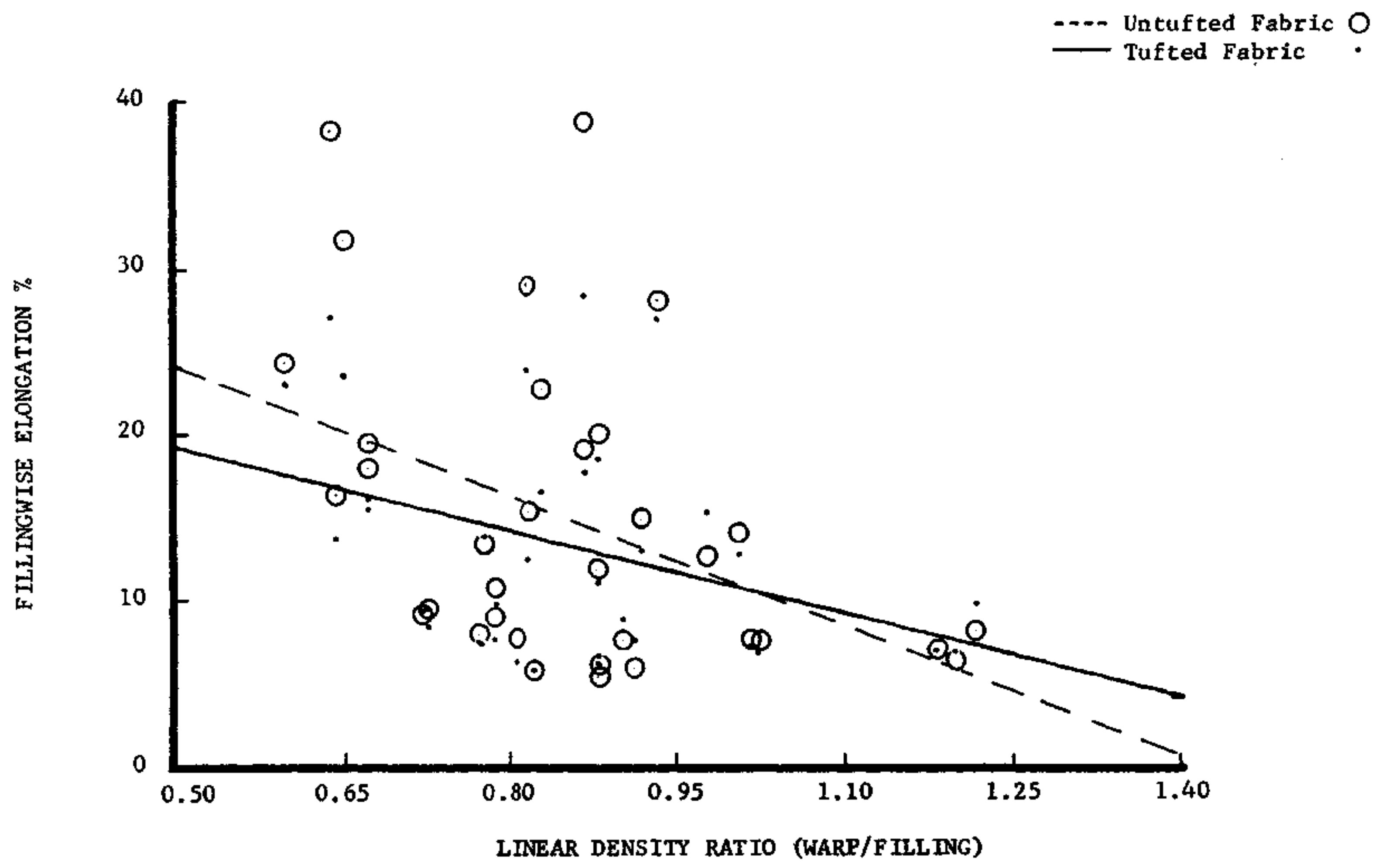

Figure 23. The Effect of Linear Density Ratio on Fillingwise Elongation

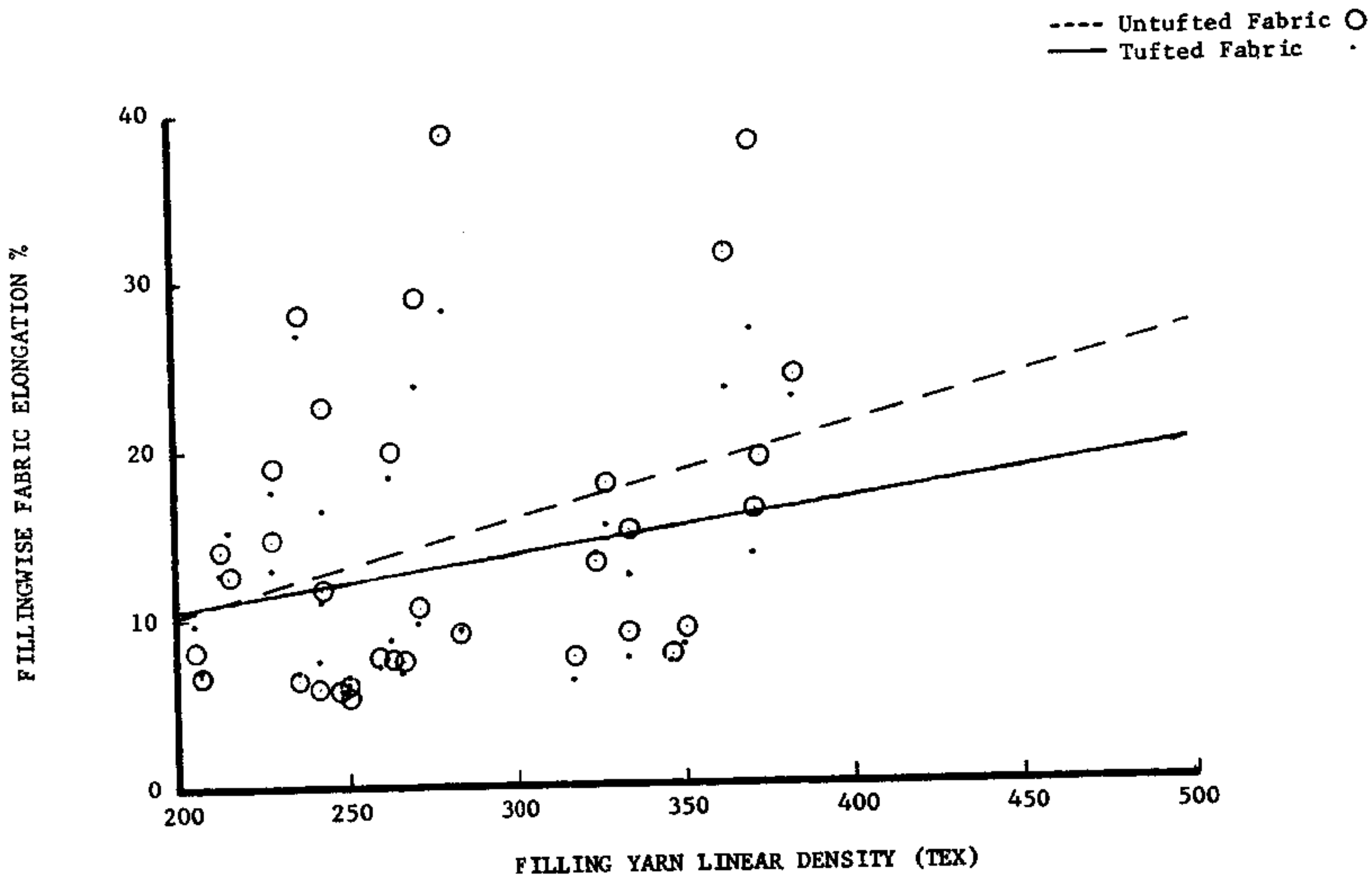

Figure 24. The Effect of Filling Yarn Linear Density on Fillingwise Fabric Elongation

filling strength retention was examined. The filling strength retention is expressed by the ratio of the untufted fabric fillingwise strength and the tufted fabric fillingwise strength. A high value of this ratio means low strength retention. For example, when the strength ratio is 2, it means one half of the strength has been lost after tufting. And when the strength ratio is 4, it means only one quarter of the strength is retained after tufting.

The relation of the strength ratio to the crimp ratio was found to be highly significant. This is shown in Table 6, Equation 34. Almost 50 percent of the variation in strength retention was found to be linearly dependent on the crimp ratio. From Figure 25 it can be seen that the loss of fillingwise strength, after the fabric has been tufted, is less significant for fabrics with higher filling crimp. Therefore, higher fillingwise strength retention can be achieved by increasing the filling crimp.

The Relationship Between Crimp Ratio and Weave Factor

An attempt was made to correlate the weave factor with the crimp ratio in order to see if there was any interaction between these two variables. As shown in Figure 18 and Equation 33 of Table 6, the relationship was found to be insignificant, therefore, it can be said that these two variables are independent of each other. However, there was a significant relationship between the individual yarn crimp levels and the weave factor. Both warp and filling yarn crimp were found to be significantly related to the weave factor at the 95 percent level. This can be seen in Table 6, Equations 40 and 41. Both warp and filling yarn crimp increase as the weave factor increases or as the density of interlacing

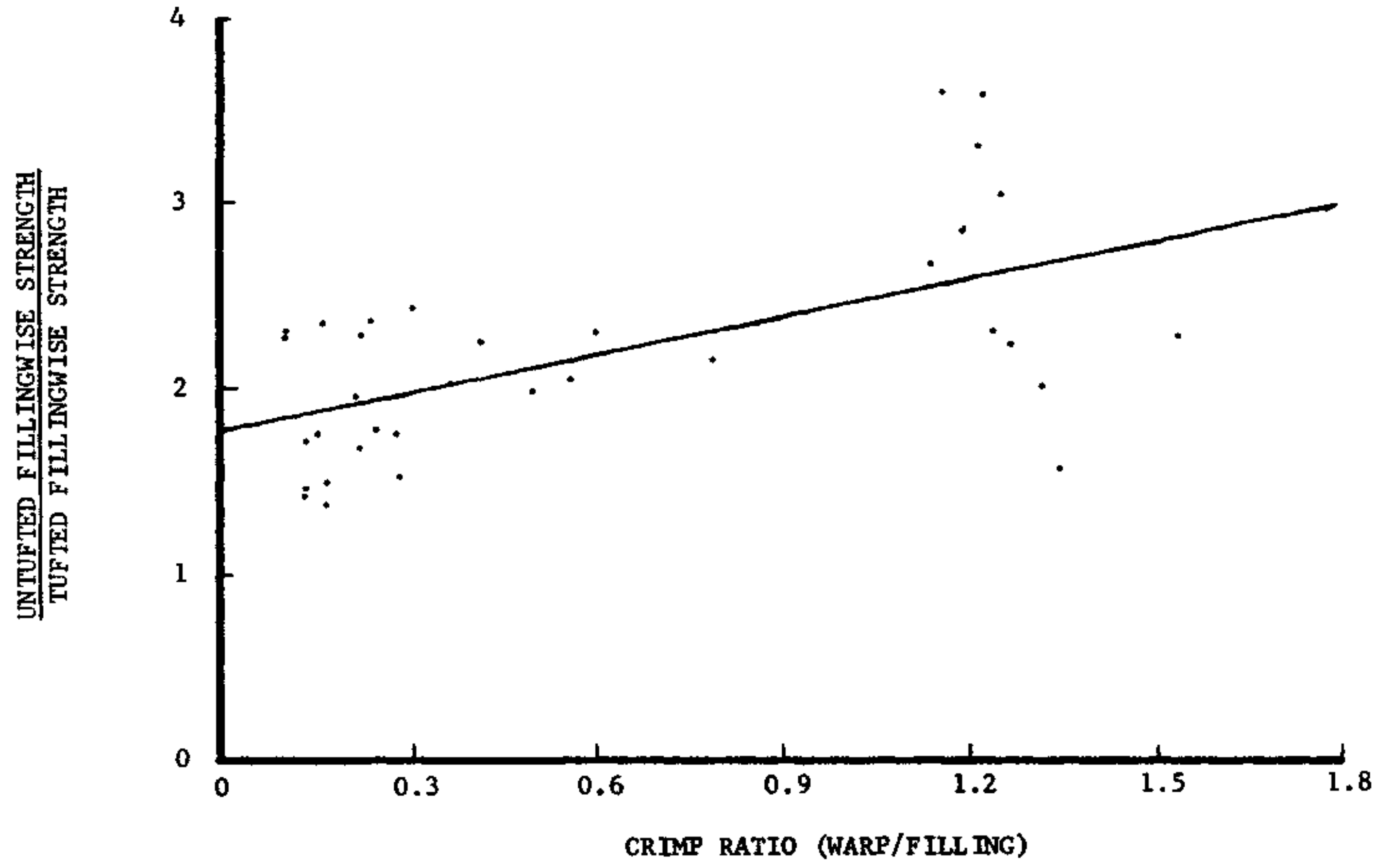

Figure 25. The Effect of Crimp Ratio on the Fillingwise Strength Ratio (Untufted Fabric/Tufted Fabric)

increases. For the same value of weave factor, the filling yarn crimp is always higher than the warp crimp. So as the weave factor increases, the difference between the warp yarn crimp and the filling yarn crimp becomes greater. This is illustrated in Figure 26.

Prediction of the Tuftability

After investigating the relationship between tuftability and each individual parameter, weave factor and crimp ratio were found to be the parameters having the best correlation with tuftability. So, weave factor and crimp ratio were selected to establish prediction equations which will express the mathematical relationship between tuftability and fabric construction.

The coefficient of determination for each regression is shown in Table 8. The coefficient of determination, R^2, is the square of the correlation coefficient, R, for each regression. A high value of R^2 indicates high linear contribution of the independent variables to the variance of the dependent variable.

By combining the weave factor and the crimp ratio, a highly significant improvement was found in the prediction of tuftability, especially in those equations for elongation. This can be seen in Table 7, Equations 5 to 8 which have an average correlation coefficient higher than 0.8. This means the combination of the weave factor and crimp ratio contributed over 60 percent of the variance to elongation, on a linear relationship.

A 90 percent and 95 percent confidence limit was calculated, assuming the errors were distributed normally, which is an indication of the goodness of fit of the prediction equation. This is also shown in

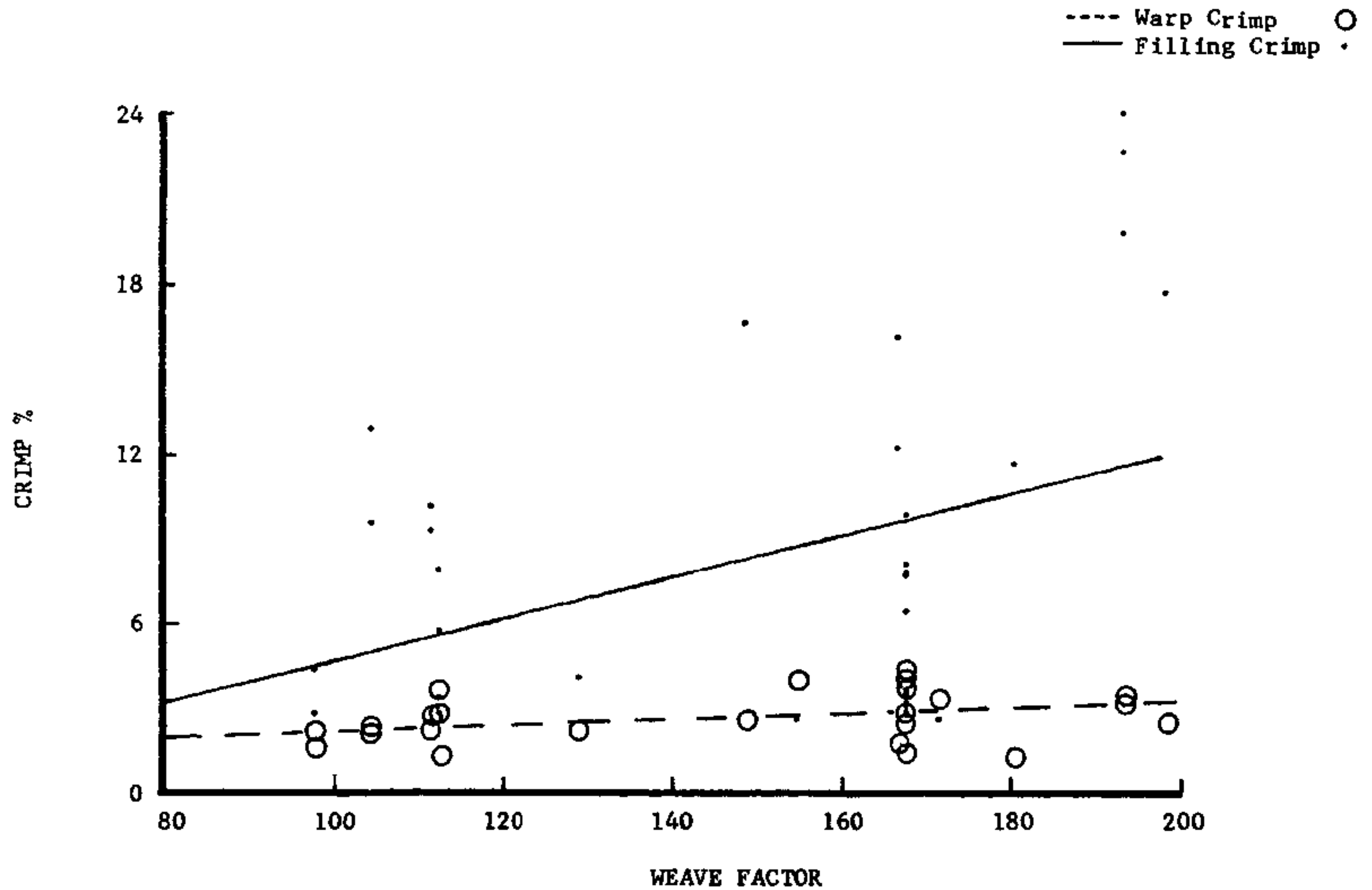

Figure 26. The Relationship of Yarn Crimp to Weave Factor

Table 7.

The range of the data from which these equations were calculated is given in Table 9.

With these eight prediction equations, the stress-strain properties of jute backing fabrics in both untufted and tufted states can be predicted. By setting up some empirical values of the weave factor and crimp ratio the optimum weave construction and relative crimp level for different functional requirements can be found without producing the fabric. On the other hand, a backing fabric of unknown structure could be analyzed for fabric construction, weave factor, and crimp ratio. Then by using the appropriate equation in Table 7, the strength and elongation of both untufted and tufted fabrics could be predicted.

Table 6. Simple Linear Regression Equations

No.	Regression	Equation	Correlation Coefficient	Significance Level %
1	Untufted Warpwise Strength on Weave Multiplier	$UWS = 101.4700 + 22.9737\ W_m$	0.4871	99
2	Tufted Warpwise Strength on Weave Multiplier	$TWS = 100.1984 + 16.5948\ W_m$	0.4653	99
3	Untufted Fillingwise Strength on Weave Multiplier	$UFS = 171.7133 - 14.7694\ W_m$	-0.1924	60
4	Tufted Fillingwise Strength on Weave Multiplier	$TFS = 62.7930 + 7.4625\ W_m$	0.1815	60
5	Untufted Warpwise Strength on Weave Factor	$UWS = 162.9431 - 0.2057\ W_f$	-0.3574	98
6	Tufted Warpwise Strength on Weave Factor	$TWS = 155.9914 - 0.2232\ W_f$	-0.5121	99.8
7	Untufted Fillingwise Strength on Weave Factor	$UFS = 107.0804 + 0.2968\ W_f$	0.3168	90
8	Tufted Fillingwise Strength on Weave Factor	$TFS = 55.3308 + 0.1129\ W_f$	0.2249	80
9	Untufted Warpwise Strength on Crimp Ratio	$UWS = 125.8593 + 10.0345\ C$	0.2625	80
10	Tufted Warpwise Strength on Crimp Ratio	$TWS = 115.3117 + 11.6726\ C$	0.4038	98

Table 6. Simple Linear Regression Equations (continued)

No.	Regression	Equation	Correlation Coefficient	Significance Level %
11	Untufted Fillingwise Strength on Crimp Ratio	$UFS = 134.2802 + 31.9691\ C$	0.5143	** Highly Significant
12	Tufted Fillingwise Strength on Crimp Ratio	$TFS = 78.6962 - 10.8415\ C$	-0.3253	90
13	Untufted Warpwise Strength on Linear Density Ratio	$UWS = 84.8650 + 54.5781\ L$	0.4599	99
14	Tufted Warpwise Strength on Linear Density Ratio	$TWS = 81.3342 + 47.4570\ L$	0.5288	99.8
15	Untufted Fillingwise Strength on Linear Density Ratio	$UFS = 143.0264 + 10.9409\ L$	0.0567	20
16	Tufted Fillingwise Strength on Linear Density Ratio	$TFS = 66.5249 + 7.0572\ L$	0.0682	20
17	Untufted Warpwise Elongation on Weave Multiplier	$UWE = 8.1535 - 1.8186\ W_m$	-0.4130	98
18	Tufted Warpwise Elongation on Weave Multiplier	$TWE = 8.0291 - 1.2384\ W_m$	-0.2975	90
19	Untufted Fillingwise Elongation on Weave Multiplier	$UFE = 19.2384 - 3.3547\ W_m$	-0.1400	40
20	Tufted Fillingwise Elongation on Weave Multiplier	$TFE = 14.0221 - 0.6512\ W_m$	-0.0374	*Insignificant

Table 6. Simple Linear Regression Equations (continued)

No.	Regression	Equation	Correlation Coefficient	Significance Level %
21	Untufted Warpwise Elongation on Weave Factor	$UWE = 2.2586 + 0.0232\ W_f$	0.4294	98
22	Tufted Warpwise Elongation on Weave Factor	$TWE = 3.8934 + 0.0166\ W_f$	0.3250	90
23	Untufted Fillingwise Elongation on Weave Factor	$UFE = -6.6536 + 0.1412\ W_f$	0.4801	**Highly Significant
24	Tufted Fillingwise Elongation on Weave Factor	$TWE = 0.0860 + 0.0858\ W_f$	0.4010	90
25	Untufted Warpwise Elongation on Crimp Ratio	$UWE = 4.1899 + 2.8448\ C$	0.7931	**Highly Significant
26	Tufted Warpwise Elongation on Crimp Ratio	$TWE = 5.0050 + 2.5115\ C$	0.7408	**Highly Significant
27	Untufted Fillingwise Elongation on Crimp Ratio	$UFE = 22.3901 - 13.2392\ C$	-0.6781	**Highly Significant
28	Tufted Fillingwise Elongation on Crimp Ratio	$TFE = 19.0771 - 10.4204\ C$	-0.7338	**Highly Significant
29	Untufted Warpwise Elongation on Linear Density Ratio	$UWE = 5.8895 - 0.1047\ L$	-0.0094	*Insignificant
30	Tufted Warpwise Elongation on Linear Density Ratio	$TWE = 6.3423 + 0.0985\ L$	0.0094	*Insignificant

Table 6. Simple Linear Regression Equations (continued)

No.	Regression	Equation	Correlation Coefficient	Significance Level %
31	Untufted Fillingwise Elongation on Linear Density Ratio	UFE = 37.0220 - 25.8720 L	-0.4268	98
32	Tufted Fillingwise Elongation on Linear Density Ratio	TFE = 27.3078 - 16.5212 L	-0.3747	95
33	Crimp Ratio on Weave Factor	C = 0.4898 + 0.0005 W_f	0.0331	*Insignificant
34	Fillingwise Strength Ratio on Crimp Ratio	FSR = 1.7226 + 0.8079 C	0.6717	**Highly Significant
35	Untufted Fillingwise Strength on Filling Yarn Tex	UFS = 138.7239 + 0.0483 FT	0.0892	60
36	Tufted Fillingwise Strength on Filling Yarn Tex	TFS = 86.5099 - 0.0494 FT	-0.1701	70
37	Untufted Fillingwise Elongation on Filling Yarn Tex	UFE = -1.2945 + 0.0573 FT	0.3370	95
38	Tufted Fillingwise Elongation on Filling Yarn Tex	TFE = 4.0915 + 0.0322 FT	0.2600	80
39	Tufted Fillingwise Strength on Untufted Fillingwise Elongation	TFS = 59.2956 + 0.8904 UFE	0.5217	99.8
40	Filling Crimp on Weave Factor	FC = -2.7625 + 0.0744 W_f	0.3812	95
41	Warp Crimp on Weave Factor	WC = 1.2118 + 0.1020 W_f	0.3480	95

Table 6. Simple Linear Regression Equations (continued)

No.	Regression	Equation	Correlation Coefficient	Significance Level %
42	Untufted Fillingwise Strength on Filling Crimp	UFS = 166.3770 - 1.6278 FC	-0.3385	95
43	Tufted Fillingwise Strength on Filling Crimp	TFS = 61.2304 + 1.3152 FC	0.5092	99
44	Untufted Fillingwise Elongation on Filling Crimp	UFE = 2.3650 + 1.4577 FC	0.9657	**Highly Significant
45	Tufted Fillingwise Elongation on Filling Crimp	TFE = 4.2105 + 0.9926 FC	0.8895	**Highly Significant
46	Tufted Fillingwise Strength on Untufted Filling Yarn Elongation	TFS = 60.1464 + 0.4598 UYE	0.4598	98

W_m = Weave Multiplier
W_f = Weave Factor
C = Crimp Ratio (Warp/Filling)
L = Yarn Linear Density Ratio (Warp/Filling)
FT = Filling Yarn Linear Density in Tex
UWS = Untufted Fabric Warpwise Strength
TWS = Tufted Fabric Warpwise Strength
UFS = Untufted Fabric Fillingwise Strength
TFS = Tufted Fabric Fillingwise Strength

UWE = Untufted Fabric Warpwise Elongation
TWE = Tufted Fabric Warpwise Elongation
UFE = Untufted Fabric Fillingwise Elongation
TFE = Tufted Fabric Fillingwise Elongation
UYE = Untufted Fabric Filling Yarn Elongation

* Insignificant means t test value < 0.256 and
** Highly Significant indicates t test values > 3.646 with 33 degree of freedom

Table 7. Multiple Linear Regression of Strength and Elongation on Weave Factor and Crimp Ratio

No.	Description	Prediction Equation	*Confidence 90%	Limit 95%	Correlation Coefficient
1	Untufted Warpwise Strength	$UWS = 164.8336 - 0.2473\ W_f + 9.4642\ C$	$\pm$ 6.5988	$\pm$ 7.8623	0.4506
2	Tufted Warpwise Strength	$TWS = 152.3360 - 0.2412\ W_f + 11.8376\ C$	$\pm$13.4313	$\pm$16.0032	0.6629
3	Untufted Fillingwise Strength	$UFS = 91.1542 + 0.2840\ W_f + 31.4603\ C$	$\pm$39.2505	$\pm$46.7666	0.5954
4	Tufted Fillingwise Strength	$TFS = 56.4090 + 0.1410\ W_f - 10.4607\ C$	$\pm$25.8920	$\pm$30.8500	0.4018
5	Untufted Warpwise Elongation	$UWE = 0.7458 + 0.0225\ W_f + 2.8178\ C$	$\pm$ 1.3913	$\pm$ 1.6578	0.8898
6	Tufted Warpwise Elongation	$TWE = 2.9862 + 0.0138\ W_f + 2.4326\ C$	$\pm$ 1.3805	$\pm$ 1.6448	0.7995
7	Untufted Fillingwise Elongation	$UFE = 0.0315 + 0.1477\ W_f - 13.5710\ C$	$\pm$ 8.1557	$\pm$ 9.7175	0.8442
8	Tufted Fillingwise Elongation	$TFE = 4.5895 + 0.0947\ W_f - 10.5181\ C$	$\pm$ 6.1034	$\pm$ 7.2722	0.8483

UWS = Untufted Fabric Warpwise Strength
TWS = Tufted Fabric Warpwise Strength
UFS = Untufted Fabric Fillingwise Strength
TFS = Tufted Fabric Fillingwise Strength
UWE = Untufted Fabric Warpwise Elongation

* Assume a Gaussian (Normal) Distribution of Error, a 90% and 95% confidence limit means the prediction will be correct within these limits with 90% or 95% confidence.

Table 7. Multiple Linear Regression of Strength and Elongation on Weave Factor and Crimp Ratio (continued)

TWE = Tufted Fabric Warpwise Elongation
UFE = Untufted Fabric Fillingwise Elongation
TFE = Tufted Fabric Fillingwise Elongation
W_f = Weave Factor
C = Crimp Ratio (Warp Crimp/Filling Crimp)

Table 8. Coefficient of Determination for Simple Regression and Multiple Regression

Independent Variables / Dependent Variables	Simple Regression on W_f	Simple Regression on C	Multiple Regression on W_f, C
UWS	0.1277	0.0689	0.2030
TWS	0.2622	0.1631	0.4394
UFS	0.1004	0.2645	0.3545
TFS	0.0506	0.1058	0.1614
UWE	0.1844	0.6290	0.7917
TWE	0.1056	0.5488	0.6392
UFE	0.2305	0.4598	0.7127
TFE	0.1608	0.5385	0.7196

Table 9. Range of Dependent and Independent Variables in Regression

Ranges	Dependent Variables								Independent Variables	
	UWS	TWS	UFS	TFS	UWE	TWE	UFE	TFE	W_f	C
Maximum	168.6703	155.6288	218.0187	105.3937	9.8	9.1	38.7	28.3	200	1.5385
Minimum	101.6994	97.7982	92.7909	45.1884	3.2	3.4	5.3	5.7	98	0.1017

CHAPTER V

CONCLUSION AND RECOMMENDATIONS

The effect of the jute backing fabric geometry on the functional performance (tuftability) has been examined statistically. After observation of the relationships of the individual parameters with the fabric strength and elongation in both untufted and tufted states, the independent variables, weave factor and crimp ratio, were added to establish a better mathematical model to predict the tuftability.

The general results of these studies can be summarized as follows:

(1) The strength of the untufted and tufted fabrics in the warpwise direction increases as the weave multiplier increases while the fillingwise strength decreases in the untufted fabric and increases in the tufted fabric as the weave multiplier increases.

(2) The warpwise strength for both untufted and tufted fabrics decreases as the weave factor increases while the fillingwise strength tends to increase as the weave factor increases.

(3) The warpwise strength of both untufted and tufted fabrics increases as the crimp ratio increases while the fillingwise strength increases in the untufted fabrics and decreases in the tufted fabrics as the crimp ratio increases.

(4) Both the warpwise and fillingwise strength of untufted and tufted fabrics increase as the linear density ratio increases.

(5) Warpwise and fillingwise elongation of both untufted and

tufted fabrics decrease as the weave multiplier increases.

(6) Warpwise and fillingwise elongation of both untufted and tufted fabrics increase as the weave factor increases.

(7) Warpwise elongation for both untufted and tufted fabrics increases as the crimp ratio increases while fillingwise elongation tends to decrease as the crimp ratio increases.

(8) Both warpwise and fillingwise elongation of untufted and tufted fabrics decrease as the yarn linear density ratio increases.

(9) The yarn crimp increases as the weave factor increases.

(10) The crimp ratio was found to be a satisfactory parameter to represent the relative and true effect of crimp on tuftability.

From these results it can be seen that fabric construction does affect tuftability. Tufted fabric fillingwise strength can be improved with a backing fabric of higher weave factor or a fabric with higher density of interlacing. This can be achieved by either increasing the ends and picks per inch for the same type of weave or changing to a tighter woven construction for the same ends and picks per inch.

To minimize the loss of fillingwise strength after the fabric has been tufted, the filling yarn crimp can be increased by increasing the weave factor or by chemical treatments.

Another possibility of minimizing the fillingwise strength degradation is to use filling yarns of lower linear density relative to the warp yarn. This means increasing the yarn linear density ratio.

Since untufted fabric elongation was found to be related to the tufted fabric strength especially in the filling direction, the tufted fabric fillingwise strength can be increased by increasing the untufted fabric fillingwise elongation by increasing the value of the weave factor and decreasing the crimp ratio.

After understanding the influences of each parameter, the tuftability of the fabric or the stress-strain properties of the tufted fabric can be predicted by knowing only the construction and the crimp ratio of the backing fabric.

Since the crimp ratios, obtained with the three methods mentioned in Chapter III, were proved to be not significantly different from each other, one can, by using the hand method to obtain the crimp data, even predict the stress-strain properties of the backing fabric, as well as the stress-strain properties of the tufted fabrics, without using the Instron Tensile Tester. Therefore, the tuftability of the backing fabrics can now be optimized by merely manipulating the value of the weave factor and crimp ratio within logical ranges. However, it should be noted that the eight prediction equations listed in Table 7 were generated from a relatively small sample size, a total of 34 fabrics in which the majority were plain fabrics. Therefore, the usefulness of these eight prediction equations will have to be tested intensively.

Any errors in this study could have resulted from various treatments that the yarn or fabric may have previously undergone without the author's knowledge. But this study does give an idea how the geometry of the fabric in our uncontrolled experiment would affect the functional properties of the fabric in both untufted and tufted stages. In addition, the relative degree of influences between these two stages can also be seen. However, if we wish further confirmation of the results of this study and a more complete understanding of the geometrical effects of the fabric on tuftability, as well as other factors that might influence the tuftability of a fabric, a controlled experiment is recommended.

In a controlled experiment, the range of the factors to be studied can be controlled and also the other possible unknown factors that may contribute to the variation of the dependent variable--tuftability-- can be limited or even eliminated.

In this study, all relationships are assumed to be linear, but according to some of the scatter diagrams, non-linear relationships may exist between some parameters. This phenomenon was found to be more obvious in the relationship between fabric elongation and crimp. Therefore, in future studies, with a better knowledge of the materials, higher order polynomials should be investigated in order to have a better mathematical model to explain the relationship between the independent and dependent variables. Then a multiple regression method could be used to demonstrate the joint effect of all the independent variables. A stepwise multiple regression method is suggested to obtain the best regression equation.

After the best equation has been established, calculated charts or diagrams of the nomograph type can be prepared for industrial references. Furthermore, in future studies, besides strength and elongation of the fabric, the textile modulus should be included to express the tuftability of the backing fabric because it is an indication of the fabric toughness and stability.

Finally, it is suggested that after sufficient understanding of the factors affecting tuftability as well as fabric geometry is achieved through these experimental results, theoretical study should follow and then be compared with the experimental results. Therefore, the backing fabrics may be engineered more accurately and scientifically to achieve the best possible product.

APPENDIX

Table 10. Weave Multiplier for Different Types of Fabric Construction

Weave Type	Weave Multiplier
Plain	1
Double Weft	1.5
2/1 Twill	1.5
2/2 Twill	2
3/1 Twill	2
2-2 Basket	2
2/2 Herringbone	2
4 Harness Sateen	2
3/2 Twill	2.5
4/1 Twill	2.5

Table 11. Comparison of Crimp Ratio Obtained with Different Methods

Analysis of Variance Table

Source	Sum of Squares	Degrees of Freedom	Mean Square	F Ratio	$F_{0.5;2,99}$
Between Method	0.0796	2	0.0398	0.1508	3.09
Error	26.1261	99	0.2639		
Total	26.2057	101	0.2595		

Conclusion: There are no significant differences among the crimp ratios obtained by the three methods stated in Chapter III.

Table 12. Calculation of the Coefficient of Linear Multiple Correlation

For a linear multiple regression with two independent variables such as:

$$X_1 = a_1 + a_2X_2 + a_3X_3$$

where

X_1 is the dependent variable

X_2, X_3 are the independent variables

a_1, a_2, a_3 are the regression coefficients

The coefficient of multiple correlation is as follows:

$$R_{1.23} = \left(\frac{r^2_{12} + r^2_{13} - 2r_{12}r_{13}r_{23}}{1 - r^2_{23}} \right)^{\frac{1}{2}}$$

where

$R_{1.23}$ = Coefficient of Linear Multiple Correlation which shows the linear relationship between the variables.

r_{12} = Correlation Coefficient between X_1 and X_2

r_{13} = Correlation Coefficient between X_1 and X_3

r_{14} = Correlation Coefficient between X_2 and X_3

Table 13. Calculation of the Confidence Limit for Linear Multiple Regression

For a linear prediction equation of the following form:

$$X_1 = a_1 + a_2X_2 + a_3X_3$$

where

X_1 is the dependent variable

X_2, X_3 are the independent variables

a_1, a_2, a_3 are the regression coefficients

The Confidence Limit is

$$\pm t_{\alpha,v}(\sigma_\epsilon)$$

where

t is the "t" statistic

α is the level of significance

v is the degree of freedom

σ_ϵ is the standard error of the prediction

$$\sigma_\epsilon = \left(\frac{\Sigma X_1^{\,2} - a_1\Sigma X_1 - a_2\Sigma X_2X_1 - a_3\Sigma X_3X_1}{N} \right)^{\frac{1}{2}}$$

where

N = number of collected values for each variable

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