TECHNICAL REPORT

68-10-GP

THE MECHANICS OF RUPTURE

OF

COTTON-DACRON BLENDED YARNS

Constantin J. Monego

July 1967

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General Equipment & Packaging Laboratory

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THE MECHANICS OF RUPTURE OF COTTON-DACRON BLENDED YARNS

by

Constantin J. Monego
Shelters Division

Project Reference
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July 1967

General Equipment and Packaging Laboratory
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FOREWORD

This work was accomplished under an exploratory development project, "Studies in the Structural Mechanics of Tentage", Project Number 1M624101D503. Mr. Constantin I. Monego served as Project Officer.

The report was submitted to the Massachusetts Institute of Technology (M.I.T.) in partial fulfillment for a master's degree in textile technology.

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TABLE OF CONTENTS

SYMBOLS

σ	stress of fiber, gm
ε	strain of fiber, dimensionless ratio
E	Young's modulus of a fiber, Kg/cm^2 or lbs/in^2
S	tensile load on model yarn structure, Kg
ε_Y	yarn elongation, %
t	twist per cm. at elongation ε_Y, turns/cm
t_0	twist per cm. at zero strain, turns/cm
θ	twist angle of a fiber at radius r, radians
r	radial position of fiber, dimensionless ratio
R	model yarn radius, mm
P	pressure inside the model yarn at radius r, Kg/cm^2
P_c	pressure at the center of the model yarn, Kg/cm^2
ρ	radius of curvature of the fiber at radius r, $\frac{r}{\sin^2\theta}$
ϕ	packing factor, dimensionless ratio
μ	coefficient of friction between constituent fibers (Dacron and Cotton), dimensionless ratio
f	normal force acting on the cotton yarn per unit length, gm/cm
D	cotton yarn diameter, inch or mm
T_b	rupture strength of cotton yarn, gm
T	tensile force acting on the cotton yarn in the structure, lbs or Kg
L	initial cotton yarn length in the structure, cm
l_c	critical broken length of cotton yarn, i.e., the length below which cotton yarn will not be broken, mm

n	number of breaks of cotton yarn in the structure, unit
l	broken length of cotton yarn, mm
$\bar{l}$	average broken length of cotton yarn, mm
Y_b	yarn break, gm/denier
X_{fb}	number of fibers, breaking strength, gm/denier

ABSTRACT

The tensile behavior of cotton-Dacron blends has been studied in a twisted model yarn structure composed of Dacron filament yarns (70 denier, 34 filament) and combed cotton staple yarns (79 cotton count (c.c.)) in blend ratios of 1.1, 2.2, 11, 22, 33, 44, 56, 67, and 89 percent cotton content.

The contribution of the cotton component to the blended structure at all strain levels is the main subject of this study.

This report covers the experimental studies on the load extension characteristics of 72 model yarns at elongations of 5 percent through break and the effect of twist (0.55 twist multiple (TM) through 4.4 TM), blend ratio and position of the cotton component in the yarn (cotton core or cotton shell) on the strength of the blended yarn are discussed.

These studies extend Machida's theoretical approach to the problem of blended yarn strength to include cotton-Dacron blended yarns in blend ratios of practical significance.

THE MECHANICS OF RUPTURE OF COTTON-DACRON BLENDED YARNS

Introduction

The rate at which new fibers have been added to the textile market in the past thirty years has increased enormously the fiber combinations available to industry. Thus, the textile engineer can develop yarns for specific end use applications. In areas where high strength is to be achieved at minimum weight, the tensile behavior of a blended yarn is one of the most fundamental and important properties to consider. While some excellent work has been done in this area, the fiber-to-fiber load transfer in a yarn and the mechanism of yarn rupture are still not clearly understood. This report is concerned with the tensile properties of cotton-polyester blends. The tensile properties of the blended yarns are studied, using physical models of blended yarns and the mathematical models developed by Kazuo Machida, with the view toward establishing a better understanding of yarn behavior under tensile stress up to and including yarn rupture.

The cotton-polyester blend was selected for two reasons. The first reason is a practical one. This fiber combination has wide acceptance in the consumer market; therefore, the results obtained would have immediate practical significance. The second reason is a theoretical one. The blend of a strong extensible fiber, such as a polyester, with a weaker less extensible fiber, such as cotton, provides a mechanism for studying the combined effects of pressure and friction in the yarn cross-section when the blended yarn is twisted and elongated. In this situation, as the polyester fibers are extending and the cotton fiber is breaking, the polyester fibers are developing an axial tension which grips the cotton fibers like a vise, thereby extending the cotton fibers beyond their rupture elongation. Thus, the cotton yarn in the blend acts as tracer material for measuring the combined effects of pressure and friction in a yarn which is being elongated.

This report discusses the tensile behavior of cotton-polyester fibers as determined experimentally for the following blend ratios: 0, 1.1, 2.2, 11.0, 22.0, 33.0, 44.0, 56, 67, 89, and 100 percent cotton content.

Literature Review

The literature reviewed is shown in the list of references. The literature cited covers the abrasion and tensile behavior of yarns, blending irregularities and blend ratio testing as well as processing techniques for blended yarns.

Papers of review interest to this study are given in chronological order as follows: Sullivan, 1942(36)*; Platt, 1950(32); Hamburger, 1950(11); Gregory, 1953(10); Kemp and Owen 1957(21); Shorter, 1957(34); Hearle, 1957(14); Noshi, 1960(28); Azuma, 1960(1); Hearle et all, 1961(16); Treloar and Riding, 1963(37); and Machida, 1963(26).

In the outstanding works listed above, analytical techniques of applied mechanics were used to describe the stress-strain behavior of two fiber component yarn blends. In all of these works, the major portions were carried out with a full appreciation of, but with a purposeful disregard for, quantitative determination of some of the forces acting on and within component parts of the yarn structure. This disregard of forces results from the simplifying assumptions made by the investigators to make their equations tractable. For example, Sullivan has studied the theoretical strength of staple yarn with the assumption that the fiber tension is uniform in a yarn cross section.

Platt has studied the theoretical strength of continuous filament yarn. The extension of his theory to spun yarns assumes the assimilation of the combined effect of fiber stretch and slippage to that of pure stretch of the filaments of a continuous filament yarn. This condition implies that the ratio of stretch to slippage should be constant, both within the body of a single yarn and among yarns of different twists. This condition can be fulfilled only in highly twisted yarns. However, Platt's equations can be used over a wide range of different yarns if the constants are derived from different sets of experimental results.

Gregory studied the relation between the strength of yarn elements relative to the strength of the constituent fibers. He found that no simple function exists for linking critical pressure within the yarn with twist for maximum strength. Gregory derived an empirical relation between critical pressure and the reduction in strength of the yarn at high twist and attributed the loss in strength to the obliquity of the twisted fibers. On this basis, he developed a formula relating the maximum strength of the yarn element to fiber characteristics.

Shorter has attempted to present a unified picture of the process of stretching a yarn to its breaking point. He listed two factors as operative in determining breaking tension which previous theories have dealt with separately. The two factors relate to the effect of twist on (a) the relative incidence of fiber slippage and breakage and (b) the degree of nonsimultaneity of the breaks. Shorter compares the relevance of Sullivan's and Platt's theories, and the predictions of the

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*Numbers in parentheses refer to the literature references.

various theories are compared with experimental data. He found rough agreement between predicted and experimental results with Sullivan's theory(36) with twists below the optimum twist and agreement with Platt's theory(32) with twists above the optimum.

Azuma's theory(1) assumes a uniform pressure in the yarn cross section. Noshi et al(29) have studied the tensile strength of twisted blended continuous filament yarns. However, in their theoretical analysis, they neglected the study of yarn pressure. Like Azuma, they apparently assumed a constant pressure; for this reason, their theory would be useful over a limited range of the stress-strain curve, probably at the higher levels of strain.

In 1957, Hearle(14) studied the theoretical strength of yarns at low strains. Here his theory takes into account the lateral pressure between filaments, while retaining the essential geometric assumptions of Platt and the assumption of no change in the radial position of the filament under deformation.

Hearle, El Behery and Thakur(15) attempted to obtain a closer approximation to the real yarn system. Here they have introduced a modification to Hearle's theory in which the strain geometry of the yarn is defined by an axial extension together with a radial contraction, the latter being described by a yarn Poisson's ratio. The original theory now becomes a special case for which Poisson's ratio equals zero. The new theory, while accounting for lateral pressure between the filaments, is restricted to small strains. In the same paper the authors have also considered a further modification in a form which is valid for large strains. However, in this latter case the lateral pressure between filaments was not taken into account. In this study the analysis has not included the effects of both lateral pressure and large strains. Therefore, the results can be applied, for a given value of constants, only over a limited range of strain.

Treloar and Riding(37) have studied the tensile properties of twisted continuous filament yarns in terms of their geometric structure and the properties of their constituent filaments. Their theory has the following features: (1) it is a large strain theory; (2) constancy of volume is assumed for both filaments and yarn during deformation; and (3) the analysis is carried out on a strain-energy system which leads to a more tractable mathematical treatment than the customary stress analysis methods. Material properties are introduced in the form of a complete stress-strain curve. The stress-strain curve of the yarn over the whole range of extension is calculated. The authors found that the stress-strain data for Tenasco* yarns show good agreement

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* High tenacity rayon filament: American Viscose Corp.

with the theoretical curves, except in the region of small extension and high twists. No attempt was made by the authors to discuss the theoretical breaking load of the yarns.

The works of Hamburger(11), Kemp and Owen(21), and Machida(26) are directly related to the work in this paper and will be discussed below; however, before leaving the literature review, a general summary of the state of this work should be given. This summary has been well expressed and is reflected by a statement made by Hearle, El Behery and Thakur(15) as follows:

"The critical assessment of theories of yarn tensile properties serves to increase our understanding of the behavior of yarns. In the initial regions of extension where yarn tension is proportional to extension, the more highly developed theories fit the experimental results better. But above the limit of proportionality, and in the prediction of breakage, the later theories are but little improvement on the simplest impression ($Y_b/X_{fb} = \cos^2 a$) given by Gegauff in 1907. The considerable divergence between experiment and theory must be attributed to more complicated forms in yarn structure and to a more complex mechanism of breakage. Both of these problems merit further study."

As a result of the studies listed above and other literature on the strength of blended yarns, it is an accepted fact that the strength of the blended yarn is in general lower than might be expected from the proportional strength of the component fibers.

In 1949, Hamburger(11) proposed a mechanism to explain this behavior. Hamburger suggested the superposition of the stress-strain curves of the two component fibers to give a new stress-strain for the blended filament yarns. His procedure is illustrated in Figures 1 and 2.

In Figure 1, curve "A" is the engineering stress-strain curve of the lower strength less extensible fiber (cotton); and curve "B" is the stress-strain curve of the stronger more extensible fiber. The superimposed curve of the two component yarns are shown as a dashed line. The dashed line has two peaks corresponding to the rupture points of the "A" and "B" fibers. This is characteristic of the stress-strain curves of blended yarns. In Figure 2, the strength of the blended yarn is shown as two crossed lines. It should be noted in Figure 1 that the stronger and more extensible yarn (polyester) is stiffer than the cotton; therefore, in Figure 2 no minimum point in strength occurs as a function of the blending ratio, but the cotton-polyester blend will always be stronger than the all-cotton yarn. This principle, proposed by Hamburger, applies strictly to continuous filament yarns, neglecting such integrating forces as friction and compression on the component fibers. Nevertheless, this technique provides a powerful tool to predict the strength of two component blended yarns. Because of its simplicity, it is widely used by industry for this purpose, even for blended staple yarns.

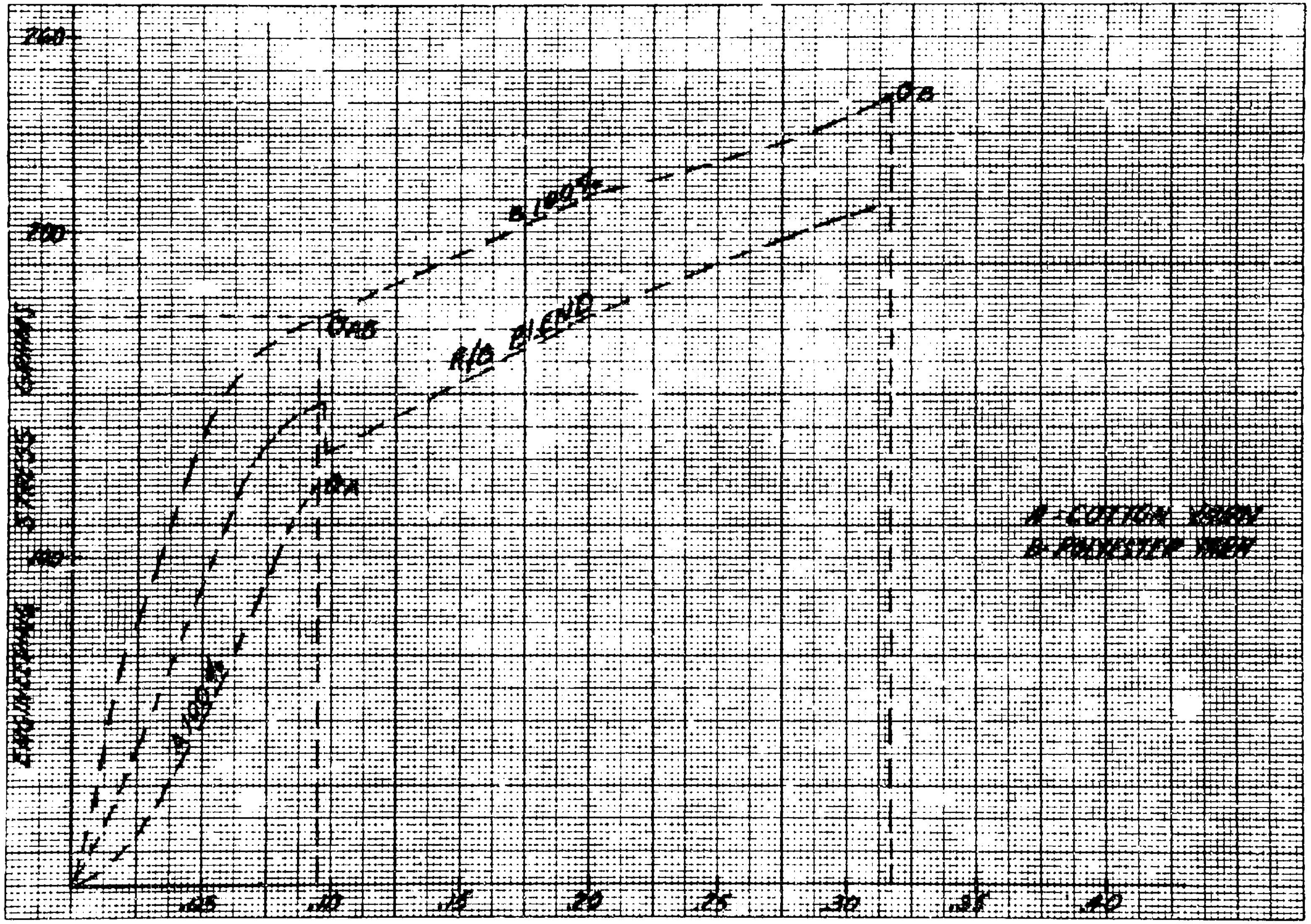

Figure 1 Stress-Strain Properties of Blended Yarn

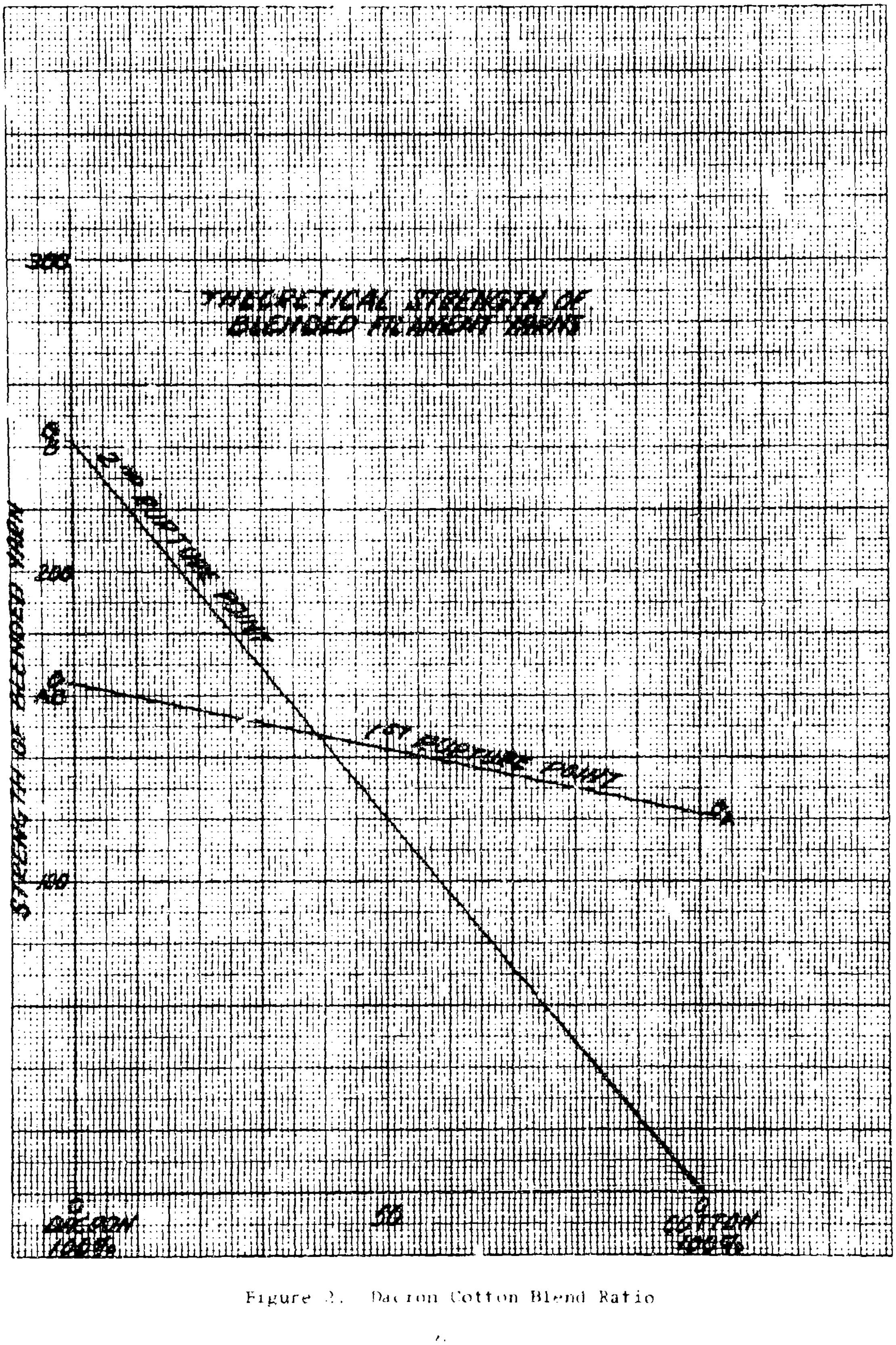

Figure 2. Dacron Cotton Blend Ratio

Kemp and Owen(21) studied the tensile behavior of cotton-nylon staple fiber blends. They presented experimental data which show that for blends of staple fibers the prediction of strength of the blended cotton-nylon yarns by the stress-strain method proposed by Hamburger leads to large discrepancies in the 60 percent and 80 percent Nylon blends with cotton (Figure 3).

In their paper Kemp and Owen observed a larger number of broken cotton fiber segments in yarn strains at higher levels than those found in the unstrained yarn or yarn subjected to lower strains (Figure 4).

They concluded that the comparatively low strength of the blended Yarn is primarily due to the difference in the breaking strains of the component fibers. They observed that the breakage of cotton fibers is continuous from very low strains to the breaking strain of the blended yarn. From this they concluded that cotton fibers continue to contribute to yarn strength at strains greater than their rupture point. Kemp and Owen also attempted to calculate the theoretical contribution of cotton fiber in a blended yarn assuming a constant critical length in the broken segments. The critical length is that length of the portion at each end of the fiber over which slippage occurs (Appendix 1); for fibers of a length less than the critical length, slippage takes place over the whole fiber length. Therefore, this critical length is a function of inner yarn pressure, frictional characteristics of the two fibers, and yarn elongation. The critical length does not remain constant, but varies with a change in pressure and elongation. It is to the analysis of this particular mechanism that Machida addressed his study of blended yarn structure.

Machida proposed a more rigorous treatment to the problem of yarn strength. His approach provides a more theoretical approach in the analysis of the mechanisms by which cotton fibers contribute to yarn strength. Machida studied the strength contribution of the cotton component to the blended structure at strain levels exceeding cotton fiber rupture elongation by using a model yarn technique to conduct mathematical and experimental studies on the pressure distribution and on the frictional force in the twisted structure.

His work has provided a mathematical analysis of the pressure distribution in the twisted filament structure as well as an equation for the average theoretical broken length of cotton. Both equations are as follows:

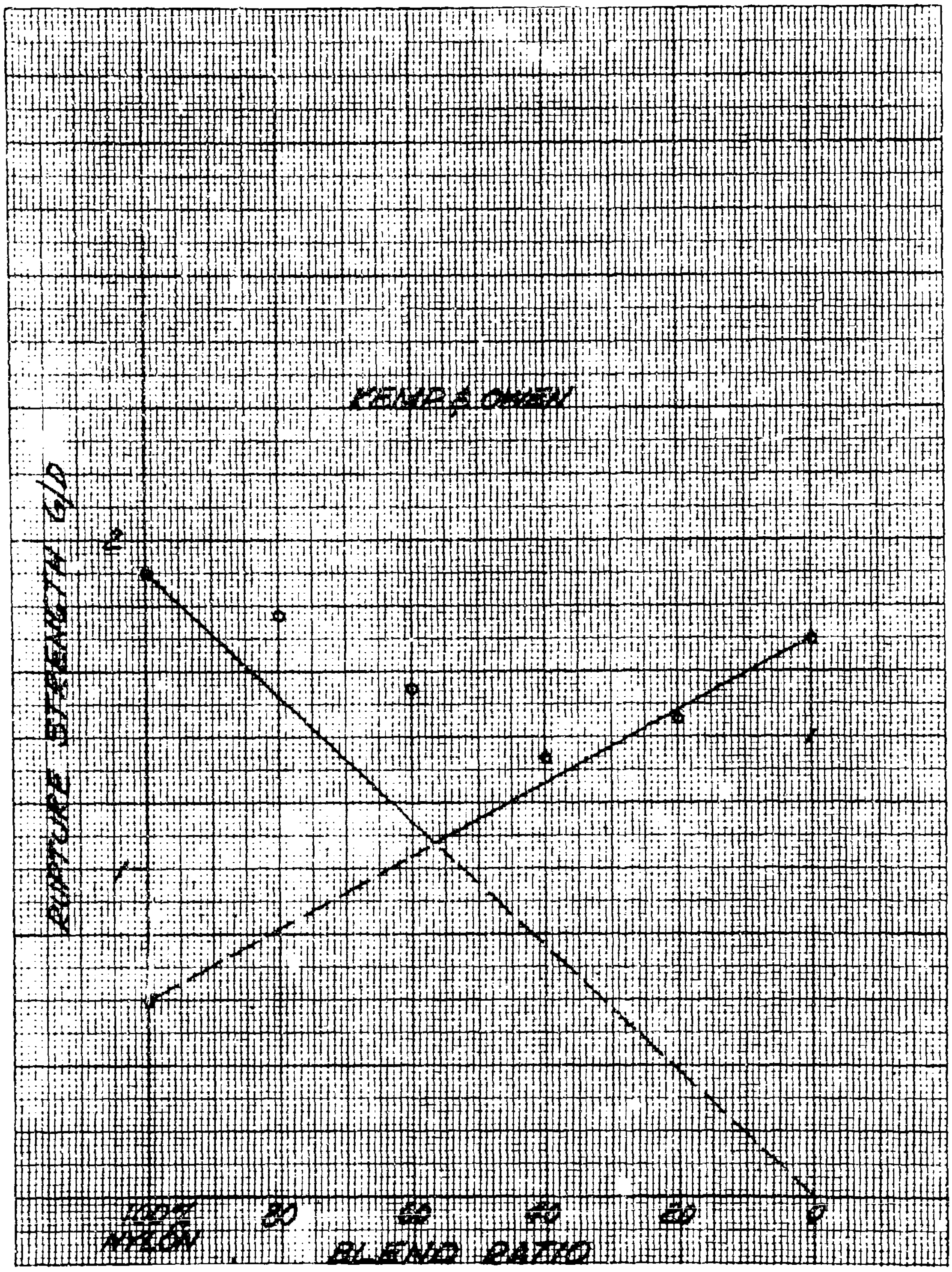

Figure 3. Cotton Nylon Blend (Kemp & Owen)

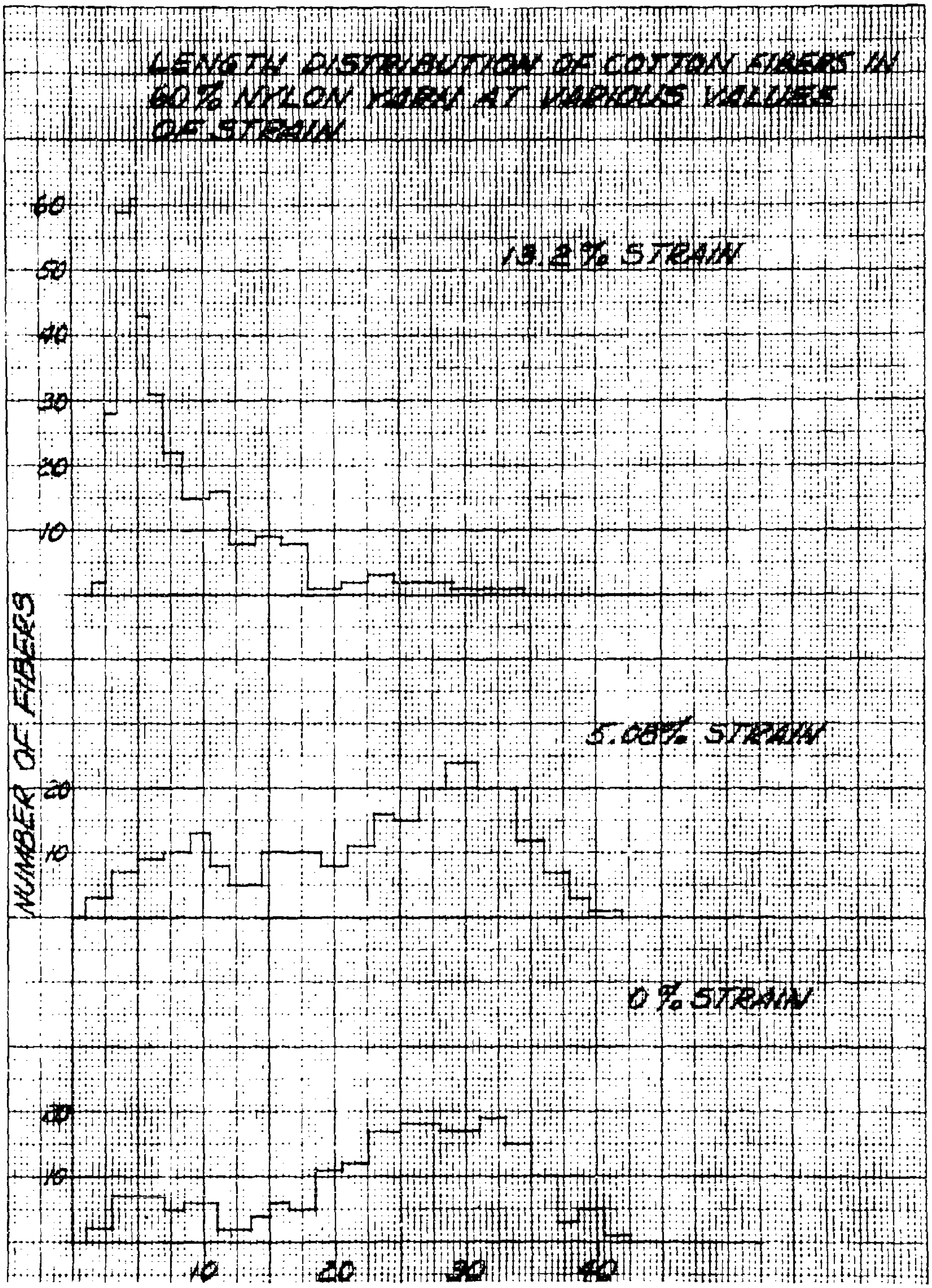

Figure 4. Fiber Length Can

A pressure distribution as a function of tension on the yarn structure for small twist angles.

$$P = \frac{2 \pi t_o^2 \quad S}{(1 + E_y)^2} (1 - \frac{r^2}{R^2})$$

where P is the pressure in the yarn

t_o is the twist before loading

s is the yarn load

E_y is the yarn elongation

r is the radial position of the fiber in the yarn cross section

R is the radius of the yarn

All of the parameters are easily determined.

The average broken length of the cotton is given as follows:

$$\bar{l} = \frac{3T_b}{2 \pi \mu \quad D P}$$

Where T_b is the breaking load of the cotton yarn

μ is the coefficient of friction (0.24)

D is a diameter of the cotton yarn

P is the pressure in the yarn cross section due to tensile load

Machida shows the experimental results to confirm the validity of his theory, Table 1, Figure 5. An independent check was made; the experimental results of which are shown in Table I and Figure 5.

Table I

Theoretical and Experimental Broken Length

							Machida	
	TM	t_c	u	D	T_b	S	Theor	Exp
		t/cm		cm	g	Kg	l mm	$\bar{l}$ mm
20% Extension	0.5	0.171	0.24	0.011	195	29.6	94.0	68.8
	1.0	0.34	0.24	0.011	205	29.0	25.0	24.2
	2.0	0.68	0.24	0.011	215	28.2	6.8	10.0
	3.0	1.03	0.24	0.011	230	27.2	3.4	5.4
	4.0	1.36	0.24	0.011	245	25.8	2.1	3.9

Table II

Theoretical and Experimental Average Broken Length

	TM	t_o	u	D	T_b	S	Theor	Exp
		t/cm		cm	g	Kg	$\bar{l}$ mm	$\bar{l}$ mm
20% Extension	0.55	.18	0.24	0.0091	132	24.0	69.0	44.0
	1.10	.36	0.24	0.0091	142	24.0	19.8	17.6
	2.20	.67	0.24	0.0091	165	23.2	6.7	6.1
	3.30	1.01	0.24	0.0091	175	22.5	3.2	4.2
	4.40	1.34	0.24	0.0091	185	21.8	1.8	2.6

The solid line represents the theoretical plot for average fiber lengths; the crosses represent the data in Table I; the circles represent the data in Table II. It can be readily seen that the agreement between theoretical and experimental data is good, confirming the validity of Machida's theory. Machida points out that the results of his theory are strongly dependent on the coefficient of friction; which is difficult to evaluate under conditions experienced by the fibers undergoing extension.

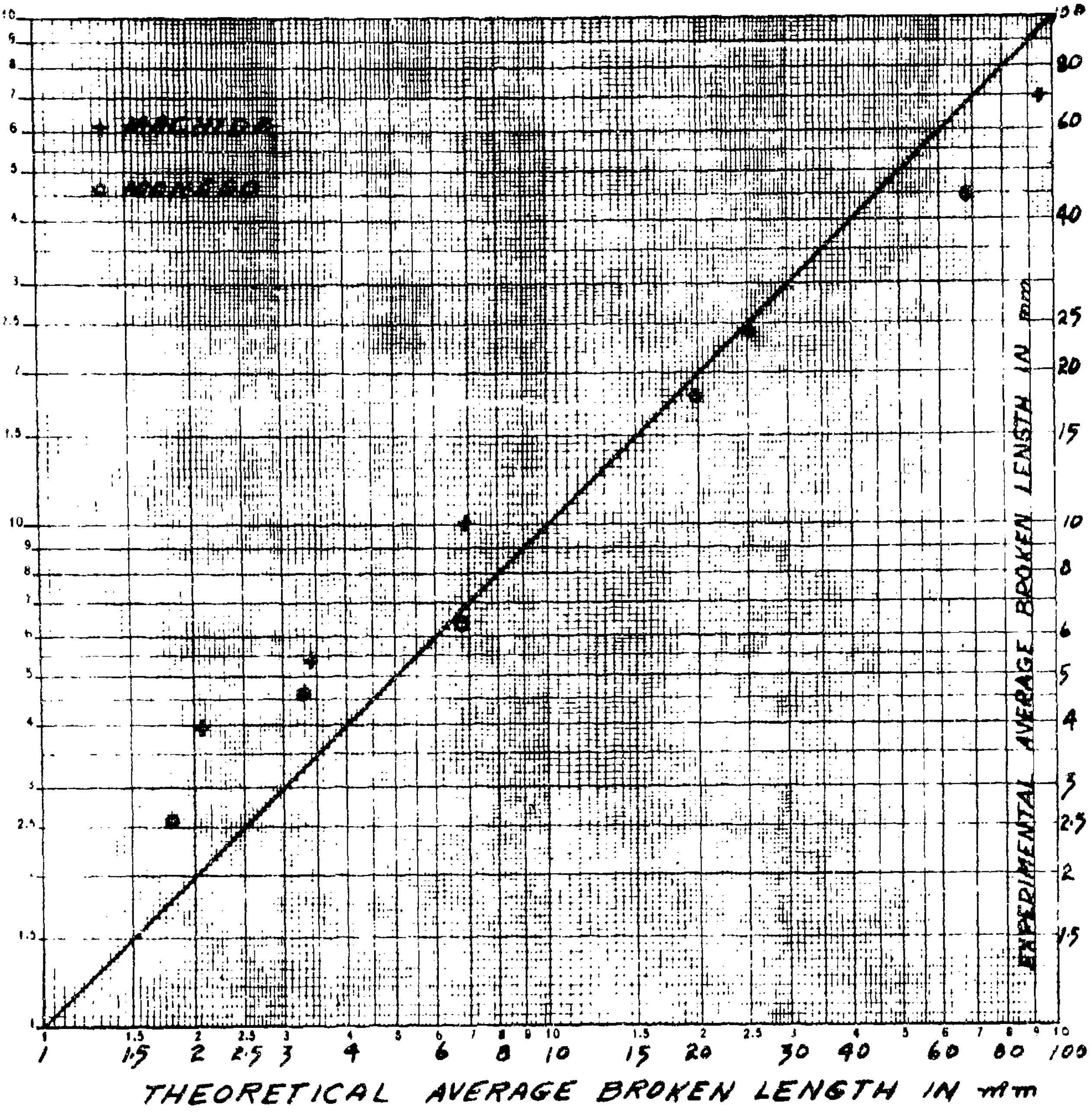

Figure 5. Correlation of Average Broken Length, Experimental and Theoretical

The agreement between experimental results with Machida's theory provided the encouragement needed to embark on an expanded program covering cotton/Dacron blends of higher cotton content.

This study covers the experimental evaluation of cotton and Dacron blends, including blend ratios of 1.1 percent cotton through 100 percent cotton.

Machida's Model Yarn Method

The development of a model yarn is the first step in a more rigorous treatment to the problem of yarn strength. This method also provides a theoretical approach which is required in the analysis of the mechanisms by which cotton fibers contribute to the strength of a cotton-Dacron blended yarn. The model used is a blended twisted structure composed of two different kinds of yarns, one which has a higher rupture elongation (Dacron) and the other yarn, cotton yarn. It must be recognized that the model blended yarn is somewhat different from actual staple blended yarns. Specifically, the pressure distribution inside an actual staple yarn structure is different from that in the model because the model yarn is composed of continuous filament Dacron and continuous spun cotton yarns. Therefore, the magnitude of the strength contribtuion of the cotton component can be expected to differ in the two systems. This difference would be one of degree only for the interaction between the cotton fibers and Dacron fibers under load must be the same.

The use of a model yarn simplifies the mathematical analysis of pressure and stress distribution in the yarn. The experimental work is also facilitated when compared with Kemp and Owen's work on staple yarns because of the large size of the cotton yarn segments measured in the model system.

Machida studied the case when a single cotton yarn was blended with Dacron. This was necessary to prove the validity of his theory, since a single cotton yarn in the center of a large number of Dacron yarns will not greatly affect the pressure distribtuion in the blended yarn structure, even though the cotton is broken into several pieces.

The physical considerations which must be accounted for in a model yarn are as follows:

When a blended yarn is twisted and elongated, Dacron fibers are strained and develop an axial tension. This tension has a component force directed toward the center of the yarn owing to the twist angle. The integration of all such component forces creates a lateral pressure in the yarn. Thus cotton yarn in the blended model yarn is subjected to tensile forces arising from pressure and elongation of the surrounding Dacron yarns. Thus, if the broken lengths of cotton yarn, tested under specified conditions, are measured, specific information will be obtained on yarn pressure and frictional characteristics. Thus, the cotton yarn in this case is used as a tracer material for measuring the combined effects of pressure and friction. It is this experimental technique which will be used to evaluate the yarns considered in this study.

Theoretical Analysis

The theoretical analysis developed by Machida is shown in Appendix A. Machida's analysis allows pressure to vary. He provides the expressions for maximum and average pressure in the yarn cross section. Pressure in relation to yarn load, the effect of yarn elongation to pressure, stress distribution in cotton yarn and theoretical broken length.

The equations for pressure in a yarn cross section are of particular interest to this study and are extracted from Appendix A as follows:

The mathematical analysis of the pressure distribution in the twisted filament structure is as follows:

Symbols are defined in Appendix A.

$$P(r) = \frac{E \ ey}{2} \ \phi \left[\frac{1}{1 + 4\pi^2 t^2 r^2} - \frac{1}{1 + 4\pi^2 t^2 R^2} \right]$$

when $4\pi^2 t^2 R^2 << 1$ (twist angle is small)

$$P_c = \frac{2\pi t_o^2 S}{(1 + E_y)^2}$$ (Pressure in center of yarn)

$$\bar{P} = 1/2 \ Pc$$ Average Pressure

$$Pr = Pc \ (1 - \frac{r^2}{R^2})$$ (Pressure at radial position r)

t_o Twist at no strain

S Yarn load

E_y Yarn elongation

Average broken length

$$\bar{l} = \frac{3 \quad T_b}{2 \pi \mu \ D \ P}$$

$\bar{l}$ = average broken length

T_b = breaking strength cotton yarn

μ = coefficient of friction

D = diameter of cotton yarn

P = pressure on cotton yarn

Experimental Studies

Yarn Structure - The yarn structure desired is one that will conform as closely as possible to the mathematical model used in the theoretical analysis, Appendix A.

The assumptions pertinent to the construction of the model yarns, and the experimental means of achieving them are as follows:

1. The whole yarn structure is large compared with the cotton yarn.

2. A model yarn consisting of a center yarn with five layers of yarns encircling it was selected. For yarns of uniform diameter, 91 yarns are required to complete the model yarn. The 91 yarns are geometrically arranged as follows: 1 yarn center; 6 yarns 1st ring; 12 yarns 2nd ring; 18 yarns 3rd ring; 24 yarns 4th ring; and 30 yarns 5th ring.

Uniform Cylindrical Structure

Uniform along its length and circular in its cross section. This condition would require the elimination of feed rolls from conventional laboratory twisters.

All fibers form concentric helices (no migration of cotton yarns takes place.) This condition would require the elimination of feed rolls from the conventional laboratory twisters and introducing a means of applying a constant tension to the yarns in each ring to control migration.

Twisting Equipment

The above conditions required the construction of a twisting device. The essential features of this new twisting device is a guide plate with 91 holes drilled in the required geometric arrangement, a creel to hold the yarn, and a guide plate with five concentric circles around the center hole. To reduce abrasion of the yarns in passing through the guide plate, the plate was made of Teflon*.

Each yarn is drawn in the appropriate hole to make up the blended structure. A separate drawing had to be made for each yarn structure tested. A creel was constructed to hold the 91 yarns. The creel was designed to hold 100 plastic spools, only 91 of which are used. The plastic spools are placed on five bars, twenty spools to a bar. Each spool measures 2½ inches in diameter and approximately 3/8 inches in width (2½-inch tape recorder reels). The yarn is drawn from the spool through a guide, then drawn through the tension bars before being threaded through the guide plate hole. The tension on each yarn was measured with a Chatillon spring scale, having a full scale reading of 50 grams. The creel, guide plate and twisting device are shown in Figure 6. The twisting head consists of a selsyn drive, mounted on a carriage. The speed of the twisting head was varied to obtain the different twist levels used in this study. The lateral speed of the twisting head is consistant.

In the operation of the spinning device, several operating techniques had to be learned for smoothness of operation and to obtain a uniform yarn.

Initially the tension in the yarn was adjusted for each concentric ring, the highest tension in the center and lowest on the outside. However, starting with a 2-3 gram tension on the outside ring and increasing the tension of each ring by 3 grams, the tension on the center yarn amounted to 18-20 grams. While the relative loads are small, the increase in tension from center yarn to outside ring represented a six-fold increase.

This was considered undesirable, since the center yarn would in effect be strained and may influence the test results. A satisfactory operating condition was achieved (i.e., the yarns formed an undistorted cone) when a 4-5 gram tension was maintained for the center yarn and a 2-3 gram tension for the remaining yarns. A load of 3/4 lbs was required to draw the yarns for spinning.

A second condition was found to be important in order to obtain a uniformly spun product, that is the distance from the guide plate to the spinning head. The initial yarn length of 3 feet was found to be unsatisfactory because of excessive yarn wrap in the outer layers. A distance

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*Fluorocarbon film; E. I. duPont de Nemours and Company

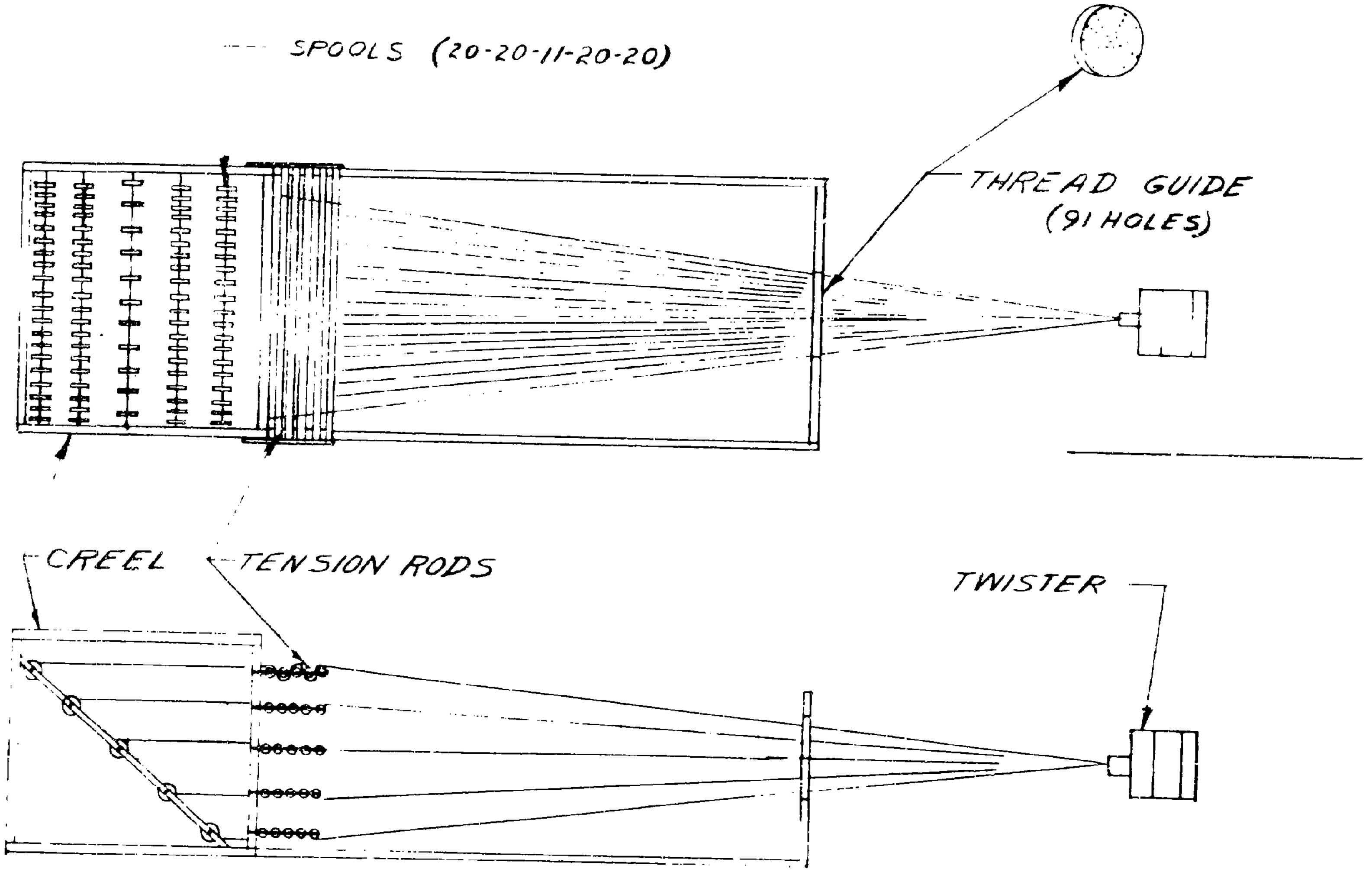


Figure 6. Creel and Twisting Machine

of 8 feet was tried next, but this distance proved too great; yarn wrap of the outer layers was reduced, but the long span introduced too much slack in the outer layers leading to greater lengths of yarn in the outer ring. A four-foot length gave the best trade balance with respect to evenness of twist and yarn length (no sag) in the outer rings. The effect of yarn wrap in the outer layers was controlled by drawing and spinning the yarns with only 3/4 of the necessary twist, then clamping the far end of the yarn and inserting the remaining twist in the yarn without drawing.

The third condition to be met is uniformity of tension. The yarn had to be wound evenly on the plastic spools under uniform tension. To do this properly a winder had to be constructed as shown in Figure 7. The winder in Figure 7 winds the plastic spools with a uniform wrap. The machine is equipped with tension bars and all yarns were wound under a constant tension of 5 grams. The reel (A) in Figure 7 was used for winding the dyed cotton skeins, while the stand was used for winding Dacron yarn.

Basic Yarns and Preparation for Twisting

Dacron Yarn. 70 denier, 34 filament, Dacron yarns were used without modification. The Dacron yarn was wound on the plastic spool for use in the twisting device.

Cotton Yarn. The cotton yarn selected was a commercially available single combed cotton yarn of 79 cotton count. Since it is desirable to match the denier of the cotton to the Dacron the comparative denier size can be calculated from the cotton count as follows:

$$\text{Comparative denier count} \approx \frac{5315}{\text{Cotton Count}}$$

$$\frac{5315}{79} = 67 \text{ denier for cotton yarn.}$$

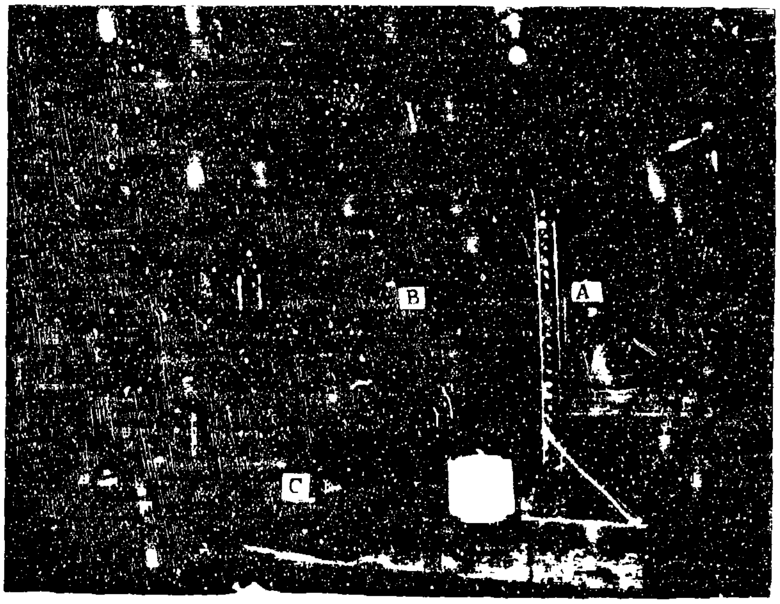
The cotton yarn was skeined, scoured and dyed, then rewound on spools for the twisting machine. A total of 91 different colors were dyed and coded to enable identification of cotton with respect to the radial position in the model yarn cross sections. The dye formulations and dyeing procedures are listed in Appendix B.

Model Yarns Spun

The total number of yarns in the model yarn assembly is 91 yarns. The following combinations of cotton and Dacron yarns were spun:

(1) 1.1% cotton - 1 cotton, 90 Dacron yarns

(2) 2.2% cotton (cotton centered) - 2 cotton, 89 Dacron yarns



A - Stand to unwind Dacron

B - Reel for unwinding cotton skeins

C - Winder

Figure 7. Winder for Winding Plastic Spools with Uniform Warp

(3) 2.2% cotton (cotton outside shell) - 2 cotton, 89 Dacron yarns

(4) 11.0% cotton (centered cotton core) - 10 cotton, 81 Dacron yarns

(5) 11.0% (cotton distributed in cross section) - 10 cotton, 81 Dacron yarns

(6) 11.0% cotton (cotton outside shell, Dacron core) - 10 cotton, 81 Dacron yarns

(7) 22.0% cotton (centered cotton core) - 20 cotton, 71 Dacron yarns

(8) 22.0% cotton (cotton distributed on cross section) - 20 cotton, 71 Dacron yarns

(9) 22.0% cotton (cotton outside shell, Dacron core) - 20 cotton, 71 Dacron yarns

(10) 33.0% cotton (centered, cotton core) - 30 cotton, 61 Dacron yarns

(11) 33.0% cotton (cotton distributed in cross section) - 30 cotton, 61 Dacron yarns

(12) 33.0% cotton (cotton outside shell, Dacron core) - 30 cotton, 61 Dacron yarns

(13) 44.0% cotton (cotton centered, cotton core) - 40 cotton, 51 Dacron yarns

(14) 44.0% cotton (cotton distributed in cross section) - 40 cotton, 51 Dacron yarns

(15) 44.0% cotton (cotton outside shell, Dacron core) - 40 cotton, 51 Dacron yarns

(16) 56.0% cotton (cotton centered, cotton core) - 51 cotton, 40 Dacron yarns

(17) 56.0% cotton (cotton distributed in cross section) - 51 cotton, 40 Dacron yarns

(18) 56.0% cotton (cotton outside shell, Dacron core) - 51 cotton, 40 Dacron yarns

(19) 67.0% cotton (cotton centered, cotton core) - 61 cotton, 30 Dacron yarns

(20) 67.0% cotton (cotton distributed in cross section) - 61 cotton, 30 Dacron yarns

(21) 67.0% cotton (cotton outside shell, Dacron core) - 61 cotton, 30 Dacron yarns

(22) 89.0% cotton (cotton centered, cotton core) - 81 cotton, 10 Dacron yarns

(23) 89.0% cotton (cotton distributed in cross section) - 81 cotton, 10 Dacron yarns

(24) 89.0% cotton (cotton outside shell, Dacron core) - 81 cotton, 10 Dacron yarns

(25) 100.0% cotton - 91 cotton yarns

(26) 100.0% Dacron - 91 Dacron yarns

Each of yarn combinations listed above required a complete rearrangement of the 91 yarns and redrawing through the guide plate with its attendant measuring of the tension in each yarn.

Model yarn with cotton yarns distributed in the cross section, items 1, 2, 5, 8, 11, 14, 17, 20, 23, 25, and 26 were spun at 5 different TM levels--0.55, 1.1, 2.2, 3.3, and 4.4 TM, respectively.

A TM of 1 or 3 was used for cotton core yarns.

A TM of 2 or 4 was used for Dacron core yarns.

The blend ratio and count of the model yarn spun is shown in Table III.

Table III

Blend Ratio and Count of Model Yarns

No. of Dacron Yarns 70/34d.	No. of cotton Yarns 67d.	Denier Dacron	Denier Cotton	Dacron & Cotton Denier	Cotton Count Blend
91	0	6370	0	6370	0.835
90	1	6300	67	6367	0.836
89	2	6230	134	6364	0.837
81	10	5670	670	6340	0.840

Table III (Continued)

Blend Ratio and Count of Model Yarns

No. of Dacron Yarns 70/34d.	No. of cotton Yarns 67d.	Denier Dacron	Denier Cotton	Dacron & Cotton Denier	Cotton Count Blend
71	20	4970	1340	6310	0.842
61	30	4270	2010	6280	0.847
51	40	3570	2680	6250	0.851
40	51	2800	3417	6217	0.855
30	61	2100	4087	6187	0.860
10	81	700	5427	6127	0.869
0	91	0	6097	6097	0.874

Testing Techniques:

a. Cotton yarn

Cotton rupture strength vs gauge length was checked by testing for the following gauge lengths: 4, 8, 20, 40, 60, 80, 100, 150, and 200 mm. The cotton was tested as received, i.e., undyed, scoured and dyed and for the effect of added twist. The rupture strength for each gauge length will serve as a basis for evaluating the forces exerted on the cotton in the blended yarn. The length of the cotton yarn fragments will be compared with the load elongation data obtained on the cotton yarns and the load data on the model yarns.

b. Model yarn tests

The blended model yarns were elongated in the Instron tensile testing machine to several strain levels up to and including rupture. The radial position of cotton yarns in the cross section can be obtained by microscopic examination of the yarn.

The number of cotton yarns in the blended yarn can be obtained by direct count or by blend level.

The twist can be determined by untwisting each specimen.

The yarn elongation and load level can be read from the Instron chart.

The number of broken pieces can be established by direct count of the number of pieces taken from the dissected yarn.

The average gauge length of 200 mm (8 inches) was selected for this portion of the test.

The strained yarns were set aside and allowed to recover. The yarns were then untwisted and all the yarn segments picked up and measured.

Factors to be considered in the analysis of the strained yarn:

a. Number of cotton fibers in the blended yarn.

b. Twist level.

c. Yarn elongation level.

d. Load level for indicated elongation.

e. Number of broken cotton pieces for each cotton yarn in the blend.

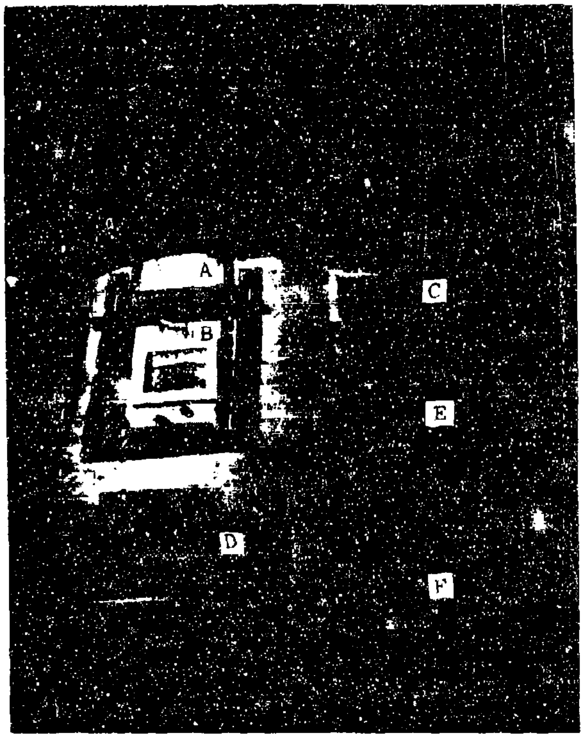
f. Average length of broken cotton pieces.

g. The position of the cotton yarn in the cross section of the model.

The length of the cotton segments were obtained by direct measurement. For pieces greater than 25 mm a conventional rule was used; for pieces less than 25 mm a wedge was used (Figure 8). The direct measurement of small cotton segments using the wedge presented some difficulty. The broken cotton segments contained tails at each end which could not be distinguished from the body of the broken segment. The tails had to be included in the measurement of segment length. Thus the measured cotton segments, when added, total a length much greater than the original length of the original cotton yarn. This difficulty was not experienced with the longer broken cotton pieces, 25 mm or greater in length, because the tails of the broken pieces were small in comparison to the cotton segment measured. To obtain an accurate evaluation of the critical cotton length it was necessary to collect and count all the broken segments, then divide the number of segments into the extended and relaxed length of the tested specimen.

The radial position of the cotton yarn in the cross section of the model yarn is established by observing a yarn cross section and identifying the yarn by color code (Appendix B) and radial spacing, ring 1, 2, 3, 4, or 5. Fractional ring designations were not used, but the yarn was fitted into the ring containing the largest portion of the yarn's cross sectional area.

The yarns for cross sectionizing were mounted in a frame and tensioned to 5 percent extension (approximately 20-lb tension). Five sections of yarn were used, each section representing a segment of four foot length of yarn. Five segments of yarn under tension were fitted in a form. A resin was poured in the form and allowed to cure at room temperature. The types of resin used and the procedures are listed in Appendix C. The tension frame and resin mold is shown in Figure 8.



A - Frame to stretch yarns

B - Silicon frame for holding yarns for impregnation

C - Clamp for holding yarns which resin cures

D - Mold for silicon frame

E - Chatillon spring scale - 50 grams

F - Wedge for measuring fiber length

Figure 8. Tension Frame and Resin Mold

The resin impregnated yarns were sectioned with a hand microtome. Sections less than 10/1000-inch were unsatisfactory--the yarn segments dropping out of the resin. Sections 15/1000-inch thick were mounted on a standard microscope slide and examined under the microscope for diameter of model yarn, diameter of cotton yarns, and radial position of cotton yarns. Five cross sections were examined for each yarn, only one of which was mounted into a permanent slide and photographed. The microphotographs were made with a Unitron adaptor for 35 mm camera. Ektachrome B indoor film with an ASA rating of 125 was used. A Unitron substage illuminator was used. The camera speed was 30 seconds at f1.9.

Calibration of Cotton Yarns

Cotton yarn diameter (D): The cotton yarn diameter was measured in the model yarn cross section. The low cotton content model yarns (up to 44 percent cotton) were extended 5 percent, corresponding to an approximate load of 20 lbs. This places the cotton yarn under load both in tension and pressure which serves to compact the cotton yarn, reducing the diameter to more closely approximate the condition of test.

The diameter of the cotton yarn varied considerably, from a low of 0.06 millimeter to a high of 0.18 millimeter--a threefold change. The average diameter of the cotton yarn based on 100 measurements was found to be 0.091 millimeters.

D = 0.091 millimeters average diameter of cotton yarn.

Breaking strength of cotton yarns (T_b) - The measured strength of a cotton yarn is strongly dependent on the gauge length tested, in particular, gauge lengths less than 10 centimeters. This dependence of breaking strength on specimen length is due to a variety of causes; irregularities in the yarn of mass or twist, variation in thickness of the yarn, and variations in the fiber itself. In addition to variation in the strength along the length of the yarn, differences in strength among different yarns must be evaluated. In this study the effect of dyeing the yarns, and the effect of added twist had to be evaluated.

The cotton yarns were tested on the Instron machine using the B cell and a load range of 200 grams. Several schemes were tried to eliminate the effect of jaw penetration. The first of these was to clamp the yarn in the steel jaws. The test results, particularly for short gauge length, were extremely low. The second scheme tried was to imbed the yarn ends in a rosin. This scheme was discarded when no improvement was noted in the breaking strength tested using the steel jaws. The highest strengths were obtained when the cotton yarns were mounted on cardboard tabs and taped with a good grade of adhesive tape and then clamped in the standard Instron jaws.

The smallest piece of cotton yarn which could be picked up without disintegrating was 2 millimeters. Twice this length is 4 millimeters, the shortest piece for which rupture strength was evaluated. The gauge lengths tested were 4, 8, 20, 40, 60, 80, 100, 150, and 200 mm.

To test the effect of twist, two twist levels were checked--2 turns per inch, and 1 and 4 turns per inch. To test the effect of dyeing the yarns, all 91 dyed yarns were used. The yarns were separated into 10 groups. An average of 100 tests were run on each group. Each group contained the gauge length variation listed above. Each color was tested twice. On those colored yarns in each group of 10 which showed a very high or very low load, five additional tests were run. It was found that extremely high loads or extremely low loads were due to local variations in the yarn structure (yarn irregularity). It was further found that the effect of added twist and color was negligible and a composite curve for all colors could be used for the strength of cotton yarn at different gauge lengths. Four typical curves of the 10 test runs are shown in Figure 9. These curves represent the highest and lowest values found.

Coefficient of Friction

Machida found that the coefficient of friction between cotton and Dacron is difficult to determine under conditions of test. Since this coefficient is a compromise value, the value selected for this study is given below:

$$\mu = 0.25$$

Test Results

The data for all yarns are shown graphically in Appendix D, Figures 1 through 90. Six sets of data are presented as follows:

1. The effect of twist on the load elongation behavior of the yarn.

2. The effect of cotton core (Dacron shell) on the load elongation behavior of the yarn.

3. The effect of Dacron core (cotton shell) on the load elongation behavior of the yarn.

4. The number of broken pieces of cotton yarn found after stretching the model yarn to a given extension.

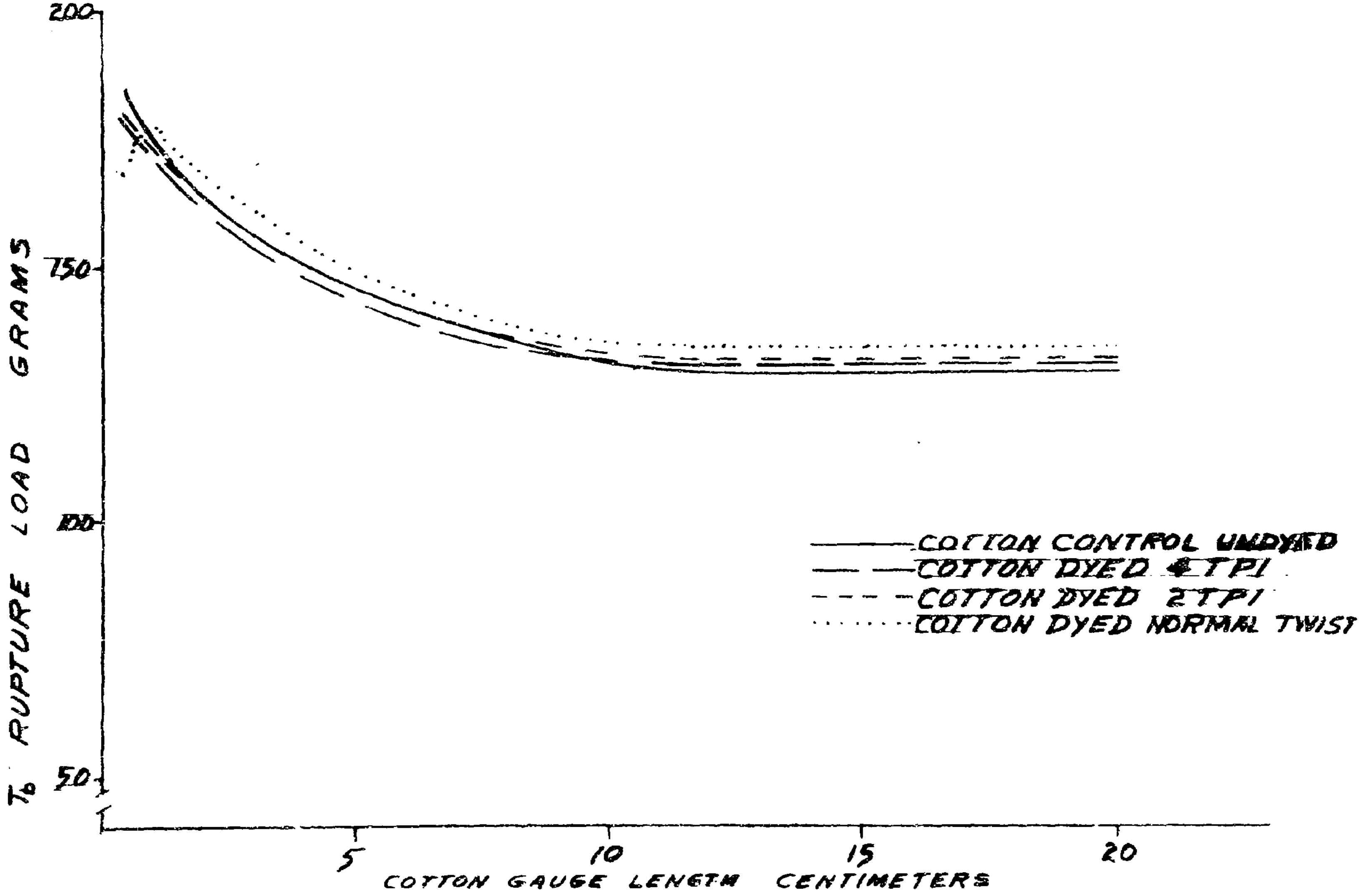


Figure [illegible]. Strength of Cotton Yarn vs Gauge Length

5. The method of propagation of cotton breaks and their location in the yarn model.

6. A tabulation of critical fiber lengths as a function of the cotton-Dacron blend ratio and radial position in the yarn cross section.

In the following discussion, the radial position of the cotton represents an average of 5 separate observations. The observations were made on 5 different cross sections, each cross section representing a different 4-foot length of model yarn. Although special precautions were taken to prevent migration of the yarns, migration of the yarn by one ring position was found. The extent of this migration can be seen by selecting one yarn as a typical example: a blend of 22 percent cotton, 78 percent Dacron with a Dacron core (cotton shell). The model yarn cross section is represented by 91 circles geometrically arranged as shown in Figure 10. The numbered circles represent the location of cotton yarns. The method of numbering will be discussed below in describing the location and propagation of the yarn breaks. The 20 yarns were inserted in the fourth ring (Figure 10a) and carefully twisted. The average radial position of the yarns found is shown in Figure 10b. This represents a change in radial position of one ring. It can be assumed that the yarn has moved either outward or inward ± 0.2 $^{r}/_{R}$. However, since the stress-strain curves are averages of 2 tests for the breaking extensions and averages of 4 to 14 tests for the lower extension, it is assumed that radial positions of the cotton yarns as shown represent their average position for all the yarns analyzed.

Discussion

This discussion will cover the following conditions of test, not in the order listed:

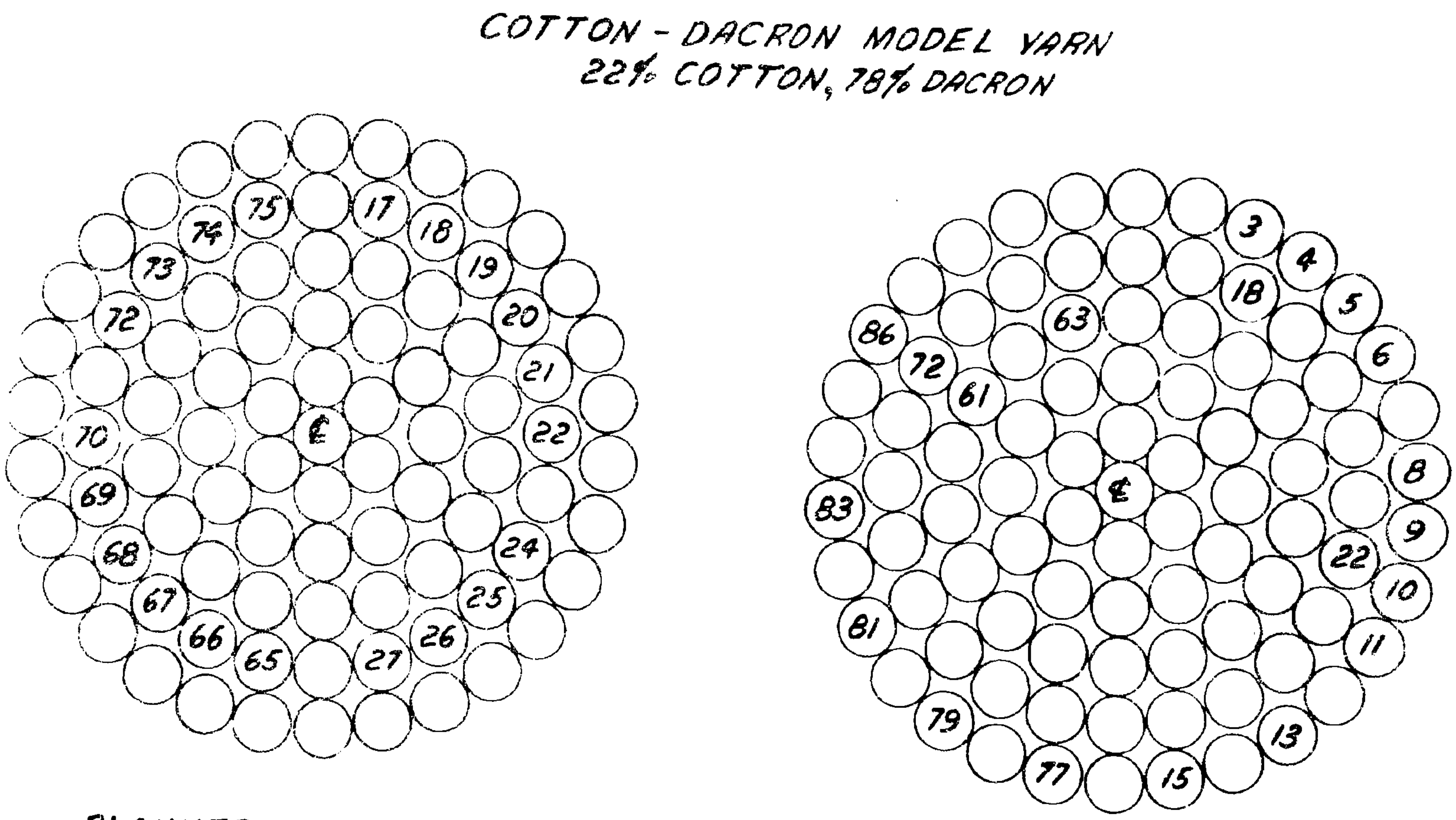
1. Dacron-cotton blend ratios covering cotton content of 0, 1.1, 2.2, 11, 22, 33, 44, 56, 67, 89 and 100 percent.

2. The following twist levels are considered: 0.55, 1.1, 2.2, 3.3 and 4.4 TM.

3. The effect of placing cotton or Dacron in the core of the yarn.

4. Effect of radial position on the critical length of the cotton yarn as an indication of pressure generated in the yarn cross-section.

5. Yarn elongation versus cotton breaks.



a. PLANNED ARRANGEMENT OF COTTON YARNS

b. AVERAGE ARRANGEMENT OF COTTON YARNS FOUND

Figure 10. Yarn Migration

6. Propagation of cotton breaks in a Dacron-cotton blend.

7. Summary of factors describing the mechanism of fiber to fiber load transfer and the mechanics of rupture of Dacron-cotton blend.

Effect of Dacron-Cotton Blend Ratio on Strength of Yarn

The strength of the 70/34 Dacron yarn as tested has a strength of 3.86 grams per denier while the strength of the cotton yarn was found to be 2.09 grams/denier. The predicted strength of blends of the two yarns, using the technique proposed by Hamburger(11), is given in Figure 11a which shows that the strength of the blended yarn should never be less than that of the cotton fiber. This is generally the case and is shown in Figures 11b, 0.55 TM; 11c, 1.1 TM; 11d, 2.2 TM; 11e, 3.3 TM; and 11f, 4.4 TM. In each of the figures, there appears to be fair to good agreement with the predicted curve at low cotton contents, but after passing the 50 percent cotton blend level, the strength of the blended yarn is much below the predicted strength. At 0.55 TM, the departure of actual yarn strength from the predicted strength can be explained as follows: the low twist level does not allow the inter yarn friction to build to a level where the yarns reinforce one another, adding to the strength of the yarn structure. At 0.55 TM twist the individual yarns in the model yarn act more or less independently, and where there is a high percentage of yarn of uniform strength (Dacron), closer agreement will be reached with the predicted behavior; where the higher proportion of the yarn is less uniform in strength (cotton), a greater divergence from the predicted strength will occur. Additional insight to this phenomenon will be obtained under the discussion of the effect of twist. As twist is increased, Figure 11c, 1.1 TM and 11d, 2.2 TM, the agreement between experimental and theoretical results, while not good, show an improvement over 0.55 TM yarn, Figure 11b, particularly in the region of high cotton content. It is suggested that the reason for this is the greater friction between the yarns, causing the cotton yarns to react to the load in a group, reducing the early breakage of the weaker fibers. With 1.1 TM and 2.2 TM yarns, not only is there better agreement with the theoretical predicted strength but, as expected, the strength of the yarn is increased. With the 3 TM yarn, the overall strength of the blended yarn has passed the optimum strength twist relationship, and while the strength of the 3.3 TM yarn is not much different from the 2.2 TM a slight decrease in breaking strength is noted. A further decrease in strength as well as poorer agreement with the theoretical curve occurs with the 4.4 TM blend as shown in Figure 11f. It will be shown later under the effect of twist that a different mechanism of break is operative at the higher TM levels. The breaking elongations of the blended yarns are shown in Figures 12a, .55 TM; 12b, 1.1 TM; 12c, 2.2 TM; 12d, 3.3 TM; and 12e, 4.4 TM. An examination of Figures 12a, .55 TM, and 12b, 1.1 TM, shows that for cotton content of up to 33 percent, the breaking elongation

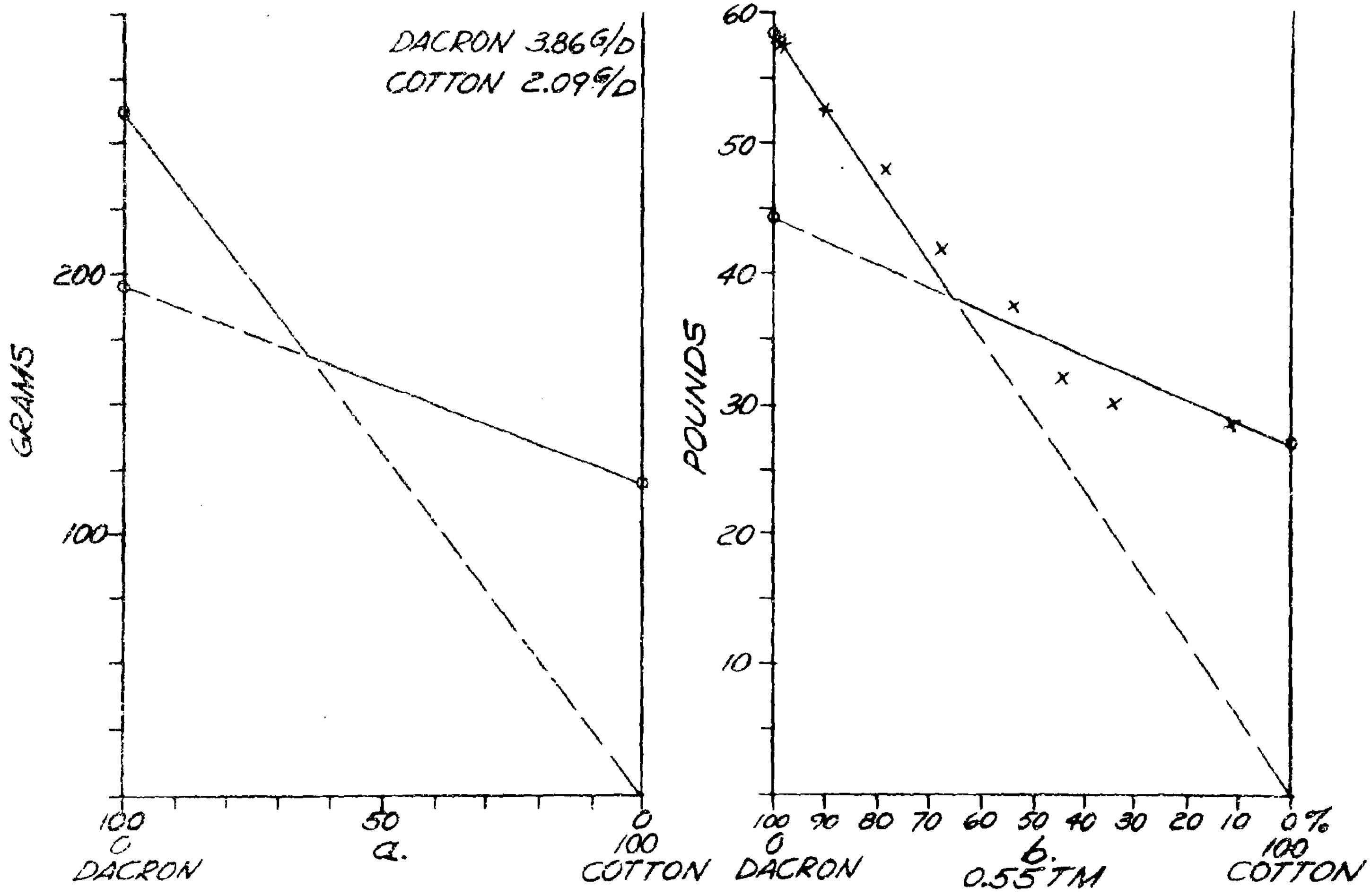


Figure 11. Strength of Cotton Dacron Blend

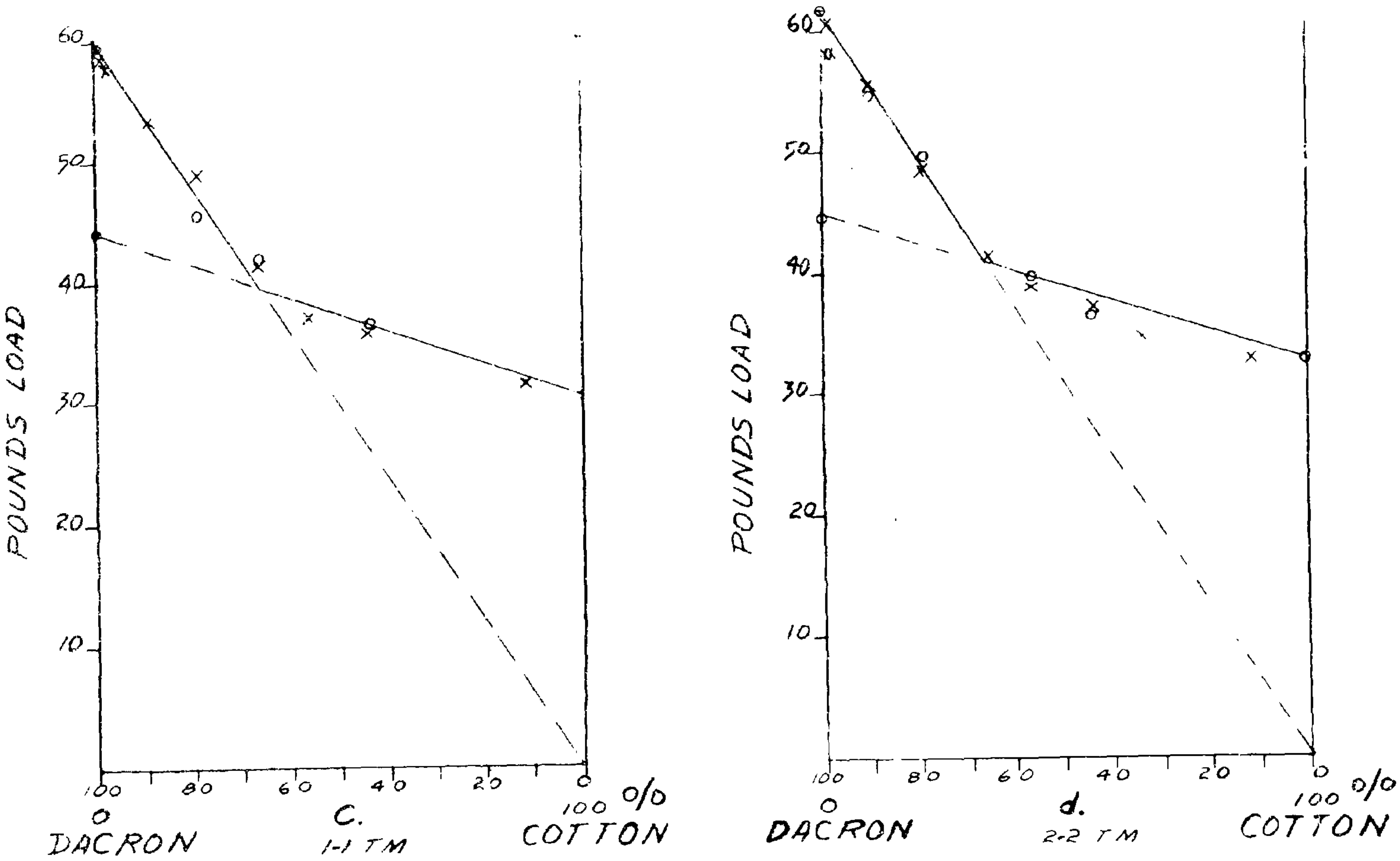


Figure 11. Strength of Cotton Dacron Blend

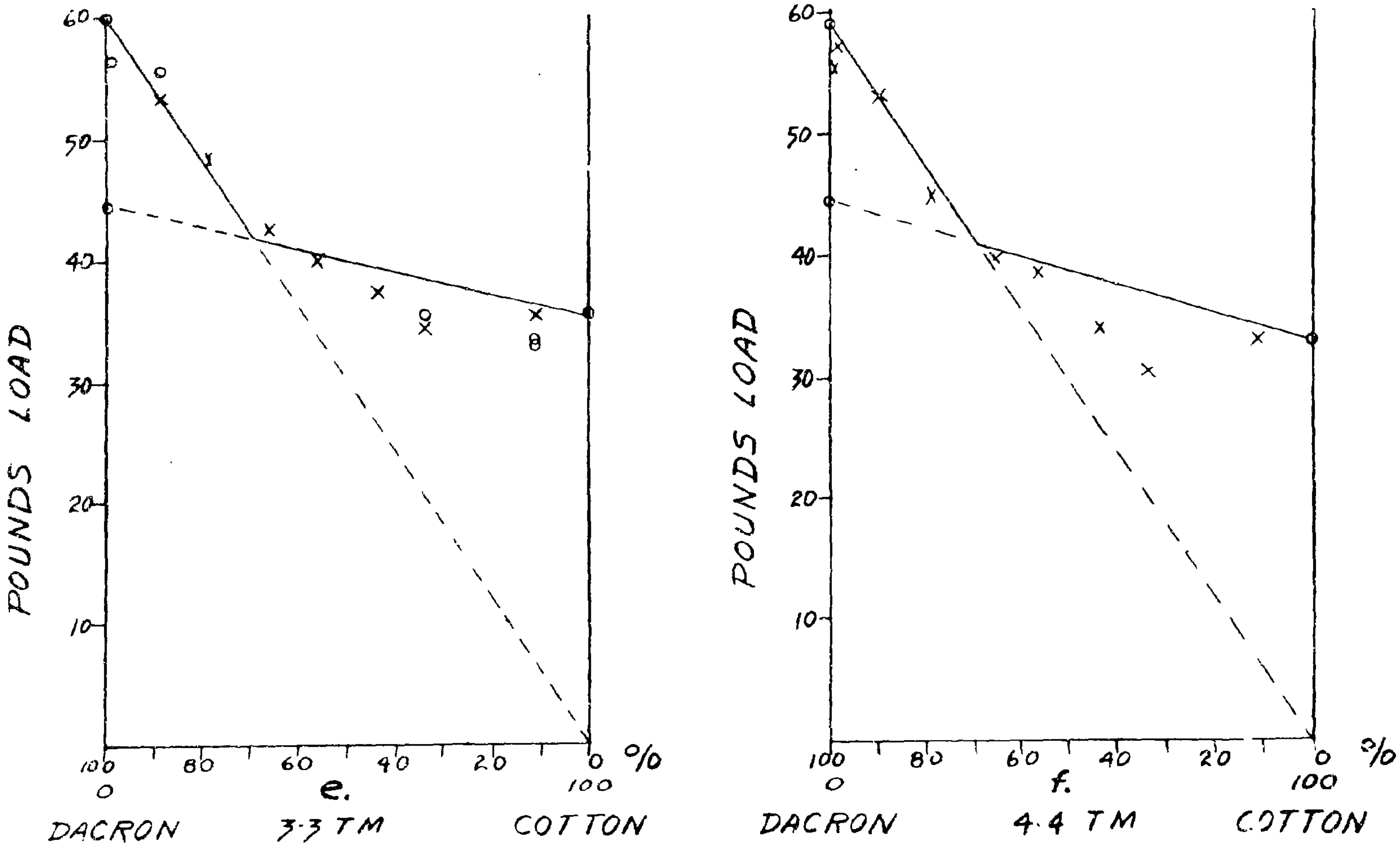
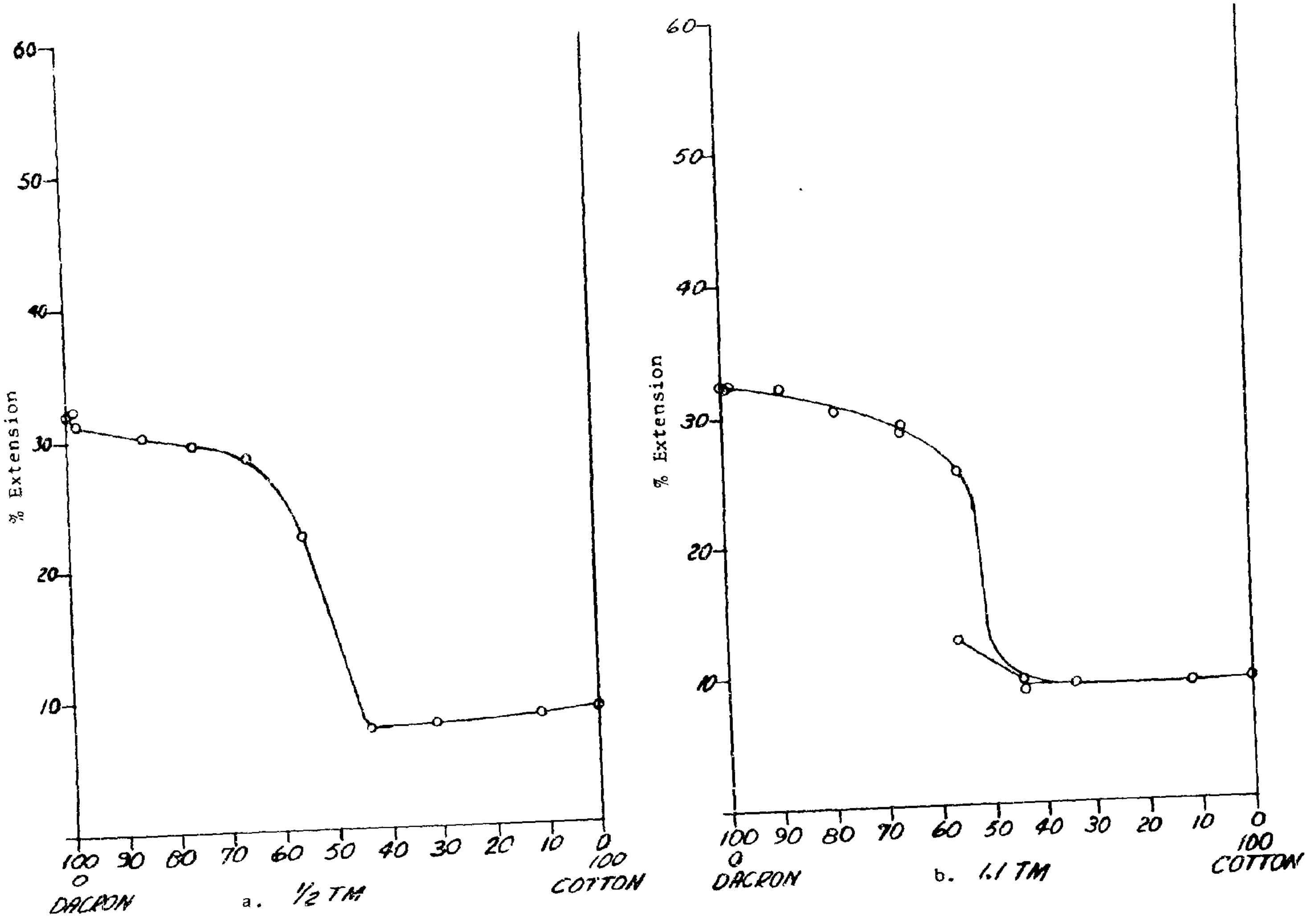


Figure 11. Strength of Cotton Dacron Blend



a. ½ TM

b. 1.1 TM

Figure 12. Extension of Cotton Dacron Blend

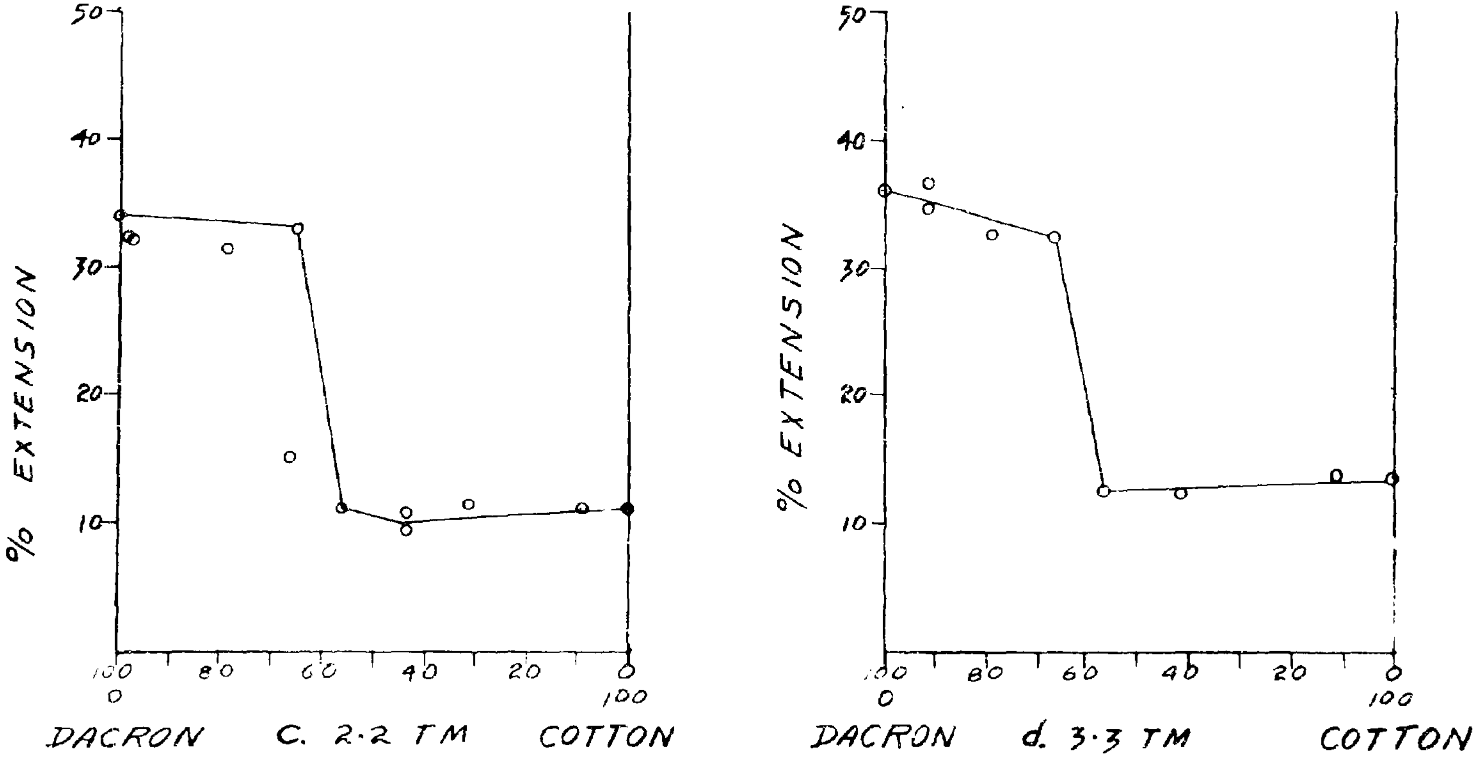


Figure 12. Extension of Cotton Dacron Blend

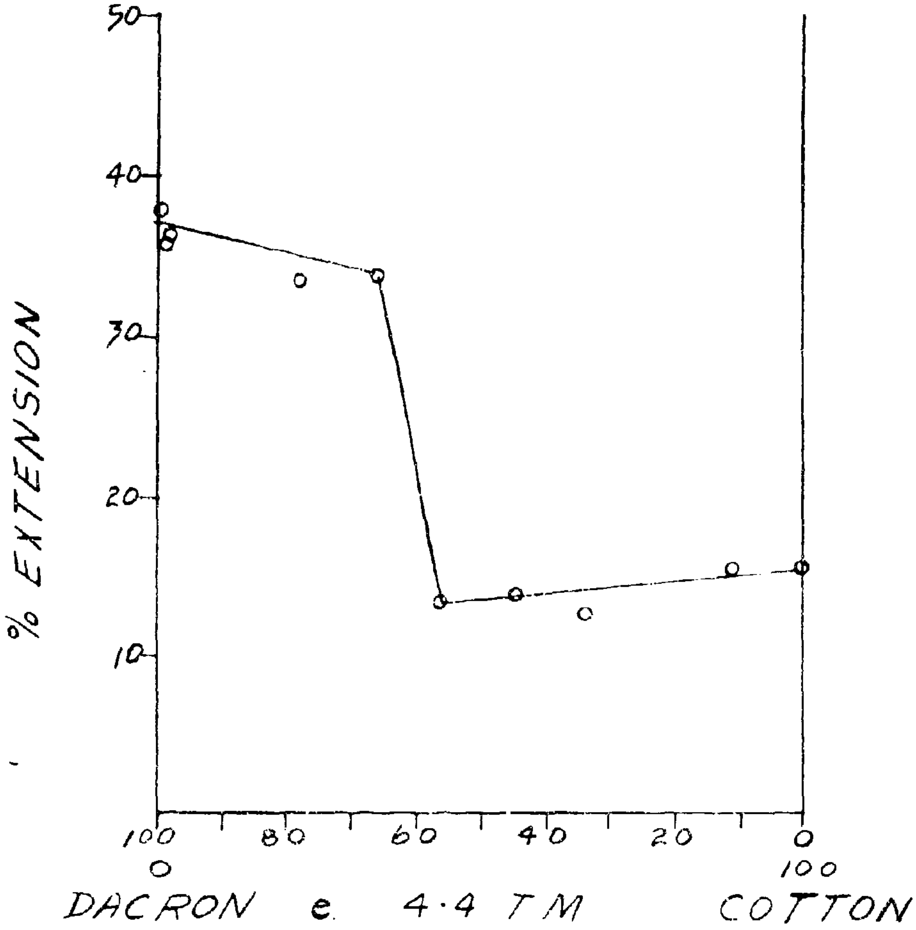


Figure 12. Extension of Cotton Dacron Blend

is not very different from that of 100% Dacron. At 44% cotton (Fig. 12b) two breaking **extensions** were obtained, one approaching the breaking extension for Dacron and the other approaching the breaking extension for cotton. It is suggested that this lower point (cotton breaking extension) results from yarn slippage at the low twist levels. In fact, in Figure 12b, the upper point reflects the slippage due to friction between the yarns while the lower point reflects a cotton core yarn, where the surface contact between cotton and Dacron is minimized and a catastrophic failure of the 40 cotton yarns caused the Dacron yarn to fail. A suggested mechanism of failure will be explained below under the effect of twist, Figures 12c, 2.2 TM; 12d, 3.3 TM; and 12e, 4.4 TM. It should be evident that for cotton contents of over 33%, the breaking extension is equivalent to that of cotton and for cotton content of 33% or less, the breaking extension of the blended yarn is equivalent to that of Dacron. The second point on Figure 12c at 33% cotton content is for a yarn with the cotton primarily in the shell (Fig. 57, Appendix D). In this case the 30 cotton yarns broke but the Dacron core was still intact. However, with the cotton shell broken, the yarn was not considered serviceable and the test terminated. It would appear from the data on breaking extensions for Dacron-cotton blends that two levels of breaking extensions are possible; at cotton contents of 33% or less, the breaking extension of the blended yarn decreases only slightly from the breaking extension of 100% Dacron. At low twist levels of 0.55 TM and 1.1 TM, a fairly high breaking extension is realized up to 44% cotton content. At 44% cotton content and TMs 2.2 through 4.4, and for blends with cotton content greater than 44%, the breaking extensions are primarily the same as those for 100% cotton yarns.

It is interesting to note that the discrepancy between theoretical and experimental results found in this study was with the yarns of high cotton content. Kemp and Owen, with their cotton-Nylon staple blends, found a discrepancy in the region of low cotton content of 20 to 40% cotton in a blend of Nylon. It should be remembered that the theoretical basis for predicting the strength of blends does not account for the interaction between the component fibers. However, nonetheless, it would be interesting to investigate the reason for the differences found. Whether the difference in behavior is due to the difference between the model yarn and a staple fiber yarn, or whether the difference is due to the stress-strain behavior of the component fibers, would form the subject of an interesting paper.

Effect of Twist on Strength of Dacron-Cotton Blends

The load elongation curves for cotton-Dacron blends are shown in Appendix D, as follows:

Figure 1 - 100% Dacron
Figure 2 - 1.1%
Figure 3 - 2.2%
Figure 4 - 11.0%
Figure 5 - 22.0%

Figure 6 - 33%
Figure 7 - 44%
Figure 8 - 56%
Figure 9 - 67%
Figure 10 - 89%
Figure 11 - 100%
cotton content

An examination of these figures shows that as twist increases from 0.55 TM to 4.4 TM, the breaking extension increases and in general the strength of the yarn does not change significantly from the strength of the 1 TM twist for each blend level. Each blend level must be examined separately. The 100% Dacron should increase in breaking extension and the strength increases from 0.54 TM to 1.1 TM then decreases. The lower strength for the 0.54 TM yarn is attributed to the low twist which, as will be shown later, does not develop high frictional forces between the yarns; this is noticeable by the drop in strength at the higher levels of extension. Generally, the same reaction to load is shown in 1.1 and 2.2% cotton content. In this case, the cotton content is too low to exert any influence on the behavior of the load elongation characteristics of the Dacron yarn. It should be noted that the 3.38 TM curve in Figure 2 shows a slightly greater extension than the higher twist 4.37 TM curve. This was due to a 2% greater length in the cotton yarn before testing (20.4 cm instead of 20.0 cm). In Figure 4, 11% cotton content, the load elongation of the model blended yarn shows a slight change in shape; a dip appears just beyond the yield stress and it will be shown that this dip is due to rupture of the cotton yarns, Machida's first yield point. The strength of the yarn after this initial dip continues to increase until the rupture elongation of the yarn is reached (Machida's second breaking load). The dip in the load elongation curve is not apparent in the higher twist yarns (3.25 and 4.37 TM). This is due to the cotton yarns in different radial positions not reaching their breaking elongation at the same extension. The level of elongation at break is only slightly less than the 100% Dacron and the overall strength is lower because of the replacement of the stronger yarn for a weaker one. The yarns with 22% cotton and 33% cotton show a deeper dip after the first rupture point; the curve at higher loads is flatter than the higher content Dacron yarns. This is due to the higher proportion of cotton which contributes to the strength of the blended yarn by continuing to break as the blended yarn is elongated to its breaking extension. The yarns at the low twist levels did not break cleanly, but some of the Dacron yarns remained intact, only to break at a higher extension. This phenomenon can only occur when the frictional forces are low and, in the situation where the Dacron yarns break at a higher extension, these yarns are not fully contributing to increasing the breaking strength of the blended yarn. In 44% cotton, 56% cotton, 67% cotton, 89% cotton and 100% cotton, the first break in the blended yarn is accentuated as the cotton content is increased; also, at low twists (0.54 and 1.1 TM), the strength of the Dacron yarns is not fully utilized, since some of the Dacron yarns break over a range of extensions because of the frictional forces being too low to allow the yarn bundles to react to the imposed loads as a unit. The effect of blend ratio in a cotton-Dacron blend and the strength and extension properties of the yarns are summarized in Figures 13, 0.54 TM; 14, 1.1 TM; 15, 2.2 TM; 16, 3.3 TM; and 17, 4.4 TM. Each figure shows four load elongation curves at different blend levels: the 100% cotton and 100% Dacron controls, the 33% cotton content, and the 44% cotton content yarns. The blend levels selected represent a break in the load elongation behavior of the blended yarns. At low twist levels, 0.54 TM and 1.1 TM (Figures 13 and 14), the blended yarns increase in strength until the first rupture point is reached, then the strength of the yarn drops to the level of the strength of the Dacron yarns. This drop in strength is due to the rupture of the cotton yarns and the low frictional forces between the yarns which allow the extending Dacron yarns to slide over the broken cotton yarns. As the blended yarn extends, the pressure within the yarn increases, increasing the frictional force between the cotton and Dacron yarns, thereby reducing the slippage between the yarns in which case the strength of the blended yarn is increased. This mechanism occurs for each peak shown in the stress-strain curve. It will be shown that after each peak additional cotton yarns break, or each cotton yarn breaks into smaller fragments. At higher twist levels (2.2 TM, Figure 15; 3.3 TM, Figure 16; and 4.4 TM, Figure 17), the load elongation behavior of the 33% cotton content blend reacts as a Dacron yarn; i.e., the yarn carried a load over three times the elongation of the first break in the blended yarn. The flat shape of the curve beyond the yield point is an indication that the cotton is contributing to yarn strength beyond its breaking extension. The yarns with 44% cotton content show a different behavior to load where the yarn reaches its rupture extension, right after the first break. This is due primarily to a change in the mechanism of rupture. The cotton yarn rupture at the higher twists is probably due to the frictional forces between the Dacron and cotton yarns which prevent the Dacron yarn from slipping past the cotton; therefore, after the cotton yarns rupture, the gauge length of the Dacron yarns now becomes the width of the cotton yarn break; extension of the Dacron yarns is accelerated, and rupture of the Dacron yarn is quickly reached, almost simultaneously with the cotton break. This finding is in agreement with Machida's observation that in Nylon-cotton and Dacron-cotton blends, the maximum blend ratio of cotton is found experimentally to be less than 50%, in order to extend the blended yarn over the first rupture point.

It should be noted that the stiffness of the 44% cotton blend is lower than that of the 33% cotton blend at 2.2 TM; however, at 3.3 TM the stiffness of the 44% blend is equal to or greater than that of the 33% cotton, and at 4.4 TM it is greater still. This can be attributed to a difference in the absence of cotton yarn rupture. In the case of the 44% blend, the cotton yarn rupture for all cotton fibers is catastrophic; in the case where the cotton yarn breaks into fragments, the load is relieved and frictional slipping occurs, lowering the ultimate load and permitting a load sharing between yarns of different rupture extensions. A further investigation of this phenomenon would make an interesting subject for a separate paper.

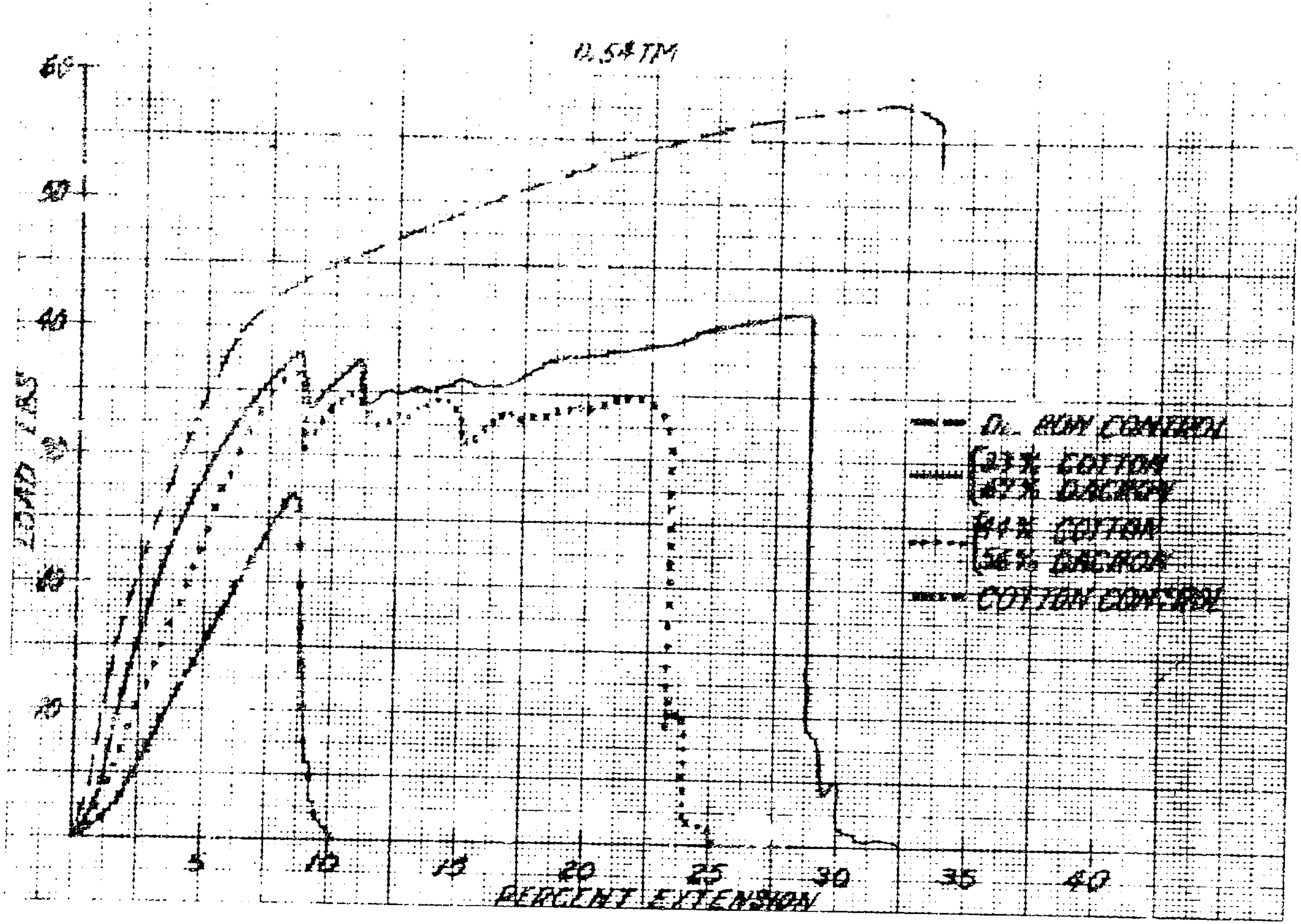


Figure 1 . Summary Load-Elongation
otton-Dacron Blend .54 TM)

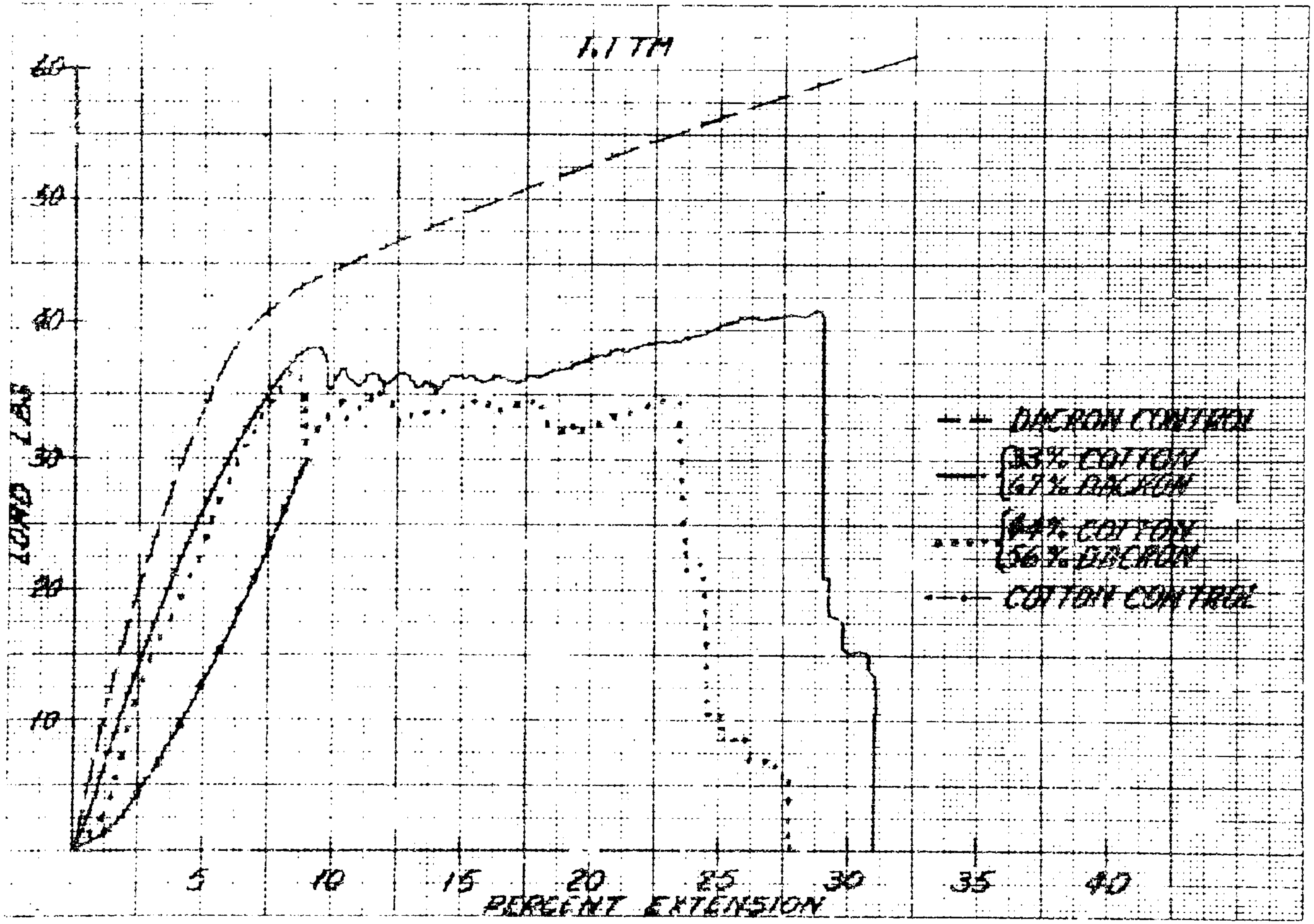


Figure 14. Summary Load-Elongation
(Cotton-Dacron Blend 1.1 TM)

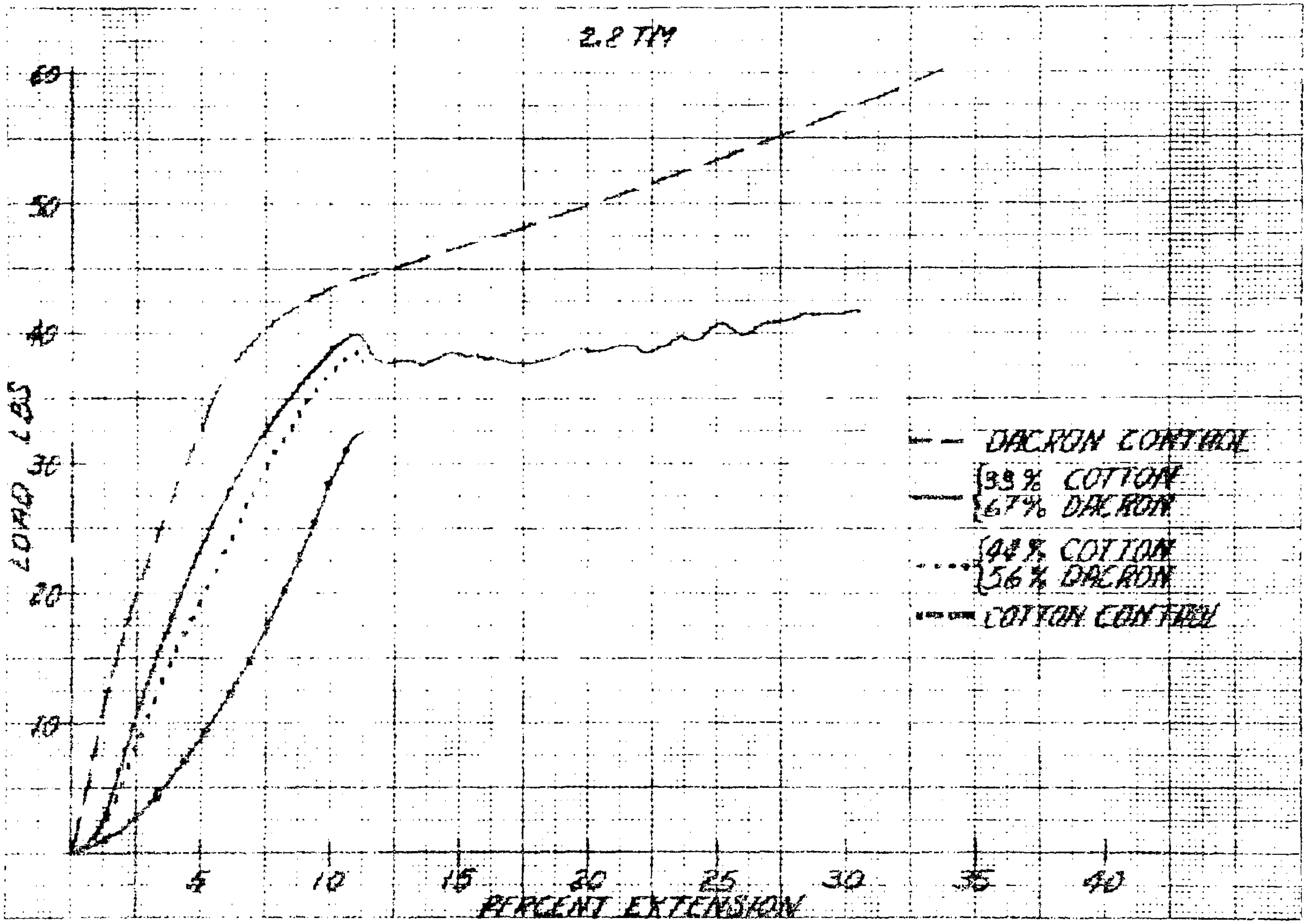


Figure 15 Summary Load-Elongation
(Cotton-Dacron Blend 2.2 TM)

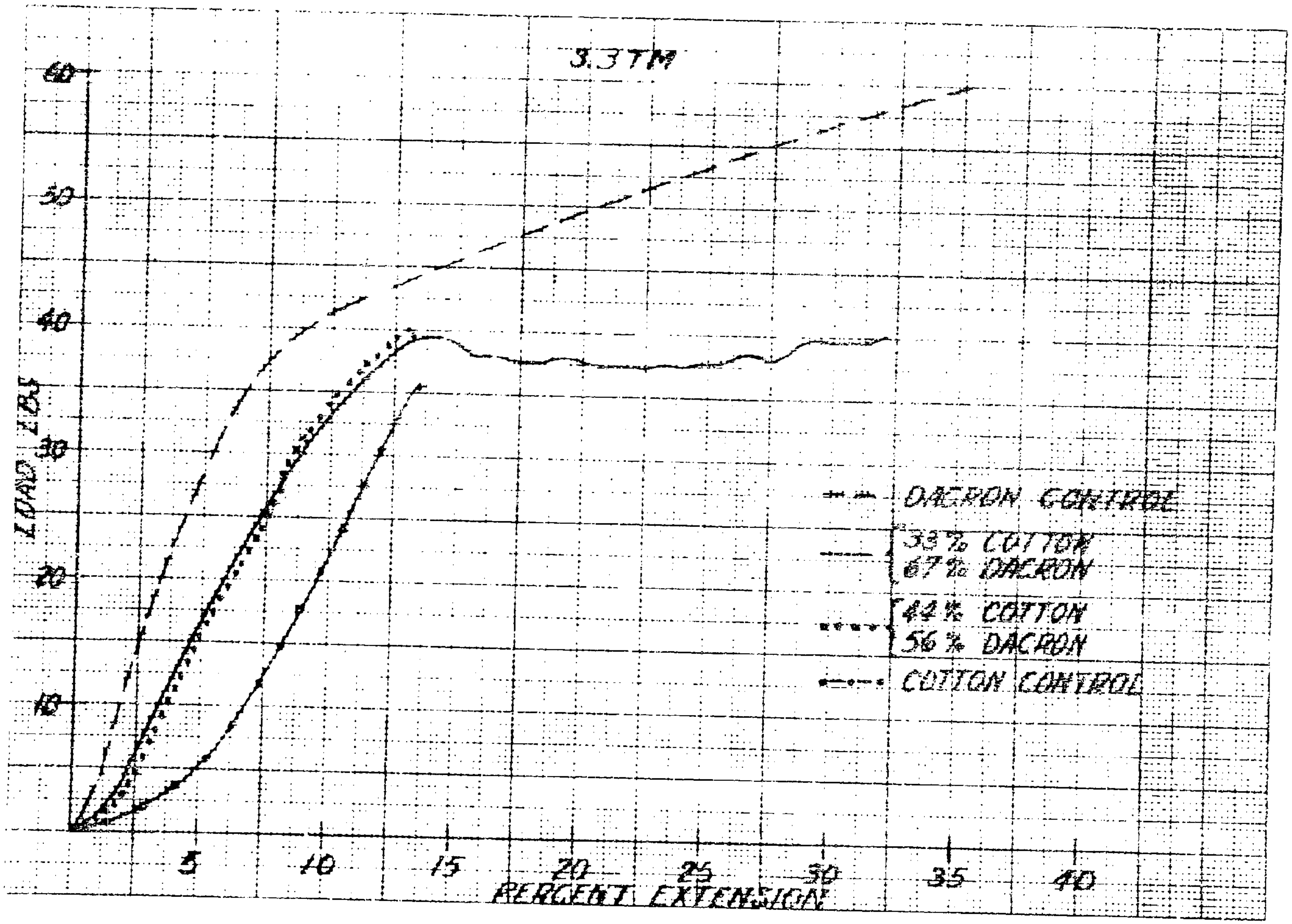


Figure 16. Summary Load-Elongation
(Cotton-Dacron Blend 3.3 TM)

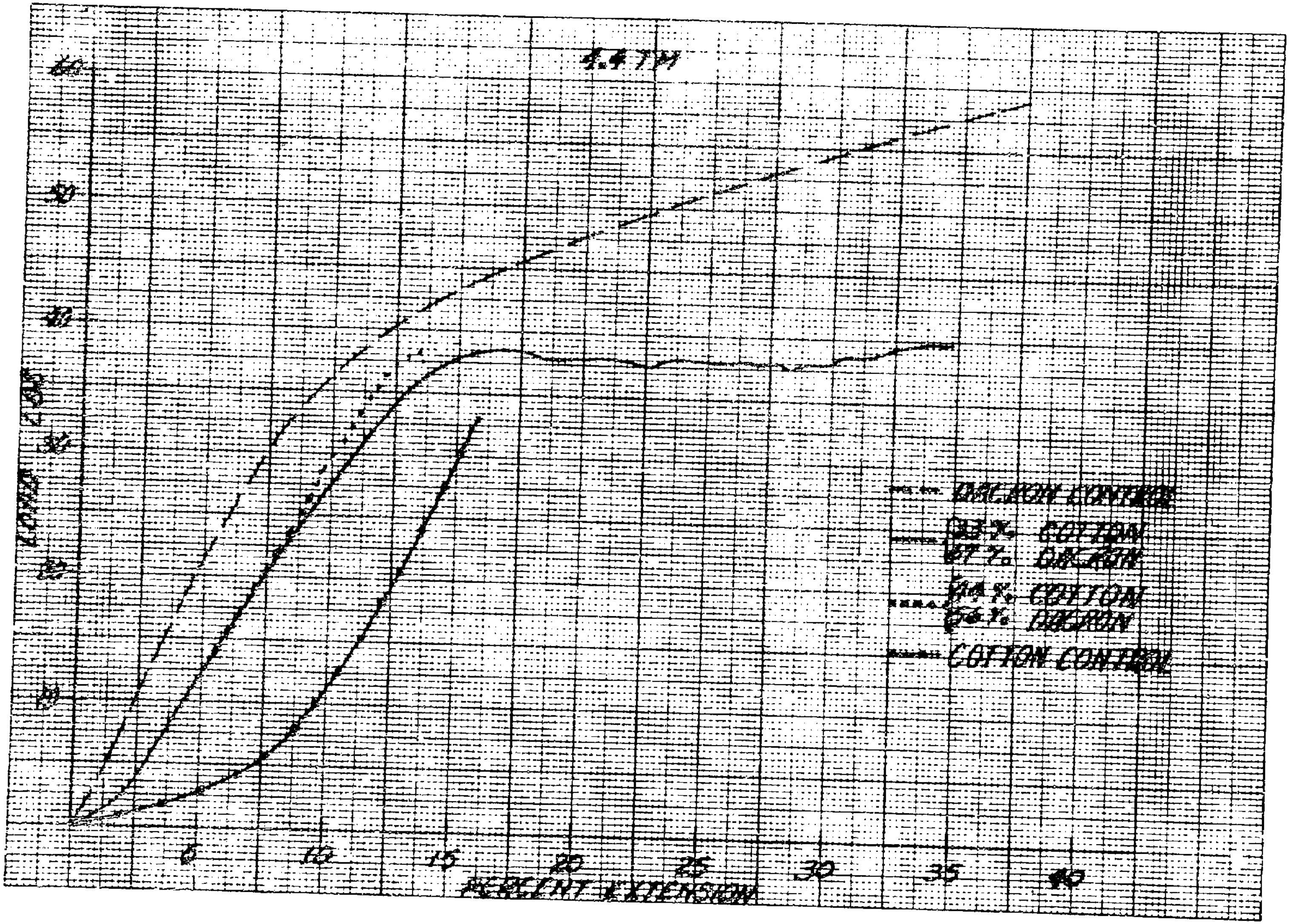


Figure 17. Summary Load-Elongation
(Cotton-Dacron Blend 4.4 TM)

In summary, the effect of cotton-Dacron blend ratio on the load elongation behavior of the blended yarn is as follows: for cotton contents of 33% or less, the yarn carries its load beyond its first rupture point. The load extension behavior is similar to an all-Dacron yarn. Between 33% and 44% cotton content, the load elongation behavior becomes twist sensitive. At low twists, 0.54 and 1.1 TM, the 44% cotton content yarn carries its load beyond the first rupture point. At twist levels of 2.2 TM through 4.4 TM, the yarn did not carry its load beyond its first rupture point. In this respect, the blended yarn at the higher twist levels reacted as a 100% cotton yarn, but it is stronger than an all-cotton yarn.

Effect of Dacron Core

The effects of Dacron core are shown in Appendix D, (Fig. 12, 11% cotton; Fig. 13, 22% cotton; Fig. 14, 33% cotton; Fig. 15, 44% cotton; Fig. 16, 56% cotton; Fig. 17, 67% cotton; and Fig. 18, 89% cotton). The results of placing the Dacron in the center of the yarn appear to be inconclusive for the twist levels tested. More positive information is obtained from the examination of critical fiber lengths. A study of the effect of Dacron core should be investigated further, covering a greater range of twist levels than was included in this study.

Effect of Cotton Core

The load extension curves for the cotton-Dacron blends having a cotton core are shown in Appendix D, (Fig. 19, 11% cotton; Fig. 20, 22% cotton; Fig. 21, 33% cotton; Fig. 22, 44% cotton; Fig. 23, 56% cotton; Fig. 24, 67% cotton; and Fig. 18, 89% cotton). The results shown appear to be inclusive for the twist levels tested. As above, an examination of the critical fiber length provides a better insight on the effect of the Dacron core on the strength of the blended yarn. A study of the effect of Dacron core on the strength of the yarn should be extended to cover a greater range of twist than those covered in this study.

Average Broken Length of Cotton Yarns

The data in this section are shown in Appendix D, (Fig. 25 through 90). The results found in this portion of the study contain many points of similarity of one yarn blend to another; therefore, it is not intended in this discussion to present a detailed analysis of all the figures shown--rather, the pertinent findings will be discussed using selected figures with references made to the other yarns showing similar characteristics.

The data presented in this very interesting section contain the following:

a. The load elongation.
b. The average number of broken lengths of cotton yarns.
c. The radial locations of the cotton yarns in an idealized yarn cross section.

d. The number of broken pieces and the location of the breaks in the yarn.

An explanation of the methods used in presenting the data is in order. The plot of the load elongation curve is computed to include yarn rupture. The average number of broken cotton pieces are shown as vertical lines superimposed on the load elongation curve at the extension where yarns were tested. Each small square on the graph represents one piece of cotton yarn. Each line represents an average of two determinations. The idealized cross section of the model yarn is added as an insert on the load elongation chart. The cross section contains 91 circles--each circle represents one yarn in the model. The numbered circles represent cotton yarns--the blank circles represent the Dacron yarns. In each case, the cotton yarns are located in accordance with the radial position in the model yarn tested. The number of cotton pieces, their lengths, and approximate location of the breaks are included as separate diagrams. To show the progression of this propagation of breaks in the cotton yarn (increasing pressure), one diagram was included for each level of extension tested. The diagrams represent the 91 yarns used to spin this model. The yarns are arranged in accordance with number of yarns in each concentric ring. In addition, the yarns are numbered. (The yarn number on the diagram coincides with the number of the cotton yarns shown in the idealized cross sections.) The diagrams are designated as the a & b part of the figure number given to the accompanying load elongation curve.

To simplify the following discussion, the figure number given will include all data including the load elongation curve, the number of broken cotton pieces, the radial position of the cotton yarns, and the cotton break diagrams for different extensions.

The effect of twist on pressure generated in an extending yarn can best be illustrated with the 1.1% cotton-98.9% Dacron blend, Appendix D, Figures 25 through 29, inclusive.

Since this blend ratio is analogous to that used by Machida, direct comparison may be made with his theoretical work. The relationship between internal yarn pressure and twist in a yarn being extended is given (Appendix A) as:

$$P(r) = \frac{2 \quad t_o^2 S}{(1 + E_y)^2} \quad (1 - \frac{r^2}{R^2})$$

This equation shows that the pressure is directly related to the initial twist squared, load, and the fractional component of the radial position of the yarn. It is inversely related to the yarn extension squared.

An examination of Figure 25, 0.54 TM; Figure 26, 1.1 TM; Figure 27, 2.2 TM; Figure 28, 3.3 TM; and Figure 29, 4.4 TM (Appendix D), shows a rapid increase in the number of broken yarns with increasing twist. It can readily be seen that as the twist is increased, the number of cotton pieces increases for any given extension in the 5 curves. Now, for any given gauge length, the increase in the number of pieces would be reflected in shorter cotton yarn lengths. The shorter the yarn segment, the greater must be the frictional force to cause the cotton component in the blend to reach its rupture strength. The frictional force on the cotton segment can only be developed by pressure on the cotton yarn. The greater the pressure, the greater the frictional force between yarn elements; therefore, there must be a direct relationship between internal yarn pressure and the number of cotton pieces found in an extended blended yarn. With this explanation of the relationship between cotton yarn pieces and internal pressure in an extending yarn, it may be assumed that good agreement is found between the test results shown in Figures 25 through 29 (Appendix D) and the theoretical expression given above. The curves show a continual increase in pressure as the yarn is extended, reaching a peak at 15 to 20% extension; i.e., the number of broken cotton pieces reach a maximum in this region. Beyond the 20% extension, the number of pieces should remain constant. This was not the case in this study. The results were erratic. For some yarns, the number of broken pieces found at extensions above 20% increased; for other yarns it decreased; still other yarns showed an up and down variation. To obtain more consistent values, statistical techniques must be used. It should be pointed out that the pressure peak found between 15 and 20% extension is lower (20% to 25%) than that found by Machida(26). The difference may be due to a difference in the radial positions of the yarn.

The load-extension data for the four 1.1% cotton 98.9% Dacron curves also provide an insight to the mechanism for fiber to fiber load transfer in a yarn undergoing extension to break. This mechanism may be divided into three phases as follows:

a. At low extension and up to the first rupture point, the load carrying capacity is shared between the Dacron and cotton.

b. After the first rupture point, the cotton component continues to contribute to yarn strength by the combined mechanism of frictional resistance and by breaking up into successively smaller pieces. This mechanism is operative until the yarn reaches 15 to 20% extension. The evidence for this is the increasing number of broken cotton yarn pieces found as the yarn is extended to 20%.

c. Above 20% extension, the mechanism is one of frictional resistance encountered by the still extending Dacron yarn as it slips by the cotton segments. The evidence for this is the relatively small difference in the number of cotton pieces found in yarns extended beyond 20%. Another interesting observation is the extension at which the cotton yarn breaks for each twist (Appendix D, Figure 25, 0.54 TM). The first break is observed at 6% extension. This breaking extension is close to that of the cotton yarn above 5.5% indicating low internal yarn pressure. In Appendix D, Figure 26, 1.1 TM and 2.2 TM, the first cotton yarn breaks for both yarns occurred at 7%

extension, but the 2.2 TM yarn had more broken pieces indicating a higher internal yarn pressure due to greater twist.

In the 3.3 TM yarn, Figure 28, Appendix D, the first break was found at 8% extension while in the 4.4 TM yarn the first break was found at the 11% extension. In the latter yarn, the initial breaks consisted of 6 to 8 yarn pieces indicating a high pressure in the yarns even at these low extensions. The increase in the initial breaking extension with an increased twist level is probably due to the increased length of the helical path of the yarn with increasing twist.

The number of broken yarn pieces in a given gauge length is the reciprocal of the average broken length of cotton. The correlation between the theoretical and experimental broken lengths was previously shown in Figure 5. It was the good agreement found which provided the encouragement to expand the study to cover other cotton-Dacron blend ratios.

The mechanisms for fiber to fiber load transfer discussed above appear to be operative for cotton-Dacron blends up to and including 33% cotton.

The effect of radial position of the yarn with the number of broken pieces is best illustrated with the 2.2% cotton, 97.8% Dacron blend, Appendix D, Figure 30 through Figure 36, inclusive. An examination of the load elongation curves shows an increase in the number of pieces as the extension increases. The number of broken pieces increases more rapidly at extensions up to 15 to 20% than at extensions greater than 20%. This is consistent with the results found for the 1.1% cotton, 98.9% Dacron blend. In all but two yarns, the number of broken pieces is greater for the yarn closer to the center. The two exceptions are the 0.54 TM yarn and the 2.2 TM yarn, Figures 30 and 36, Appendix D. The 0.54 TM yarn showed slightly more breaks in the outer yarn. The difference in the number of breaks is small (5 for the inner yarn and 7 for the outer yarn). There are two possible explanations for this. One is that the level of twist is too low to build up much pressure in the yarn, thereby reducing the frictional force and permitting slippage between the cotton and Dacron yarns. In the second yarn, 2.2 TM, Figure 36, both yarns are in the outside ring. The difference in the number of yarn pieces is greater and the only possible explanation is that of yarn migration.

The mechanisms of fiber-to-fiber load transfer are operative for cotton-Dacron blend ratios of 11% cotton, 89% Dacron; 22% cotton, 78% Dacron; and 33% cotton, 67% Dacron; Figures 37 through 57, Appendix D. Of these yarns, Figures 37, 50, and 51, represent cotton core yarns; Figures 43, 44, and 57, represent Dacron core yarns; the cotton in this remaining yarn is distributed in accordance with the idealized cross-section shown on the graph. The three cores will be discussed separately. Figures 38 through 42, Appendix D, show the results for the 11% cotton, 89% Dacron blend; Figures 45 through 49 show the results for 22% cotton, 88% Dacron blend; and Figures 52 through 56 show the results for 33% cotton, 77% Dacron blend. The vertical lines on the load elongation chart represent the average number of breaks for all the cotton yarns in the model. The number above the vertical lines indicates the number of cotton yarns broken for the indicated extension. The three blends have many features in common; for example, the yarn break diagrams attached to the load elongation curves show that the cotton yarns sustaining the higher number of breaks are closest to the center of the yarn. Also, the diagrams show that the breaks start at the center of the yarn and propagate outward. All blends show an increasing number of cotton yarn breaks with increasing twist.

The specific differences among the curves reflect the increasing amount of cotton in the blend. The greatest difference is shown in the 0.54 TM curves, Figure 38, 11% cotton; Figure 45, 22% cotton; and Figure 52, 33% cotton. An examination of these curves shows a dip right after the first rupture elongation. This reflects the rupture of the cotton yarns, and a low frictional force which allows slippage between the yarns. Figure 52, 33% cotton, shows an interesting phenomenon which possibly best illustrates the two mechanisms of fiber to fiber load transfer which are operative in an extending yarn. This curve shows two peaks, one at the first rupture point (8.5% extension) and the second at 11% extension. It is suggested that after the first rupture elongation the yarn started to recover its strength by the mechanism of fiber breakage as well as frictional resistance. The additional 18 fibers broken at the second peak, the 30 yarns broken at 12-1/2% extension, and the increase in the number of pieces at 12-1/2% extension all indicate this. Beyond 12-1/2% extension, the average number of broken pieces remained constant indicating that the cotton contributed to the strength of the yarn by providing frictional resistance only.

Except for the effect of the dip in the curves after the first break for the three blends, and the lower strength as the cotton content increases, the three blends react in the same manner to increasing twist. As twist is increased the shape of the curve at the first break rounds off. The reason for this can be seen by examining Figures 38 and 42, 0.54 TM and 4.4 TM, 11% cotton, 89% Dacron blend (Appendix D). At the low twist, all ten cotton yarns break within a change of 1/2% extension, with the higher twist the cotton yarn, breaks are not as abrupt but extend over a 3% change in extension.

Dacron Core Yarns

Figures 40 and 43, Appendix D, 11% cotton content at the 2.18 TM level, illustrate the general behavior of a Dacron core yarn with that of a yarn with the cotton distributed in the cross section. As shown previously, there is little difference in the breaking load or extension. However, fewer cotton pieces were found at each breaking extension for the Dacron core yarn in Figure 43 than for the yarn with the cotton distributed. This finding suggests that in a Dacron core yarn the cotton component is not being utilized to its maximum potential in contributing to the strength of the blended yarn and, theoretically, this could lead to a lower efficiency with respect to yarn strength than with the same amount of cotton distributed in the cross section.

The same general observations may be made for the 22% and 33% cotton content, Dacron core yarns, except for the 33% Dacron core yarn, Figure 57, Appendix D. The cotton shell was lost at the 15% extension level, and the cotton ceased to contribute to the yarn strength. It would prove interesting to investigate the effect of Dacron core yarns at different twist levels than the 2.18 TM used here.

Cotton Core Yarns

The 11% cotton content yarns are shown in Figure 37, cotton core, and Figure 41, cotton distributed. The cotton core yarn at this level of twist appears to be slightly stronger and more extensible than the yarn where the cotton is distributed in its cross section. This increase in strength is accompanied by a greater number of cotton pieces found in the cotton core yarn. The greater number of cotton pieces found for the cotton core yarn is consistent with the relative positions of the cotton yarns in the two models. Figure 37, cotton core, shows the cotton yarns near the center of the yarn (the area of highest pressure), while Figure 41, cotton distributed, shows the yarns scattered throughout with only 3 of the cotton yarns in the relative position of the cotton core. It must be concluded that for this blend level and twist placing the cotton in the core of the yarn improves its strength. However, it will be necessary to conduct additional studies at other twist levels to determine the general application of the results obtained above.

The results obtained with cotton core yarns with more cotton (22% and 33% cotton) are not as conclusive; however, these blends were spun at a lower twist level (1.09 TM) and presumably more slippage occurred between the cotton and Dacron yarns. This is indicated by the greater extensions shown in Figure 50, 22% cotton content, and Figure 51, 33% cotton content, when compared with the curves for the distributed cotton yarns (Fig. 46, 22% cotton content, and Fig. 53, 33% cotton content, Appendix D). In both cases, fewer cotton pieces were found for the cored yarns than for the case where the cotton was distributed in the cross section. This should indicate a higher strength for the yarns with cotton distributed. This was indeed the case for the 22% cotton blend (Fig. 50), cotton core, and Figure 53, cotton distributed, but did not hold for the 33% blend (Fig. 51), cotton core, and Figure 53, cotton distributed. One possible reason for this may be obtained by examining the curve for the curve yarn, Figure 51. This curve shows a real slipstick phenomenon. It has six peaks. The evidence of slippage here is the slow rise in the average number of breaks and the ragged peaks. The pattern of breaks is also different. With the cored yarns, the breaks appeared to be in bundles of 20 or 30 yarns breaking to equal length. When the bundles were separated, some yarns inside the bundle showed additional breaks. In view of the results obtained with the 11% cotton blend at the higher twist level, one hesitates to draw any conclusions from the results shown above without first testing the 22% and 33% core yarns at higher twist levels.

The 44% cotton, 56% Dacron, blend represents a transition blend from cotton-Dacron blends which retain their strength after the first break to the blends that rupture at the first break. The data on the 44% blends are shown in Appendix D, Figures 58 through 64. Figure 58 should be a Dacron core yarn. An examination of the cross sectional diagram shows that except for seven Dacron yarns in the center, the core effect was not achieved. Nonetheless, when this yarn is compared with Figure 61, 44% cotton, 56% Dacron, 2.17 TM, the seven Dacron yarn cores appeared to be effective. The core yarn started to lose the effect of cotton on its strength at an extension just beyond 10%. The yarn then started to recover its strength when more cotton yarns broke and at 11% extension the cotton ceased to contribute to the yarn strength. This is shown by the number of cotton pieces found at extensions above 11% which remained constant. The 44% cotton distributed yarn did not carry through the first rupture point. The mechanism of yarn rupture here was previously discussed--it is due to the rapid elongation of the Dacron after the cotton yarns rupture. The same comparison and comments can be made for 56% and 67% cotton content yarns, as shown in Figures 68 and 71, and Figures 72 and 75, Appendix D, respectively.

The 44% cotton content yarns at low twist, 0.54 TM and 1.09 TM, carry their strength through the first rupture point. Figure 59, 0.54 TM, and Figure 60, 1.09 TM, Appendix D, illustrate this. The curves also indicate that there is a good deal of slippage among the fibers as they are being extended. This is shown by the ragged shape of the load elongation curve and the low average number of pieces found in the yarns.

Figure 62, 3.26 TM, and Figure 63, 4.35 TM, Appendix D, represent 44% cotton distributed yarns which did not carry their load beyond the first rupture point.

Figure 64, 44% cotton, 56% Dacron, 1.01 TM, Appendix D, was intended for a core yarn. Except for 13 cotton yarns which are in the center, the rest are distributed. Interestingly enough, the cotton yarns are clustered and the effect shown by the curve must be a combination cotton core yarn and clustering effect. It can be seen that by comparison with Figure 60, 44% cotton distributed, the 44% cotton distributed yarn does carry its load more efficiently over greater extensions than in the cotton core case.

One method by which a blended yarn loses strength efficiency is by low frictional resistance among the fibers. The effect of low frictional resistance among yarns in the model is clearly shown in the high cotton content yarns where there are too few cotton to Dacron contacts because of the low amount of Dacron present. In this situation, when the cotton fibers reach their first rupture point, they quickly cease to contribute to yarn strength. The Dacron continues to extend. The phenomenon of fibers breaking at different extension reduces the overall load the yarn will sustain. Typical examples of this phenomenon are shown in Figure 65, 56% cotton, 44% Dacron, 1.08 TM; Figure 66, 56% cotton, 44% Dacron, 0.54 TM; Figure 67, 56% cotton, 44% Dacron, 1.09 TM; Figure 73, 67% cotton, 33% Dacron, 0.54 TM; and Figure 74, 67% cotton, 33% Dacron, 1.08 TM, Appendix D (all yarns with low twist). These blends with higher twist (2.17 TM, 3.38 TM, and 4.35 TM) do not carry their load beyond the first rupture point.

At the blend level of 89% and 100% cotton, the yarns of interest are those of low twist. In testing the yarns, the individual strands broke at their weakest point. The yarns remained intact, but they would sustain no loads/extensions. The yarns which exhibited this phenomenon are found on Figure 79, 89% cotton, 11% Dacron, 0.54 TM; Figure 80, 89% cotton content, 11% Dacron, 1.07 TM; and Figure 86, 100% cotton, 0.54 TM.

In examining the curves showing the number of broken pieces found in the yarns, one observes that the average number of broken pieces found decreased as the cotton content of the yarn increased. The average number of broken pieces found in the yarns as a function of blend ratio and twist level is shown in Figure 18. The data appear to be somewhat erratic, but it is clear that the cotton in blends over 33% do not share the load beyond the first break. This is indicated by the number of cotton pieces found in blends over 44% which vary from 1-2 at 40 and 50% blend and just one piece. It is also of interest to plot the average yarn length for each yarn ring as a function of blend. A plot of this type was made for one twist (2.2 TM and 20% extension). This is shown as Figure 19. It is clear from Figure 19 that the critical length for 2.2 TM for cotton-Dacron blends over 33% is over 100 mm. This is expected because of the number of broken pieces shown in Figure 18. One can see from Figure 19 that the pressure difference among the first 3 rings is small. A drop in fiber length (increase pressure) was not expected, so no connection was made between these points. The increased length shown by the outer rings indicates that the pressure drops rapidly as it approaches the outer ring. It is expected that increasing extension will cause the pressure to build up rapidly and the gap between the lines for all rings will be narrowed. This is shown to be so by the break diagrams attached to the fiber load extension curves. The large number of breaks found in the cotton yarn in the outer rings show that they were subjected to some pressure. It is understood that pressure in the outer ring is untenable. Some of the pressure may have resulted from yarn migration. However, it must be remembered that the yarn element in question fully occupies the outer 20% of the yarn radius.

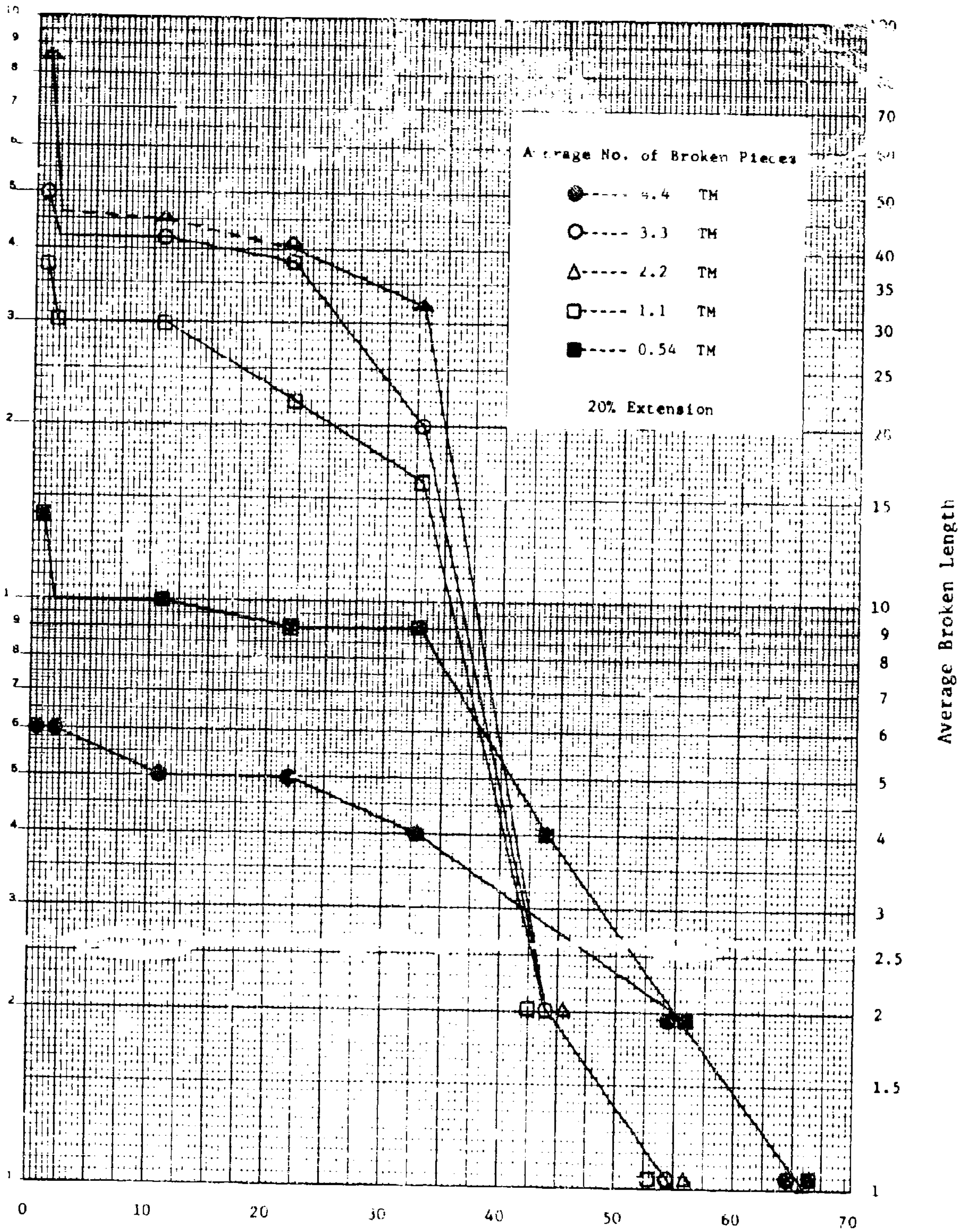


Figure 18. Effect of Cotton Content in Cotton-Dacron Blend on Average Cotton Pieces.

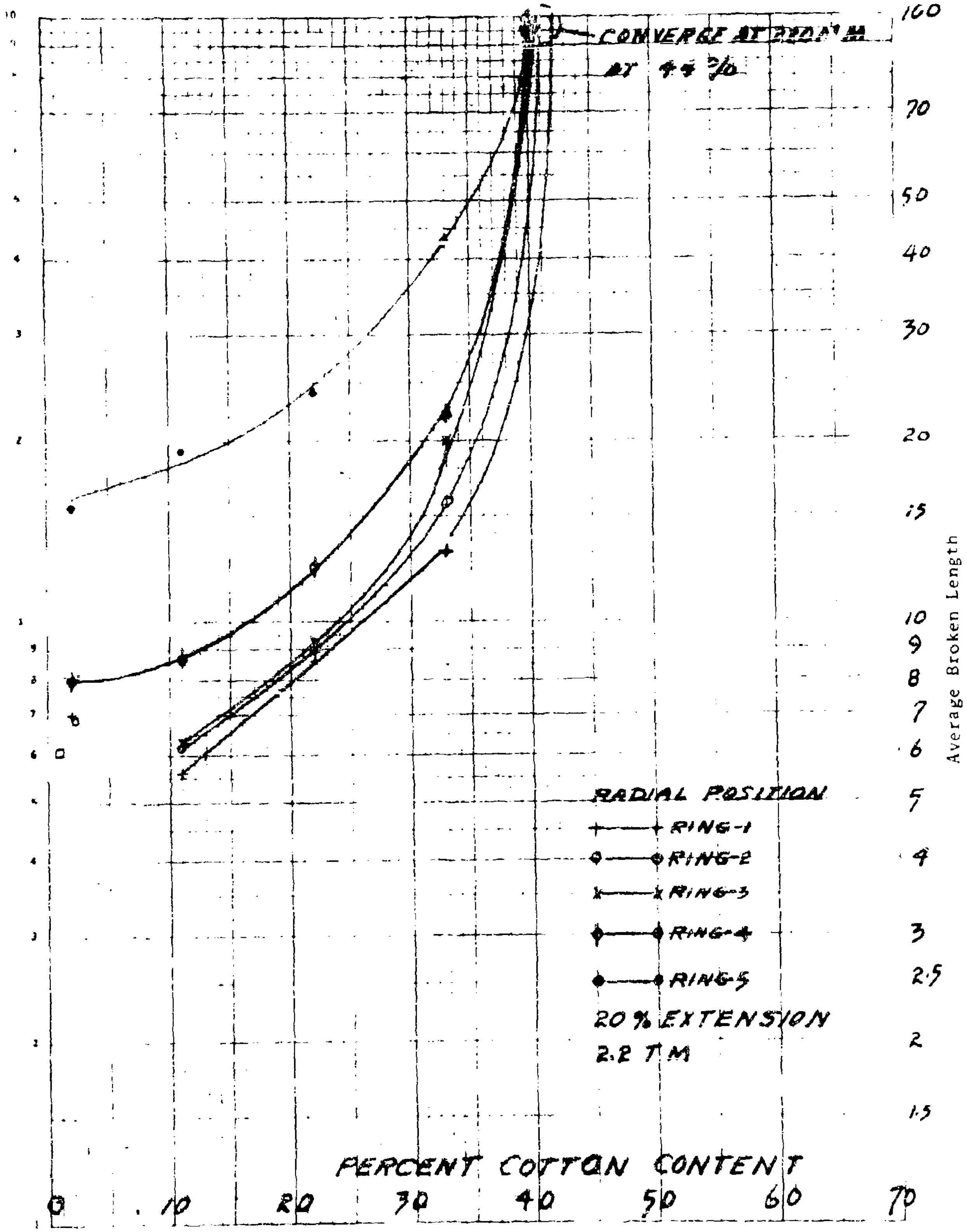


Figure 19. Effect of Radial Position and Blend Ratio on Average Length of Cotton

Conclusions

As a result of this experimental study on the load elongation behavior of cotton-Dacron blends, the following may be concluded:

The blend ratio of cotton-Dacron must not exceed 33% cotton content if full advantage is to be taken of continued strength after the first breaking point of the yarn.

Blends of 33 to 44% cotton content appear to be twist sensitive at low twists, 0.54 TM and 1.1 TM. The cotton continues to contribute to the strength of the yarn past the first rupture point. At higher levels of twist 2.2, 3.3 and 4.4 TM the yarn breaks at the first rupture point.

At blend levels above 44% through 100% cotton the yarns break at the first rupture point.

The results obtained on the Dacron and cotton core yarns are inconclusive because of the limited number of twist levels tested for each blend level.

Good agreement was reached between the experimental results found here and Machida's theoretical studies.

The mechanism of the cotton fiber's contribution to yarn strength is fairly well defined for the cotton distributed case. Additional studies must be made to fully understand the effect of cotton and Dacron core and the strength of the blended yarn.

Suggestions for Additional Work

The differences between actual staple yarn and model yarns should be studied. The work should be directed toward establishing a correlation between Machida's theoretical work and this experimental work with actual staple yarns.

Further studies should be made in establishing the effect of cotton or Dacron core yarns on the strength efficiency of the yarn.

Experimental work should be directed toward a development of a technique for measuring yarn pressure. A suggested procedure would be to compare the difference in diameter of a compressible cotton yarn.

To develop a technique for measuring the coefficient of friction between fiber elements in a yarn, one procedure suggests itself for the measurement of the coefficient of friction between yarns in a model such as those used in this study. The close agreement found between this experimental work and Machida's average yarn length suggests the use of his equation for the theoretical number of broken yarn elements. This equation is:

$$n = \frac{4\pi^2 \; t_o{}^2 \mu \; DSL}{3 \; T_b \; (1 - \epsilon y^2)} \; (1 - \frac{r^2}{R^2})$$

By rearranging the equation

$$\mu = \frac{3T_b \; (1 - \epsilon y)^2 \; n}{4\pi^2 \; t_o{}^2 \; DSL \; (1 - \frac{r^2}{R^2})}$$

μ coefficient
of friction

all the terms on the right hand side of the equation are measurable.

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APPENDIX A

Theoretical Analysis
Machida, Kazuo(26) Mechanics of Rupture
in Blended Yarns. Master's Thesis MIT 1963.

A. Assumptions

There are several papers which have studied the pressure in the yarn and roving structures.(25) (26) (27)

Each paper starts with different assumptions and comes to different results.

In our case assumptions are made as follows:

1. Fiber diameter is small compared with cotton yarn diameter. (There are enough Dacron contacts points around the cotton yarn.)
2. Whole yarn structure is large compared with cotton yarn. (So that the effect of a single cotton yarn in the structure is negligible.)
3. Uniform cylindrical structure (Uniform along its length and circular in its cross section.)
4. All fibers form concentric helices (No migration of cotton yarn takes place.)
5. Stress-strain relationship of fiber is expressed by

   A. $\sigma = E \varepsilon$

   B. $\sigma = a + b \varepsilon$

Symbols used

σ	stress of fiber
ε	strain of fiber
E	Young's modulus of a fiber
S	tensile load on model yarn structure
ε_y	yarn elongation
t	twist per cm. at elongation ε_y
t_0	twist per cm. at zero strain
θ	twist angle of a fiber at radius r.
r	radial position of fiber
R	model yarn radius
P	pressure inside the model yarn at radius r
P_c	pressure at the center of the model yarn
$\rho = \frac{r}{\sin^2 \theta}$	radius of curvature of the fiber at radius r
Φ	packing factor
μ	coefficient of friction between constituent fibers (Dacron & Cotton)
f	normal force acting on the cotton yarn per unit length
D	cotton yarn diameter
T_b	rupture strength of cotton yarn
T	tensile force acting on the cotton yarn in the structure
L	initial cotton yarn length in the structure
l_c	critical broken length of cotton yarn, i.e., the length below which cotton yarn will not be broken.

n	number of breaks of cotton yarn in the structure
l	broken length of cotton yarn
$\bar{l}$	average broken length of cotton yarn

B. Pressure in Twisted Structure

Fundamental Equations

Let $P(r)$ be a pressure inside yarn at radius of r, and consider a small section ABCD in the yarn cross section in Fig. 12.

We obtain a force balance equation

$$P(r+dr)(r+dr)d\psi + dF = P(r)\,r\,d\psi + 2P(r+\frac{dr}{2})\sin\frac{d\psi}{2} \qquad (1)$$

where $d\psi$ is a small angle of $\angle$ AOB

dF is a force per unit length within a section ABCD, working towards the center of yarn due to tension and twist of fibers in that section

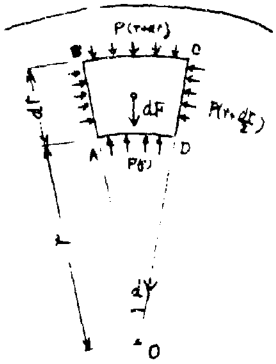


Figure 12

By geometry of twisted yarn structure, (Appendix)

$$dF = \frac{\sigma \cos\theta}{\rho}\,dA\,\frac{1}{\cos\theta} = \frac{\sigma\,dA}{\rho}$$

where $\rho = \frac{r}{\sin^2\theta}$

dA = are of section ABCD

θ = twist angle at radius r

We assume $\sigma = E\,\varepsilon$

then, $\sigma = E\,\varepsilon_y \cos^2\theta$

Thus $dF = E\,\varepsilon_y \cos^2\theta \sin^2\theta \; dr \; d\psi$

Substituting this into equation (1), we obtain

$$P(r+dr)(r+dr)\,d\psi + E\,\varepsilon_y \cos^2\theta \sin^2\theta \, dr \, d\psi$$
$$= P(r)\, r \cdot d\psi + 2\,P(r+\tfrac{dr}{2})\, dr \sin\frac{d\psi}{2}$$

Considering

$$P(r+dr) = P(r) + \frac{\partial P}{\partial r} dr$$
$$\sin\frac{d\psi}{2} \fallingdotseq \frac{d\psi}{2}$$

And neglecting higher order of derivative terms, we finally obtain,

$$\frac{\partial P}{\partial r} = -\frac{E\,\varepsilon_y \cos^2\theta \sin^2\theta}{r}$$
$$= -\frac{E\,\varepsilon_y\, 4\pi^2 t^2 r}{(1 + 4\pi^2 t^2 r^2)^2} \qquad \text{------ (2)}$$

Maximum and Average Pressure in a Yarn Cross Section

Integrating equation (2) from r = 0 to r = R with boundary condition of $P(r)_{r=0} = 0$, we obtain,

$$P(r) = \frac{E\varepsilon_y}{2}\left(\frac{1}{1+4\pi^2t^2r^2} - \frac{1}{1+4\pi^2t^2R^2} \right) \tag{3}$$

$$= \frac{E\varepsilon_y}{2}\left[4\pi^2t^2(R^2-r^2) - 16\pi^4t^4(R^4-r^4) + \cdots\cdots \right\}$$

$$\fallingdotseq P_c\left[1 - \frac{r^2}{R^2} \right) \tag{3-a}$$

Maximum Pressure

$$P_c = \frac{E\varepsilon_y}{2}\left(1 - \frac{1}{1+4\pi^2t^2R^2} \right) \tag{4}$$

$$= \frac{E\varepsilon_y}{2}\left(4\pi^2t^2R^2 - 16\pi^4t^4R^4 + \cdots\cdots \right)$$

Average Pressure

$$\bar{P} = \frac{\int_0^R P2\pi r\,dr}{\pi R^2} = \frac{E\varepsilon_y}{2}\left[\frac{1}{4\pi^2t^2R^2}\ln(1+4\pi^2t^2R^2) - \frac{1}{1+4\pi^2t^2R^2} \right] \tag{5}$$

$$= \frac{E\varepsilon_y}{2}\left[\frac{1}{2}(4\pi^2t^2R^2) - \frac{2}{3}(16\pi^4t^4R^4) + \frac{3}{4}(64\pi^6t^6R^6) - \cdots\cdots \right]$$

Relation to Yarn Load

The load of twisted filament yarn is given in terms of t, R, E, and ε_y as follows (Appendix)

$$S = \pi R^2\left[\frac{E\varepsilon_y}{4\pi^2t^2R^2}\left(1 - \frac{1}{1+4\pi^2t^2R^2} \right) \right]$$

Comparing with equation (4), we obtain a simple relationship between pressure at center P_c, and yarn load and twist,

$$P_c = 2\pi t^2 S \tag{6}$$

Consideration to Yarn Packing Factor

When we use equation (6) to calculate yarn pressure, S and t are measured values and no consideration for packing factor is necessary.

But if we use equations (3) (4) (5) to calculate pressure, we have to consider packing factor. It is defined as

$$\phi = \frac{N \frac{\pi}{4} d^2}{\pi R^2} = \frac{N d^2}{4 R^2}$$

where N is number of fibers in a cross section

R is radius of yarn

d is diameter of fibers

Thus equations (3) (4) (5) become

$$P(r) = \frac{E \varepsilon_y}{2} \phi \left[\frac{1}{1 + 4\pi^2 t^2 r^2} - \frac{1}{1 + 4\pi^2 t^2 R^2} \right] \qquad (3)'$$

$$P_c = \frac{E \varepsilon_y}{2} \phi \left[1 - \frac{1}{1 + 4\pi^2 t^2 R^2} \right] \qquad (4)'$$

$$\overline{P} = \frac{E \varepsilon_y}{2} \phi \left[\frac{1}{4\pi^2 t^2 R^2} \ln (1 + 4\pi^2 t^2 R^2) - \frac{1}{1 + 4\pi^2 t^2 R^2} \right] \qquad (5)'$$

In Case of Fiber S-S Curve $\sigma = a + b\varepsilon$

For the most fibers $\sigma = a + b\,\varepsilon$ is more general expression of S-S curves up to rupture points. In this case, equation (2) becomes

$$\frac{\partial P}{\partial r} = -\frac{1}{r} \left[a \sin^2\theta + b\, \varepsilon_y \sin^2\theta \cos^2\theta \right]$$

Solving this, we obtain

$$P_c = \frac{a}{2} \ln(1+4\pi^2 t^2 R^2) + \frac{b\varepsilon_y}{2}\left(1 - \frac{1}{1+4\pi^2 t^2 R^2}\right)$$

Considering S is expressed by (Appendix)

$$S = \pi R^2 \left[\frac{a}{4\pi t^2 R^2} \ln(1+4\pi^2 t^2 R^2) + \frac{b\varepsilon_y}{4\pi^2 t^2 R^2}\left(1 - \frac{1}{1+4\pi^2 t^2 R^2}\right)\right]$$

P_c is again simplified to the same equation (6)

$$P_c = 2\pi t^2 S \qquad (6)'$$

Effect of Yarn Elongation to Pressure

This discussion is based on the assumption that the strain level of a twisted yarn is so small that we can neglect the change of twist due to yarn elongation. In the calculation of load or breaking strength of yarn this effect is negligible up to rupture point.

But since the pressure is influenced by the factor of t^2 as seen in equation (6), we have to take this factor into account. Assume the load elongation curve of yarn is expressed by

$$S = A + B\,\varepsilon_y$$

and twist at yarn elongation of ε_y is given as

$$t = \frac{t_0}{1+\varepsilon_y}$$

then

$$P_c = 2\pi t_o^2 A \left[\frac{1}{(1+\varepsilon_y)^2} + \frac{B/A\ \varepsilon_y}{(1+\varepsilon_y)^2} \right]$$

Differenciating this with ε_y, we obtain the strain which gives maximum pressure at the center of yarn.

$$\frac{\partial P_c}{\partial \varepsilon_y} = 2\pi t_o^2 A \left\{ \frac{1}{(1+\varepsilon_y)^3} \left[-2 + \frac{B}{A} - \frac{B}{A}\varepsilon_y \right] \right\} = 0$$

$$\varepsilon_{y \text{ for } P_c \max} = 1 - \frac{2A}{B}$$

Figure 13 and Figure 14 illustrate one example of pressure calculation. Five different load-elongation curves are shown in Figure 13, all of them having the same rupture point of load S_o and elongation 25%. Pressure at the center of yarn for each load-elongation curve is shown in Figure 14.

C. Stress Distribution in Cotton Yarn and Theoretical Broken Length

Stress and strain of cotton yarn in this blended system is explained in a simplified model shown in Figure 15. Cotton yarn is surrounded by Dacron fibers under normal pressure of P and then Dacron fibers are extended to strain level of ε_y by pulling both ends.

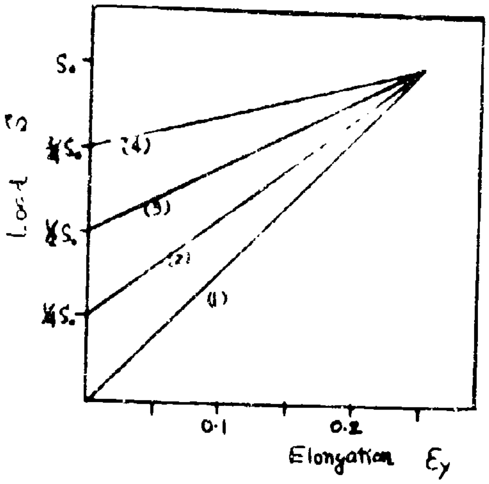


Figure 13

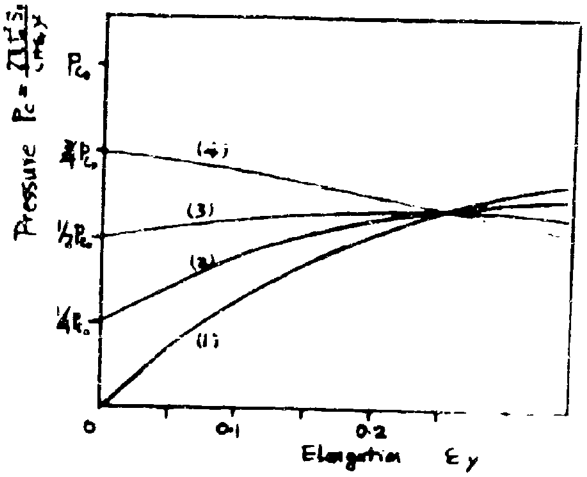


Figure 14

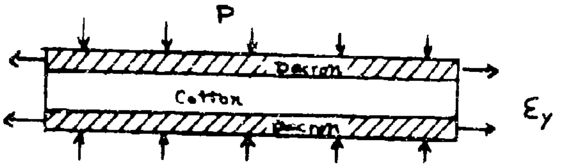


Figure 15

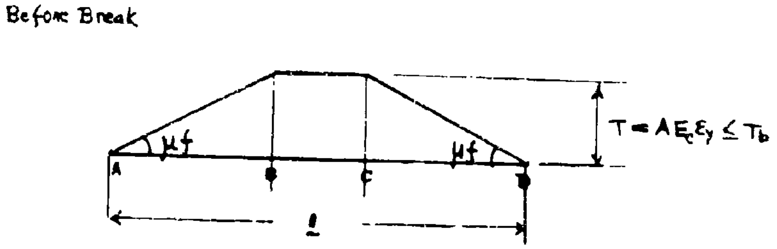


Figure 16-a

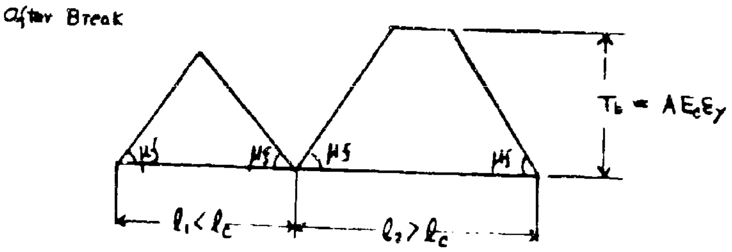


Figure 16-b

Pressure and elongation of the Dacron fibers cause frictional forces to elongate cotton yarn and as a result, a tensile force, T, in the cotton yarn is built up from both ends of cotton yarn with a slope of μf to the center portion of the yarn until the force reaches to the magnitude where cotton yarn is elongated to the same level of Dacron fibers. Here μ is the coefficient of friction between the cotton and Dacron fibers, f is the normal force working on cotton yarn per unit length. Thus the center portion of cotton yarn ($\overline{BC}$ in Figure 16a) remains in the same tensile force and if we assume linear stress-strain relation in cotton yarn, tensile force in $\overline{BC}$ region is

$$T = A E_c \varepsilon_y$$

where A is cross sectional area of cotton yarn

E_c is modulus of the cotton yarn

As Dacron fibers are elongated ε_y goes up, consequently T also goes up and finally when T exceeds rupture strength of cotton yarn T_b, then cotton yarn breaks. After the cotton yarn is broken, the tensile force at the point of rupture falls to zero and the broken portions behave as two short fibers.(Figure 16-b)

On the other hand the Dacron fibers still continue being elongated. The pressure P is a function of elongation of Dacron fibers, therefore pressure is going up regardless of cotton yarn breakage. Thus the tensile forces in two broken yarns go up again due to the increase of μf, and when we get enough pressure to build up tensile force to a new rupture strength on these short segments, they are broken again. The yarn length $\overline{AB} + \overline{CD}$ in Figure 16-a at the time tensile force reaches rupture strength T_b is called the critical length, since at this condition no cotton yarn shorter than this length will be broken.

By definition

$$T_b = \mu f \frac{l_c}{2}$$

Assuming liquid pressure around cotton yarn

$$f = \pi D P$$

Hence

$$l_c = \frac{2 T_b}{\pi \mu D P}$$

Theoretical broken lengths are distributed between 1_c and $1_c/2$, because yarn breaks can happen at any point within a length of $(1 - 1_c)$ and broken lengths will be statistically distributed. If we consider the yarn length just less than 1_c, it will not be broken and will be maximum segments length, and yarn length just over 1_c will be broken into two $1_c/2$ lengths and these will be minimum segments lengths. Thus we may expect an average broken length of $3/4\ 1_c$.

Hence

$$\bar{l} = \frac{3T_b}{2\pi\mu DP} \qquad (7)$$

If cotton yarn is placed at the center of blended yarn, P is given in equation (6), then

$$\bar{l} = \frac{3T_b(1+\varepsilon_y)^2}{4\pi^2 t_o^2 \mu DS} \qquad (8)$$

Number of breaks within a gage length of L is

$$n = \frac{L}{\bar{l}} = \frac{4\pi^2 t_o^2 \mu DSL}{3T_b(1+\varepsilon_y)^2} \qquad (9)$$

If cotton yarn is placed at the position of radius r,

$$\bar{l} \doteq \frac{3T_b(1+\varepsilon_y)^2}{4\pi^2 t_o^2 \mu DS} \cdot \frac{1}{(1-\frac{r^2}{R^2})} \qquad (10)$$

$$n \doteq \frac{4\pi^2 t_o^2 \mu DSL}{3T_b(1+\varepsilon_y)^2}\left[1-\frac{r^2}{R^2}\right] \qquad (11)$$

APPENDIX B

Dyeing Procedure and Dye Formulation

The cotton yarns were dyed with direct cotton dyes. The dyestuff used and their color index numbers are as follows:

CI No.	CI Name	Dyestuff	Manufacturer
		Cupraphenyl Rubine RL	Geigy
		Cupraphenyl Yellow 3 GL	"
		Cupraphenyl Green 2BL	"
		Cupraphenyl Blue 2GLL	"
35780	Direct Red 80	Pyrazol Fast Red 7BSW	Sandoz
	Direct Yellow 105	Pyrazol Fast Orange LUF	"
	Direct Yellow 106	Lumicrease Yellow 3 LG	"
34045	Direct Green 26	Pyrazol Fast green BL	"
29125	Direct Violet 48	Pyrazol Fast Violet 5BL	"

The cotton yarns were scoured by boiling for two hours in a 2% caustic soda solution. After scouring the yarns were dyed, using the following procedure.

The skeins are entered in the dye bath at 120°F. The dyebath was brought to a boil in 20 minutes. Salt was added to the boiling bath to exhaust the dye. After boiling for 20 minutes the dyebath was allowed to cool to 160°F. The dyed cotton skein was then rinsed and allowed to air dry.

The following dye formulations were used:

Color	Percent	Dye Formulation
1-2	0.5	Cupraphenyl Rubine RL
1-3	0.5 0.625	Cupraphenyl Rubine RL Cupraphenyl Yellow 3GL
1-4	0.5	Cupraphenyl Green 2BL

Color	Percent	Dye Formulation
1-6	0.5	Cupraphenyl Blue 2GLL
1-7R	2.0 0.25	Pyrazol Fast Red 7BSW Pyrazol Fast Blue 2GLN
1-8	3.0	Pyrazol Fast Green 2BL
1-9	1.0	Pyrazol Fast Green 2BL
1-10	3.0	Pyrazol Fast Red 7BSW
1-11	2.0	Pyrazol Fast Violet 5BL
1-12	3.0	Pyrazol Fast Violet 5BL
2-2	1.0	Cupraphenyl Rubine RL
2-3	1.0 1.2	Cupraphenyl Rubine RL Cupraphenyl Yellow 3GL
2-4	1.0	Cupraphenyl Green 2BL
2-5	2.0	Cupraphenyl Yellow 3GL
2-6	1.0	Cupraphenyl Blue 2GLL
2-8	0.5	Pyrazol Fast Red 7BSW
2-9	0.5	Pyrazol Fast Green BL
2-10	1.0	Pyrazol Fast Red 7BSW
2-11	1.0	Pyrazol Fast Violet 5BL
2-12	3.0	Pyrazol Fast Orange LUF
1-13	1.0	Pyrazol Fast Orange LUF
1-14	1.0	Cupraphenyl Yellow 3GL
1-15	3.0	Lumicrease Yellow 3LG
1-16R	1.0 0.25 0.5	Lumicrease Yellow 3LG Pyrazol Fast Green BL Pyrazol Fast Orange LUF

Color	Percent	Dye Formulation
1-18R	1.0	Lumicrease Yellow 3LG
	0.13	Pyrazol Fast Blue 2GLN
	0.5	Pyrazol Fast Green BL
1-19R	1.5	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Orange LUF
	0.5	Pyrazol Fast Red 7BSW
1-20	0.25	Pyrazol Blue 2GLN
	1.0	Pyrazol Fast Violet 5BL
1-21	1.0	Pyrazol Fast Violet 5BL
	0.25	Pyrazol Fast Red 7BSW
1-22	0.5	Pyrazol Fast Red 7BSW
	0.5	Pyrazol Fast Blue 2BLN
1-23	0.5	Pyrazol Fast Red 7BSW
	0.5	Lumicrease Yellow 3LG
2-13	1.0	Pyrazol Fast Orange LUF
2-14	1.0	Cupraphenyl Yellow 3GL
2-15	0.5	Pyrazol Fast Blue 2GLN
2-16R	1.0	Pyrazol Fast Blue 2GLN
	0.25	Pyrazol Fast Orange LUF
	0.25	Pyrazol Fast Red 7BSW
2-17	1.0	Lumicrease Yellow 3LG
	0.07	Pyrazol Fast Blue 2GLN
2-18	0.25	Pyrazol Fast Orange LUF
	1.50	Lumicrease Yellow 3LG
2-19R	1.5	Lumicrease Yellow 3LG
	0.375	Pyrazol Fast Orange LUF
	0.375	Pyrazol Fast Red 7BSW
2-20	0.5	Pyrazol Fast Violet 5BL
	0.5	Pyrazol Fast Blue 2GLN
2-21	1.0	Pyrazol Fast Violet 5BL
	0.5	Pyrazol Fast Red 7BSW
2-22	0.5	Pyrazol Fast Violet 5BL
	0.5	Pyrazol Fast Red 7BSW

Color	Percent	Dye Formulation
1-24	0.5	Pyrazol Fast Green BL
	0.5	Lumicrease Yellow 3LG
1-25	0.5	Pyrazol Fast Green BL
	0.5	Pyrazol Fast Violet 5BL
1-26	0.5	Pyrazol Fast Violet 5BL
	0.5	Pyrazol Fast Blue 2GLN
1-27	0.25	Pyrazol Fast Red 7BSW
	0.25	Pyrazol Fast Blue 2GLN
1-28	0.25	Pyrazol Fast Red 7BSW
	0.25	Pyrazol Fast Violet 5BL
1-29	0.25	Pyrazol Fast Red 7BSW
	0.25	Lumicrease Yellow 3LG
1-30	0.25	Pyrazol Fast Red 7BSW
	0.25	Pyrazol Fast Green BL
1-31	0.25	Pyrazol Fast Green BL
	0.25	Pyrazol Fast Blue 2GLN
1-32	0.375	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Violet 5BL
1-33	0.375	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Violet 5BL
2-23	0.5	Pyrazol Fast Red 7BSW
	0.5	Pyrazol Fast Orange LUF
2-24	0.5	Pyrazol Fast Green BL
	0.5	Pyrazol Fast Red 7BSW
2-25	0.5	Pyrazol Fast Green BL
	0.5	Pyrazol Fast Blue 2GLN
2-26	0.5	Pyrazol Fast Violet 5BL
	0.5	Pyrazol Fast Orange LUF
2-27	0.25	Pyrazol Fast Blue 2GLN
	0.25	Pyrazol Fast Violet 5BL
2-29	0.25	Pyrazol Fast Green BL
	0.25	Lumicrease Yellow 3LG

Color	Percent	Dye Formulation
2-30	0.25	Pyrazol Fast Green BL
	0.25	Pyrazol Fast Violet 5BL
2-31	0.25	Pyrazol Fast Violet 5BL
	0.25	Pyrazol Fast Blue 2GLN
2-32	0.375	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Green BL
2-33	0.375	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Violet 5BL
1-34	0.375	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Orange LUF
1-35	0.375	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Green BL
1-36	0.375	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Red 7BSW
1-37	0.375	Pyrazol Fast Green BL
	0.125	Lumicrease Yellow 3LG
1-38	0.375	Pyrazol Fast Orange LUF
	0.125	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Violet 5BL
1-39	0.375	Pyrazol Fast Orange LUF
	0.125	Pyrazol Fast Green BL
1-40	0.375	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Red 7BSW
1-41	0.375	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Green BL
1-42	0.375	Pyrazol Fast Red 7BSW
	0.125	Lumicrease Yellow 3LG
2-34	0.375	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Blue 2GLN
2-35	0.375	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Red 7BSW
2-36	0.375	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Blue 2GLN

Color	Percent	Dye Formulation
2-37	0.375	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Orange LUF
2-38	0.375	Pyrazol Fast Orange LUF
	0.125	Pyrazol Fast Blue 2GLN
2-39	0.375	Pyrazol Fast Orange LUF
	0.135	Pyrazol Fast Violet 5BL
2-40	0.375	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Blue 2GLN
2-41	0.375	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Violet BL
2-42	0.375	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Green BL
2-43	0.375	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Blue 2GLN
1-44	0.375	Pyrazol Fast Blue 2GLN
	0.125	Lumicrease Yellow 3LG
1-45	0.375	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Orange LUF
1-46	0.25	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Orange LUF
1-47	0.25	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Orange LUF
1-48	0.25	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Red 7BSW
	0.125	Lumicrease Yellow 3LG
1-50	0.25	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Violet 5BL
	0.125	Lumicrease Yellow 3LG
1-51	0.125	Pyrazol Fast Green BL
	0.25	Pyrazol Fast Red 7BSW
	0.125	Lumicrease Yellow 3LG

Color	Percent	Dye Formulation
1-52	0.25	Pyrazol Fast Orange LUF
	0.125	Lumicrease Yellow 3LG
	0.125	Pyrazol Fast Red 7BSW
2-44	0.375	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Red 7BSW
2-45	0.375	Pyrazol Fast Violet 5BL
	0.125	Lumicrease Yellow 3LG
2-46	0.25	Pyrazol Fast Violet 5BL
	0.125	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Orange LUF
2-47	0.125	Pyrazol Fast Violet 5BL
	0.25	Pyrazol Fast Blue 2GLN
	0.125	Pyrazol Fast Orange LUF
2-49	0.25	Pyrazol Fast Green BL
	0.125	Pyrazol Fast Blue 2GLN
	0.125	Lumicrease Yellow 3LG
2-50	0.32	Pyrazol Fast Red BSW
	0.125	Pyrazol Fast Orange LUF
	0.07	Pyrazol Fast Blue 2GLN
2-51	0.25	Pyrazol Fast Red 7BSW
	0.125	Pyrazol Fast Orange LUF
	0.125	Pyrazol Fast Violet 5BL
2-52	0.32	Pyrazol Fast Orange LUF
	0.125	Lumicrease Yellow 3LG
	0.07	Pyrazol Fast Green BL

APPENDIX C

REVIEW OF RESINS FOR IMBEDDING YARNS FOR CROSS SECTIONS

This investigation was initiated to find an imbedding media which would hold yarns and fix Dacron yarns under strains as high as 30% (approximately 60 lbs. tension). When cured, the resin had to be soft enough so that it could be sliced using a hand microtome. For simplicity of operation, and to keep reacting temperatures as low as possible, a cold curing type resin was the only one considered.

The first resins tried were:

Butyl acrylate

Isobutyl acrylate

Methyl methacrylate

The resins were washed with 5% NaOH in a 20% salt solution to remove the inhibitor. The washing was conducted in a separatory flask with 20 parts by weight of the cleaning solution and 100 parts by weight of monomer. The mixture was shaken and allowed to separate. The washing solution was then drained. A small amount of $NaHCO_3$ was added to dry the monomer, then it was filtered through coarse filter paper.

The following preparations were made:

20 gm Isobutyl methacrylate
.1 gm Benzol peroxide

20 g. Butyl acrylate
.1 g. Benzol peroxide

20 g. Methyl methacrylate
.1 g. Benzol peroxide

The isobutyl methacrylate required heat to initiate the reaction, and the resin formed was firm; for both reasons this resin was not satisfactory.

The butyl acrylate required heat and a long time to cure, overnight; this was not satisfactory.

The methyl methacrylate also required heat to cure and an overnight reaction.

Paraplex P-40.* This is a hard resin and can be cold-cured by using the following formula:

100 g. Paraplex P-40

1 g. DDM

.6 g. Cobalt naphthanate

This resin jells in 15 minutes.

Attempts to combine resin with Paraplex P-13** to obtain a cured product, which could easily cut, did not succeed.

Epoxy.

62.5 g. Epoxy resin

25.0 g. Amide softener

12.5 g. Accelerator

This solution jelled in 12 hours.

It was somewhat softer than methyl methacrylate but still not soft enough to slice easily.

Silicone resin RTV-41. Silicone rubber.

100 g. RTV-41***

.5 g. Thermolite-12****

Resin cures in two hours, yields a rubbery compound.

This formulation was too viscous for casting yarns but suitable for making molds to hold the yarns for casting.

---

* Trademark for unsaturated polyester.
** Trademark plasticizer for coatings.
*** Brand name for silicone rubber compound.
**** Trademark for series of vinyl stabilizers.

Methyl methacrylate. This is a cold cure resin which is easy to use but yields a product too hard to cut. A cold curing formula which will set in one hour is:

20 g. Clearmount*****

.05 g. Catalyst benzol peroxide

Polyurethane resin PR-1535 Amber.****** This was the most successful resin used. The resin was mixed as follows:

32 g. Part A of PR-1535

100 g. Part B of PR-1535

The mixture was given a good mixing, using a shearing paddle and 1/4-inch electric drill. The mixed resin was poured in the mold, and the material was degassed in a dessicator under vacuum at a pressure less than 5 mm. of mercury for five minutes. The mold was then removed from the dessicator and allowed to room ~ure. It required two days to harden enough to fix and hold the yarns under tension.

***** Commercial product.
****** Commercial product.

APPENDIX D *

Load Elongation Curves and Cotton Break Diagram

Figure Numbers

Blend	Effect of Twist	Dacron Core	Cotton Core	Broken Cotton Pieces
100% Dacron	1	-	-	-
98.9% Dacron 1.1% Cotton	2	-	-	25 - 29
97.8% Dacron 2.2% Cotton	3	-	- 30	31 - 36
89% Dacron 11% Cotton	4	12 - 43	19 - 37	38 - 42
78% Dacron 22% Cotton	5	13 - 44	20 - 50	45 - 49
67% Dacron 33% Cotton	6	14 - 57	21 - 51	52 - 56
56% Dacron 44% Cotton	7	15 - 58	22 - 64	59 - 63
44% Dacron 56% Cotton	8	16 - 71	23 - 65	66 - 70
33% Dacron 67% Cotton	9	17 - 72	24 - 78	73 - 77
11% Dacron 89% Cotton	10	18 - 85	16 - 79	80 - 84
100% Cotton	11	-	-	86 - 90

* See following figures.

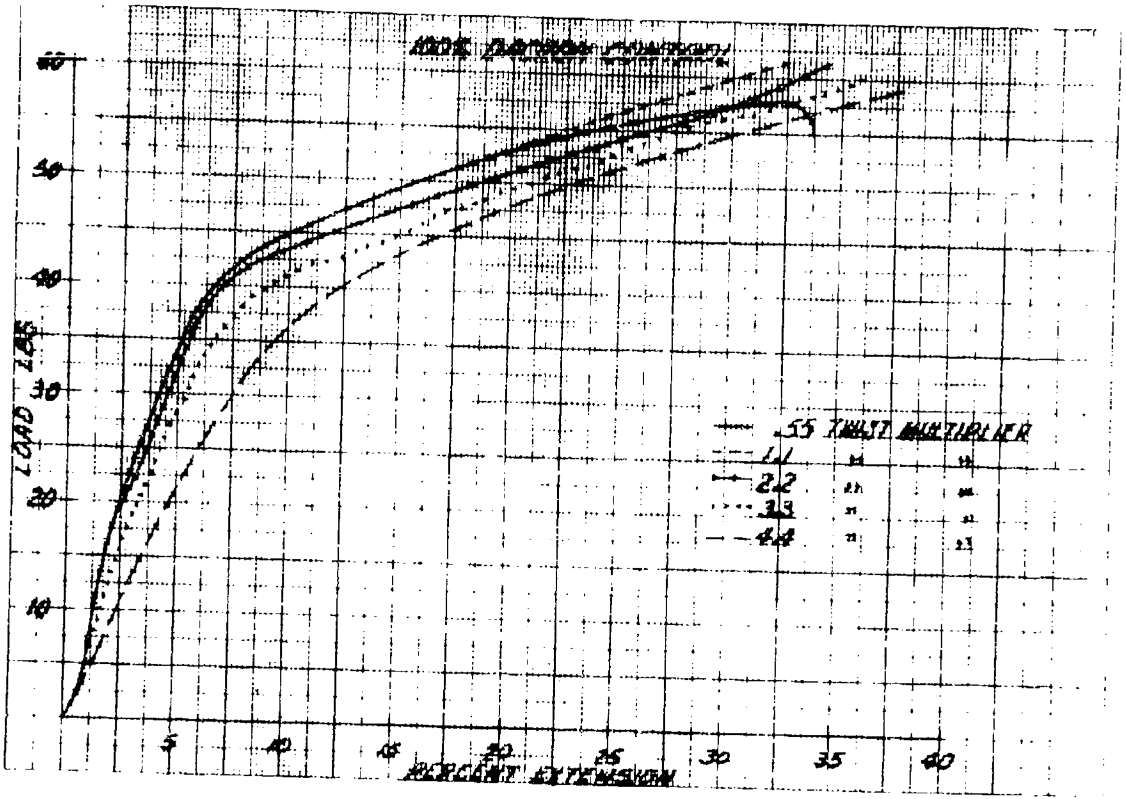


FIGURE 1 [illegible] DACRON YARNS (EFFECT OF TWIST)

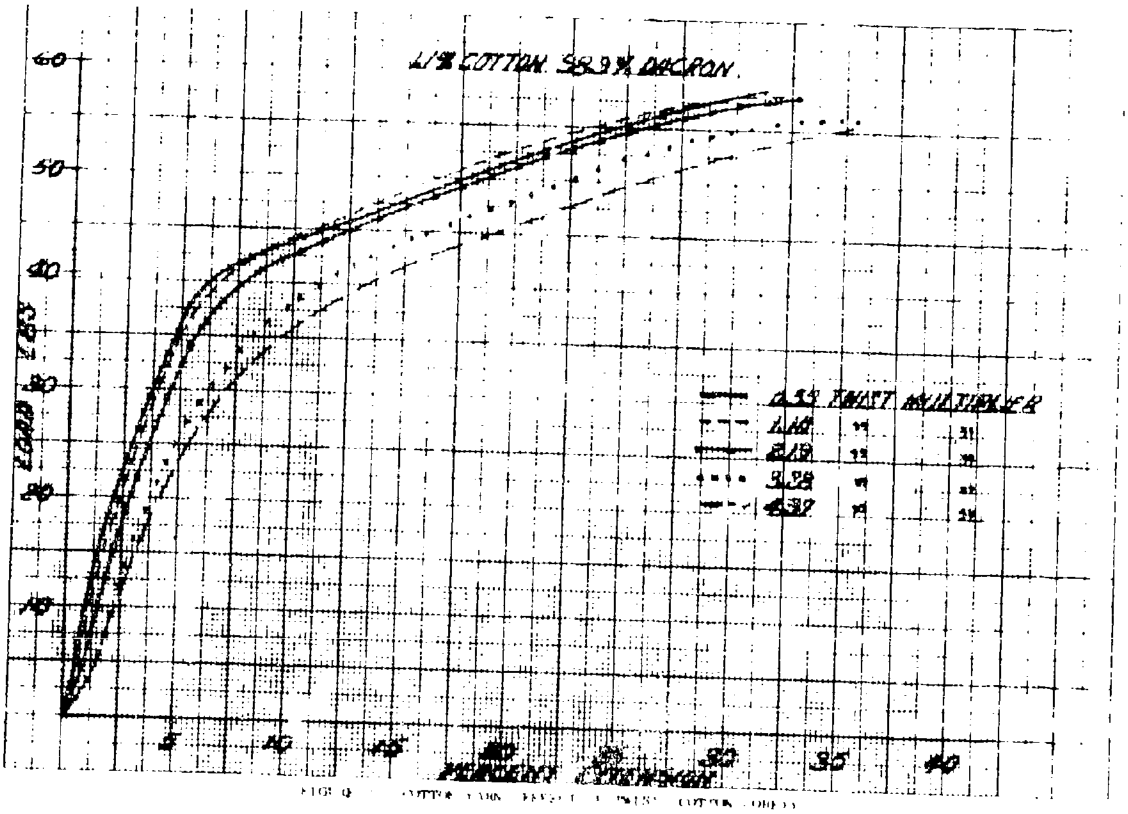
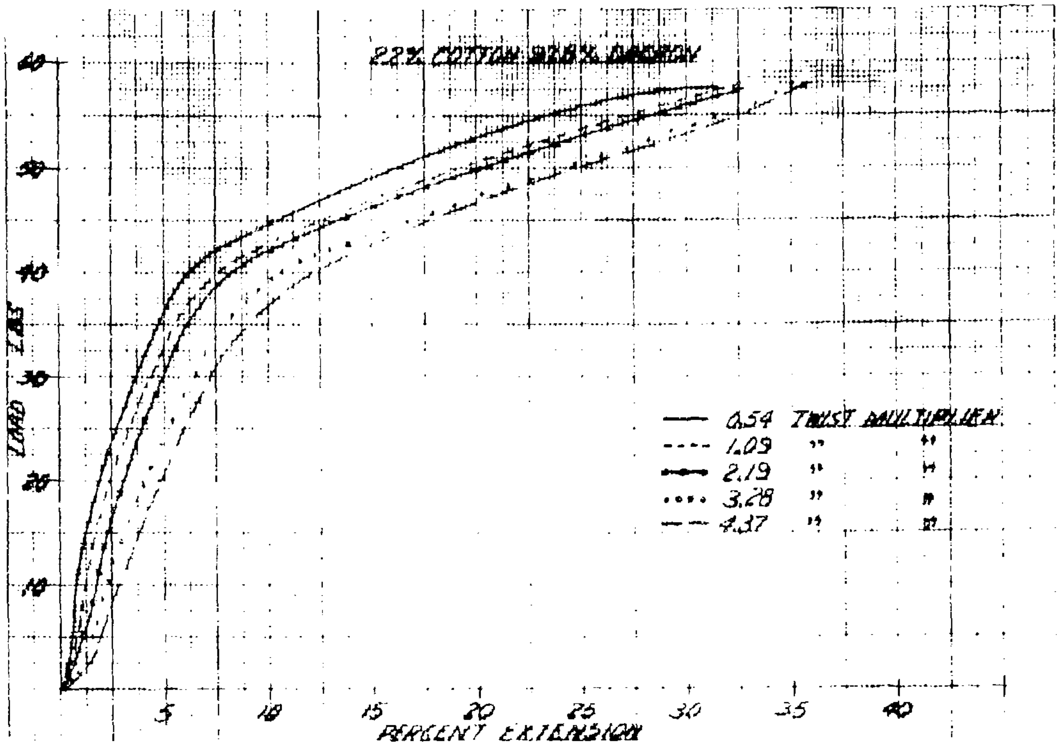
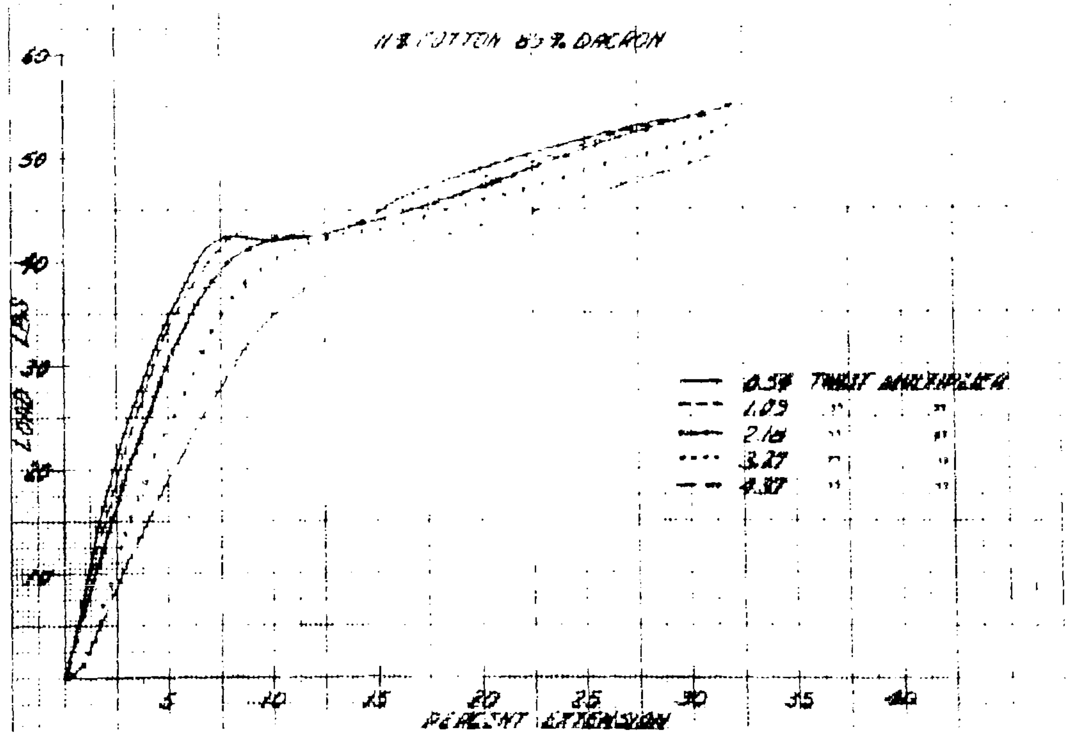


FIGURE [illegible] COTTON YARN [illegible] TWIST [illegible] COTTON [illegible]


22% COTTON 78% DACRON
60
50
40
30
20
10
LOAD LBS
5
10
15
20
25
30
35
40
PERCENT EXTENSION
0.54 TWIST MULTIPLIER
1.09 " "
2.19 " "
3.28 " "
4.37 " "


11% COTTON 89% DACRON
60
50
40
30
20
10
LOAD LBS
5
10
15
20
25
30
35
40
PERCENT EXTENSION
0.54 TWIST MULTIPLIER
1.09 " "
2.18 " "
3.27 " "
4.37 " "

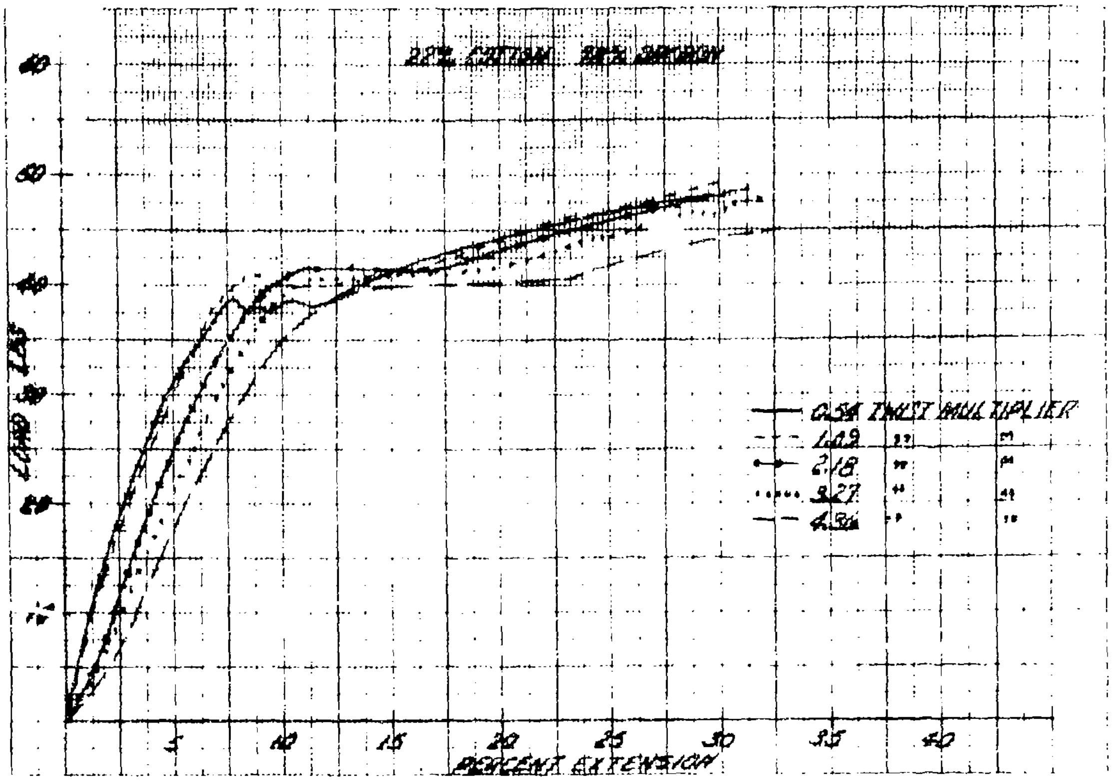


FIGURE [illegible]. [illegible] COTTON YARN (EFFECT OF TWIST — COTTON DISTRIBUTED IN YARN CROSS SECTION)

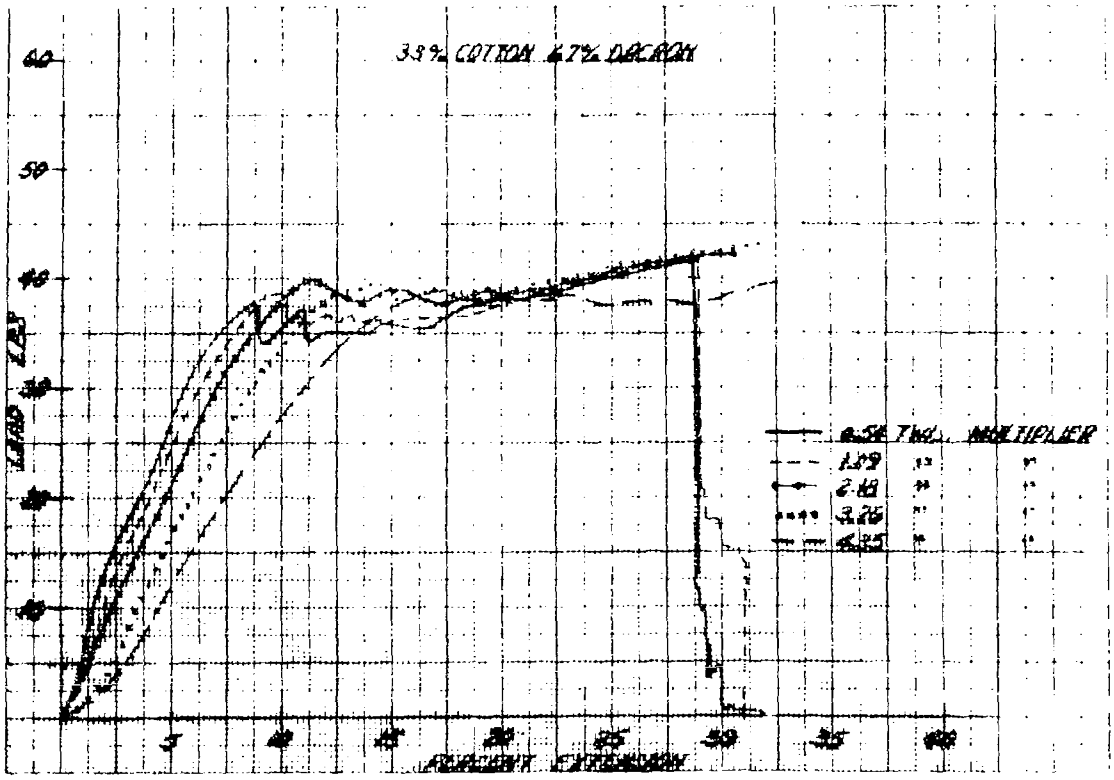


FIGURE [illegible]. [illegible] COTTON YARNS (EFFECT OF TWIST — COTTON DISTRIBUTED IN YARN CROSS SECTION)

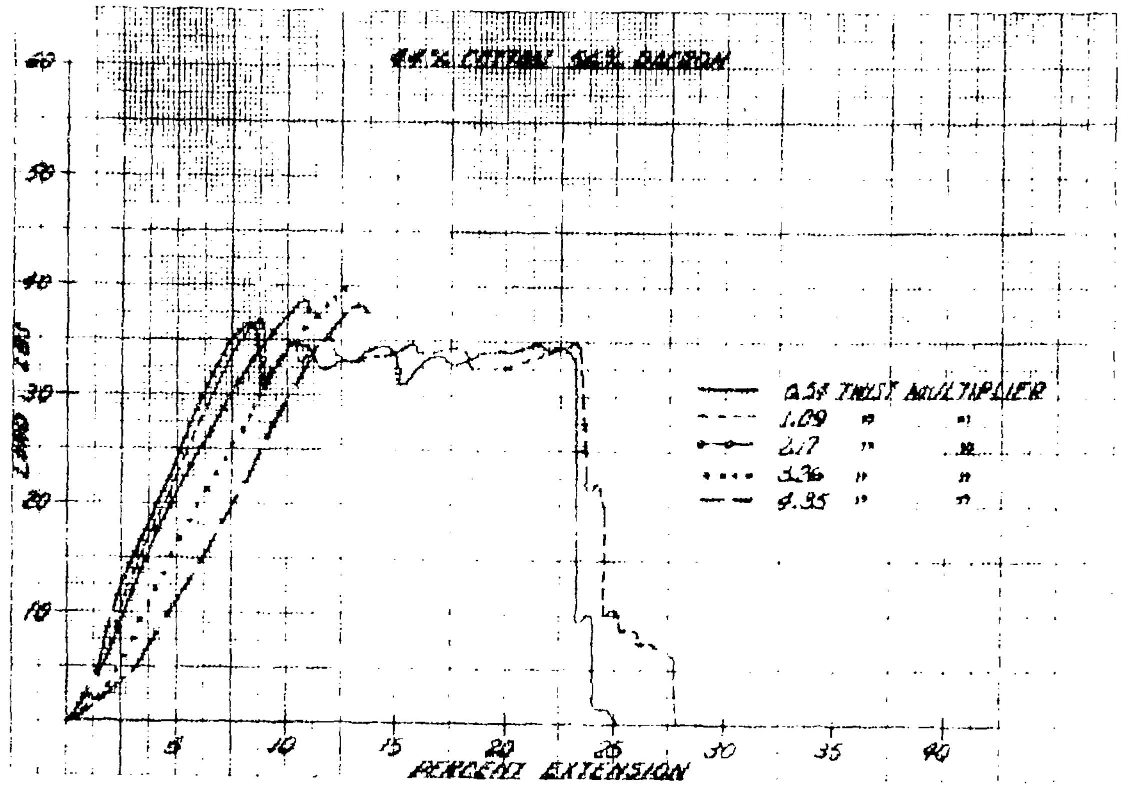


FIGURE [illegible] COTTON [illegible] OF TWIST [illegible]

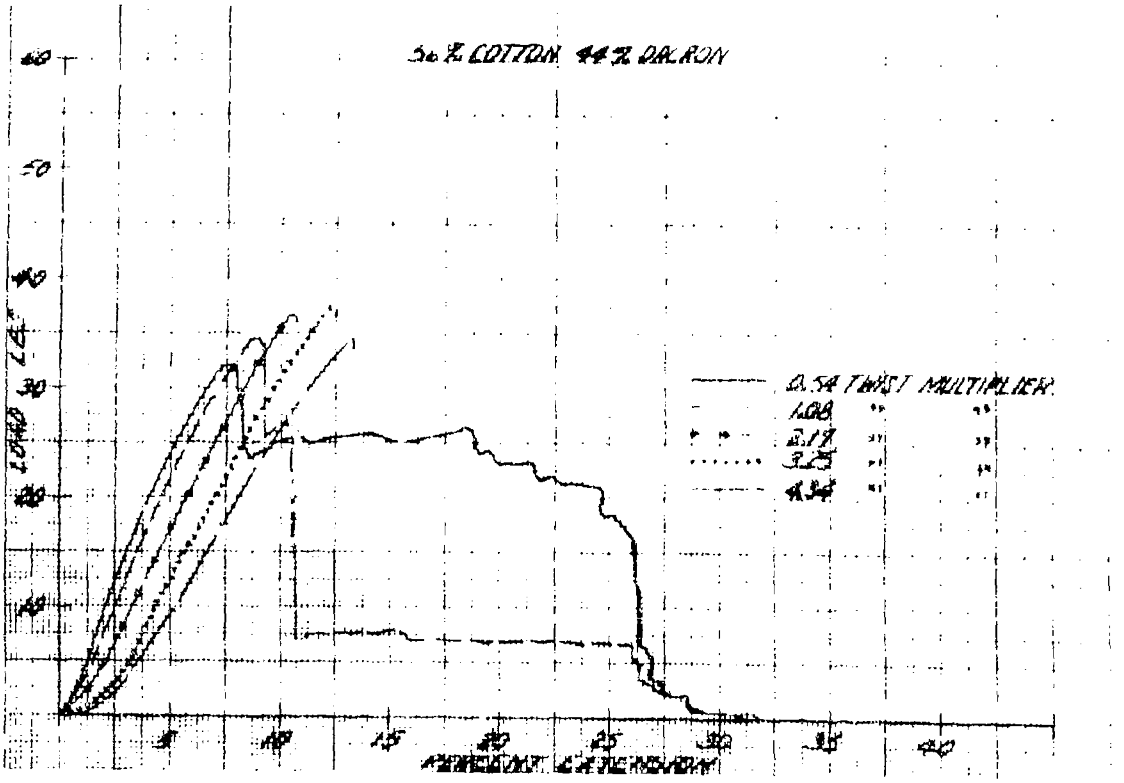


FIGURE [illegible] COTTON YARN [illegible] OF TWIST [illegible] IN YARNS [illegible]

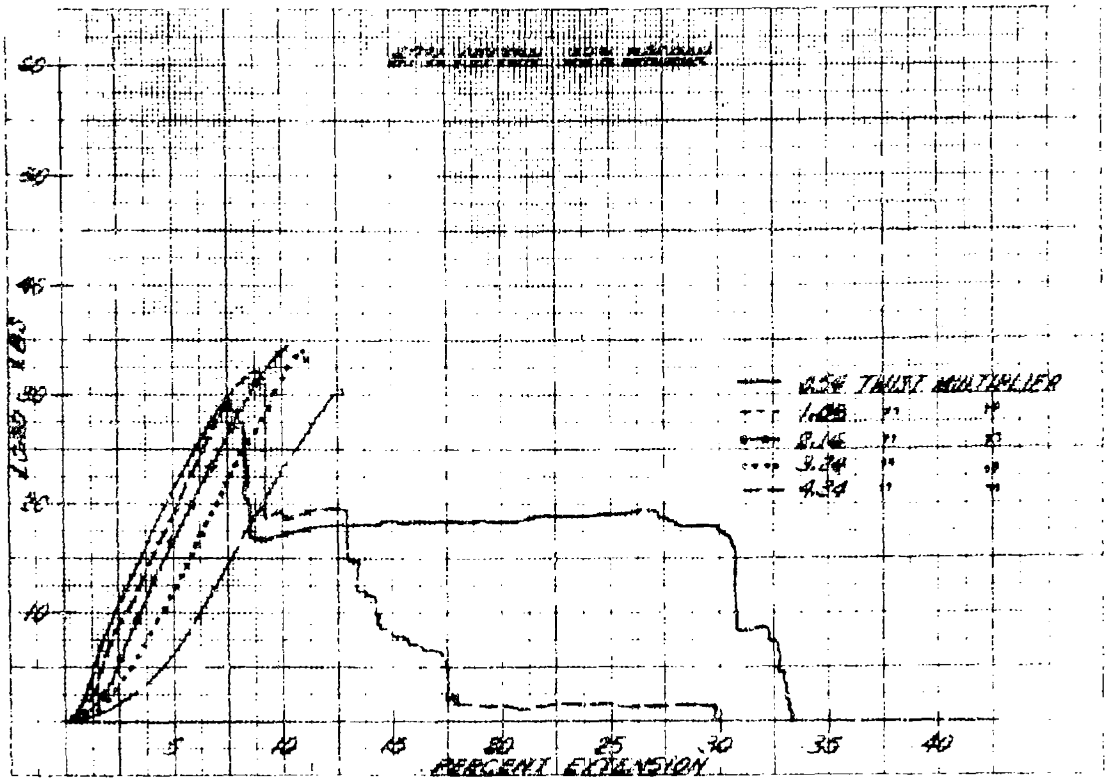


FIGURE [illegible] [illegible] COTTON YARNS (EFFECT OF TWIST) (COTTON DISTRIBUTED IN YARN CROSS SECTION)

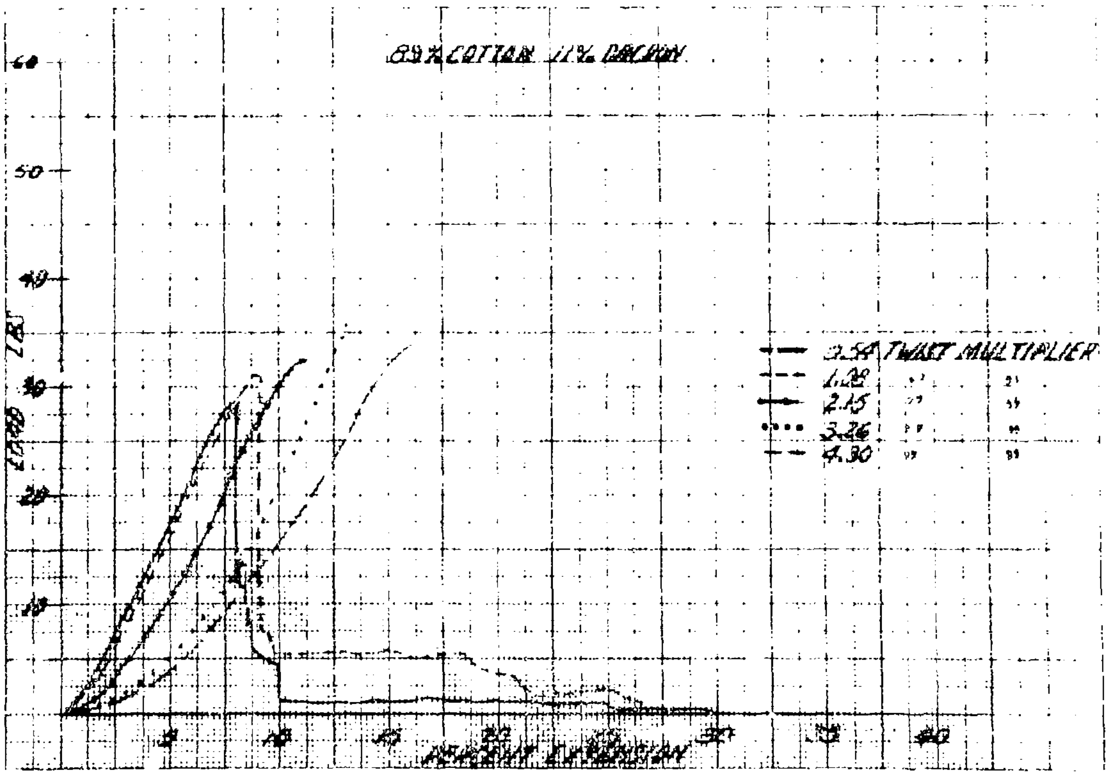
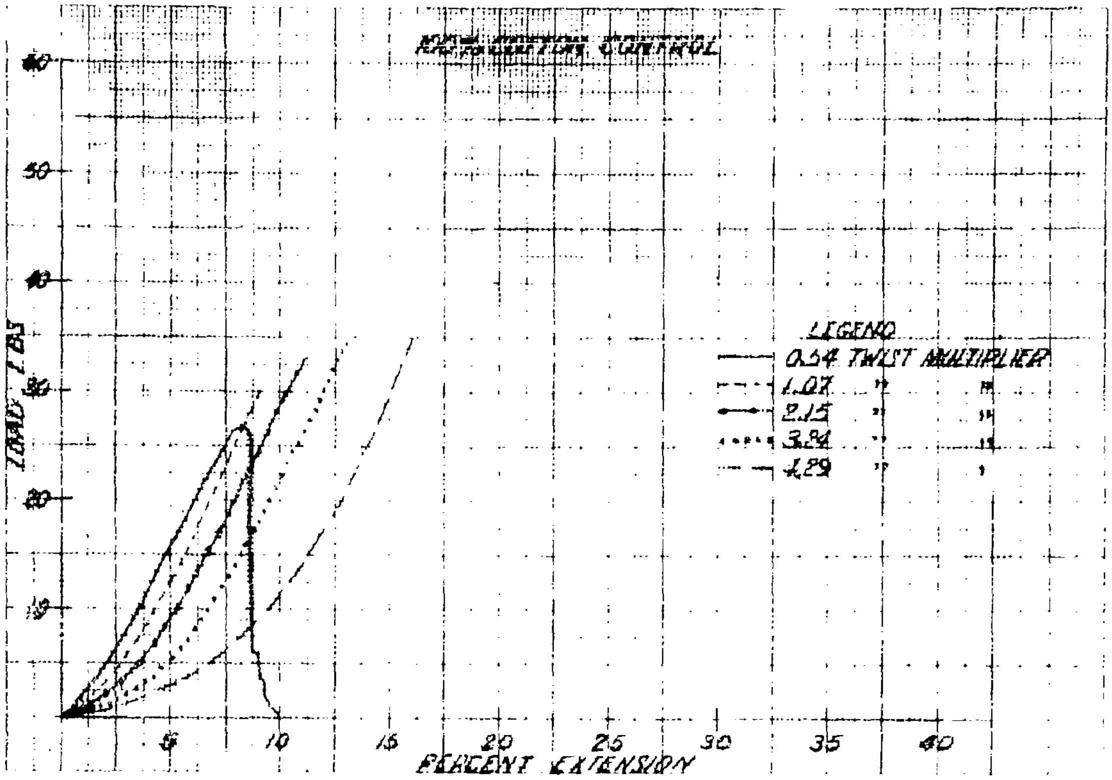
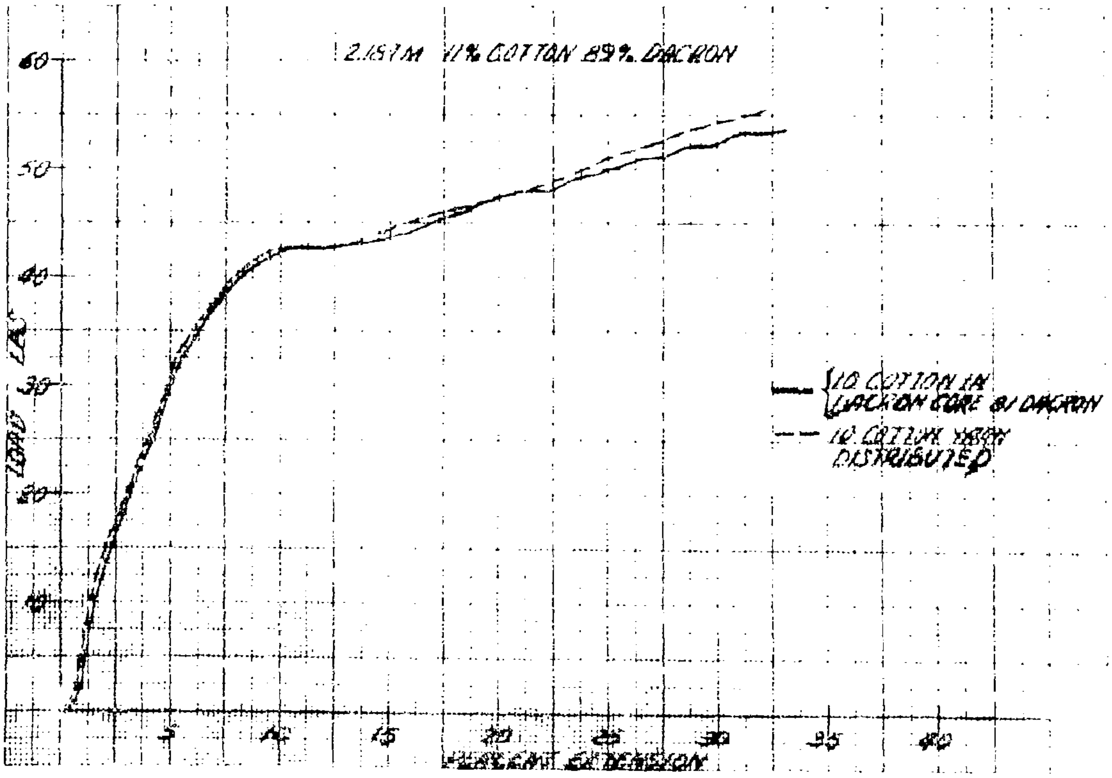


FIGURE 5[illegible] [illegible] COTTON YARNS (EFFECT OF TWIST (COTTON DISTRIBUTED IN YARN CROSS SECTION))


RAW COTTON CONTROL
60
50
40
30
20
10
LOAD LBS
LEGEND
0.54 TWIST MULTIPLIER
1.07 " "
2.15 " "
3.34 " "
4.29 " "
5
10
15
20
25
30
35
40
PERCENT EXTENSION

[illegible]


2.15 TM 11% COTTON 89% DACRON
60
50
40
30
20
10
LOAD LBS
10 COTTON IN DACRON CORE 8/ DACRON
10 COTTON YARN DISTRIBUTED
5
10
15
20
25
30
35
40
PERCENT EXTENSION

[illegible]

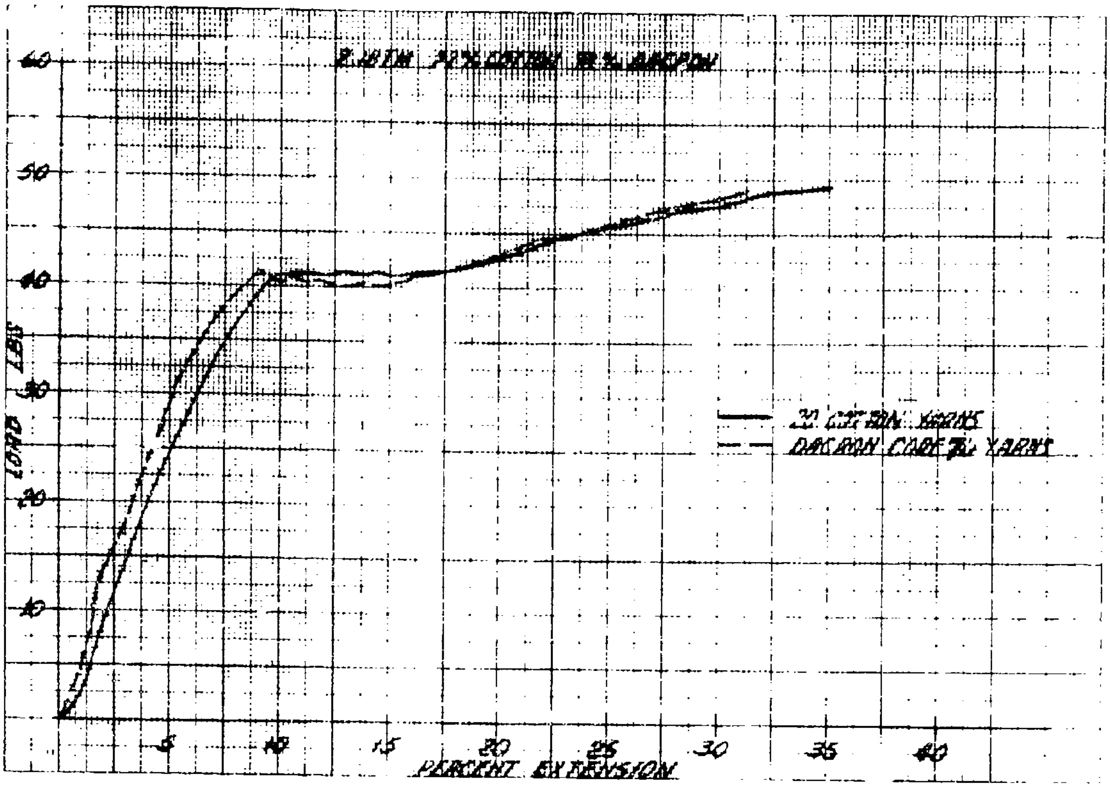


FIGURE 13   30 COTTON YARNS (DACRON CORE)

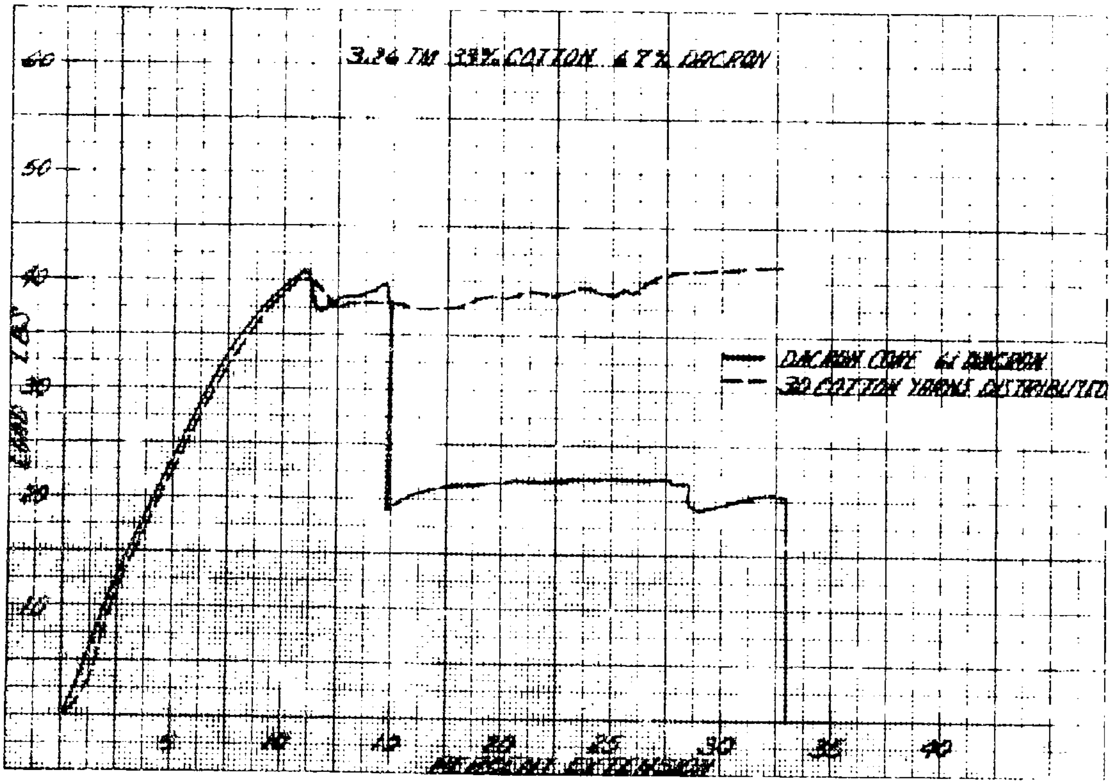
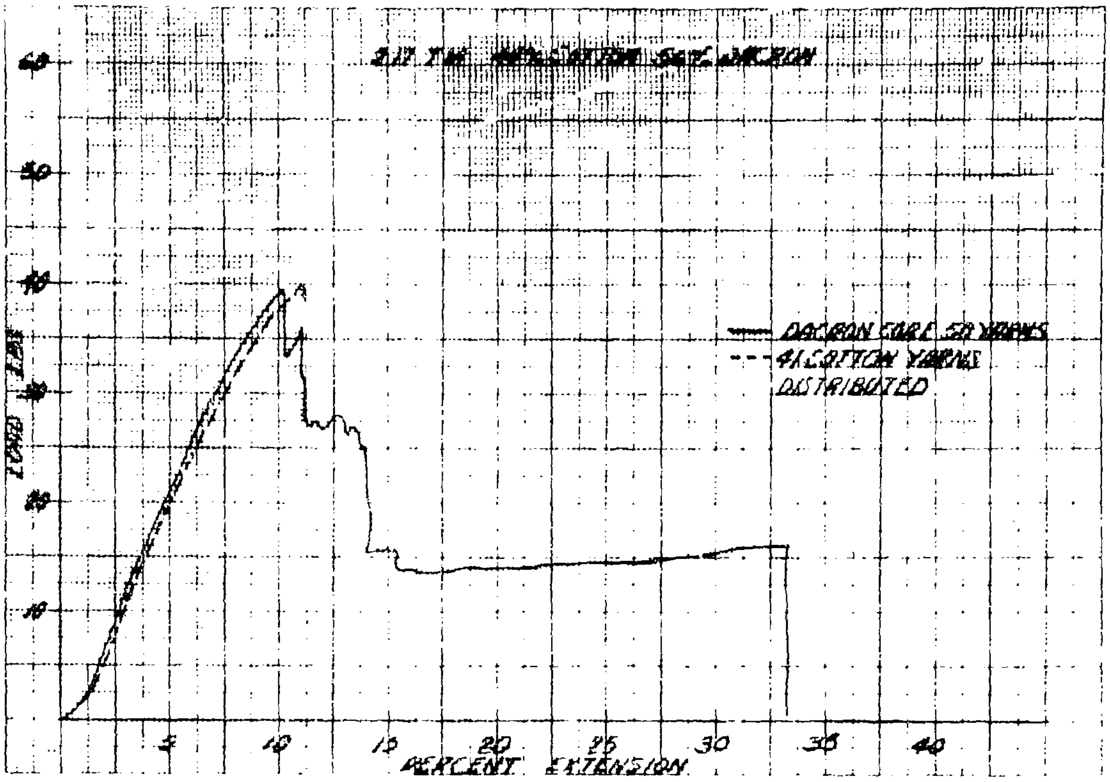


FIGURE 14   30 COTTON YARNS (DACRON CORE)



[illegible] COTTON YARNS (DACRON CORE)

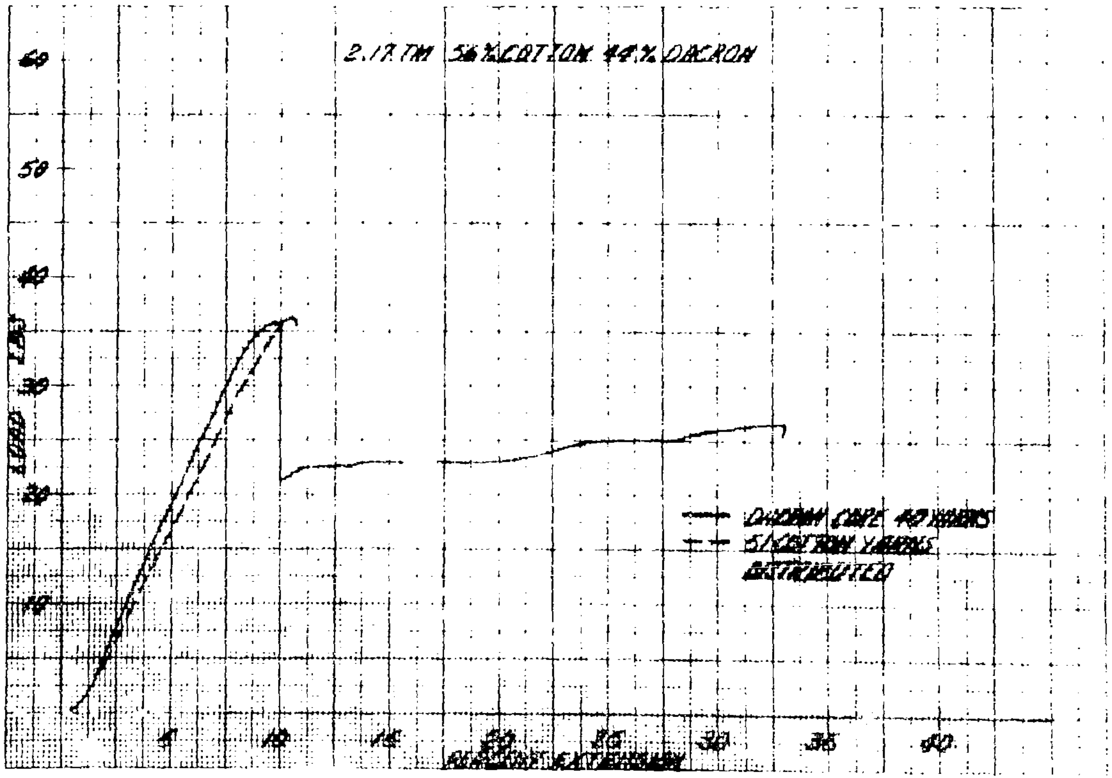


FIGURE [illegible] 51 COTTON YARNS (DACRON CORE)

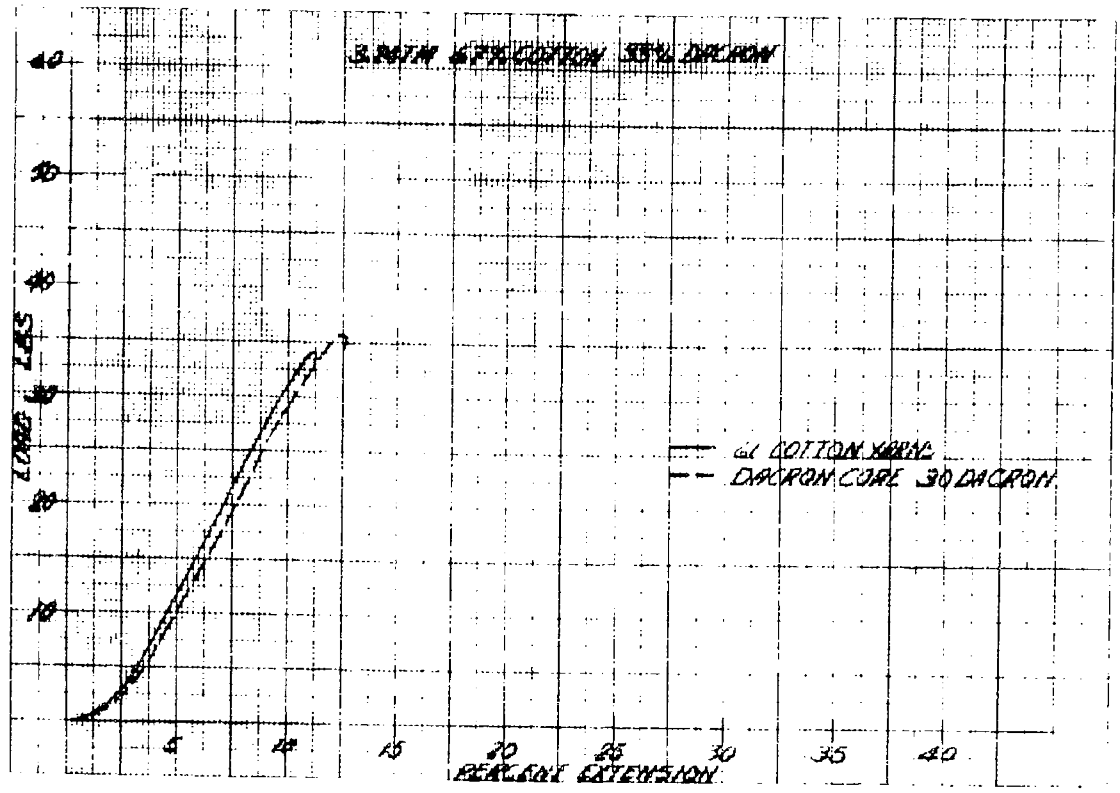


FIGURE 17. 61 COTTON YARNS (DACRON CORE)

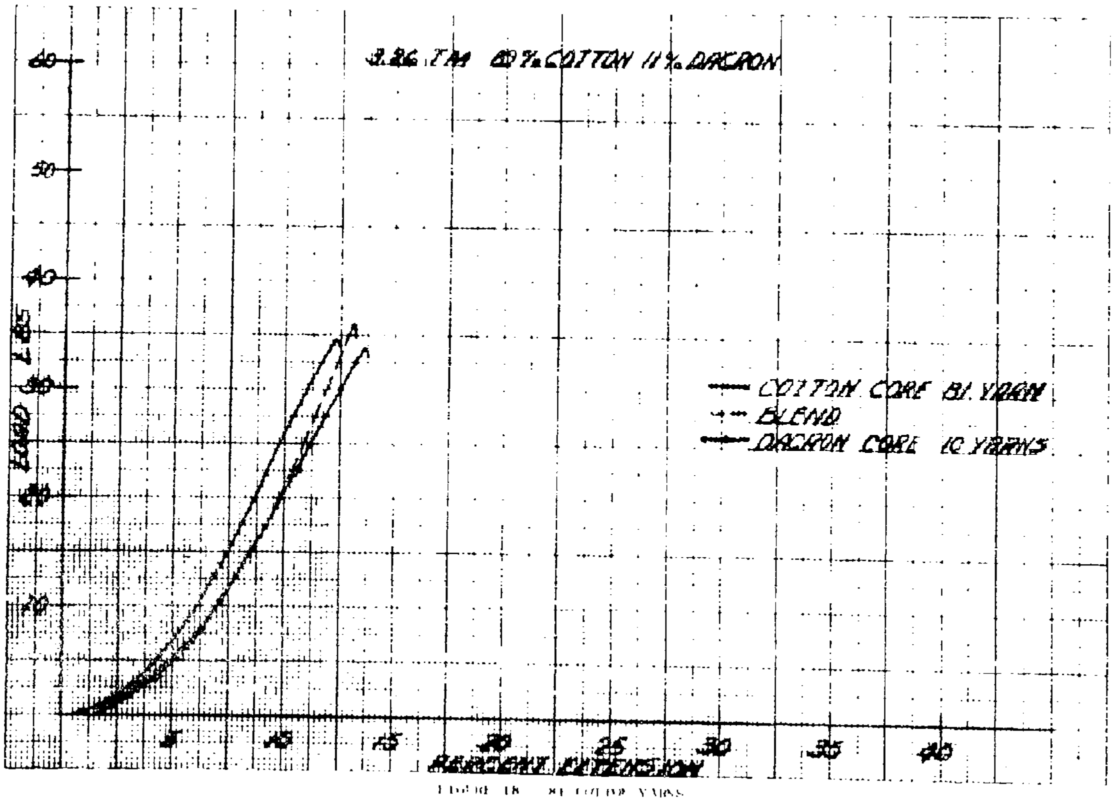


FIGURE 18. 81 COTTON YARNS

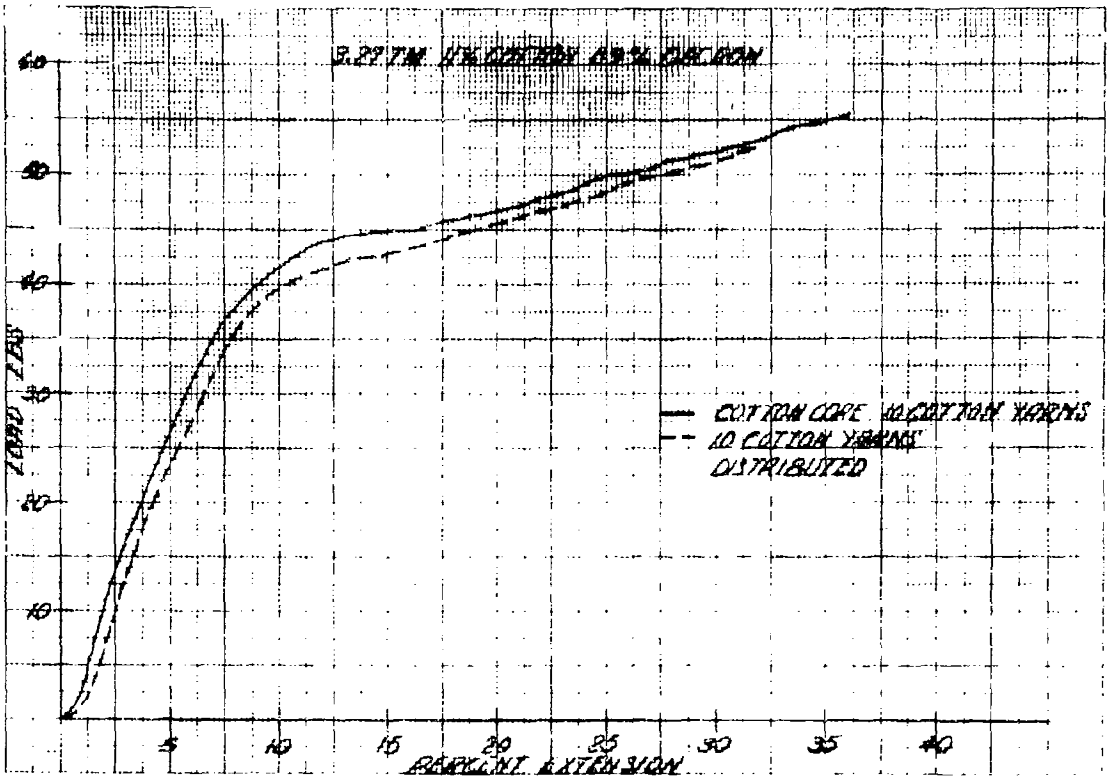


FIGURE 40 10 COTTON YARNS COTTON CORE

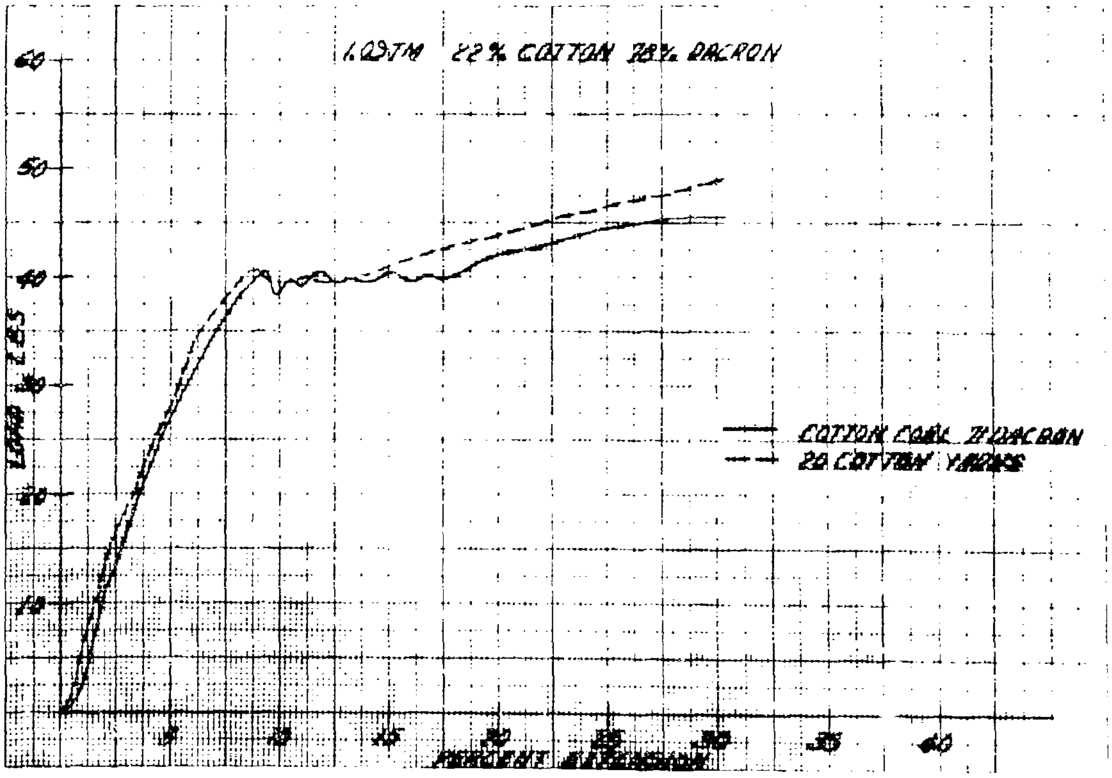


FIGURE 41 20 COTTON YARN COTTON CORE

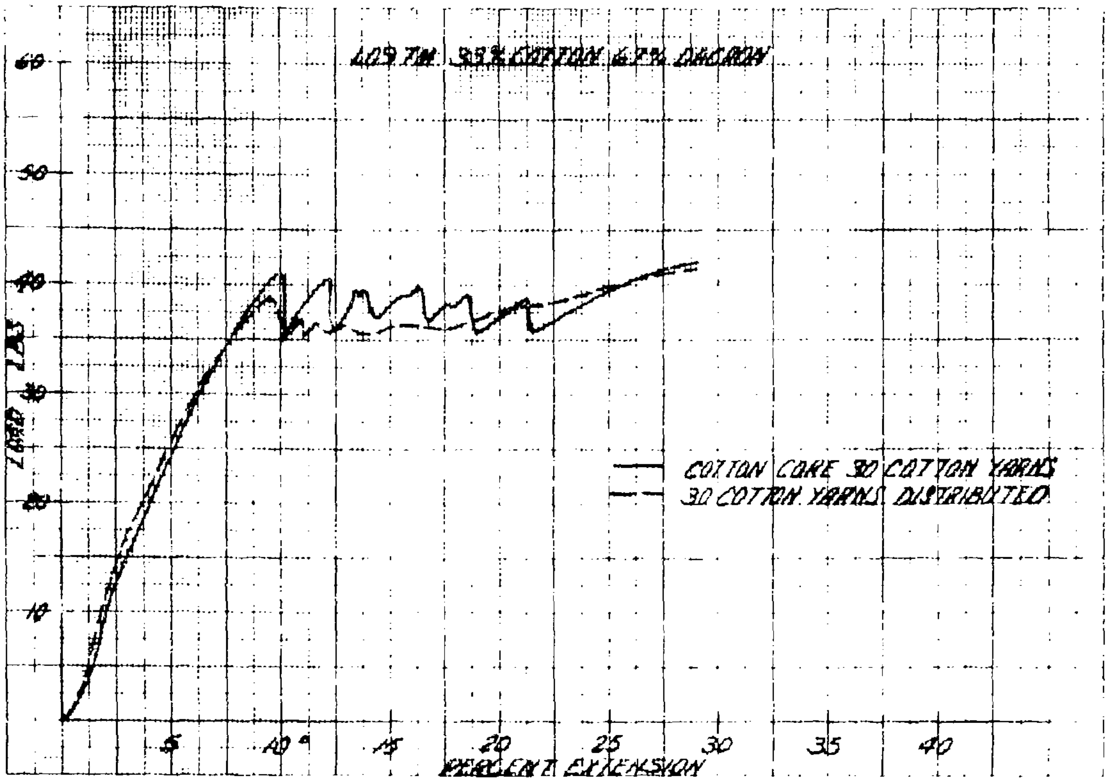


FIGURE [illegible] 30 COTTON YARNS (COTTON CORE)

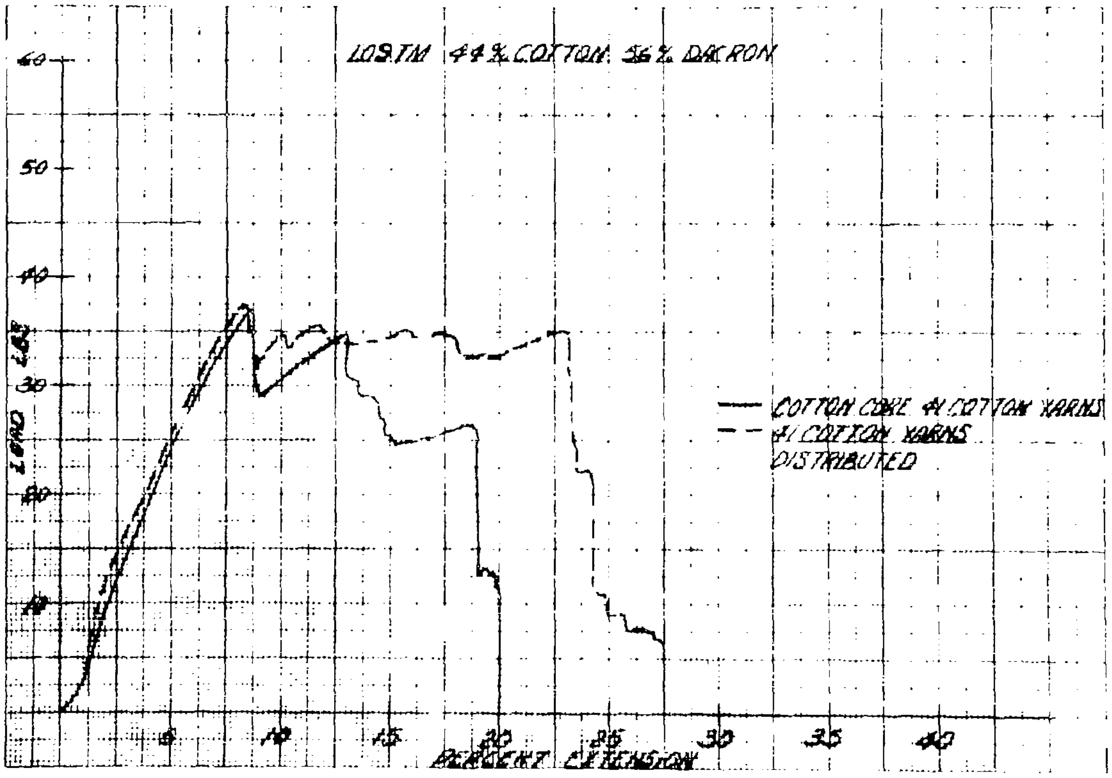
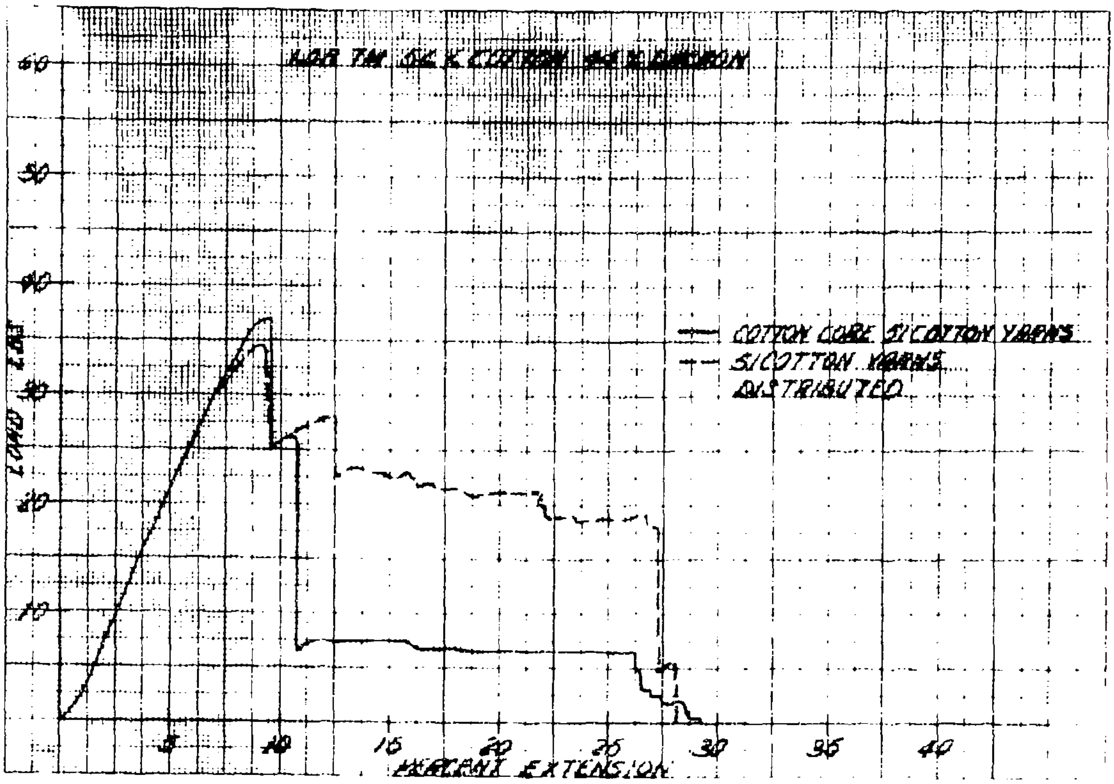


FIGURE [illegible] 41 COTTON YARNS (COTTON CORE)



[illegible] 51 COTTON YARNS (COTTON CORE)

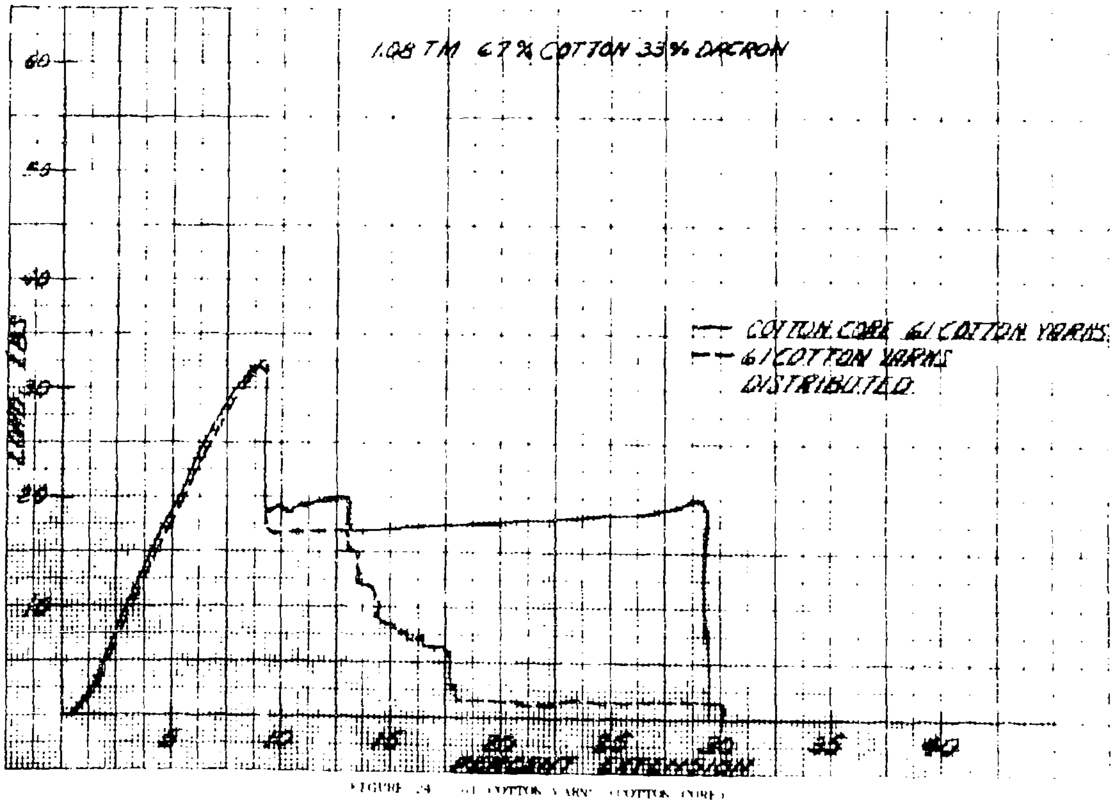
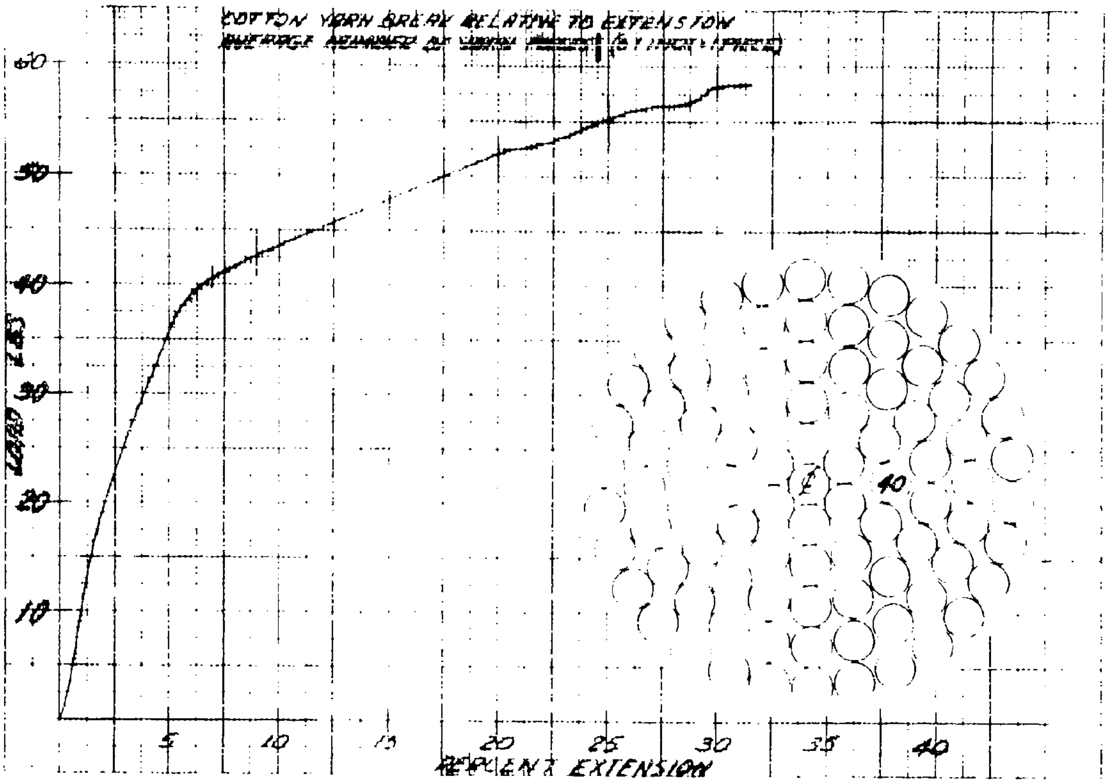
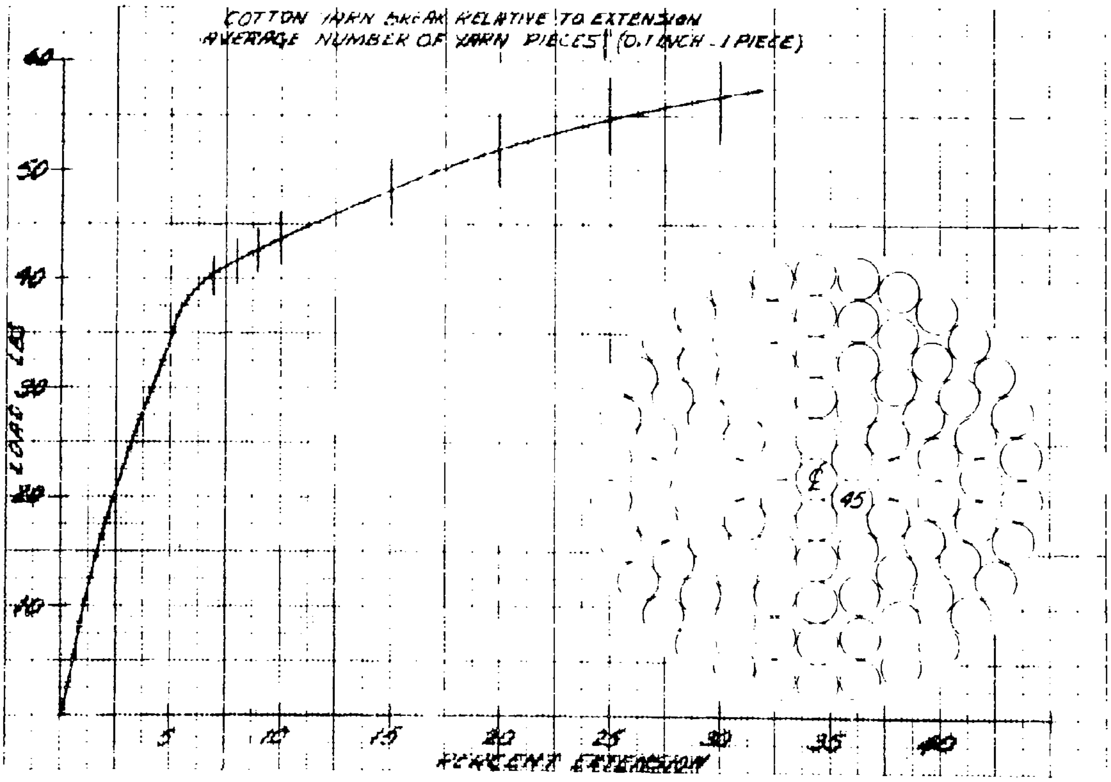


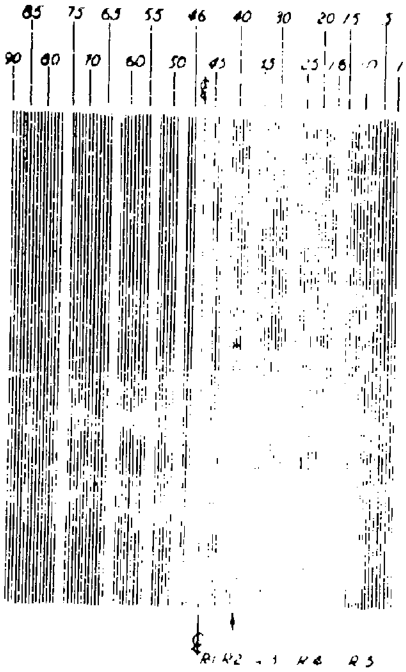
FIGURE 24 61 COTTON YARNS (COTTON CORE)


COTTON YARN BREAK RELATIVE TO EXTENSION
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
℄
40

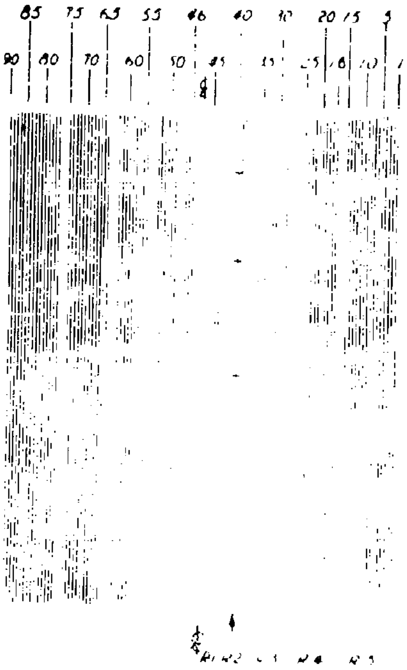
[illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES (0.1 INCH - 1 PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
℄
45

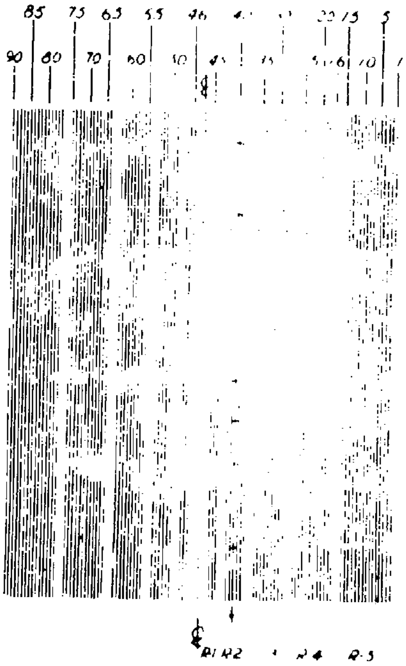
[illegible]



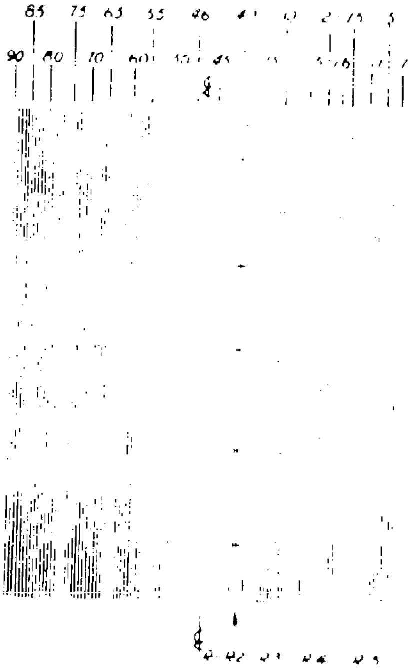
6% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON



7% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON

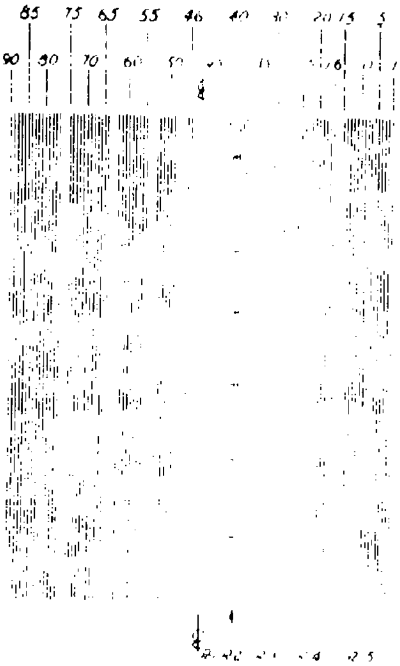


9% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON

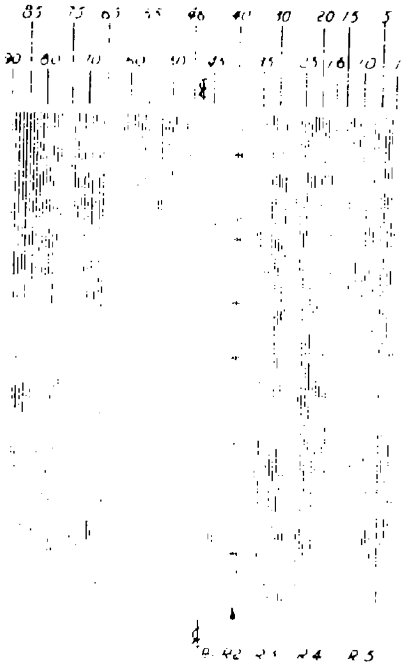


10% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON

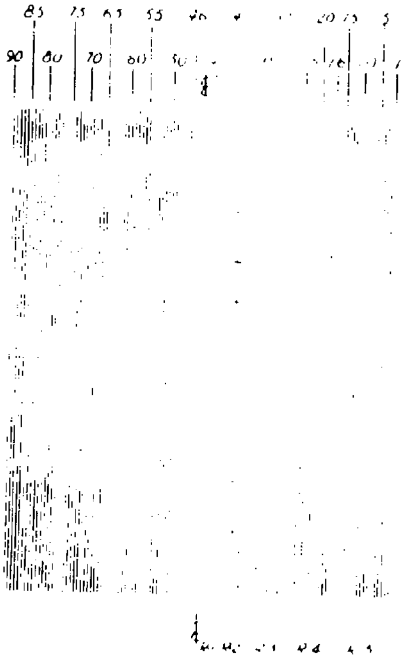
FIGURE 36a



15% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON



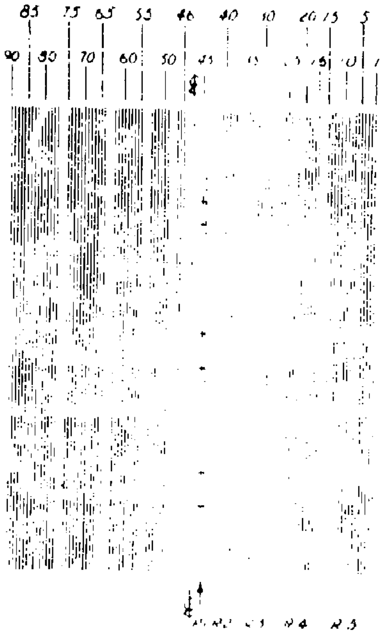
20% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON



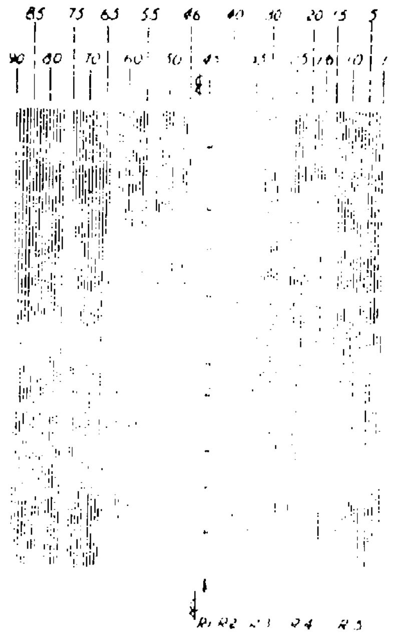
25% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON

30% EXTENSION
0.55 TM 1.1% COTTON 98.9% DACRON

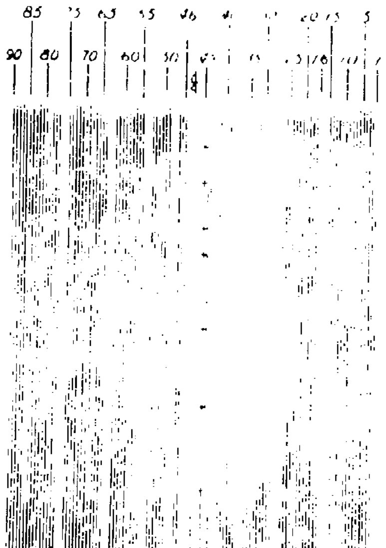
FIGURE [illegible]



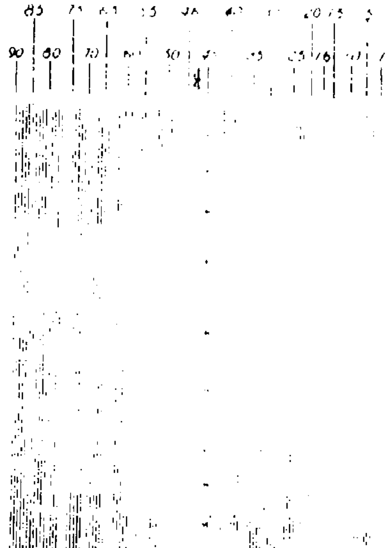
7% EXTENSION
1.09 TM 1.1% COTTON 98.9% COTTON



8% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON

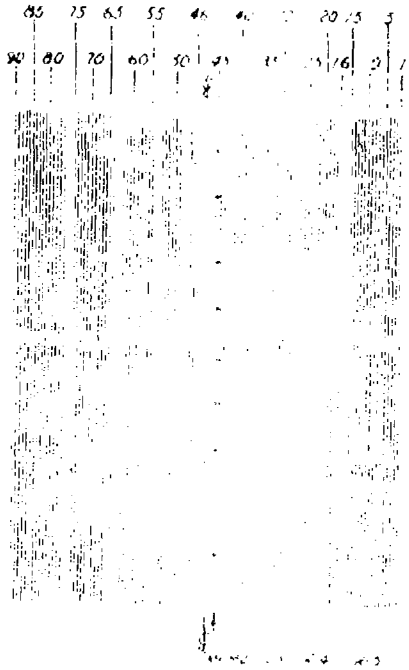


9% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON

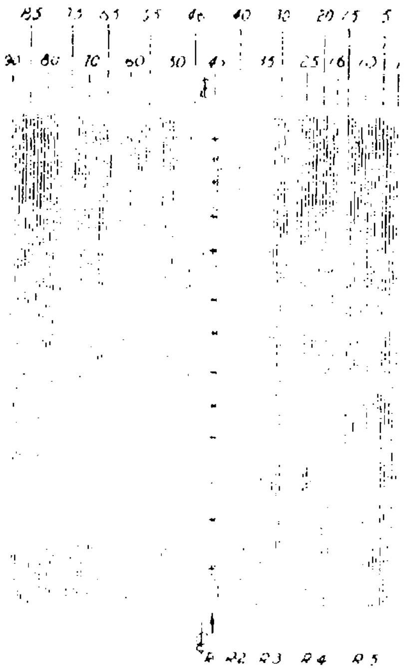


10% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON

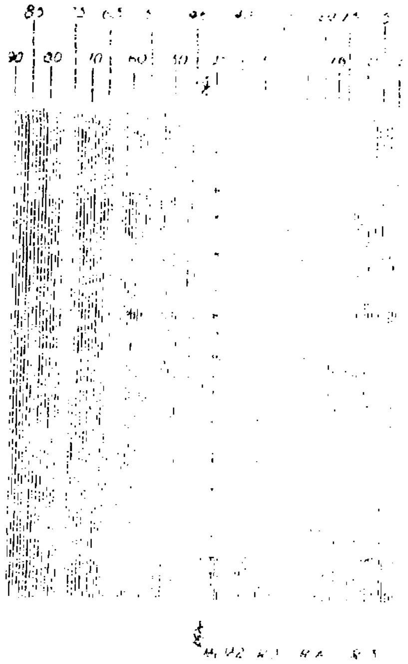
FIGURE [illegible]



15% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON



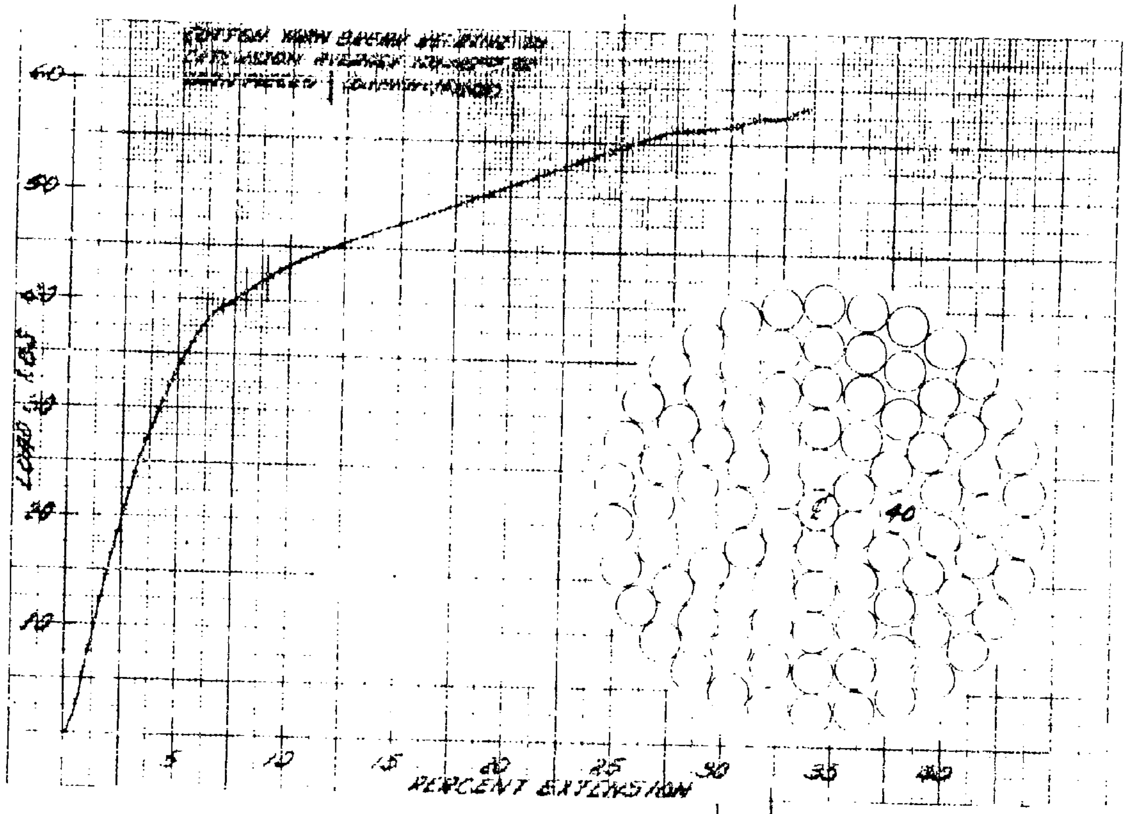
20% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON



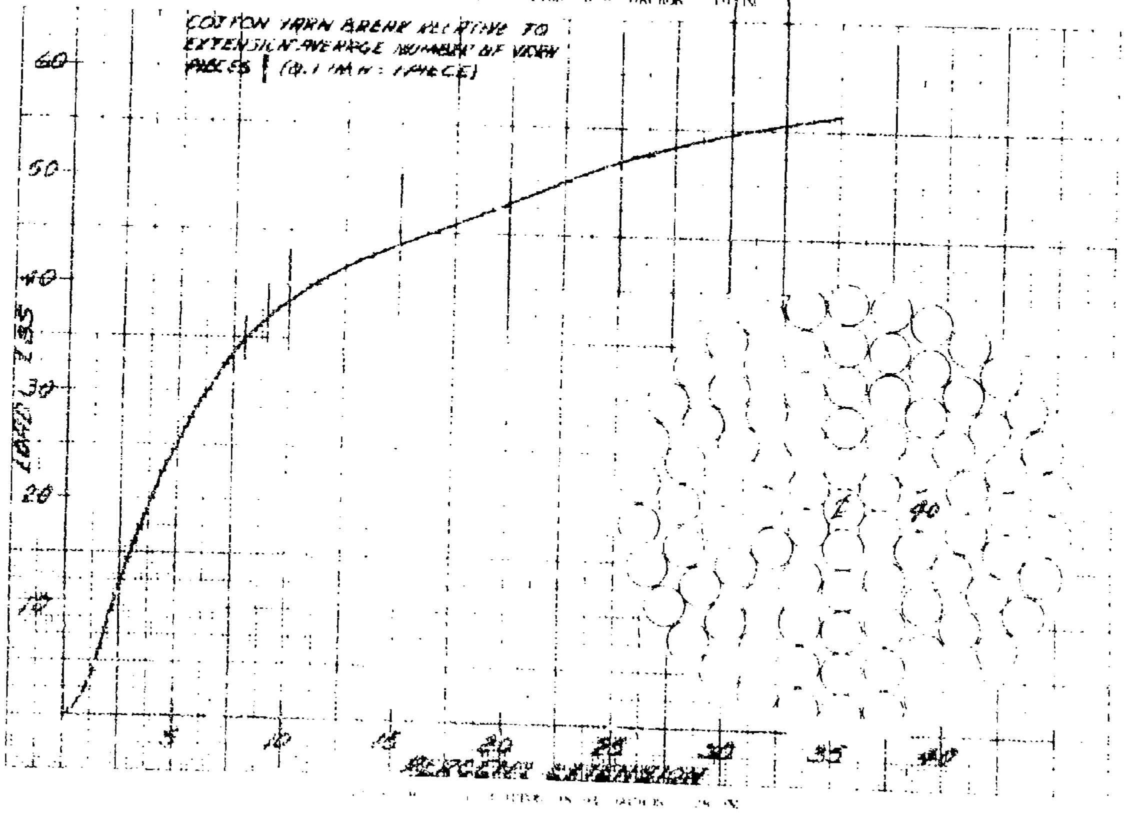
25% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON

30% EXTENSION
1.09 TM 1.1% COTTON 98.9% DACRON

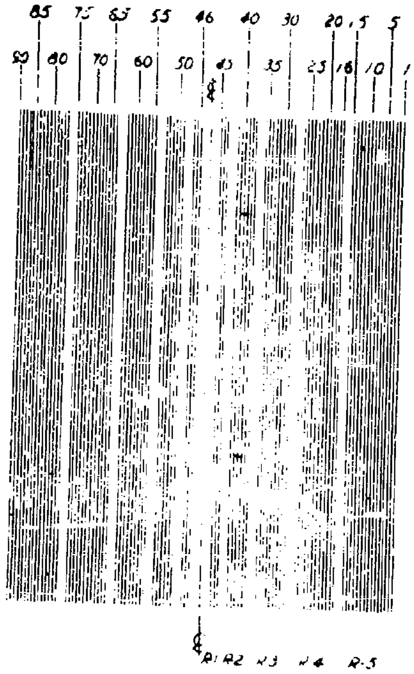
FIGURE [illegible]



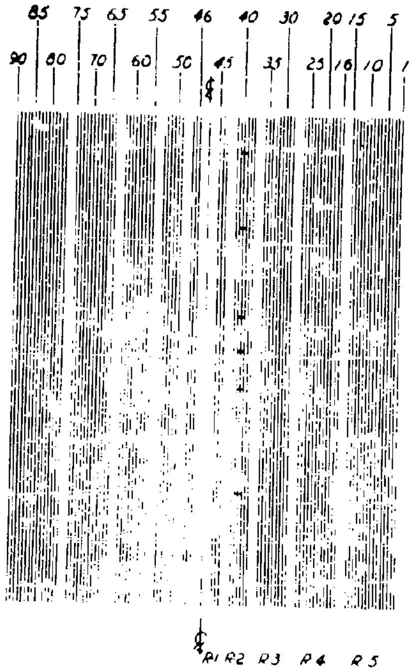
[illegible] COTTON OR [illegible] DACRON [illegible]



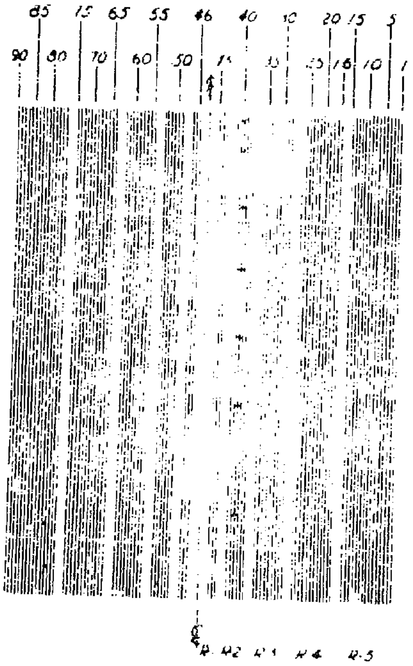
[illegible] COTTON ON [illegible] DACRON [illegible]



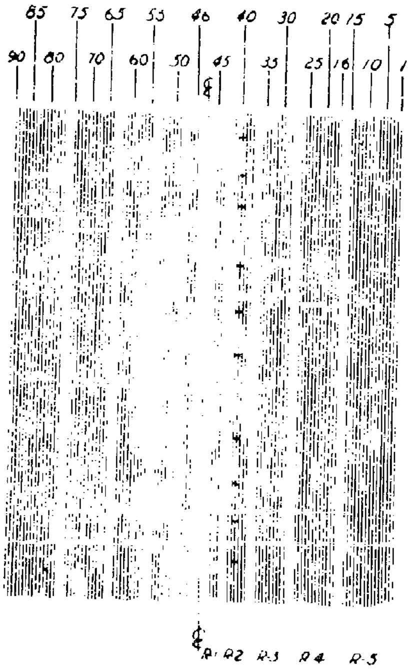
7% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON



8% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

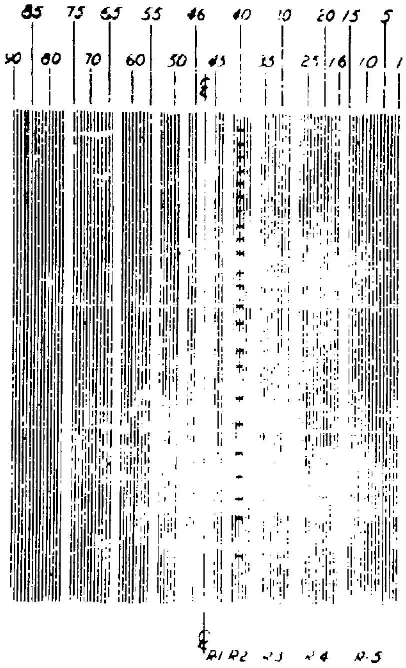


9% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

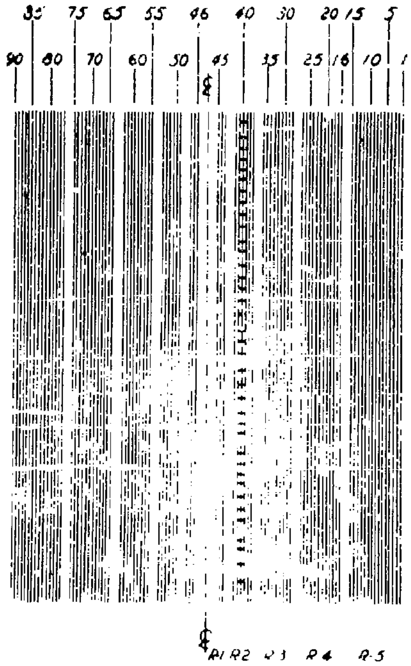


10% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

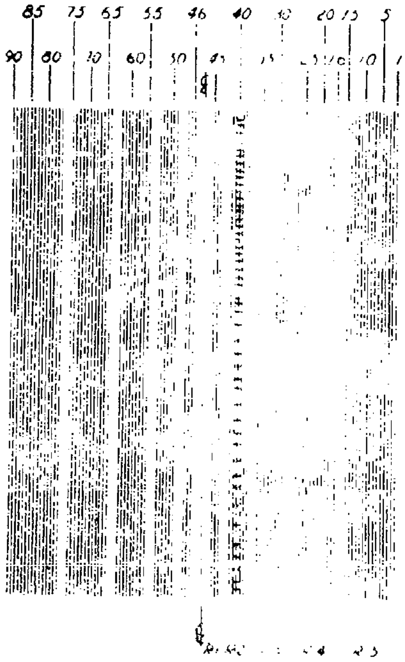
FIGURE [illegible]



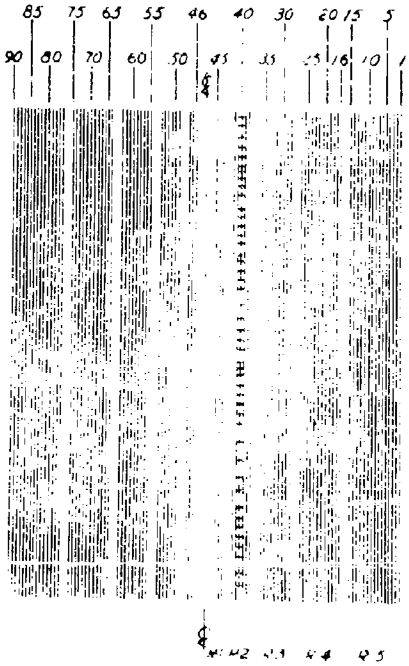
15% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON



20% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

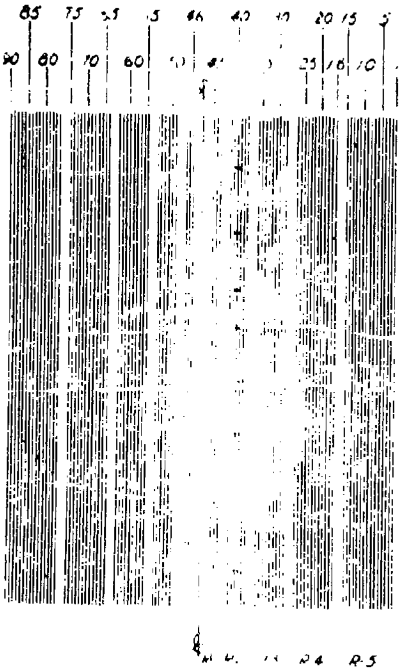


25% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

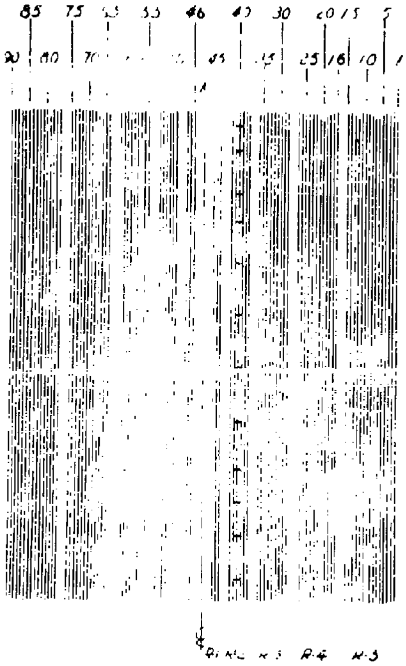


30% EXTENSION
2.19 TM 1.1% COTTON 98.9% DACRON

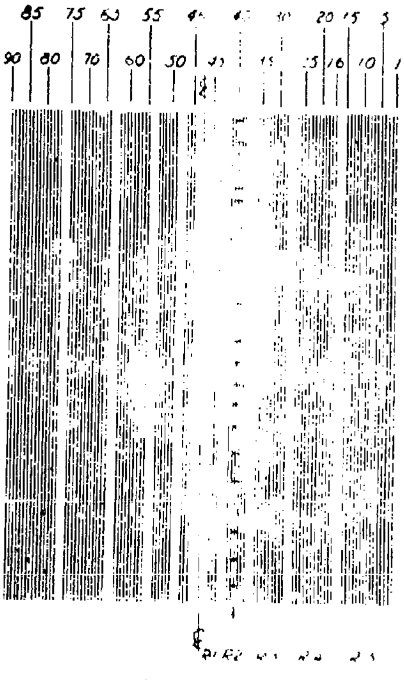
FIGURE 27b



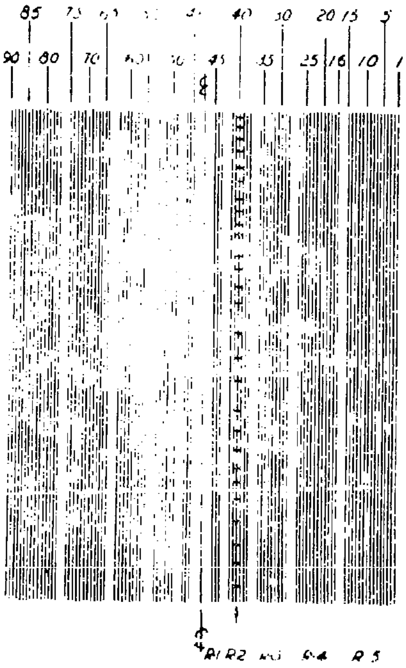
8% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON



9% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

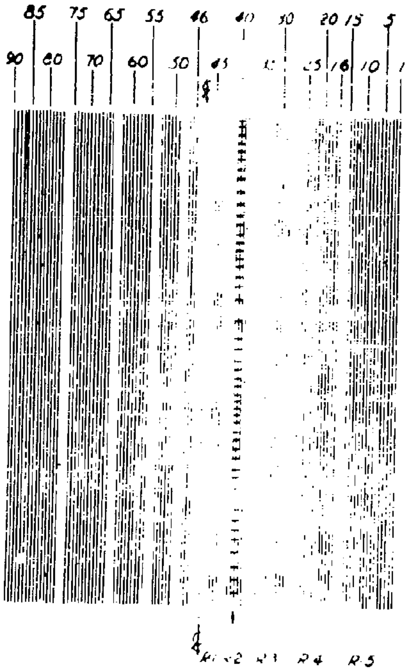


10% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

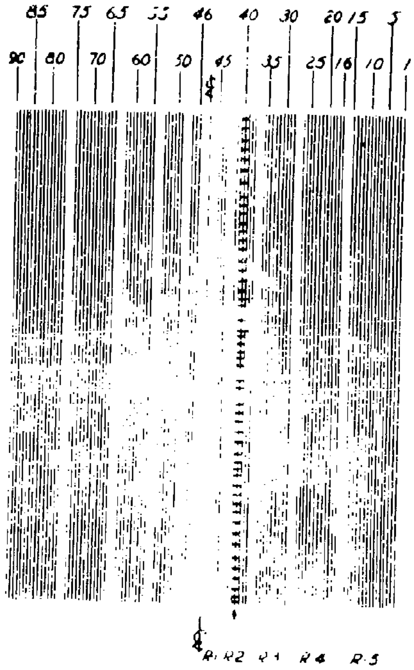


15% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

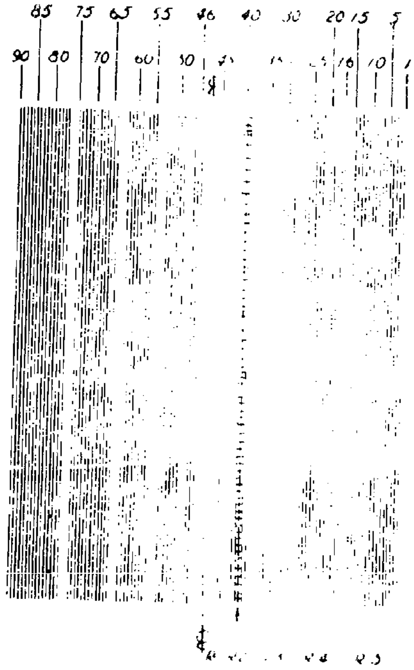
FIGURE 28a



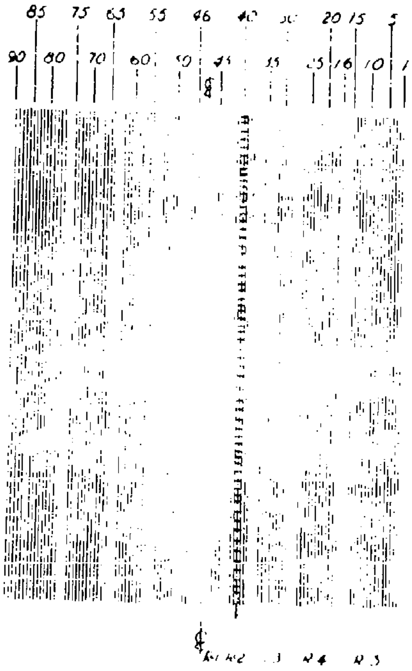
20% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON



25% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

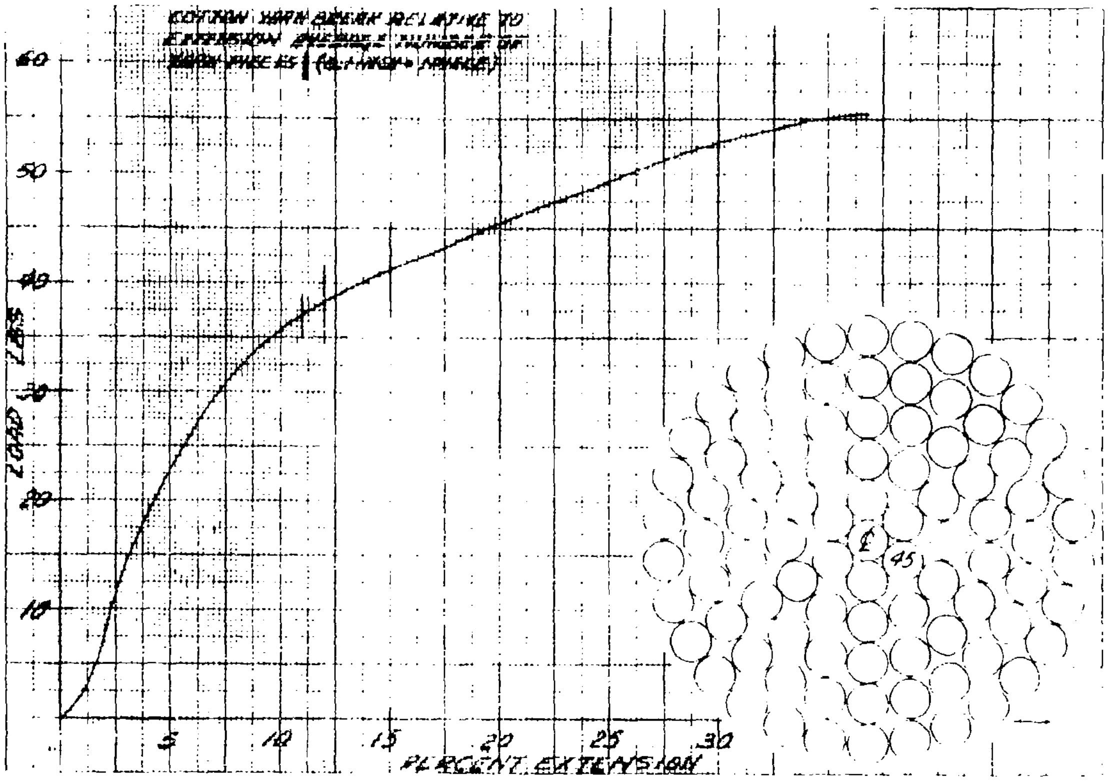


30% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

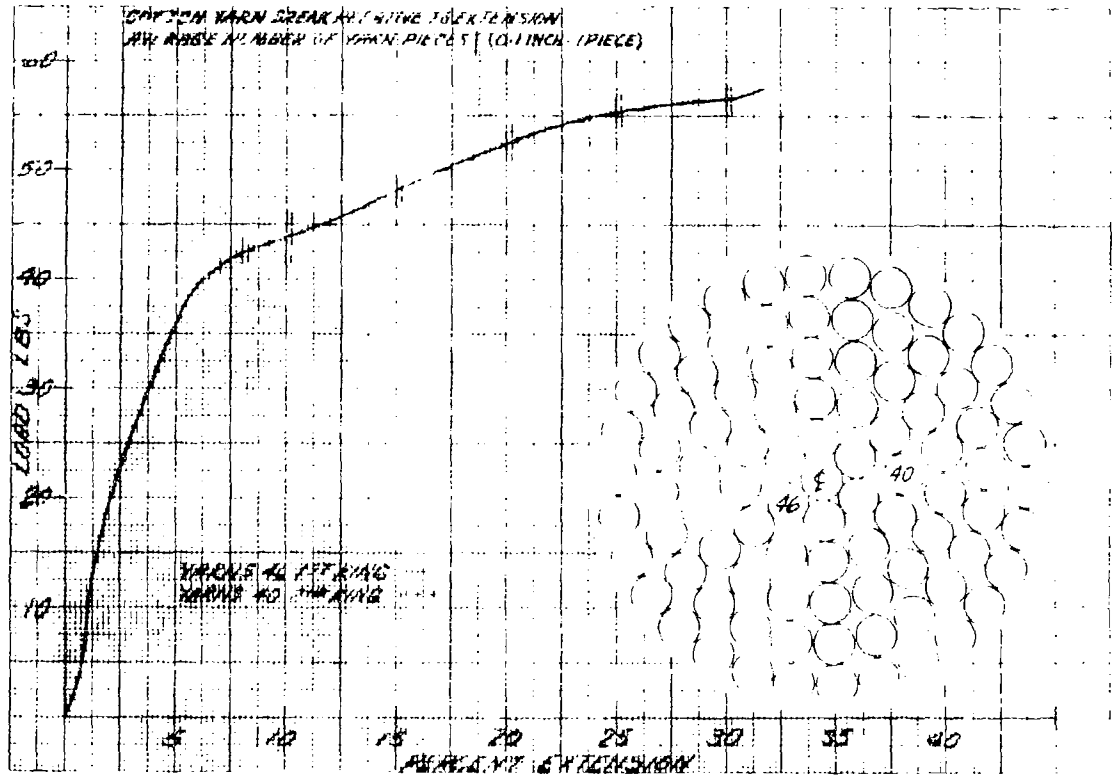


32-1/2% EXTENSION
3.28 TM 1.1% COTTON 98.9% DACRON

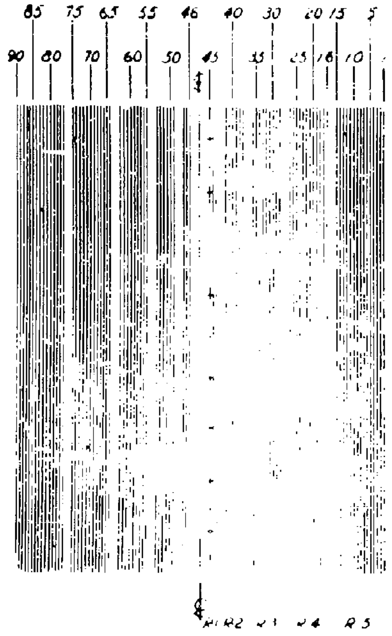
FIGURE 28b



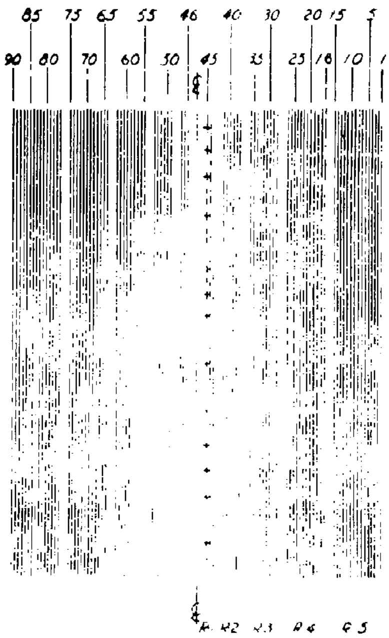
[illegible] DACRON [illegible]



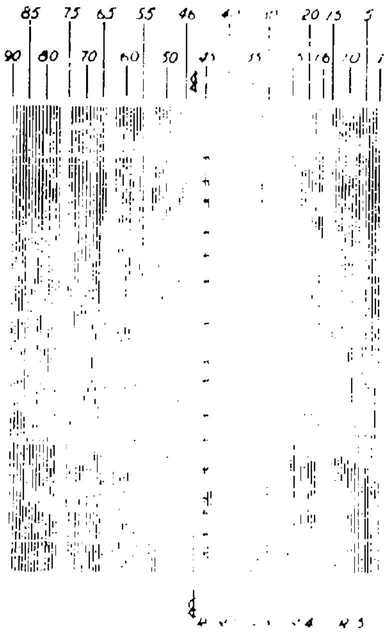
[illegible] DACRON [illegible]



11% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON



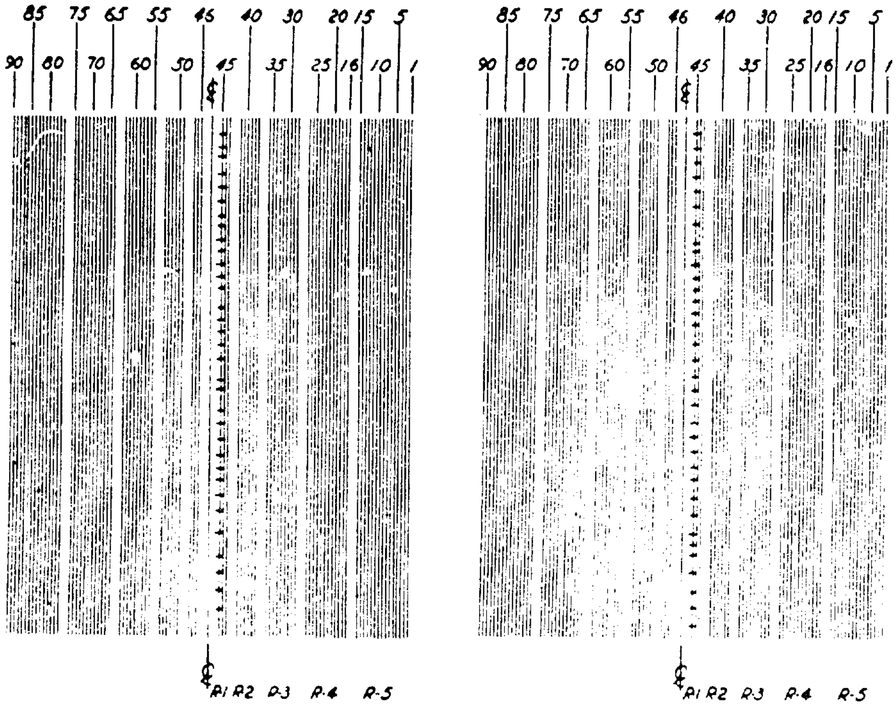
12% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON



15% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON

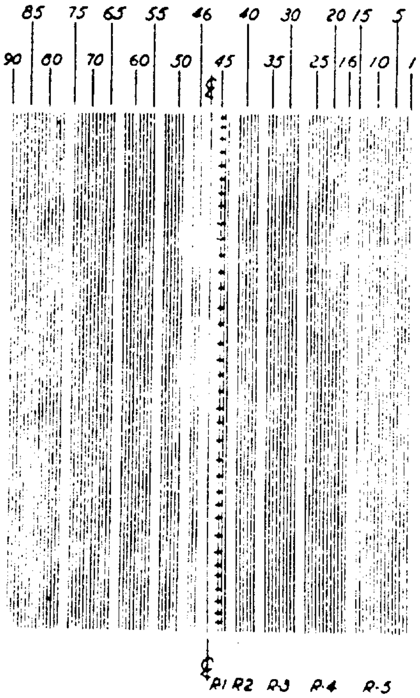
20% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON

FIGURE 26A



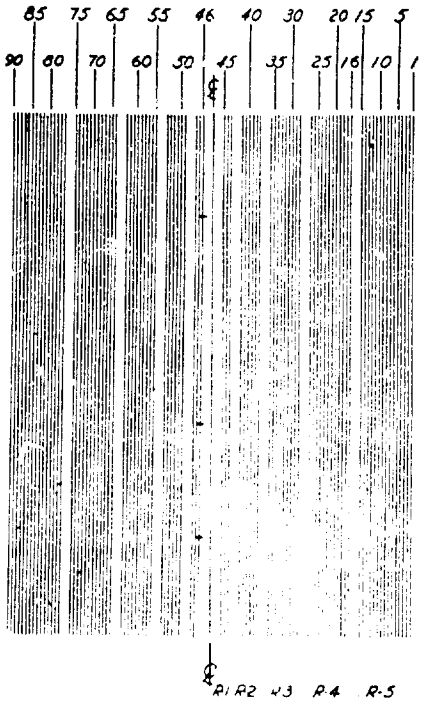
25% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON

30% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON

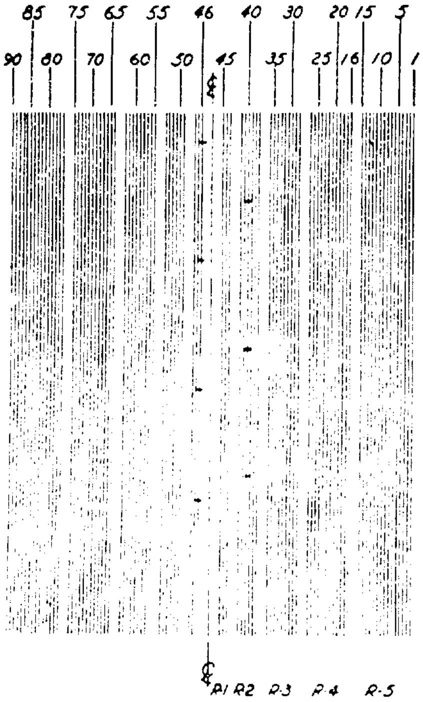


32-1/2% EXTENSION
4.38 TM 1.1% COTTON 98.9% DACRON

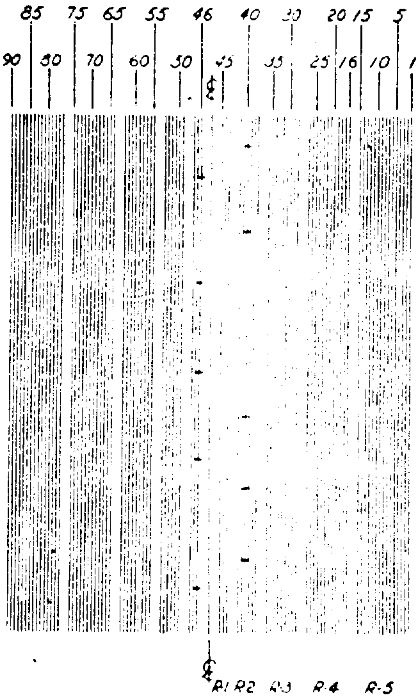
FIGURE 29b



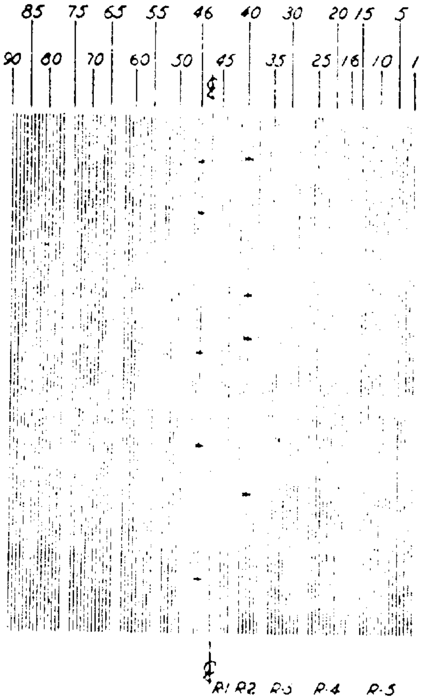
7% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON



8% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON

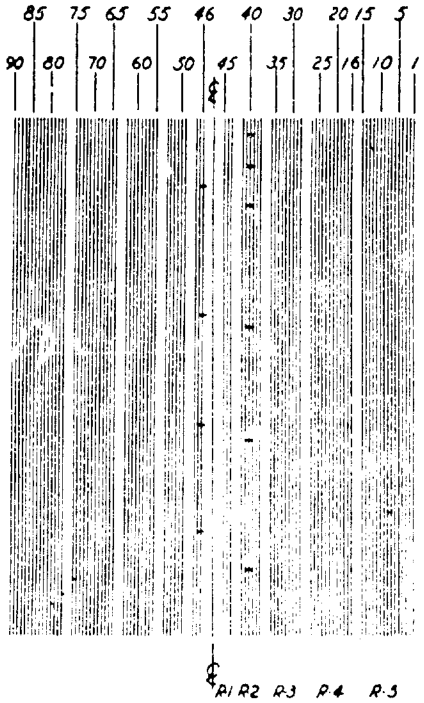


10% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON

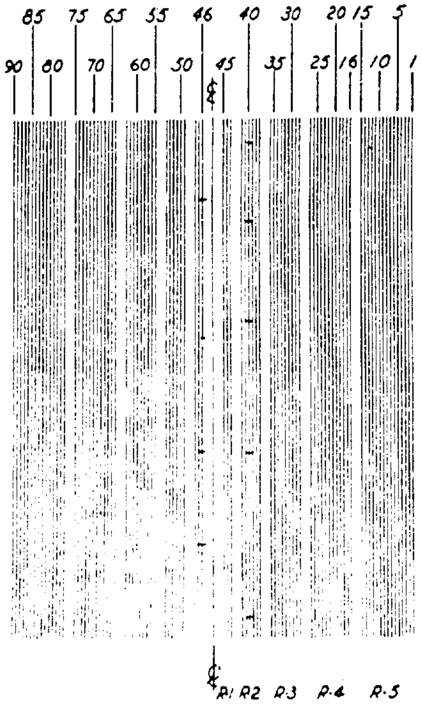


15% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON

FIGURE 30a



20% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON



25% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON

30% EXTENSION
0.55 TM 2.2% COTTON 97.8% DACRON

FIGURE 30b

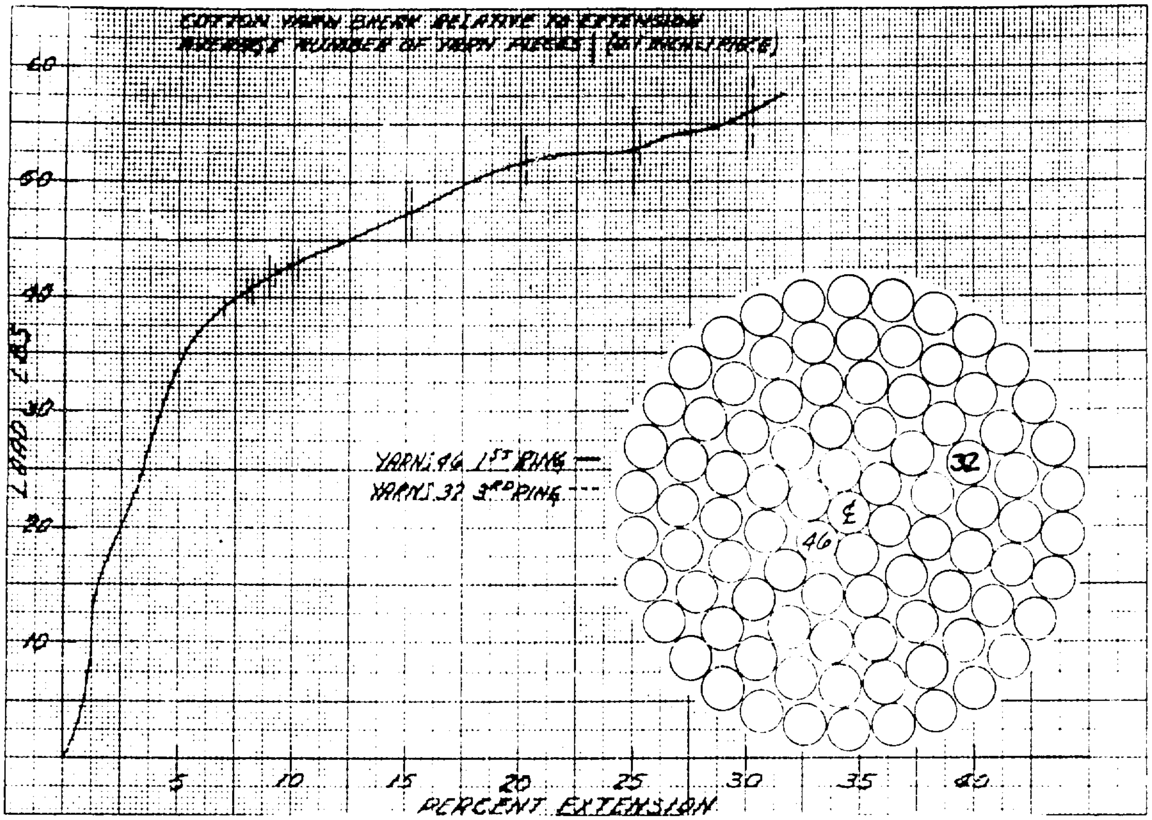


FIG [illegible] 2.2 COTTON 97.8% DACRON 1.09 TM

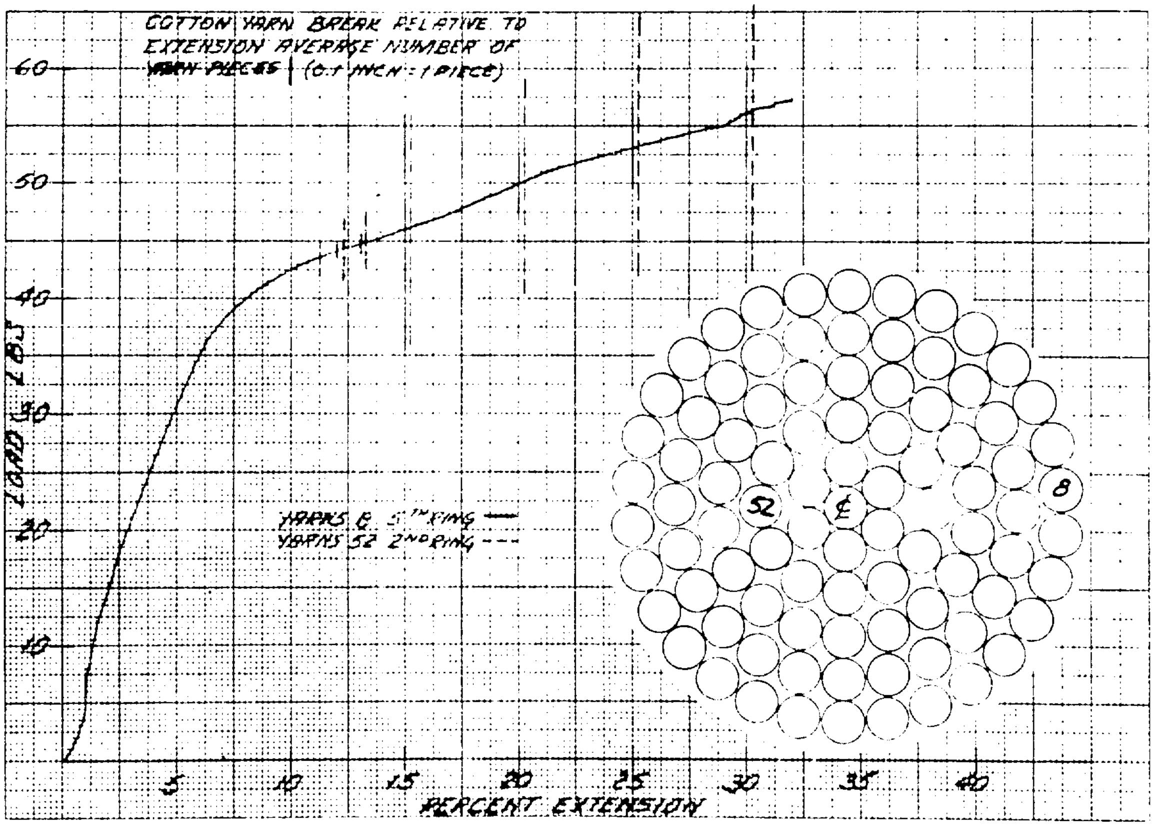
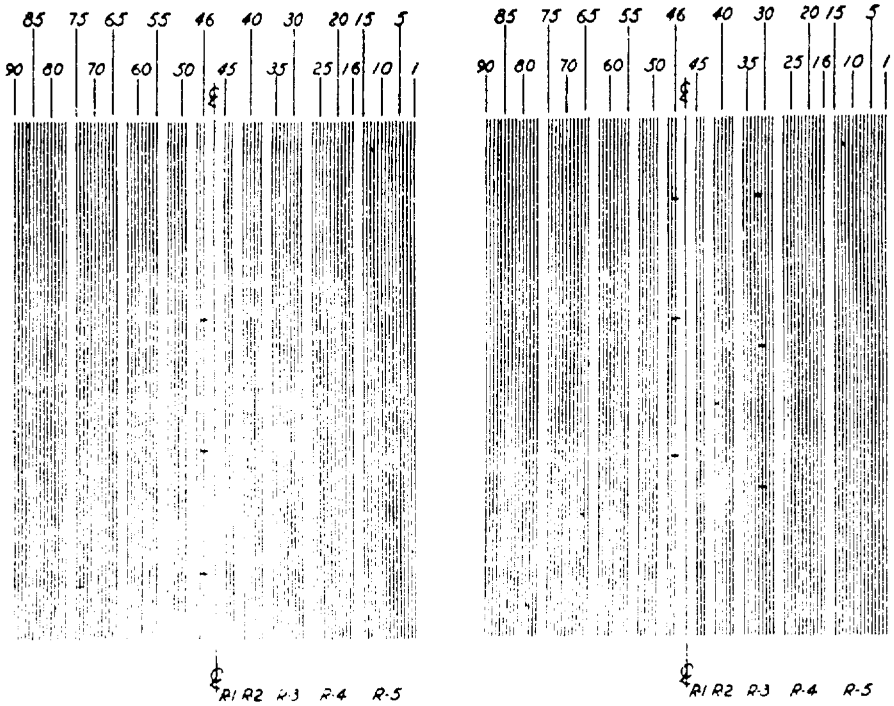
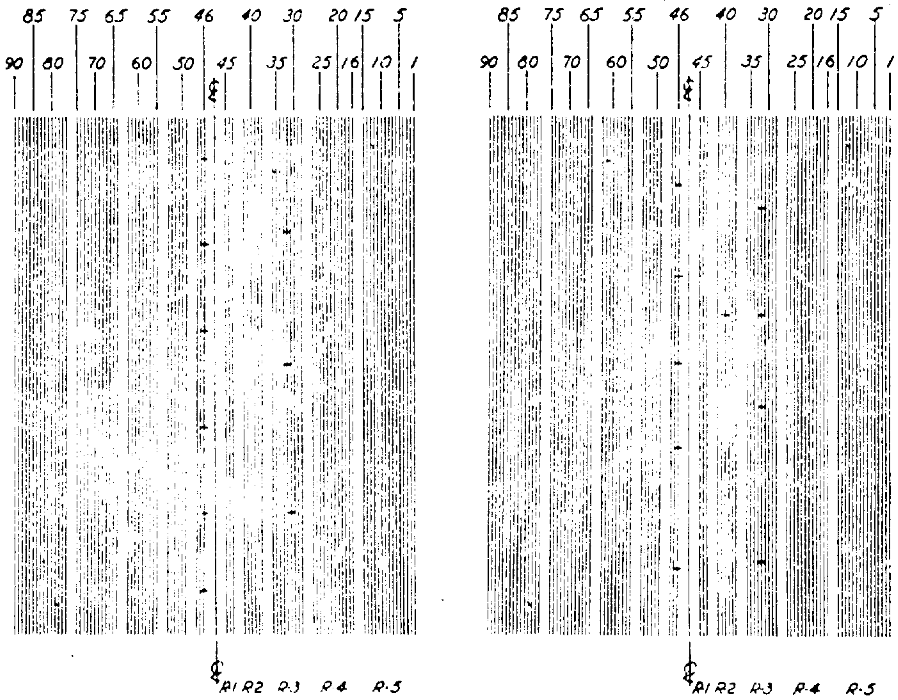


FIGURE [illegible] 2.2% COTTON 97.8% DACRON 2.19 TM



7% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON

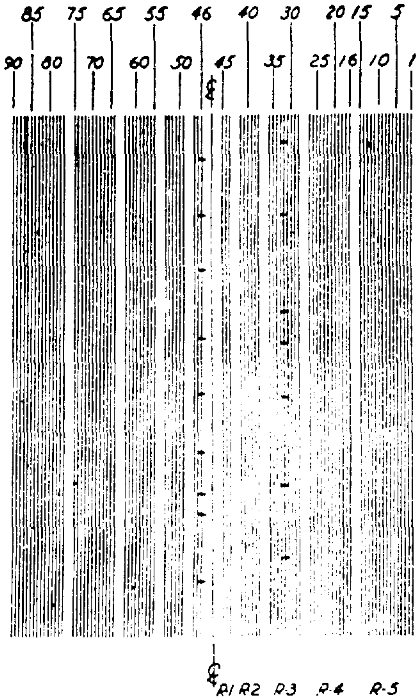
8% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON



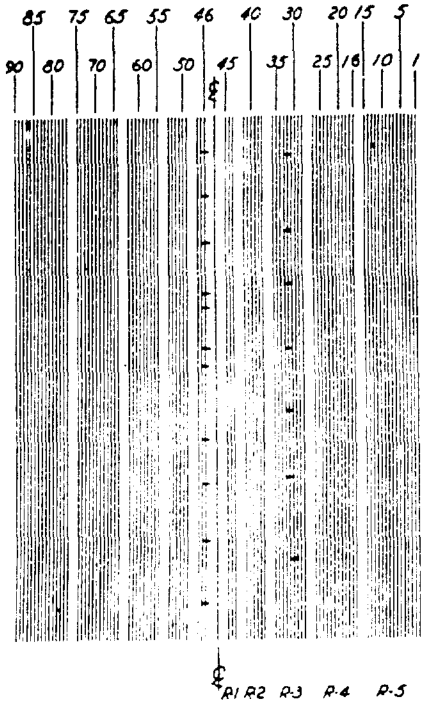
9% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON

10% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON

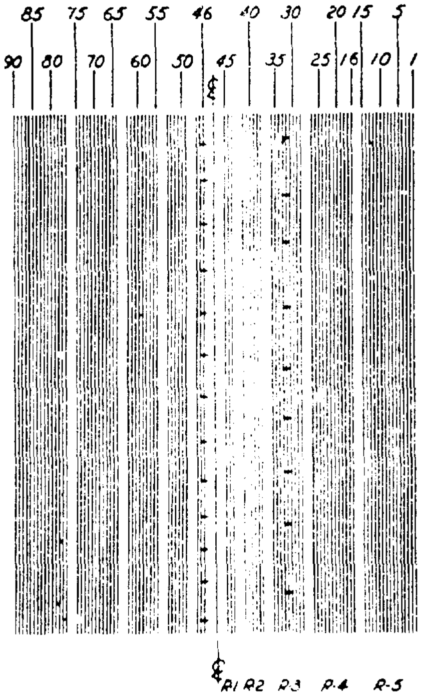
FIGURE 31a



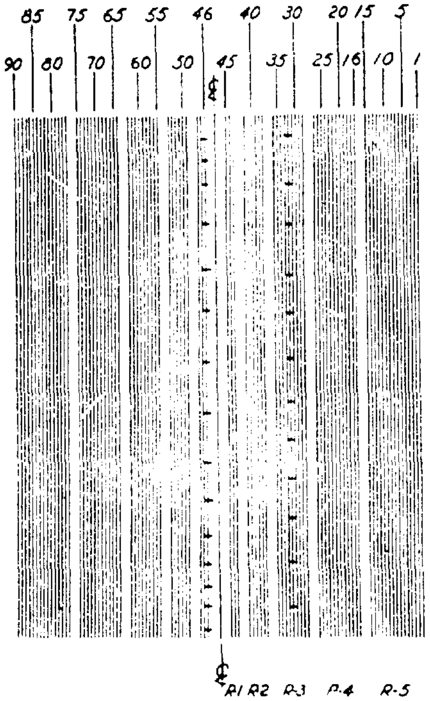
15% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON



20% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON



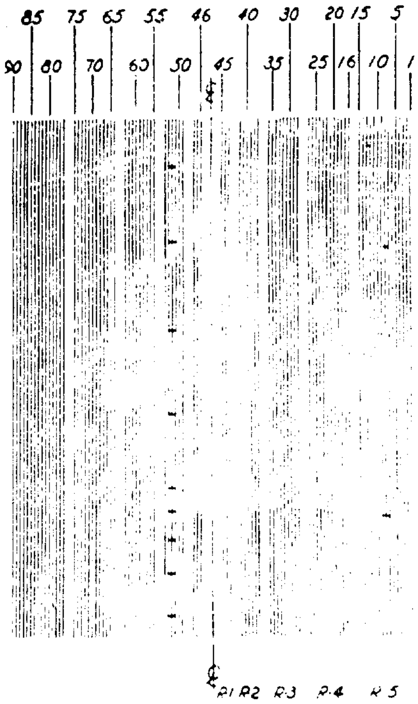
25% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON



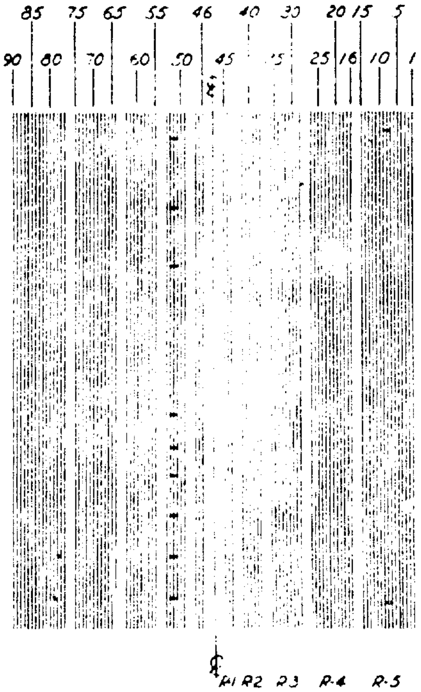
30% EXTENSION
1.09 TM 2.2% COTTON 97.8% DACRON

FIGURE 31b

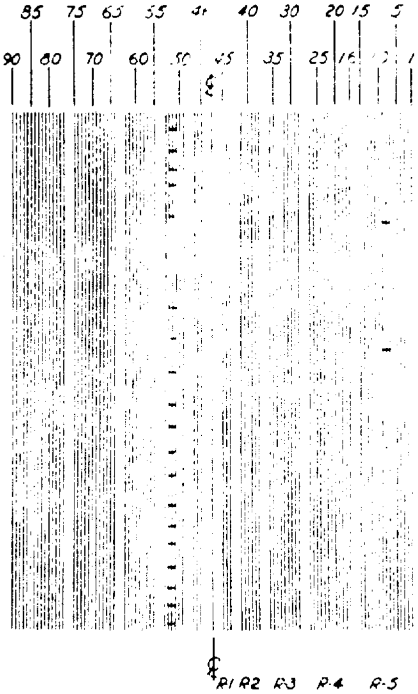
11% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON



12% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

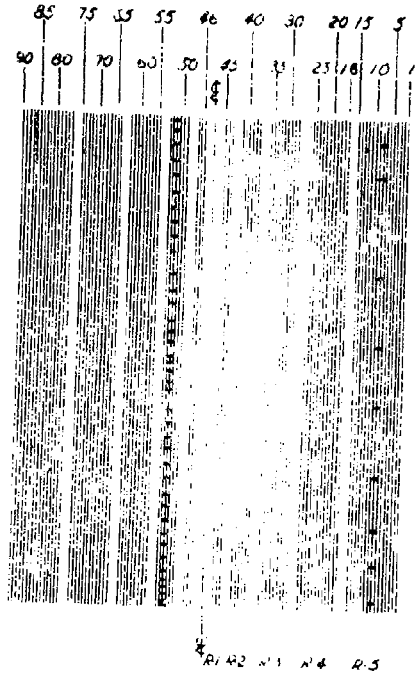


13% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

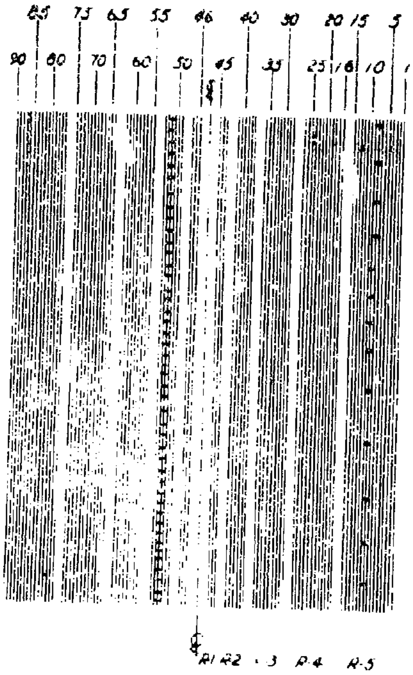


15% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

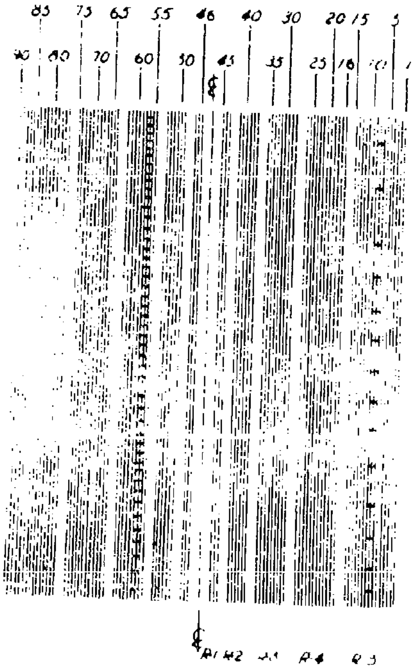
FIGURE 32a



20% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

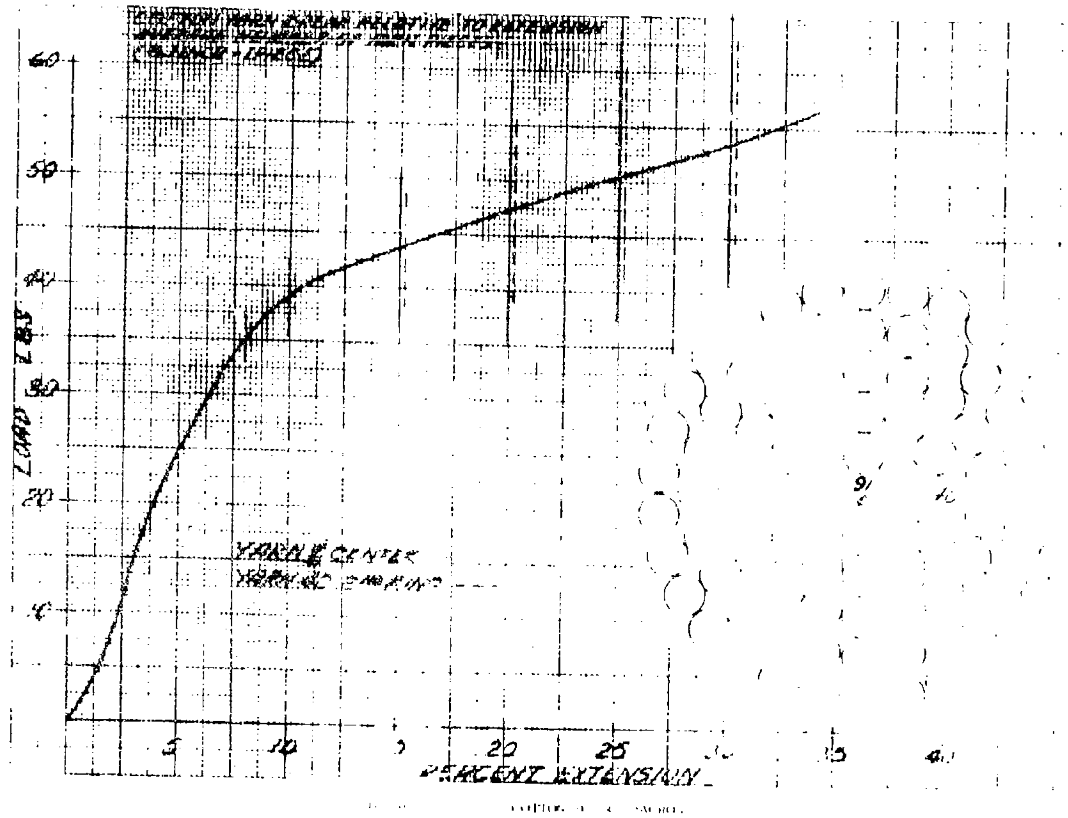


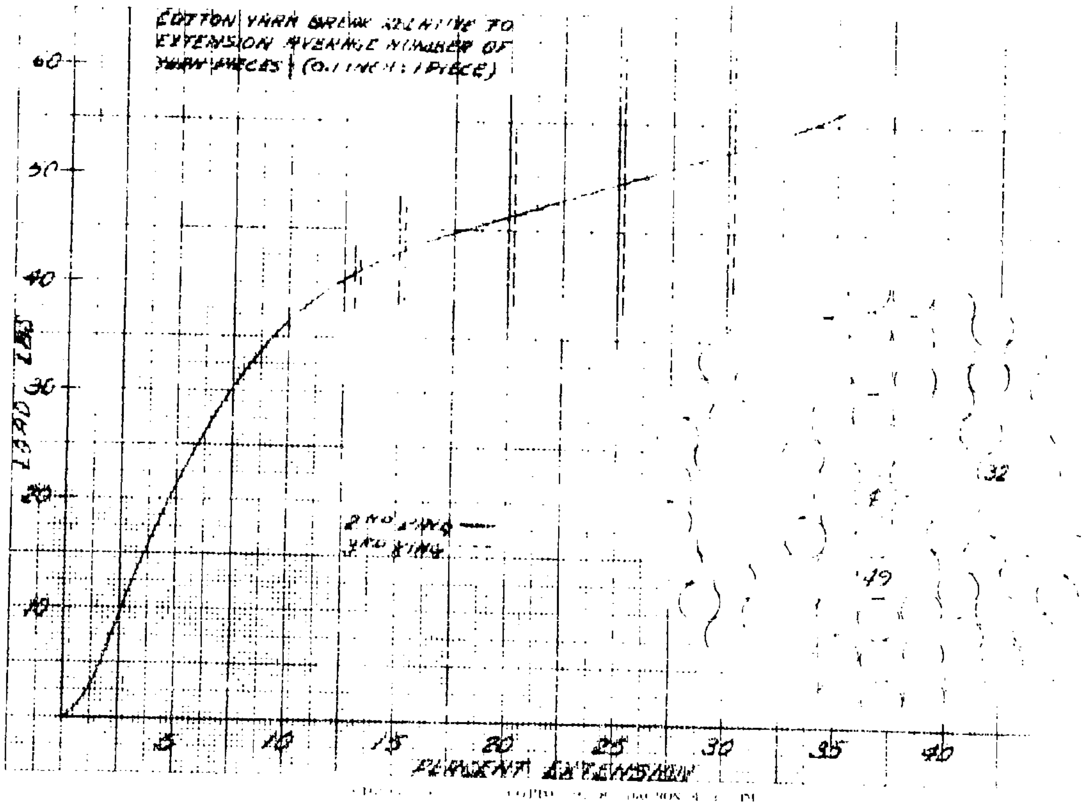
25% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

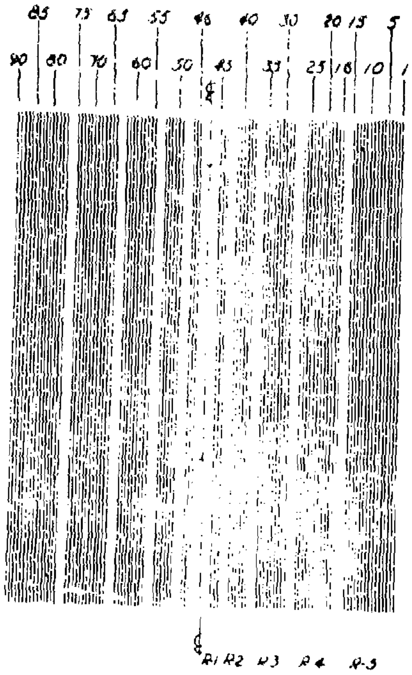


30% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

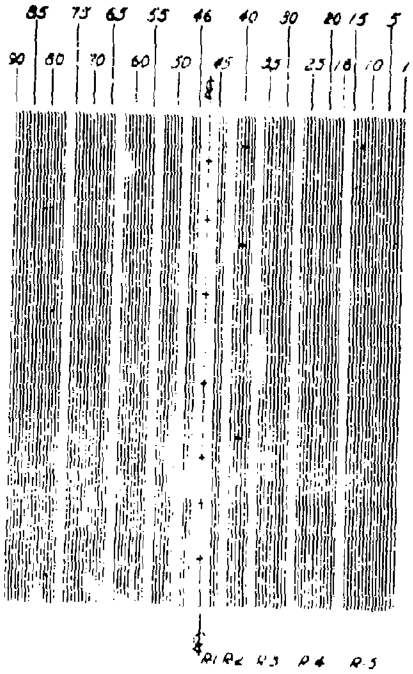
FIGURE [illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
(... - ...)
60
50
40
30
20
10
LOAD LBS
YARN @ CENTER
YARN @ 2ND RING - - -
5
10
20
25
PERCENT EXTENSION
91
46

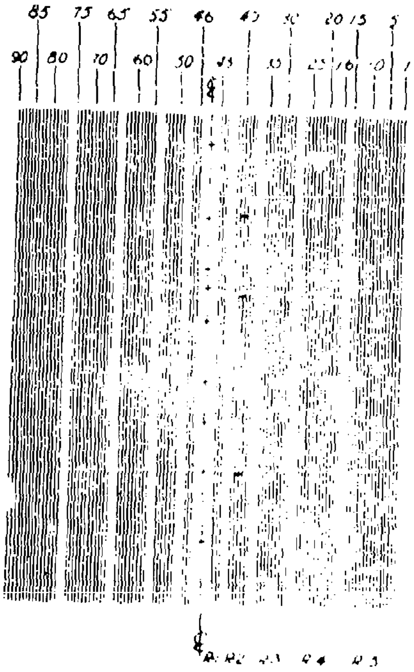

COTTON YARN BREAK RELATIVE TO EXTENSION AVERAGE NUMBER OF YARN PIECES (0.1 INCH : 1 PIECE)
60
50
40
30
20
10
LOAD LBS
2ND RING —
3RD RING - -
5
10
15
20
25
30
35
40
PERCENT EXTENSION
32
49



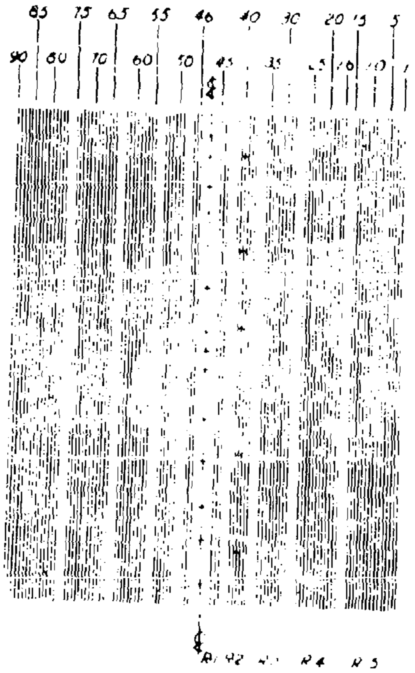
7% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON



8% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

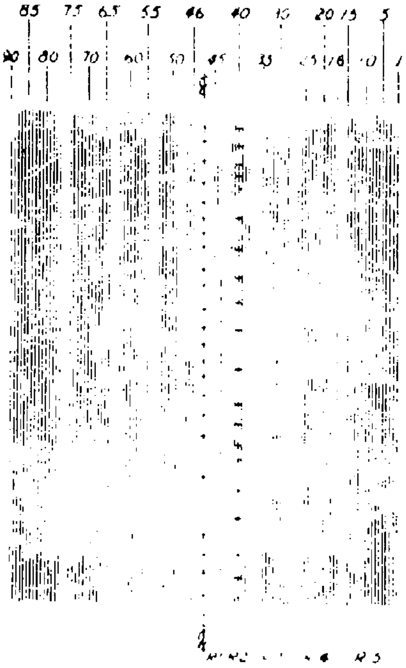


9% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

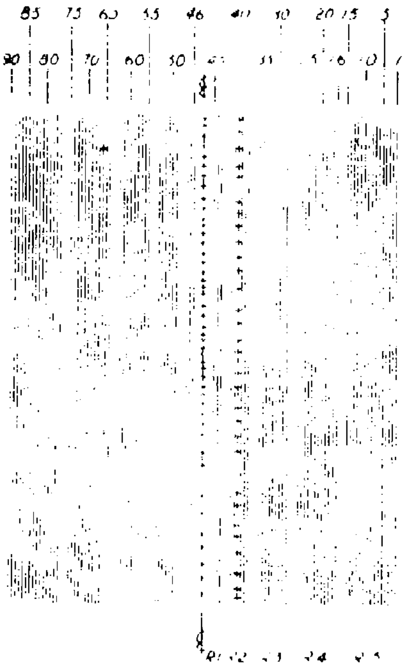


10% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

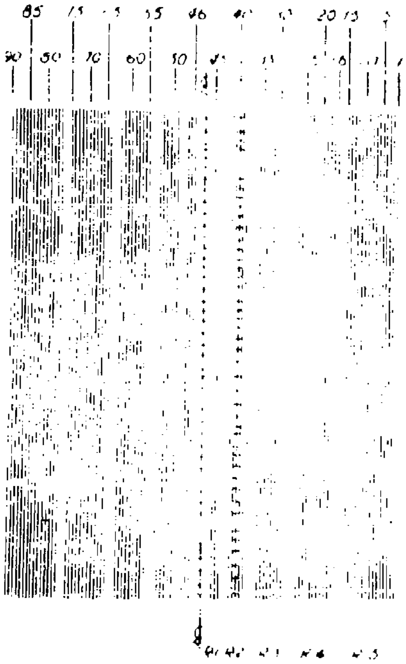
FIGURE [illegible]



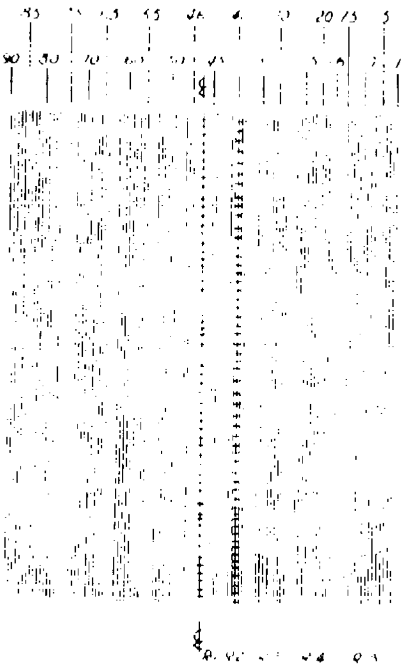
15% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON



20% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

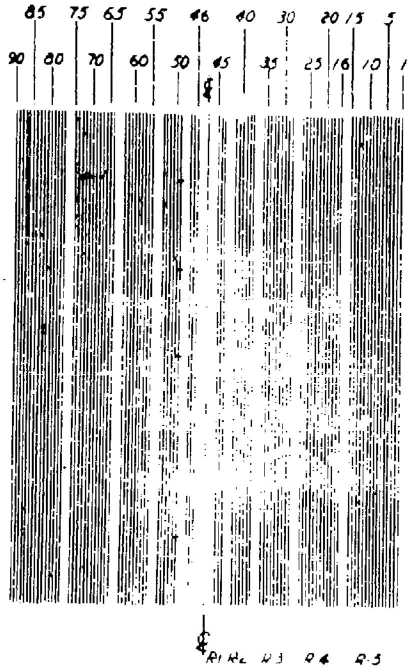


25% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

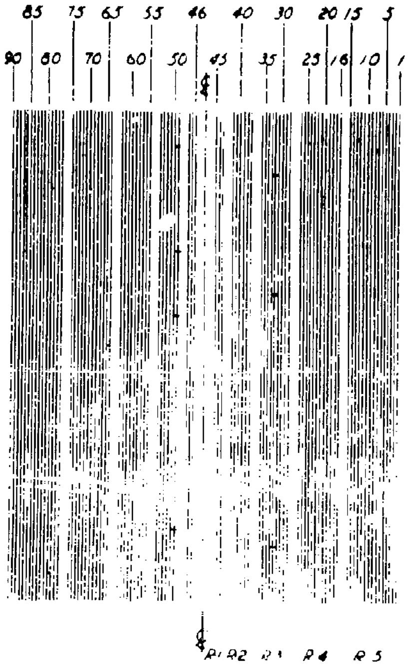


30% EXTENSION
3.28 TM 2.2% COTTON 97.8% DACRON

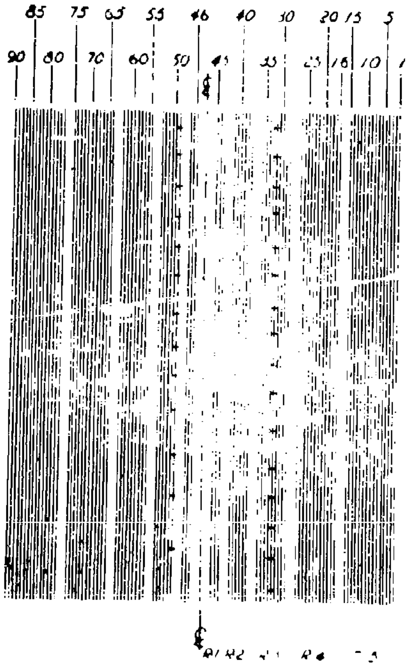
FIGURE [illegible]



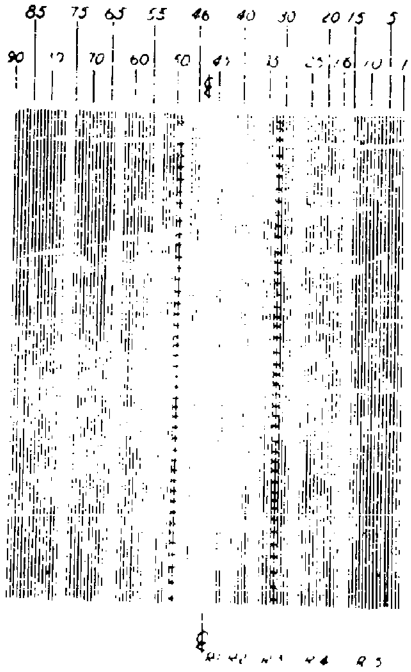
10% EXTENSION
4.37 TM 2.2% COTTON 97.8% DACRON



13% EXTENSION
4.37 TM 2.2% COTTON 97.8% DACRON

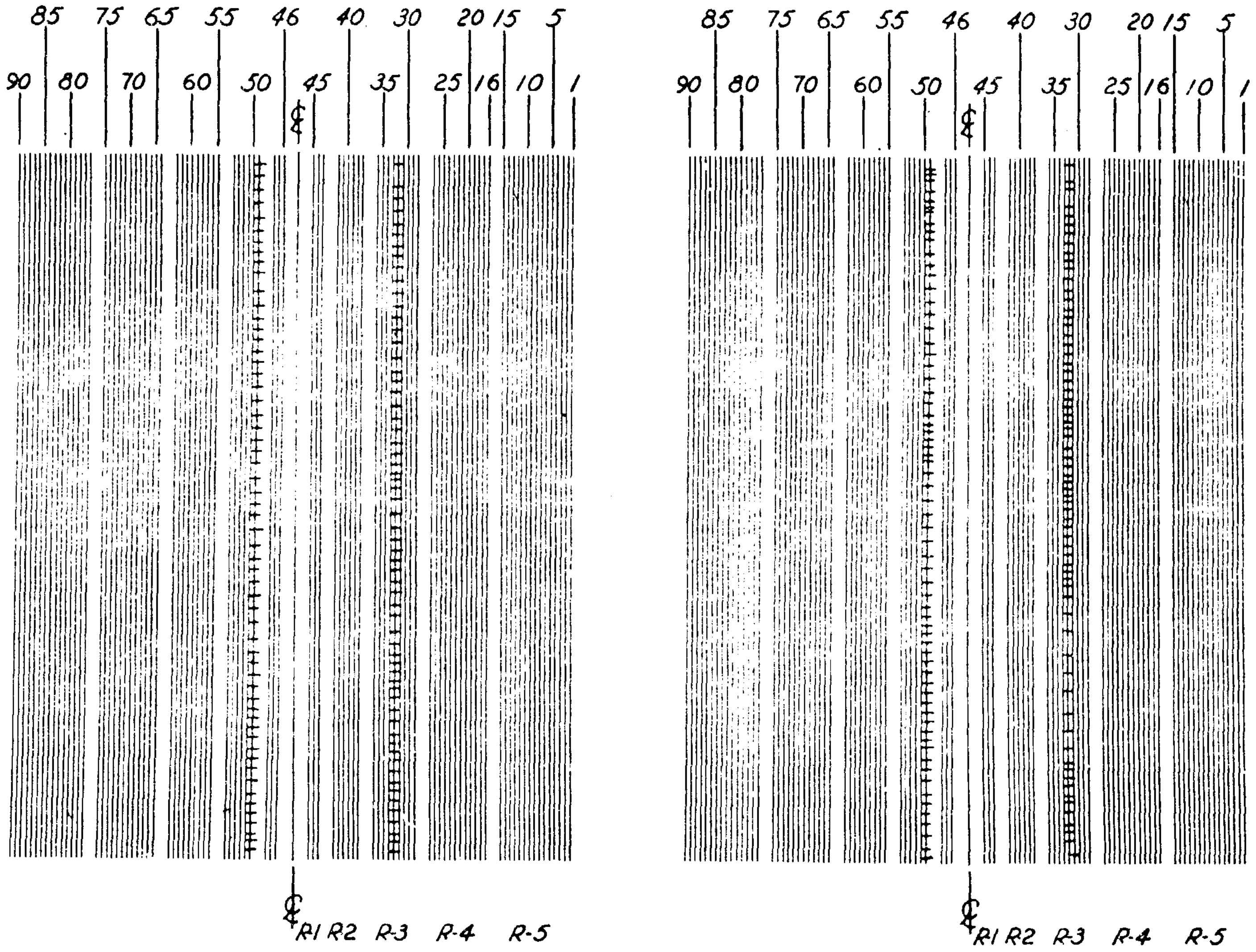


15% EXTENSION
4.37 TM 2.2% COTTON 97.8% DACRON



20% EXTENSION
4.37 TM 2.2% COTTON 97.8% DACRON

FIGURE 34.



25% EXTENSION

4.37 TM 2.2% COTTON 97.8% DACRON

30% EXTENSION

4.37 TM 2.2% COTTON 97.8% DACRON

FIGURE 34b

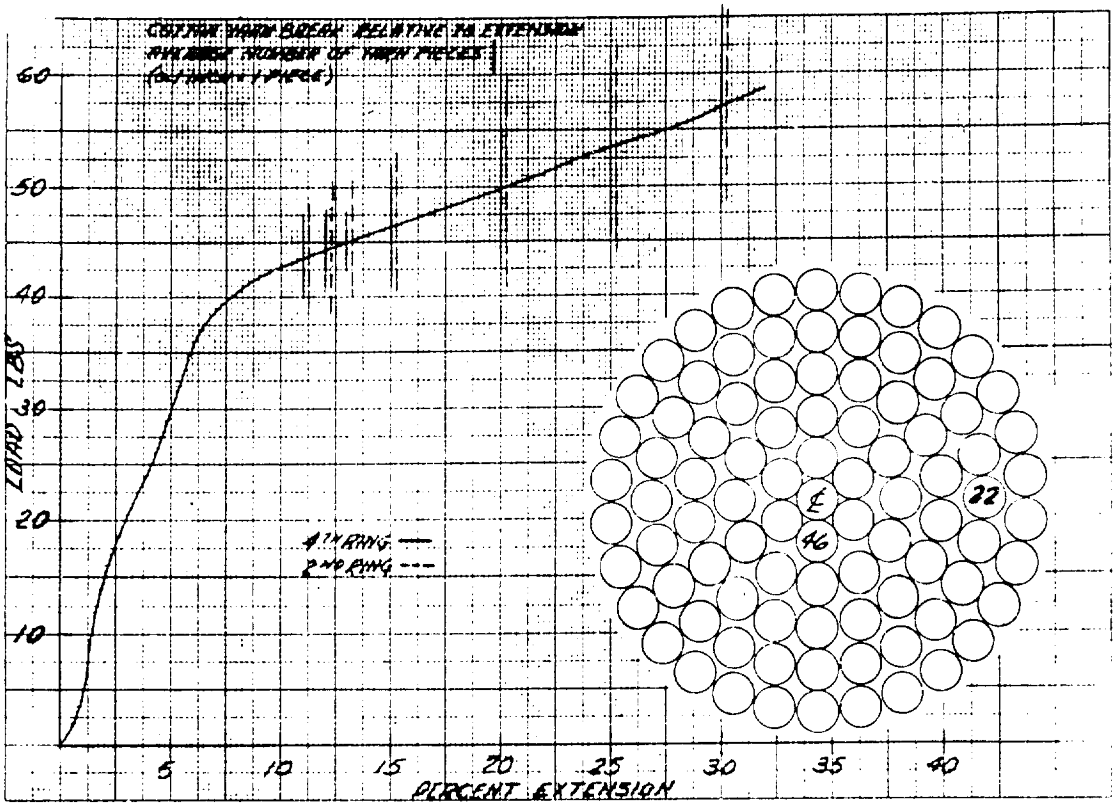


FIGURE 35. 2.2% COTTON 97.8% DACRON 2.19 TM

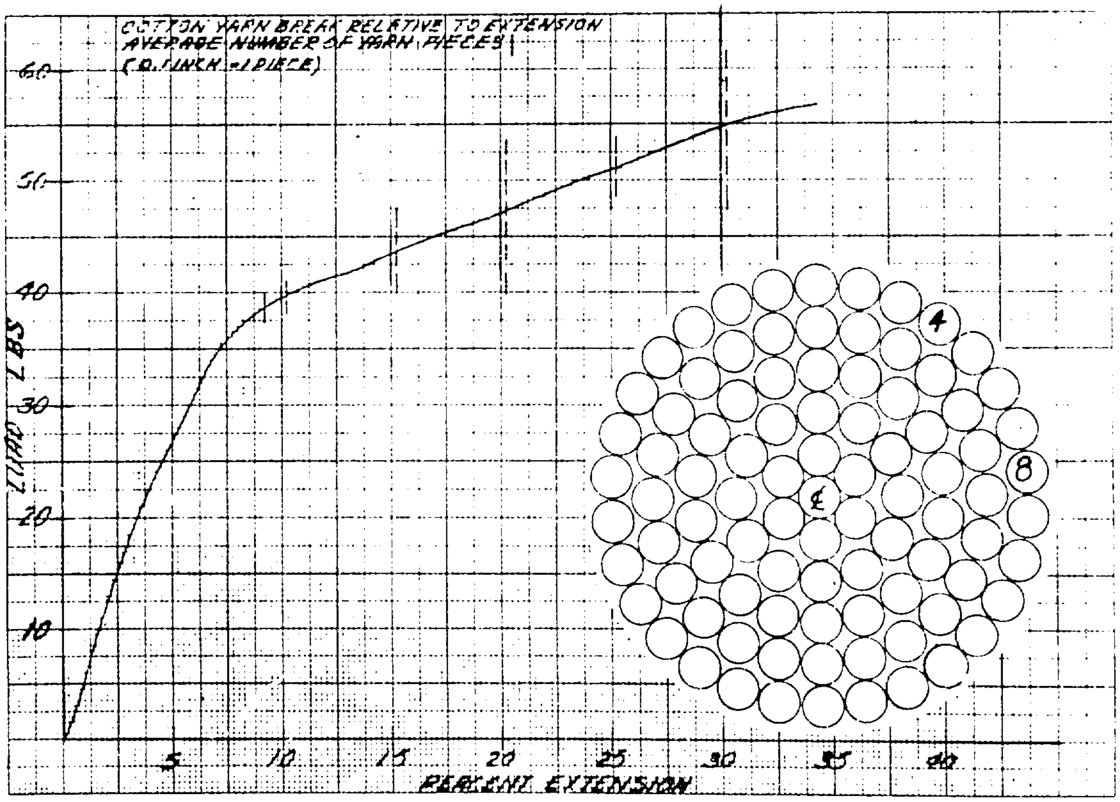
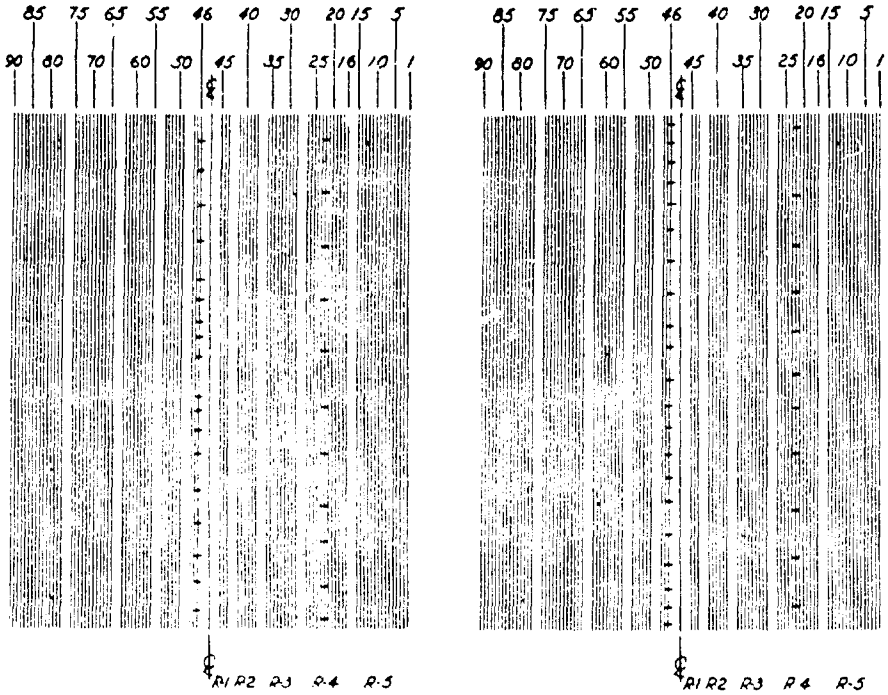
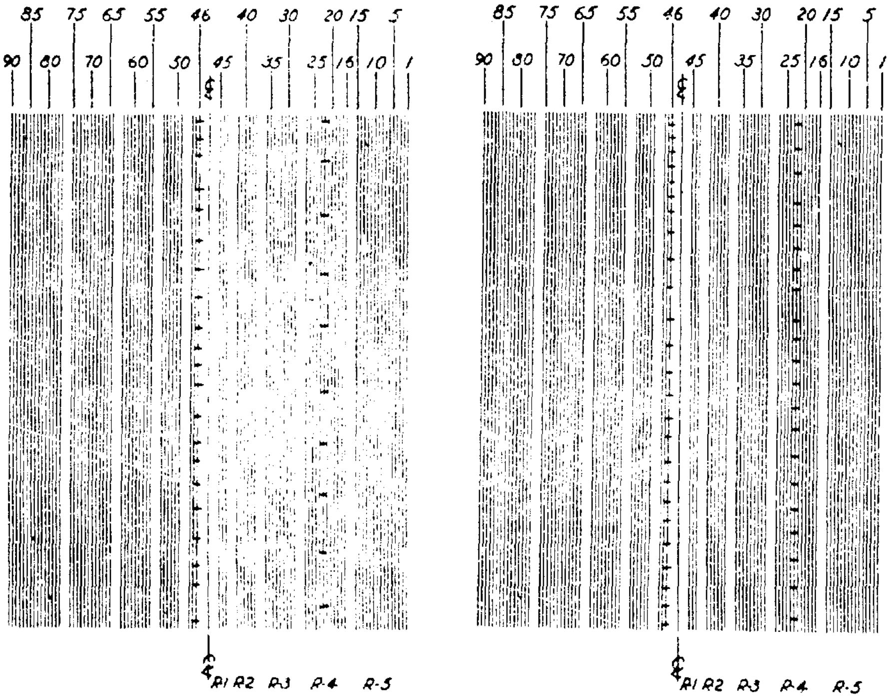


FIGURE 36. 2.2% COTTON 97.8% DACRON 2.19 TM



11% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

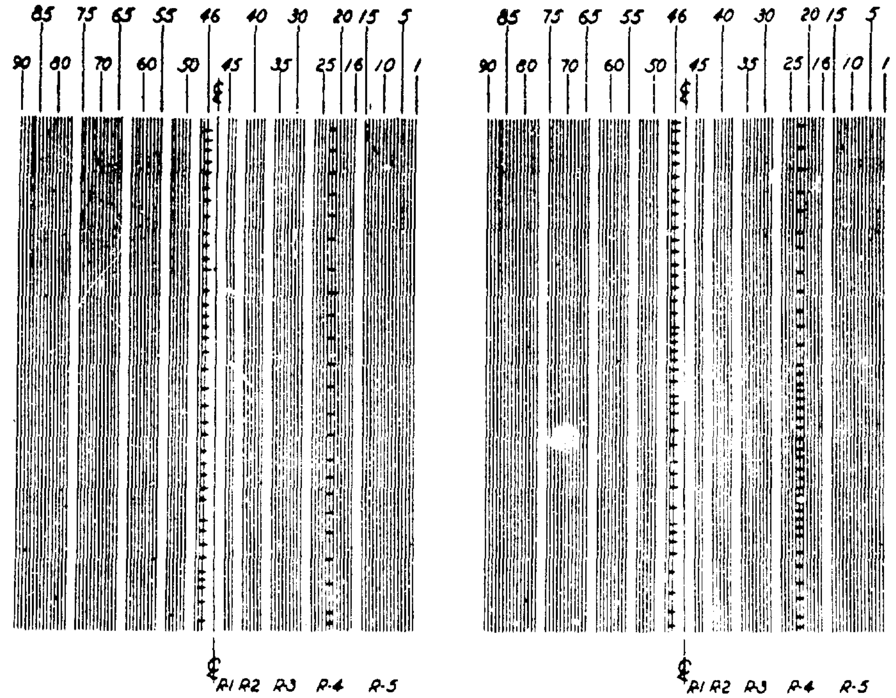
12% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON



13% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

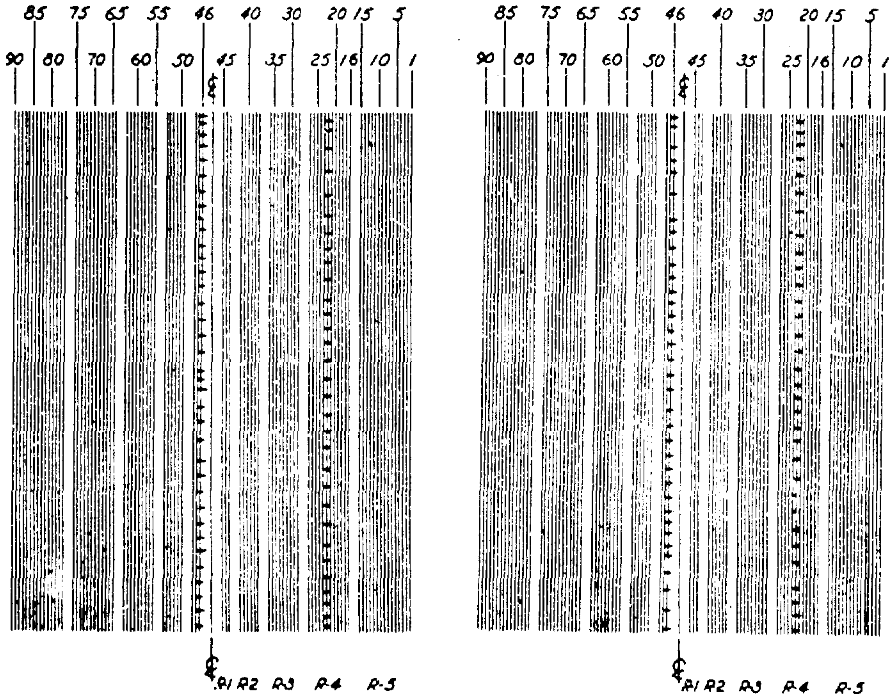
15% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

FIGURE 35a



20% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

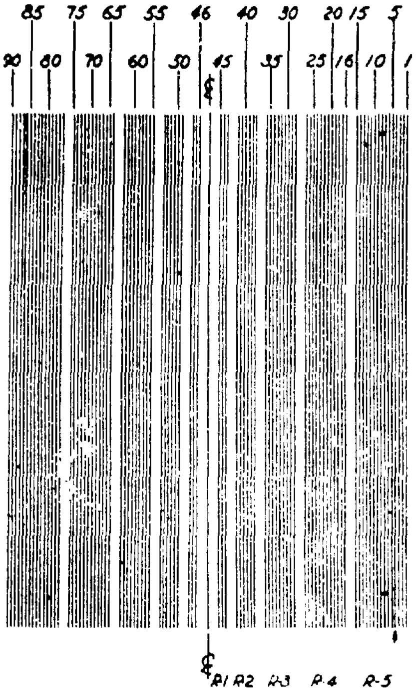
22-1/2% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON



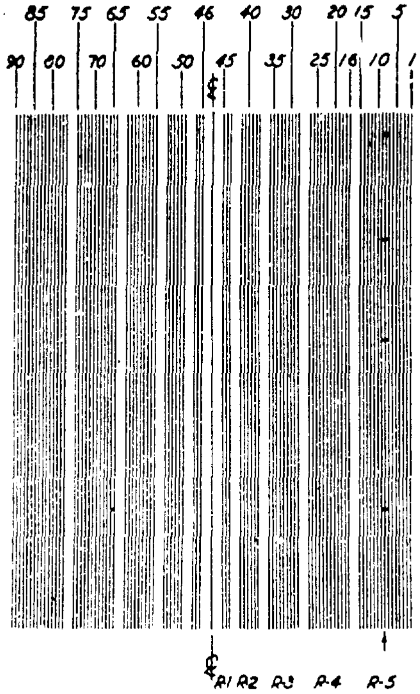
25% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

30% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

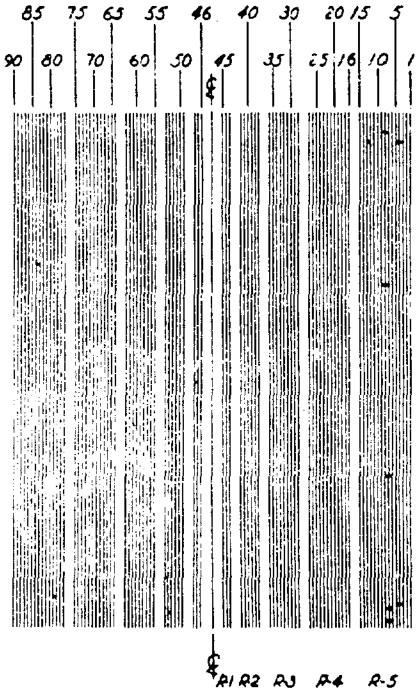
FIGURE 36b



7% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

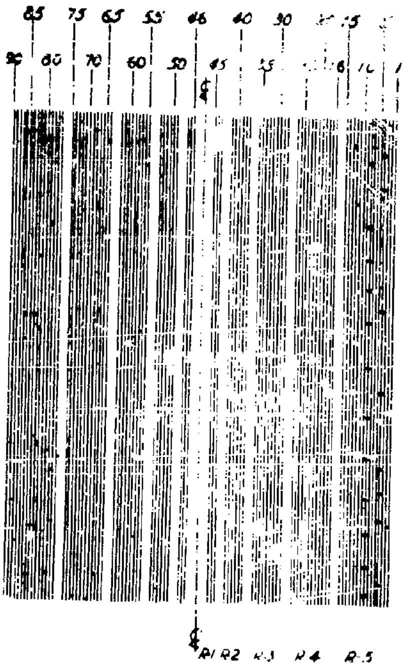


9% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

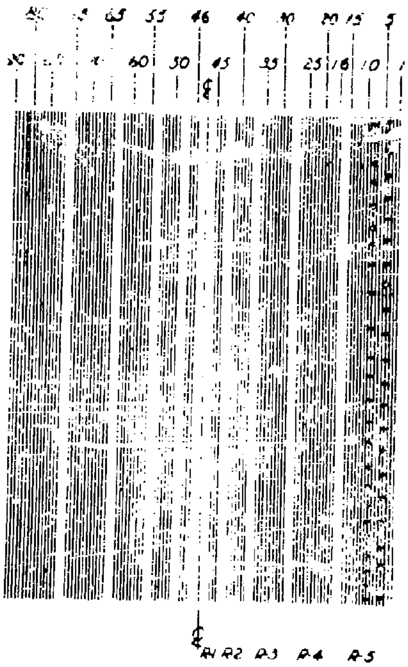


10% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

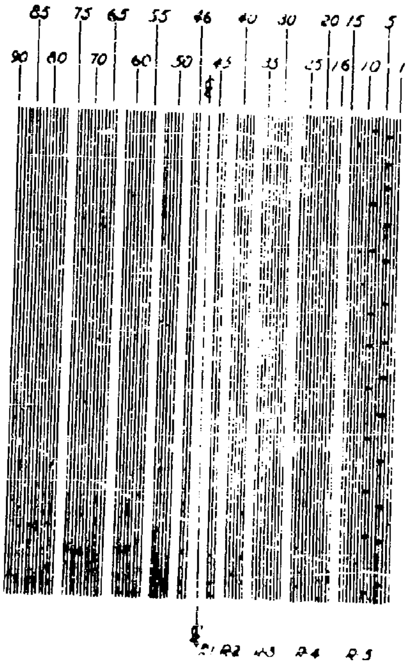
FIGURE 36a



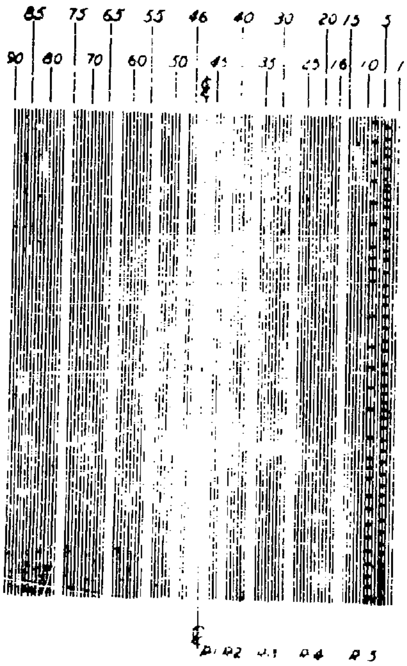
15% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON



20% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

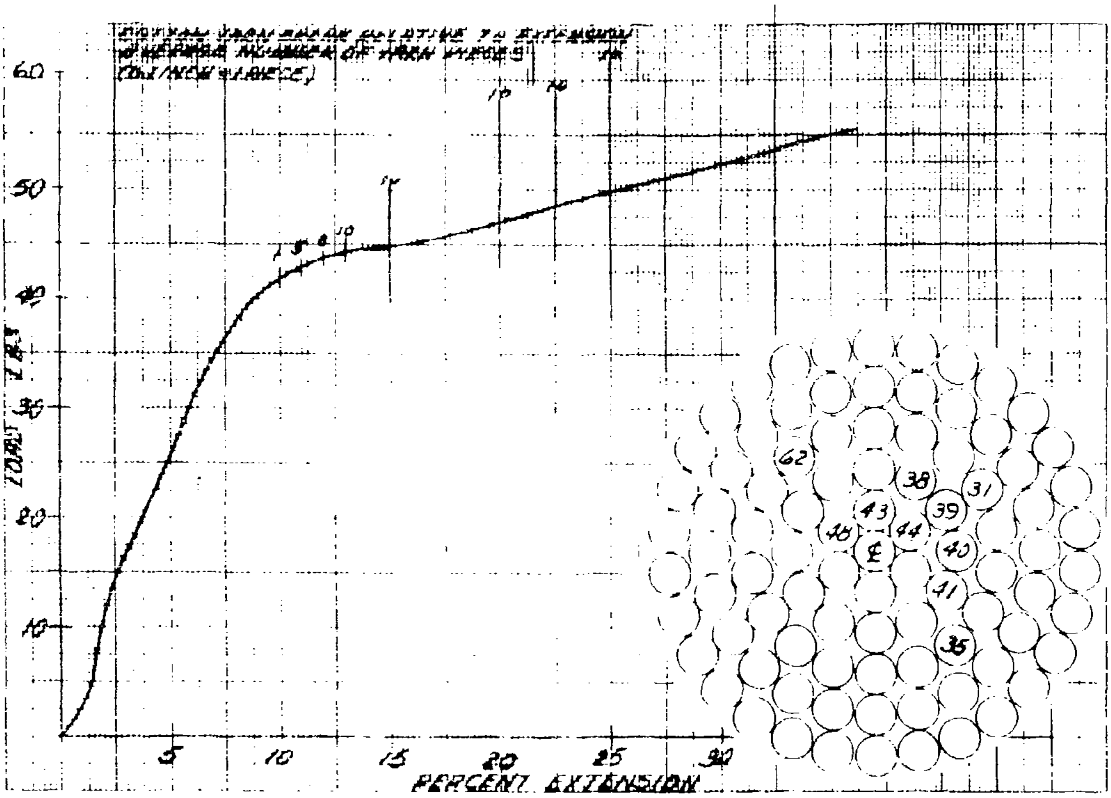


25% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

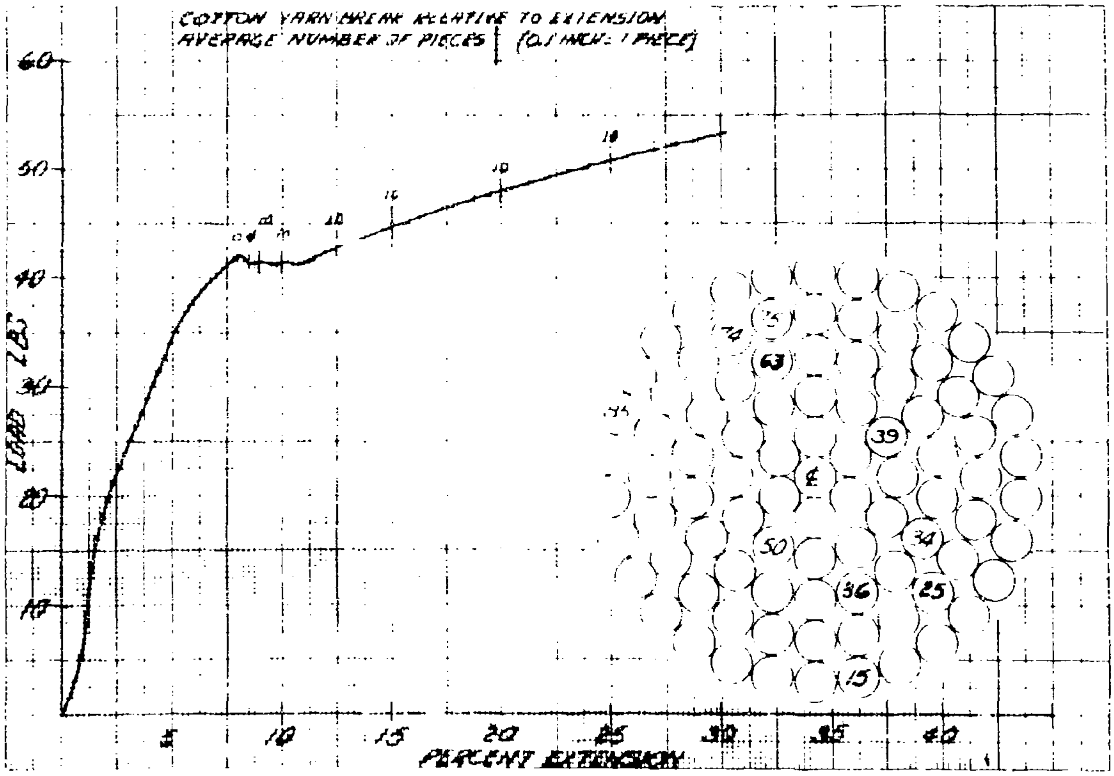


30% EXTENSION
2.19 TM 2.2% COTTON 97.8% DACRON

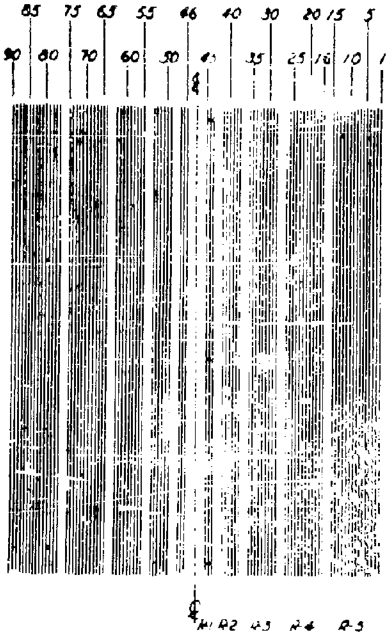
FIGURE 36b



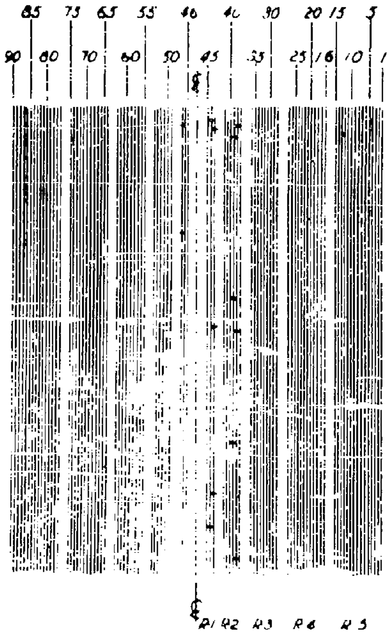
[illegible] COTTON 50% DACRON 0.28 TM



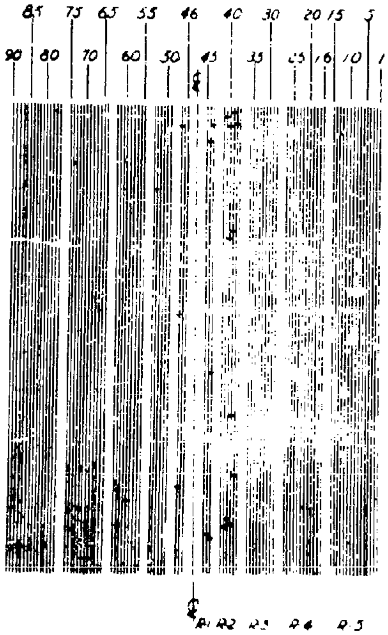
[illegible] COTTON 50% DACRON 0.55 TM



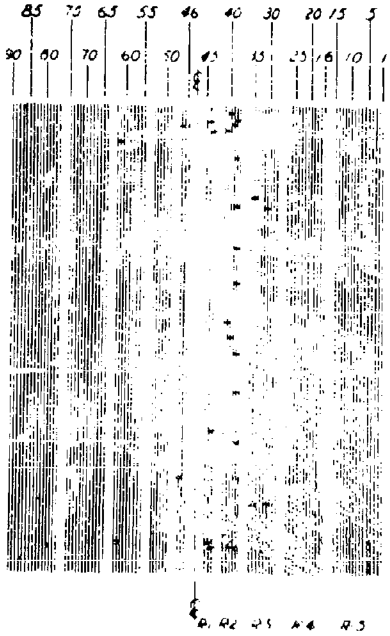
10% EXTENSION
3.28 TM 11% COTTON 89% DACRON



11% EXTENSION
3.28 TM 11% COTTON 89% DACRON

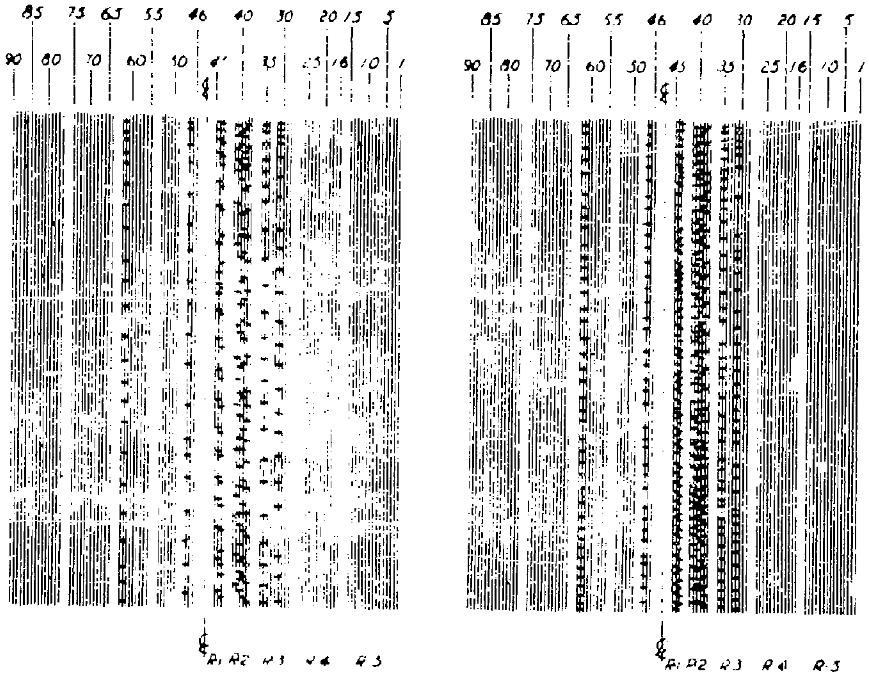


12% EXTENSION
3.28 TM 11% COTTON 89% DACRON



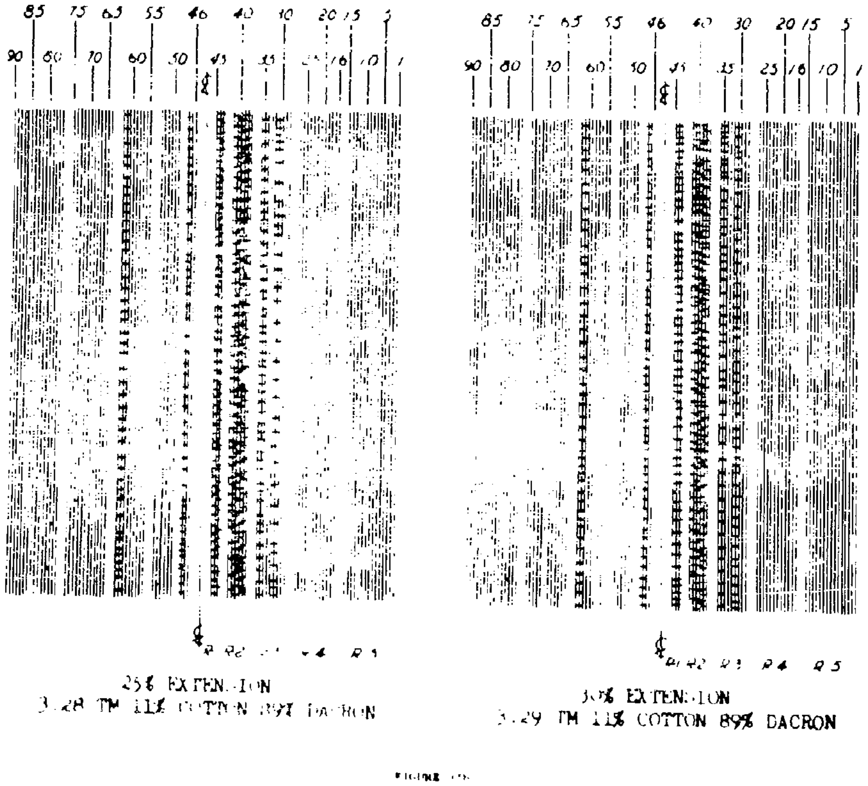
13% EXTENSION
3.28 TM 11% COTTON 89% DACRON

FIGURE 37a



15% EXTENSION
3.28 TM 11% COTTON 89% DACRON

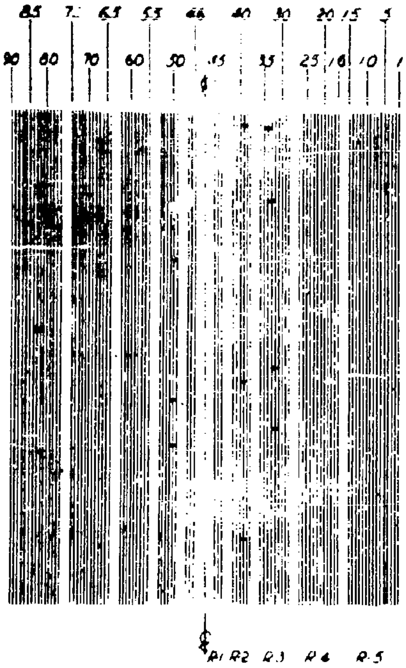
20% EXTENSION
3.28 TM 11% COTTON 89% DACRON



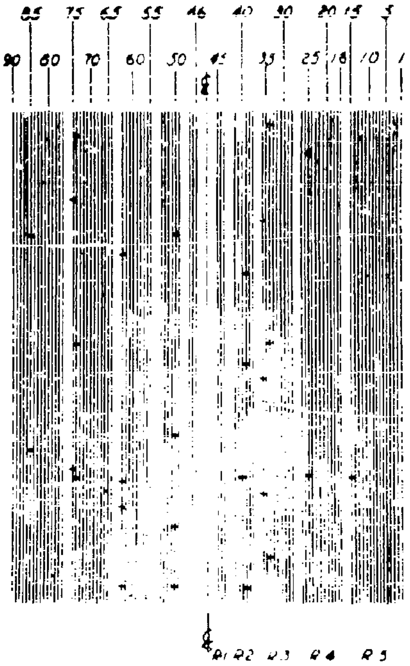
25% EXTENSION
3.28 TM 11% COTTON 89% DACRON

30% EXTENSION
3.29 TM 11% COTTON 89% DACRON

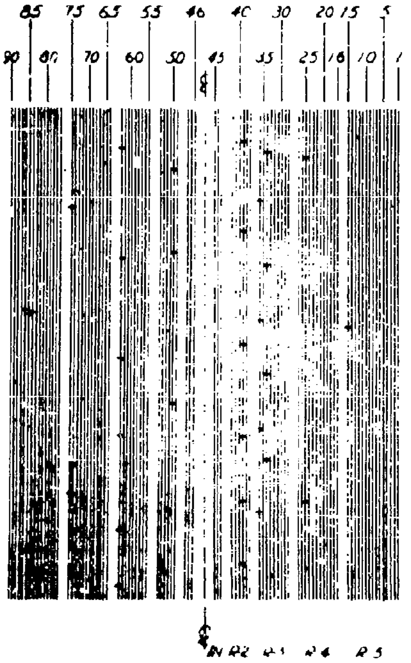
FIGURE [illegible]



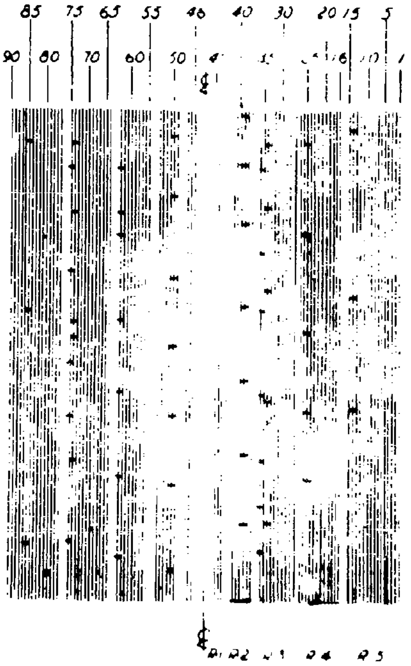
8-1/2% EXTENSION
0.55 TM 11% COTTON 89% DACRON



9% EXTENSION
0.55 TM 11% COTTON 89% DACRON



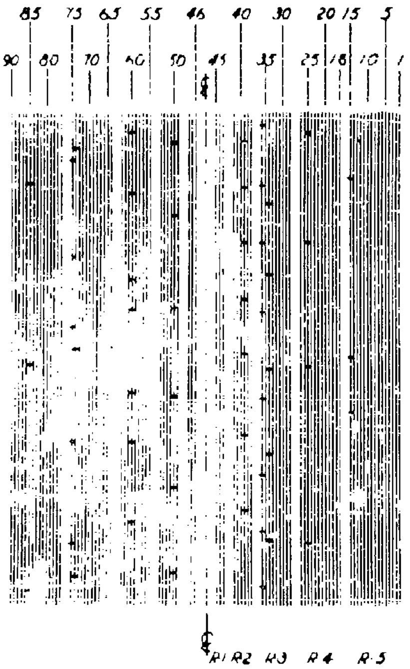
12-1/2% EXTENSION
0.55 TM 11% COTTON 89% DACRON



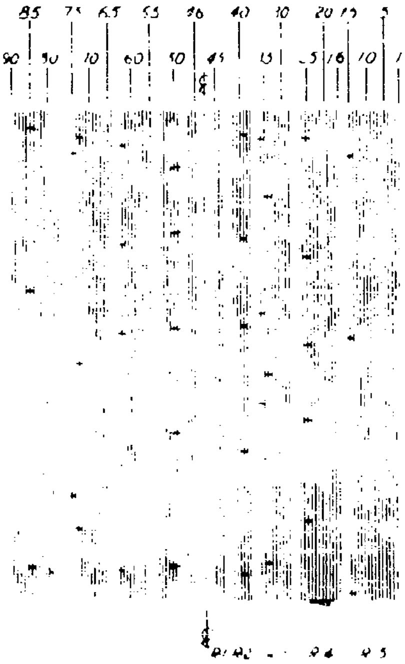
15% EXTENSION
0.55 TM 11% COTTON 89% DACRON

FIGURE 38a

20% EXTENSION
0.55 TM 11% COTTON 89% DACRON

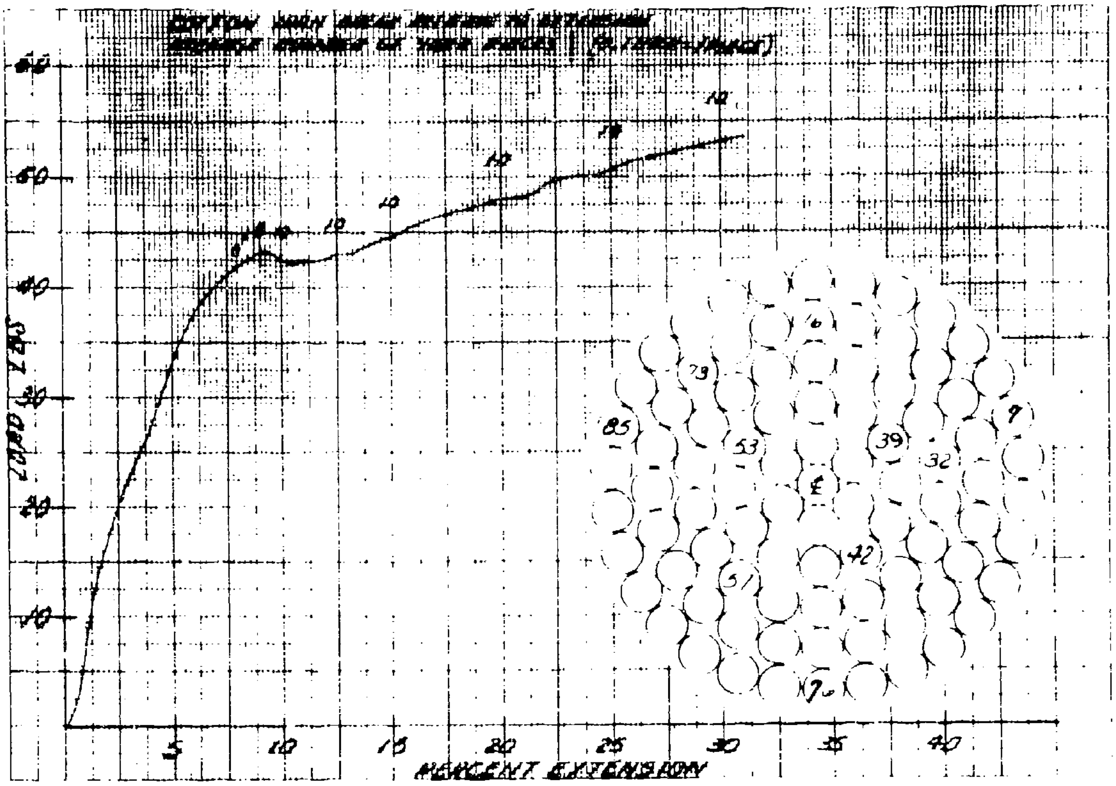


25% EXTENSION
0.55 TM 11% COTTON 89% DACRON

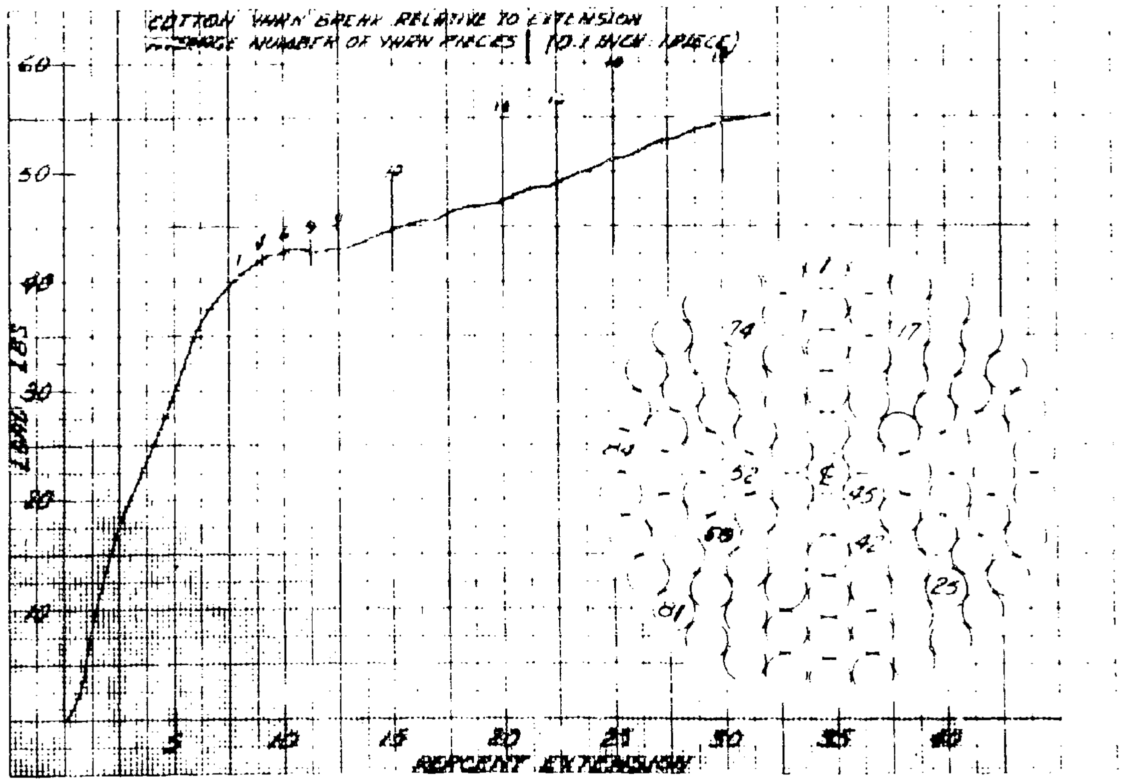


30% EXTENSION
0.55 TM 11% COTTON 89% DACRON

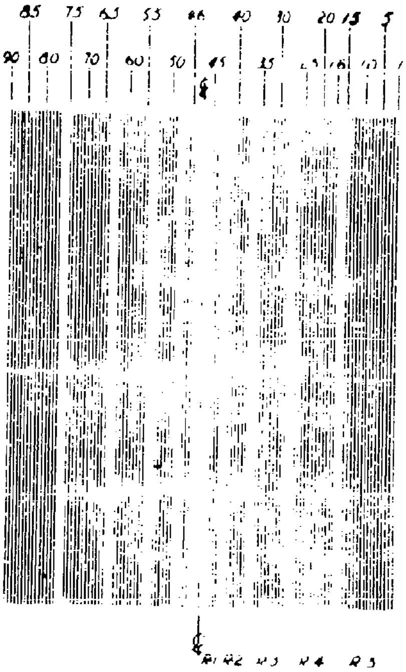
FIGURE [illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES | (0.1 INCH/PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
6
73
85
53
39
32
9
℄
42
51
70

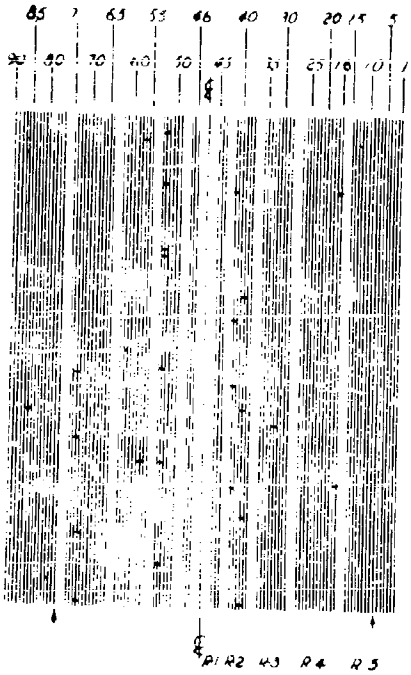
[illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES | (0.1 INCH/PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
1
74
17
52
℄
45
58
42
81
25

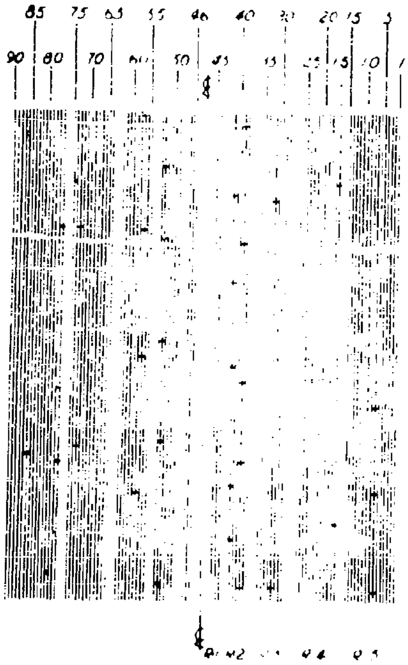
[illegible]



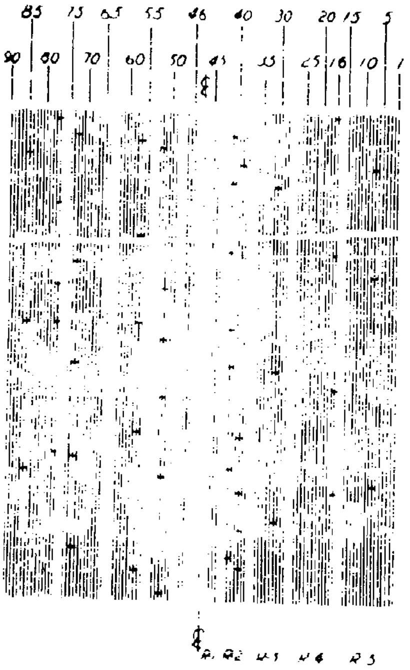
8-1/2% EXTENSION
1.09 TM 11% COTTON 89% DACRON



[illegible] EXTENSION
1.09 [illegible] COTTON 89% DACRON

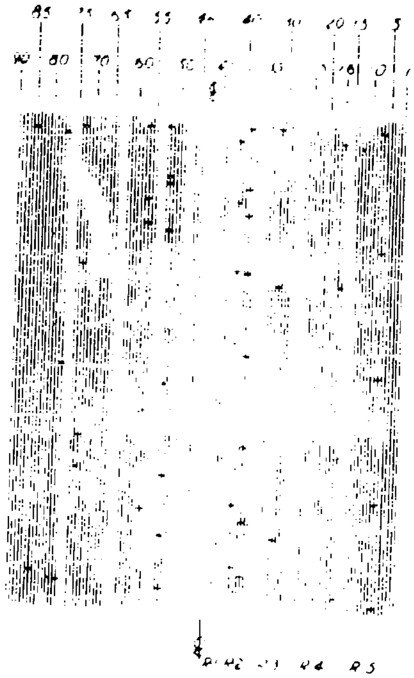


10% EXTENSION
1.09 TM 11% COTTON 89% DACRON

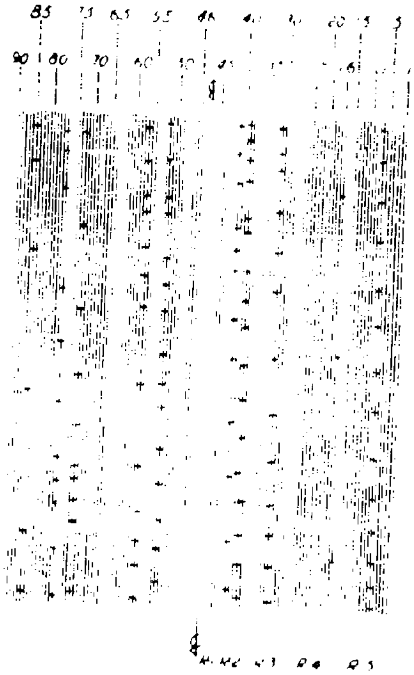


12-1/2% EXTENSION
1.09 TM 11% COTTON 89% DACRON

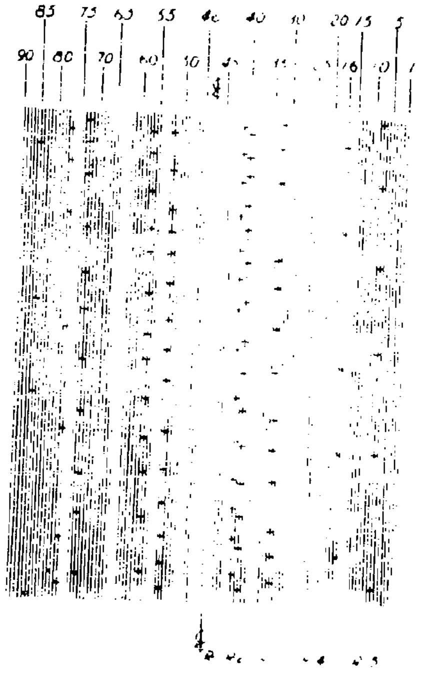
FIGURE No.



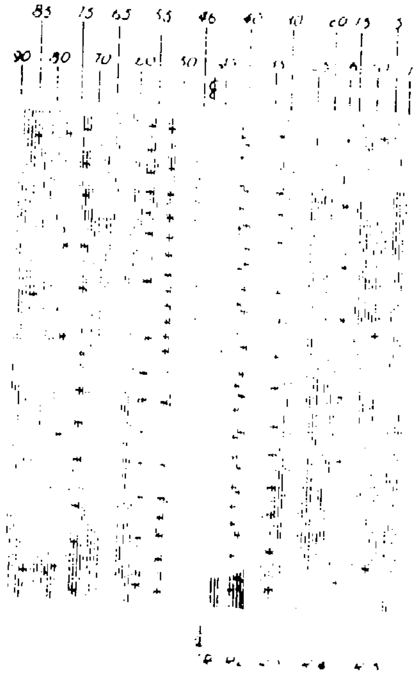
15% EXTENSION
1.09 TM 11% COTTON 89% DACRON



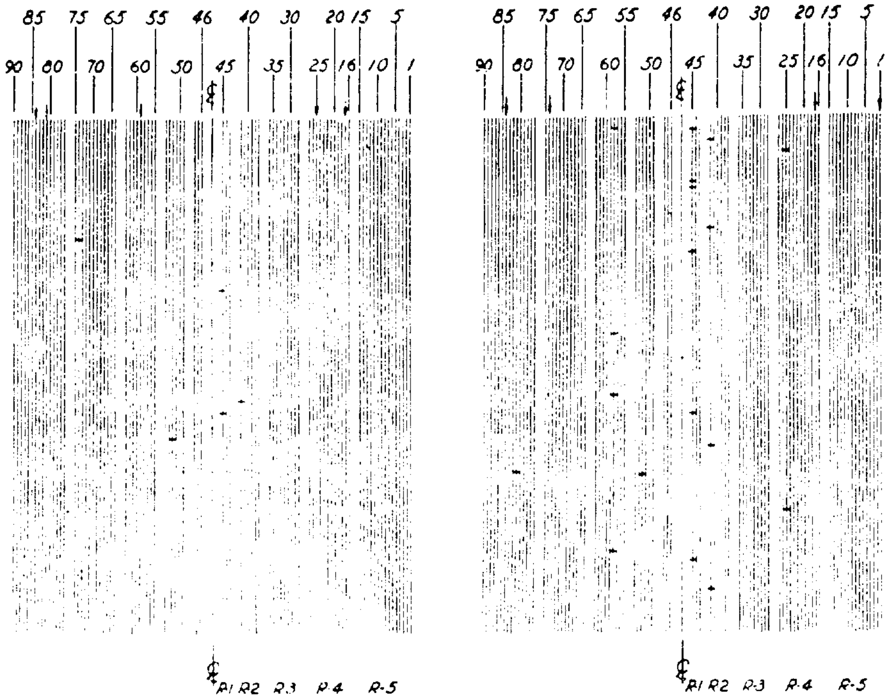
20% EXTENSION
1.09 TM 11% COTTON 89% DACRON



25% EXTENSION
1.09 TM 11% COTTON 89% DACRON

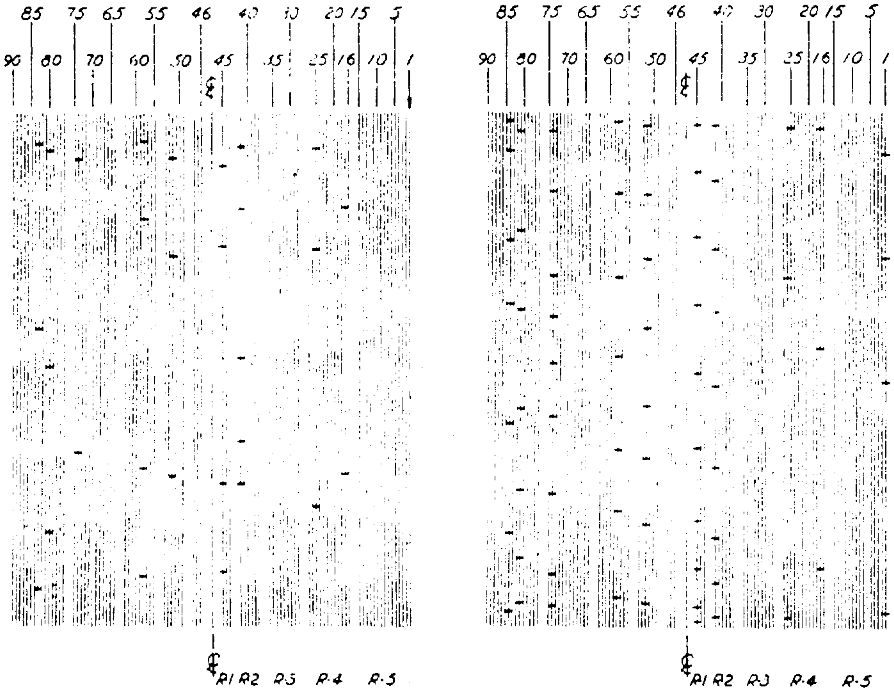


30% EXTENSION
1.09 TM 11% COTTON 89% DACRON



9% EXTENSION
2.18 TM 11% COTTON 89% DACRON

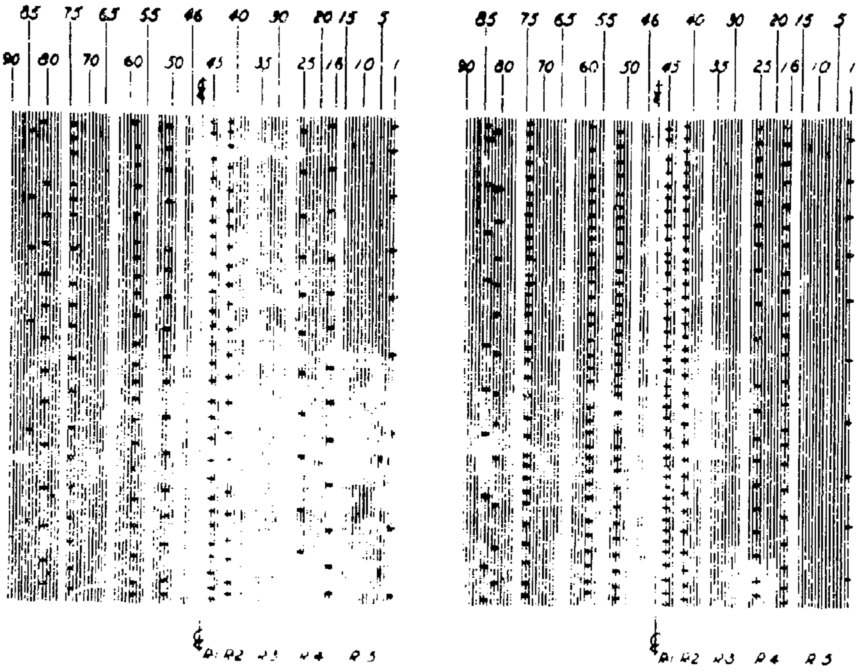
10% EXTENSION
2.18 TM 11% COTTON 89% DACRON



11% EXTENSION
2.18 TM 11% COTTON 89% DACRON

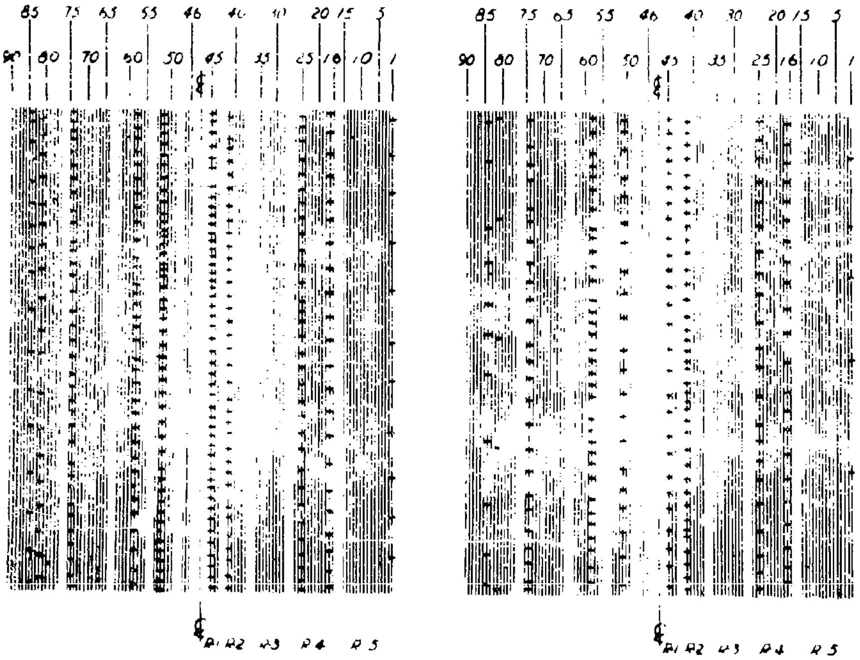
12-1/2 EXTENSION
2.18 TM 11% COTTON 89% DACRON

Figure 40a



15% EXTENSION
2.18 TM 11% COTTON 89% DACRON

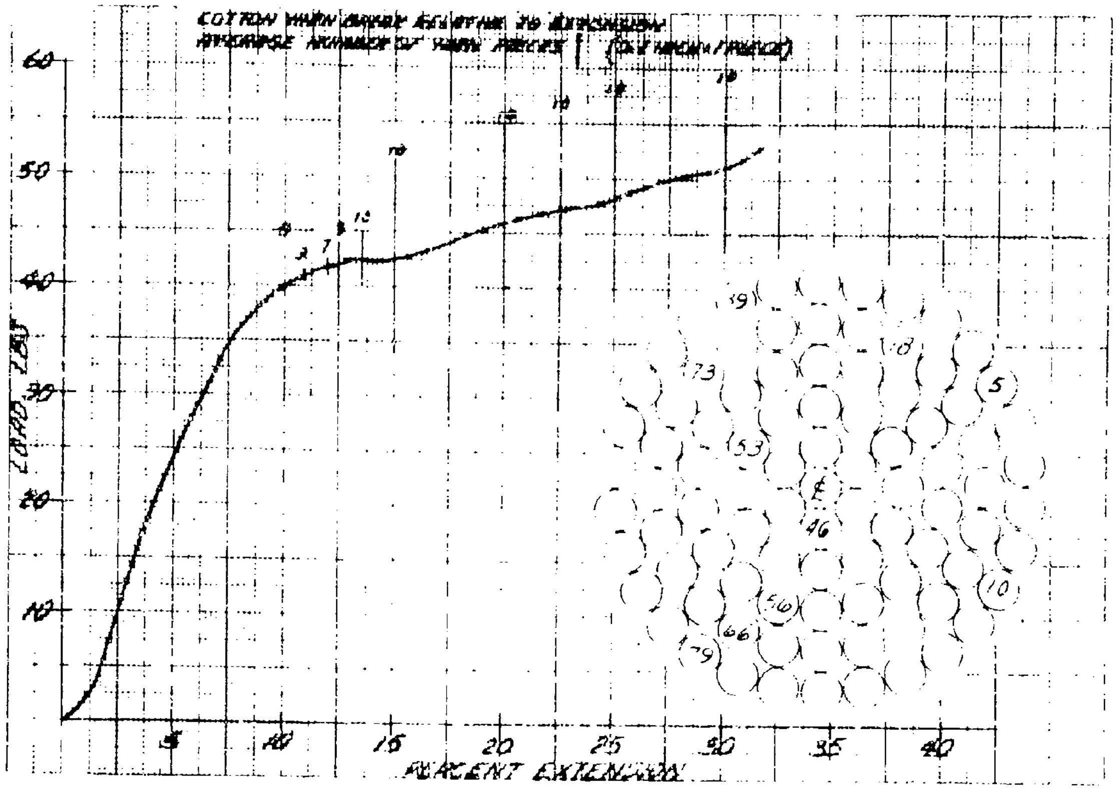
22-1/2% EXTENSION
2.18 TM 11% COTTON 89% DACRON



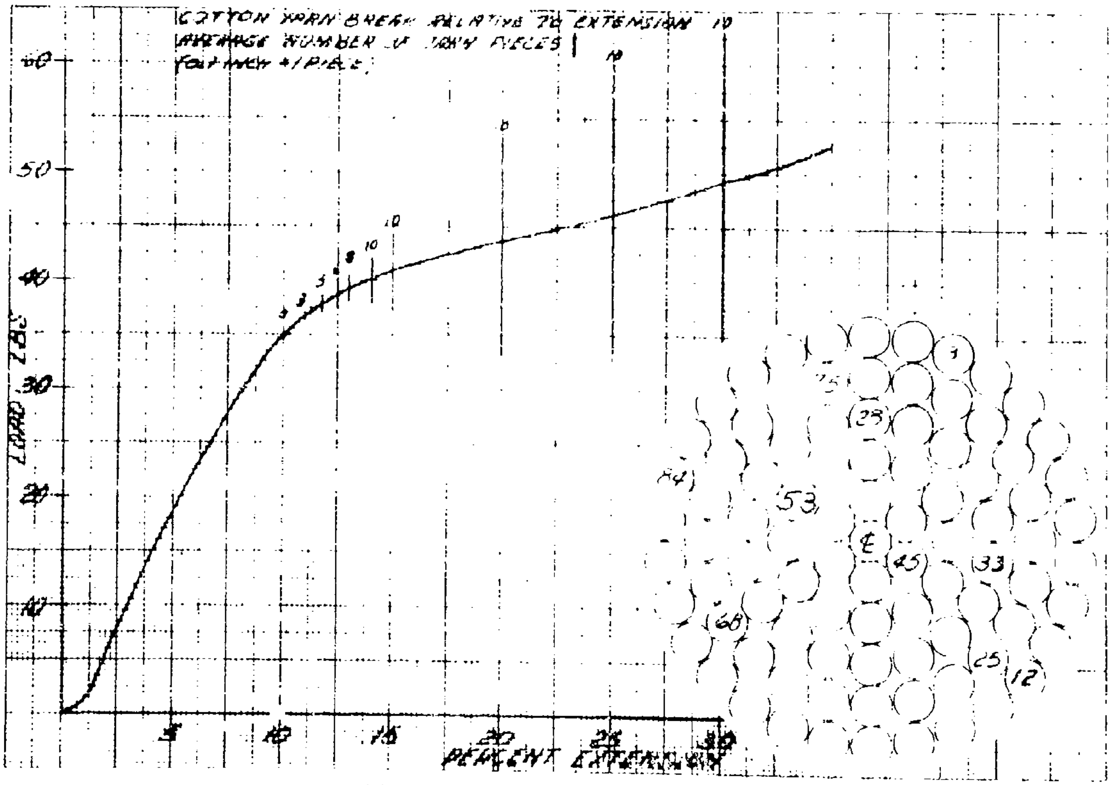
25% EXTENSION
2.18 TM 11% COTTON 89% DACRON

30% EXTENSION
2.18 TM 11% COTTON 89% DACRON

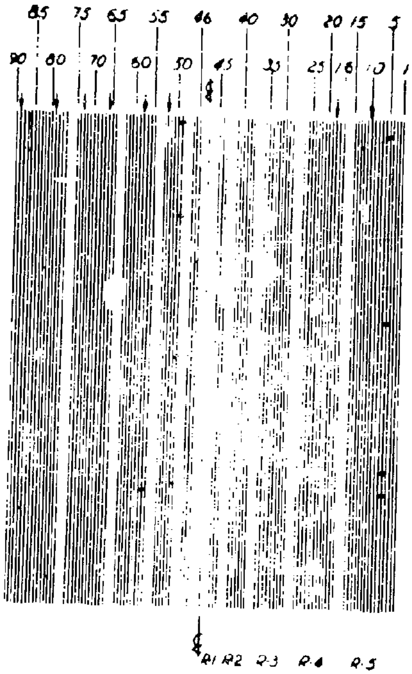
Figure 40b


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES | (ONE INCH / PIECE)
LOAD, LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
39
73
8
5
53
₵
46
10
56
66
79

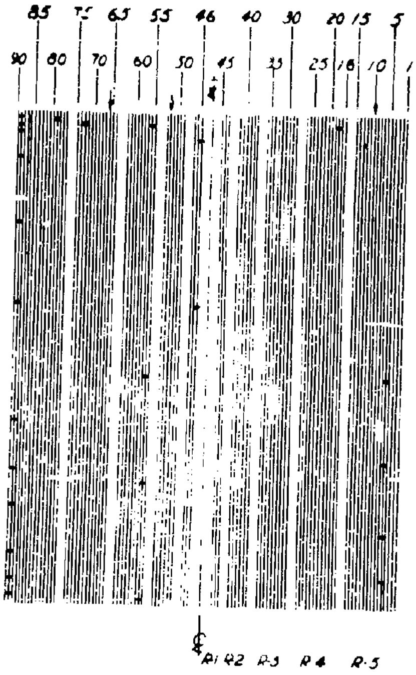
[illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES |
FOUR INCH / PIECE
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
PERCENT EXTENSION
3
25
28
84
53
₵
45
33
68
25
12

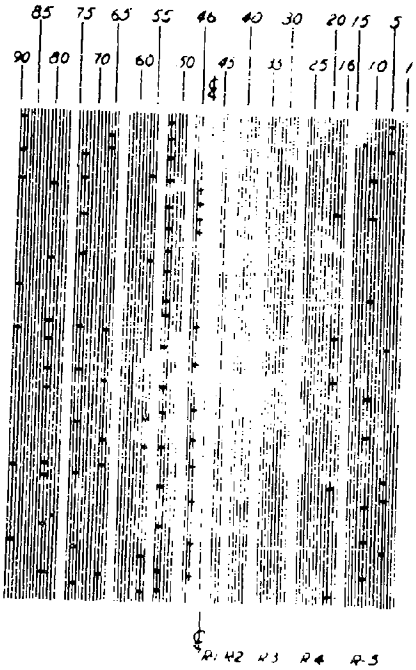
[illegible]



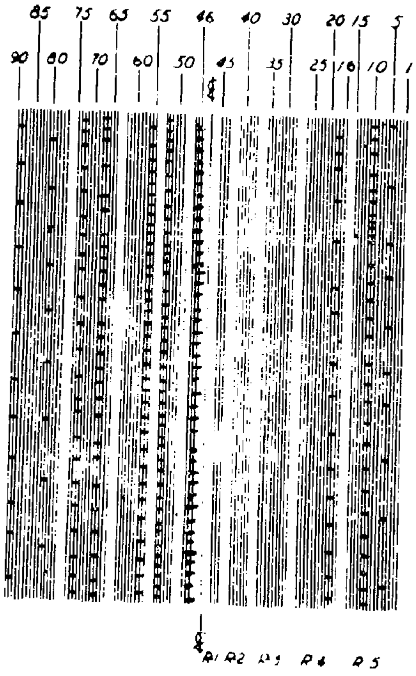
11% EXTENSION
3.27 TM 11% COTTON 89% DACRON



12% EXTENSION
3.27 TM 11% COTTON 89% DACRON

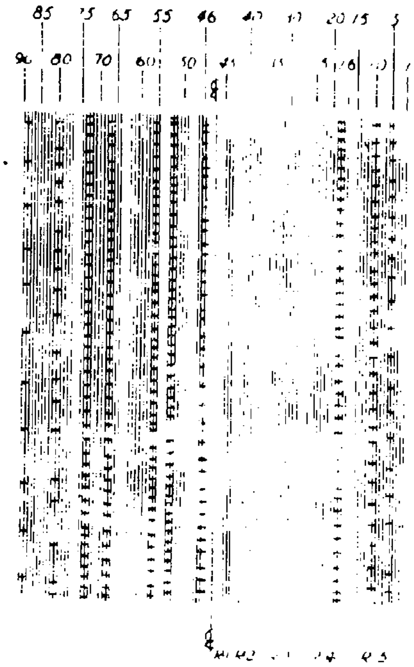


13% EXTENSION
3.27 TM 11% COTTON 89% DACRON

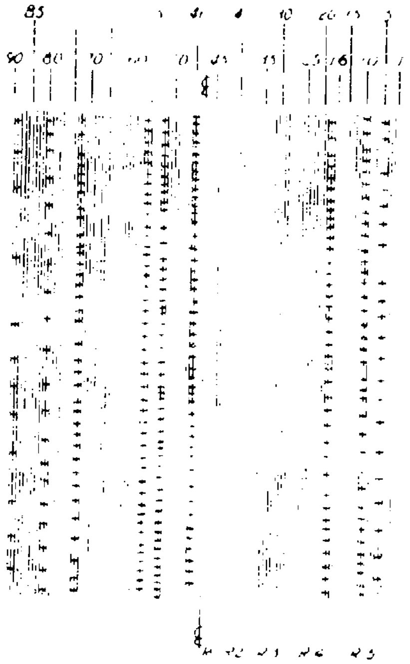


15% EXTENSION
3.27 TM 11% COTTON 89% DACRON

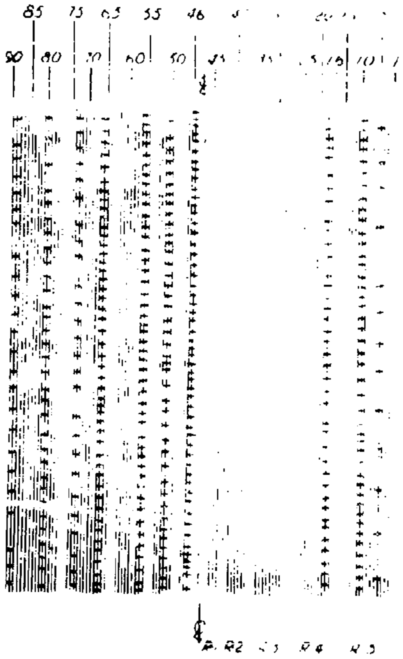
FIGURE 41a



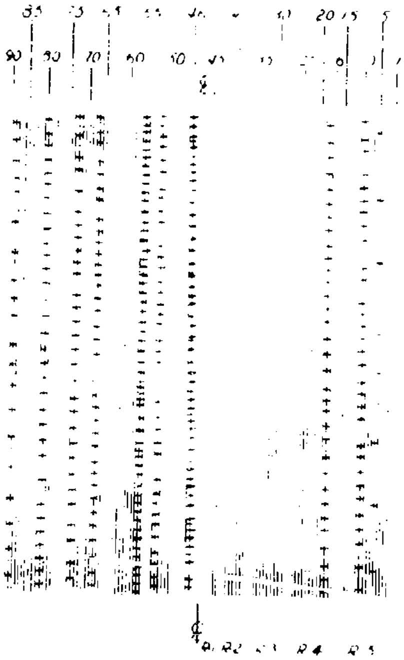
20% EXTENSION
3.27 TM 11% COTTON 89% DACRON



22-1/2 EXTENSION
3.27 TM 11% COTTON 89% DACRON

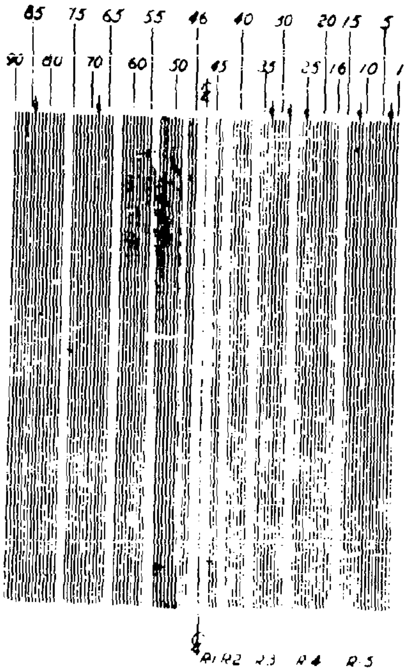


25% EXTENSION
3.27 TM 11% COTTON 89% DACRON

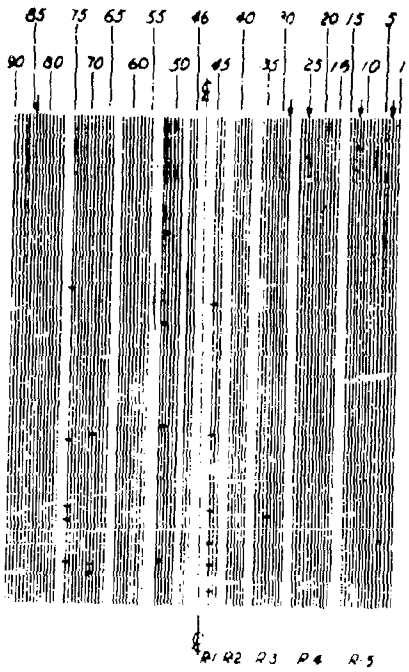


30% EXTENSION
3.27 TM 11% COTTON 89% DACRON

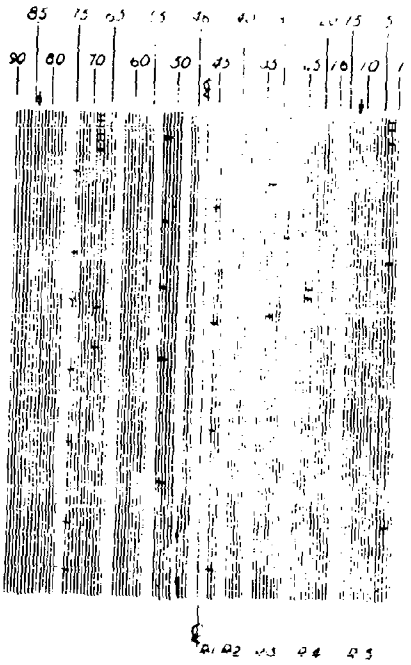
FIGURE 41b



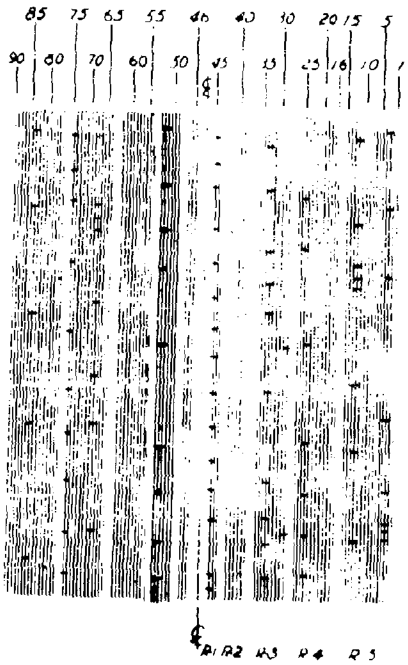
11% EXTENSION
4.37 TM 11% COTTON 89% DACRON



12% EXTENSION
4.37 TM 11% COTTON 89% DACRON

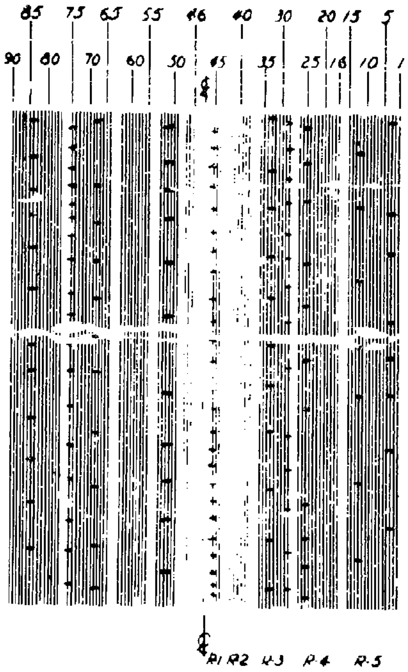


13% EXTENSION
4.37 TM 11% COTTON 89% DACRON

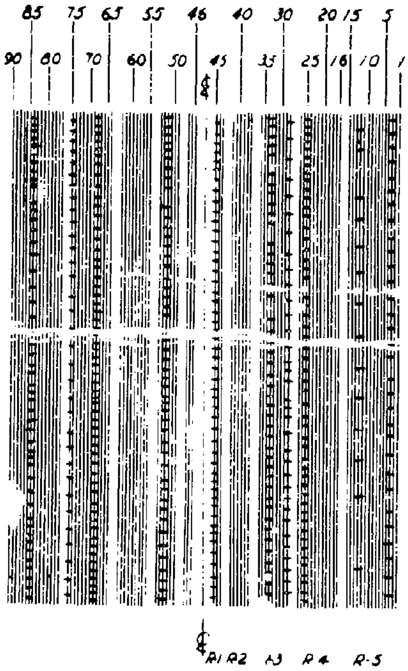


14% EXTENSION
4.37 TM 11% COTTON 89% DACRON

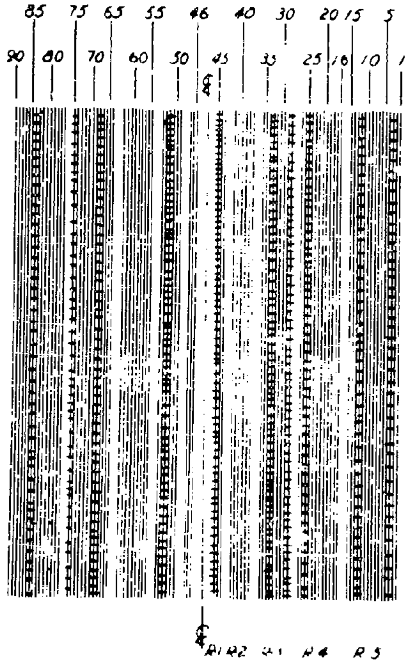
FIGURE [illegible]



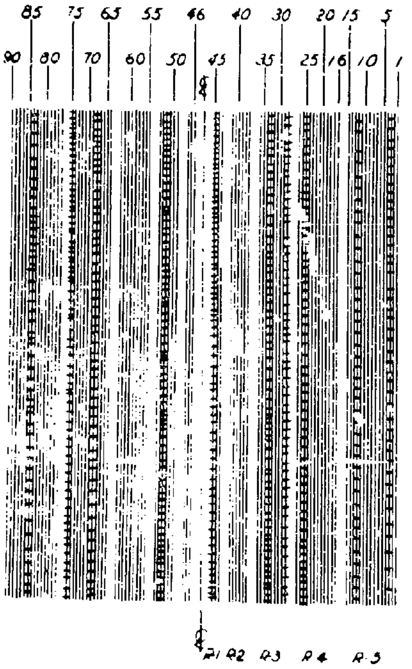
15% EXTENSION
4.37 TM 11% COTTON 89% DACRON



20% EXTENSION
4.37 TM 11% COTTON 89% DACRON



22-1/2% EXTENSION
4.37 TM 11% COTTON 89% DACRON



30% EXTENSION
4.37 TM 11% COTTON 89% DACRON

FIGURE 47b

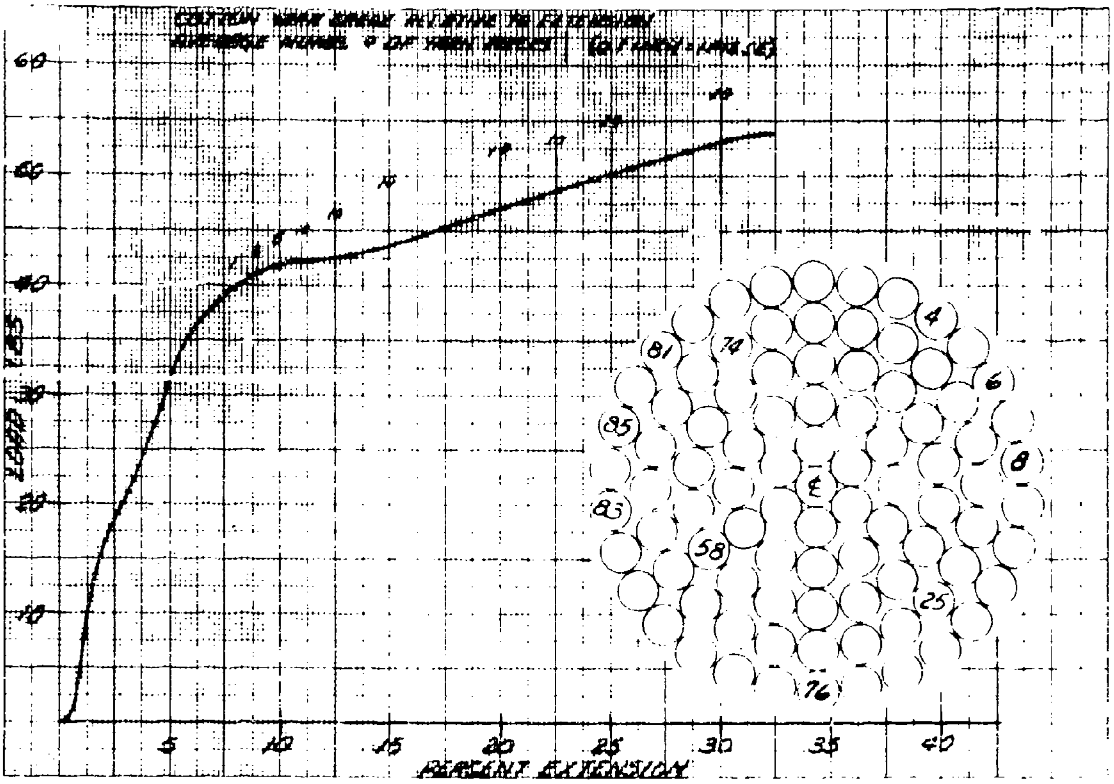


FIGURE [illegible] COTTON [illegible] DACRON [illegible]

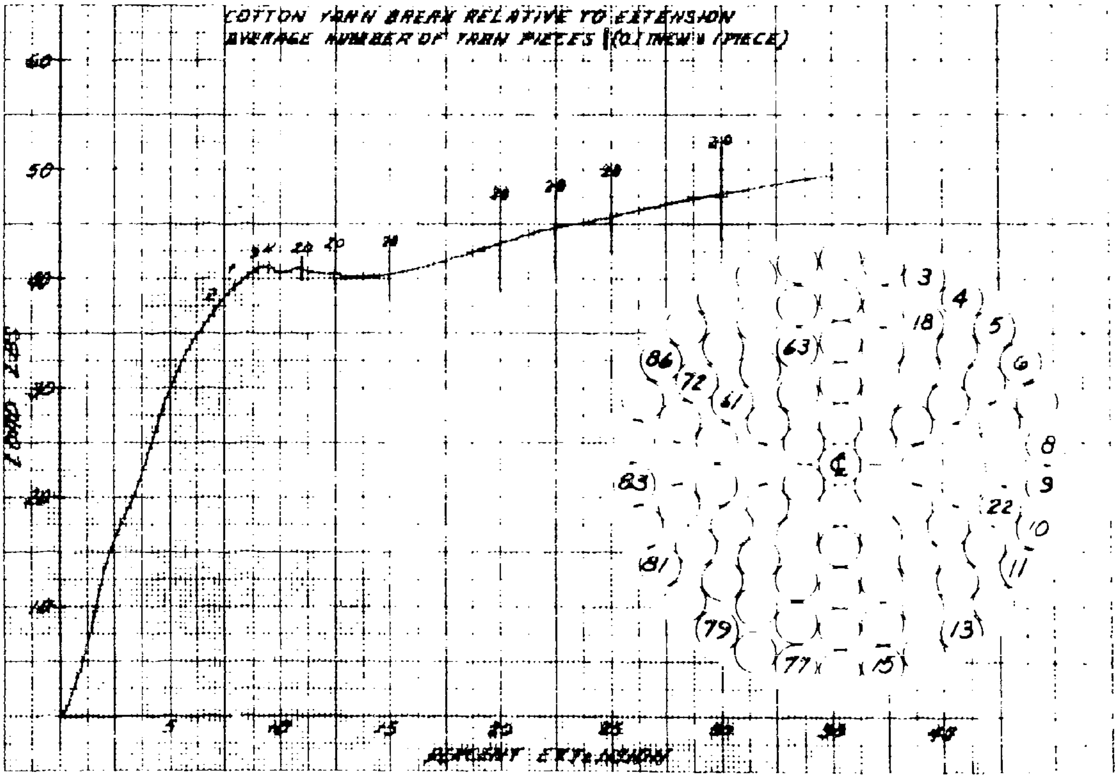
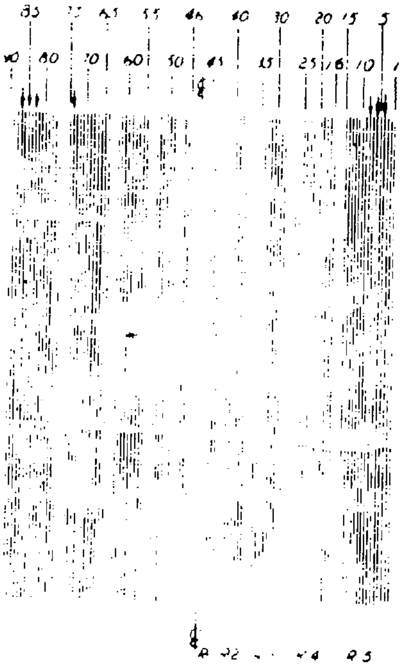
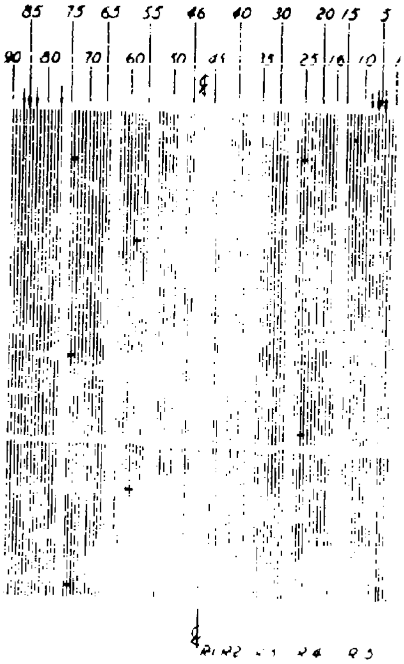


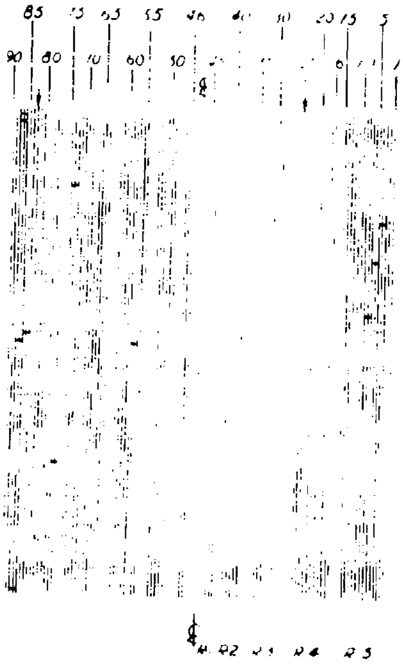
FIGURE [illegible] DACRON [illegible]



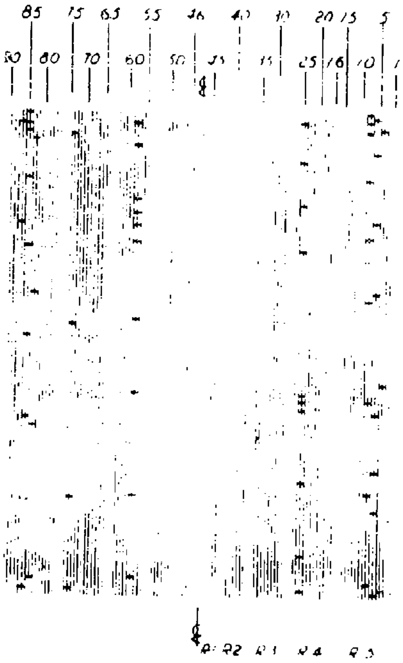
8% EXTENSION
[illegible] M 11% COTTON 89% DACRON



9% EXTENSION
2.18 TM 11% COTTON 89% DACRON

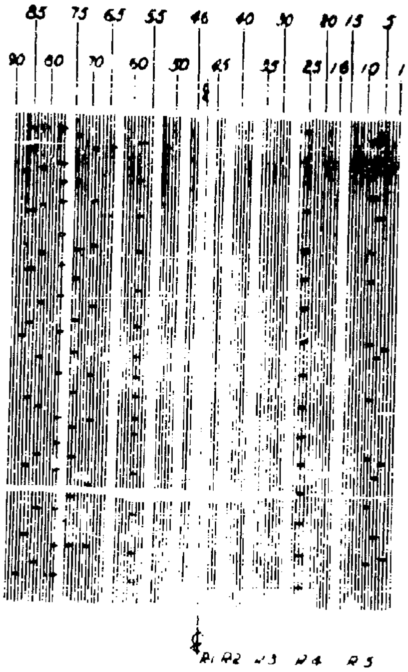


10% EXTENSION
.18 TM 11% COTTON 89% DACRON

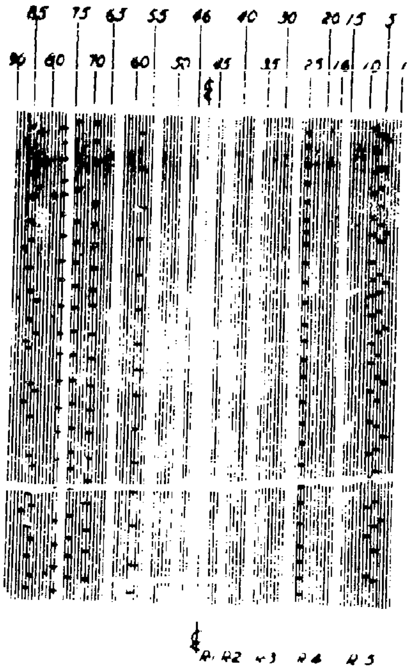


11% EXTENSION
[illegible] C[illegible] 89% DACRON

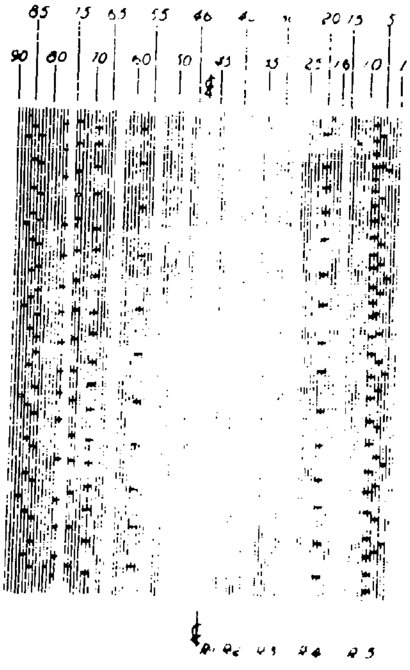
ure 43B



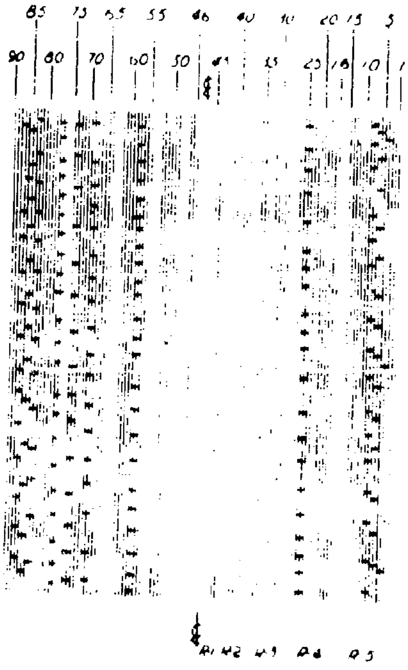
12-1/2% EXTENSION
2.18 TM 11% COTTON 89% DACRON



15% EXTENSION
2.18 TM 11% COTTON 89% DACRON

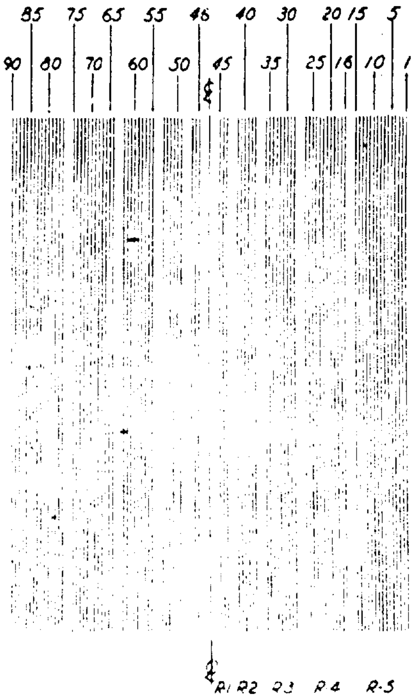


22-1/2% EXTENSION
2.18 TM 11% COTTON 89% DACRON

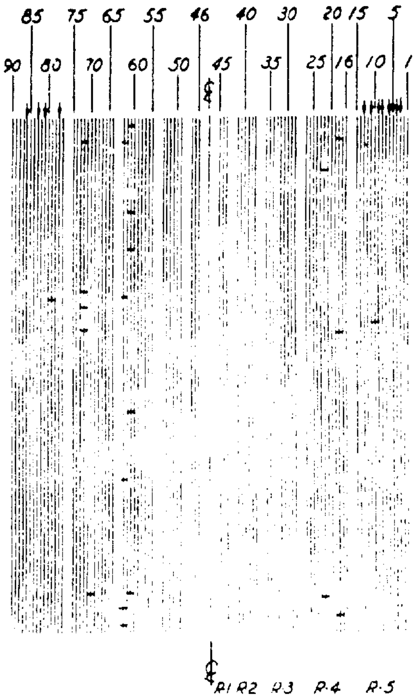


30% EXTENSION
2.18 TM 11% COTTON 89% DACRON

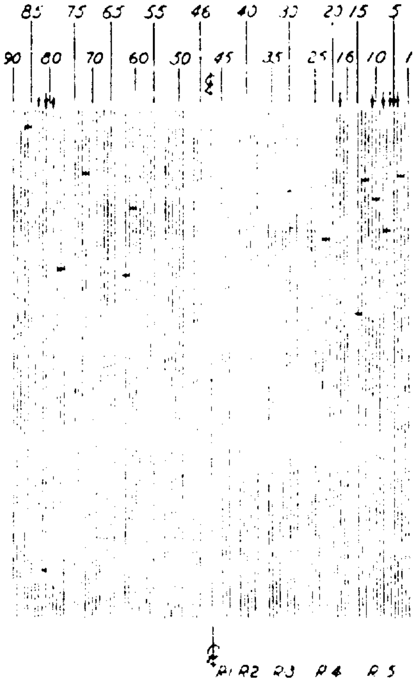
igure 43b



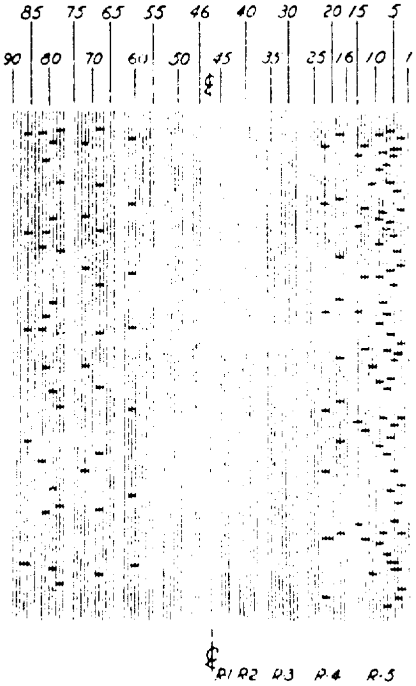
7% EXTENSION
2.18 TM 22% COTTON 78% DACRON



9% EXTENSION
2.18 TM 22% COTTON 78% DACRON

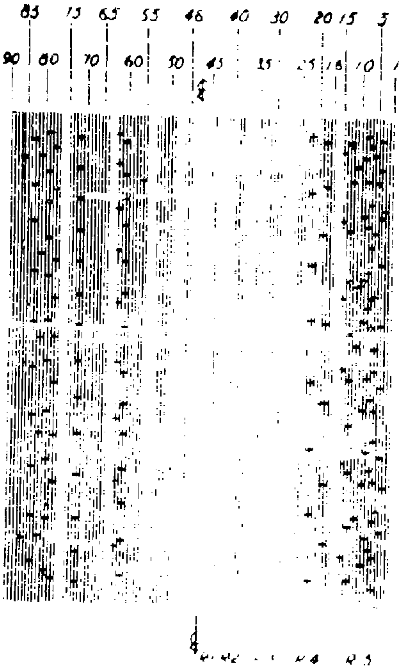


10% EXTENSION
2.18 TM 22% COTTON 78% DACRON

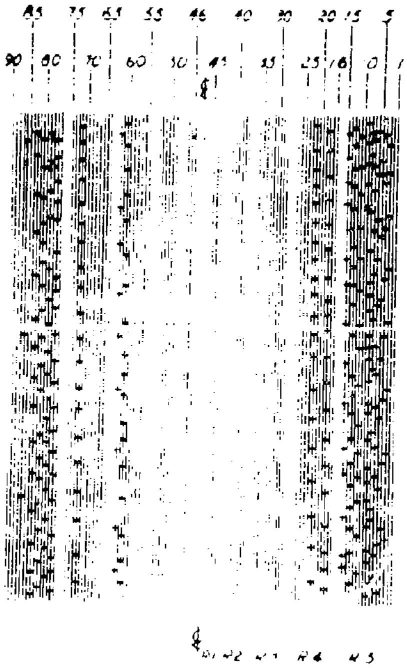


12-1/2% EXTENSION
2.18 TM 22% COTTON 78% DACRON

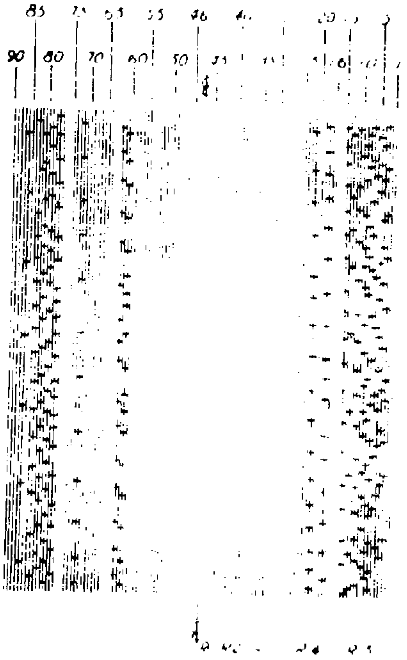
FIGURE 44a



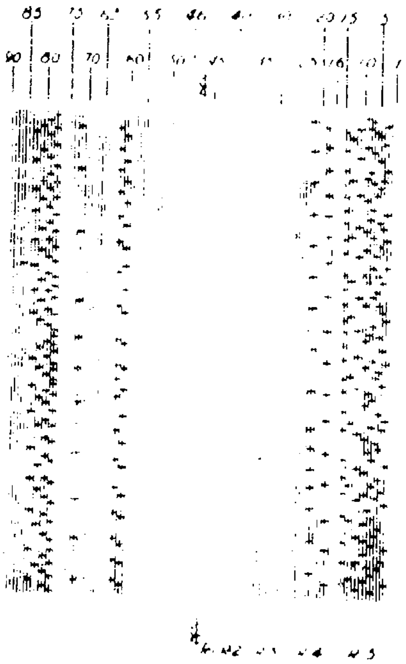
15% EXTENSION
2.18 TM 22% COTTON 78% DACRON



20% EXTENSION
2.18 TM 22% COTTON 78% DACRON

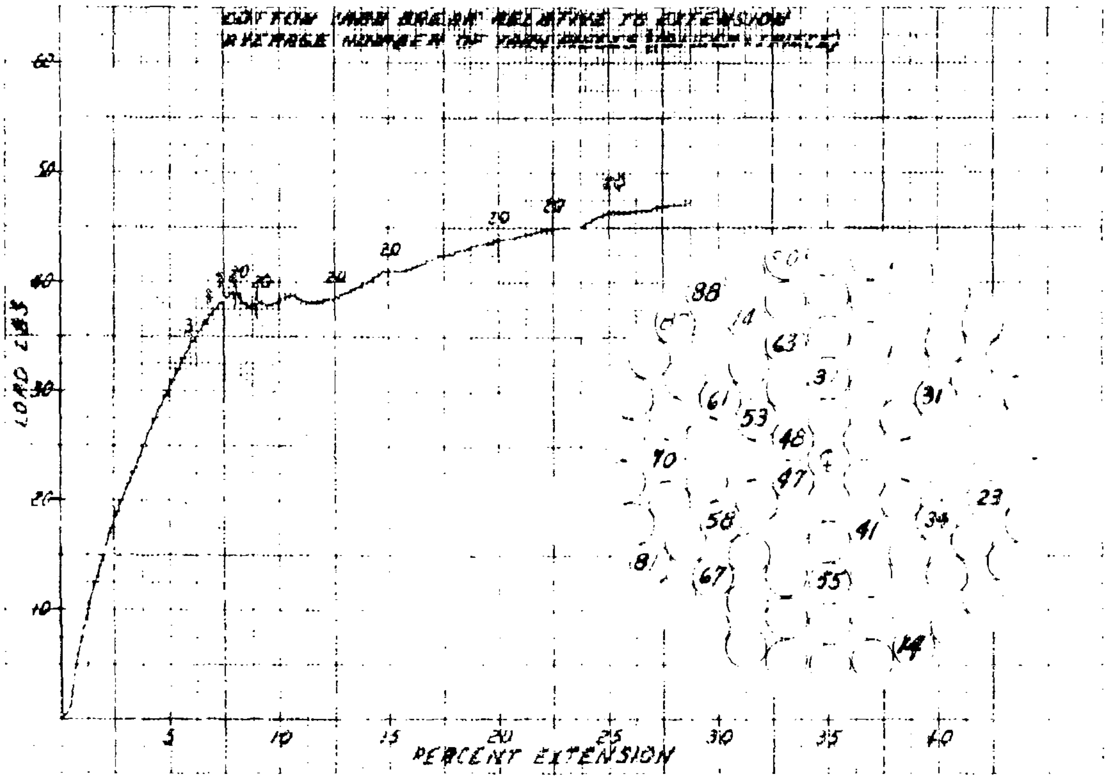


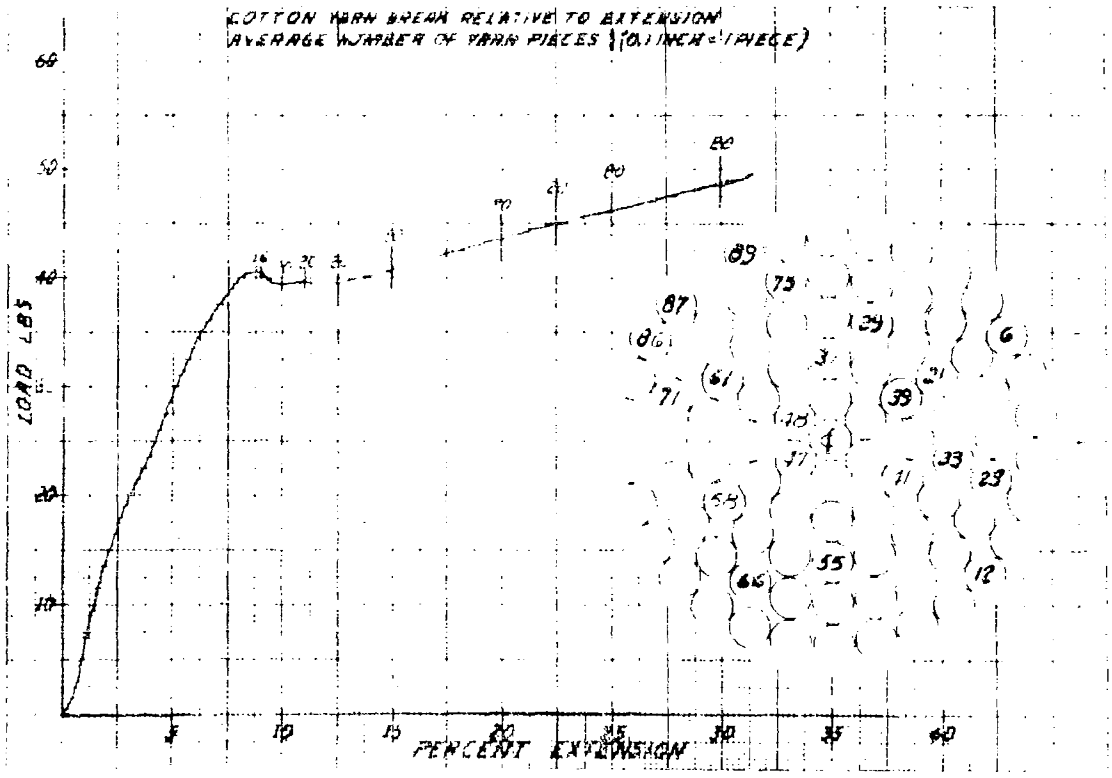
25% EXTENSION
2.18 TM 22% COTTON 78% DACRON

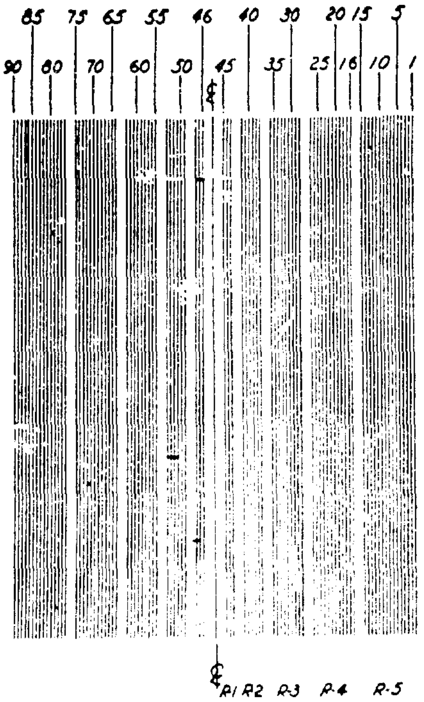


30% EXTENSION
2.18 TM 22% COTTON 78% DACRON

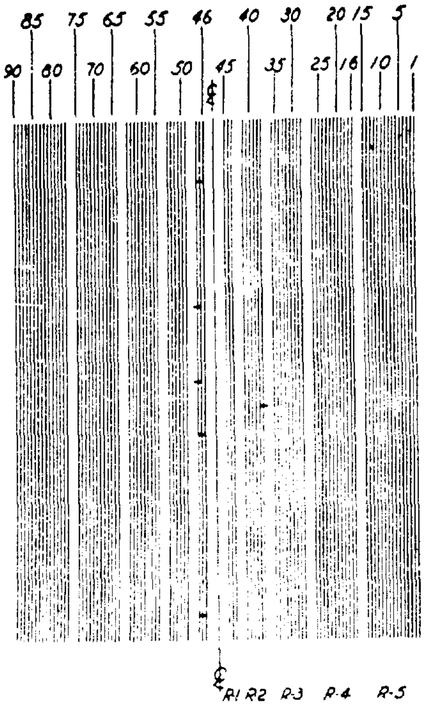
FIGURE 44C


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES (0.1 INCH = 1 PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
3
20
20
20
20
20
20
25
88
14
63
3
61
53
48
4
47
31
70
58
41
34
23
81
67
55
14

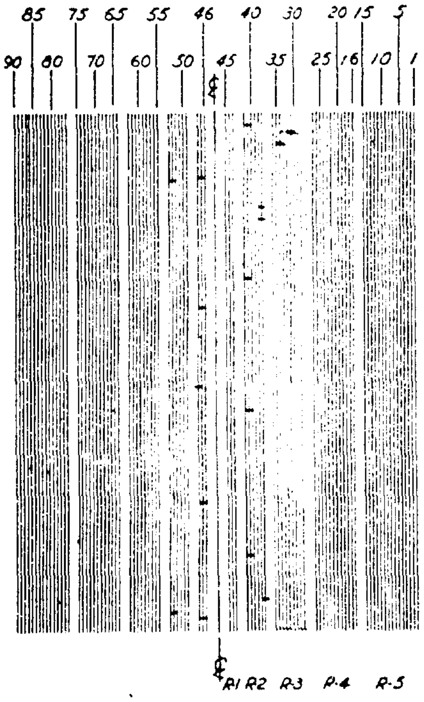

COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF YARN PIECES (0.1 INCH = 1 PIECE)
LOAD LBS
60
50
40
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION
16
20
20
80
80
89
73
87
86
29
6
3
61
71
39
21
18
4
37
11
33
23
58
55
66
12



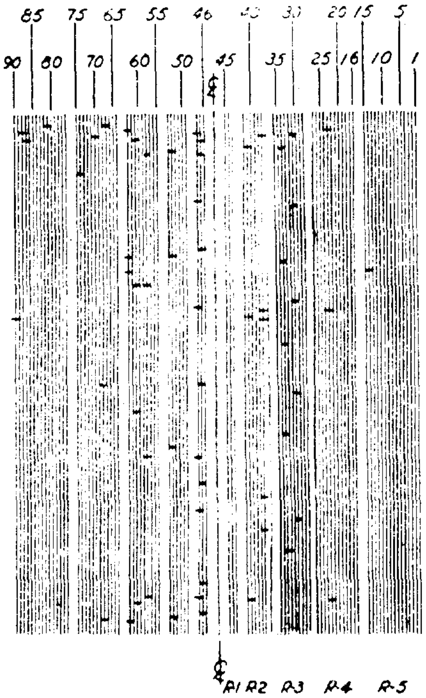
6% EXTENSION
0.54 TM 22% COTTON 78% DACRON



7% EXTENSION
0.54 TM 22% COTTON 78% DACRON

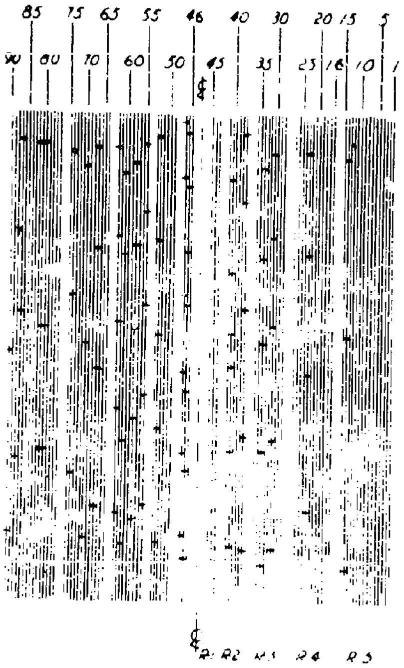


7-1/2% EXTENSION
0.54 TM 22% COTTON 78% DACRON

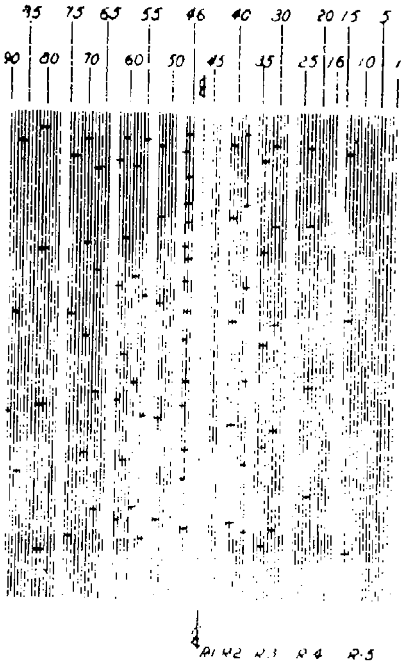


8% EXTENSION
0.54 TM 22% COTTON 78% DACRON

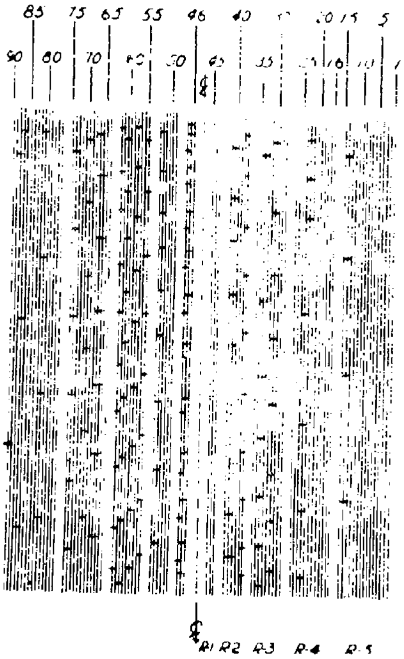
FIGURE 45a



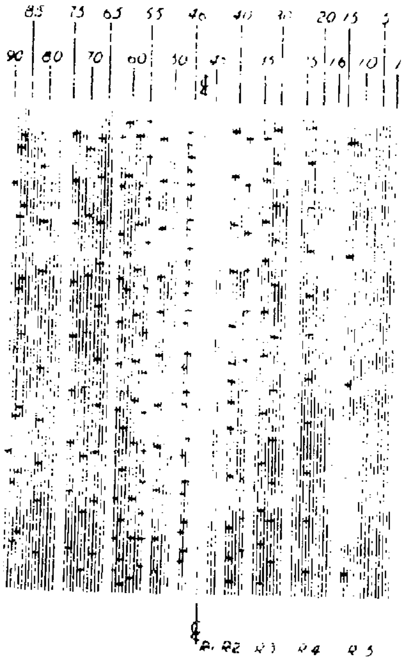
12-1/2% EXTENSION
0.54 TM 22% COTTON 78% DACRON



15% EXTENSION
0.54 TM 22% COTTON 78% DACRON

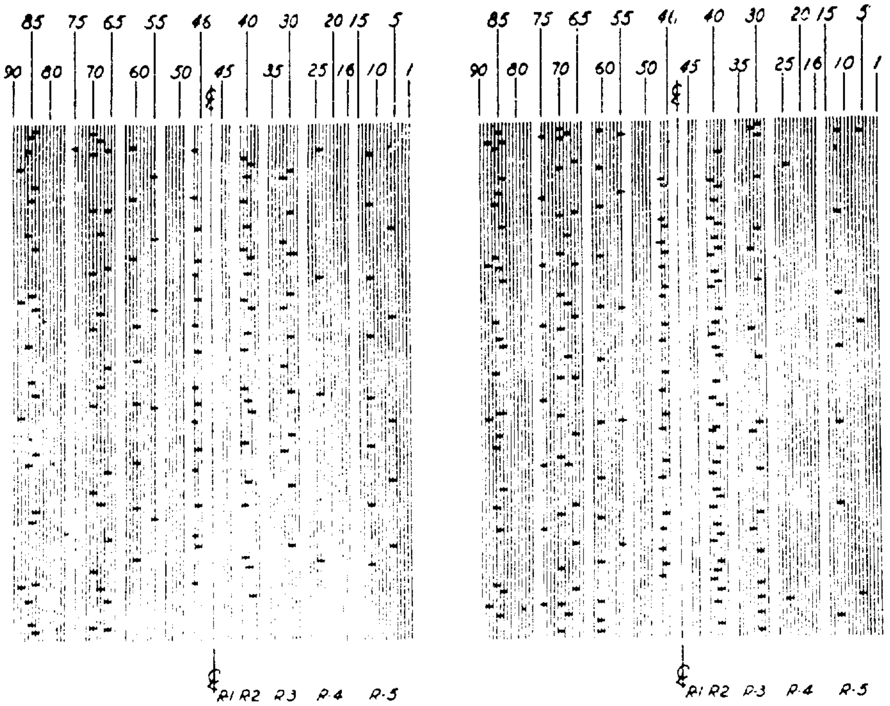


20% EXTENSION
0.54 TM 22% COTTON 78% DACRON



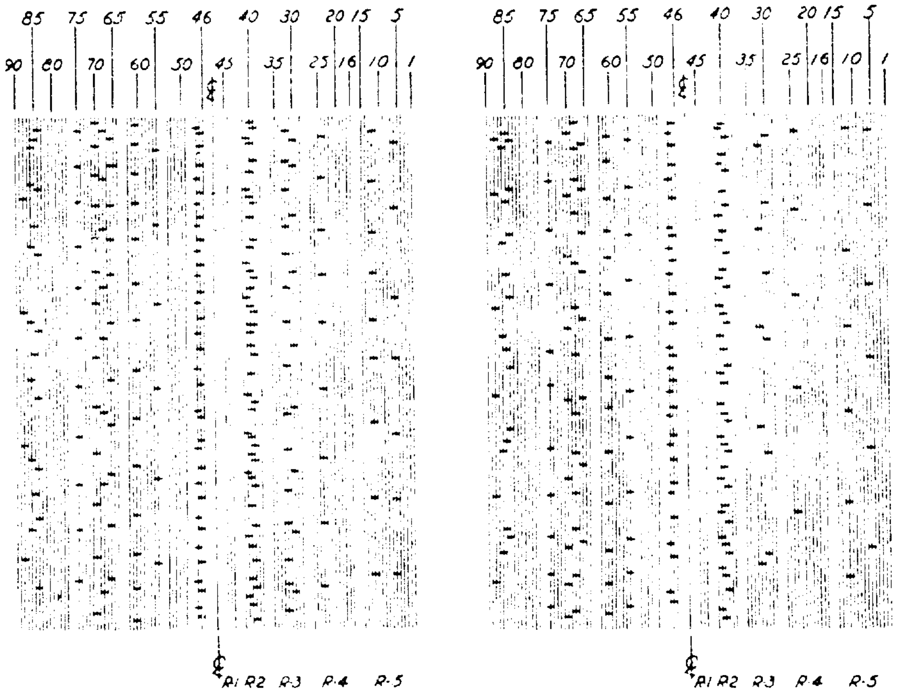
30% EXTENSION
0.54 TM 22% COTTON 78% DACRON

Figure 45f



15% EXTENSION
1.09 TM 22% COTTON 78% DACRON

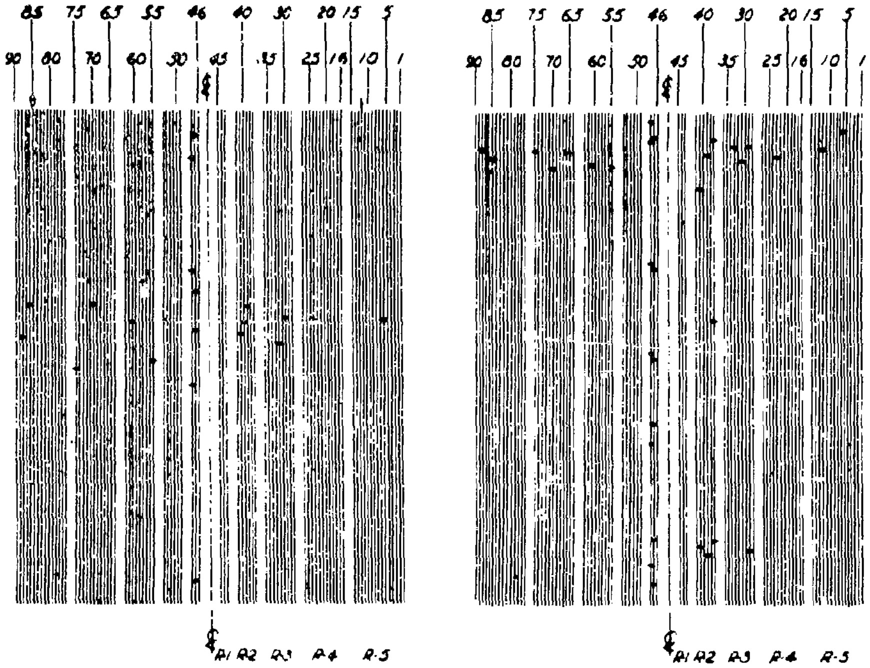
20% EXTENSION
1.09 TM 22% COTTON 78% DACRON



25% EXTENSION
1.09 TM 22% COTTON 78% DACRON

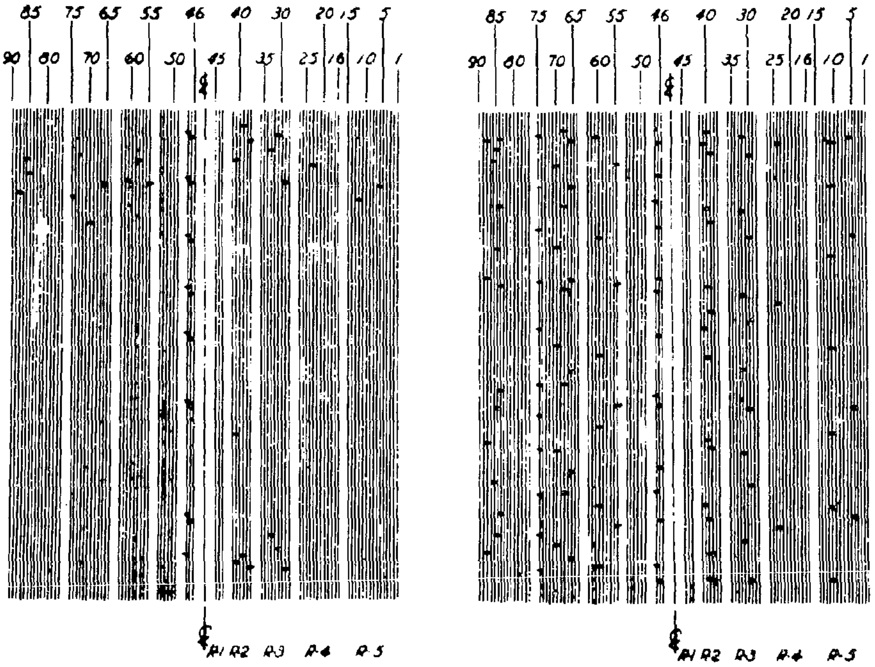
30% EXTENSION
1.09 TM 22% COTTON 78% DACRON

FIGURE 46A



9% EXTENSION
1.09TM 22% COTTON 78% DACRON

10% EXTENSION
1.09TM 22% COTTON 78% DACRON



11% EXTENSION
1.09 TM 22% COTTON 78% DACRON

12½% EXTENSION
1.09TM 22% COTTON 78% DACRON

FIGURE 46b

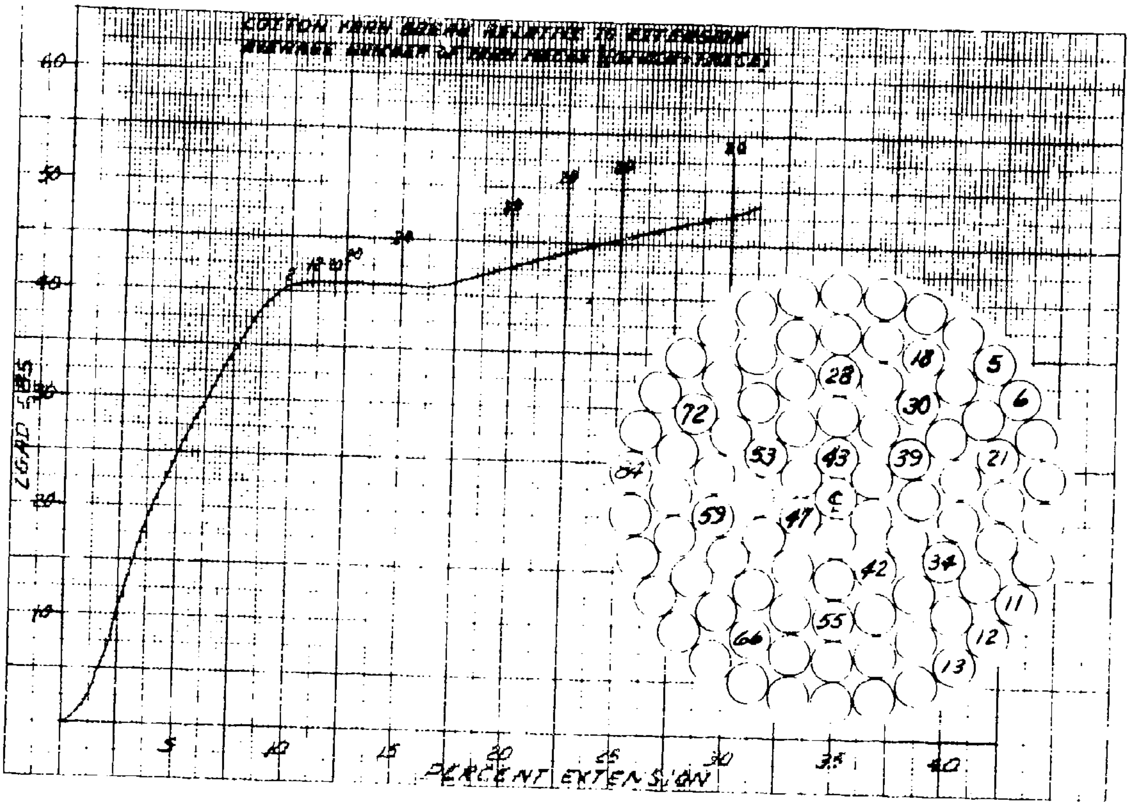


FIGURE [illegible] COTTON [illegible] DACRON [illegible]

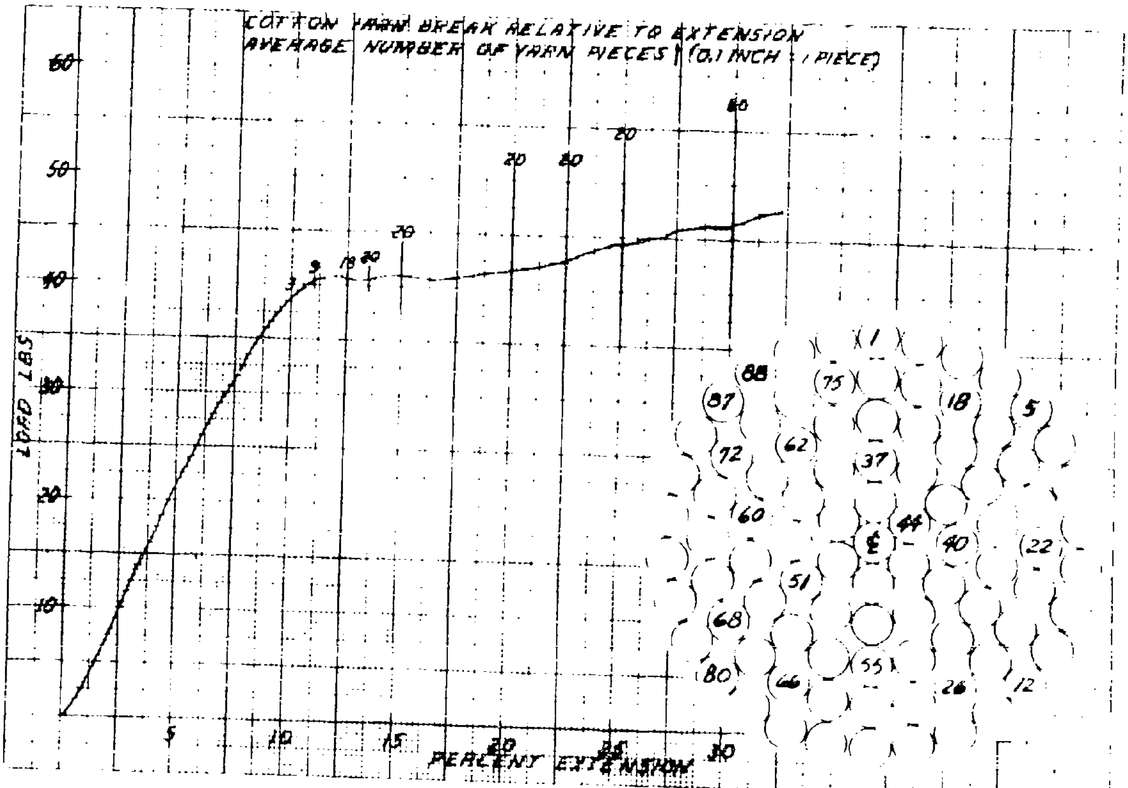
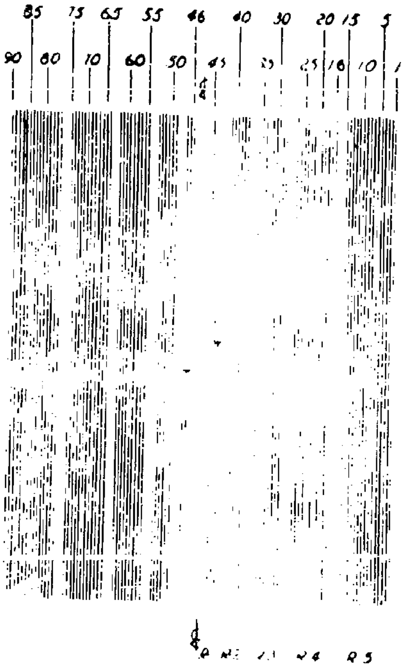
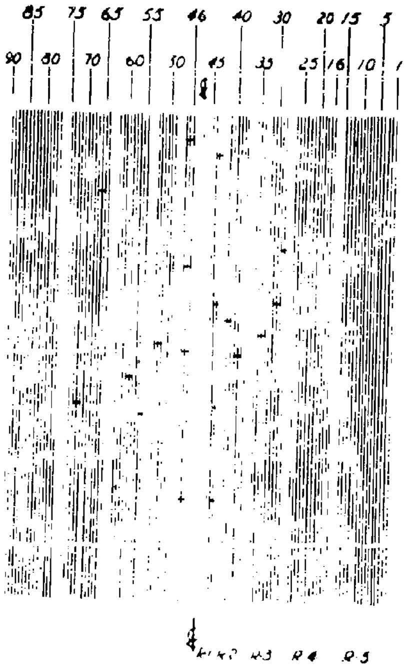


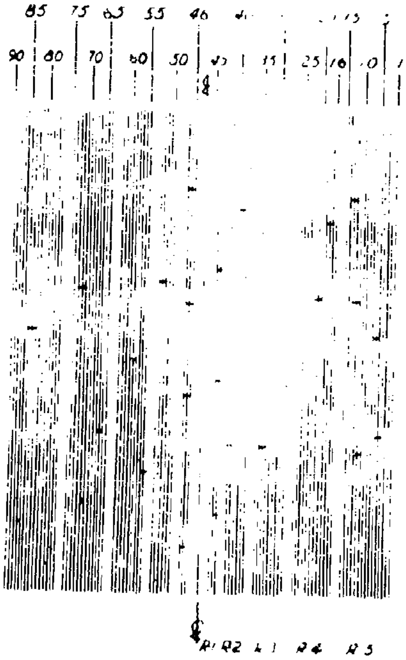
FIGURE 18 [illegible] COTTON [illegible] ACRON [illegible]



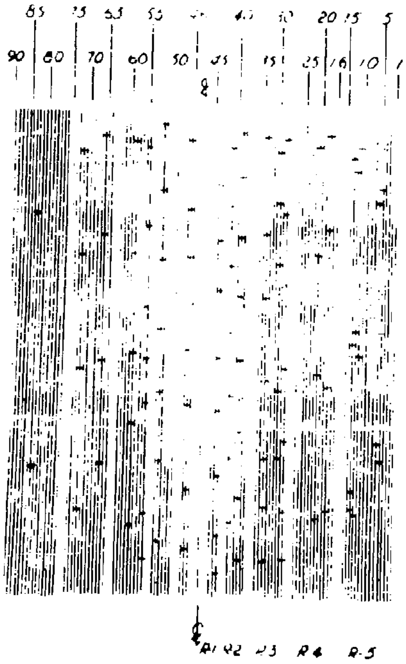
10% EXTENSION
2.18 TM 22% COTTON 78% DACRON



11% EXTENSION
2.18 TM 22% COTTON 78% DACRON

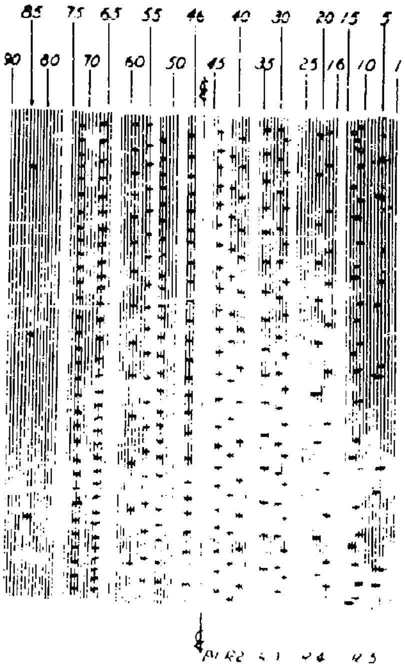


12% EXTENSION
2.18 TM 22% COTTON 78% DACRON

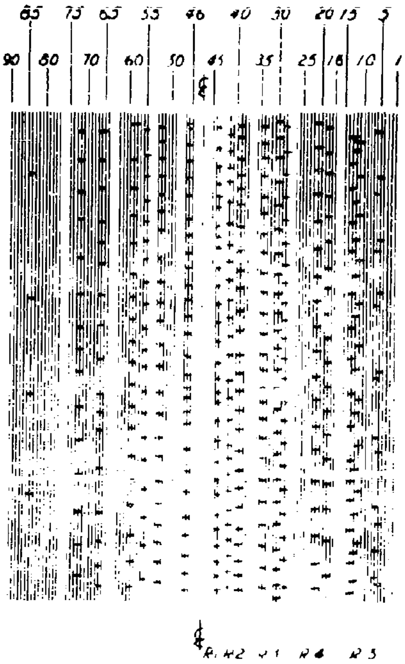


12-1/2% EXTENSION
2.18 TM 22% COTTON 78% DACRON

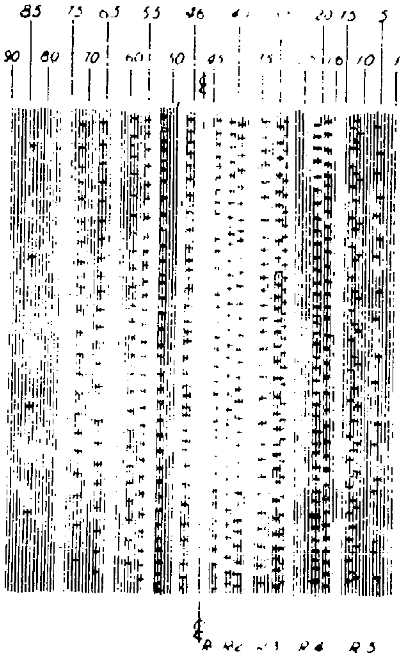
FIGURE 4.[illegible]



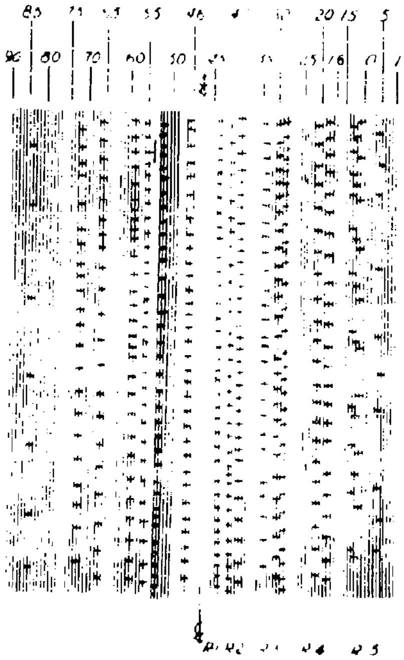
15% EXTENSION
2.18 TM 22% COTTON 78% DACRON



20% EXTENSION
2.18 TM 22% COTTON 78% DACRON

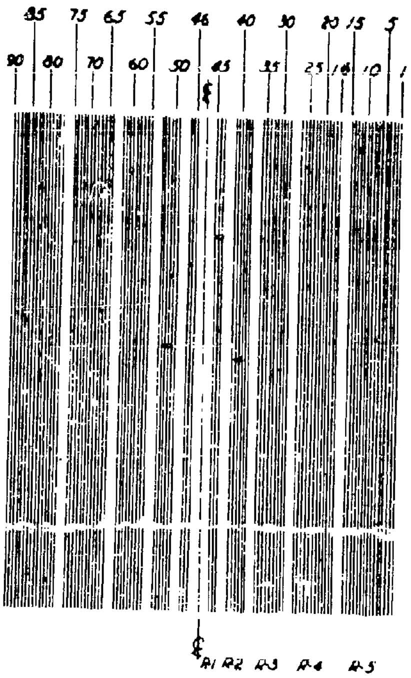


22-1/2 % EXTENSION
2.18 TM 22% COTTON 78% DACRON

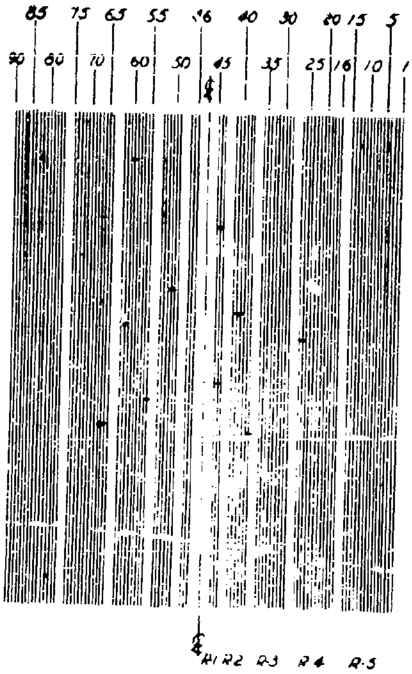


30% EXTENSION
2.18 TM 22% COTTON 78% DACRON

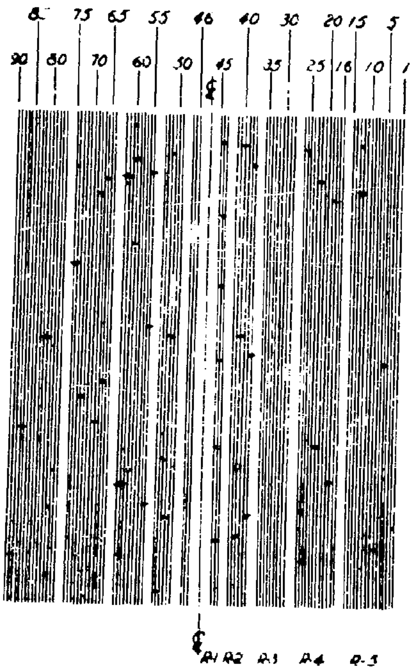
FIGURE 11



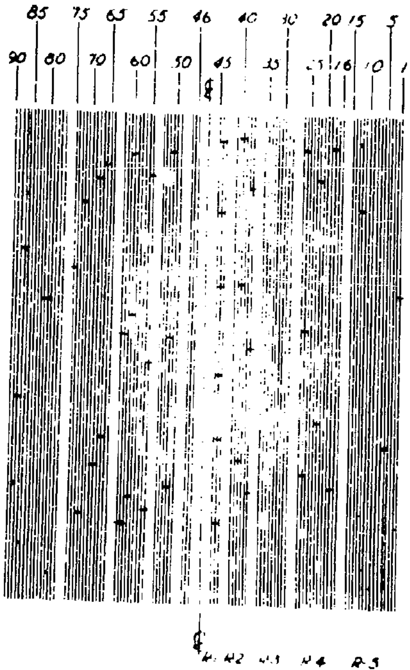
10% EXTENSION
3.27 TM 22% COTTON 78% DACRON



11% EXTENSION
3.27 TM 22% COTTON 78% DACRON

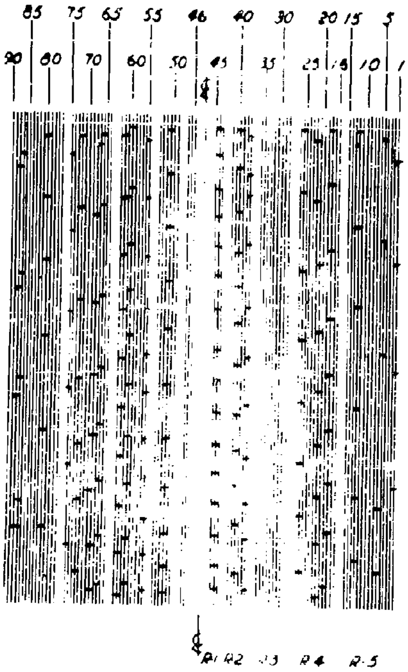


12-1/2% EXTENSION
3.27 TM 22% COTTON 78% DACRON

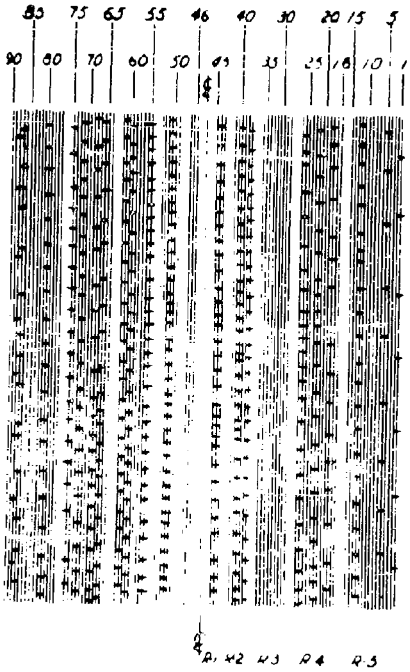


13-1/2% EXTENSION
3.27 TM 22% COTTON 78% DACRON

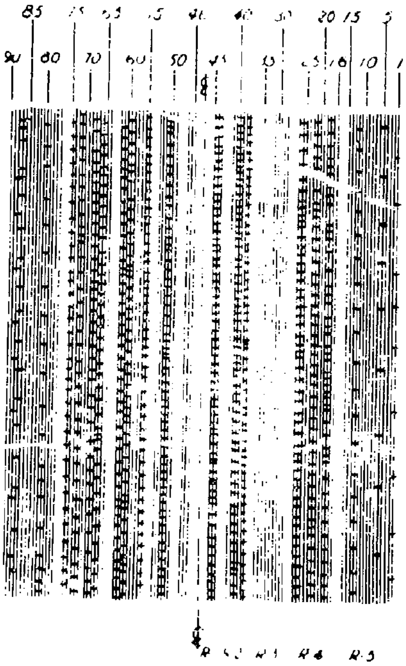
FIGURE 44a



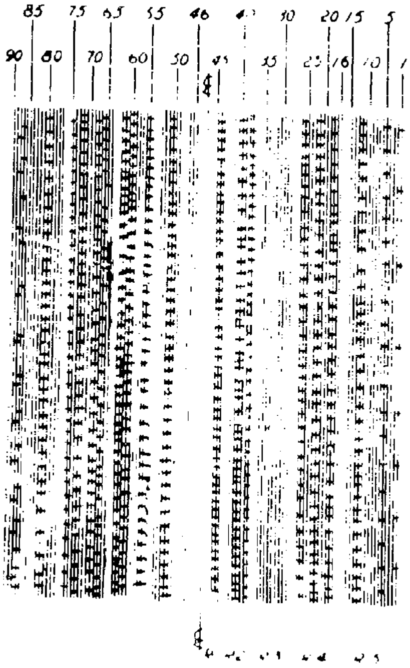
15% EXTENSION
3.27 TM 22% COTTON 78% DACRON



20% EXTENSION
3.27 TM 22% COTTON 78% DACRON



30% EXTENSION
3.27 TM 22% COTTON 78% DACRON



22-1/2% EXTENSION
3.27 TM 22% COTTON 78% DACRON

FIGURE [illegible]

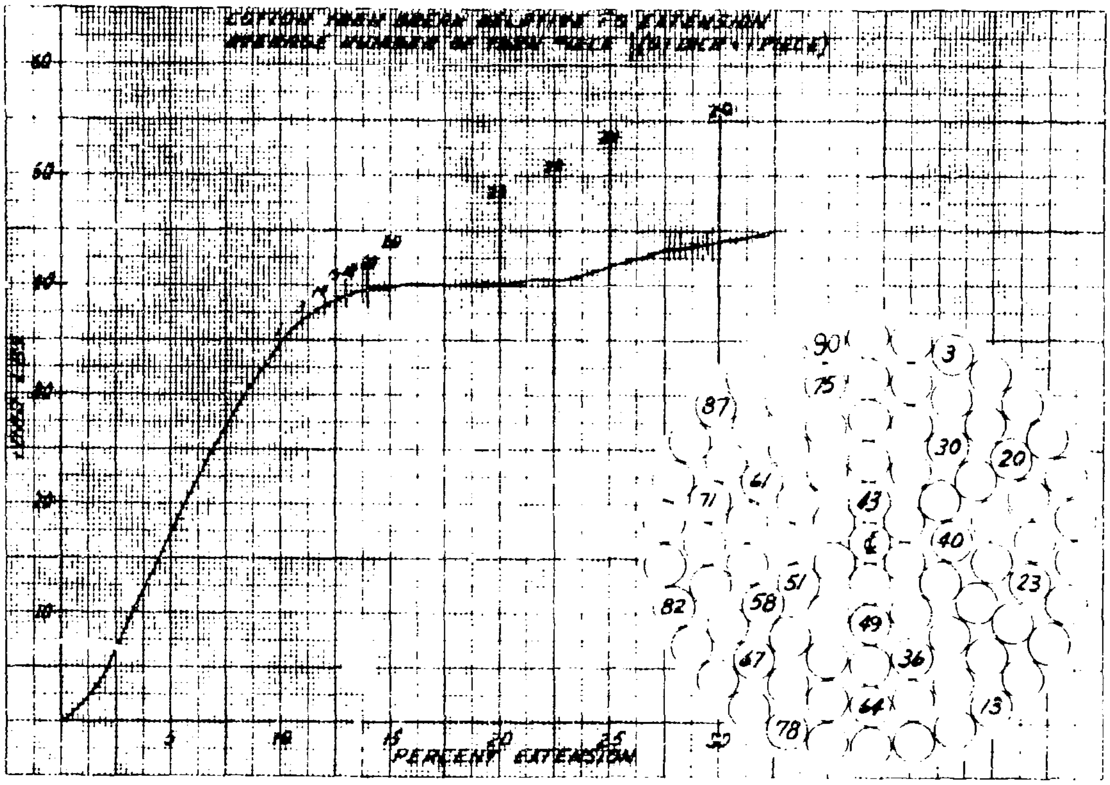


FIGURE 50 — 22% COTTON 78% DACRON 4 [illegible] IN

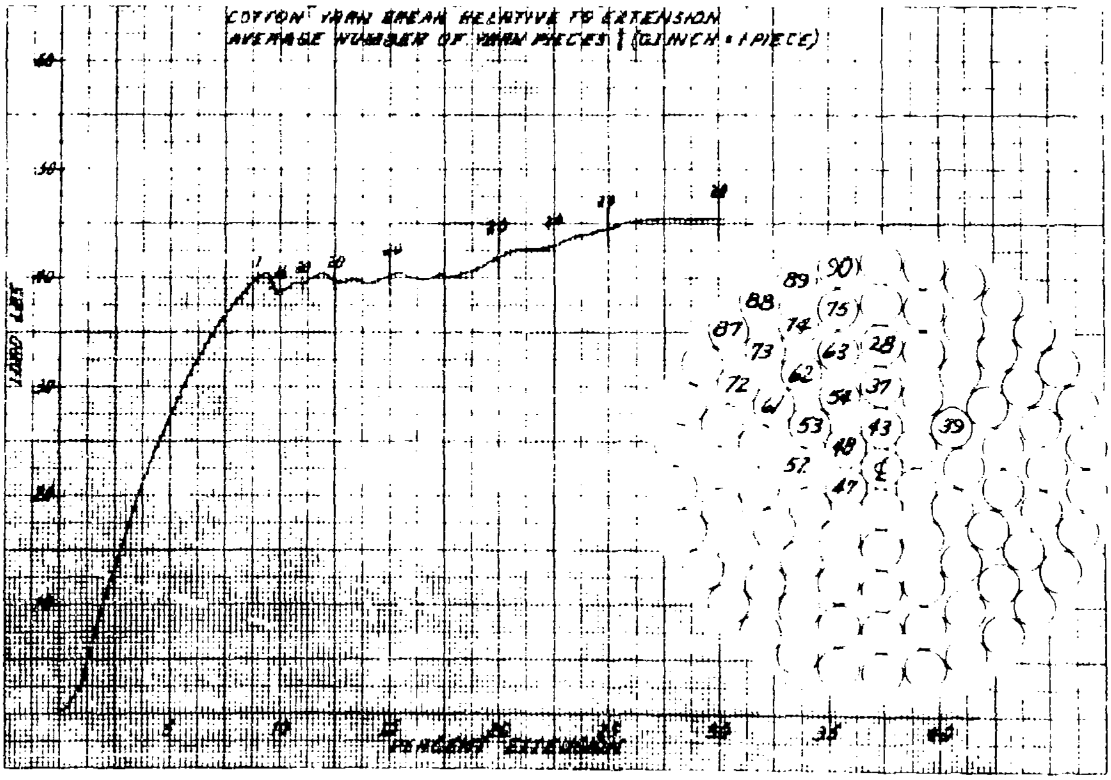
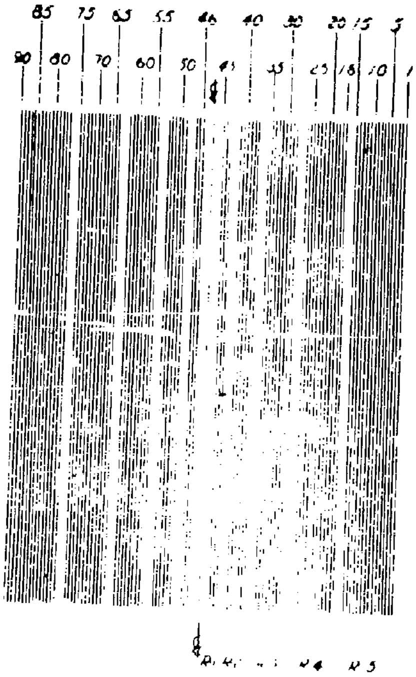
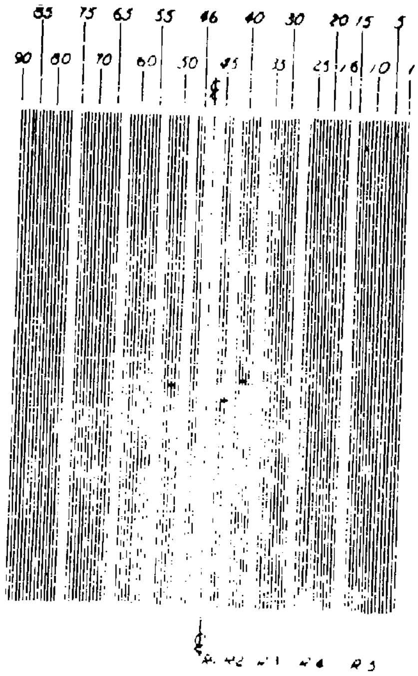


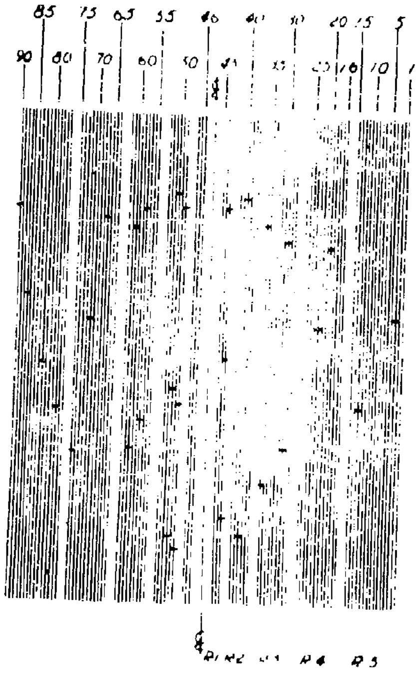
FIGURE 51 — 22% COTTON 78% DACRON 1 [illegible] IN



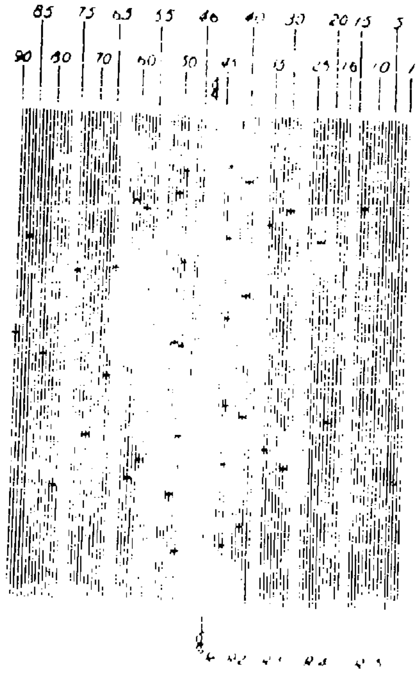
10% EXTENSION
4.36 TM 22% COTTON 78% DACRON



11% EXTENSION
4.36 TM 22% COTTON 78% DACRON

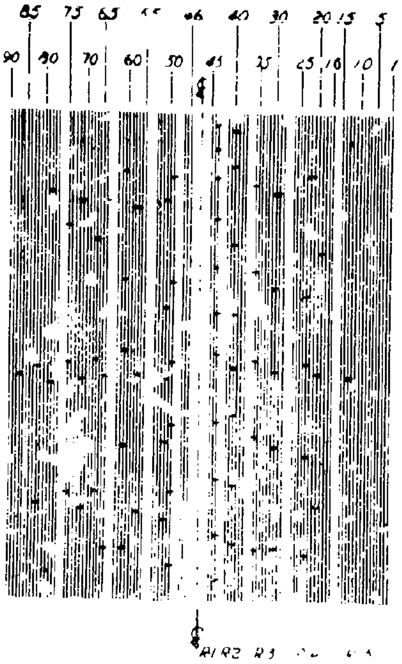


12% EXTENSION
4.36 TM 22% COTTON 78% DACRON

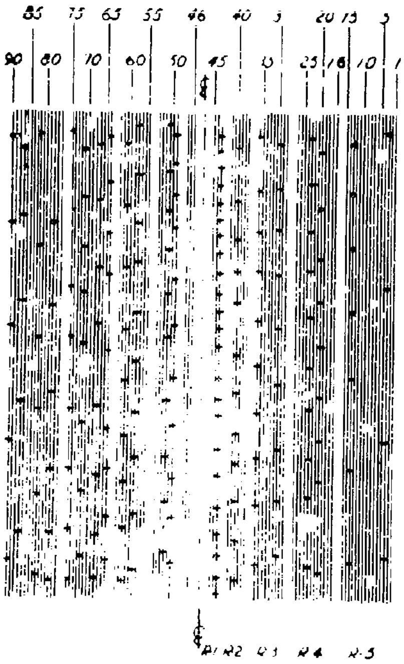


12 1/2% EXTENSION
4.36 TM 22% COTTON 78% DACRON

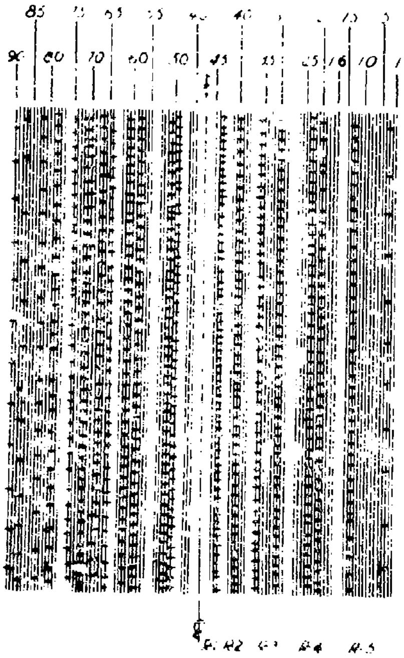
[illegible]



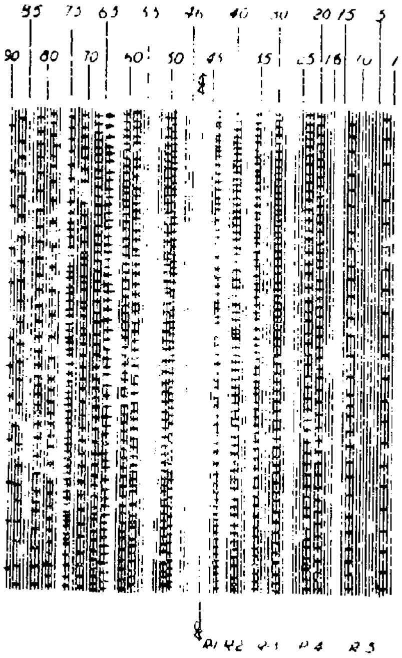
13% EXTENSION
4.36 TM 22% COTTON 78% DACRON



[illegible]5% EXTENSION
4.36 TM 22% COTTON 78% DACRON

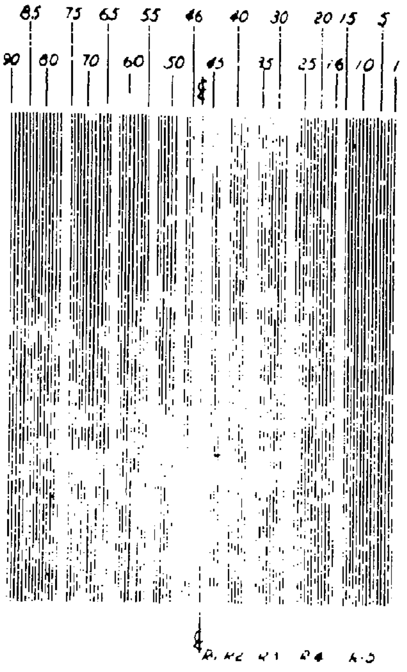


22-1/2% EXTENSION
4.36 TM 22% COTTON 78% DACRON

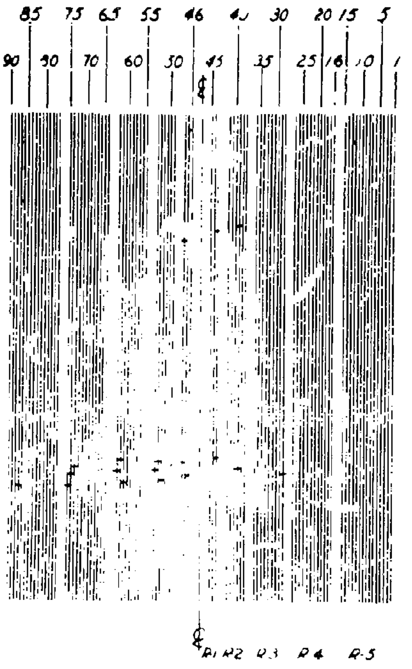


30% EXTENSION
4.36 TM 22% COTTON 78% DACRON

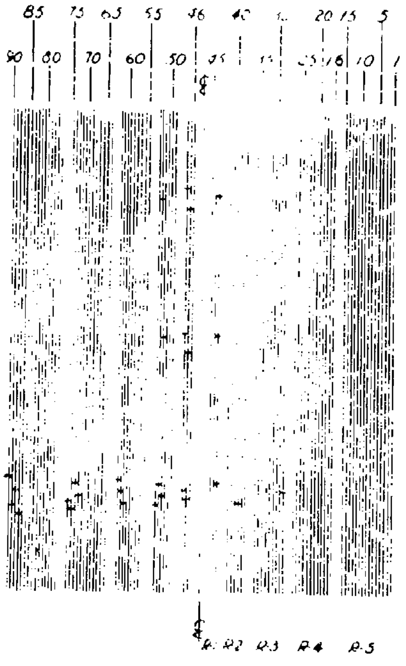
FIGURE 40



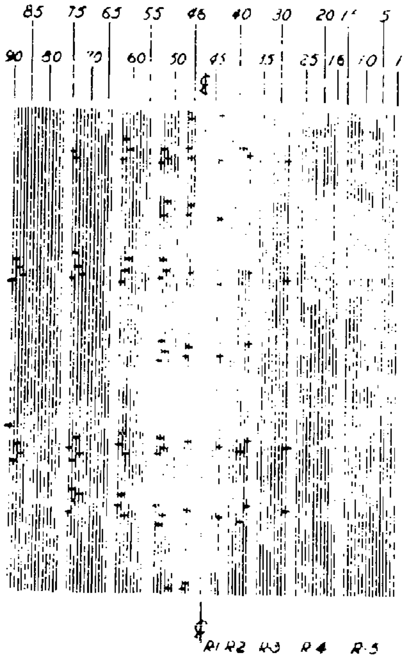
9% EXTENSION
1.09 TM 22% COTTON 78% DACRON



10% EXTENSION
1.09 TM 22% COTTON 78% DACRON

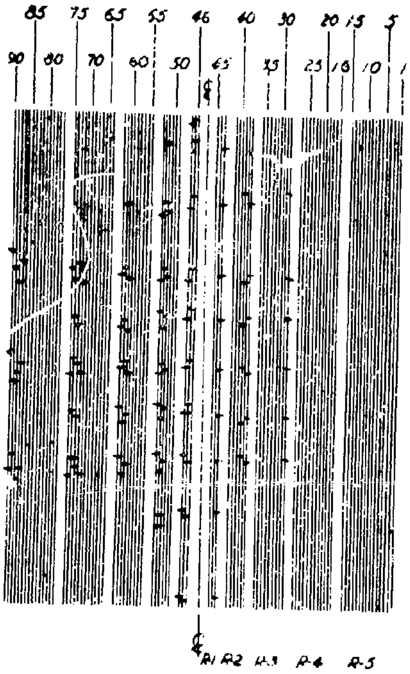


11% EXTENSION
1.09 TM 22% COTTON 78% DACRON

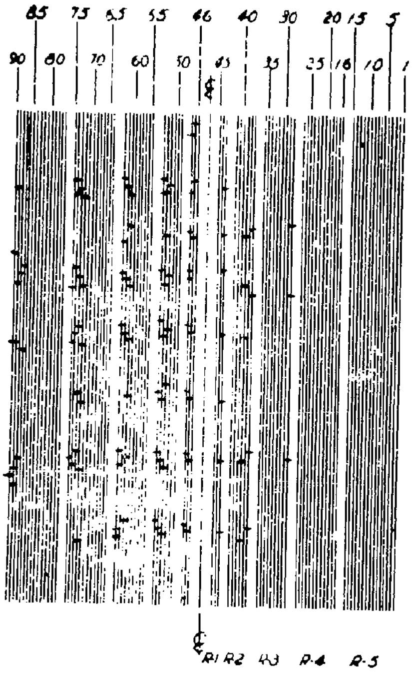


12-1/2% EXTENSION
1.09 TM 22% COTTON 78% DACRON

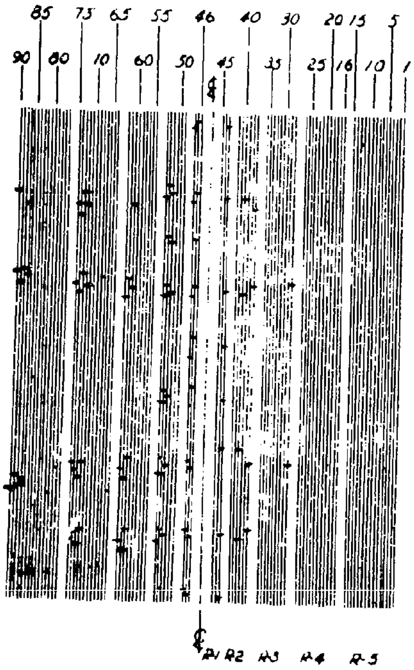
FIGURE [illegible]



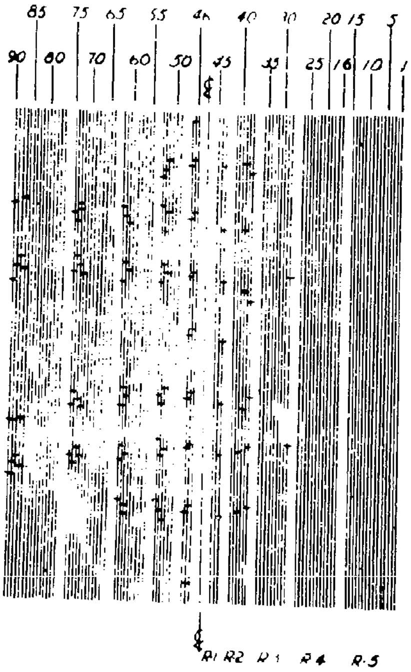
15% EXTENSION
1.09 TM 22% COTTON 78% DACRON



20% EXTENSION
1.09 TM 22% COTTON 78% DACRON

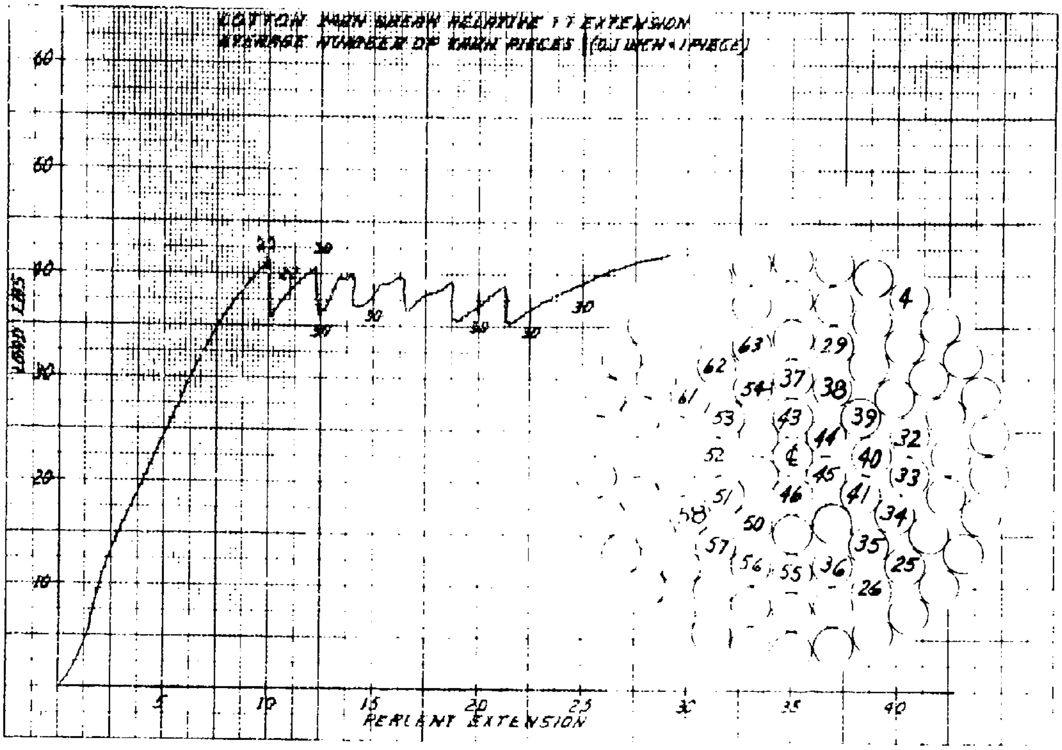


22-1/2% EXTENSION
1.09 TM 22% COTTON 78% DACRON

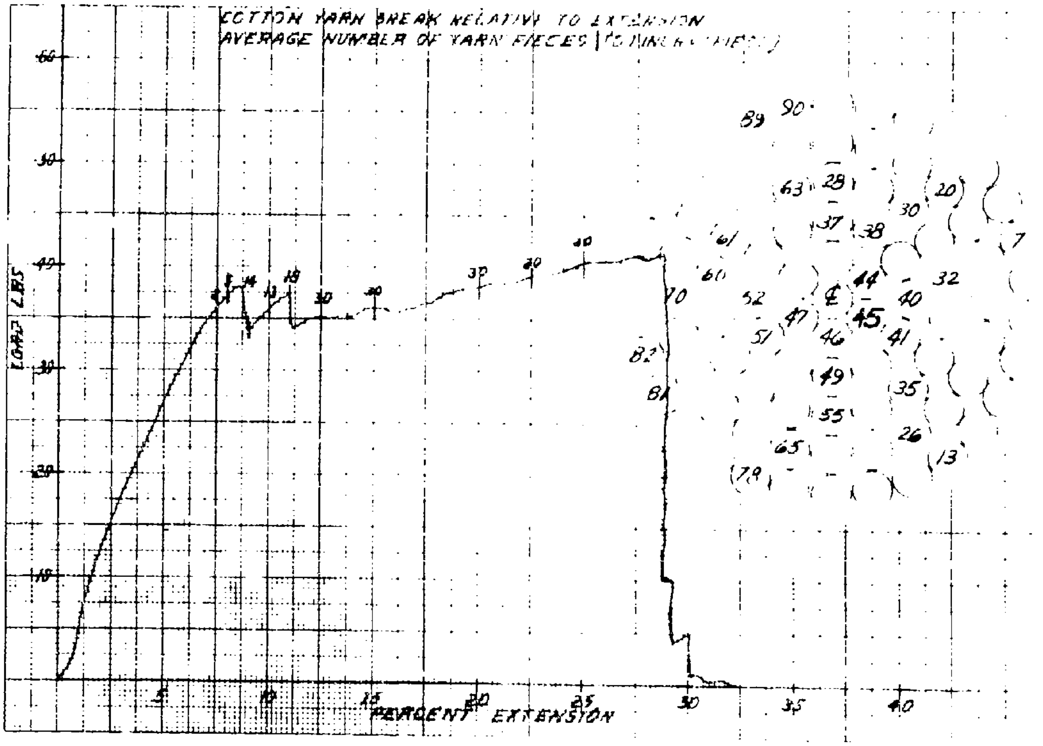


25% EXTENSION
1.09 TM 22% COTTON 78% DACRON

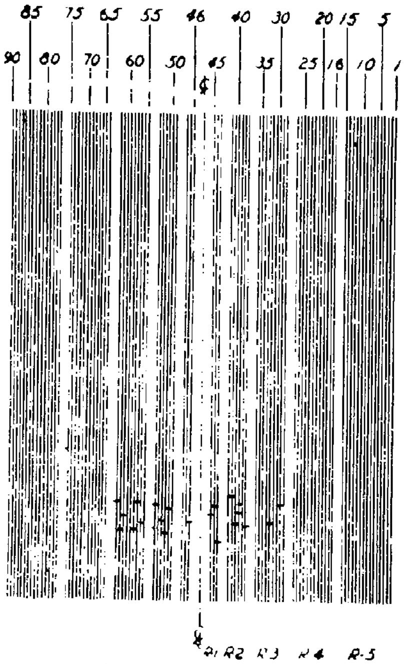
FIGURE 50b



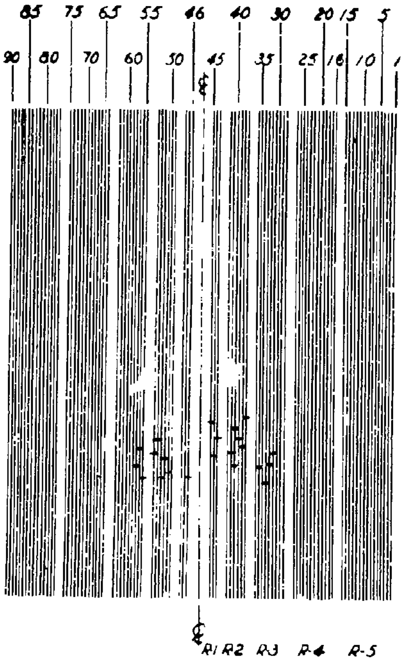
FIGURE



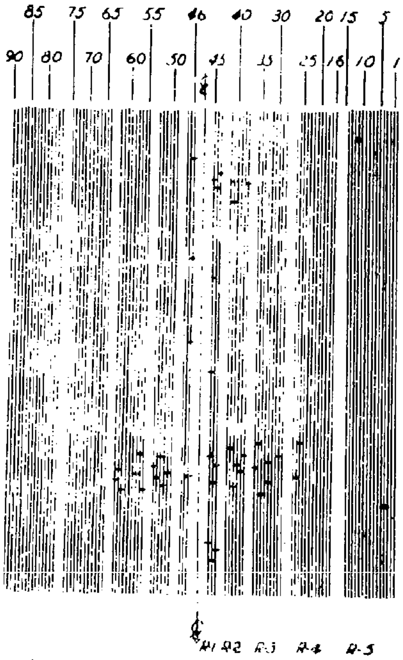
FIGURE



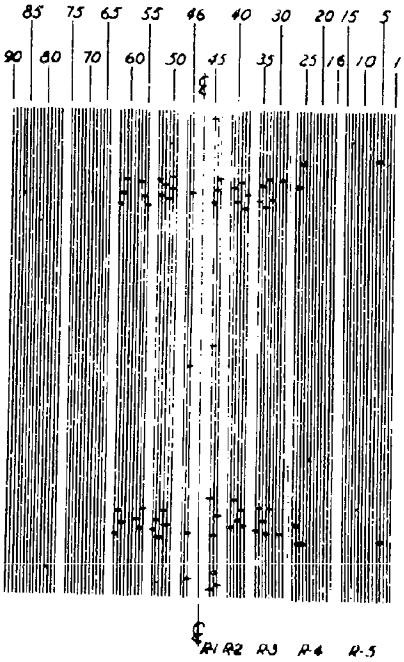
10% EXTENSION
1.09 TM 33% COTTON 67% DACRON



11% EXTENSION
1.09 TM 33% COTTON 67% DACRON

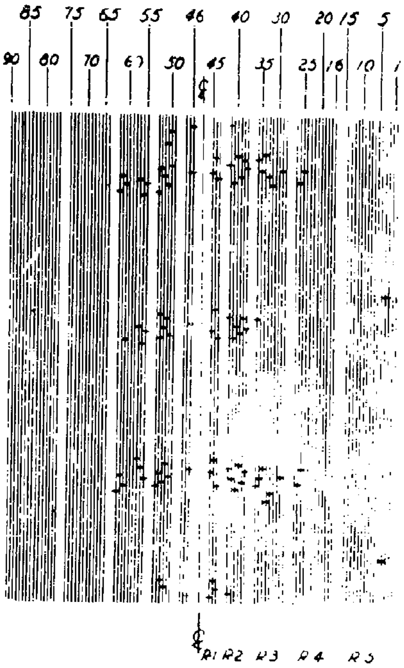


12-1/2% EXTENSION
1.09 TM 33% COTTON 67% DACRON

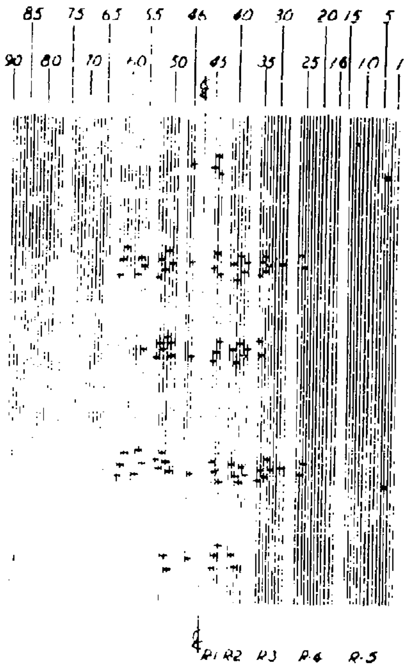


15% EXTENSION
1.09 TM 33% COTTON 67% DACRON

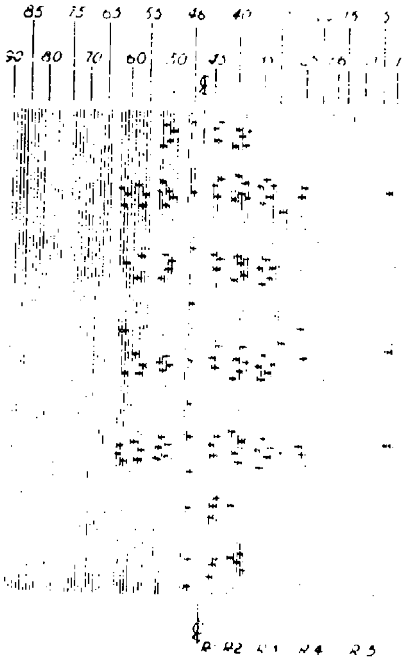
FIGURE 51a



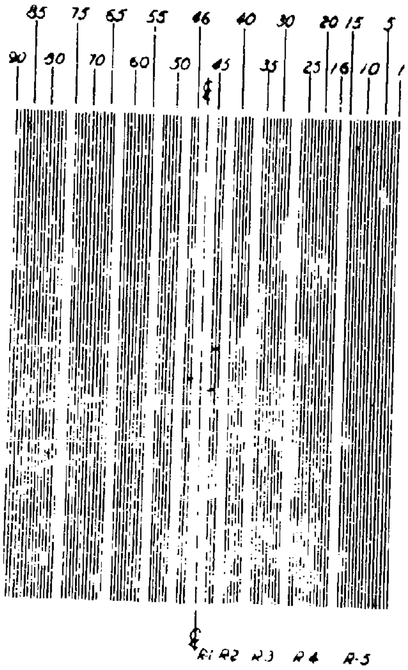
20% EXTENSION
1.09 TM 33% COTTON 67% DACRON



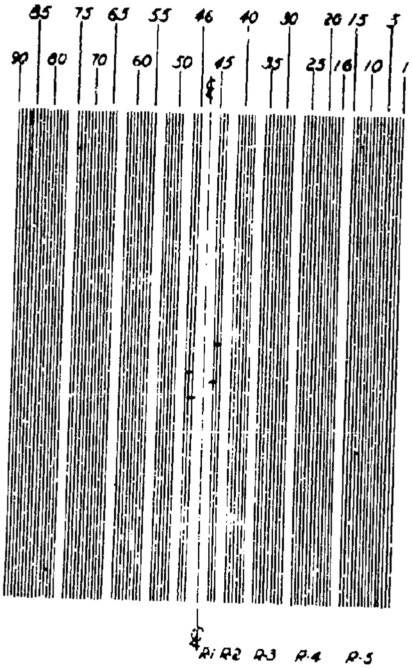
22-1/2% EXTENSION
1.09 TM 33% COTTON 67% DACRON



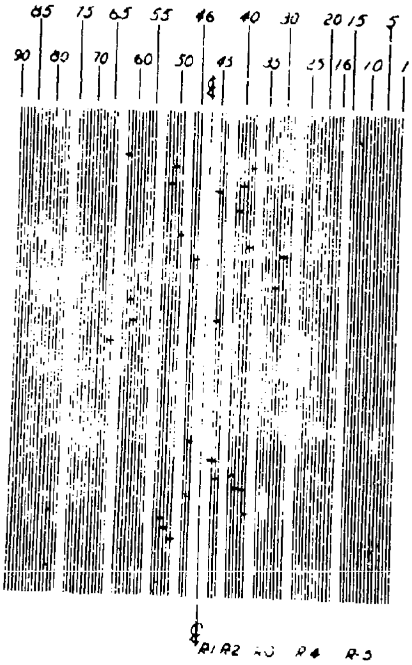
25% EXTENSION
1.09 TM 33% COTTON 67% DACRON



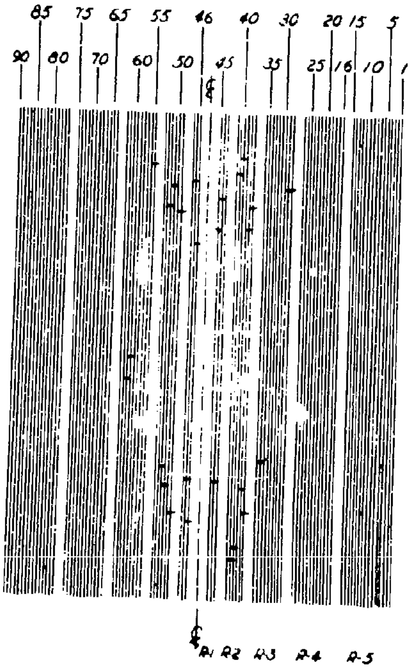
7-1/2% EXTENSION
0.54 TM 44% COTTON 56% DACRON



8% EXTENSION
0.54 TM 44% COTTON 56% DACRON

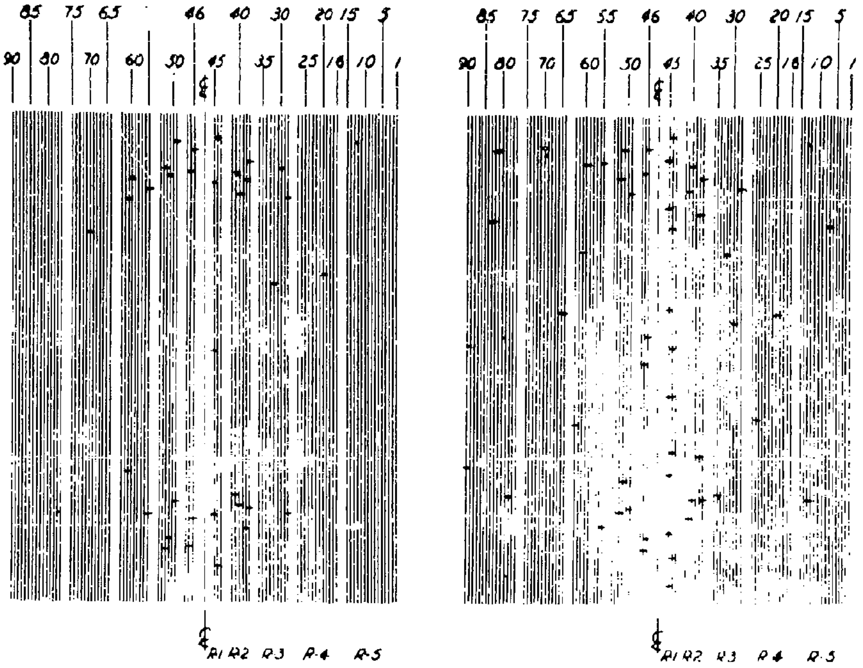


9% EXTENSION
0.54 TM 44% COTTON 56% DACRON



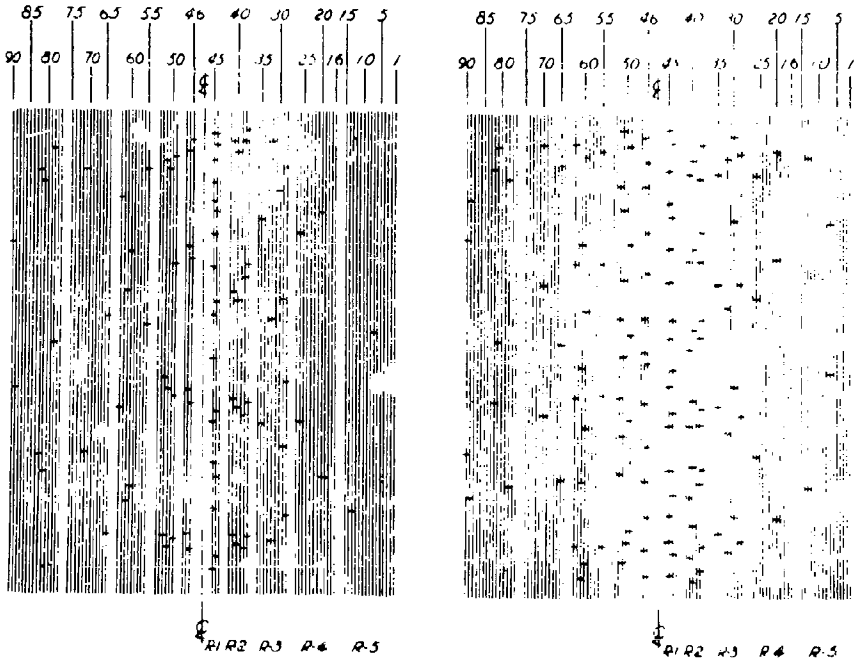
10% EXTENSION
0.54 TM 44% COTTON 56% DACRON

FIGURE 52a



11% EXTENSION
0.54 TM 44% COTTON 56% DACRON

12-1/2% EXTENSION
0.54 TM 44% COTTON 56% DACRON



15% EXTENSION
0.54 TM 44% COTTON 56% DACRON

25% EXTENSION
0.54 TM 44% COTTON 56% DACRON

FIGURE 52b

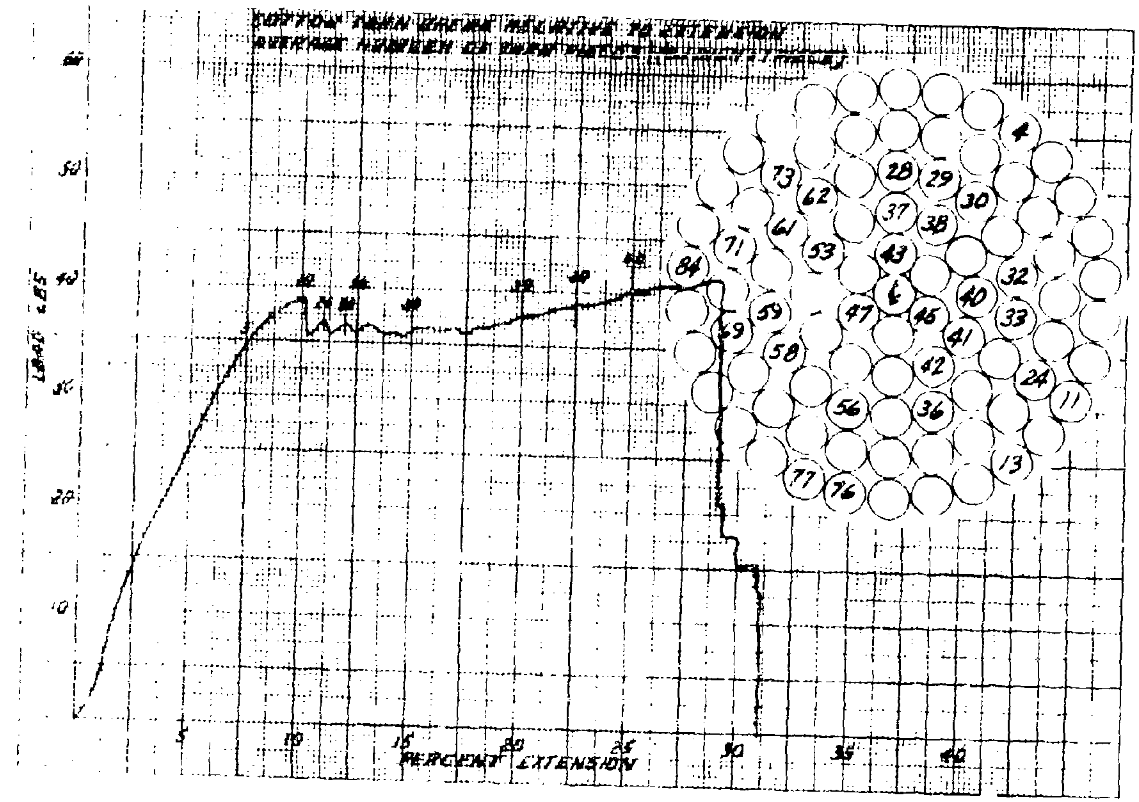


FIGURE 53 33% COTTON 67% DACRON 1.08 TM

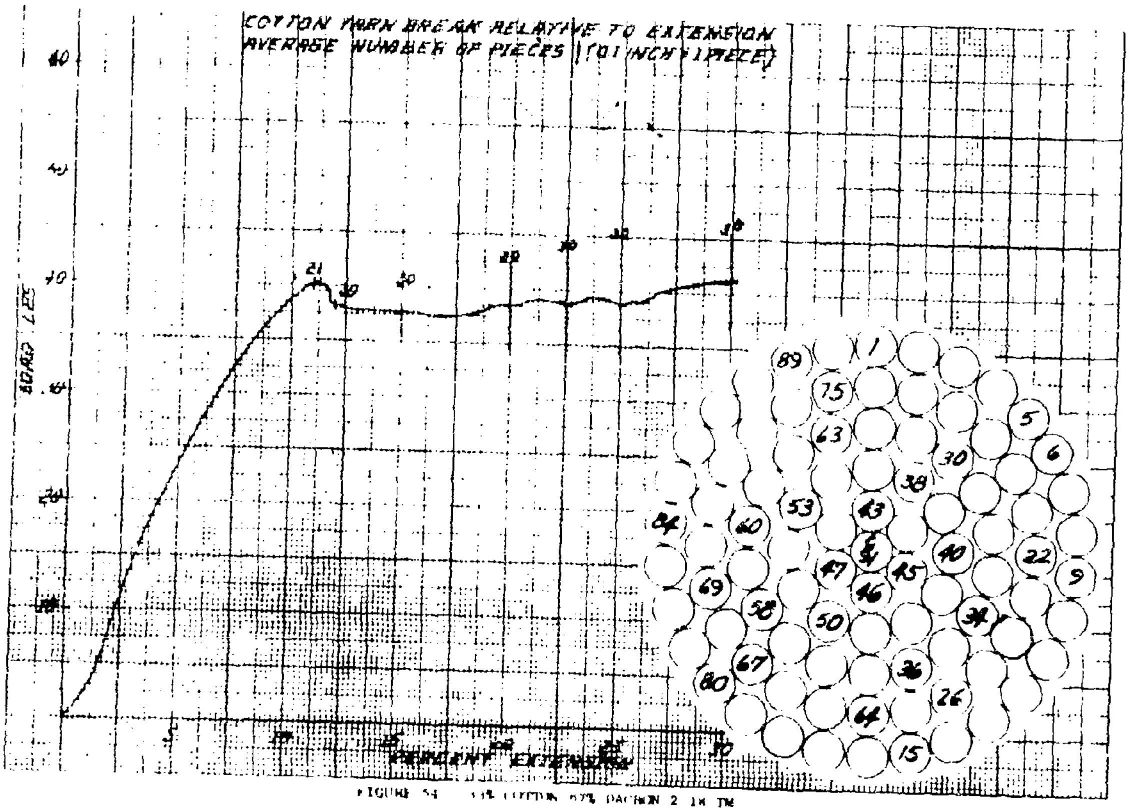
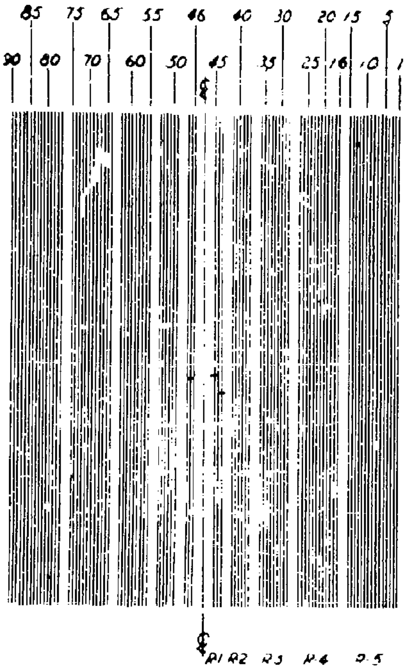
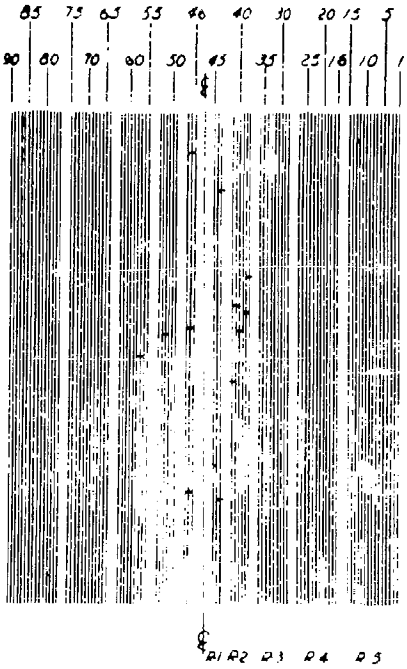


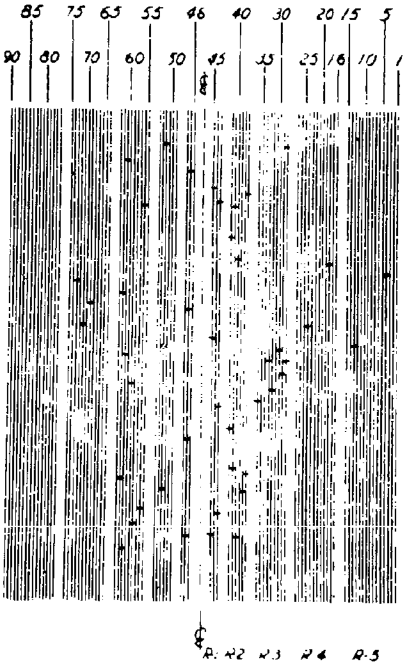
FIGURE 54 33% COTTON 67% DACRON 2.18 TM



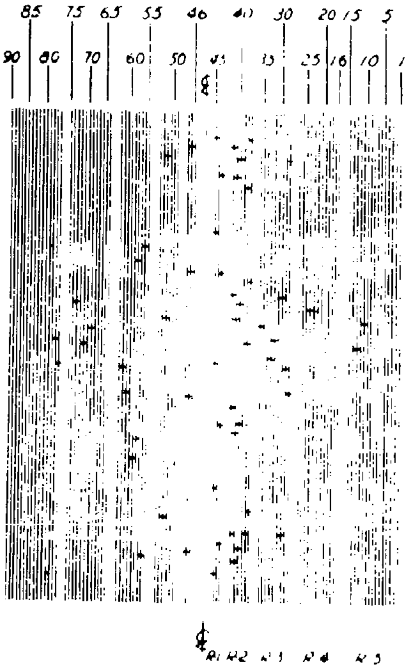
7-1/2% EXTENSION
1.09 TM 33% COTTON 67% DACRON



10% EXTENSION
1.09 TM 33% COTTON 67% DACRON

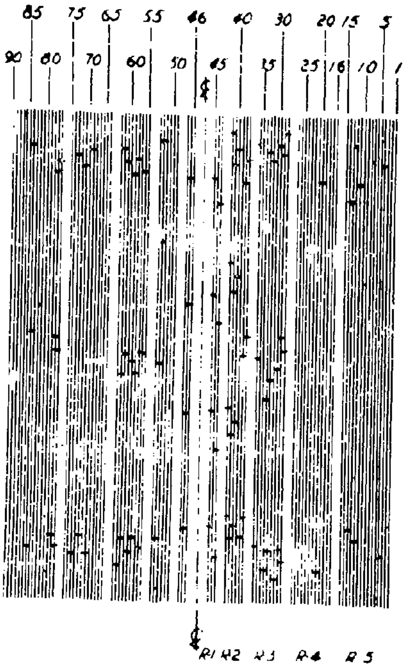


11% EXTENSION
1.09 TM 33% COTTON 67% DACRON

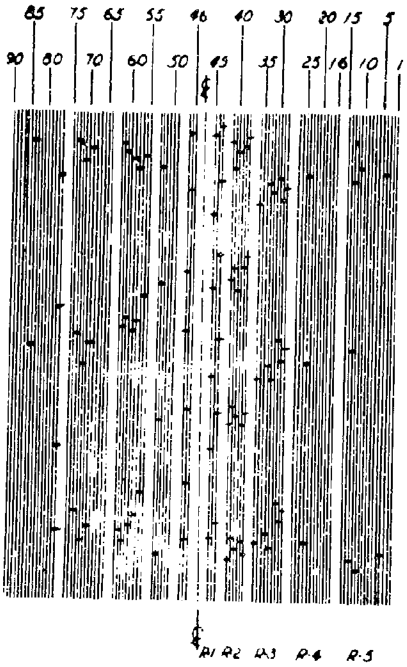


12% EXTENSION
1.09 TM 33% COTTON 67% DACRON

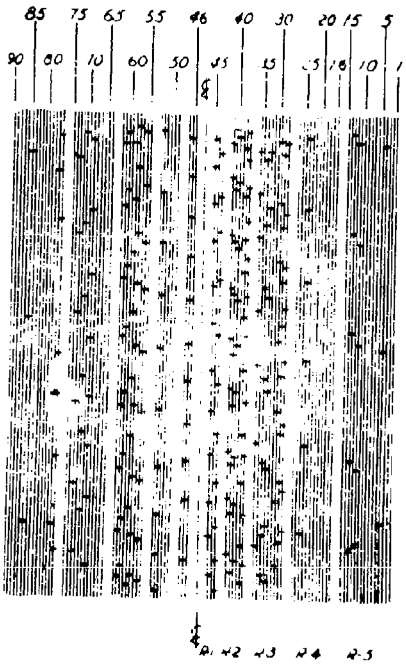
FIGURE 53a



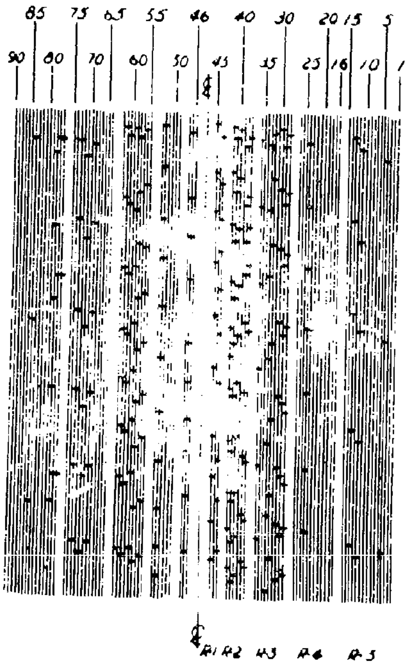
12-1/2% EXTENSION
1.09 TM 33% COTTON 67% DACRON



15% EXTENSION
1.09 TM 33% COTTON 67% DACRON

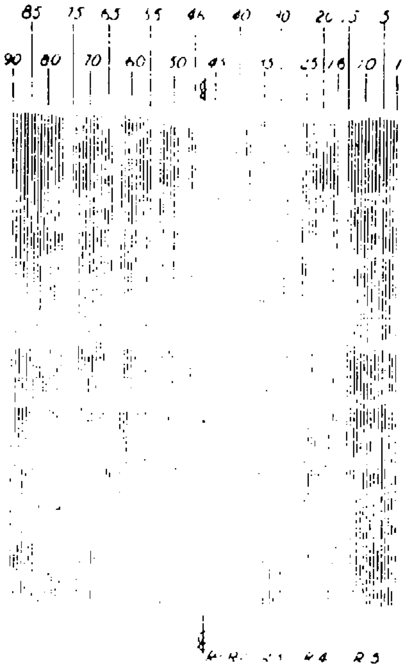


22-1/2% EXTENSION
1.09 TM 33% COTTON 67% DACRON



25% EXTENSION
1.09 TM 33% COTTON 67% DACRON

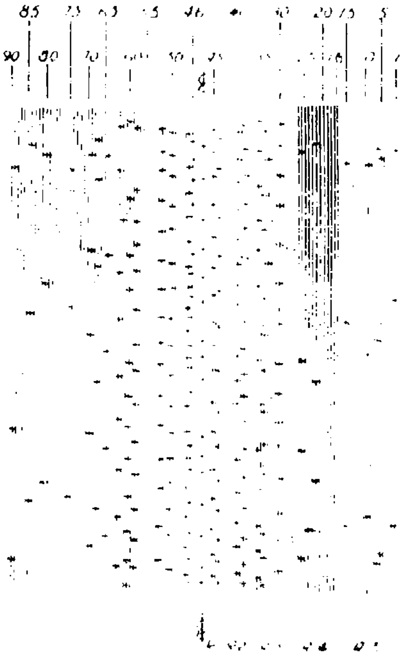
FIGURE [illegible]



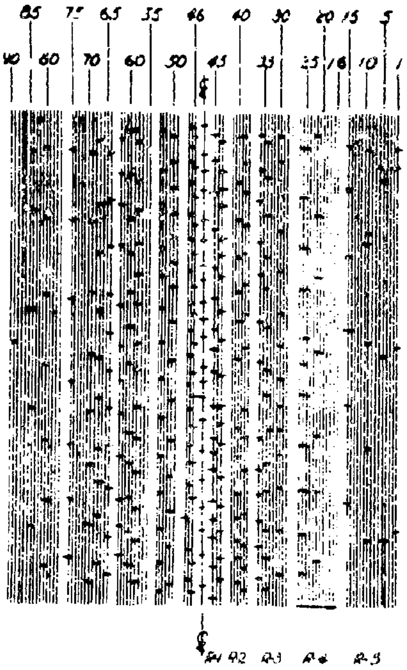
10% EXTENSION
2.18 TM 33% COTTON 67% DACRON

11% EXTENSION
2.18 TM 33% COTTON 67% DACRON

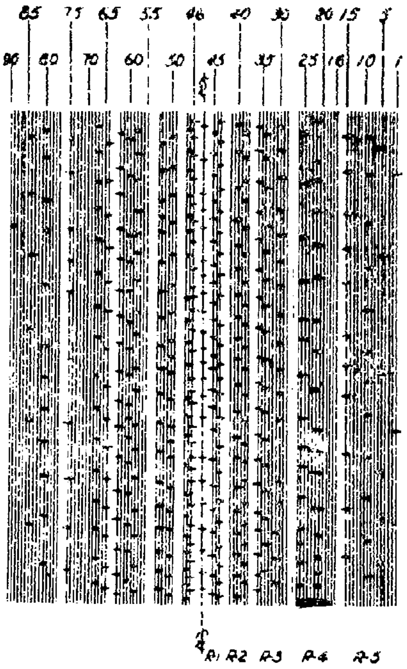
12-1/2% EXTENSION
2.18 TM 33% COTTON 67% DACRON



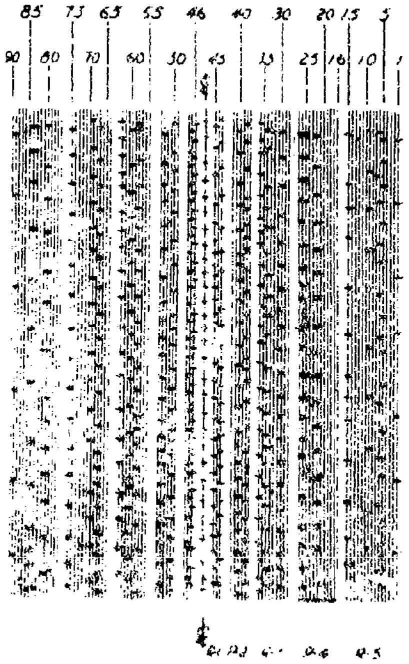
15% EXTENSION
2.18 TM 33% COTTON 67% DACRON



20% EXTENSION
2.18 TM 33% COTTON 67% DACRON



22-1/2% EXTENSION
2.18 TM 33% COTTON 67% DACRON



25% EXTENSION
2.18 TM 33% COTTON 67% DACRON

FIGURE 341

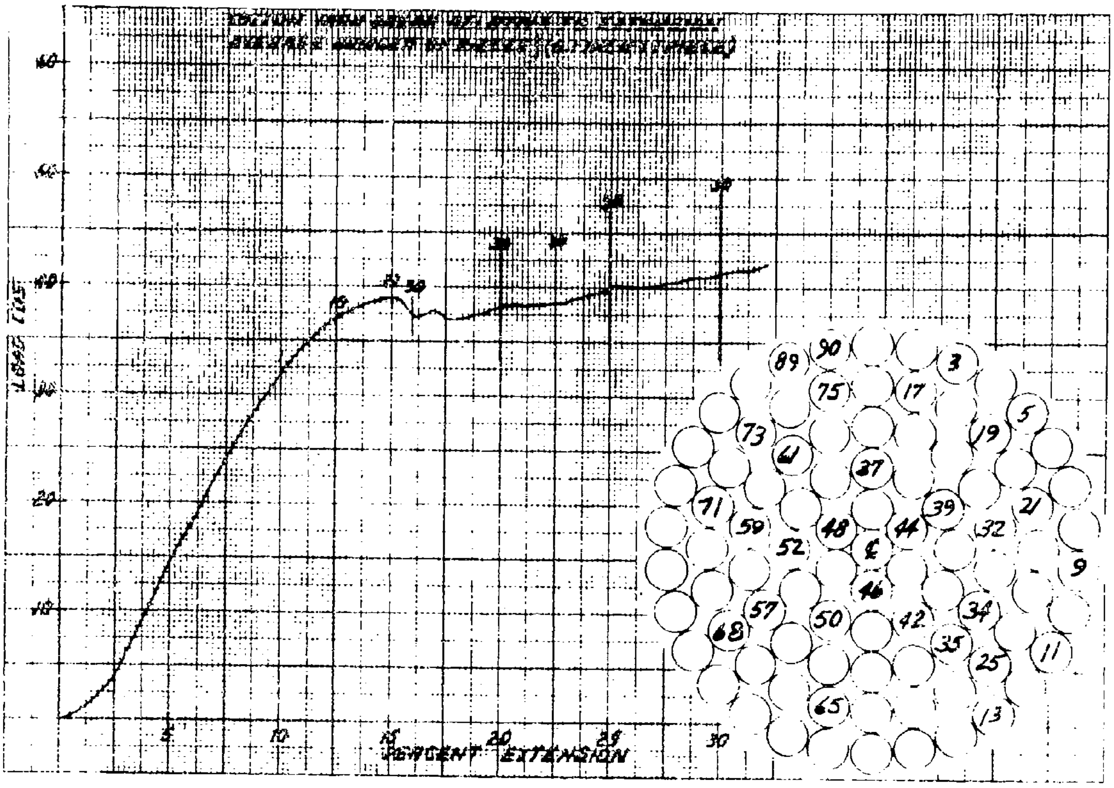


FIGURE 5[illegible]. 33% COTTON 67% DACRON [illegible].76 TM

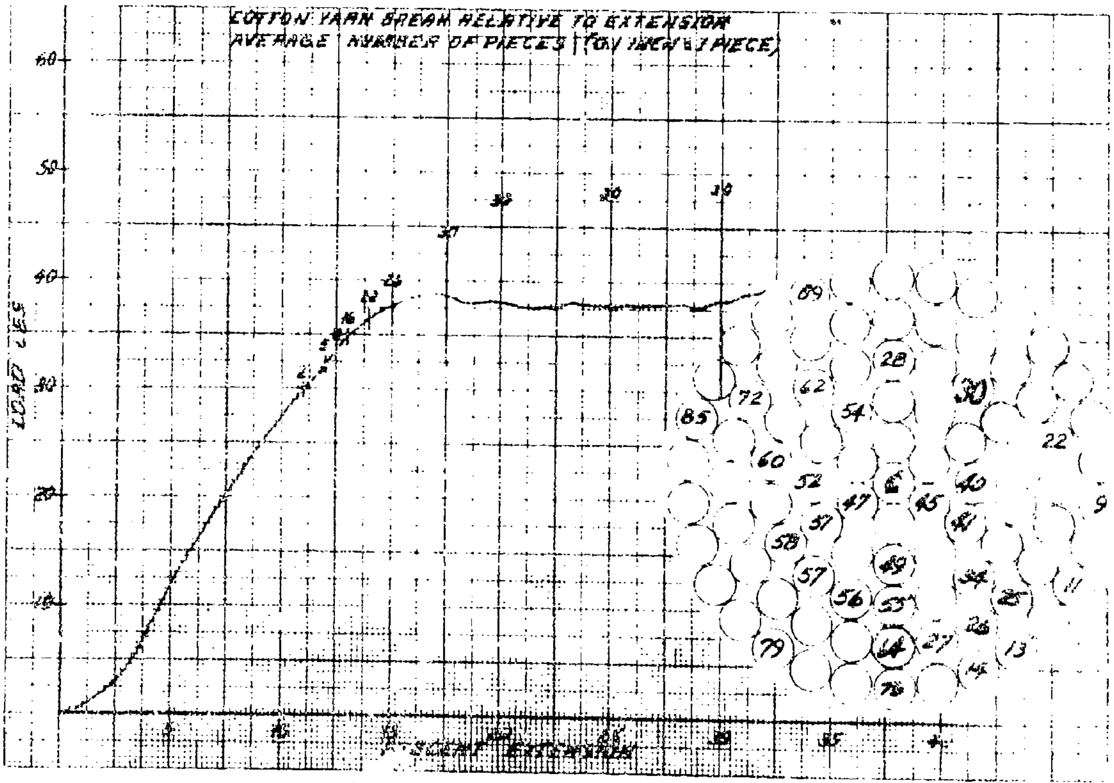
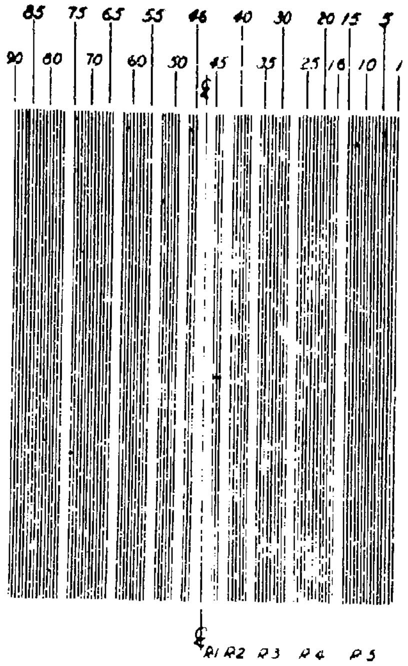
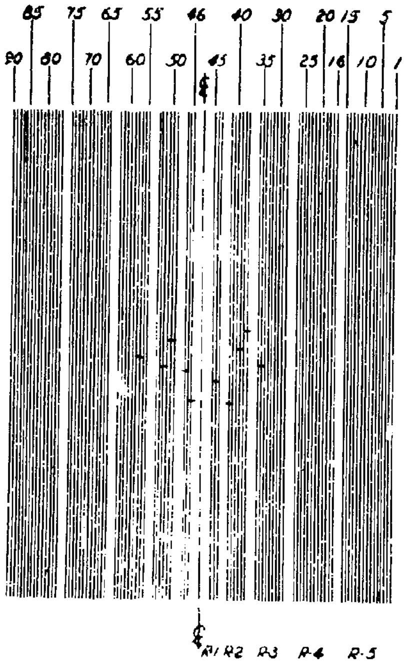


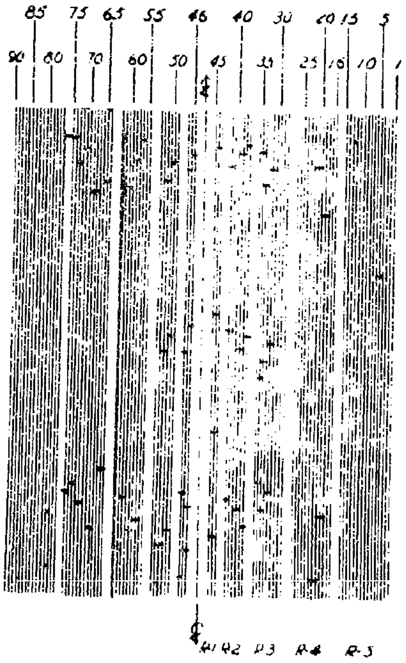
FIGURE 5[illegible]. 33% COTTON 67% DACRON 4.35 TM



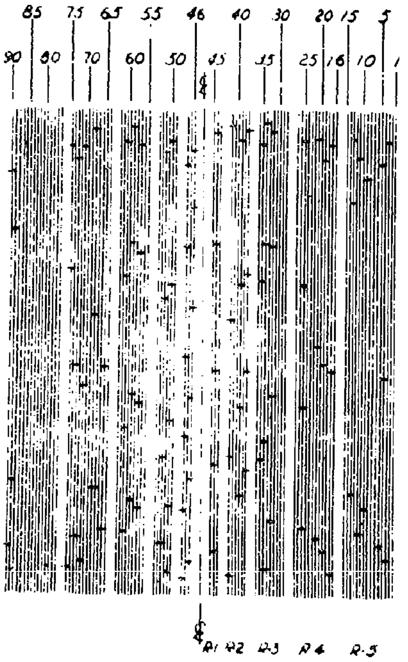
10% EXTENSION
3.26 TM 33% COTTON 67% DACRON



12-1/2% EXTENSION
3.26 TM 33% COTTON 67% DACRON

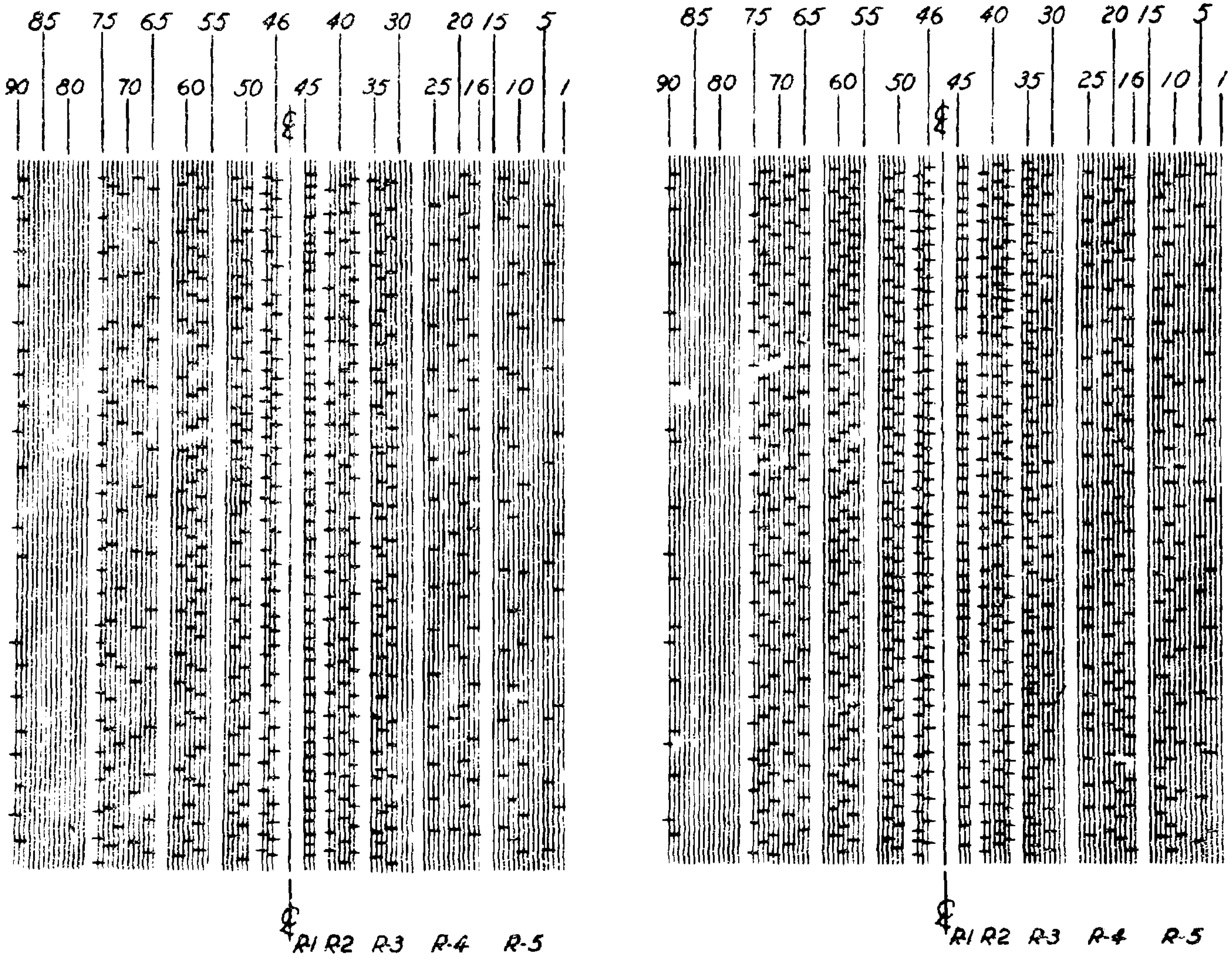


15% EXTENSION
3.26 TM 33% COTTON 67% DACRON



16% EXTENSION
3.26 TM 33% COTTON 67% DACRON

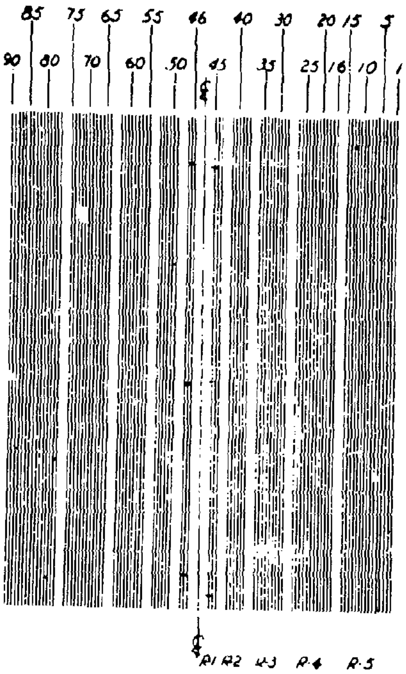
FIGURE 55a



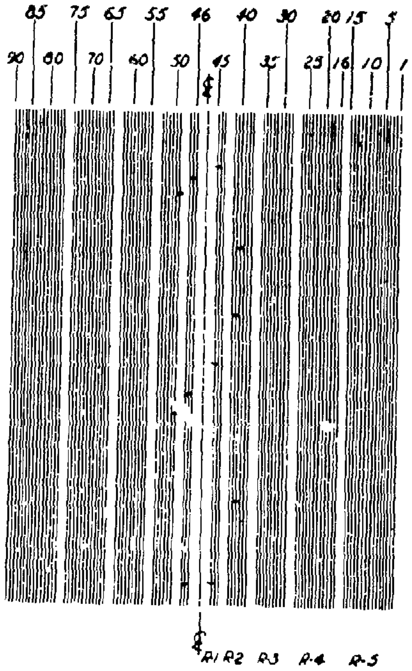
20% EXTENSION
3.26 TM 33% COTTON 67% DACRON

30% EXTENSION
3.26 TM 33% COTTON 67% DACRON

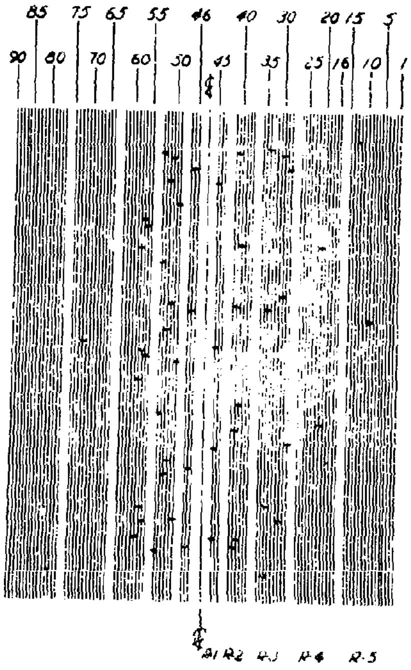
FIGURE 55b



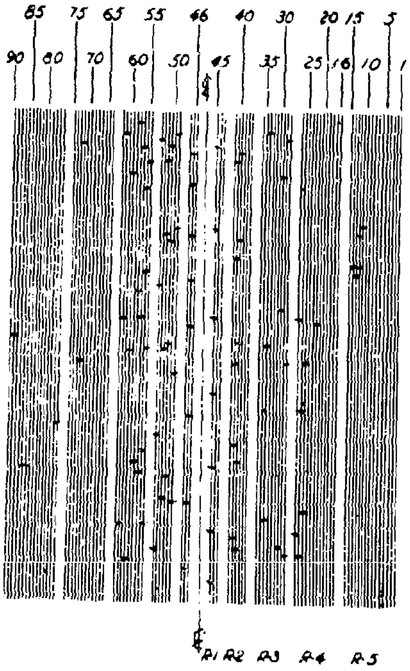
11% EXTENSION
4.35 TM 33% COTTON 67% DACRON



12% EXTENSION
4.35 TM 33% COTTON 67% DACRON

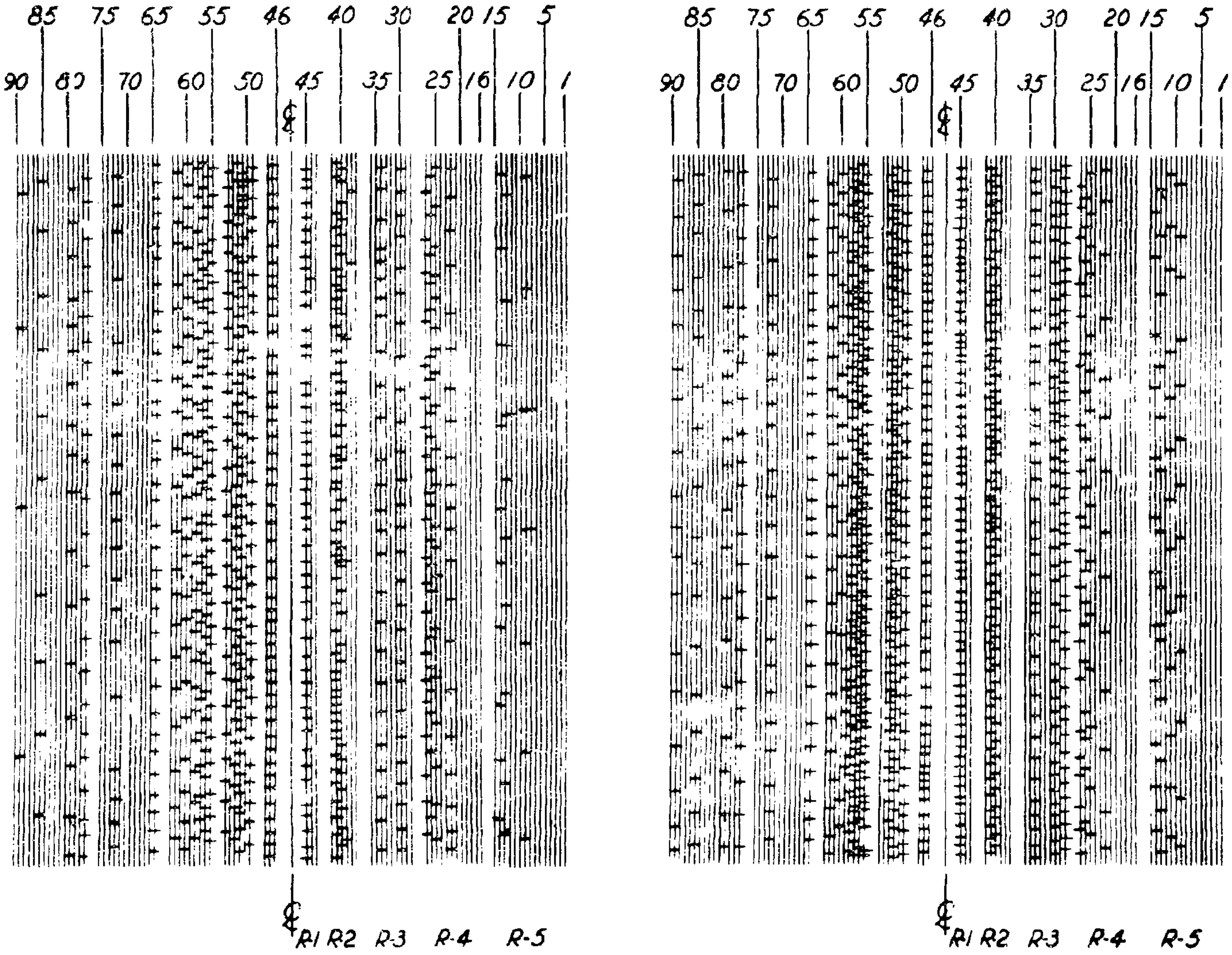


13% EXTENSION
4.35 TM 33% COTTON 67% DACRON



15% EXTENSION
4.35 TM 33% COTTON 67% DACRON

FIGURE [illegible]



20% EXTENSION
4.35 TM 33% COTTON 67% DACRON

30% EXTENSION
4.35 TM 33% COTTON 67% DACRON

FIGURE 56b

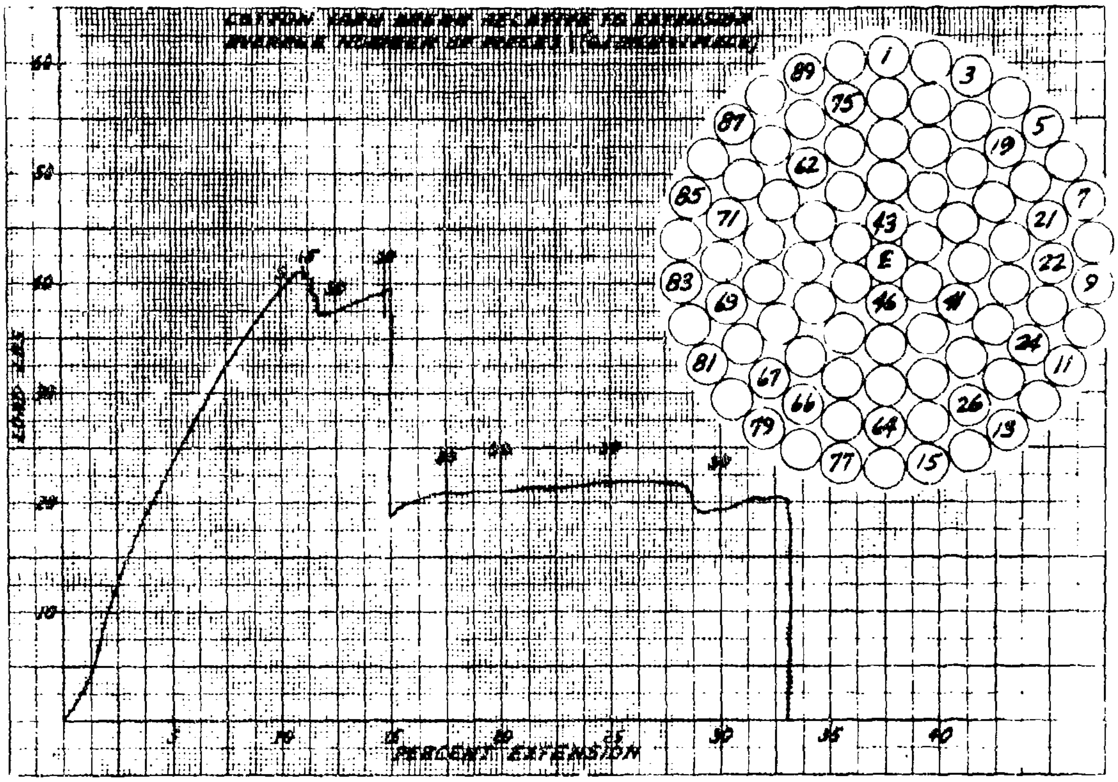


FIGURE 57. 33% COTTON 67% DACRON 2.18 TM

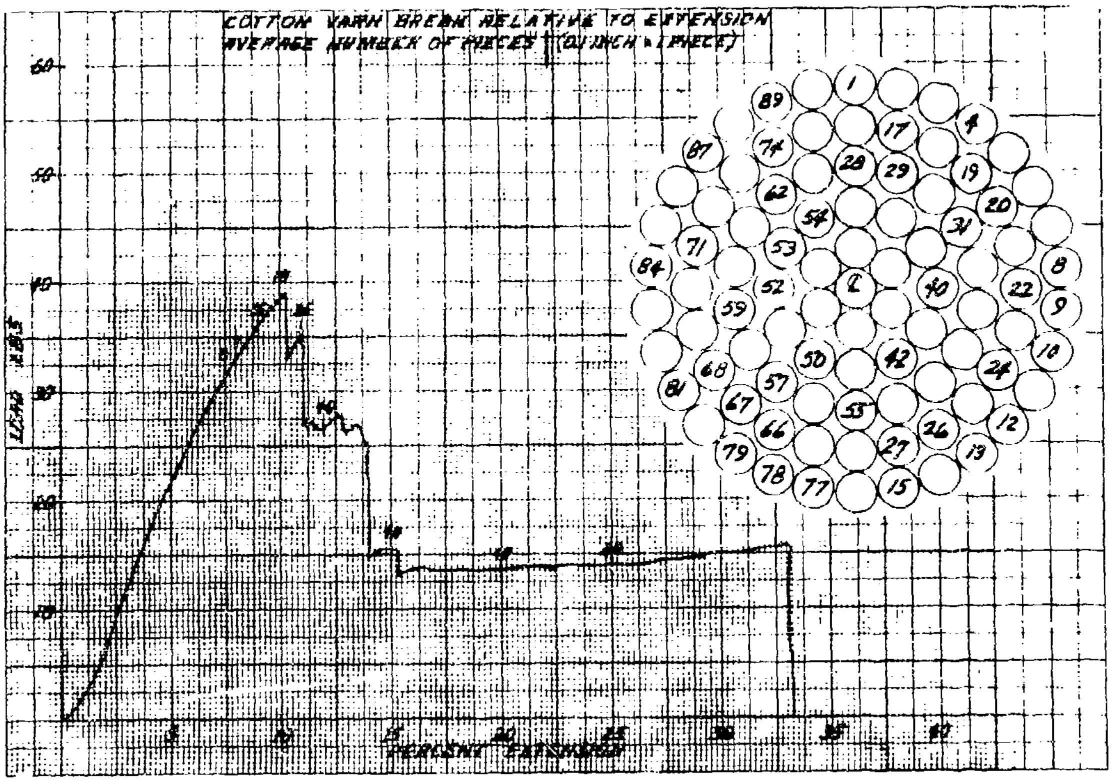
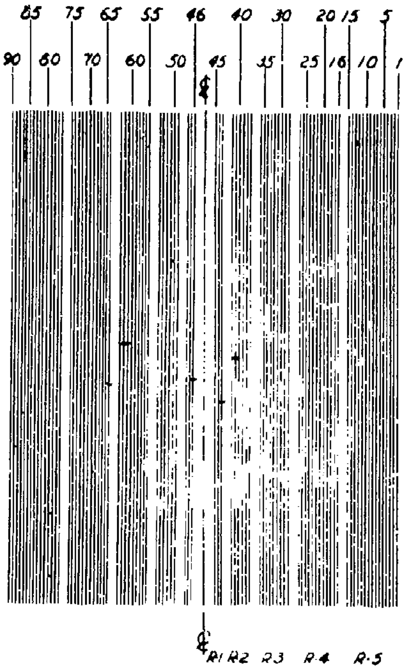
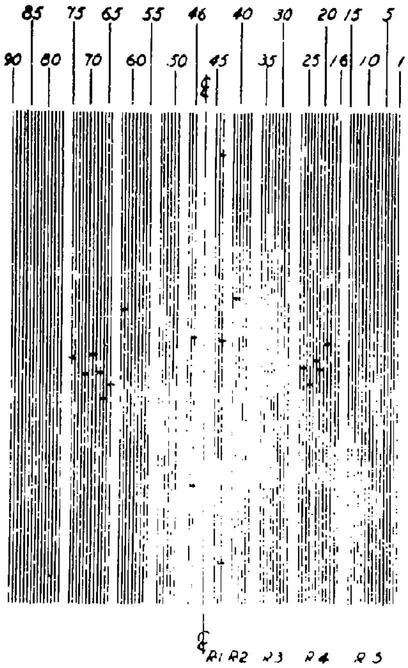


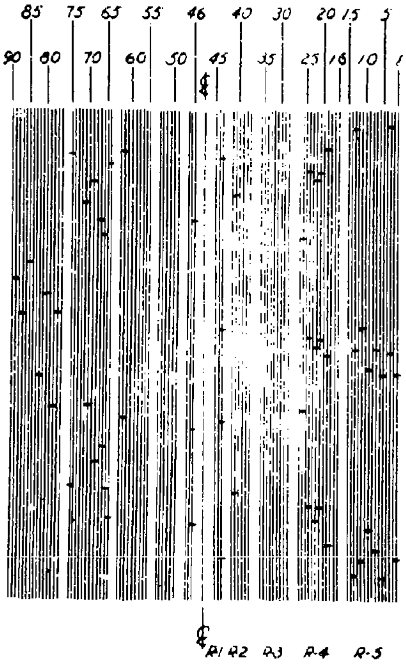
FIGURE 58. 44% COTTON 56% DACRON 2.17 TM



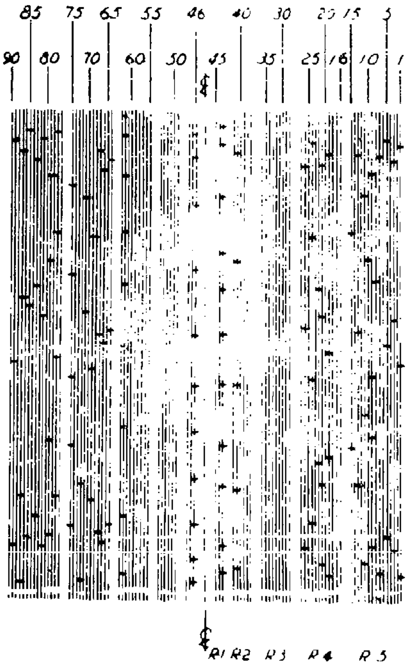
10% EXTENSION
2.17 TM 33% COTTON 67% DACRON



11% EXTENSION
2.17 TM 33% COTTON 67% DACRON

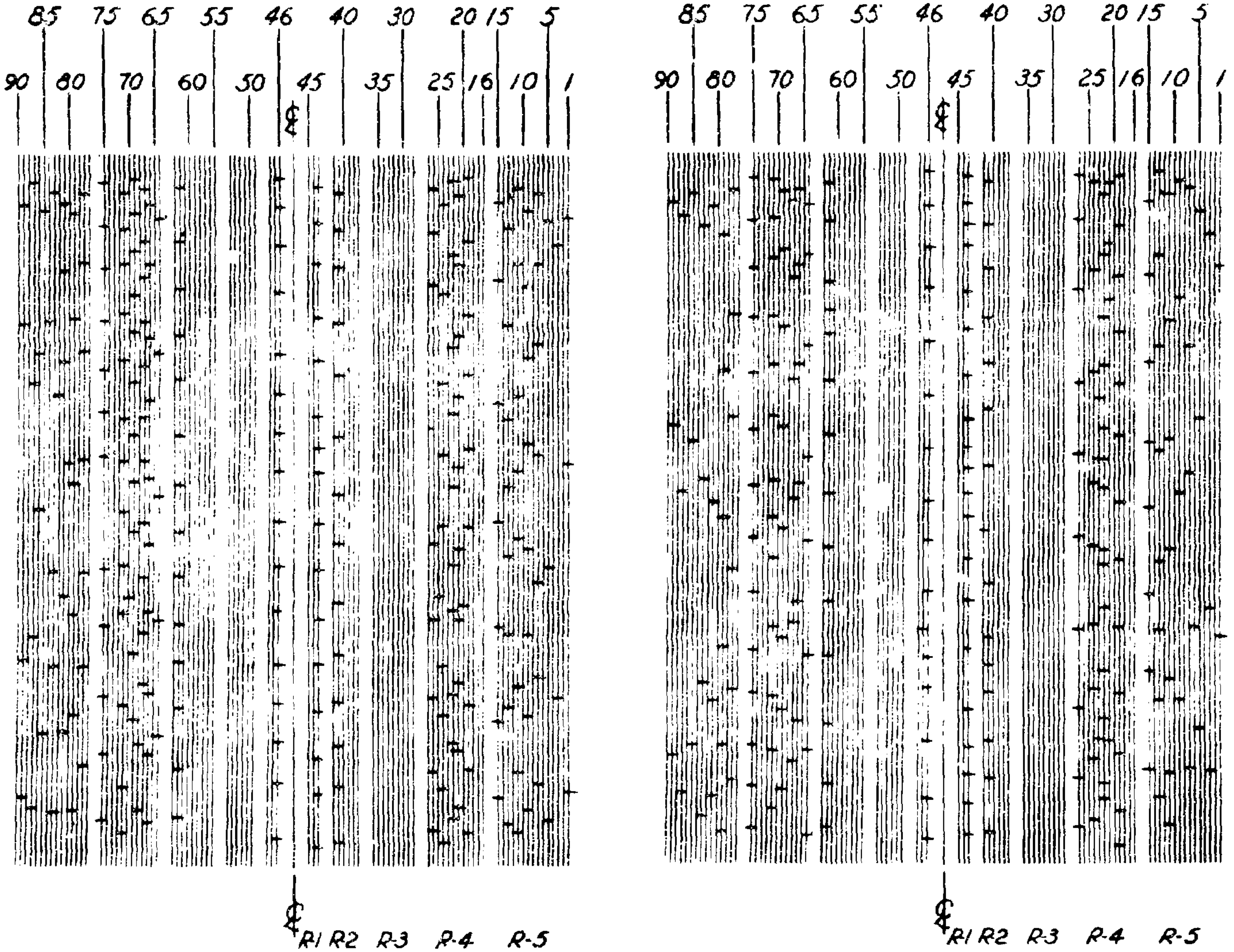


12-1/2% EXTENSION
2.17 TM 33% COTTON 67% DACRON



15% EXTENSION
2.17 TM 33% COTTON 67% DACRON

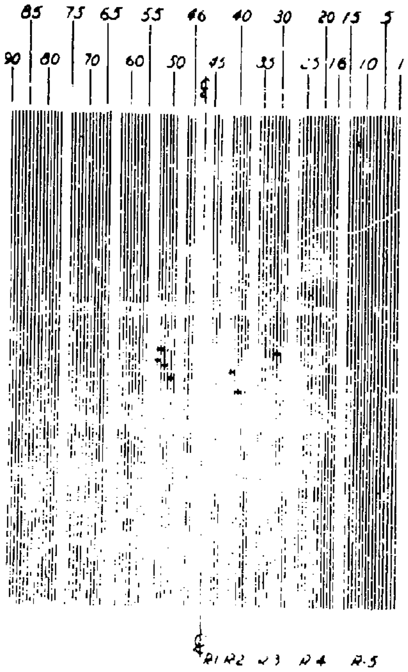
FIGURE 57a



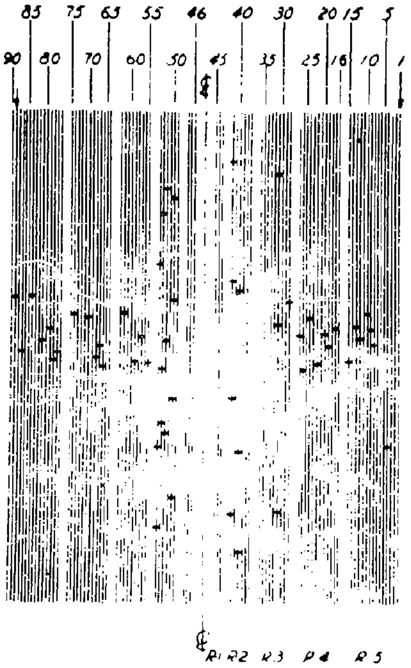
22-1/2% EXTENSION
2.17 TM 33% COTTON 67% DACRON

30% EXTENSION
2.17 TM 33% COTTON 67% DACRON

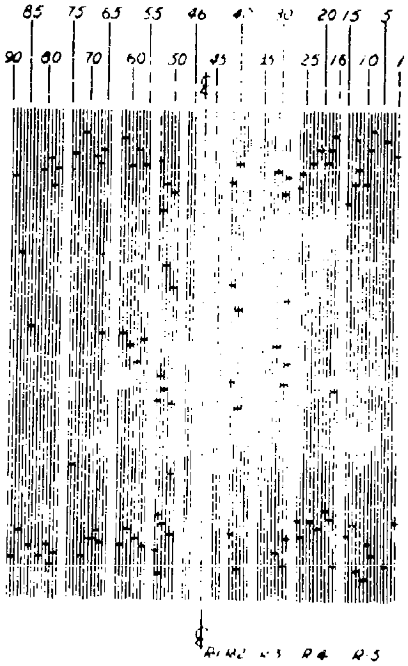
FIGURE 57b



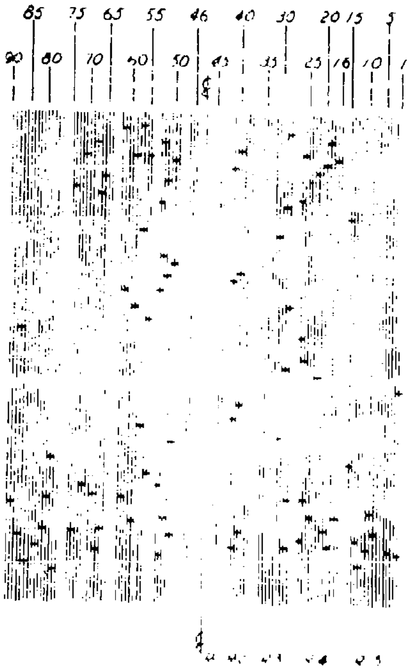
8% EXTENSION
2.17 TM 44% COTTON 56% DACRON



10% EXTENSION
2.17 TM 44% COTTON 56% DACRON

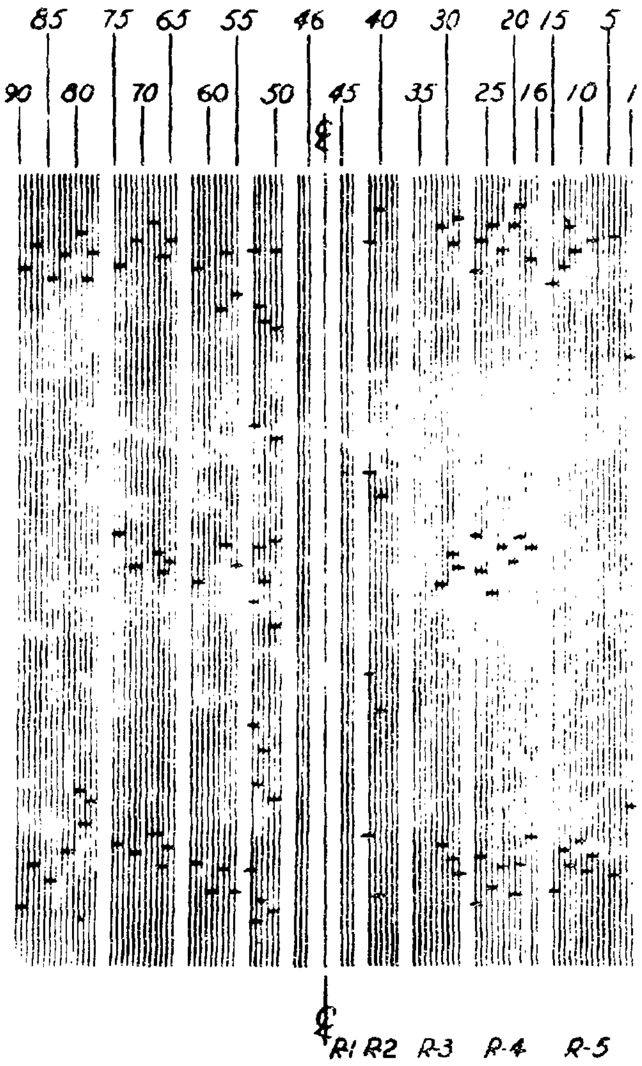


11% EXTENSION
2.17 TM 44% COTTON 56% DACRON



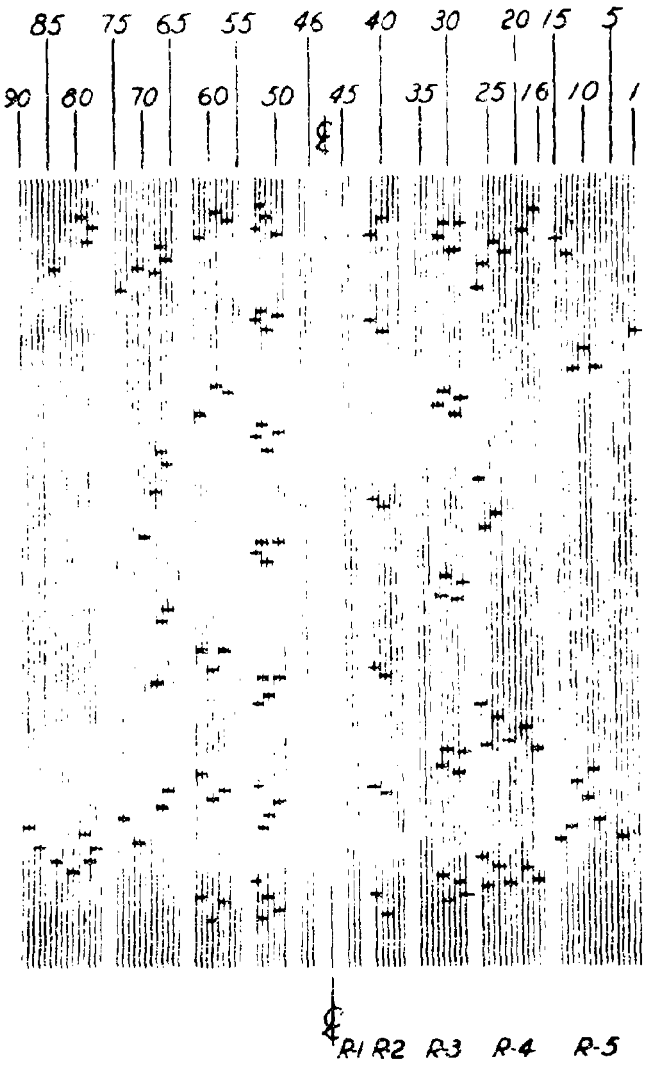
12% EXTENSION
2.17 TM 44% COTTON 56% DACRON

FIGURE NO.



15% EXTENSION

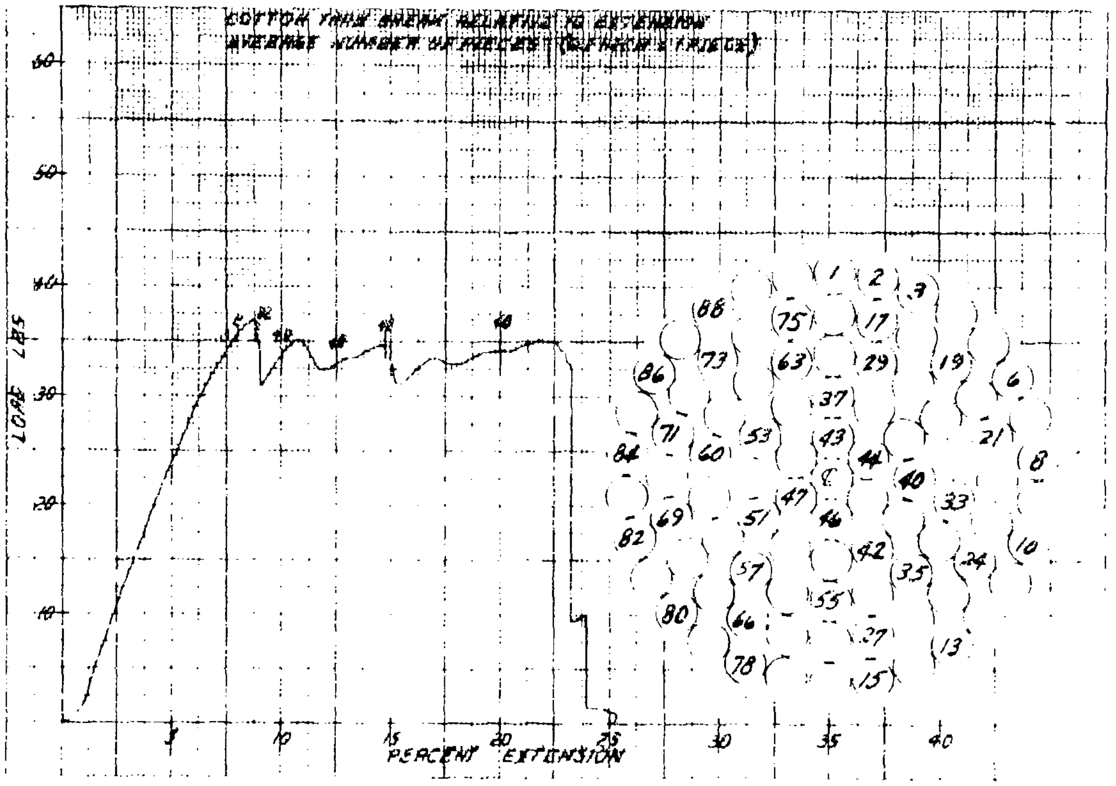
2.17 TM 44% COTTON 56% DACRON



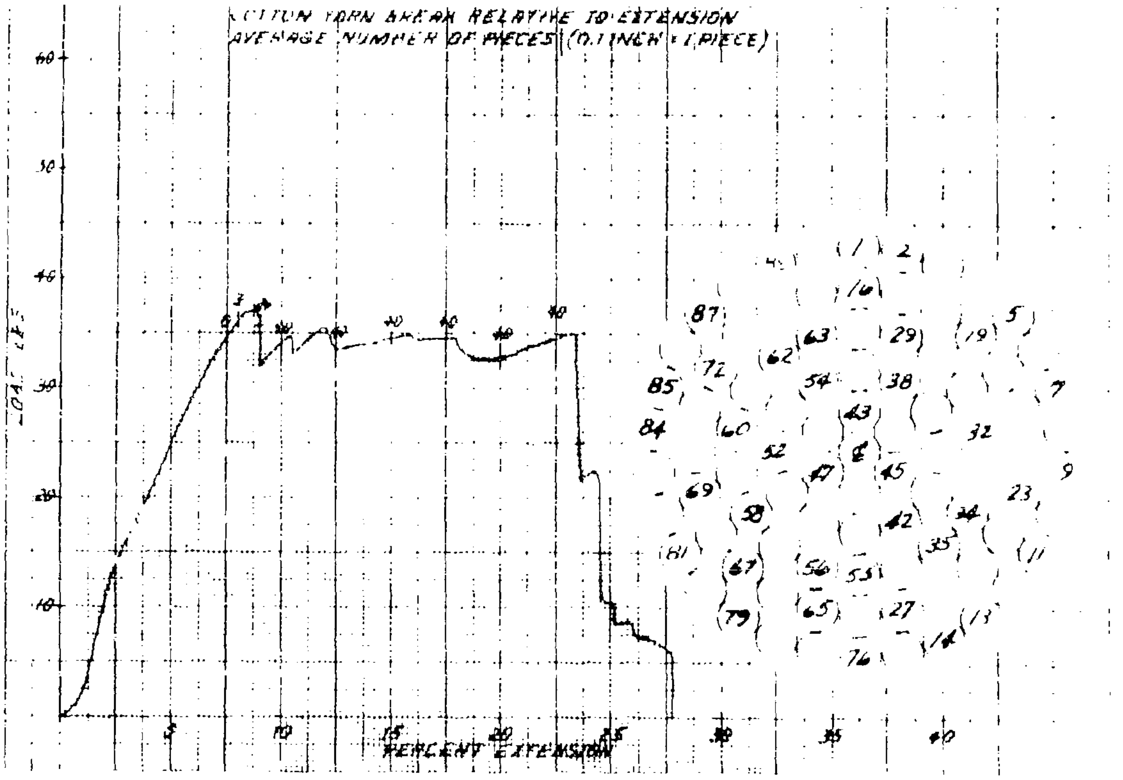
30% EXTENSION

2.17 TM 44% COTTON 56% DACRON

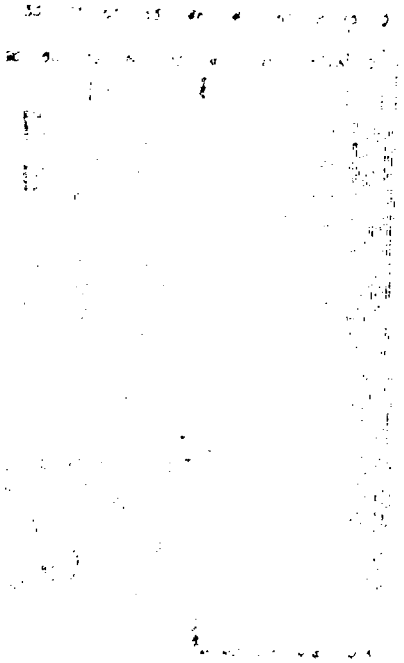
FIGURE 58b

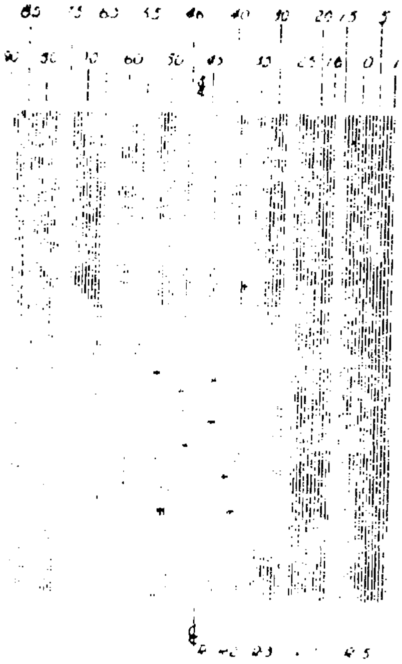

COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF PIECES (0.1 INCH = 1 PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION

[illegible]


COTTON YARN BREAK RELATIVE TO EXTENSION
AVERAGE NUMBER OF PIECES (0.1 INCH = 1 PIECE)
LOAD LBS
60
50
40
30
20
10
5
10
15
20
25
30
35
40
PERCENT EXTENSION

[illegible]

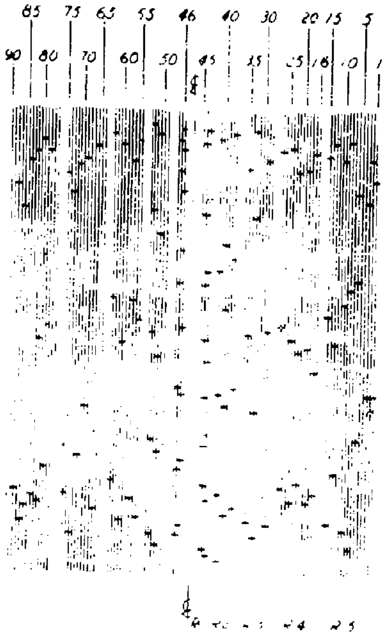

7-1/2% EXTENSION
0.54TM 44% COTTON 56% DACRON



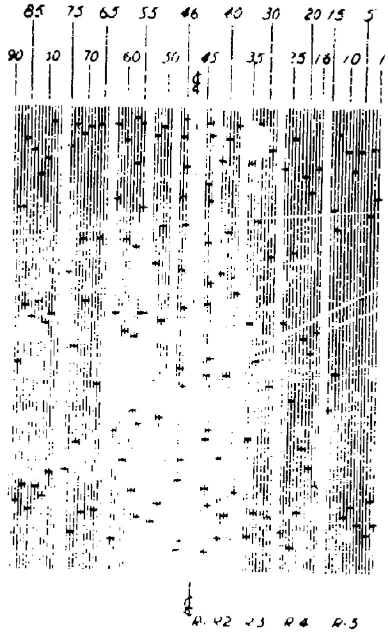
9% EXTENSION
0.54 TM 44% COTTON 56% DACRON


[illegible]

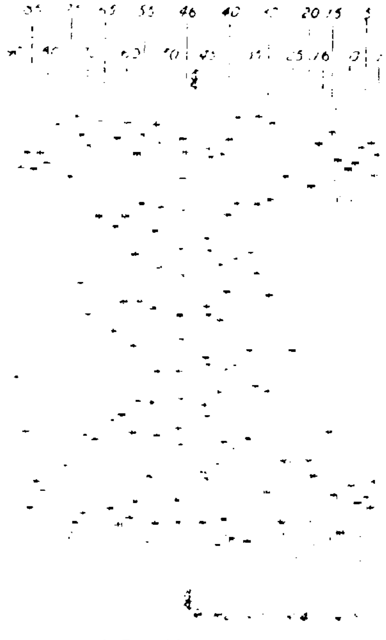
[illegible]



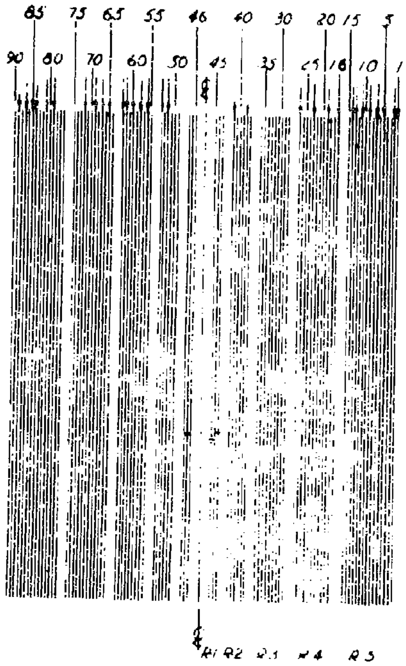
12-1/2% EXTENSION
0.54 TM 44% COTTON 56% DACRON



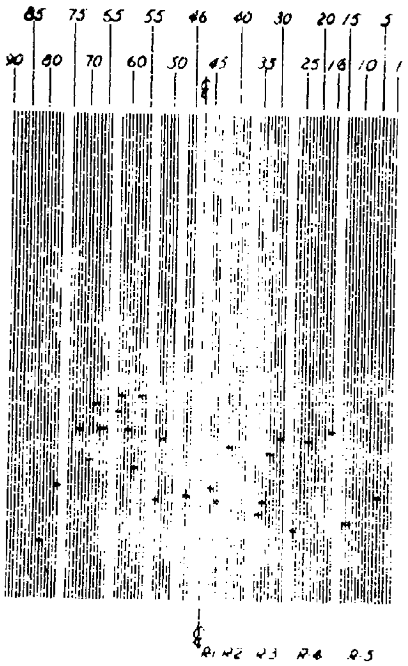
15% EXTENSION
0.54 TM 44% COTTON 56% DACRON



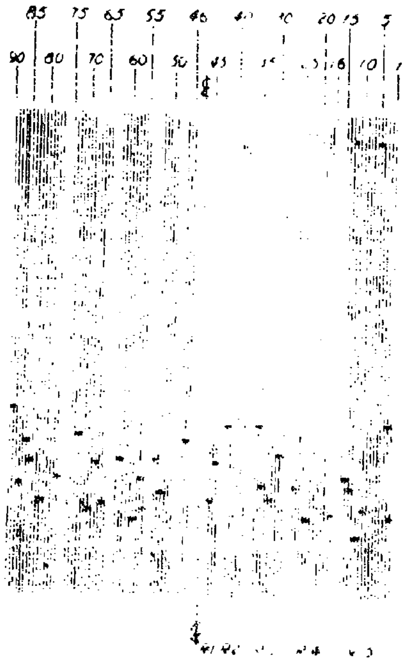
20% EXTENSION
54 TM 44% COTTON 56% DACRON



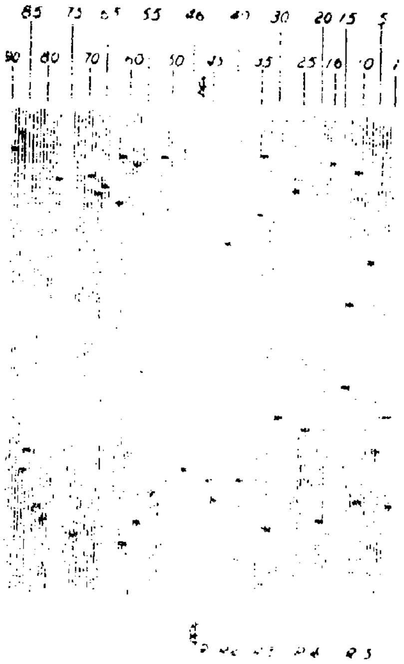
8% EXTENSION
1.09 TM 44% COTTON 56% DACRON



9% EXTENSION
1.09 TM 44% COTTON 56% DACRON

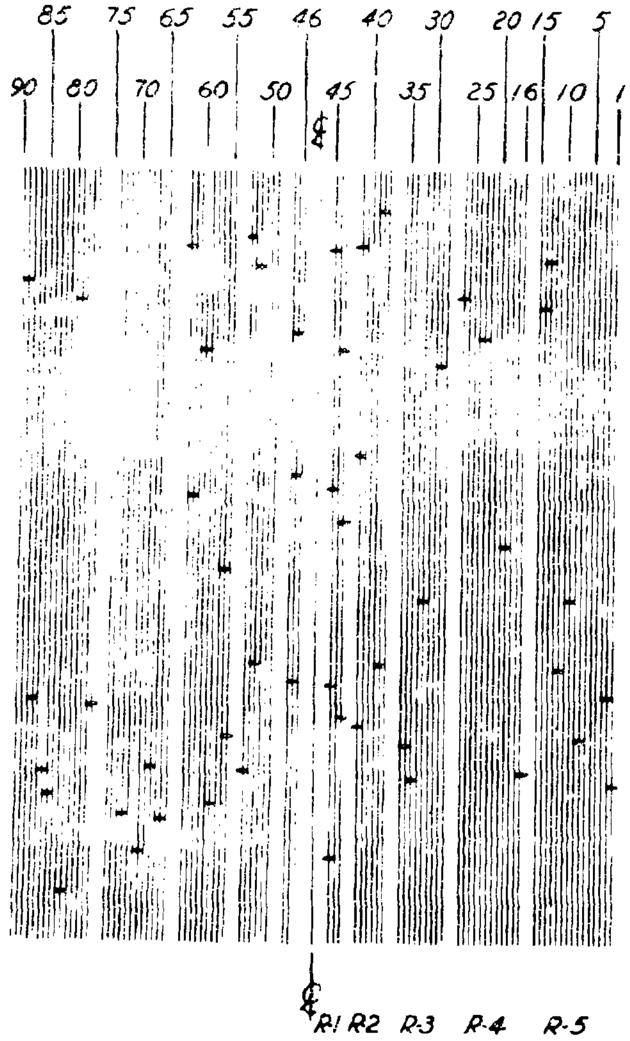


10% EXTENSION
1.09 TM 44% COTTON 56% DACRON

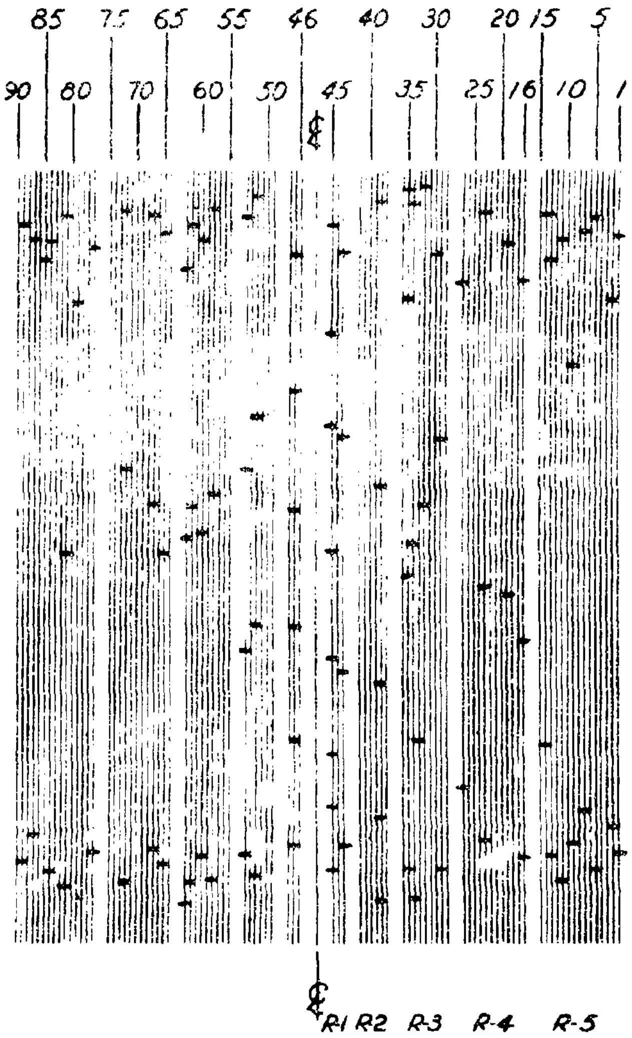


12-1/2% EXTENSION
1.09 TM 44% COTTON 56% DACRON

FIGURE [illegible]



15% EXTENSION
1.09 TM 44% COTTON 56% DACRON



22-1/2% EXTENSION
1.09 TM 44% COTTON 56% DACRON

FIGURE 60b

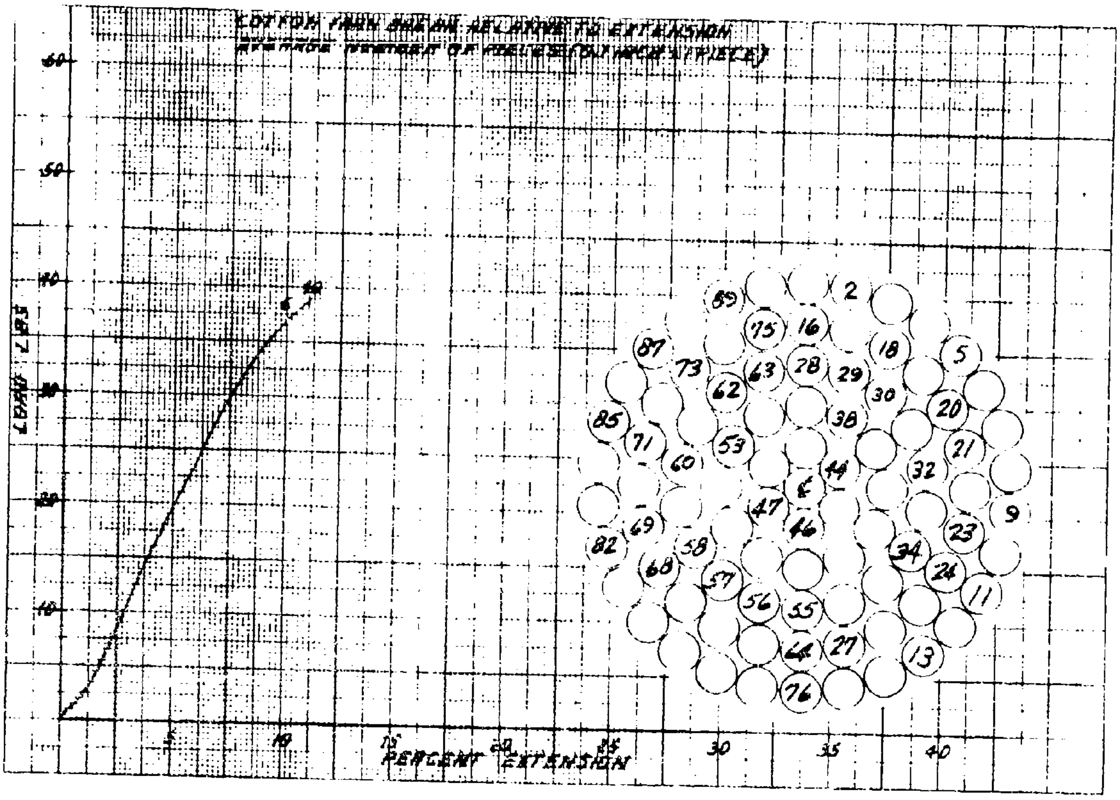


FIGURE 61 — 44% COTTON 56% DACRON 2.12 TM

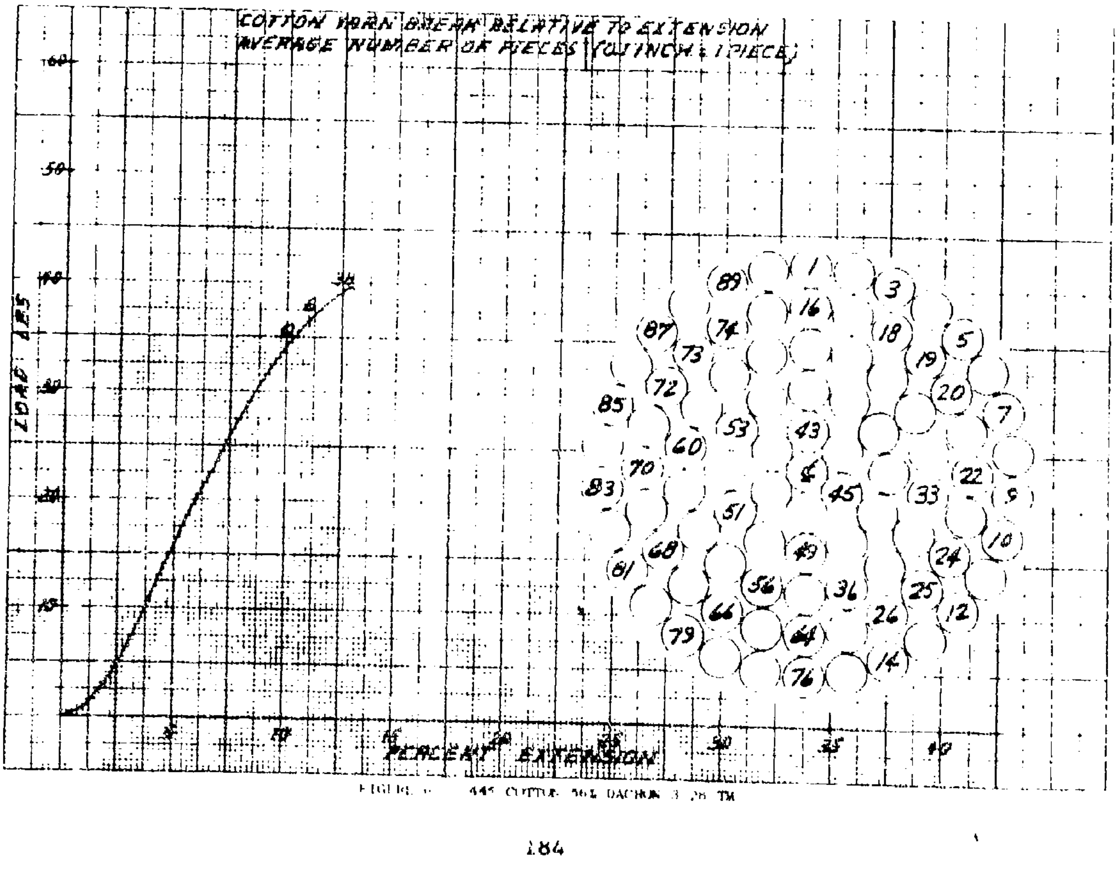
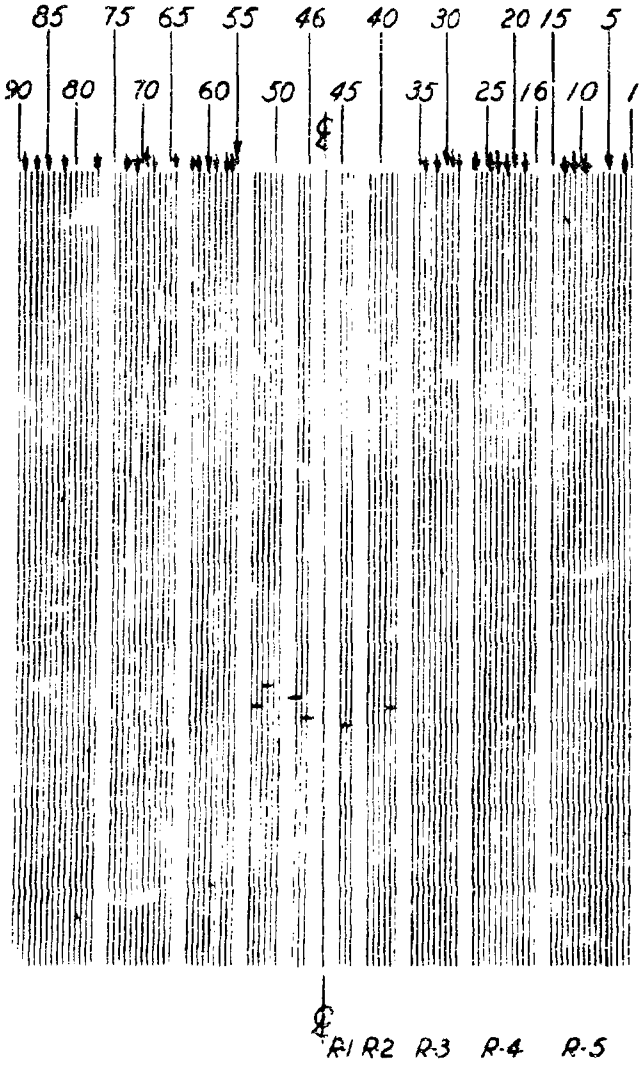
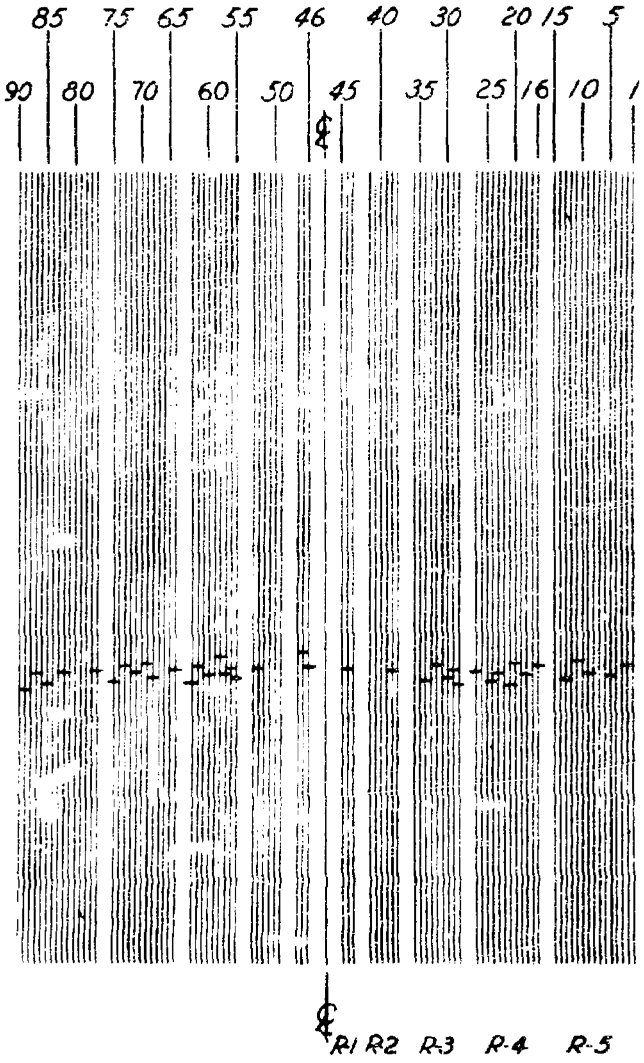


FIGURE [illegible] — 44% COTTON 56% DACRON 3.26 TM



10% EXTENSION

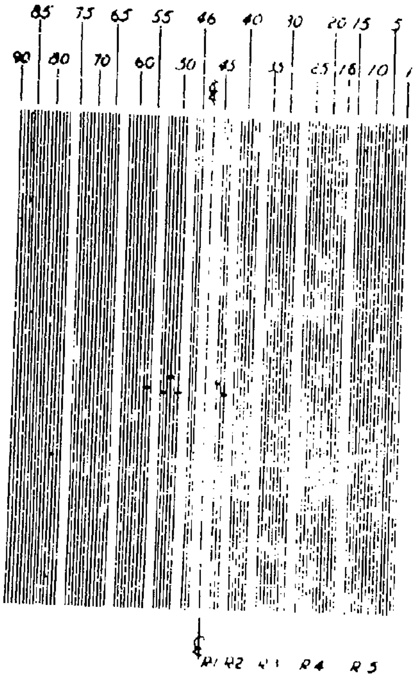
2.17 TM 44% COTTON 56% DACRON



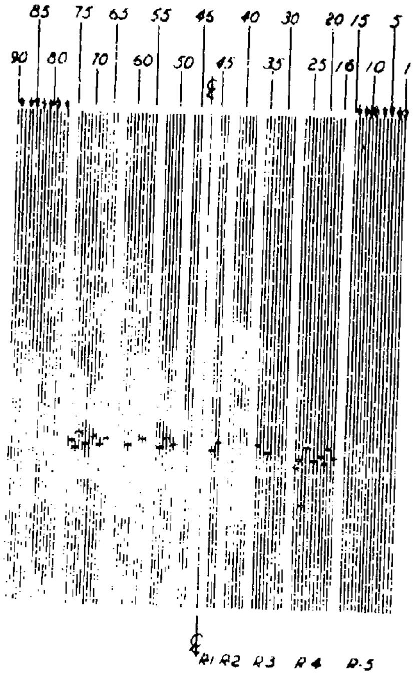
11% EXTENSION

2.17 TM 44% COTTON 56% DACRON

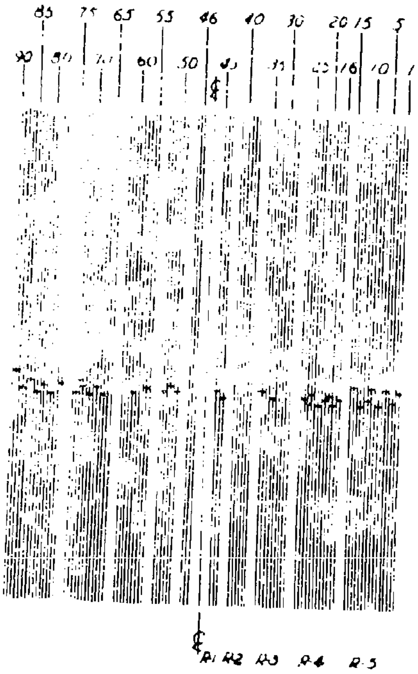
FIGURE 61a



11% EXTENSION
3.26 TM 44% COTTON 56% DACRON



12-1/2% EXTENSION
3.26 TM 44% COTTON 56% DACRON



13% EXTENSION
3.26 TM 44% COTTON 56% DACRON

FIGURE 52a

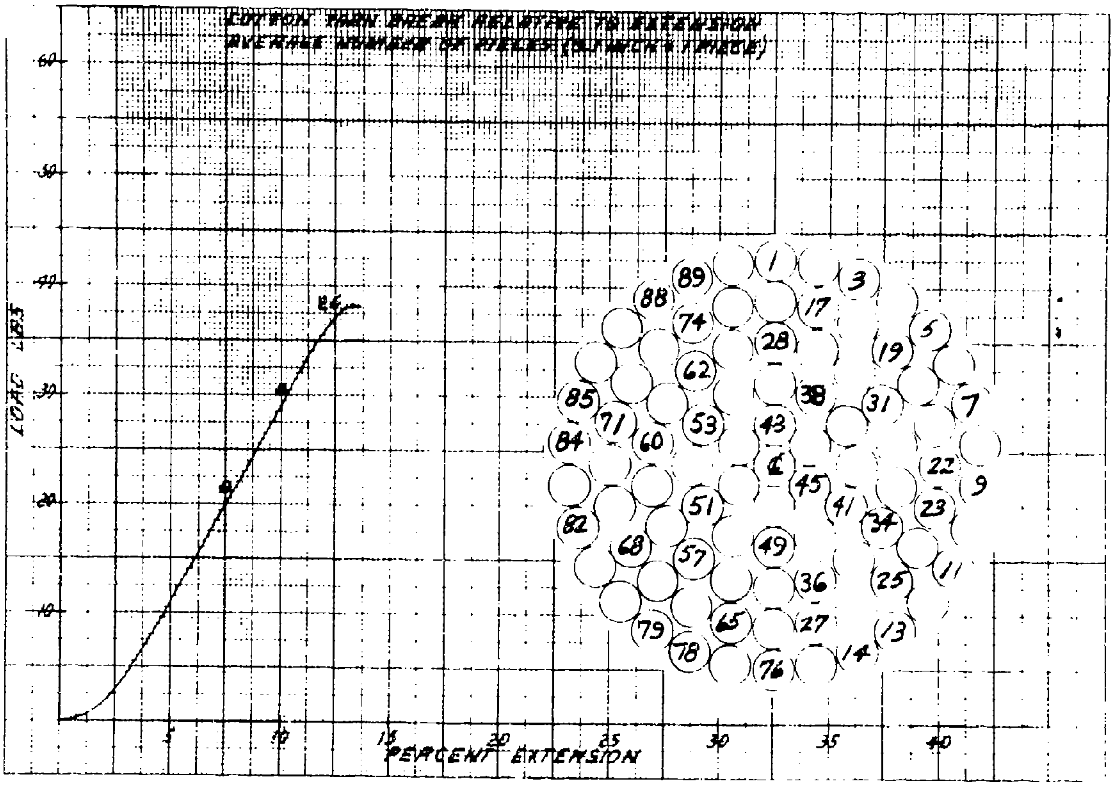


FIGURE 83 44% COTTON 56% DACRON 1.35 TM

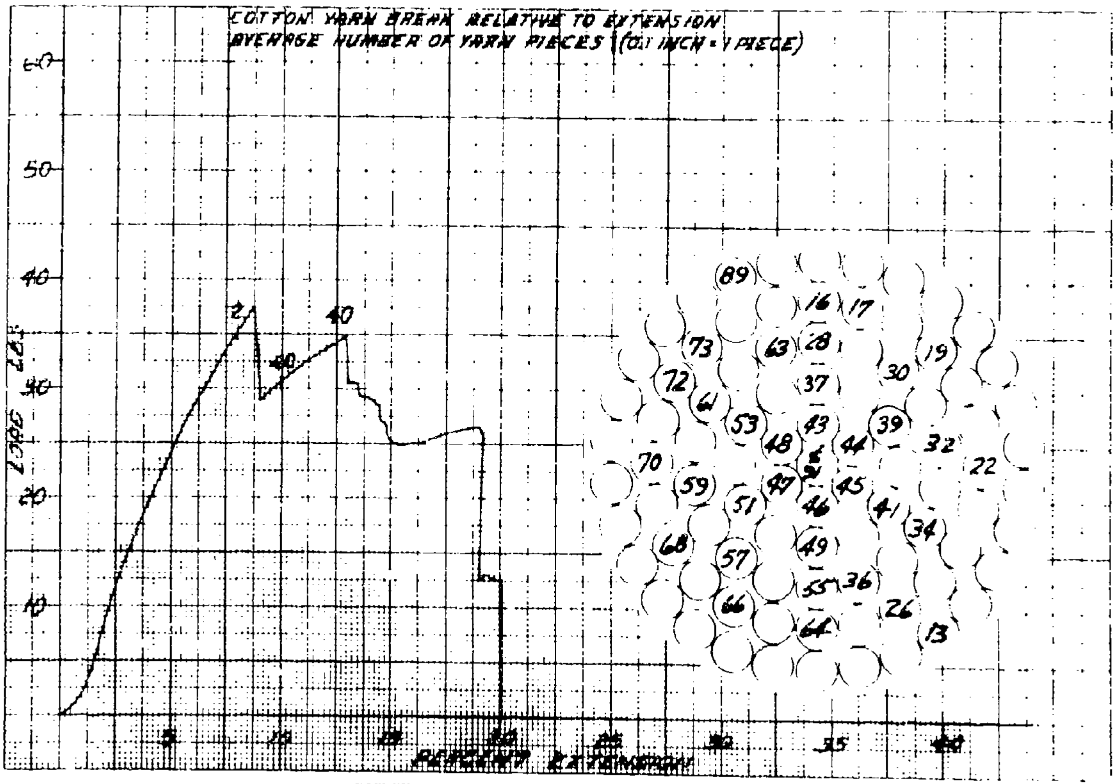
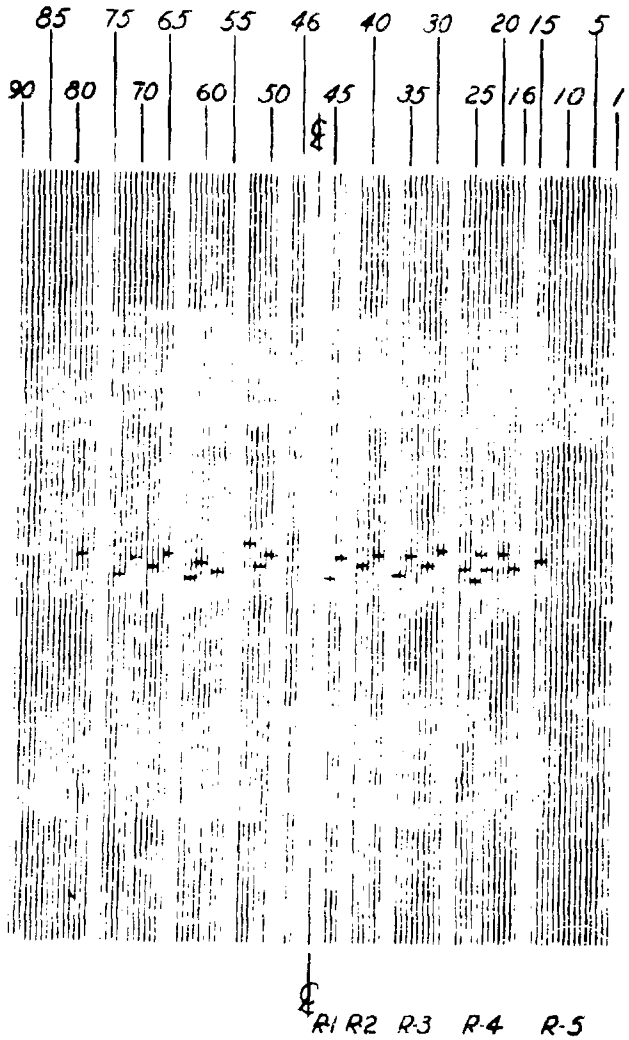
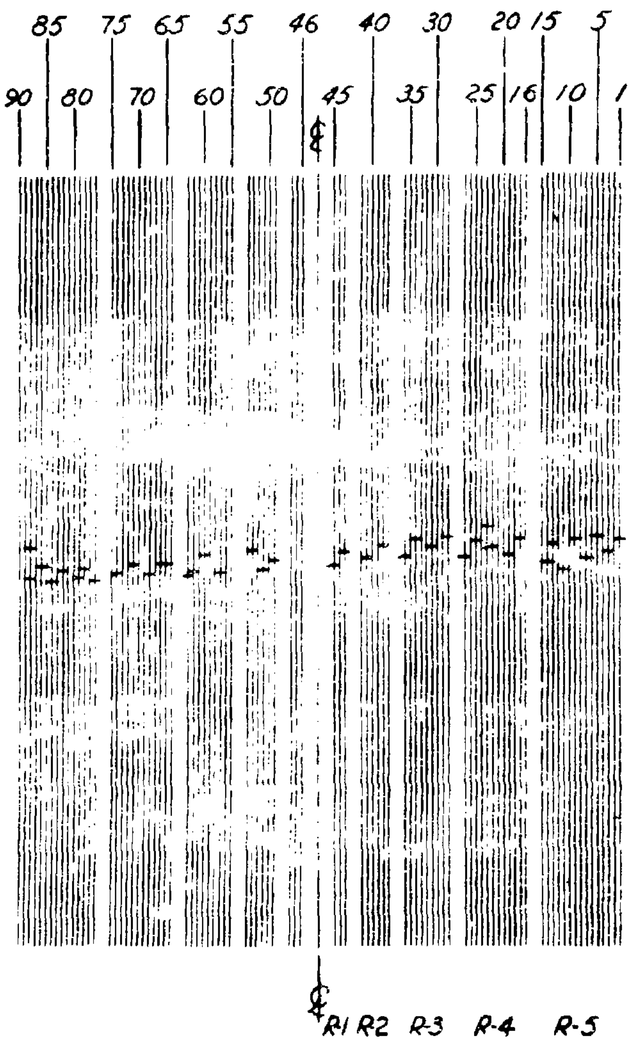


FIGURE 84 44% COTTON 56% DACRON 1.09 TM

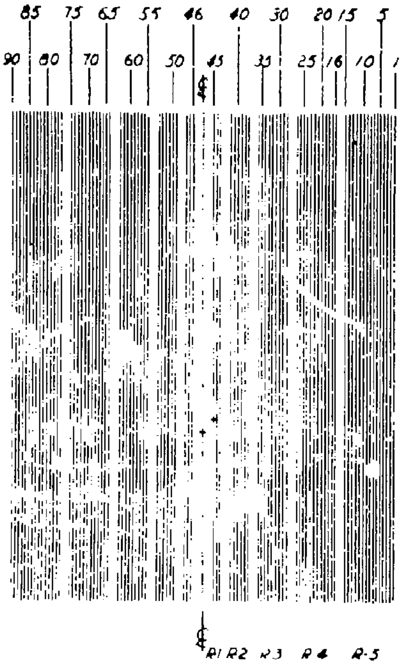


12-1/2% EXTENSION
4.35 TM 44% COTTON 56% DACRON

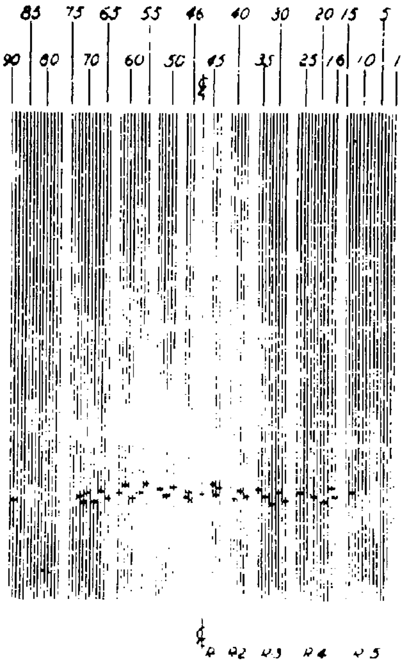


13.8% EXTENSION
4.35 TM 44% COTTON 56% DACRON

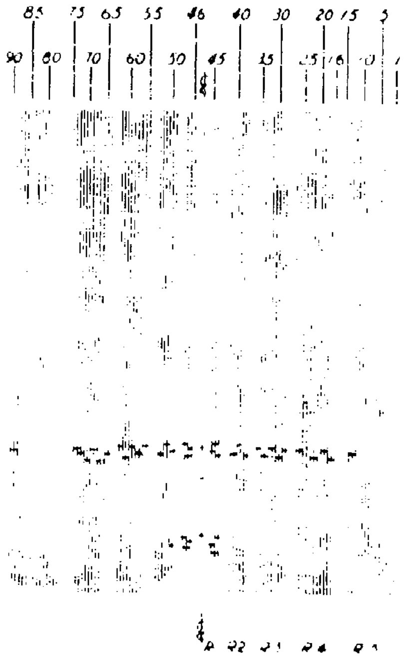
FIGURE [illegible]



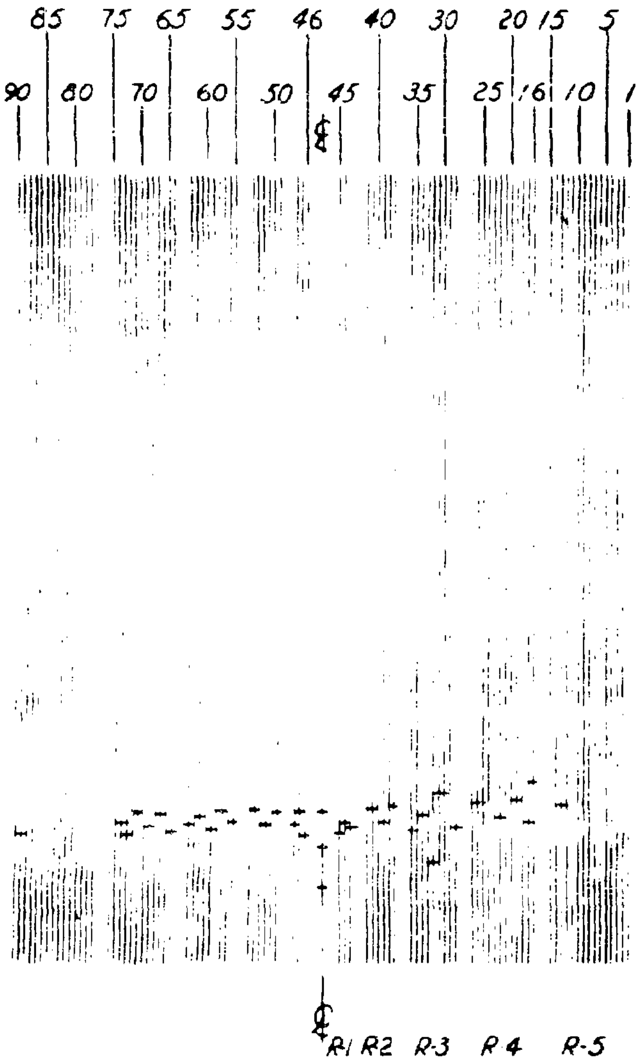
8% EXTENSION
1.09 TM 44% COTTON 56% DACRON



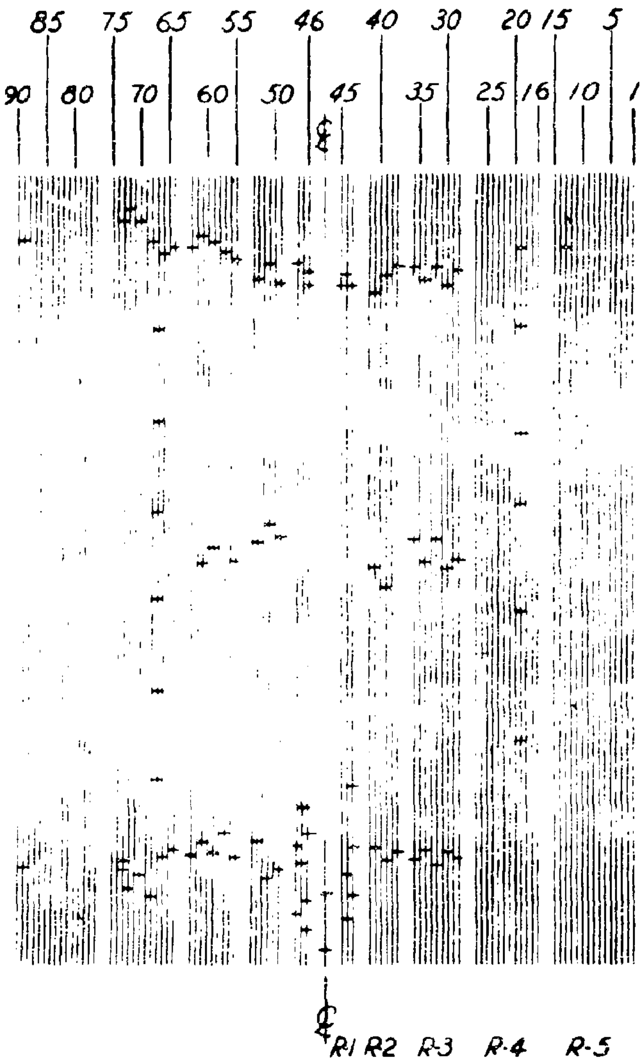
9% EXTENSION
1.09 TM 44% COTTON 56% DACRON



10% EXTENSION
1.09 TM 44% COTTON 56% DACRON



12-1/2% EXTENSION
1.09 TM 44% COTTON 56% DACRON



15% EXTENSION
1.09 TM 44% COTTON 56% DACRON

FIGURE 61b

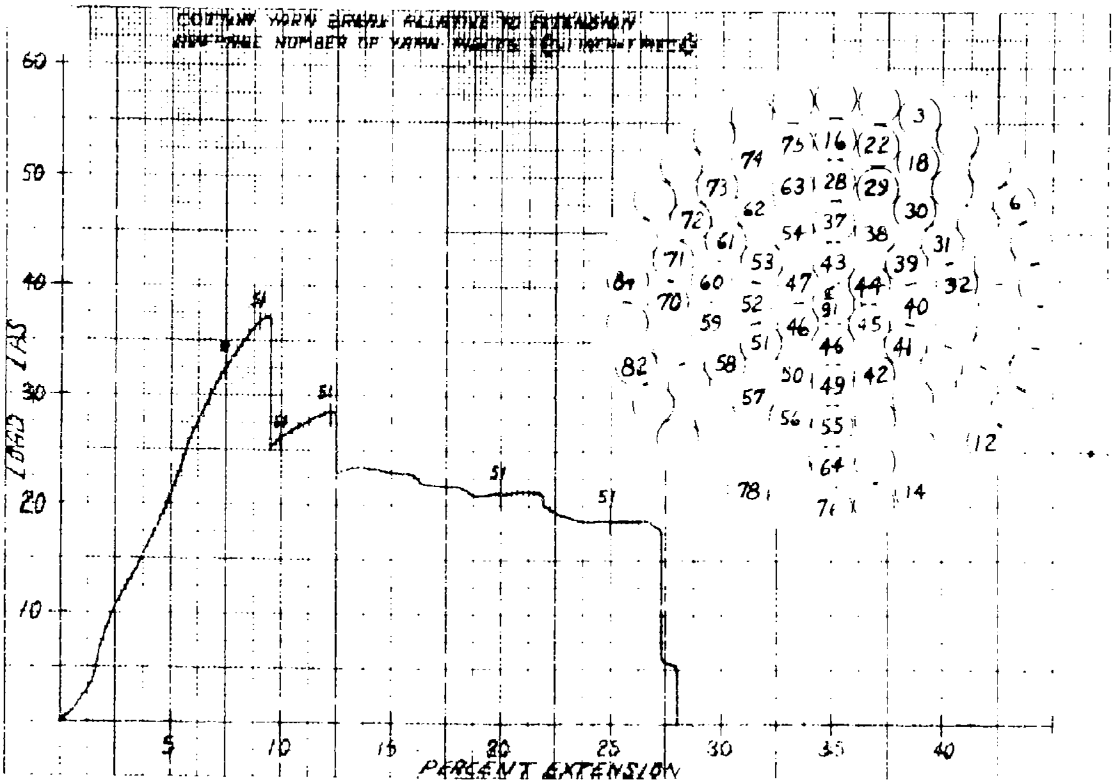


FIGURE 6 [illegible] COTTON [illegible] DACRON [illegible]

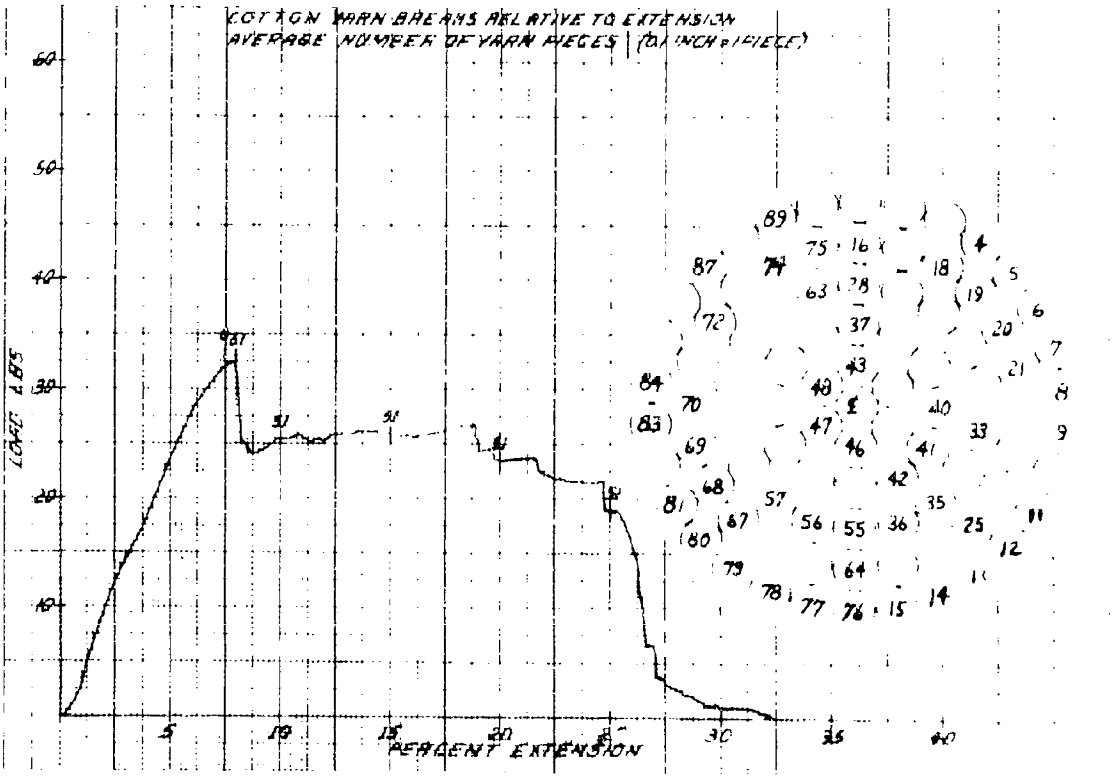
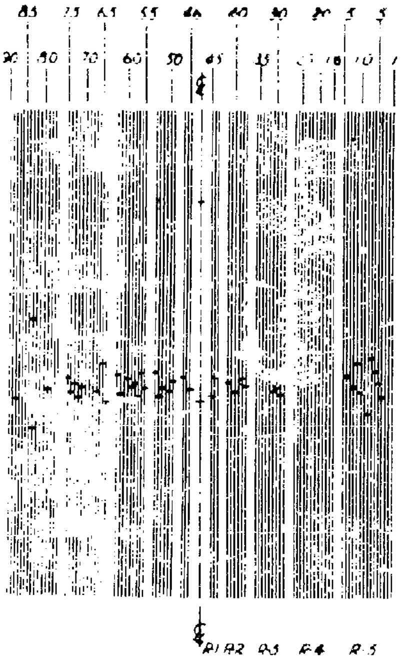
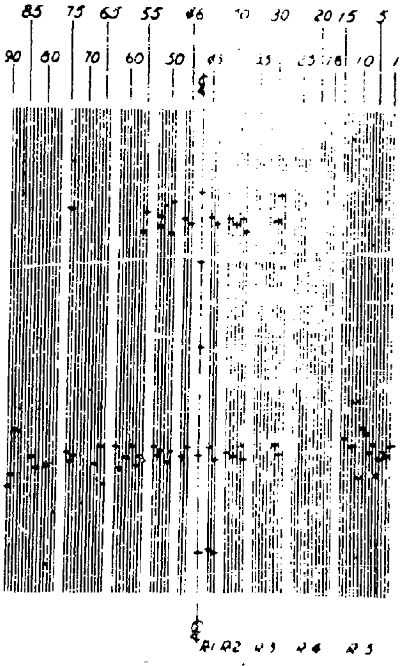


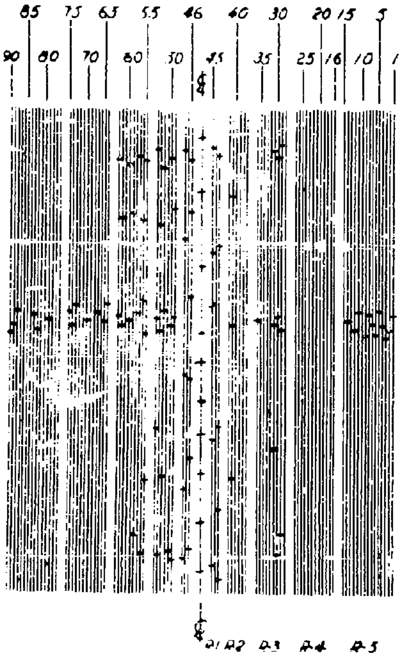
FIGURE [illegible] [illegible] [illegible]



9% EXTENSION
1.09 TM 56% COTTON 44% DACRON

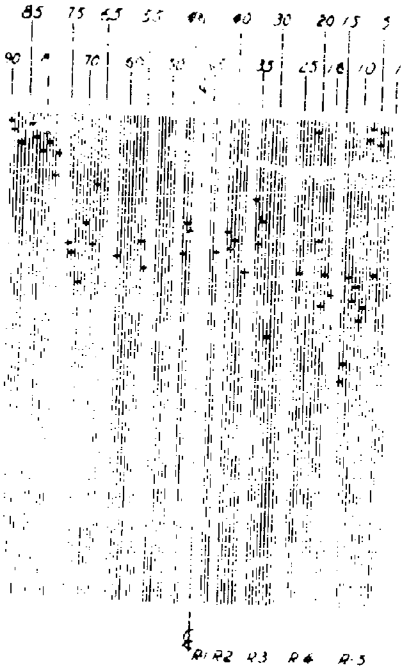


10% EXTENSION
1.09 TM 56% COTTON 44% DACRON

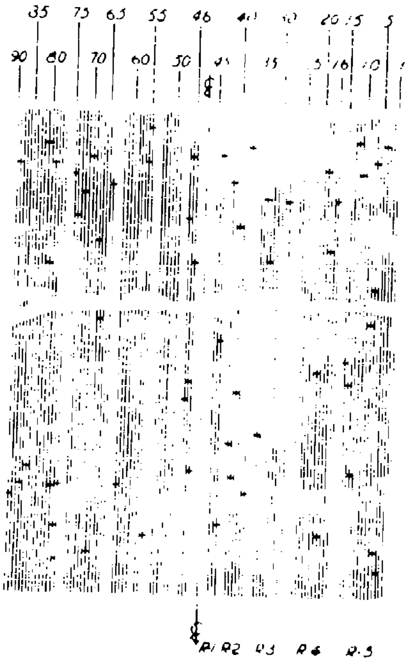


25% EXTENSION
1.09 TM 56% COTTON 44% DACRON

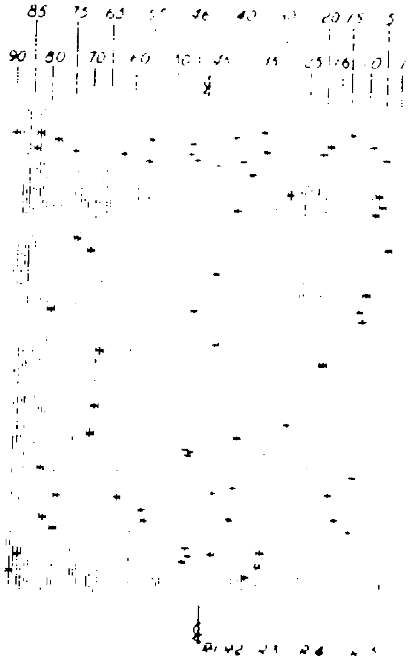
FIGURE 66a



8% EXTENSION
0.54 TM 56% COTTON 44% DACRON



15% EXTENSION
0.54 TM 56% COTTON 44% DACRON



25% EXTENSION
0.54 TM 56% COTTON 44% DACRON

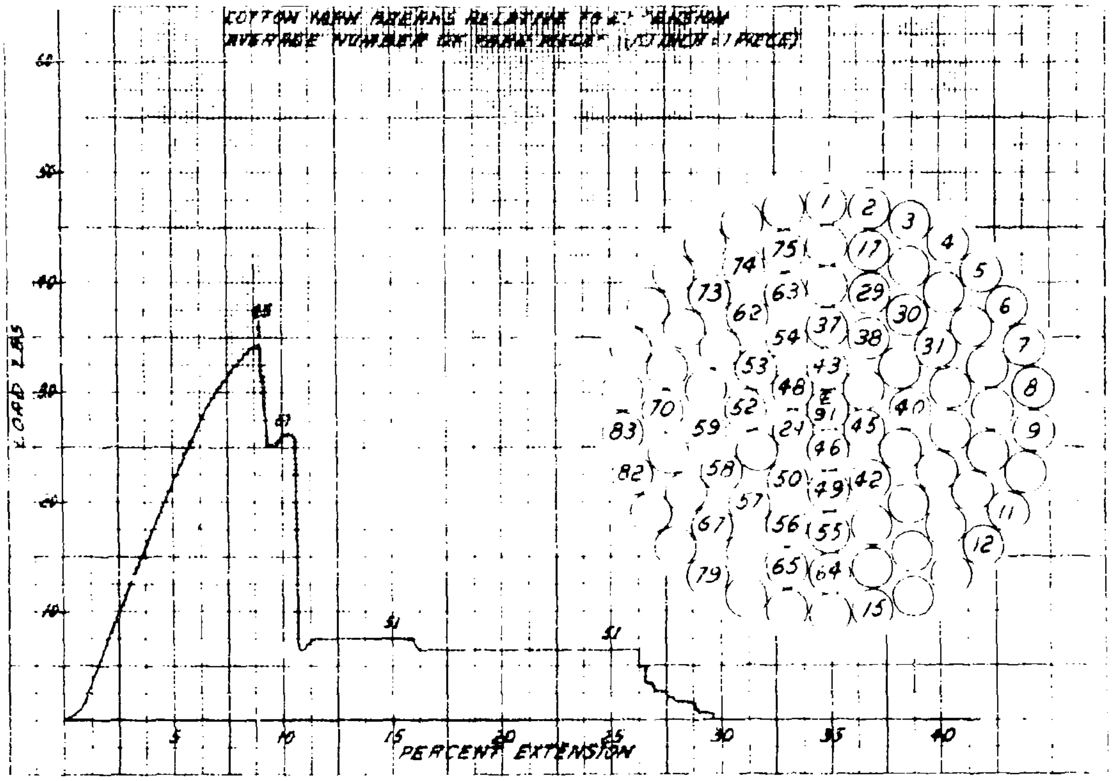


FIGURE 56 COTTON 14 DACRON [illegible]

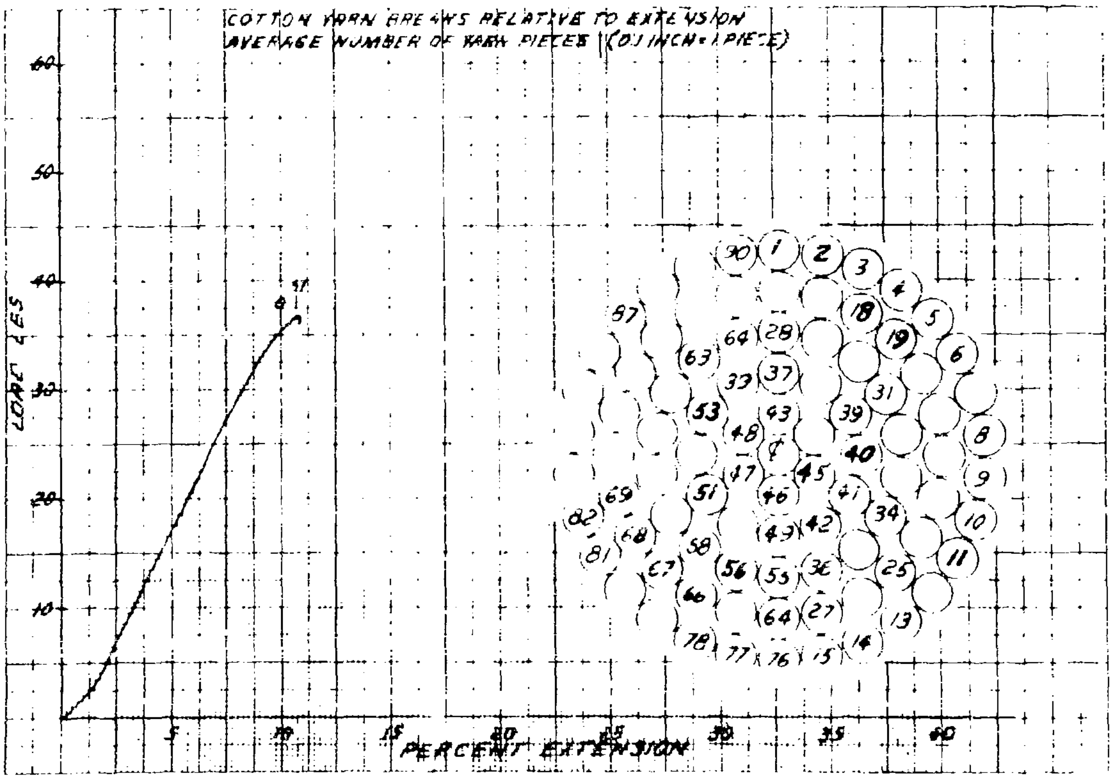
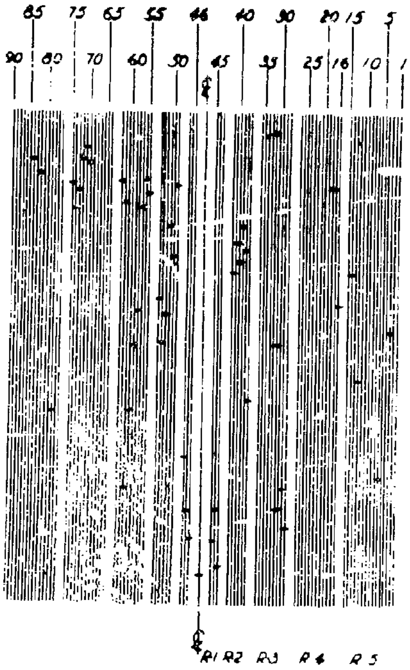
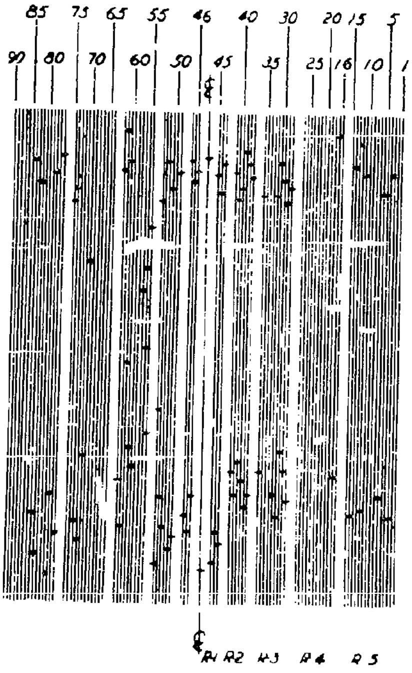


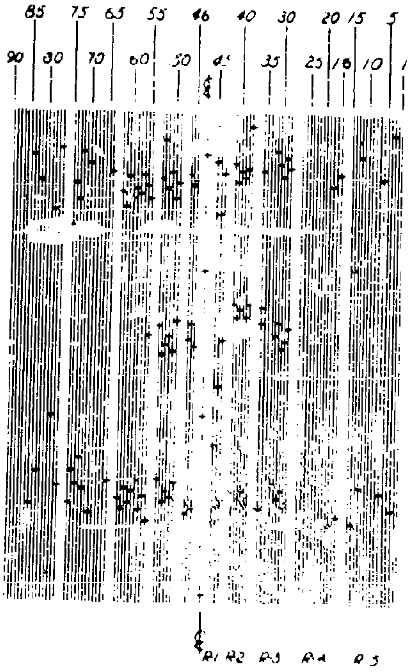
FIGURE 58 [illegible] COTTON 14% DACRON [illegible]



9% EXTENSION
1.09 TM 56% COTTON 44% DACRON

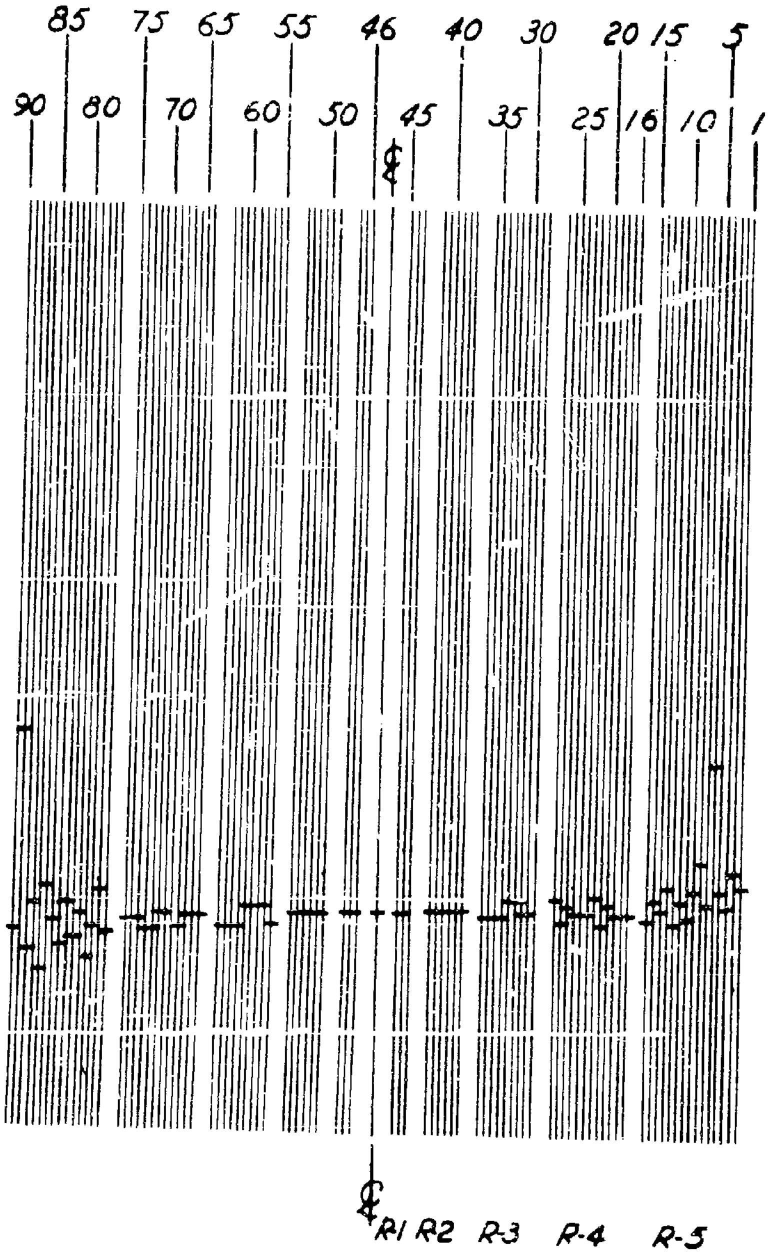


12-1/2% EXTENSION
1.09 TM 56% COTTON 44% DACRON



25% EXTENSION
1.09 TM 56% COTTON 44% DACRON

FIGURE 87a



10.8% EXTENSION
2.17 TM 56% COTTON 44% DACRON

FIGURE 68a

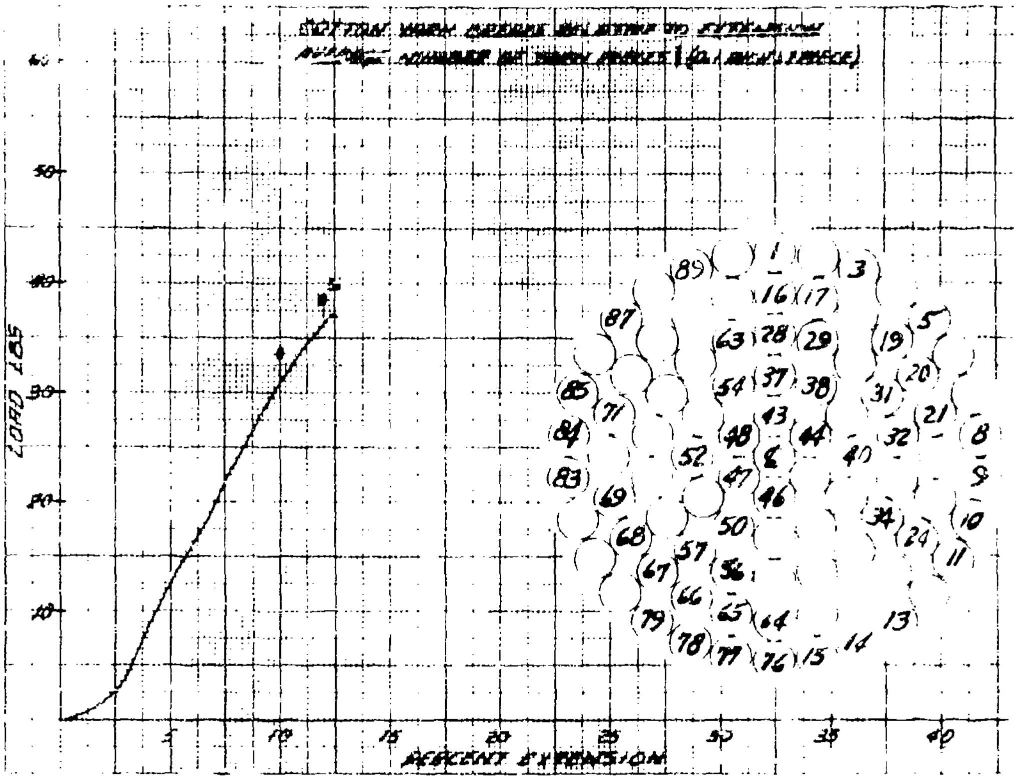


FIGURE 19. 56% COTTON 44% DACRON 3.26 IN

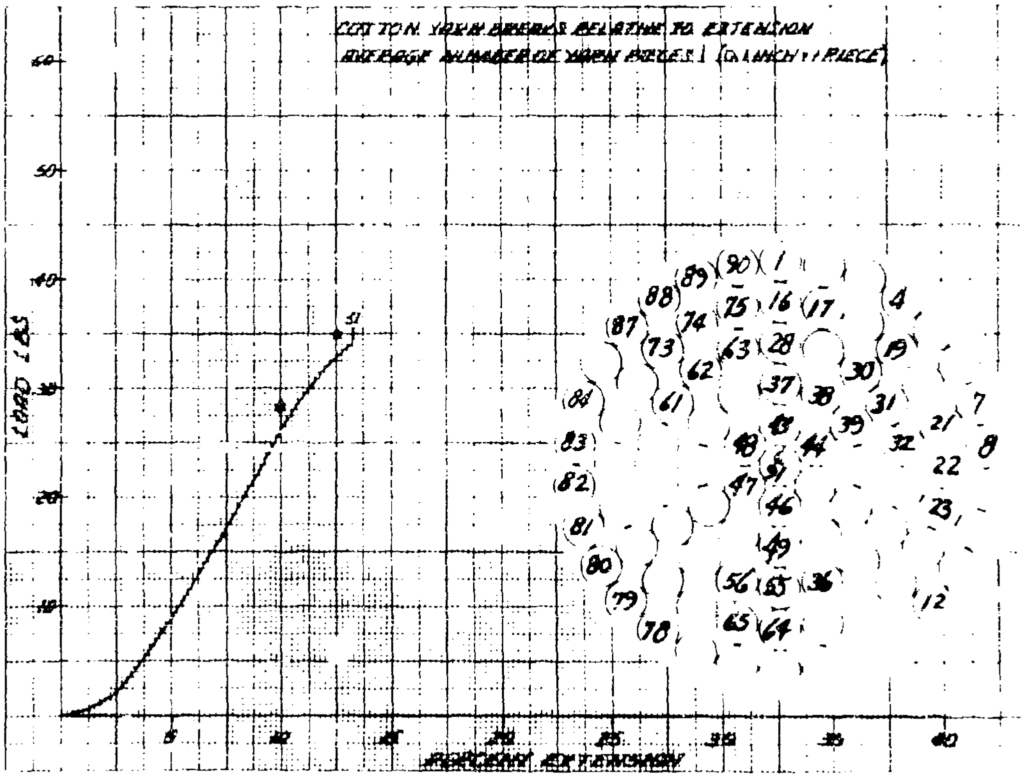
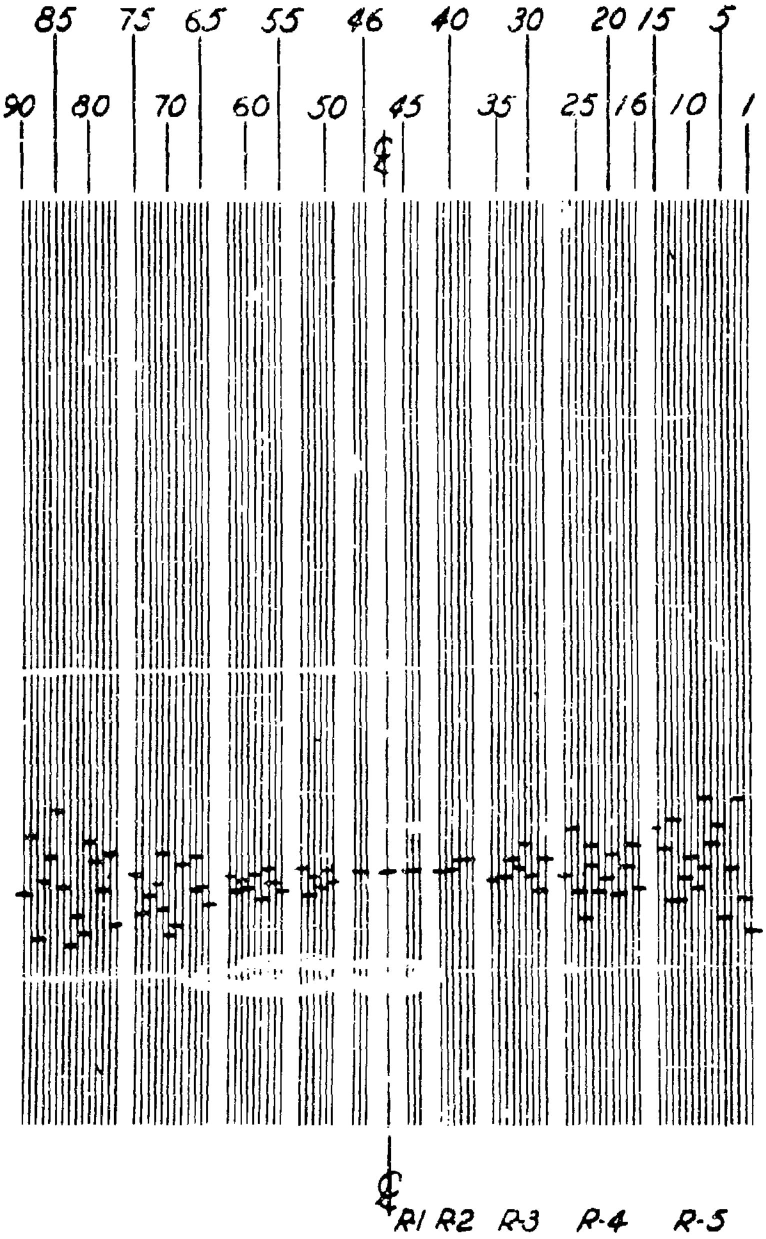
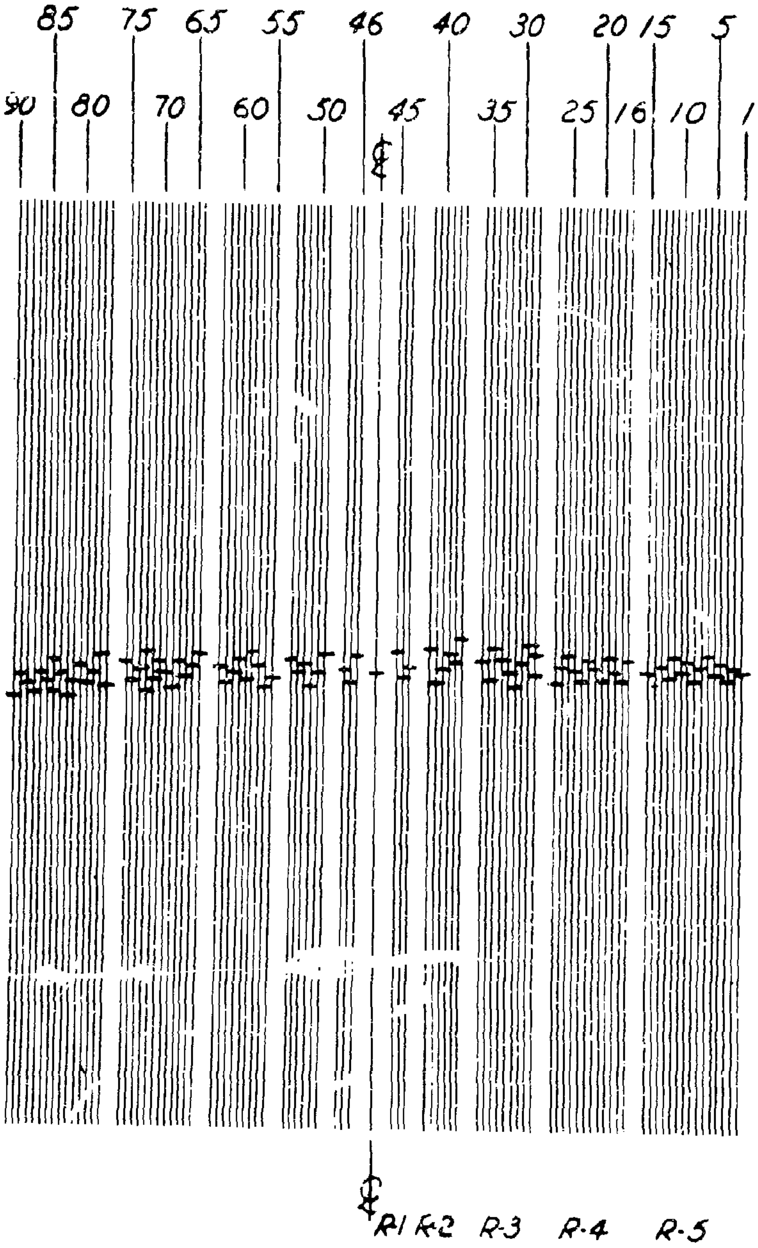


FIGURE 20. 56% COTTON 44% DACRON 3.15 IN



12.5% EXTENSION
3.26 TM 56% COTTON 44% DACRON

FIGURE 69a



13% EXTENSION

4.35 TM 56% COTTON 44% DACRON

FIGURE 70a

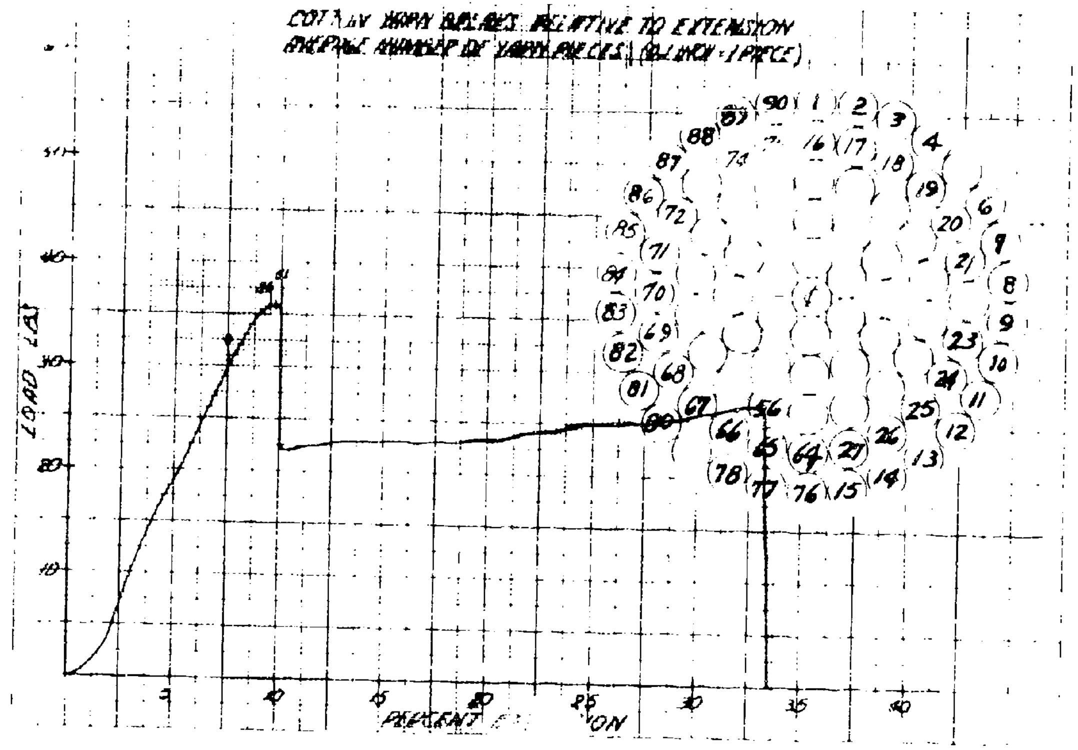


FIGURE 21 [illegible] 50% [illegible] DACRON [illegible]

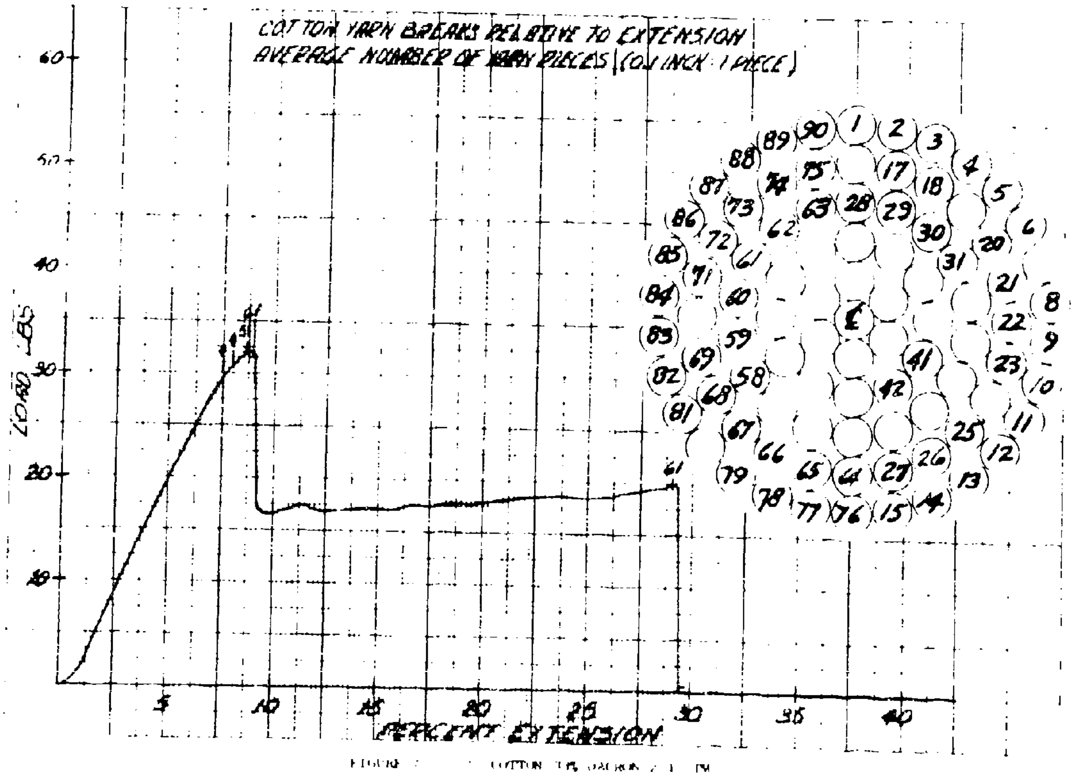
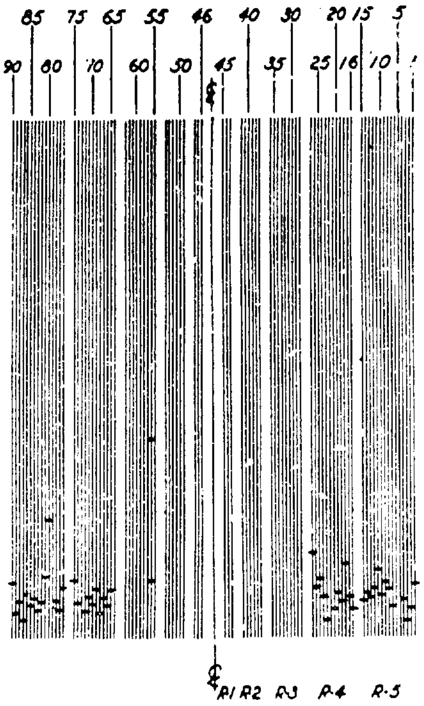
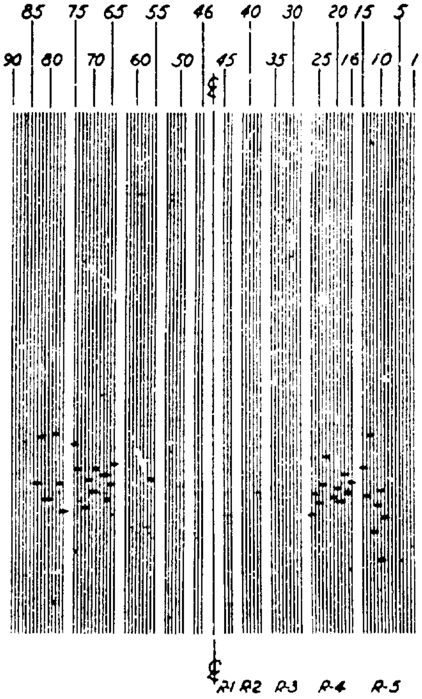


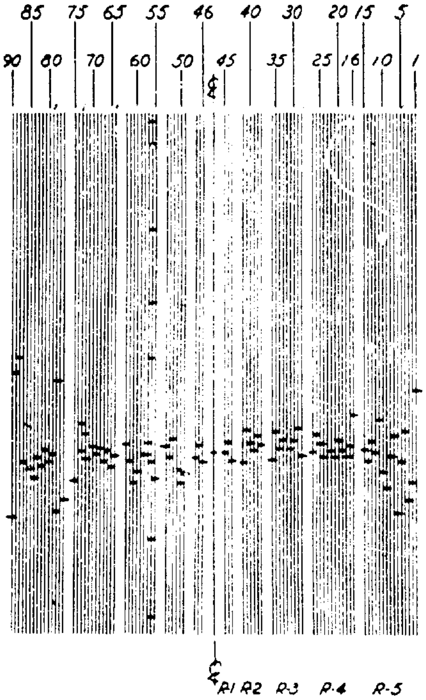
FIGURE [illegible] COTTON [illegible] DACRON [illegible]



9-1/2% EXTENSION
2.17 TM 56% COTTON 44% DACRON

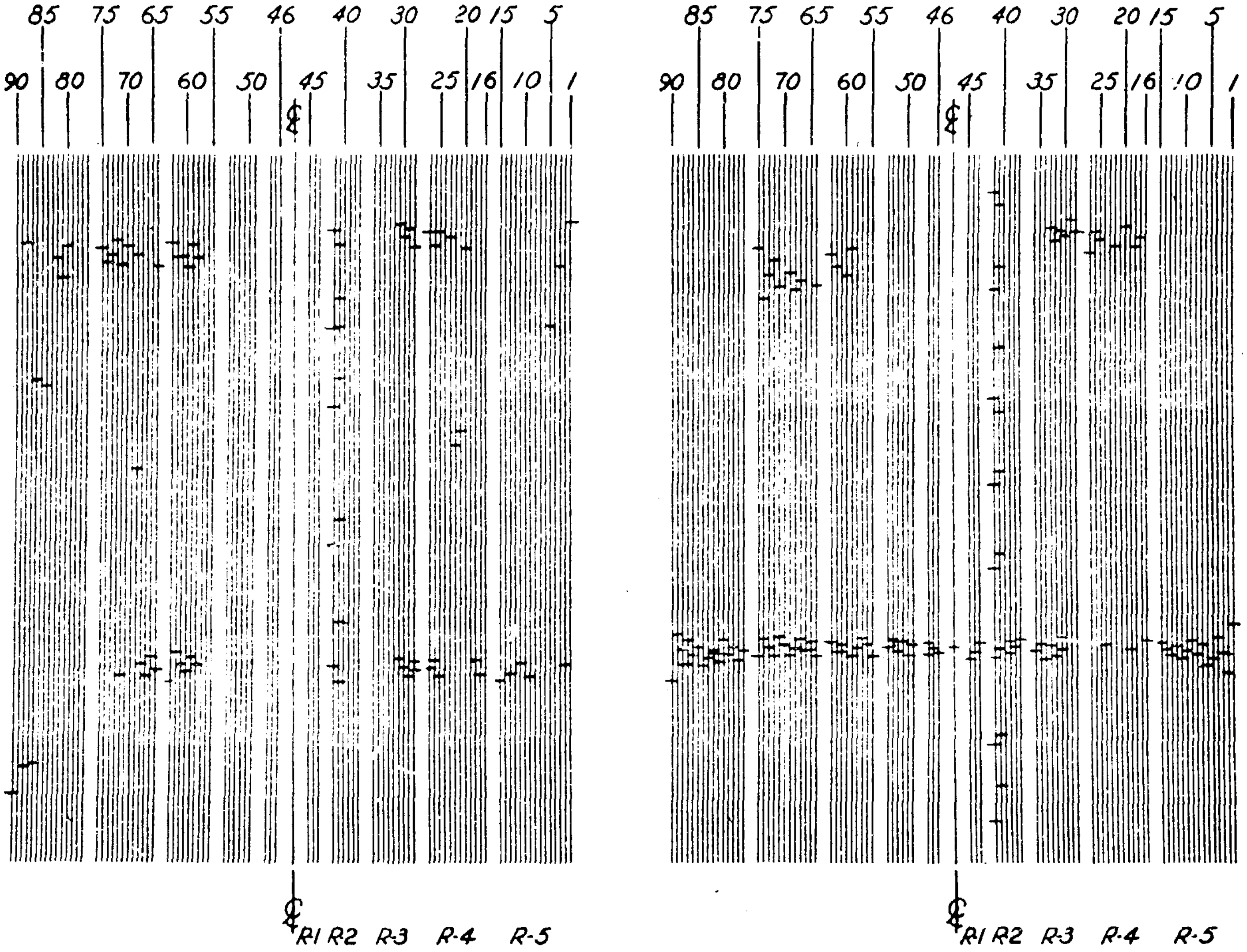


10% EXTENSION
2.17 TM 56% COTTON 44% DACRON



25% EXTENSION
2.17 TM 56% COTTON 44% DACRON

FIGURE 71a



9% EXTENSION

2.17 TM 67% COTTON 33% DACRON

9.2% EXTENSION

2.17 TM 67% COTTON 33% DACRON

FIGURE 72a

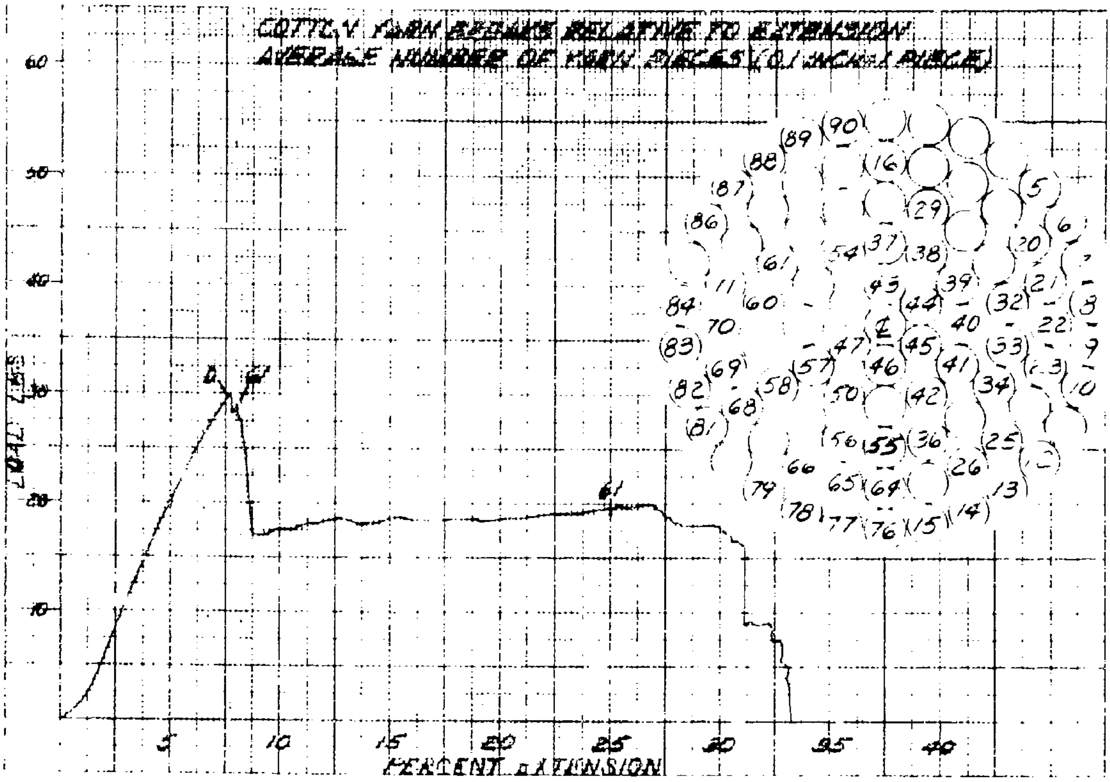


FIGURE [illegible] COTTON [illegible] DACRON [illegible]

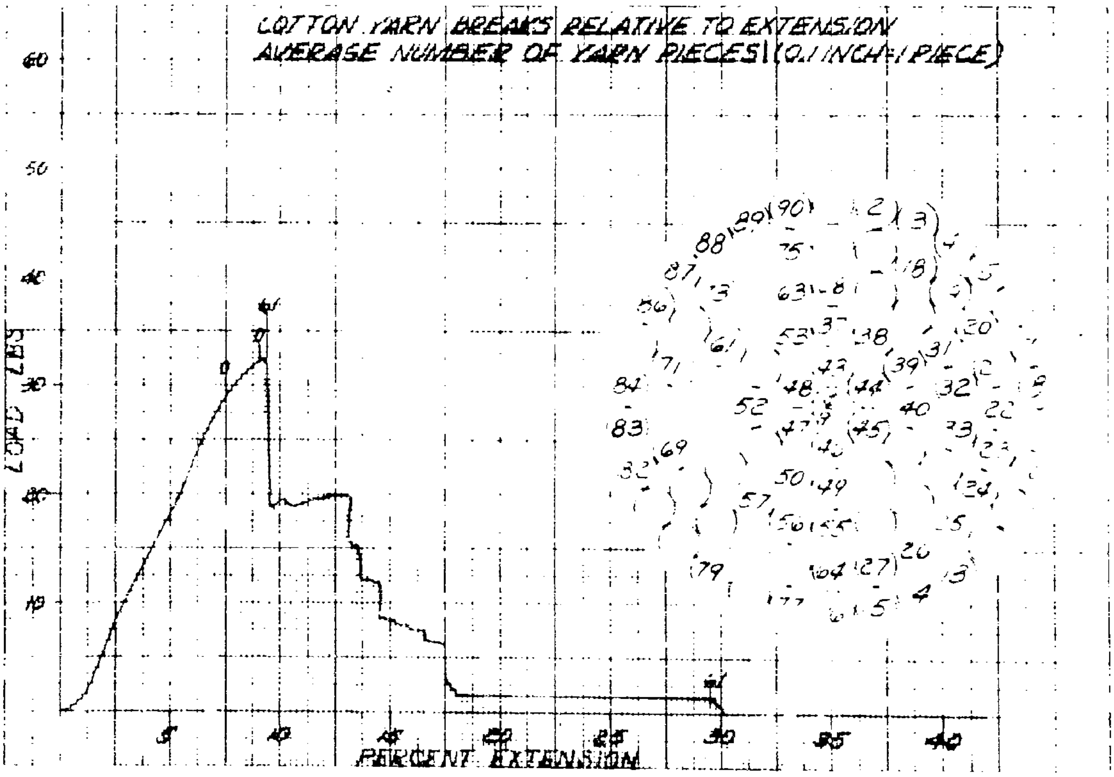
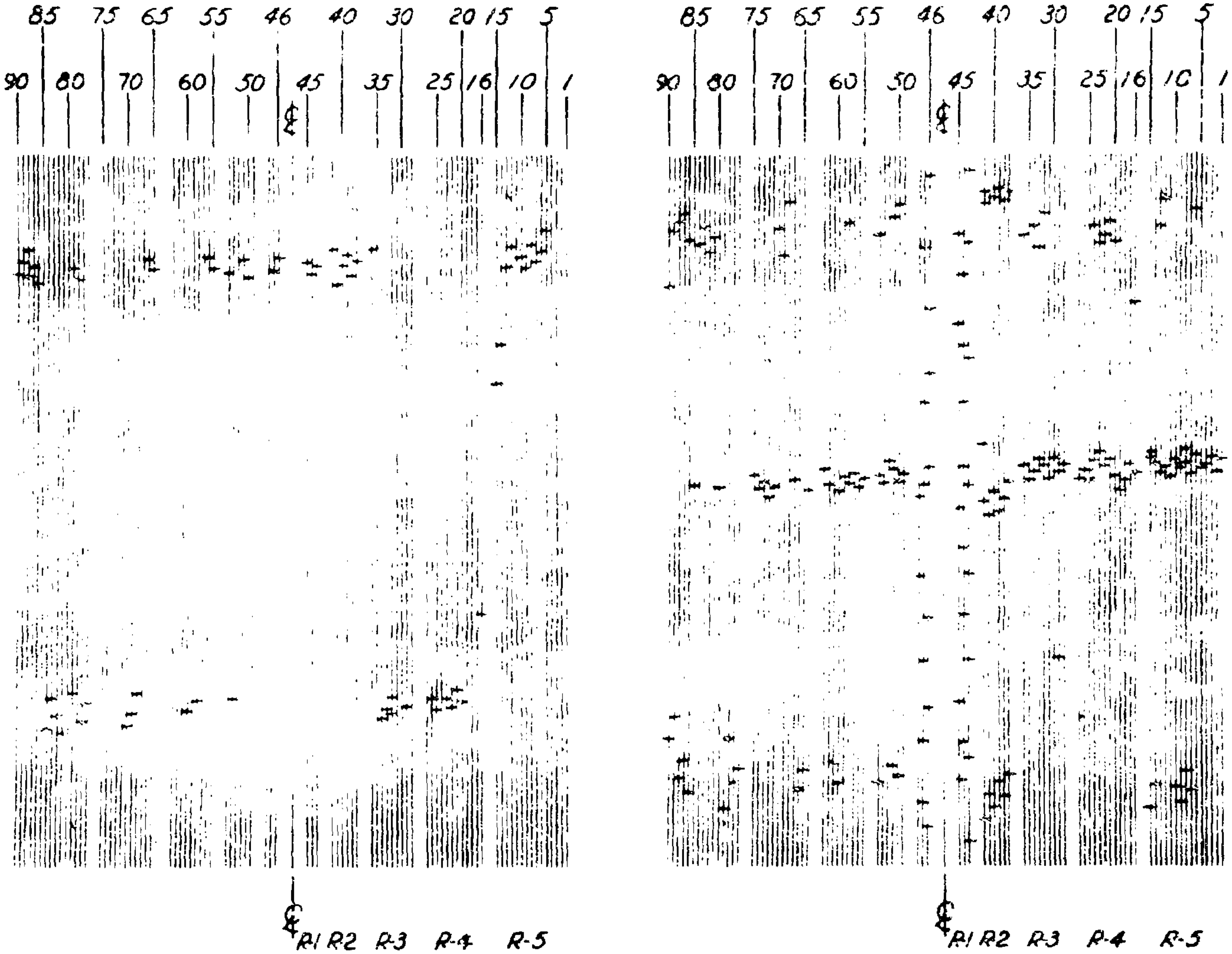


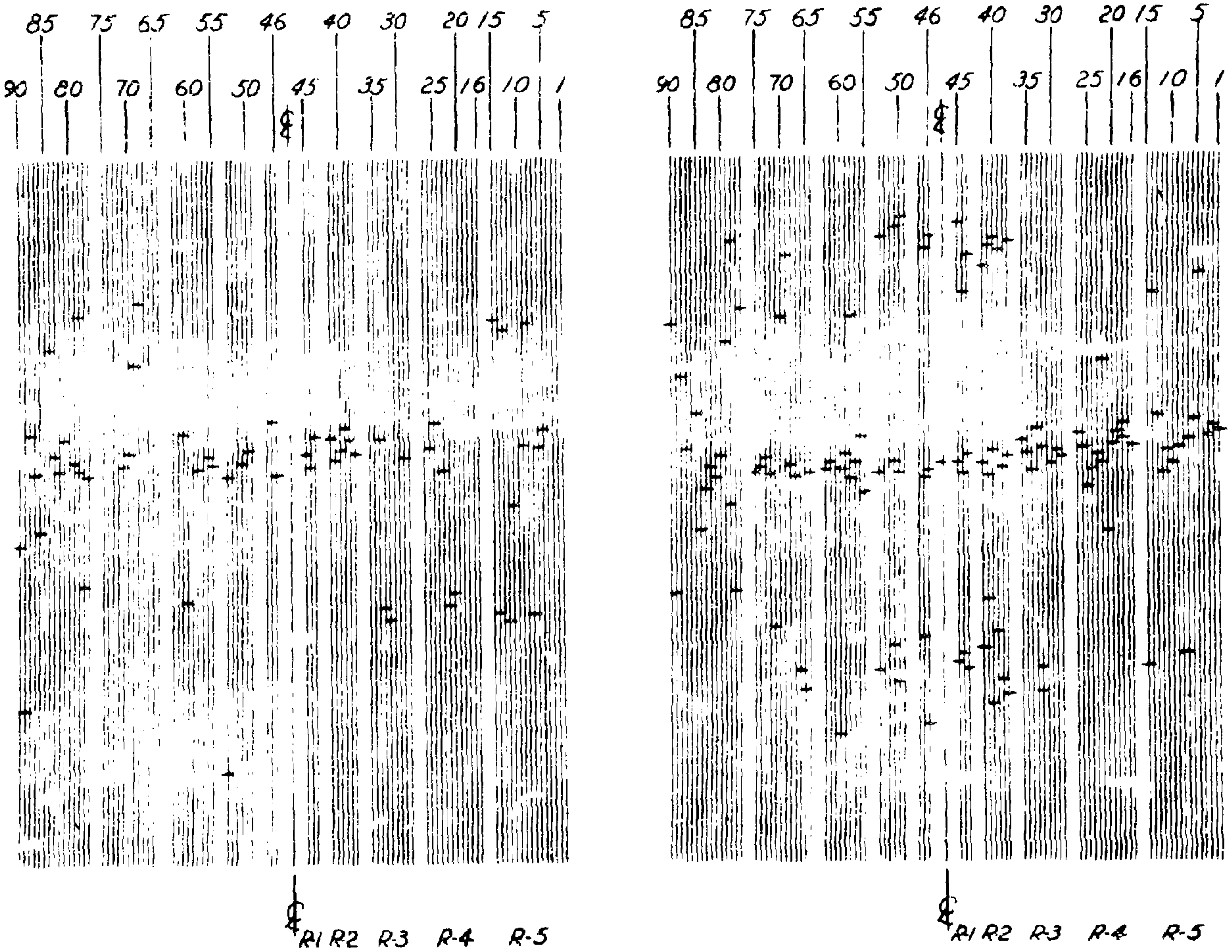
FIGURE [illegible] COTTON [illegible] DACRON [illegible]



8% EXTENSION
0.541 TM 67% COTTON 33% DACRON

25% EXTENSION
0.541 TM 67% COTTON 33% DACRON

FIGURE 73a



9.2% EXTENSION
1.08 TM 67% COTTON 33% DACRON

30% EXTENSION
1.08 TM 67% COTTON 33% DACRON

FIGURE [illegible]4a

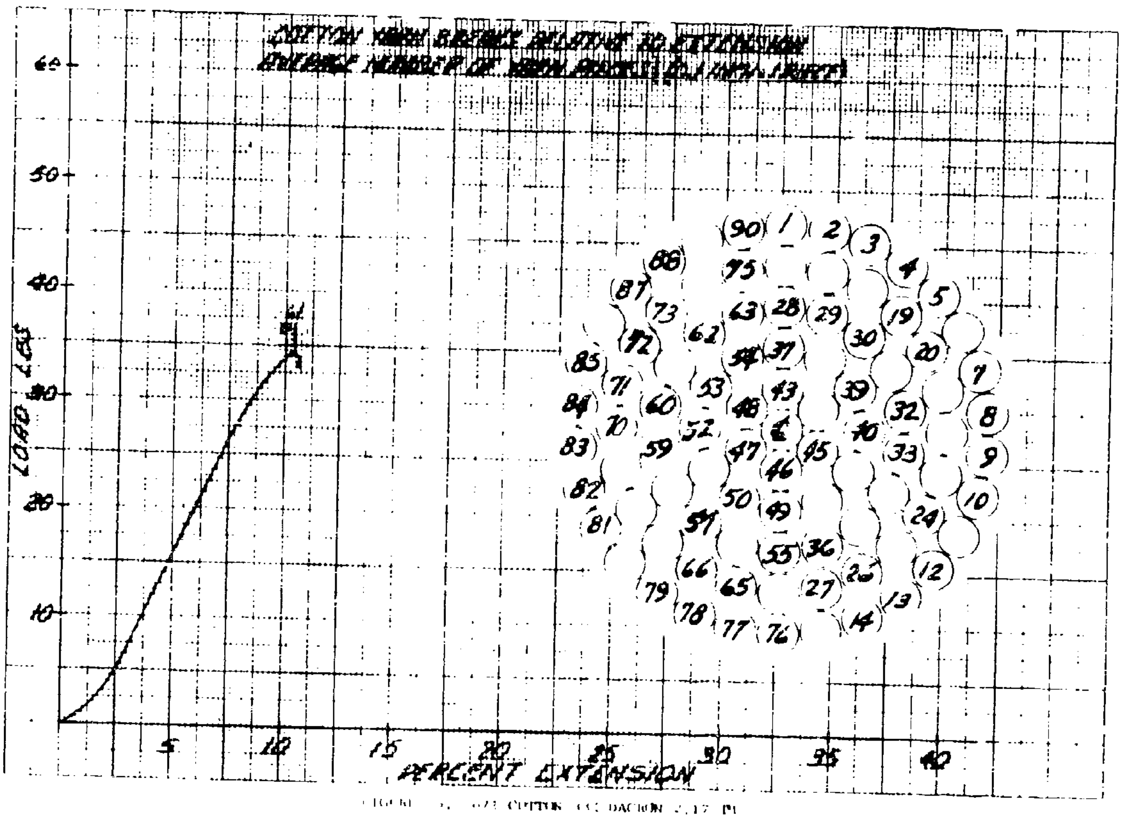


FIGURE [illegible]. 67% COTTON 33% DACRON 2.17 TM

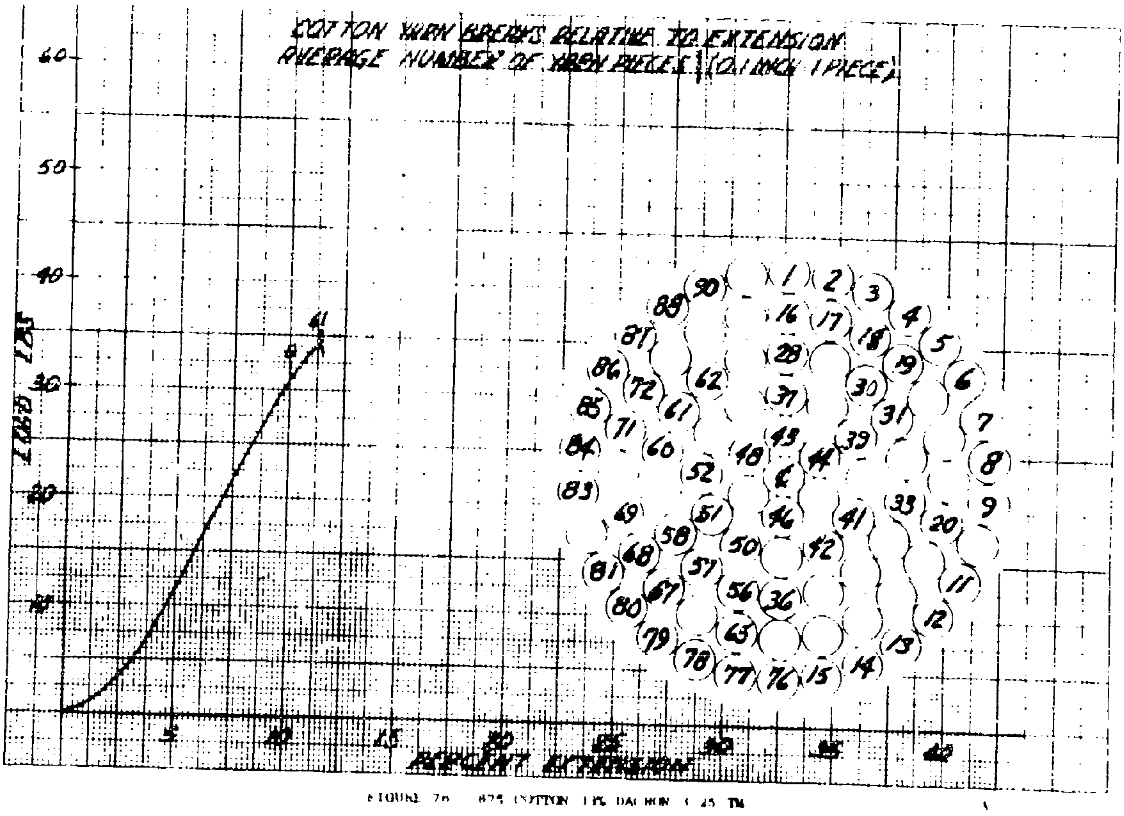
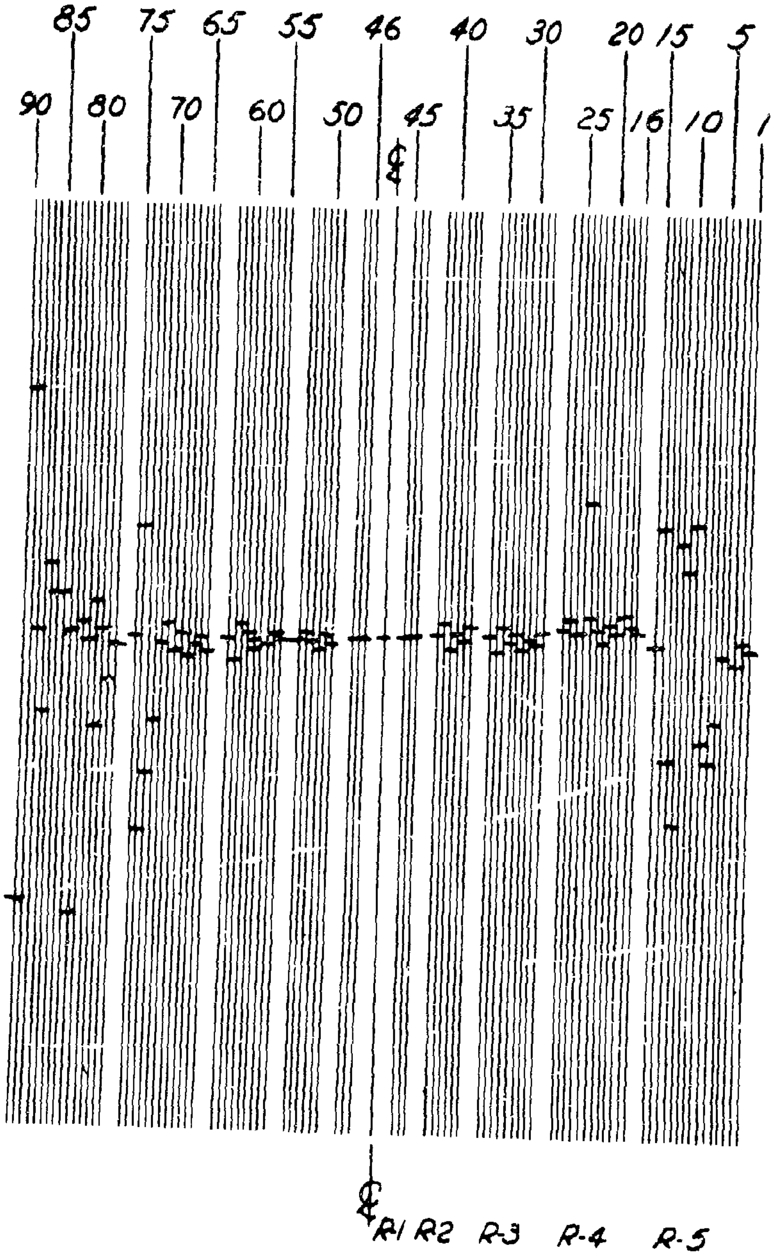
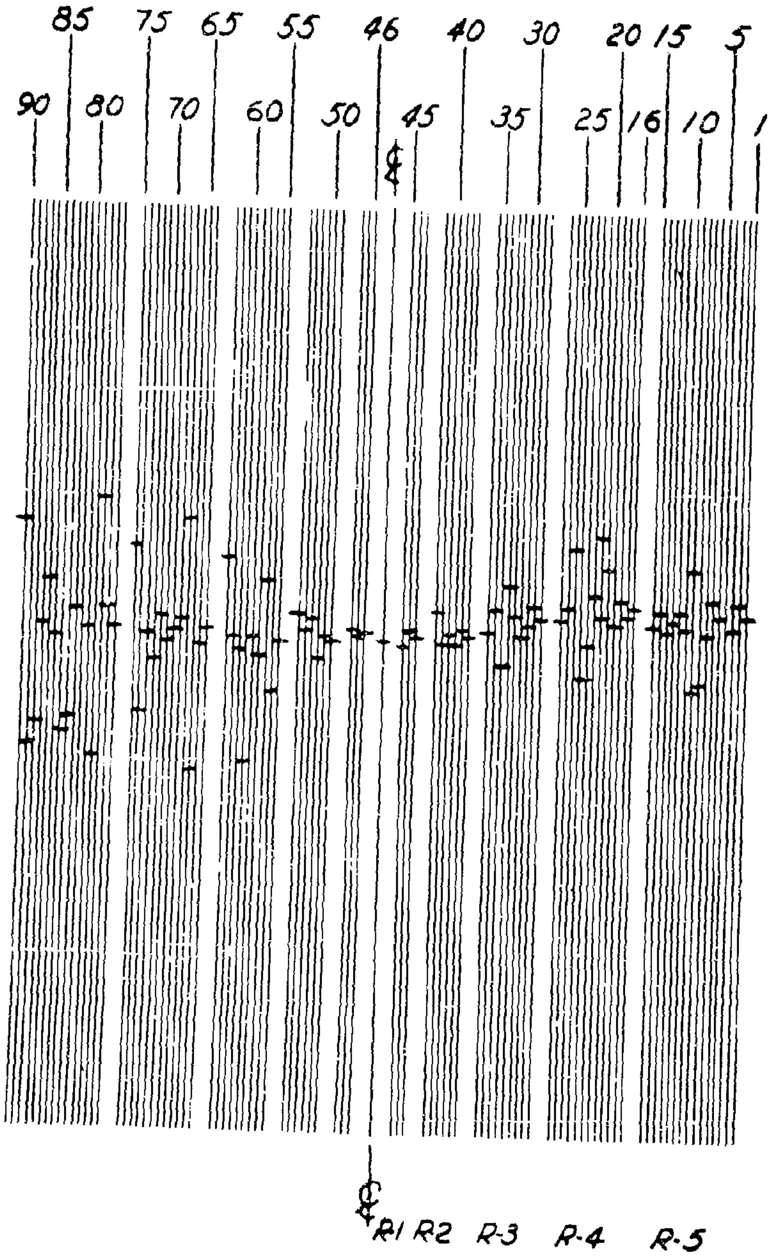


FIGURE 76. 87% COTTON 13% DACRON 3.45 TM



10.3% EXTENSION
2.17 TM 67% COTTON 33% DACRON

FIGURE 75a



11.3% EXTENSION
3.25 TM 67% COTTON 33% DACRON

FIGURE 76a

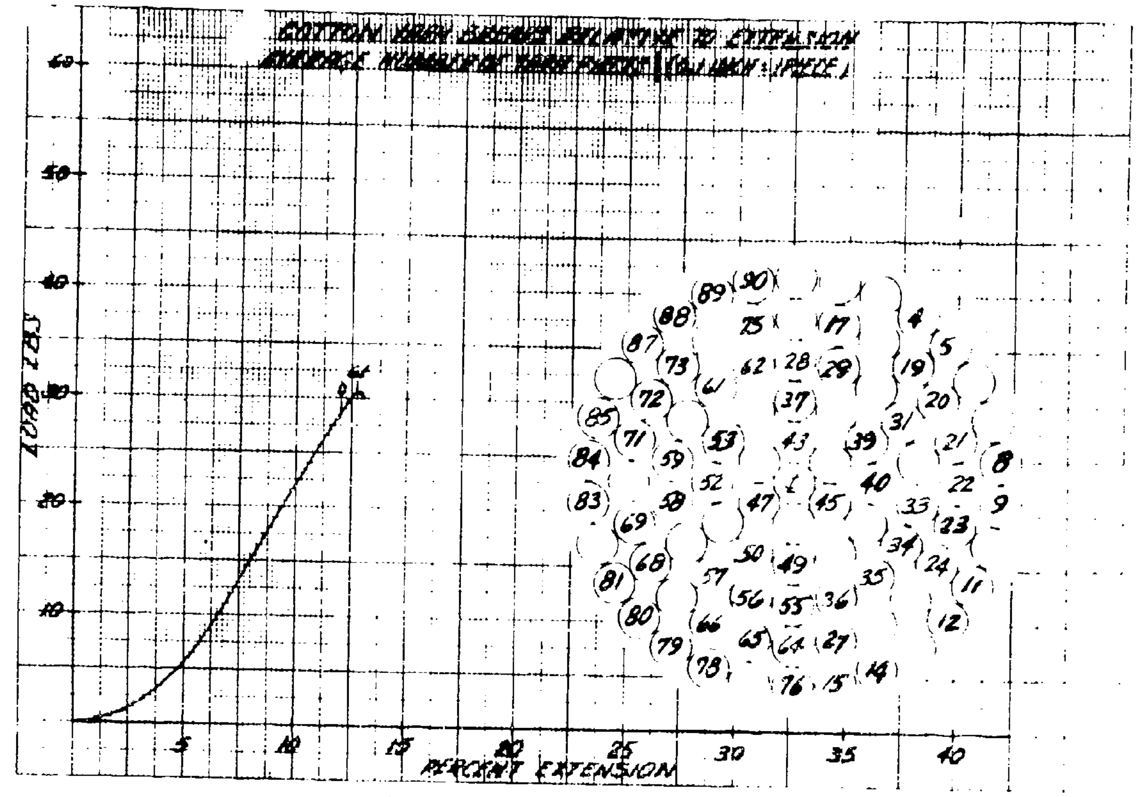


FIGURE 27. 67% COTTON 33% DACRON [illegible]

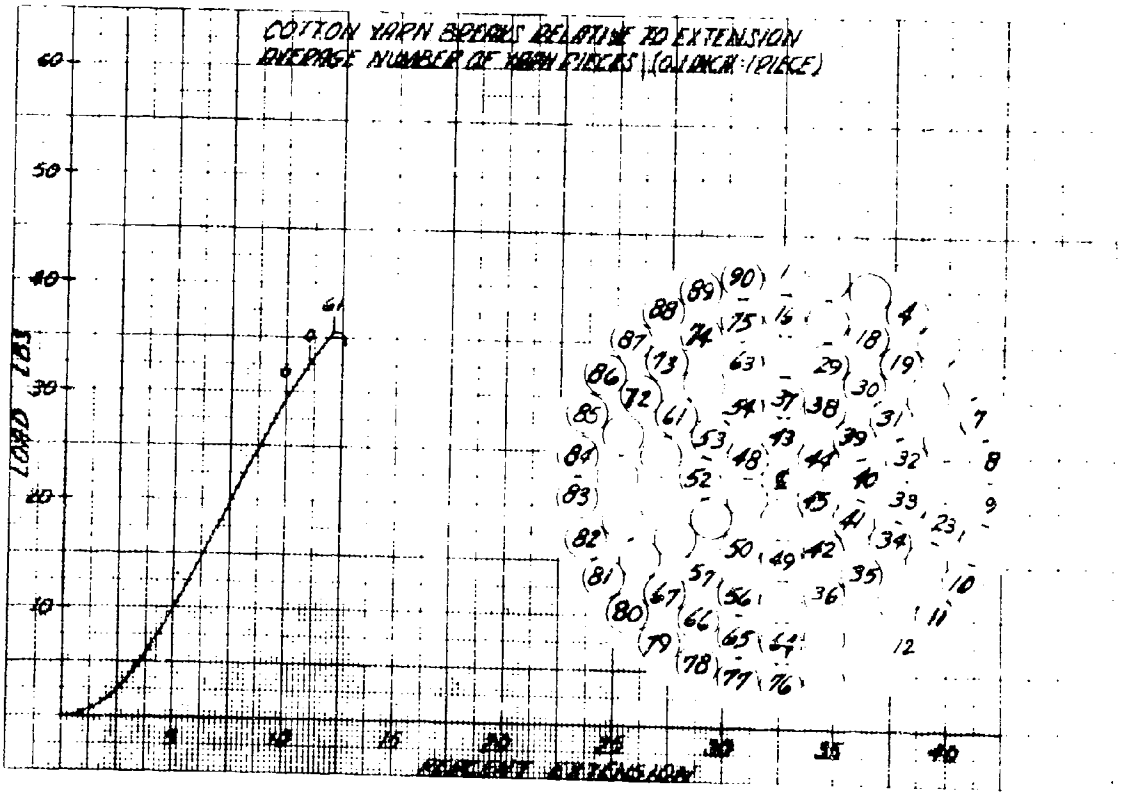
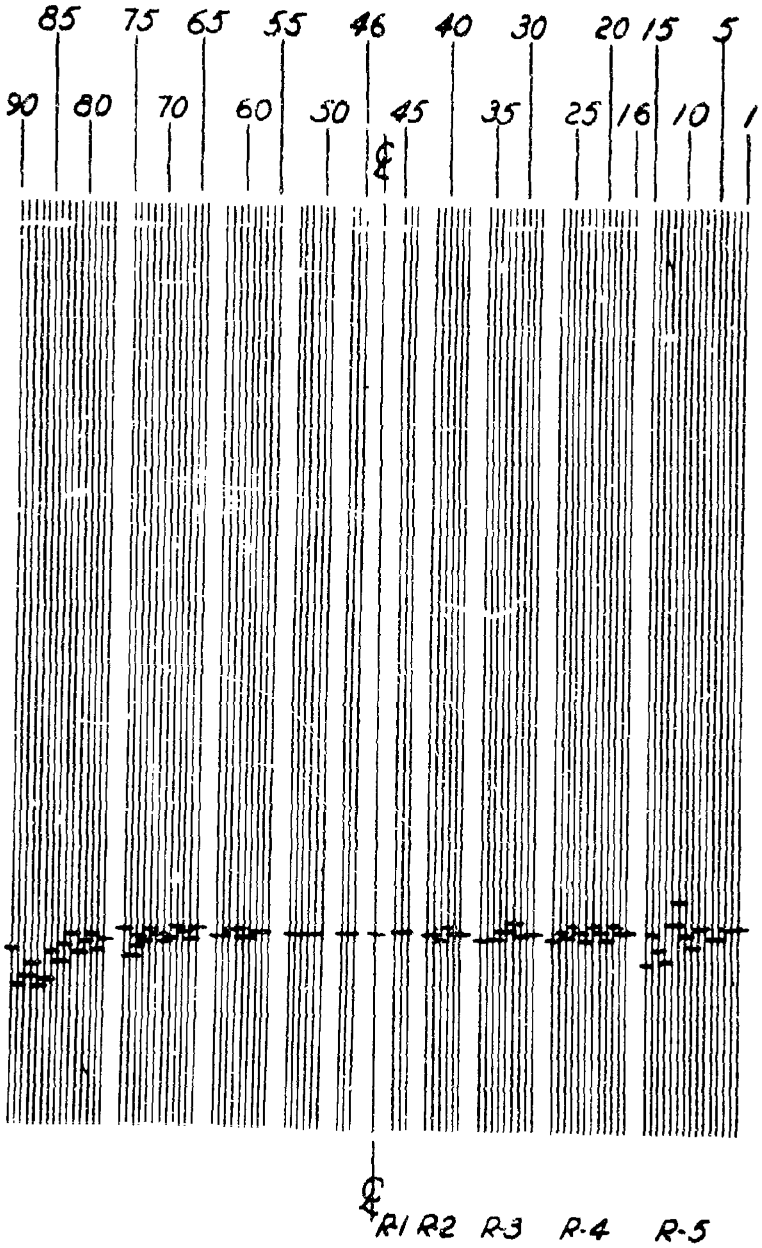
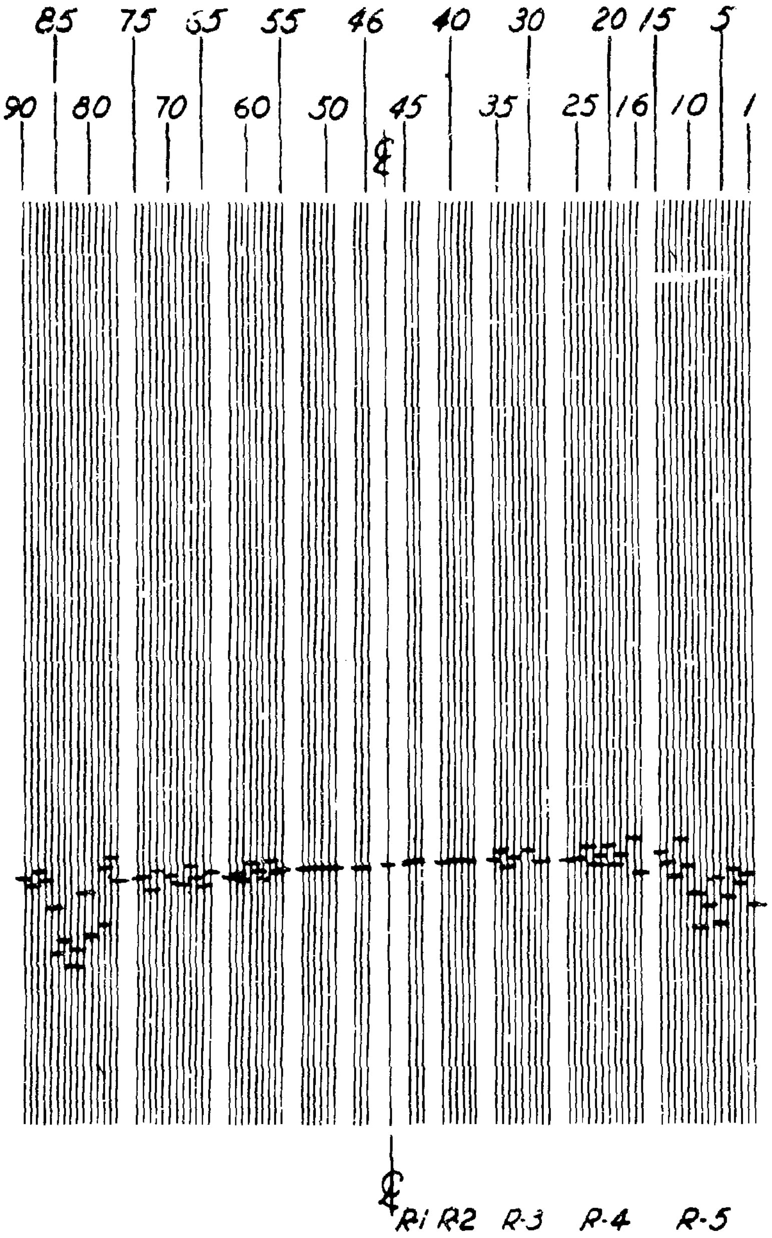


FIGURE 28. 67% COTTON 33% DACRON [illegible] IN



12.6% EXTENSION
4.34 TM 67% COTTON 33% DACRON

FIGURE 77a



12.1% EXTENSION
3.24 TM 67% COTTON 33% DACRON

FIGURE 78a

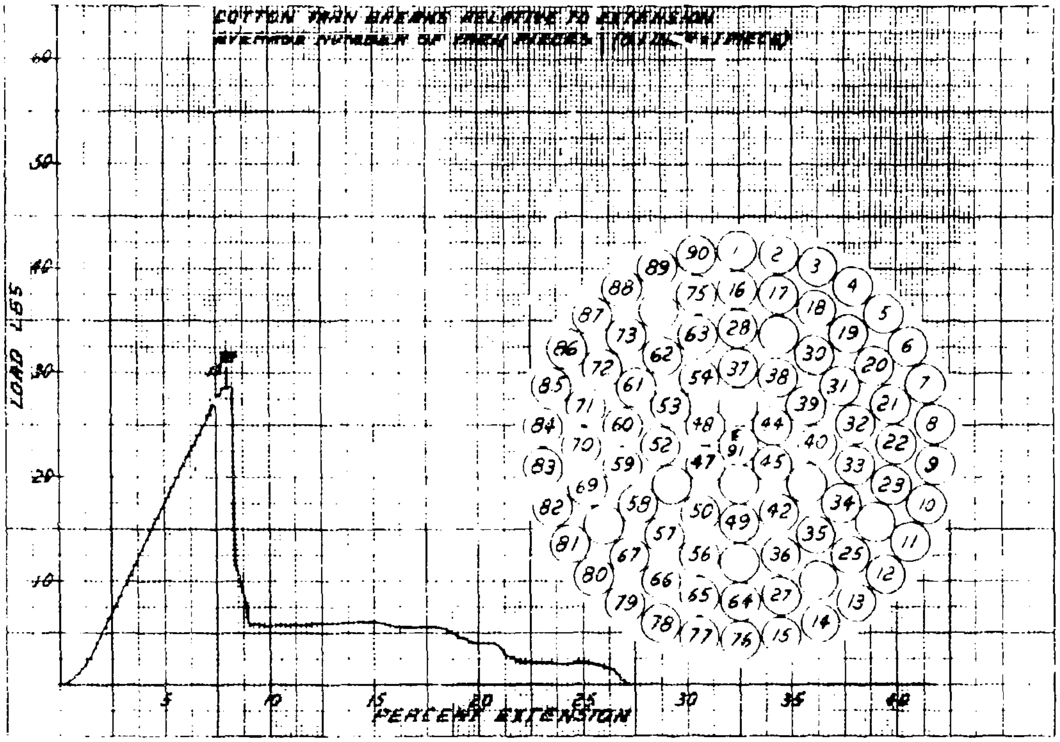


FIGURE 79. 89% COTTON 11% DACRON .54 TM

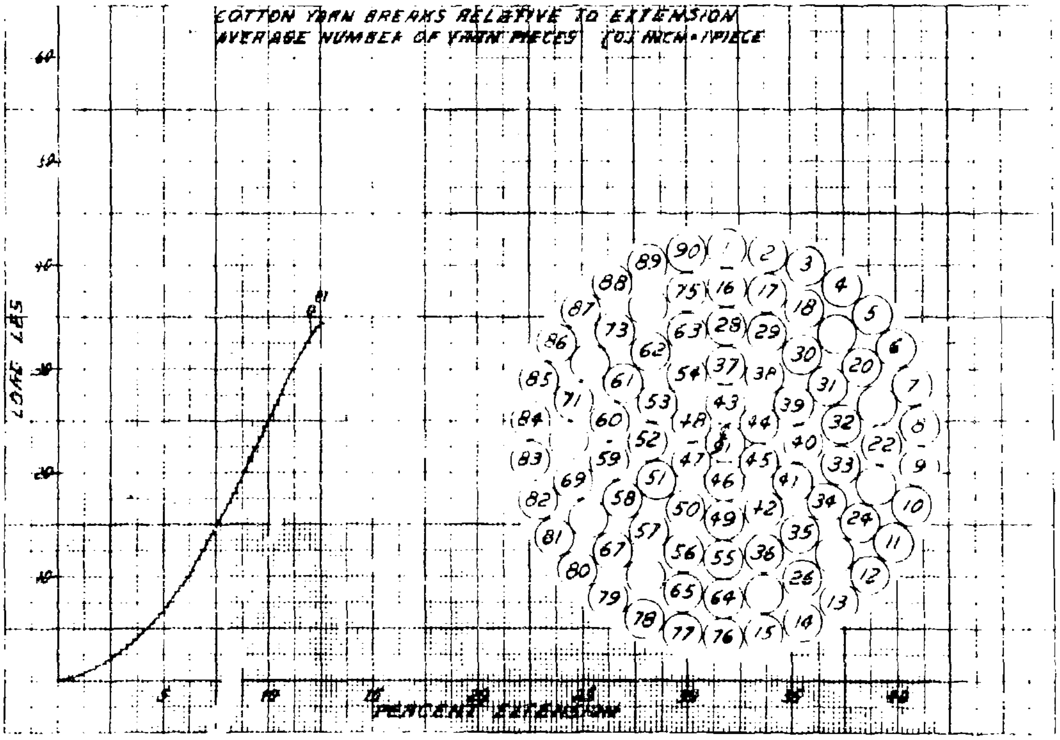
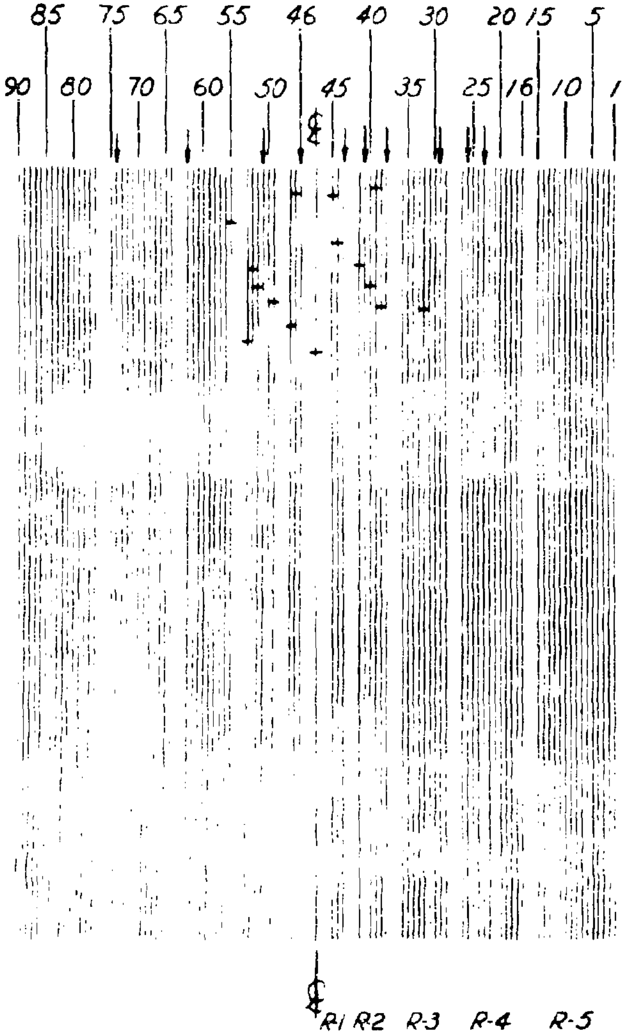
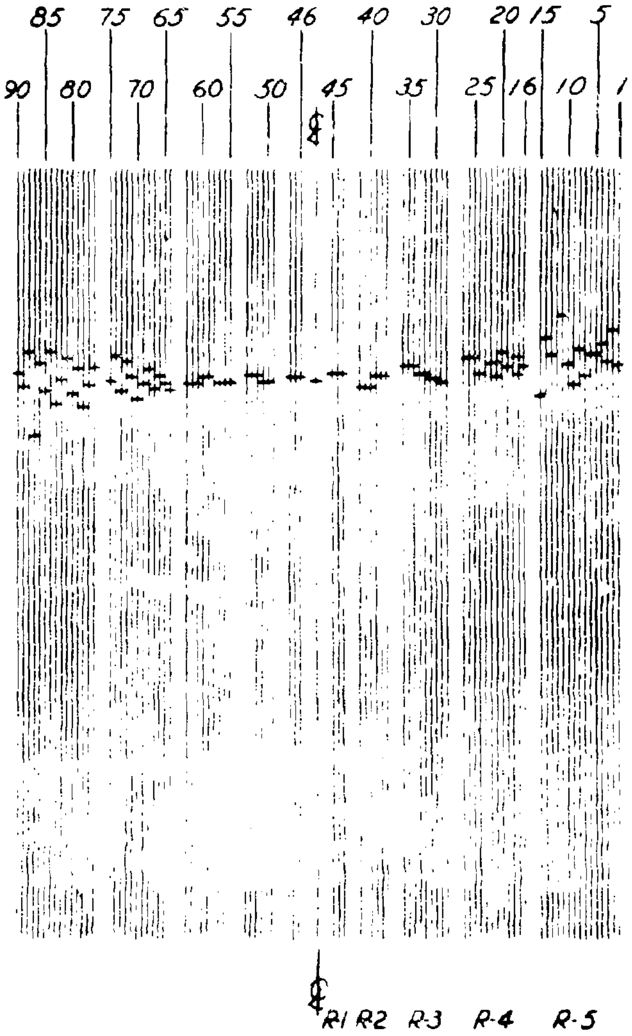


FIGURE 80. 89% COTTON 11% DACRON 1.46 TM

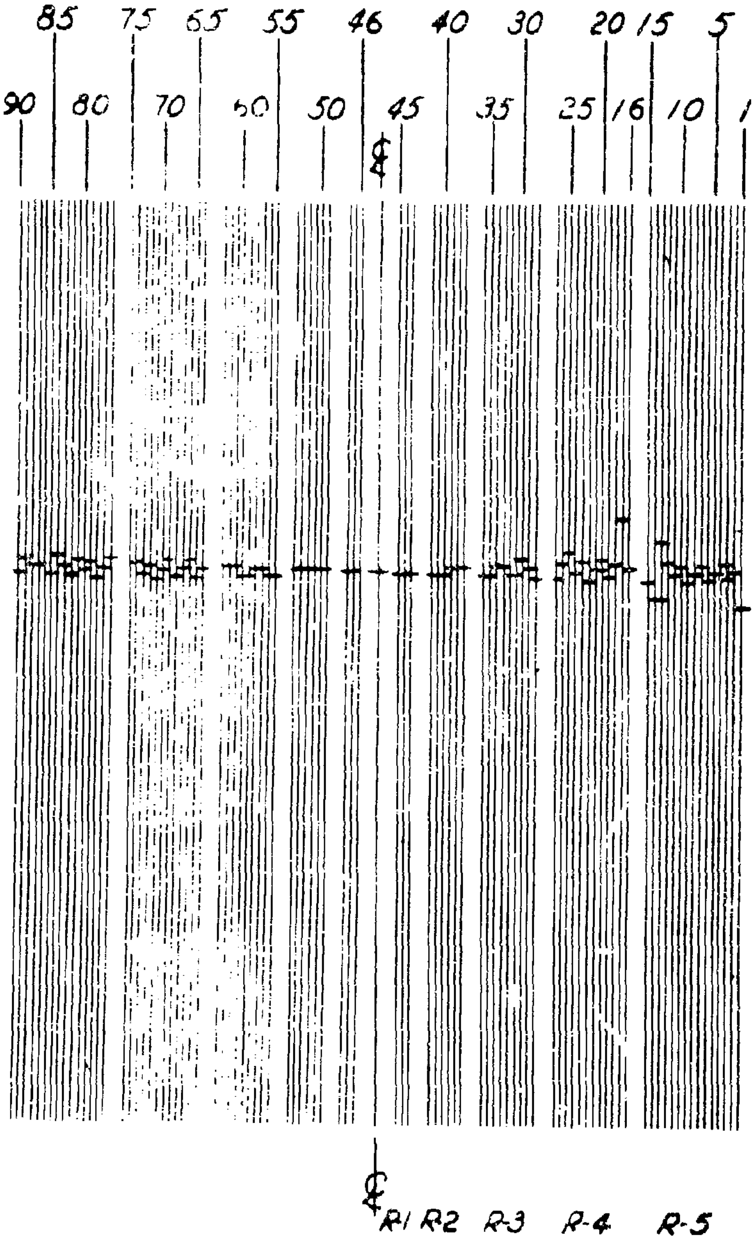


7-1/2% EXTENSION
.54 TM 89% COTTON 11% DACRON



8% EXTENSION
.54 TM 89% COTTON 11% DACRON

FIGURE [illegible]



12.5% EXTENSION
3.1 TM 89% COTTON 11% DACRON

FIGURE 80a

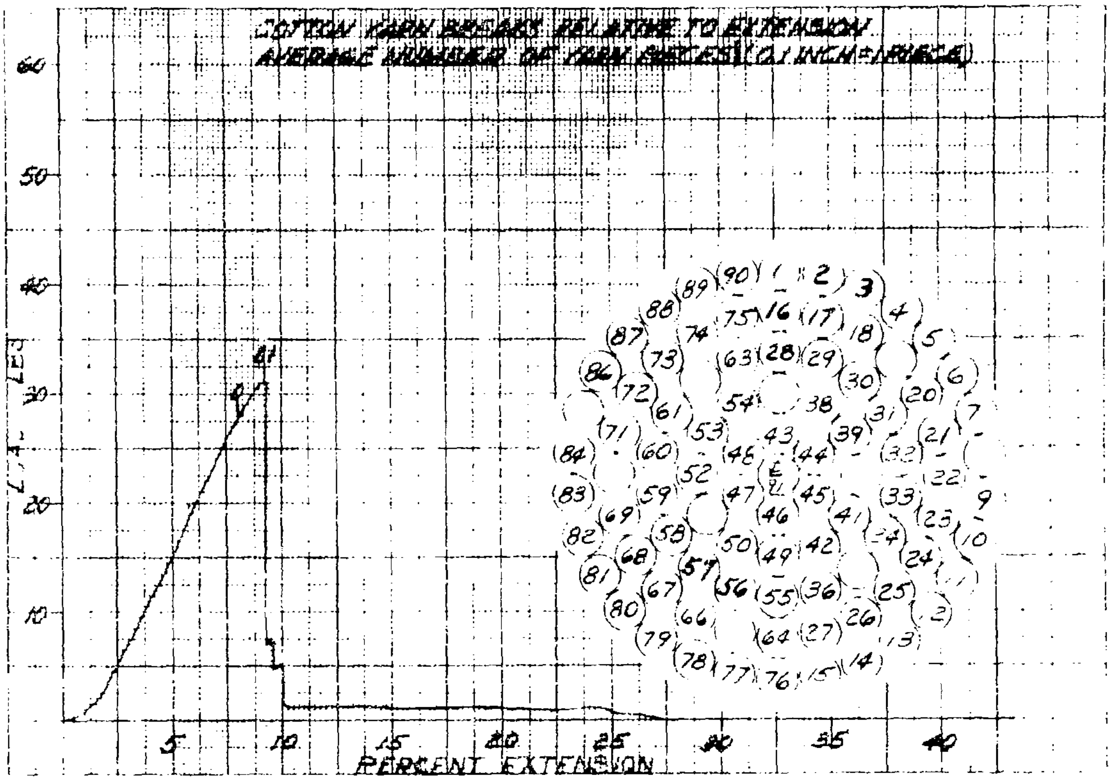


FIGURE 83. 89% COTTON 11% DACRON 1.07 TM

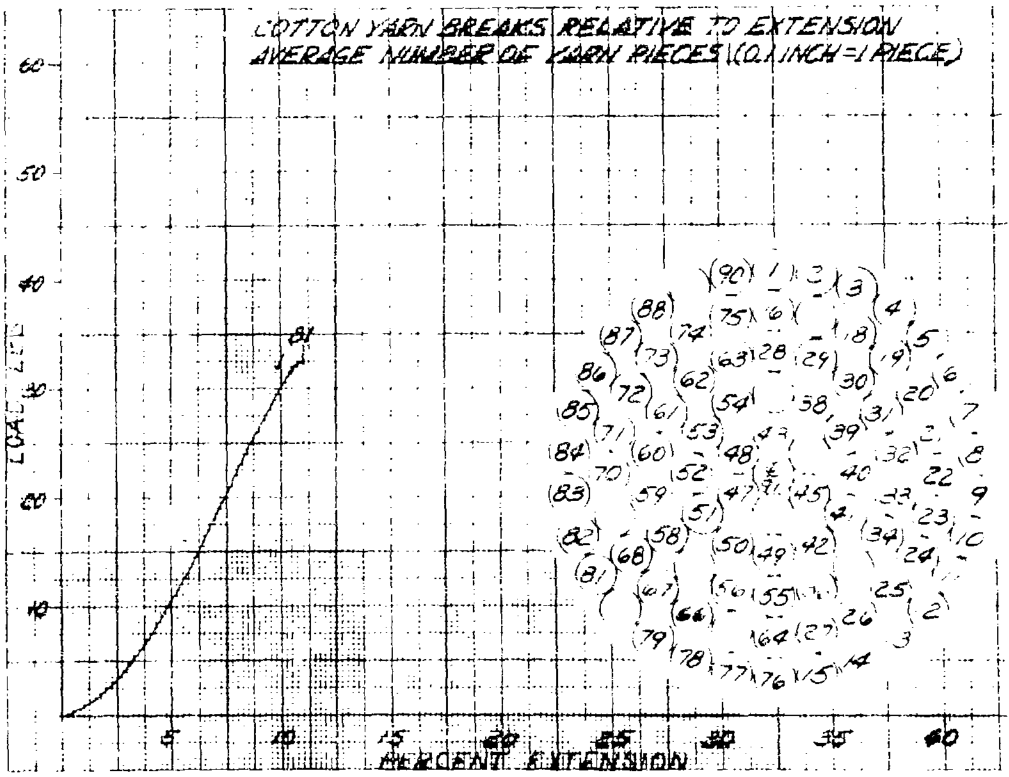
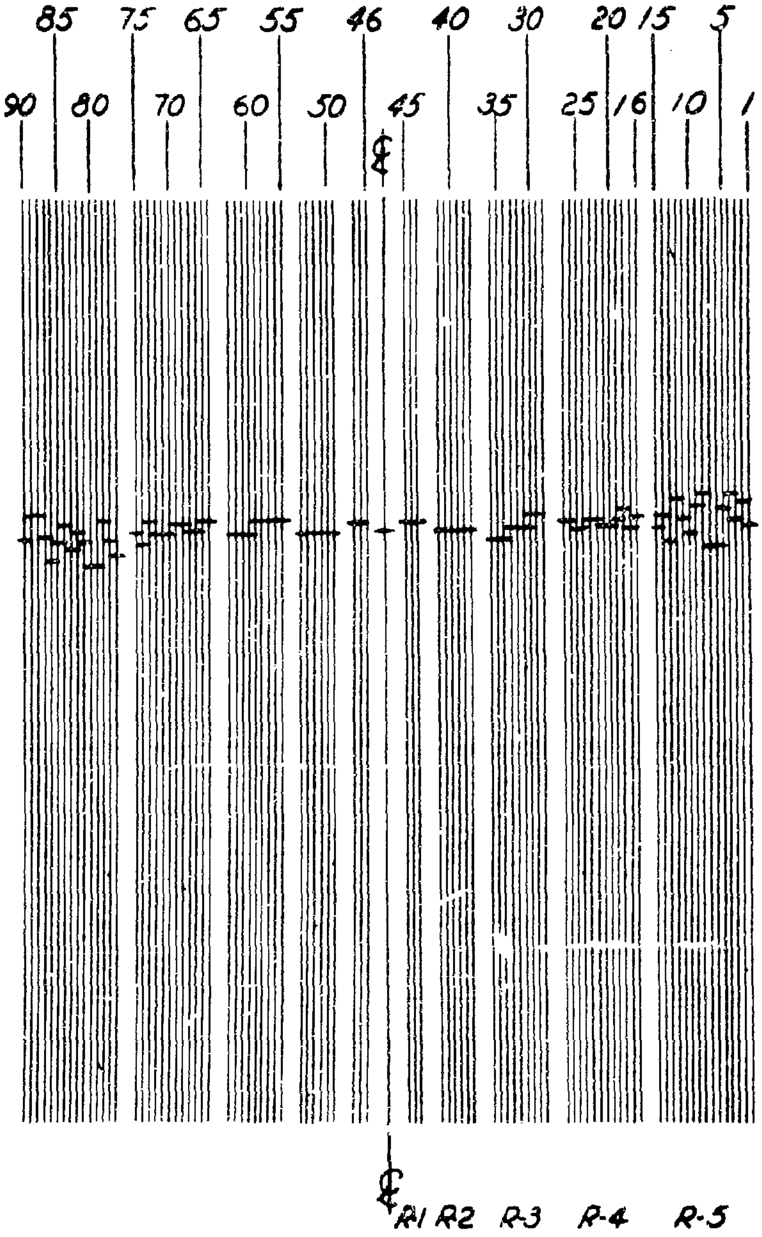


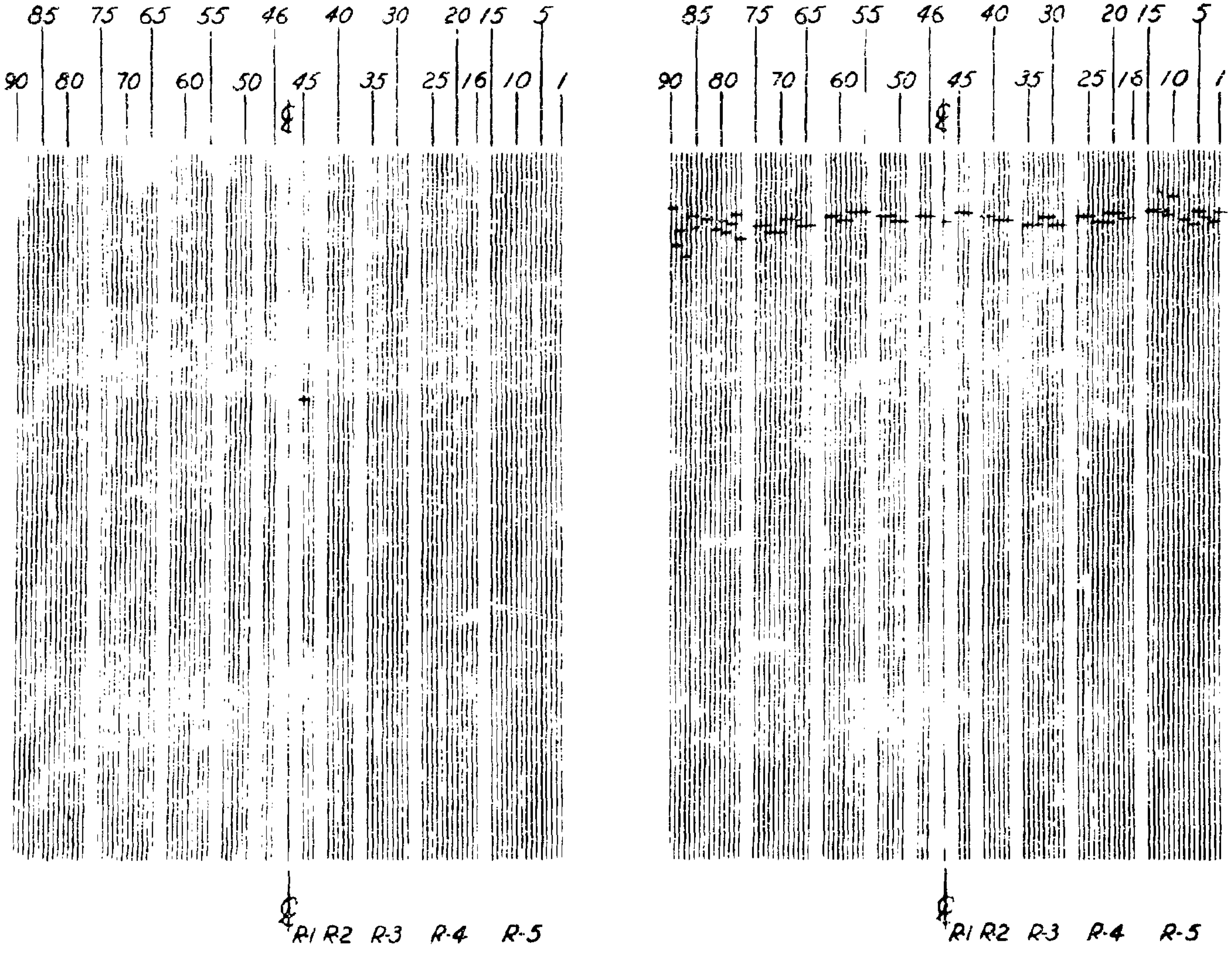
FIGURE 84. 89% COTTON 11% DACRON 1.15 TM



9.2% EXTENSION

1.07 TM 89% COTTON 11% DACRON

FIGURE 81a



10% EXTENSION
2.15 TM 89% COTTON 11% DACRON

11% EXTENSION
2.15 TM 89% COTTON 11% DACRON

FIGURE 8.a

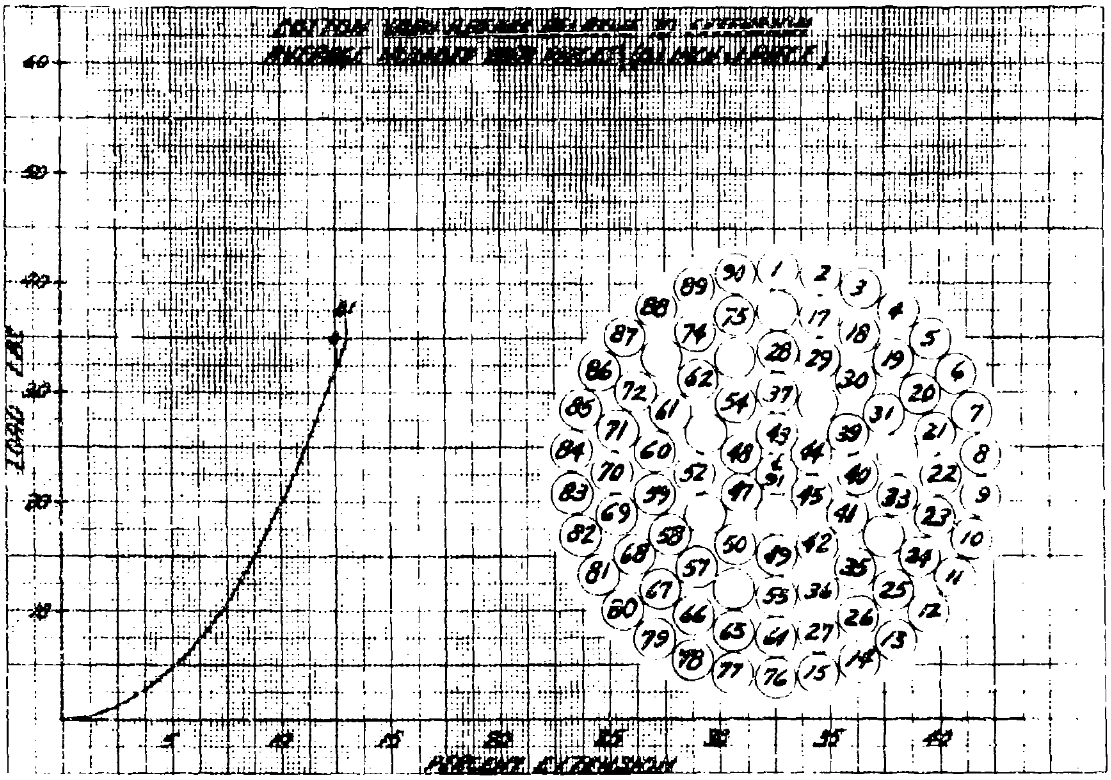


FIGURE 83. 89% COTTON 11% DACRON 3.26 TM

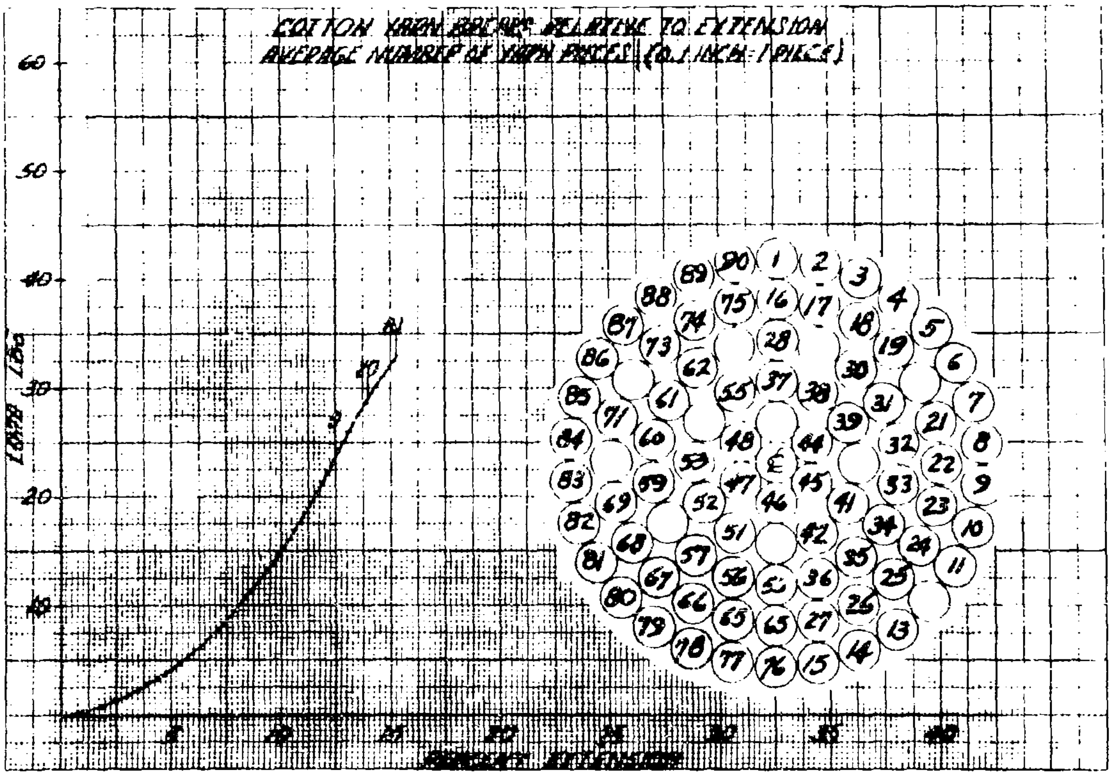
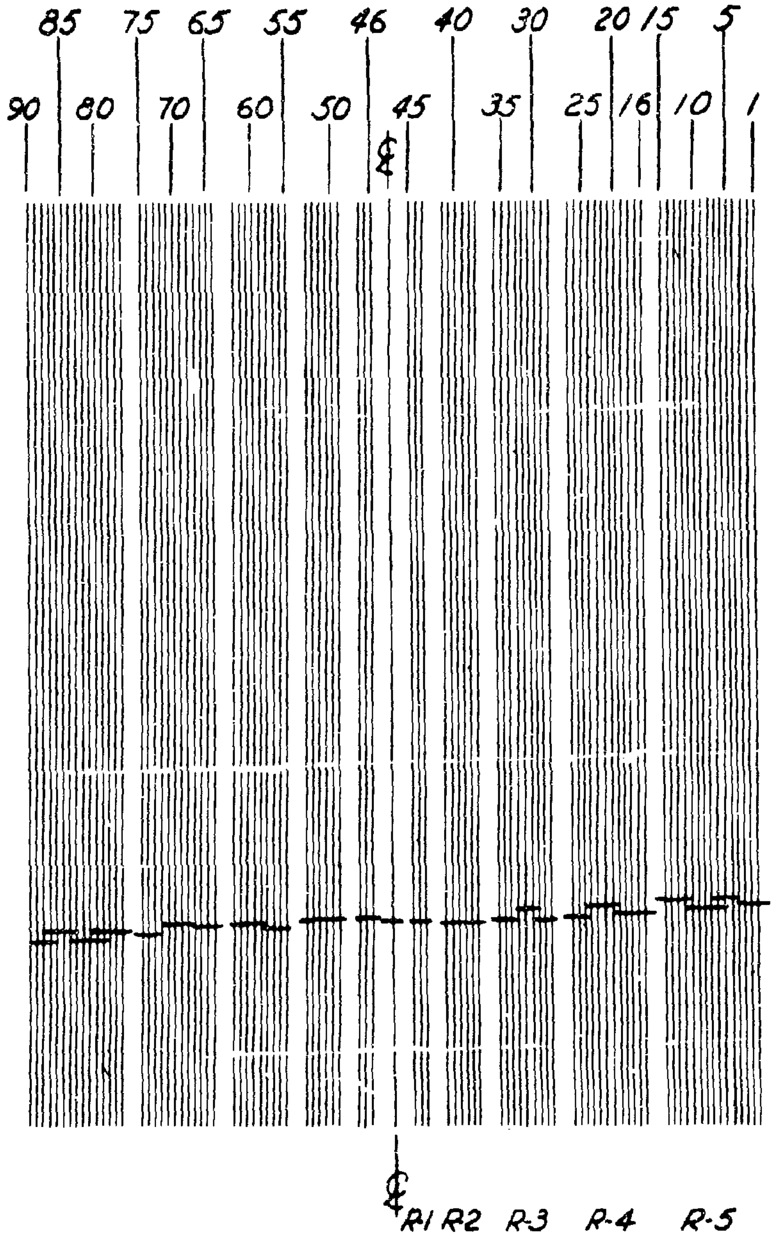


FIGURE 84. 89% COTTON 11% DACRON 4.30 TM



13% EXTENSION
3.26 TM 89% COTTON 11% DACRON

FIGURE 83a

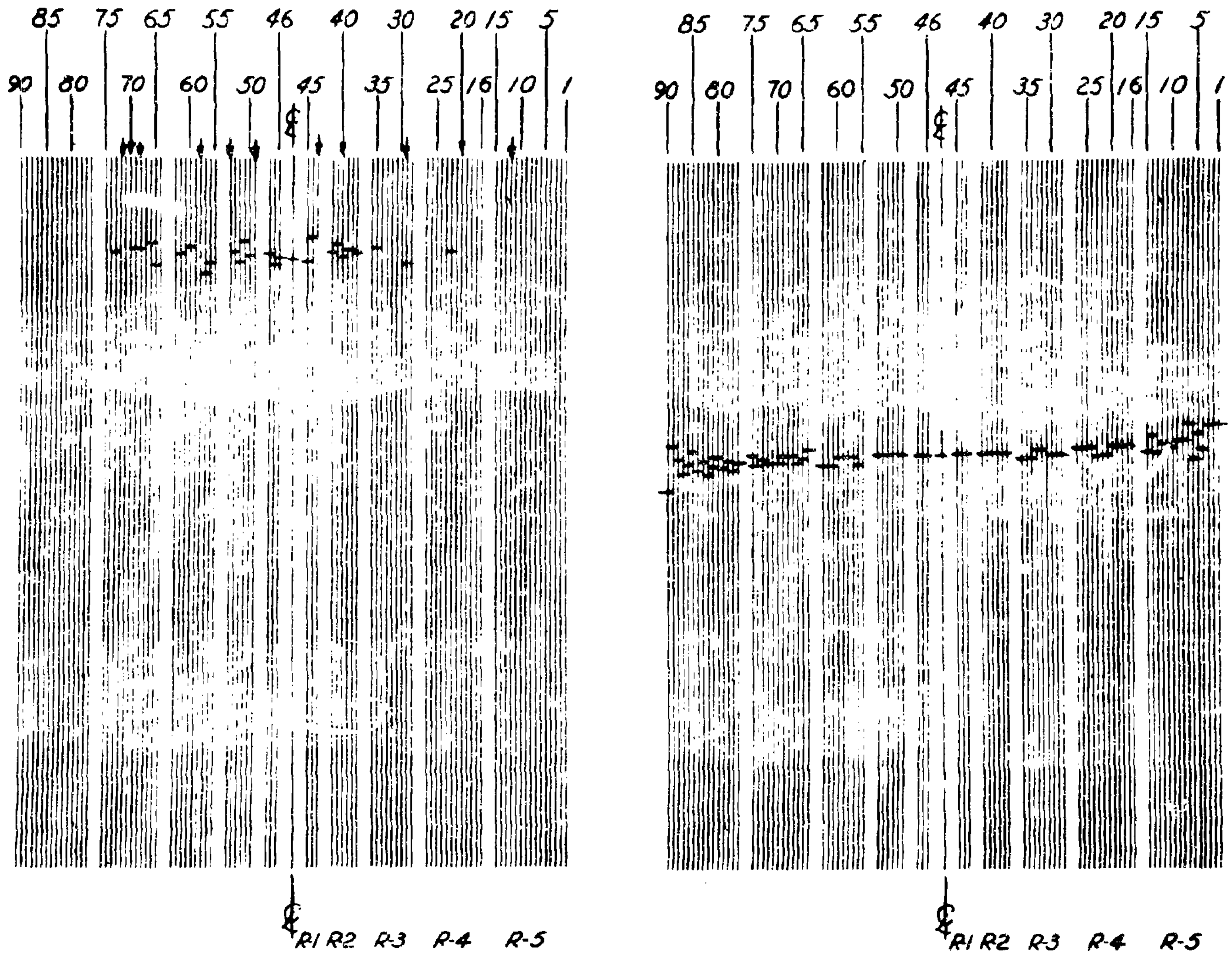

85 75 65 55 46 40 30 20 15 5
90 80 70 60 50 45 35 25 16 10 1
℄
℄ R1 R2 R-3 R-4 R-5
85 75 65 55 46 40 30 20 15 5
90 80 70 60 50 45 35 25 16 10 1
℄
℄ R1 R2 R3 R-4 R-5

FIGURE 84a

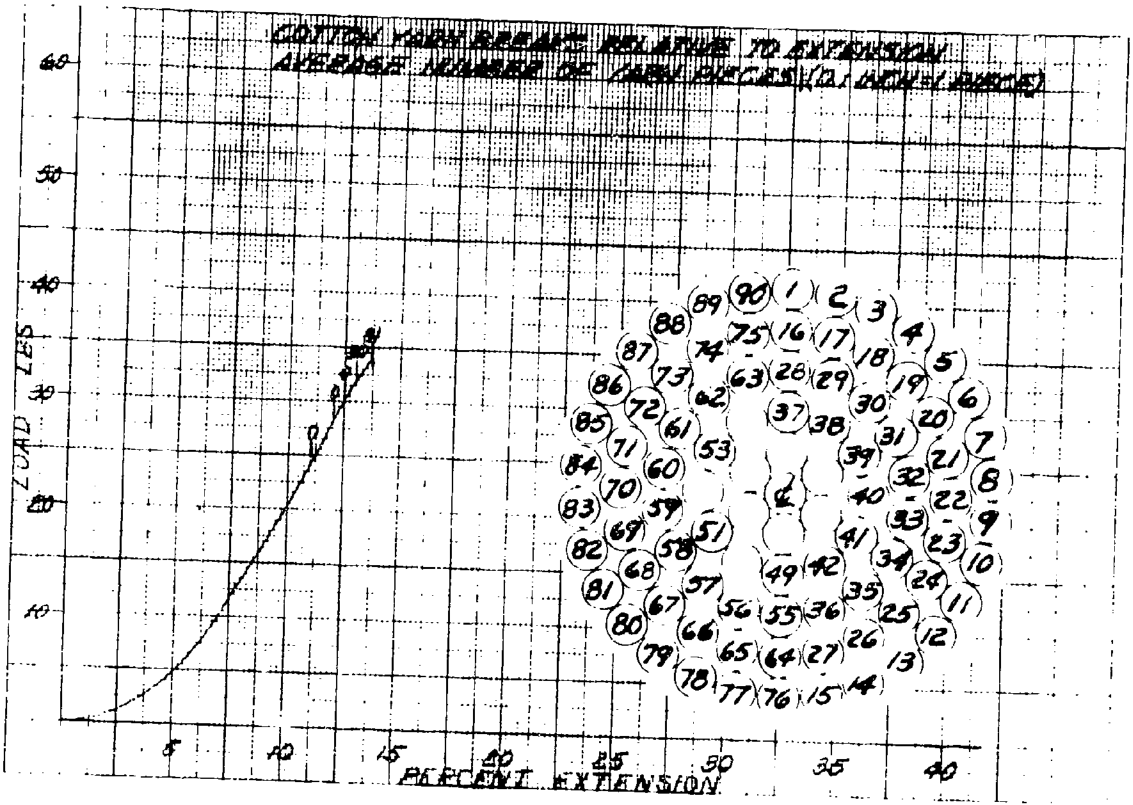


FIGURE 87. 89% COTTON 11% DACRON 3.26 TM

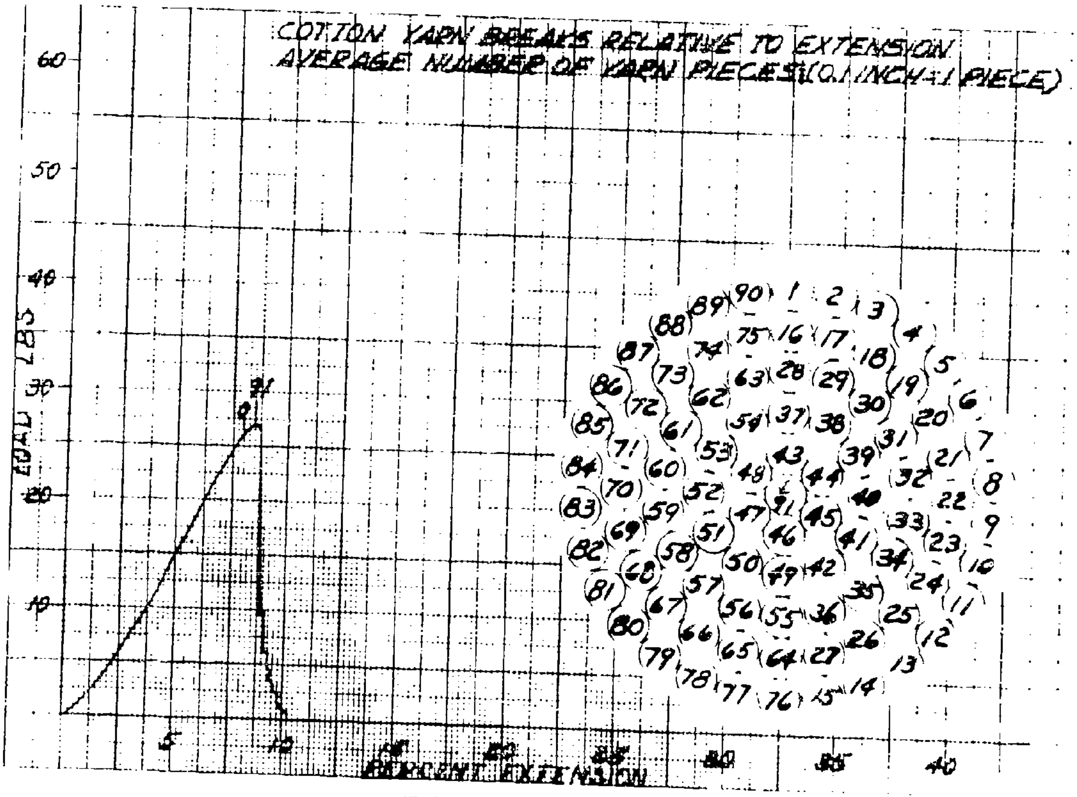
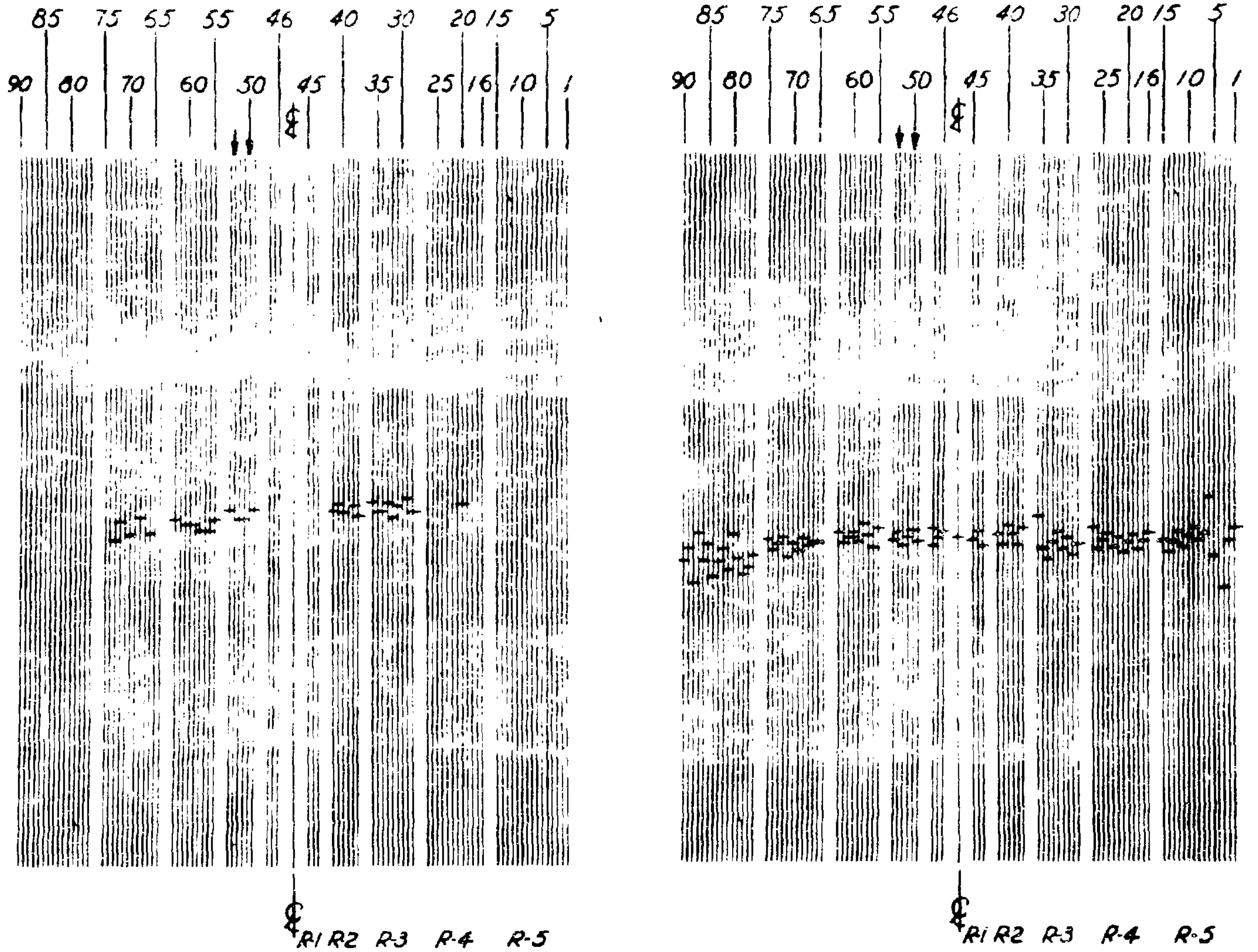


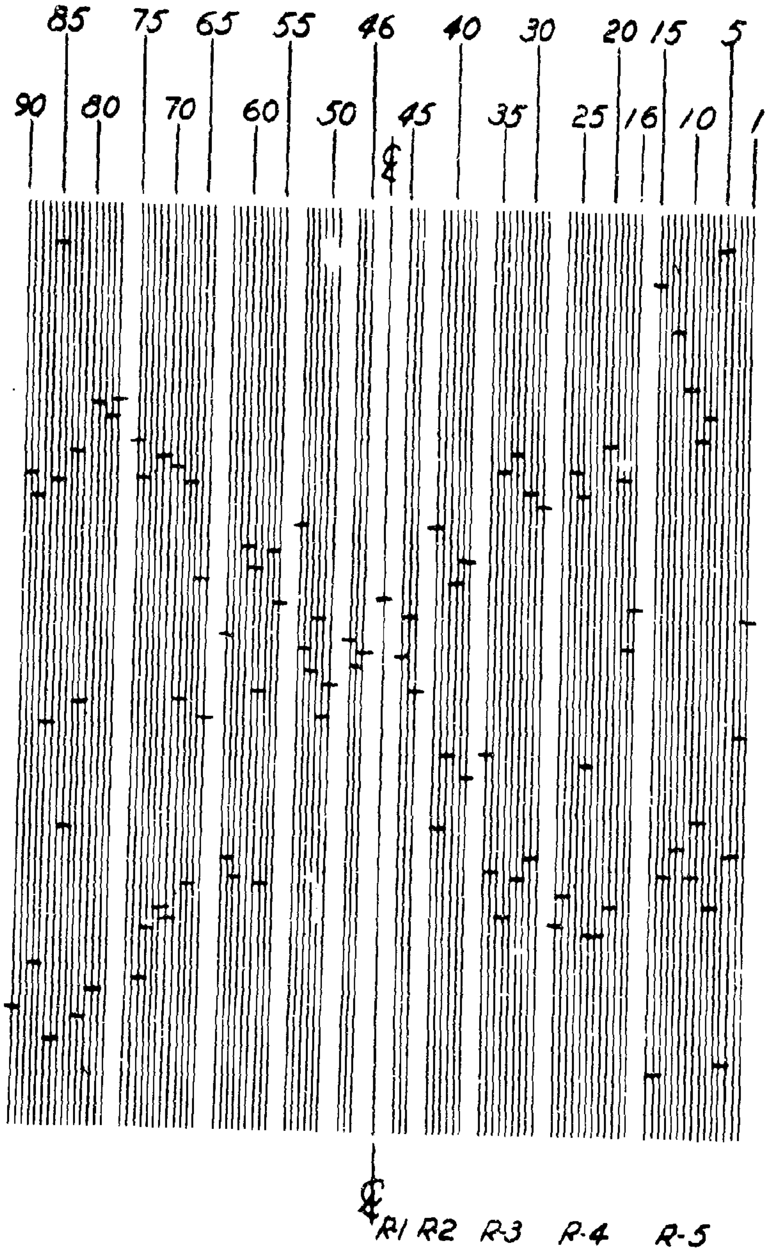
FIGURE 88. 100% COTTON 3.24 TM



13% EXTENSION
3.26 TM 89% COTTON 11% DACRON

13.7% EXTENSION
3.26 TM 89% COTTON 11% DACRON

FIGURE 85a



8½% EXTENSION
3.24 TM 100% COTTON

FIGURE 86a

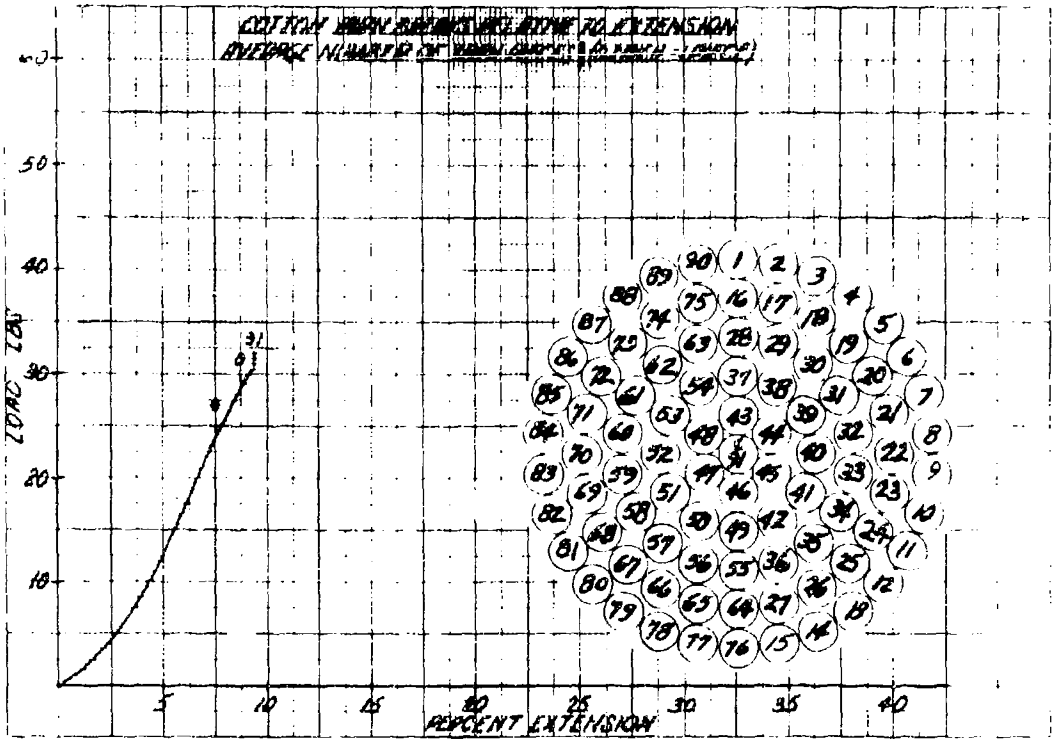


FIGURE 87. 100% COTTON 1.07 TM

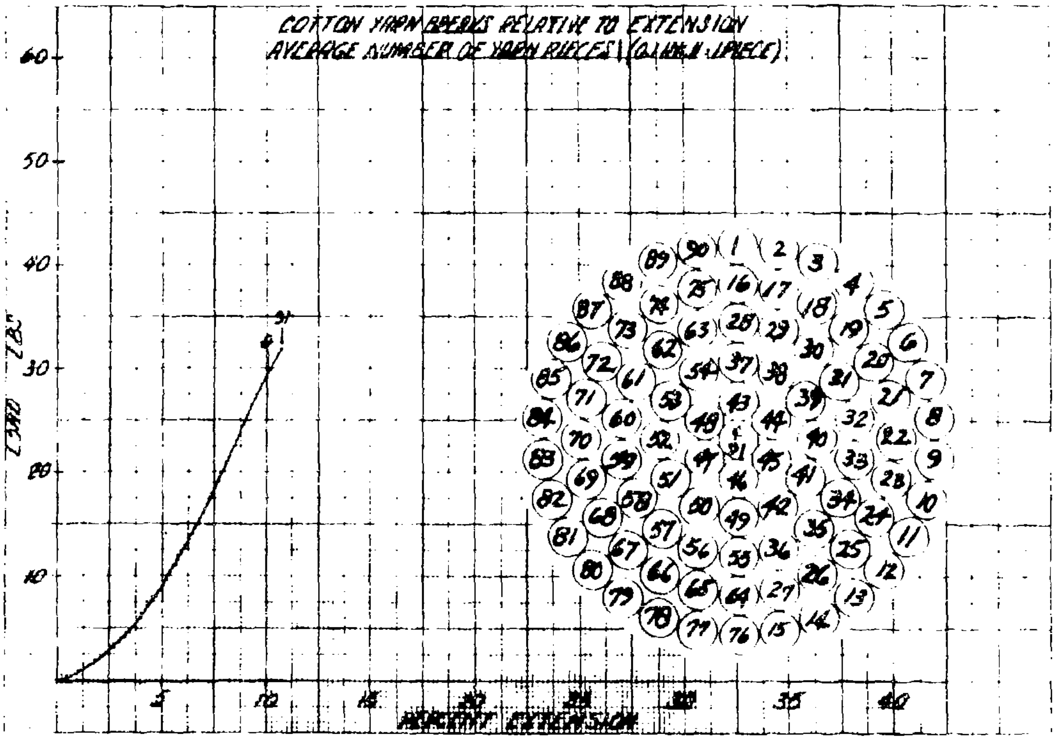
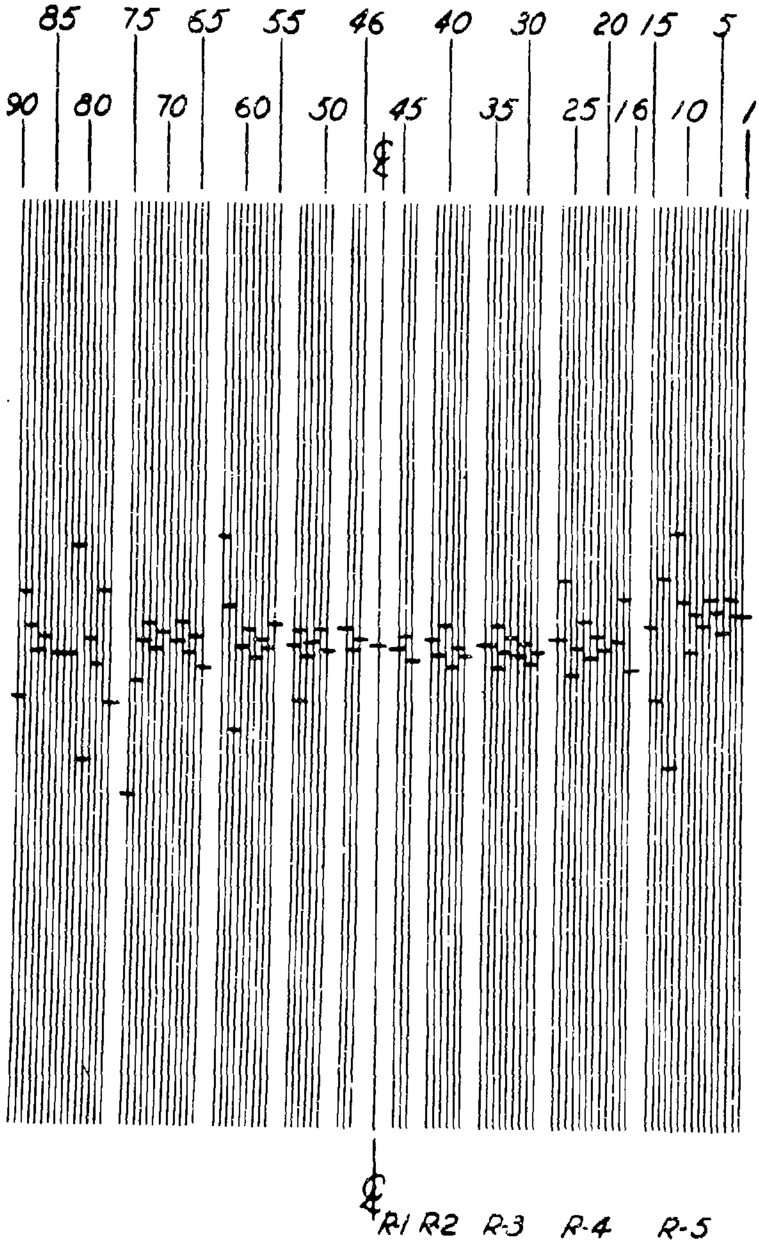
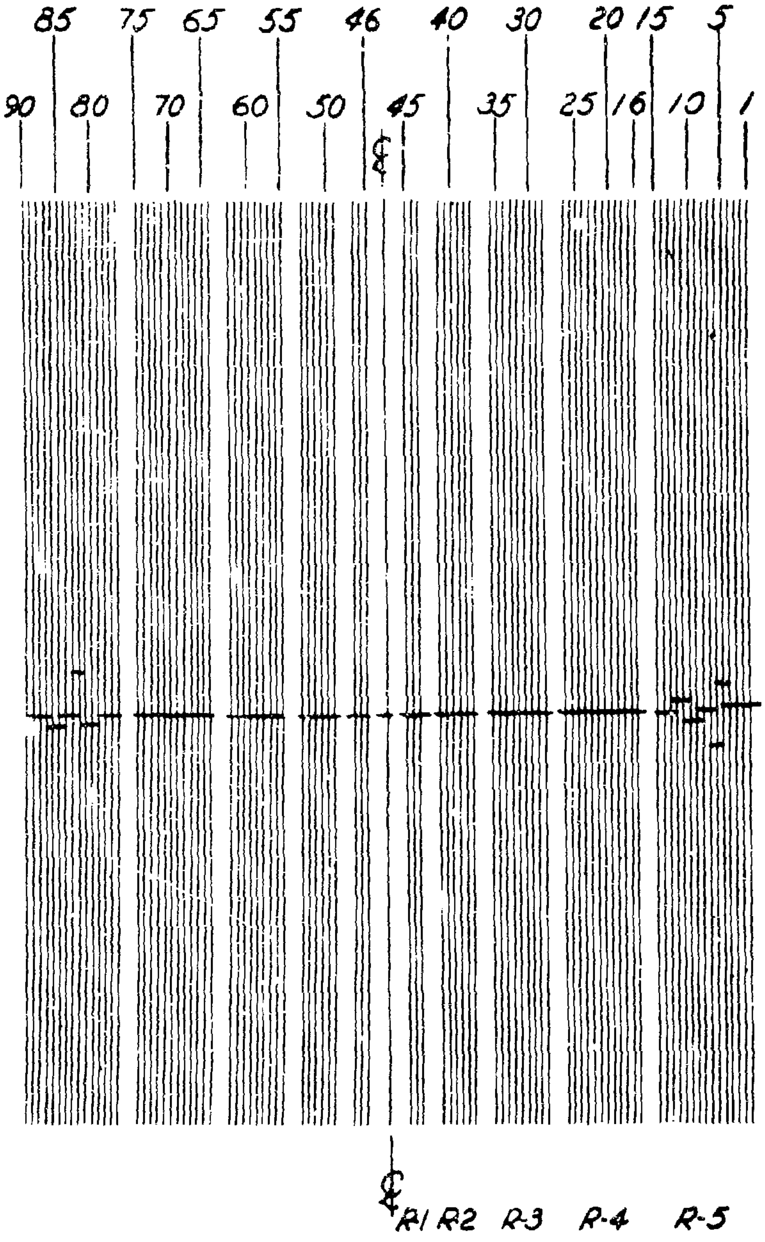


FIGURE 88. 100% COTTON 2.15 TM



9.2% EXTENSION
1.07 TM 100% COTTON

FIGURE 87a



10.6% EXTENSION

2.15 TM 100% COTTON

FIGURE 38a

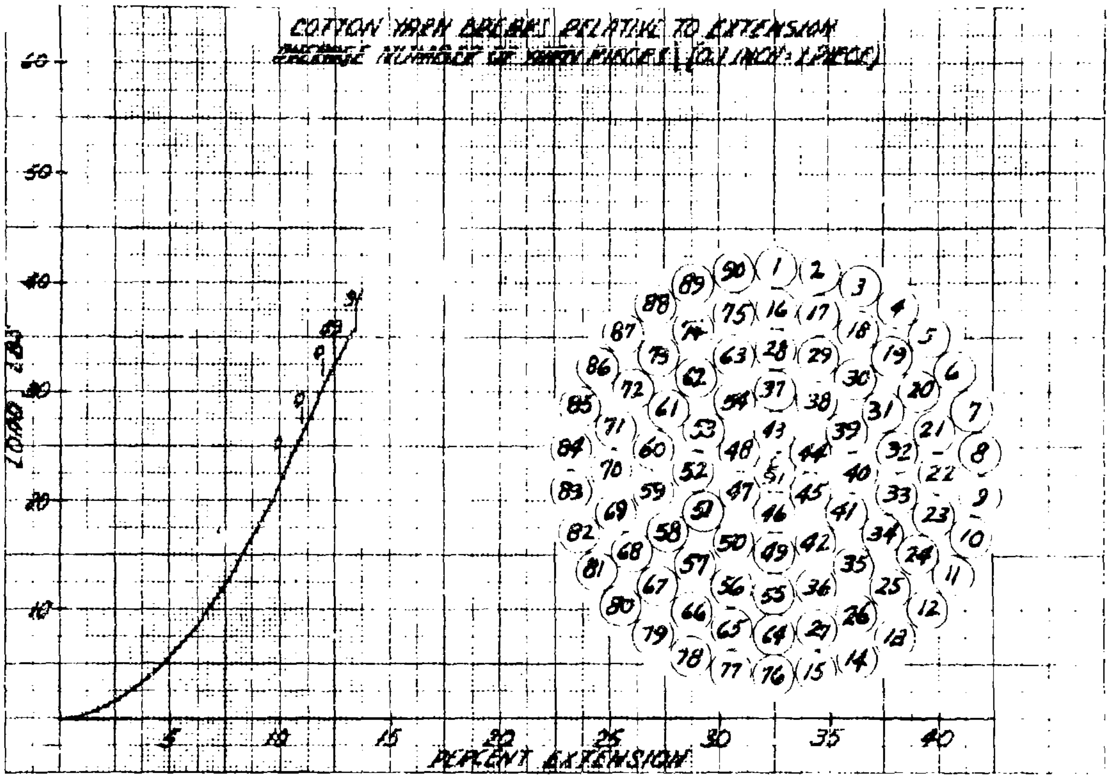


FIGURE 89. 100% COTTON 0.34 IN

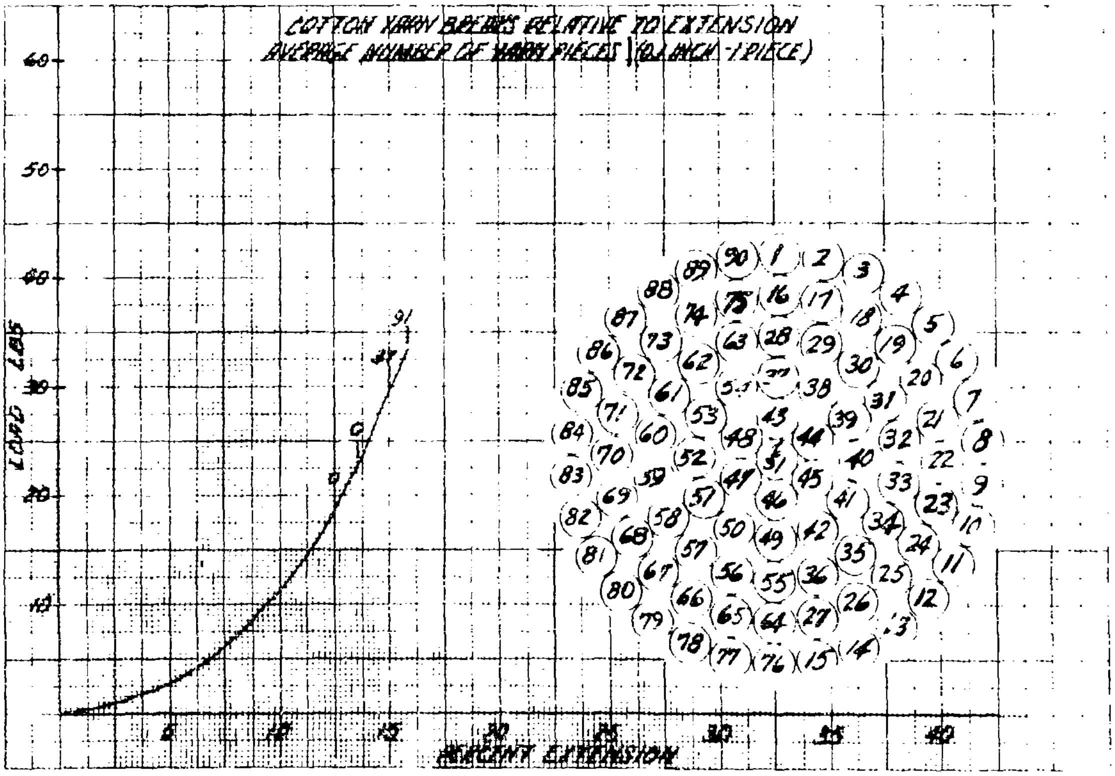
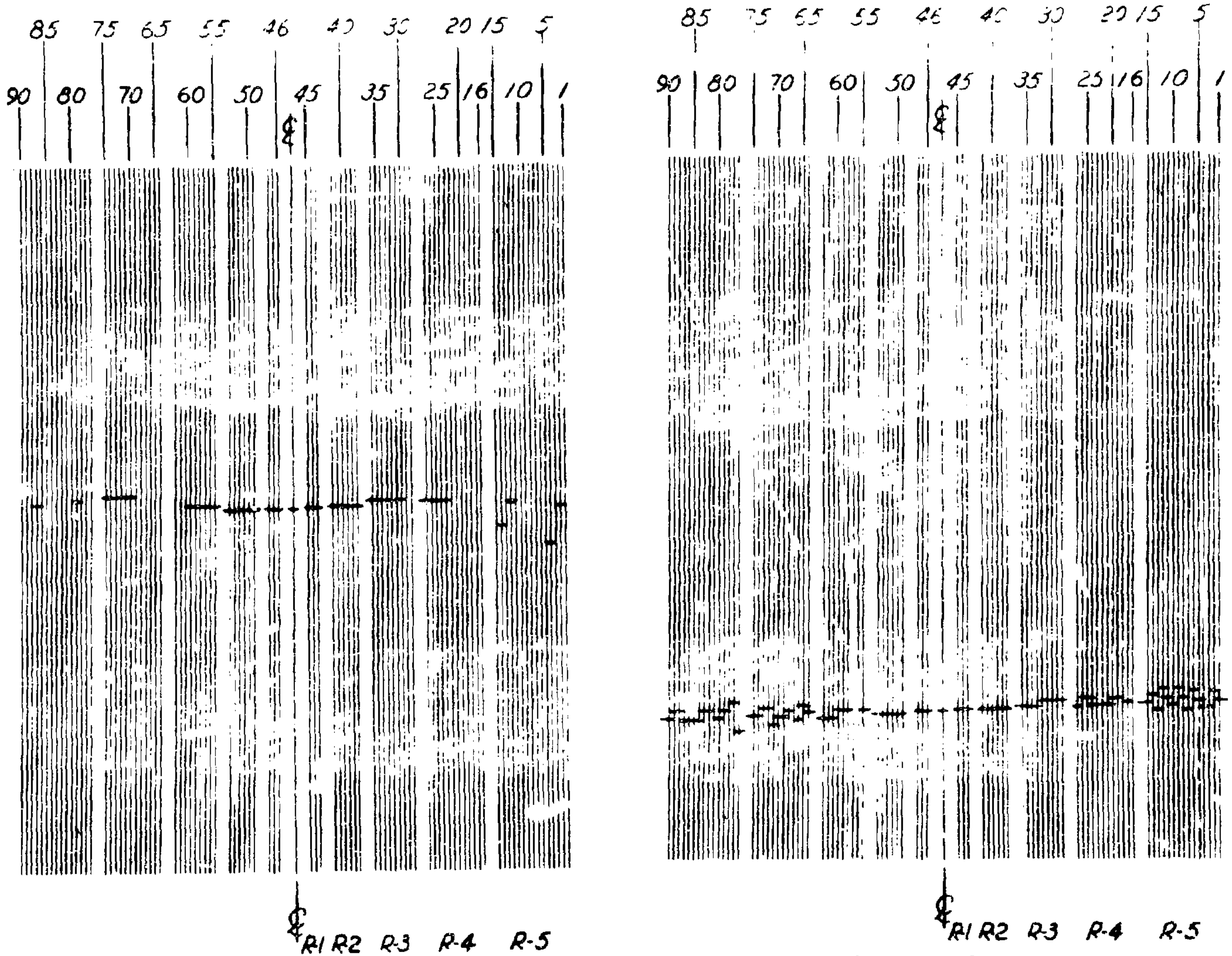


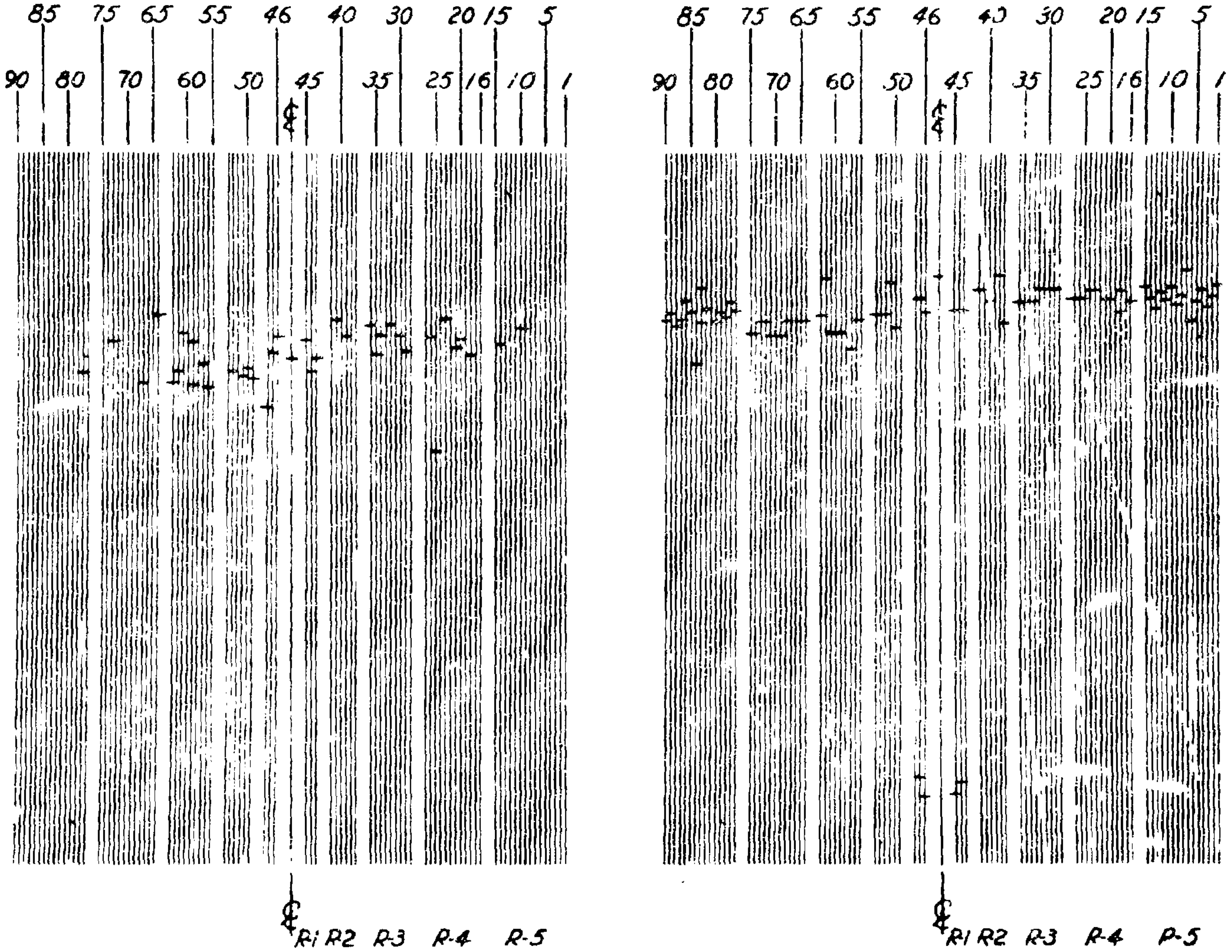
FIGURE 90. 100% COTTON [illegible] IN



12½% EXTENSION
3.24 TM 100% COTTON

13½% EXTENSION
3.24 TM 100% COTTON

FIGURE 89a



15% EXTENSION
4.29 TM 100% COTTON

15.5% EXTENSION
4.29 TM 100% COTTON

FIGURE 90a

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The Mechanics of Rupture of Cotton-Dacron Blended Yarns

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The tensile behavior of cotton-Dacron blends has been studied in a twisted model yarn structure composed of Dacron filament yarns (70 denier, 34 filament) and combed cotton staple yarns (79 cotton content (c.c.)) in blend ratios of 1.1, 2.2, 11, 22, 33, 44, 56, 67, and 89 percent cotton content.

The contribution of the cotton component to the blended structure at all strain levels is the main subject of this study.

This report covers the experimental studies on the load extension characteristics of 72 model yarns at elongations of 5 percent through break and the effect of twist (0.55 twist multiple (TM) through 4.4 TM), blend ratio and position of the cotton component in the yarn (cotton core or cotton shell) on the strength of the blended yarn are discussed.

These studies extend Machida's theoretical approach to the problem of blended yarn strength to include cotton-Dacron blended yarns in blend ratios of practical significance.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Rupture	8					
Tensile properties	8					
Cotton	2, 9					
Dacron	2, 9					
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