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WADC TECHNICAL REPORT 52-55

A STUDY OF THE EFFECT OF TWIST ON THE PROPERTIES OF SYNTHETIC FILAMENT YARNS

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WRIGHT AIR DEVELOPMENT CENTER

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FOREWORD

This report was prepared by the Georgia Institute of Technology, State Engineering Experiment Station, on U. S. Air Force Contract No. 33(038)-10179, RDO No. R602-193, "Development of Textiles for use in High Speed Parachutes." The work was administered under the direction of the Materials Laboratory, Research Division, Wright Air Development Center, with Mr. J. H. Ross acting as project engineer.

The yarns "Orlon" and "Dacron", evaluated in this report, were comparatively new in relation to the other yarns at the time work was begun. We are grateful to the manufacturer, E. I. du Pont de Nemours and Company, for making a supply of "Orlon" and "Dacron" available for this investigation.

Materials evaluated consisted of production of commercial types with the exception of "Orlon" and "Dacron", which were in pilot plant production at the time the investigation was started.

Until the publication of this report, the textile industry has been without sufficient data concerning twist in synthetic yarns. The compiling of this data, based on production yarns, will aid in the improvement of USAF materials.

ABSTRACT

As synthetic textile fibers have varied uses in today's ideas and materials, a need has been felt for an investigation into the effect of twist on synthetic yarns. It was decided that in the study of synthetic yarns, those used most in USAF materials would be evaluated.

Yarns studied included five deniers of Viscose Rayon from three producers; ten deniers of nylon; four deniers of Orlon; and three deniers of Dacron. The main objective of the program was the study of the effect of twist on the following properties of the yarns:

a. Denier

b. Diameter

c. Breaking strength

d. Elongation

e. Energy Absorption

f. Elastic Recovery

Increments of twist were added to the yarns until the breaking strength had decreased approximately 40% from the original values, or until creping or shearing occurred.

The twisting of the yarns and testing were conducted in laboratories conditioned to 70° plus or minus 2°F. and a Relative Humidity of 65 plus or minus 2%.

Each yarn has been considered separately in the evaluation, but with rayon yarns no separation was made for each different manufacturer's yarn. Generally the results show that the effect of twist on any characteristic of yarn is greater for the higher

denier yarns than for the low denier yarns. Detailed data are given in both tabular and graphic form, for the effect of twist on the properties of the individual yarns.

PUBLICATION REVIEW

Manuscript copy of this report has been reviewed and found satisfactory for publication.

FOR THE COMMANDING GENERAL:

M. E. SORTE
Colonel, USAF
Chief, Materials Laboratory
Research Division

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I. INTRODUCTION

As an outgrowth of the increasing demands being made today on the synthetic yarn industry, especially in the manufacture of vital fabrics such as parachute materials and other defense commodities, there has arisen a need for basic data pertaining to the general properties and characteristics of the various synthetic filament yarns. As a result, the State Engineering Experiment Station and the A. French Textile School of the Georgia Institute of Technology, under the sponsorship of Wright Air Development Center, Contract No. AF 33(038)-10179, have been engaged in a research program designed to investigate the characteristics of several of the better known synthetic filament yarns; namely, viscose rayon, nylon, Orlon, and Fiber V.* The main objective of the program has been the determination of the effect of twist on the following properties of the yarns:

1. Apparent Denier
2. Diameter
3. Dry Breaking Strength and Elongation
4. Energy Absorption
5. Elastic Recovery

The yarns chosen for the experimental study are given in Table I. Since, at the time of the research, Orlon and Fiber V were being produced only in experimental quantities, it was not possible to secure these yarns in a wide range of denier sizes. However, the wide selection of rayon and nylon yarns which were used afforded an opportunity to obtain much valuable and interesting data.

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*Fiber V has recently been given the official name of Dacron but will bear its former name throughout this document.

TABLE I

YARNS TESTED

Viscose Rayon	Nylon***	Orlon***	Fiber V***
150-40-2.5S*	20-7-0.5Z-200	75-30-0.3Z	40-34-1Z-ST-2
150-40-2.5S**	30-10-0.5Z-200	100-40-0.3Z	70-34-1Z-ST-2
250-60-2.5S**	40-13-0.5Z-200	200-80-0.3Z	210-34-1.5Z-5100
300-44-2.5S**	40-34-0.5Z-200	400-160-0.3Z	
300-120-2.5S***	70-34-0.5Z-100		
	70-34-0.5Z-200		
	70-34-0.5Z-300		
	100-34-0.5Z-300		
	210-34-1Z-300		
	260-17-1Z-300		

*Supplied by Industrial Rayon Corporation.
**Supplied by American Viscose Company.
***Supplied by E. I. du Pont de Nemours & Company.

The experimental program was divided into four parts. The first phase of the work was devoted to a study of the viscose rayon yarns; the second, to the nylon yarns; the third, to Fiber V; and the fourth, to Orlon. The second section discusses methods and techniques used in the studies. The data obtained in the rayon yarn experiments, along with a discussion of the results, are presented in the third section. Graphical illustrations and tables are included. Similarly, the fourth, fifth, and sixth sections present results of the nylon, Fiber V, and Orlon experimental studies, respectively. Correlation and comparison of all the data are given in the seventh section and the Appendix.

Since time is necessarily limited in an investigation of this type, it was deemed best to study as many yarns as possible at the sacrifice of detailed quantitative tests. It is felt that the results present an overall picture of the changes in the properties of yarns as twist is added.

II. GENERAL EXPERIMENTAL METHODS AND TECHNIQUES

In any research problem it is essential that all the experimental testing be performed under controlled conditions. While this criterion applies for any type of experiment, it is especially important in the field of textile research, where there are many variables. Some of the more important are variations in atmospheric conditions, operator technique, yarn characteristics from one package to another, yarn differences within one package, and machine errors. The general practices listed below were designed to minimize the effect of variation in conditions.

1. All twisting and testing of yarns was carried out in the temperature-humidity-controlled laboratory shown in Figure 1. The air in the laboratory was maintained at a temperature of 70° ± 2° F and a relative humidity of 65 ± 2 per cent, which are the standard conditions used in the testing of textile materials. These conditions prevailed for a period of two to three hours before any testing was done.

2. Wherever practicable, procedures as set forth in the A.S.T.M. Standards on Textile Materials* were used.

3. Standard statistical methods were used to determine the significant number of tests to be performed on each yarn.

4. Each yarn package was tagged with an identification label in such a manner that the yarn from the original package retained its identity throughout the entire twisting and testing operation.

5. The yarn was carefully removed from the package in a manner that would not affect the twist.

6. Whenever possible, the same series of tests on a given yarn was

---

*A.S.T.M. Standards on Textile Materials. Prepared by A.S.T.M. Committee D-13 on Textile Materials. (American Society for Testing Materials) October 1949.

Figure 1. Twisting and Testing Laboratory.

repeated on the same day and by the same operator. This procedure tended to reduce human and/or mechanical errors.

7. Tests were performed on each yarn as it was received from the manufacturer and, also, with twist added in given increments until approximately 40 per cent of the original breaking strength was lost (or until creping occurred in the yarn).

A. Twisting Procedure

Twisting of the yarn was accomplished by (1) winding of the yarn from its original package onto a twister supply spool, with a Sipp-Eastwood single deck spool winder, and (2) twisting of the yarn on an Atwood Universal Model 110 uptwister shown in Figure 2.

Whenever possible enough yarn was wound onto the supply spool so that all increments of twist for the various tests could be twisted without the spool's having to be refilled. Twenty supply spools were filled in one winding operation. This accommodated five different yarns, the use of four bobbins being assumed for each. Upon completion of the winding operation, each supply spool was carefully labeled.

B. Testing Apparatus and Procedures

The yarns were not treated with any twist setting material before the twisting nor was there any attempt made after the twisting to set the twist by steaming or other methods.

The twister was equipped with a Herr type flyer which could easily be changed to regulate the tension on the yarn. Tensions were so controlled that the maximum tension (in grams) on each yarn was equal to approximately one fourth to one third of the yarn denier. The spindle speed was maintained at 8730 r.p.m. for all twisting operations.

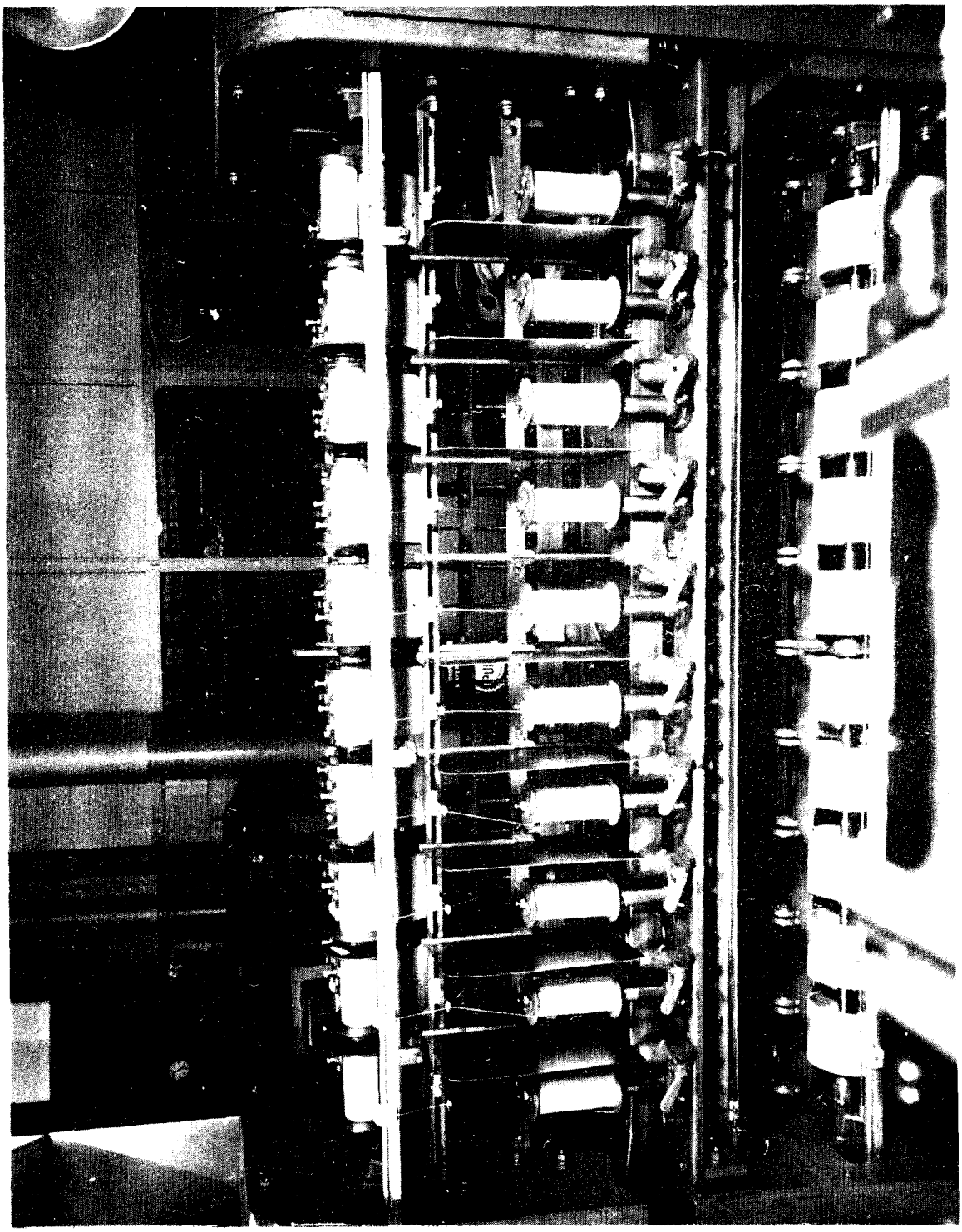

Figure 2. Atwood Universal Uptwister.

The yarn tests included in the investigation are given in Table II along with the number of samples tested in each study.

TABLE II

YARN TESTS

Test	Samples Tested
Apparent Denier	10
Diameter	20*
Twist	10
Dry Breaking Strength and Elongation	20
Energy Absorbed by Yarn to Breaking Load	20
Energy Absorbed by Yarn to 85 Per Cent Breaking Load	10
Elastic Recovery	10

*In the case of the nylon, Orlon, and Fiber V yarns, 40 tests were made on the "as received" yarn because of variations in diameter.

1. Denier Determinations

Reeling off 225 meters of yarn on a standard Suter rayon yarn reel and weighing the yarn on an analytical balance enabled determination of the apparent yarn denier. Deniers were calculated after corrections were made for the moisture content of the yarn as determined in a Brabender moisture tester. Photographs of the equipment used for these measurements are shown in Figures 3 and 4.

Since denier is numerically equal to the number of grams per 9000 meters, the following formulas were used for the denier calculations:

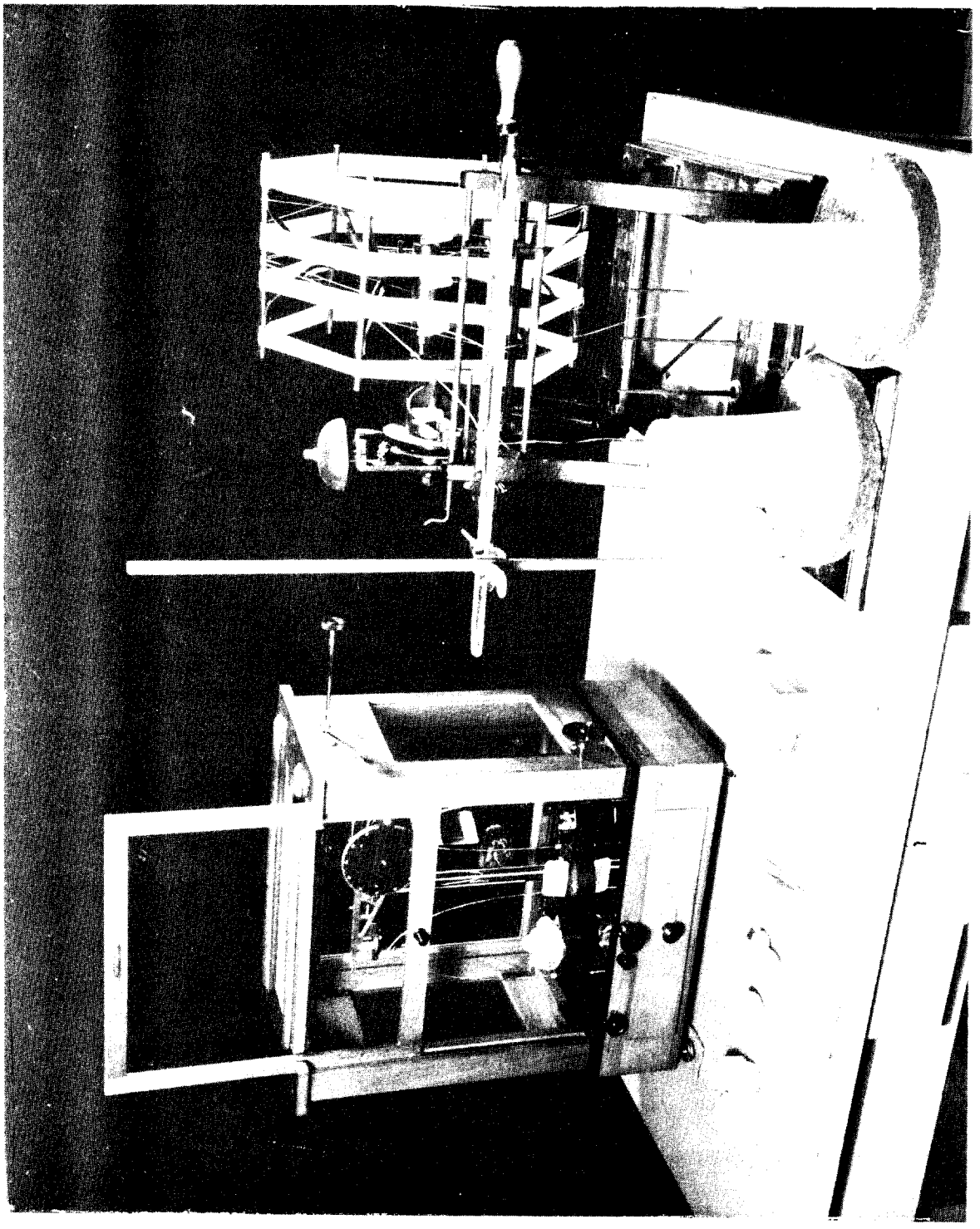

Figure 3. Analytical Balance and Yarn Reel.

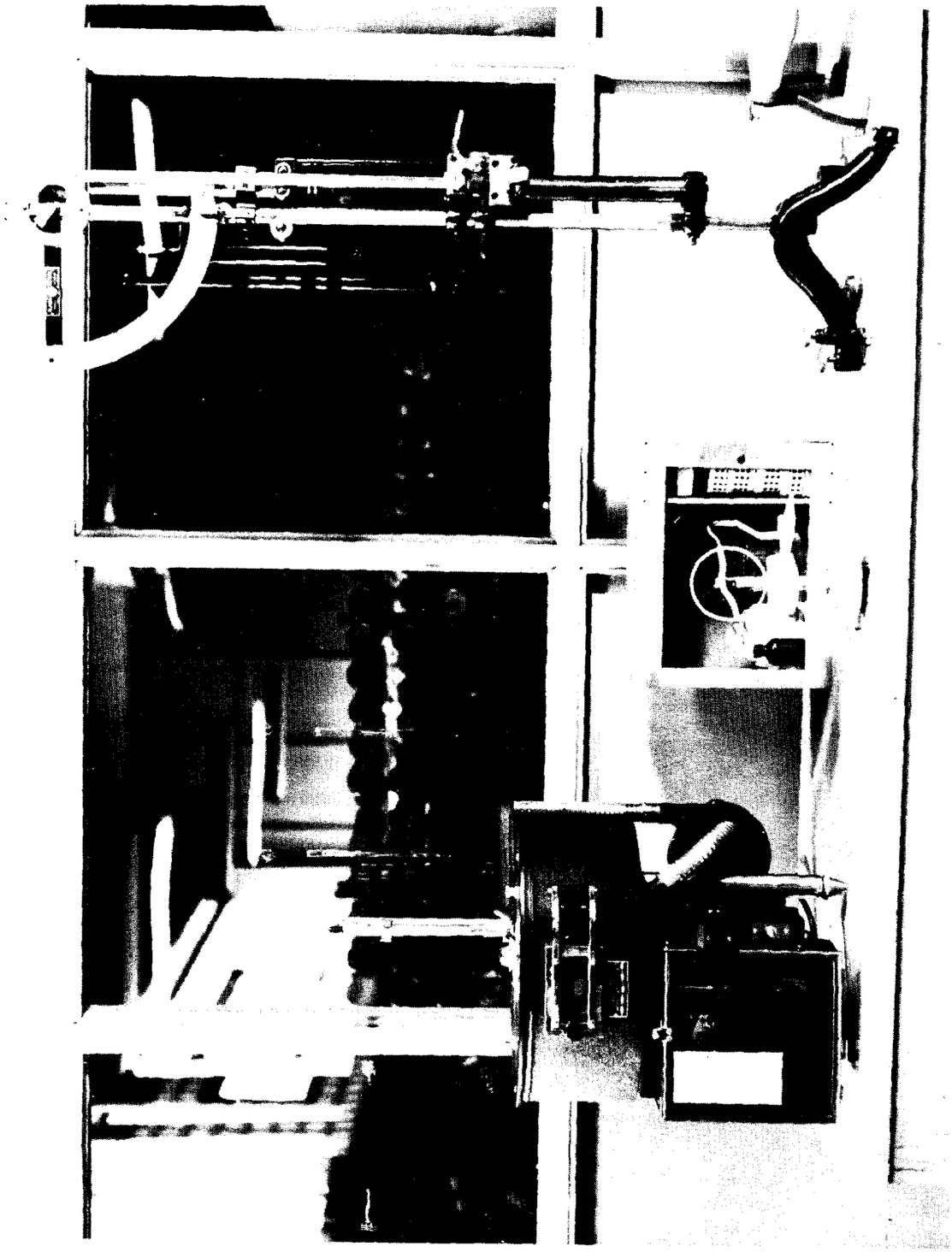

Figure 4. Brabender Moister Tester and Suter Yarn Tester.

$$\text{denier} = W \times 40$$

where W = weight of a 225-meter skein corrected to standard commercial moisture regain.

The weight, W, corrected to the commercial regain basis was calculated in the formula:

$$W = \frac{\text{actual weight of sample} \times (100 + \text{commercial regain})}{100 + \text{actual regain}},$$

where

$$\text{actual regain } (\%) = \frac{10 \times \% \text{ moisture}}{10 - (10 \times \% \text{ moisture})} \times 100.$$

Commercial regain values at conditions of 70° F and 65 per cent relative humidity were used for all weight corrections. These are as follows:

Viscose Rayon:	11.0 per cent
Nylon:	4.5 per cent
Orlon:	1.75 per cent
Fiber V:	0.4 per cent*

2. Diameter and Twist Determinations

Diameter tests were made by use of a calibrated low-power Spencer microscope and filar micrometer. Twist was measured with a standard Suter twist counter. As shown in Figure 5, the microscope was mounted on a movable base attached to the twist counter, so that the diameter and twist checks could be made in the same operation. In preparation for testing, a ten-inch sample of yarn was clamped into the jaws of the counter and tension was applied as follows:

0-150 denier yarn:	10-20 grams,
150-250 denier yarn:	20-30 grams,
250-400 denier yarn:	30-40 grams.

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*The latest data available on Fiber V were received from du Pont, January 1951.

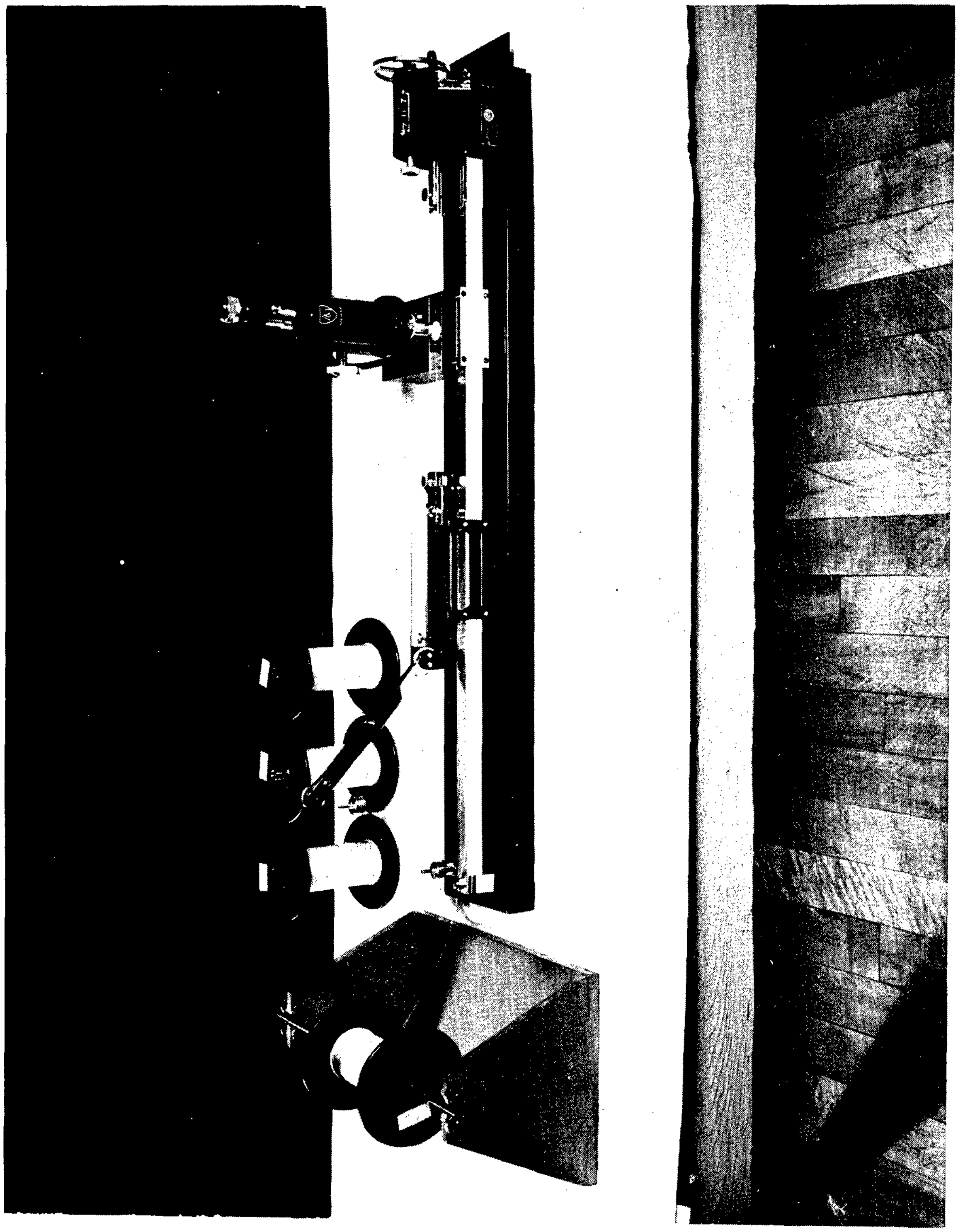


Figure 5. Twist Counter and Microscope Used in Twist and Diameter Measurements.

In each case the tension applied was just sufficient to take any kink out of the yarn without stretching it.

The yarn was first checked for diameter (measured in microns); the microscope head was rotated to one side, and a twist measurement was made (in turns per inch). To obtain a clear-cut microscopic view of the yarn, it became necessary to place a cover glass over the sample. This method was used except when the yarn appeared to be crushed or spread by the force of the cover glass, as in the case of the "as received" samples.

3. Dry Breaking Strength and Elongation Determinations

Tests for dry breaking strength and elongation were made on the Scott inclined plane (IP-2) machine and on the Suter single strand tester. This offered an opportunity for checking of results and for comparison of the two machines.

In order to facilitate the experimental work, two IP-2 machines were kept in operation; however, all tests on the same yarn were made on the same machine. Photographs of the Suter tester and the IP-2 machines used are shown in Figures 4 and 6, respectively.

a. IP-2 Tests. In preparation for testing on the IP-2 machine, a ten-inch sample of yarn, under a tension sufficient to remove any slack or kinks in the yarn, was clamped in the jaws of the machine. The necessary load was then applied to the yarn sample at a constant rate. Curves were recorded on standard serigraph charts.

A considerable amount of difficulty was encountered with the yarn breaking within one-half inch of the jaw and at the jaw. This condition appeared to be caused by a cutting or crushing action applied to the yarn at the edge of the jaws. Lining the inner faces of the jaws with tape in order to provide a cushion for the yarn reduced the jaw breaks.

Figure 6. Inclined Plane - 2 Tester and Operator.

The tapes found most successful with the different yarns are as follows:

1. Viscose Rayon: Masking Tape

2. Nylon: Masking Tape and Cellophane Tape

3. Fiber V: Cellophane Tape

4. Orlon: Masking Tape.

Clear, sharp breaks were difficult to obtain on the "as received" yarns. This was particularly true with nylon and Fiber V. In these cases, there was a gradual breakage of the filaments, which made it very difficult to determine the true point of rupture or break.

b. Suter Tests. In the Suter tests an 18-inch sample of yarn was clamped in the machine. It was stressed with the plunger falling at a rate of 12 ± 0.5 inches per minute. At the break, the elongation and the breaking strength were read on their respective scales. Very often the elongation reading could not be considered accurate; this was true especially when the yarn filaments broke gradually, since the load scaler stopped the instant the first filament broke, whereas the elongation scaler continued until all filaments had broken. The limited scale prevented use of the Suter machine on yarns with high elongation.

c. Comparison of the Suter and IP-2 Machines

(1) Since different sample lengths as well as different loading rates were used on the two machines, differences in results should be expected.

(2) As a whole it is felt that the results obtained with the IP-2 machine are more reliable than those obtained with the Suter tester. This opinion is based on the fact that, in some cases, it was not possible to get sharp breaks on the Suter machine.

4. Energy Absorption and Elastic Recovery Calculations

Energy is defined as the ability of a body to do work, and since work, by definition, is the product of the force and the distance through which the force acts, the energy absorbed by a sample of yarn can be determined by measurement of the area under the stress-strain curve. Thus, the area under curve ABC in Figure 7 would be a measure of the energy

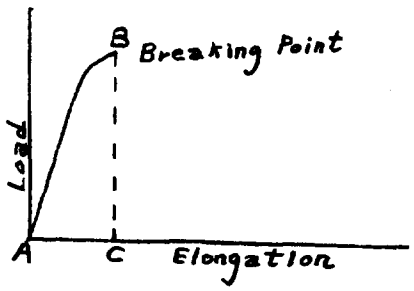
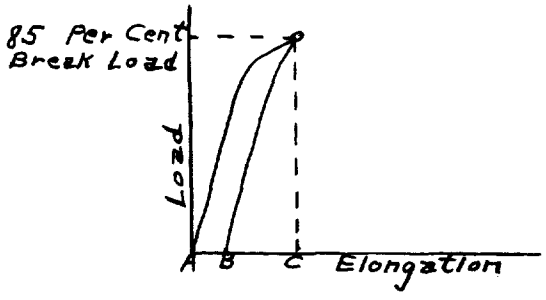


Figure 7.

absorbed by the yarn at its rupture or breaking point.

Hence plotting an average curve of the 20 original breaking strength curves and measuring the area under the curve AB-BC-CA with a planimeter yielded measurement of the energy absorbed by a yarn at rupture. Similarly, the energy absorbed by stressing of the yarn 85 per cent of the breaking load was obtained by plotting an average curve of the ten hysteresis diagrams and measuring the area of this curve.



$$\frac{BC \times 100}{AC} = \text{per cent elastic recovery}$$

Figure 8.

All energy absorption data in this report are expressed in gram-centimeter work units.

It is realized that the energy absorption and elastic recovery tests should also be conducted with mechanically conditioned yarns, but the time and funds available for the study covered by this report did not permit this extensive work.

III. VISCOSE RAYON YARNS

The initial phase of the experimental program was a study of the effect of twist on the properties of viscose rayon filament yarns. It is the purpose of this section to present and to discuss the results of the rayon yarn experimental work and to give a general analysis of the data.

Five different rayon yarns were chosen for study. A complete description of these yarns is presented in Table III. The yarn characteristics given in the table are those which were specified on the cones of yarn as received from the manufacturer.

TABLE III

VISCOSE RAYON YARN DESCRIPTIONS
("AS-RECEIVED" FROM THE MANUFACTURER)

Yarn Characteristics					
Denier	Number of Filaments	Twist (Turns/Inch)	Luster	Tenacity	Manufacturer
150	40	2.5-S	Bright	Normal	American Viscose Co.
150	40	2.5-S	Bright	Semihigh	Industrial Rayon Corp.
250	60	2.5-S	Semidull	Normal	American Viscose Co.
300	44	2.5-S	Bright	Normal	American Viscose Co.
300	120	2.5-S	Bright	Semihigh	E. I. DuPont & Co.

A. Twisting

Twist was placed in each of the rayon yarns according to the standard twisting procedure given in the "INTRODUCTION" until shearing and/or creping of the yarns occurred. The approximate twists added to the different yarns are presented in Table IV. All the yarns were tested as-received and with the added twists given in the table below. Also included in the table is the percentage loss in original breaking strength (B.S.) for each yarn at its maximum twist, as calculated from the experimental data.

TABLE IV

TWISTING DATA FOR VISCOSE RAYON YARNS

Yarn	Approximate Twist Added (TPI)	Per Cent Loss in Original Breaking Strength at Maximum Twist
150-40-2.5S* (Ind. Ray.)	5.0, 10.9, 20.4, 33.3, 53.0	36
150-40-2.5S (AVisco)	5.0, 10.9, 20.4, 33.3, 53.0	30
250-60-2.5S (AVisco)	5.0, 10.9, 20.4, 33.3, 42.3	36
300-44-2.5S (AVisco)	5.0, 10.9, 20.4, 33.3	32
300-120-2.5S* (DuPont)	5.0, 10.9, 20.4, 33.3	36

*Semihigh-tenacity yarn.

As was originally proposed, every effort was made to continue the addition of twist until a loss of 40 per cent in the original breaking strength of the yarns had been obtained. However, as is shown in the table, the

desired percentage loss was not obtained for any of the yarns because shearing and/or creping at higher twists prevented the addition of a sufficient amount. The twists at which each of the yarns sheared are as follows:

150-40-2.5S (Ind. Rayon): 56.0 TPI

150-40-2.5S (AVisco): 56.0 TPI

250-60-2.5S (AVisco): 49.0 TPI

300-44-2.5S (AVisco): 42.3 TPI

300-120-2.5S (DuPont): 42.3 TPI

B. Presentation and Analysis of Experimental Data

1. Twist Determinations

The results of the twist measurements for each of the rayon yarns are given in Table V.

TABLE V

TWIST MEASUREMENTS ON VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Measured Twist (TPI)				
	150-40-2.5S (Ind. Ray.)*	150-40-2.5S (AVisco)	250-60-2.5S (AVisco)	300-44-2.5S (AVisco)	300-120-2.5S (DuPont)*
As-Received	2.3	2.9	2.7	3.0	2.3
5.0	7.3	7.8	7.8	8.1	7.4
10.9	13.4	13.6	13.9	13.9	13.4
20.4	23.1	23.5	23.4	23.2	23.0
33.3	35.4	36.0	36.3	36.4	36.1
42.3	—	—	45.0	—	—
53.0	55.8	55.5	—	—	—

*Semihigh-tenacity yarn.

The accuracy of the twisting operation is good, as can be determined by a comparison of the sum of original and added twist with the actual measured twists.

2. Denier Determinations

Results of the denier determinations are presented in Table VI and given graphically in Figure 9.

TABLE VI

DENIER MEASUREMENTS ON VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Denier				
	150-40-2.5S (Ind. Ray.)*	150-40-2.5S (AVisco)	250-60-2.5S (AVisco)	300-44-2.5S (AVisco)	300-120-2.5S (DuPont)*
As-Received	141.9	150.6	246.4	300.2	304.2
5.0	141.9	151.6	251.1	305.4	311.8
10.9	143.1	154.7	255.7	311.9	319.1
20.4	146.5	158.5	267.1	327.4	331.6
33.3	154.3	165.7	287.2	358.4	367.5
42.3	---	---	312.4	---	---
53.0	171.0	182.5	---	---	---

*Semihigh-tenacity yarn.

With the exception of the 150-40 Industrial Rayon yarn, the measured denier of the as-received samples checked very closely with the denier specified by the manufacturers. It had been assumed that the 150-40 American Viscose and Industrial Rayon yarns were of the same initial denier and filament count, thus making possible a comparison of two 150-40 denier yarns with different tenacities and manufactured by different processes. However, study of the Industrial Rayon yarn shows its initial denier to be approximately 140.

The following conclusions were drawn from an analysis of the denier measurements:

a. For all the yarns, the denier is an increasing function of the twist.

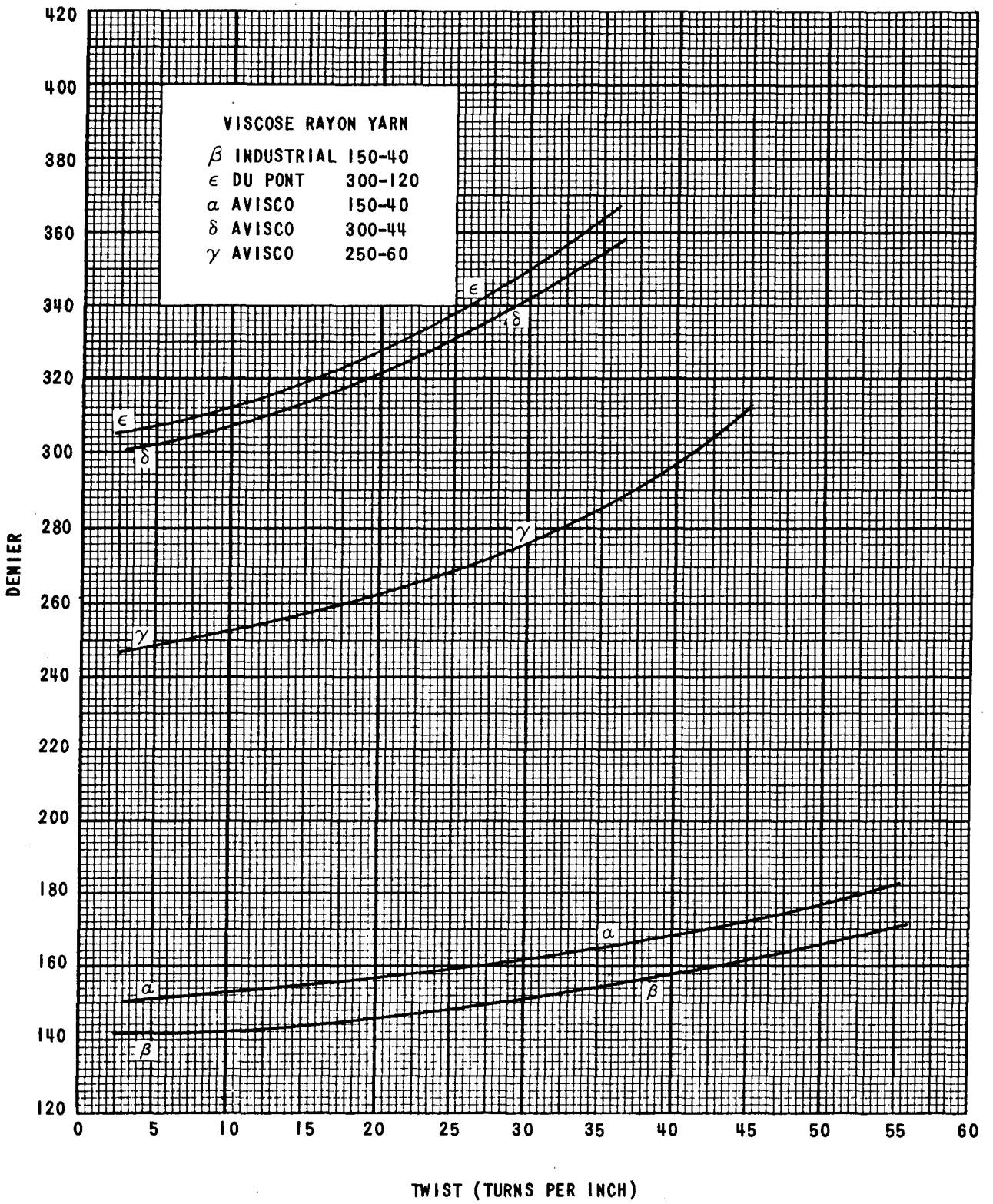


Figure 9. The Effect of Twist on the Denier of Viscose Rayon Yarn.

b. In general, the larger the initial denier, the greater the percentage increase in denier for a given increase in twist.

3. Diameter Determinations

The diameter measurements of the rayon yarns are given in Table VII and a graphical presentation of the data is included in Figure 10.

TABLE VII

DIAMETER MEASUREMENTS ON VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Diameter (Microns) 150-40-2.5S (Ind. Ray.)*	150-40-2.5S (AVisco)	250-60-2.5S (AVisco)	300-44-2.5S (AVisco)	300-120-2.5S (DuPont)*
As-Received	191.1	179.5	227.7	255.2	274.8
5.0	145.3	153.3	190.5	214.9	217.3
10.9	142.6	149.7	190.0	201.9	208.7
20.4	146.0	148.8	195.8	207.9	214.1
33.3	142.0	147.5	190.8	211.1	209.0
42.3	—	—	193.3	—	—
53.0	140.9	149.3	—	—	—

*Semihigh-tenacity yarn.

From a study of the diameter measurements it is concluded that for all the yarns there is a decrease in diameter with increase in twist through 8-13 TPI. Above this range, the diameter remains practically constant.

4. Breaking Strength Determinations

Measurements of dry breaking strength for each of the rayon yarns were made on both the IP-2 and Suter Machines. The data are given in tabular form in Table VIII and shown graphically in Figures 11 and 12.

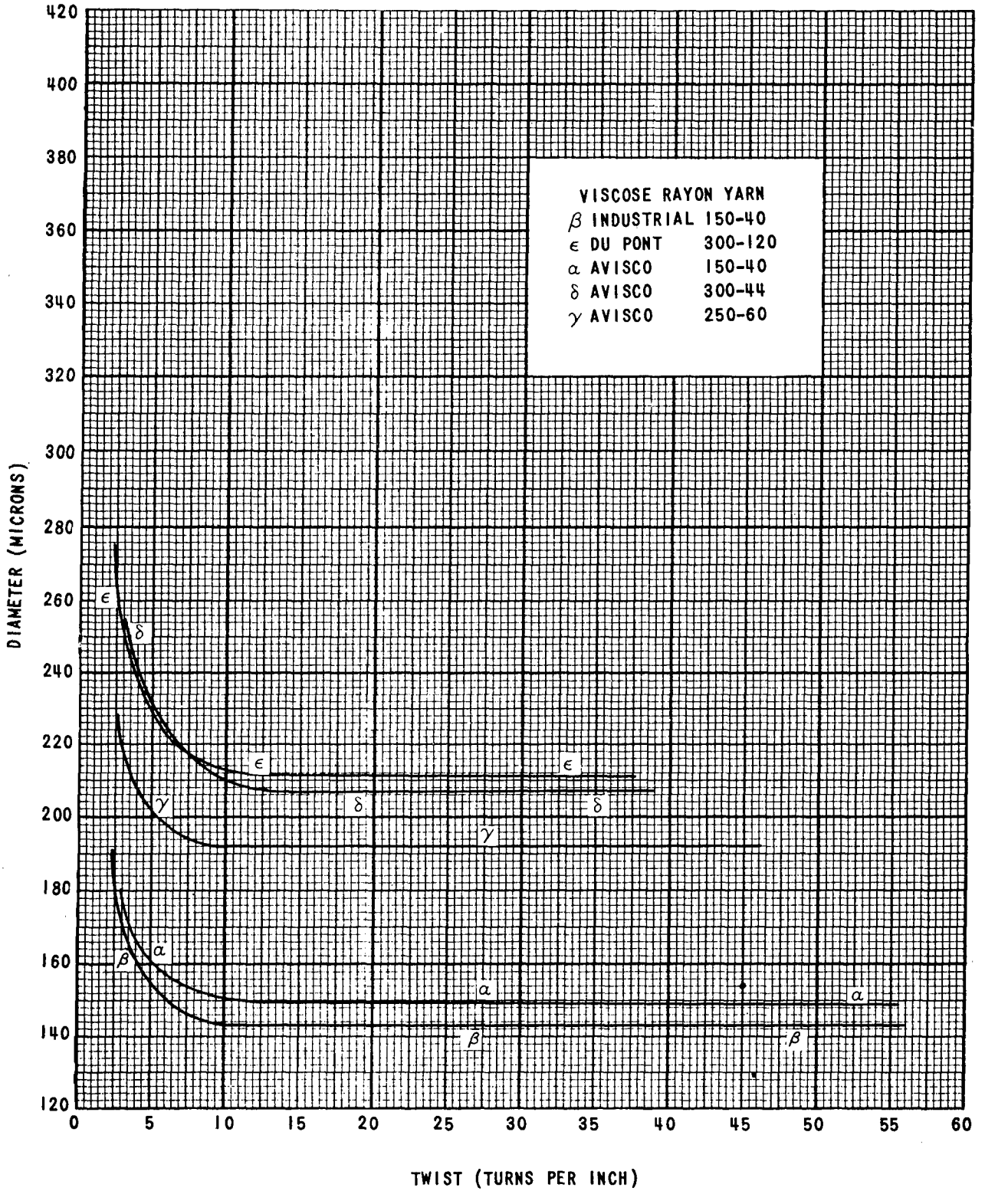


Figure 10. The Effect of Twist on the Diameter of Viscose Rayon Yarn.

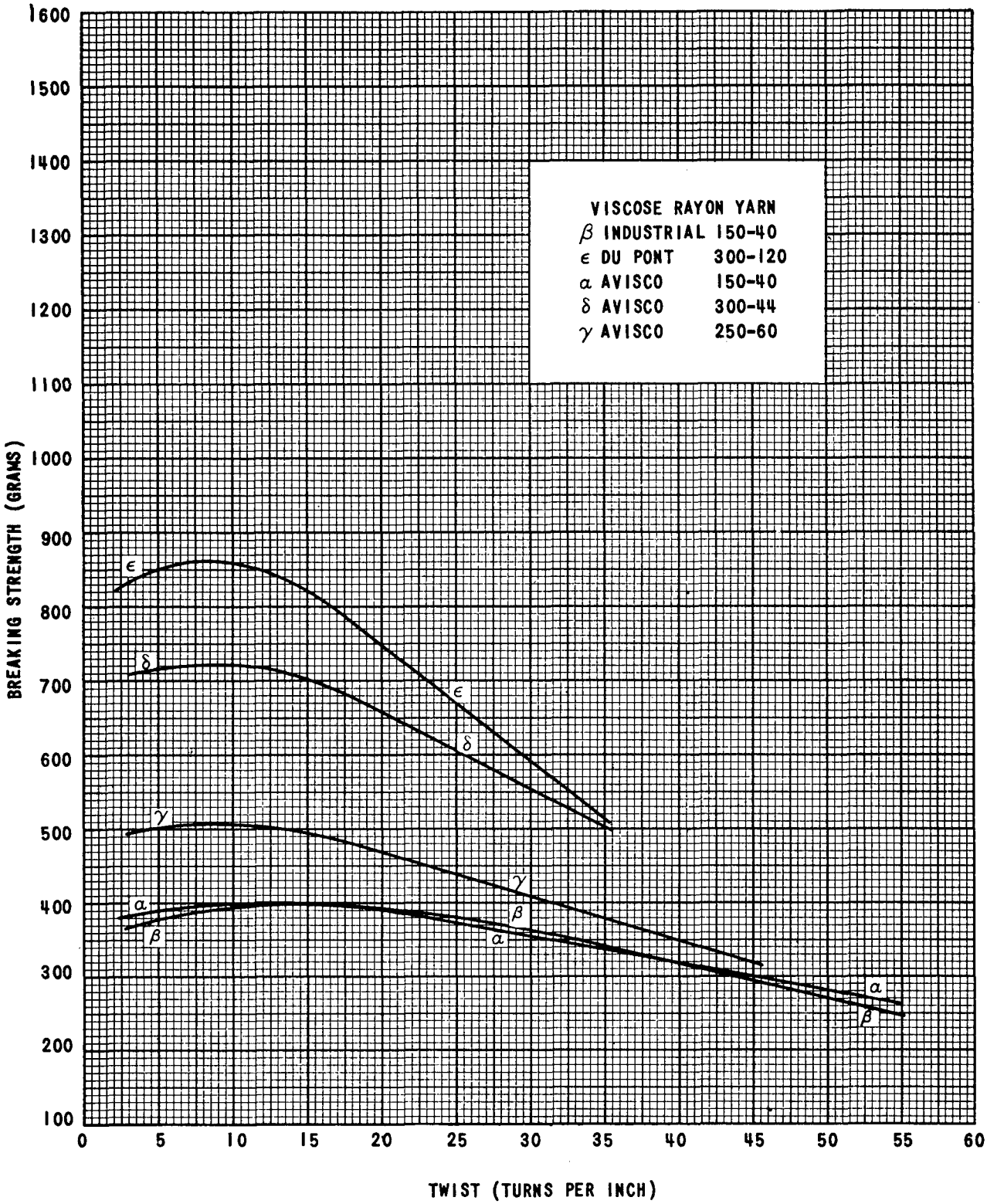


Figure 11. The Effect of Twist on the Breaking Strength of Viscose Rayon Yarn (IP-2 Machine).

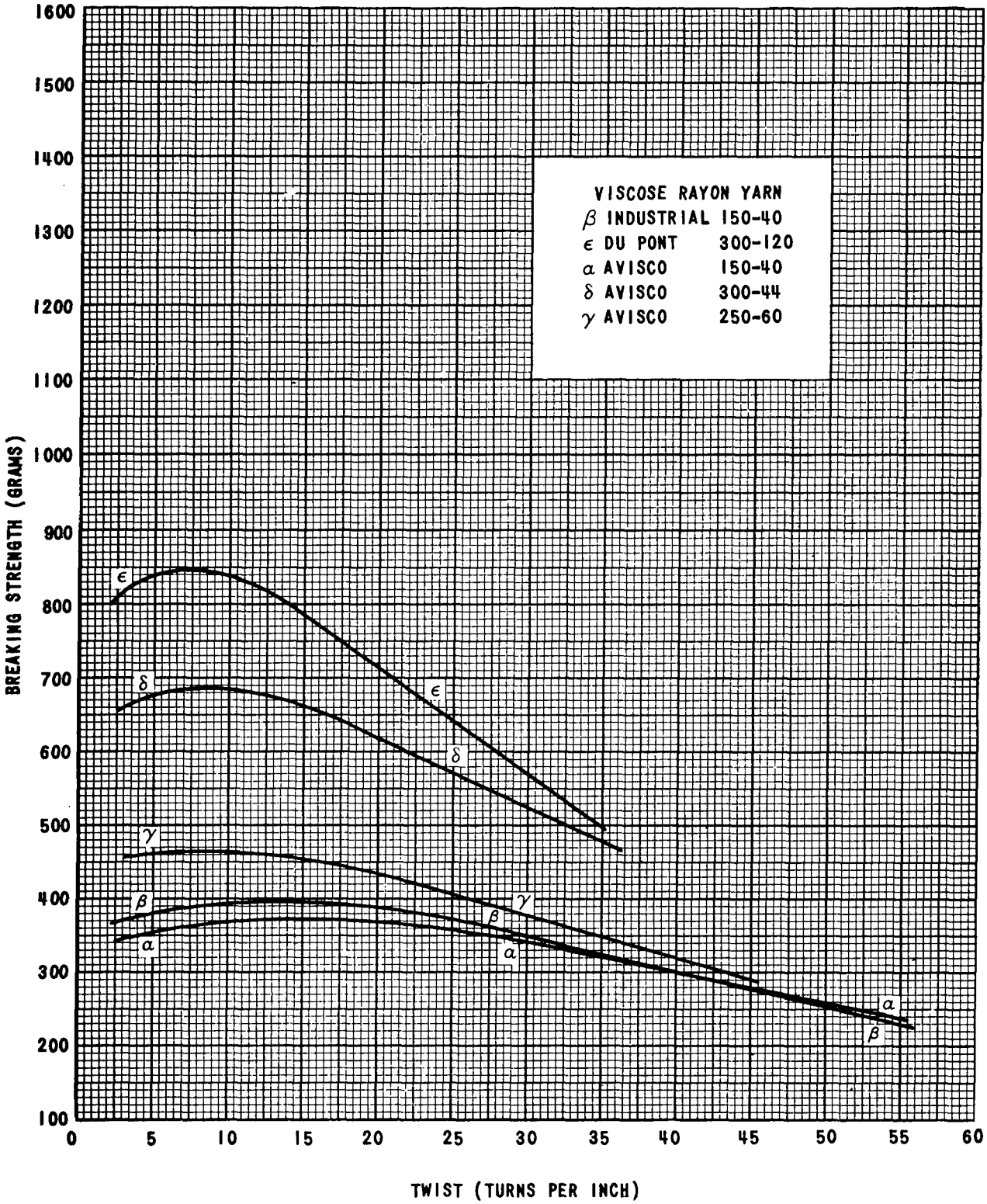


Figure 12. The Effect of Twist on the Breaking Strength of Viscose Rayon Yarn (Suter Single Strand Tester).

TABLE VIII

BREAKING STRENGTH MEASUREMENTS
ON VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Breaking Strength (Grams)									
	150-40-2.5S (Ind. Ray.)*		150-40-2.5S (AVisco)		250-60-2.5S (AVisco)		300-44-2.5S (AVisco)		300-120-2.5S (DuPont)*	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	381	368	369	348	494	455	707	661	823	803
5.0	399	393	380	359	507	464	723	692	867	851
10.9	403	396	393	372	507	464	717	679	844	812
20.4	384	380	387	368	455	415	638	600	687	657
33.3	348	336	335	319	375	337	482	453	515	485
42.3	—	—	—	—	325	288	—	—	—	—
53.0	243	213	260	233	—	—	—	—	—	—

*Semihigh-tenacity yarn.

From a study of the breaking strength data, the following are indicated:

a. A comparison of the IP-2 and Suter data indicates that the Suter results are consistently lower than the IP-2 data. However, the curves obtained by the two methods are very similar in shape.

b. For all the yarns, there is an increase over the initial breaking strength at very low twists, followed by a small twist range over which the maximum strength remains practically constant. Then there is a decrease in breaking strength for added twists above this range.

c. At all twists, the breaking strength of the 300-120 semi-high tenacity yarn is greater than that of the 300-44 normal tenacity yarn. The rate of increase and the rate of decrease in yarn strength are both greater for the 300-120 high-tenacity yarn.

d. Tests show that the rate of decrease in breaking strength

becomes greater as the denier and twist of the yarn are increased.

e. The maximum breaking strength occurs at higher twists and remains constant over a greater range of twist for the 150 and 250 denier yarns than for the 300 denier yarns.

5. Elongation Determinations

The elongation measurements at breaking load were obtained simultaneously with the breaking strength data on the IP-2 and Suter testers. Table IX and Figures 13 and 14 present the results of the elongation determinations.

TABLE IX

ELONGATION MEASUREMENTS AT BREAKING LOAD
ON VISCOSE RAYON YARNS

	Elongation (Per Cent)									
Approximate Twist Added (TPI)	150-40-2.5S (Ind. Ray.)*		150-40-2.5S (AVisco)		250-60-2.5S (AVisco)		300-44-2.5S (AVisco)		300-120-2.5S (DuPont)*	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	10.3	10.8	19.1	20.4	21.5	22.3	21.0	22.0	14.6	14.5
5.0	11.0	11.4	20.1	20.9	22.2	22.7	22.3	23.3	16.0	16.6
10.9	11.5	11.6	20.8	21.9	22.8	23.1	22.8	23.5	16.2	17.0
20.4	11.8	12.2	22.3	23.4	22.1	22.2	22.5	22.5	14.4	15.6
33.3	12.5	12.7	21.7	22.8	21.4	21.7	21.4	21.4	14.9	15.1
42.3	—	—	—	—	22.2	21.1	—	—	—	—
53.0	11.3	11.1	21.5	21.5	—	—	—	—	—	—

*Semihigh-tenacity yarn.

Results of an analysis of the elongation data are as follows:

a. The Suter and IP-2 elongation results agree closely.

b. For all the yarns, elongation is increased at low added twists; it is decreased at all greater twists. The maximum elongation is reached at lower twists in the higher denier yarns.

c. The per cent elongation of the semihigh-tenacity yarns is

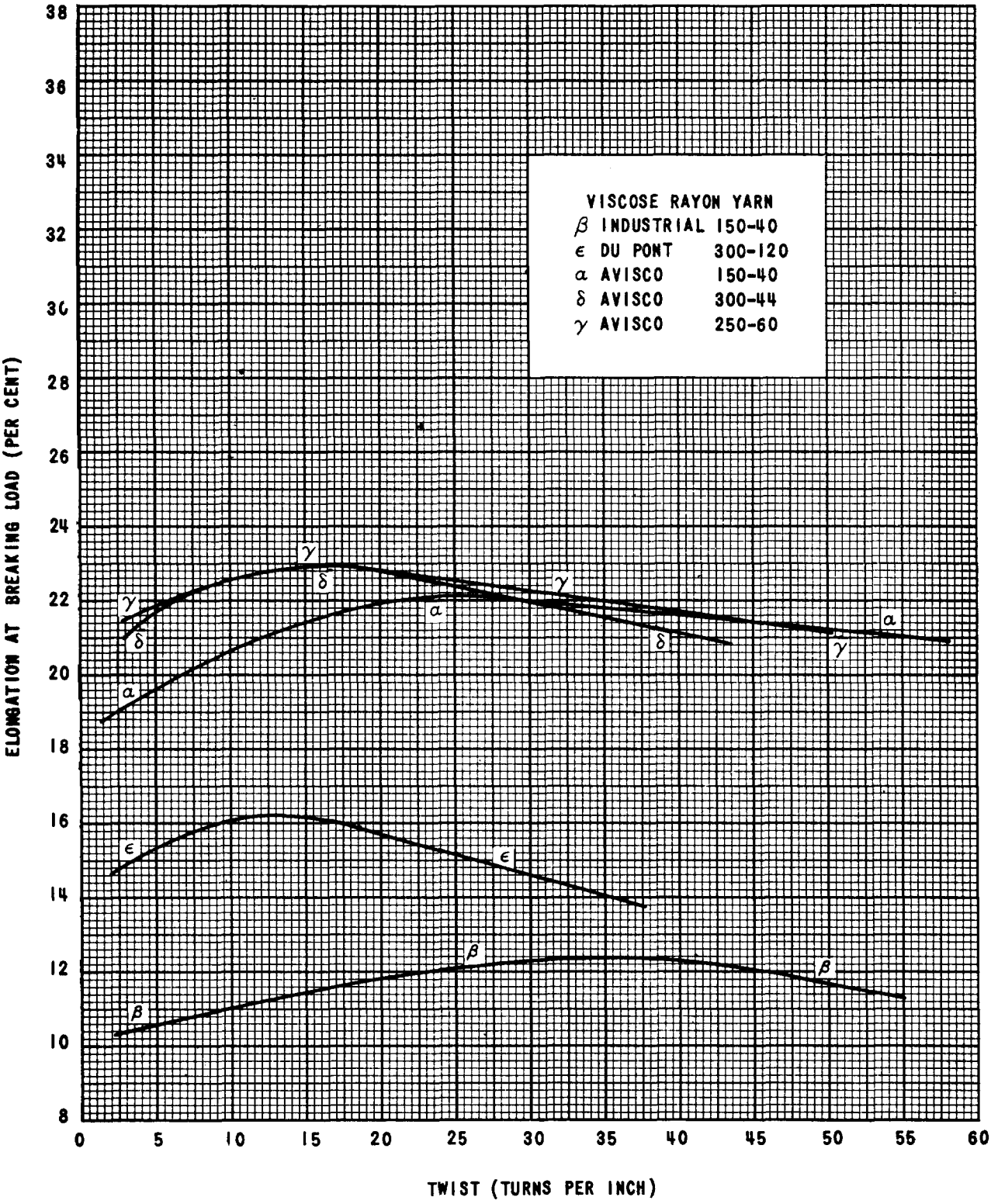


Figure 13. The Effect of Twist on the Elongation of Viscose Rayon Yarn (IP-2 Machine).

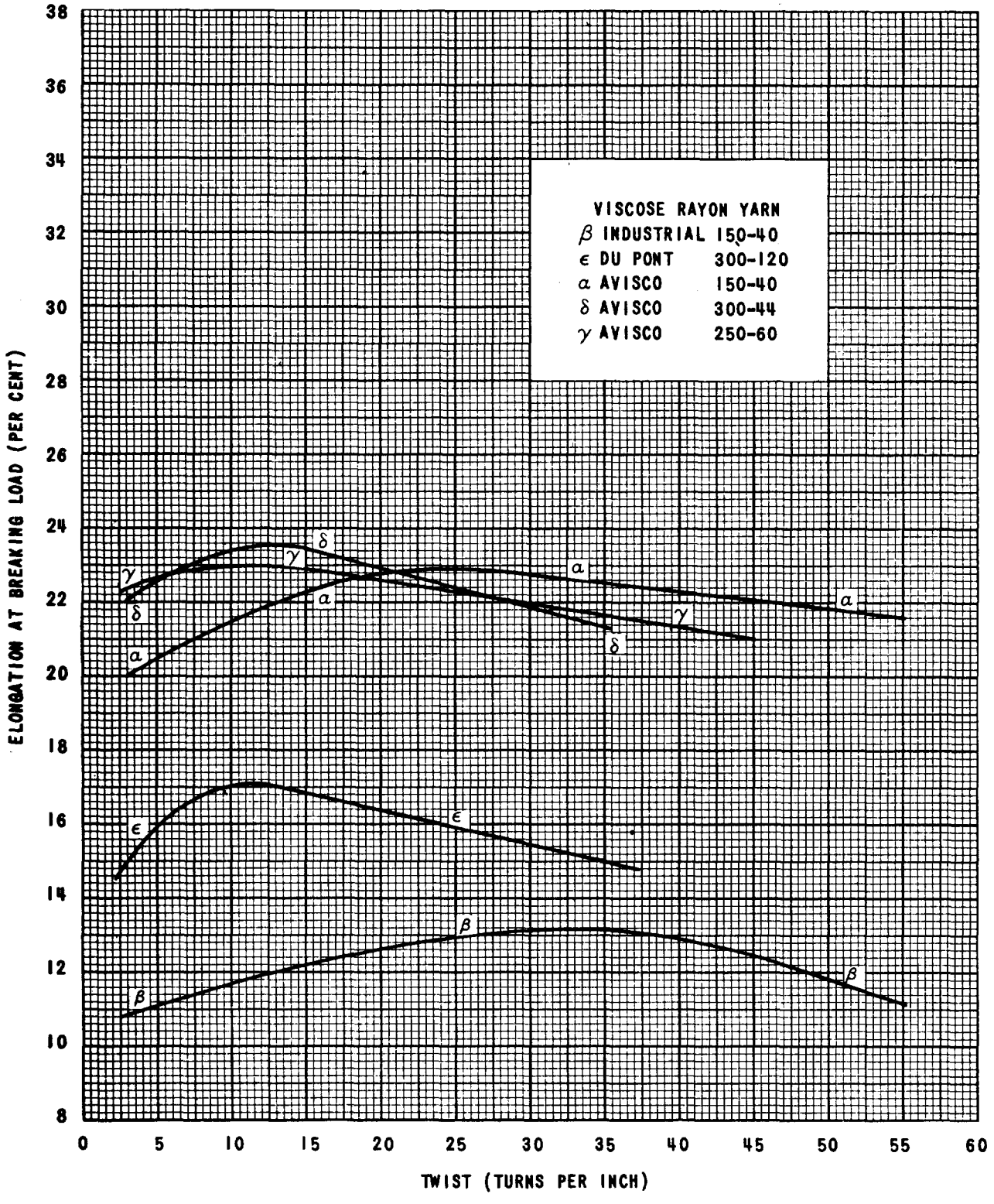


Figure 14. The Effect of Twist on the Elongation of Viscose Rayon Yarn (Suter Single Strand Tester).

considerably lower than that of the normal tenacity yarns.

d. In general, unless the mechanical properties of rayon yarns are altered, the measured elongation is only slightly affected by added twist.

6. Energy Absorption Values

Energy absorption calculations were made for each yarn at the breaking load and at 85 per cent of the breaking load. (As stated earlier in this report, these calculations were based on data obtained on the IP-2 tester.) Both sets of values are given in Table X. The graphical analysis of the energy absorbed to break is presented in Figure 15, and that for the energy absorbed to 85 per cent of breaking load is given in Figure 16.

TABLE X

ENERGY ABSORPTION VALUES
FOR VISCOSE RAYON YARNS

	Energy Absorbed (Gram-Cm.)									
Approximate Twist Added (TPI)	150-40-2.5S (Ind. Ray.)*		150-40-2.5S (AVisco)		250-60-2.5S (AVisco)		300-44-2.5S (AVisco)		300-120-2.5S (DuPont)*	
	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break
As-Received	684	352	1184	745	1832	1217	2476	1558	1904	1225
5.0	787	401	1266	773	1926	1283	2645	1643	2121	1401
10.9	814	407	1340	869	1938	1342	2667	1637	2089	1455
20.4	774	434	1384	891	1671	1177	2246	1524	1539	1046
33.3	705	452	1155	778	1310	971	1640	1147	1178	855
42.3	—	—	—	—	1191	805	—	—	—	—
53.0	429	283	861	614	—	—	—	—	—	—

*Semihigh-tenacity yarn.

In general, the following conclusions can be made from the experimental data:

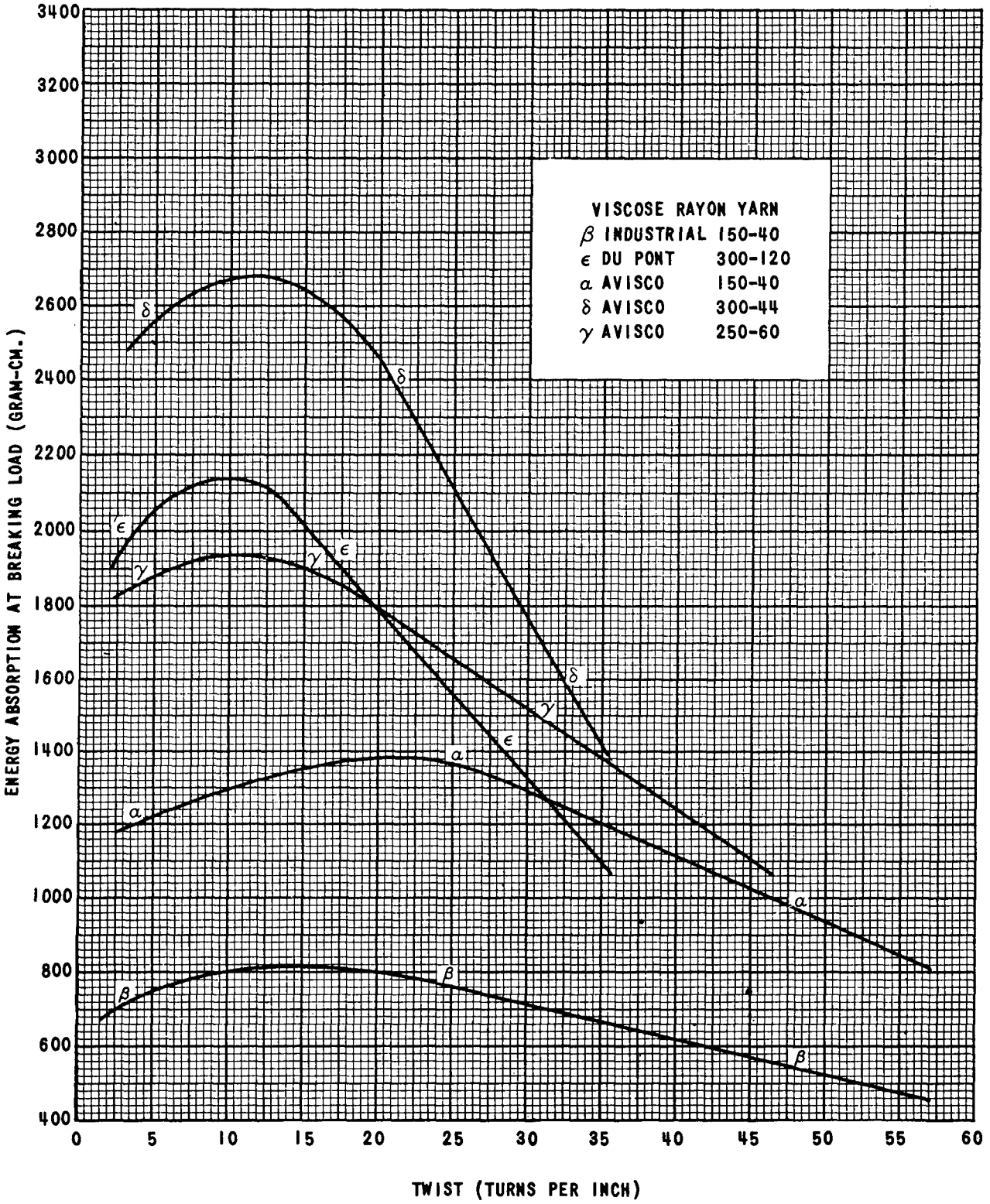


Figure 15. Energy Absorption Values at Breaking Load for Viscose Rayon Yarns.

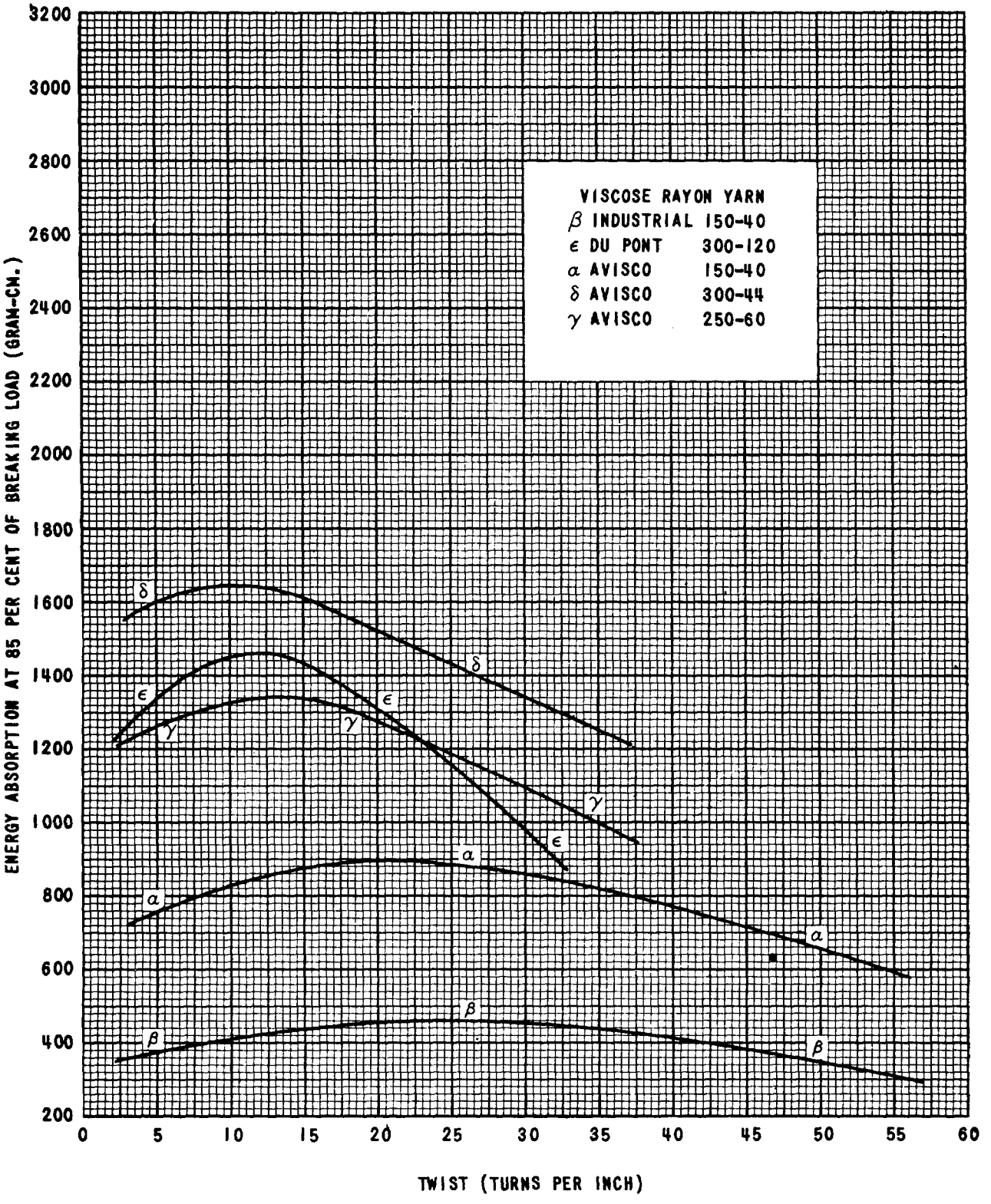


Figure 16. Energy Absorption Values at 85 Per Cent Breaking Load for Viscose Rayon Yarns.

a. For all the yarns there is an increase in the amount of energy absorbed with increase in twist up to a given point, after which there is a decrease in energy absorption. The rate of change is greater for the higher denier yarns, which require less twist to reach a maximum in energy absorption.

b. Regardless of twist added, semihigh-tenacity yarns show less energy absorbed than do normal tenacity yarns of the same denier.

c. In all cases, the amount of energy absorbed at 85 per cent of the breaking load is less than 85 per cent of the total energy absorbed at the breaking point. This may be explained by the fact that the ratio of elongation to load is greater in the upper part of the stress-strain curves.

7. Elastic Recovery Values

Values of the elastic recovery calculations are presented in Table XI and Figure 17. These values were calculated from hysteresis curves as discussed in the second section.

TABLE XI

ELASTIC RECOVERY VALUES AT 85 PER CENT BREAKING LOAD FOR VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)				
	150-40-2.5S (Ind. Ray.)*	150-40-2.5S (AVisco)	250-60-2.5S (AVisco)	300-44-2.5S (AVisco)	300-120-2.5S (DuPont)*
As-Received	32.4	18.6	14.5	13.5	23.3
5.0	30.7	17.9	13.8	14.6	25.7
10.9	33.8	17.1	13.8	14.4	20.4
20.4	31.1	17.2	15.7	14.0	16.1
33.3	29.7	17.3	14.6	14.0	19.0
42.3	—	—	15.9	—	—
53.0	28.1	15.7	—	—	—

*Semihigh-tenacity yarn.

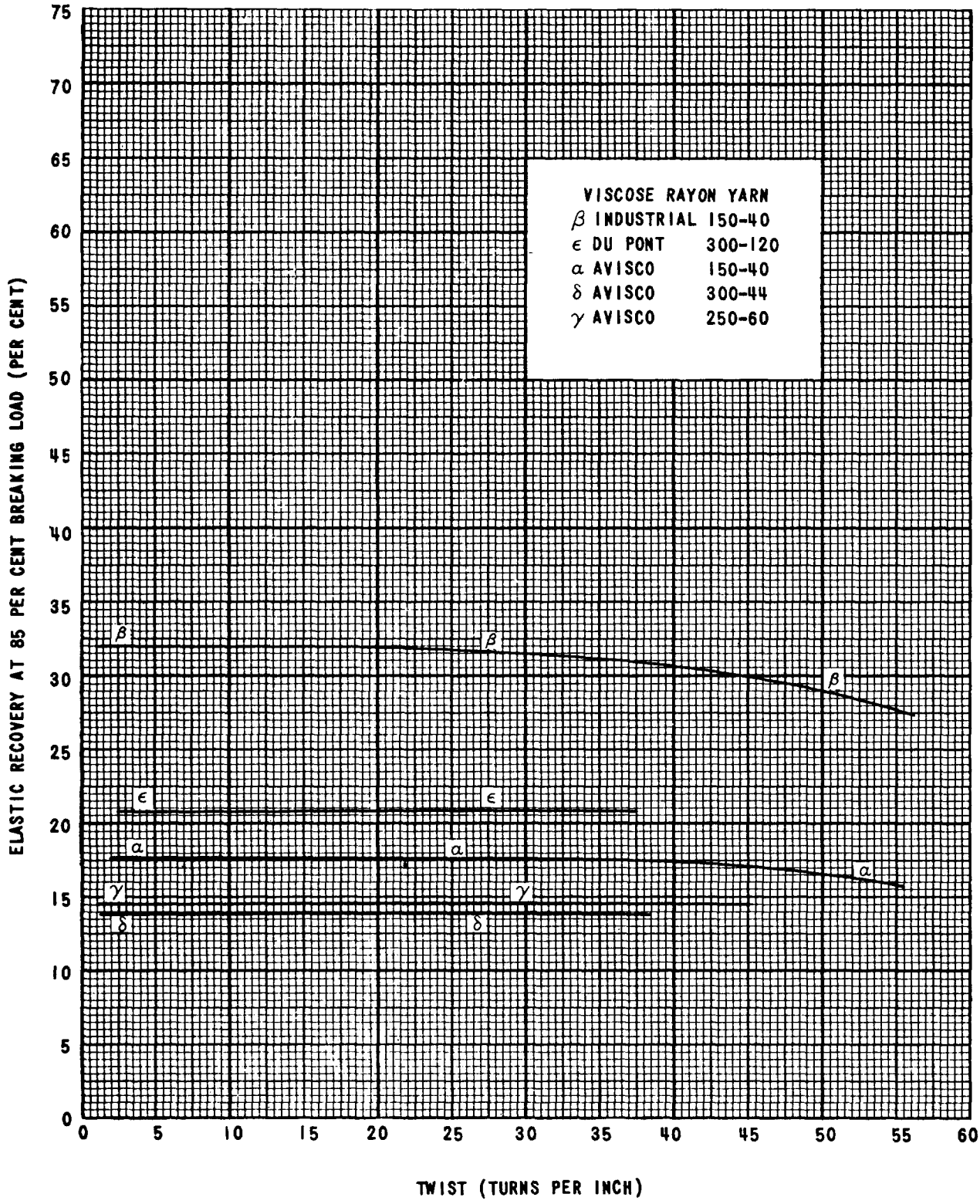


Figure 17. Elastic Recovery Values at 85 Per Cent Breaking Load for Viscose Rayon Yarns.

The following conclusions can be drawn from a study of data:

a. The higher tenacity yarns have considerably better recovery properties.

b. The elastic recovery of the rayon yarns tested is not affected by added twist up to approximately 40 TPI.

8. Tenacity Values

Tenacities of the rayon yarns were calculated from the IP-2 breaking strength data and denier measurements. The tenacity calculations are given in Table XII and curves are presented in Figure 18.

TABLE XII

TENACITY VALUES FOR VISCOSE RAYON YARNS

Approximate Twist Added (TPI)	Tenacity (Grams/Denier) 150-40-2.5S (Ind. Ray.)*	150-40-2.5S (AVisco)	250-60-2.5S (AVisco)	300-44-2.5S (AVisco)	300-120-2.5S (DuPont)*
As-Received	2.68	2.45	2.00	2.36	2.71
5.0	2.81	2.51	2.02	2.37	2.78
10.9	2.82	2.54	1.98	2.30	2.64
20.4	2.62	2.44	1.70	1.95	2.07
33.3	2.26	2.02	1.31	1.34	1.40
42.3	—	—	1.04	—	—
53.0	1.42	1.42	—	—	—

*Semihigh-tenacity yarn.

From these figures, the following conclusions can be drawn:

a. The tenacities of all the rayon yarns tested have a maximum value at relatively low added twists and then drop rapidly with additional twisting.

b. The tenacities of the higher denier yarns reach the maximum at lower values than those of the other yarns and their rate of decrease is considerably greater.

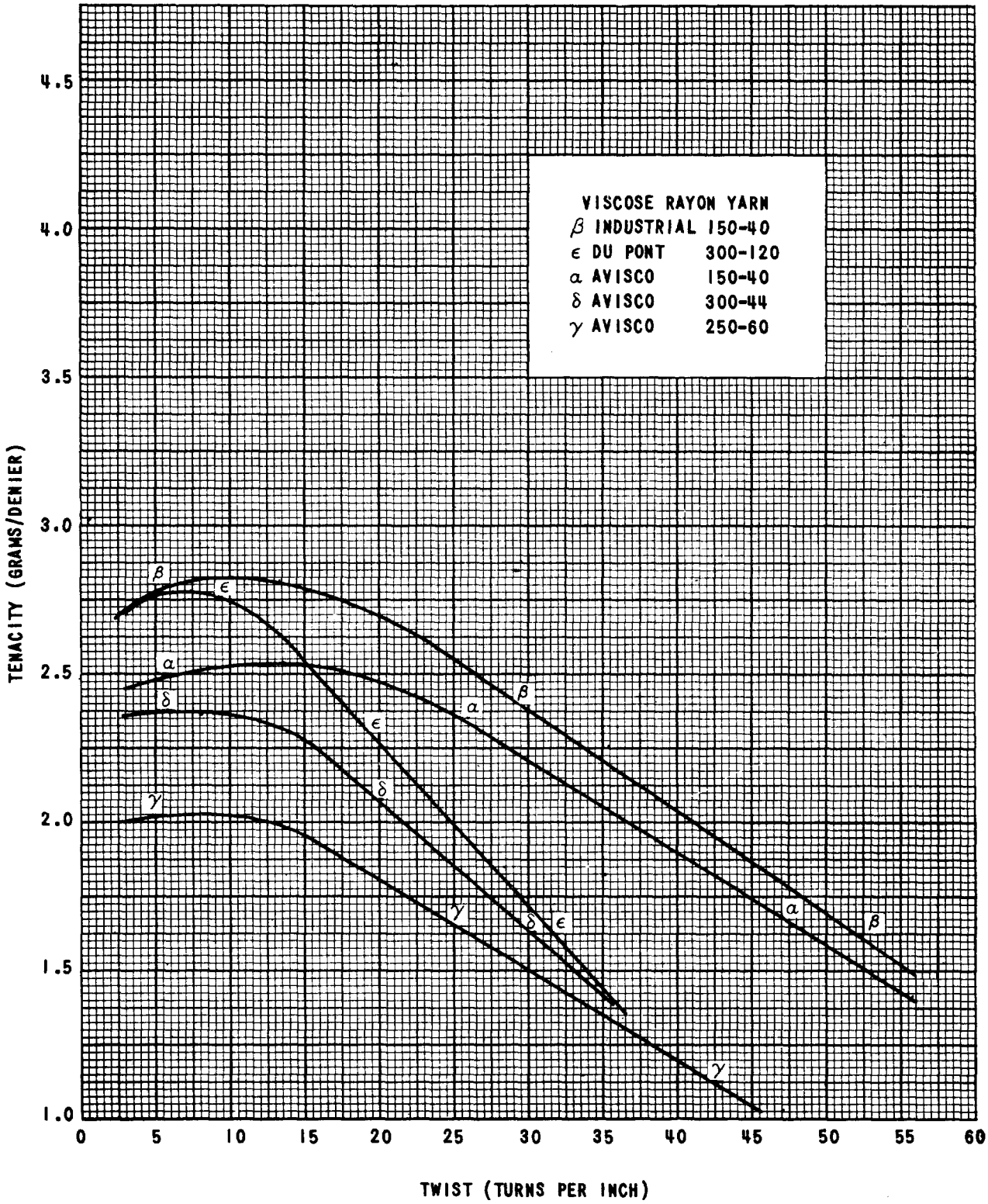


Figure 18. Tenacity Values for Viscose Rayon Yarns.

IV. NYLON YARNS

The second phase of the testing program was a study of the effect of twist on the properties of nylon yarns. Ten different yarns were selected for testing in order to compare the effect of twist on yarns having different deniers, filament size, type,* and tenacity. The yarns studied are listed in Table I.

A. Twisting

Twist was applied to each of the nylon yarns according to the method described in the second section until shearing and/or creping of the yarns occurred. The approximate twists added to the yarns are shown in Table XIII. The percentage loss in original breaking strength for each yarn at its maximum twist is included in the table.

TABLE XIII

TWISTING DATA FOR NYLON YARNS

Yarn	Approximate Twist Added (TPI)	Per Cent Loss in Original Breaking Strength at Maximum Twist
20- 7-0.5Z-200	7, 13, 23, 35, 47, 70, 100	16.4
30-10-0.5Z-200	7, 13, 23, 35, 47, 70, 100	13.9
40-13-0.5Z-200	7, 13, 23, 35, 47, 70, 100	23.0
40-34-0.5Z-200	7, 13, 23, 35, 47, 70, 100	19.1
70-34-0.5Z-100	7, 13, 23, 35, 47, 70	10.4
70-34-0.5Z-200	7, 13, 23, 35, 47, 70	10.0
70-34-0.5Z-300	7, 13, 23, 35, 47, 70	11.1
100-34-0.5Z-300	7, 13, 23, 35, 47	10.5
210-34-1.0Z-300	7, 13, 23, 35	17.7
260-17-1.0Z-300	7, 13, 23, 35	18.0

*Type 100--bright, normal tenacity, no size or oil.
Type 200--semidull, normal tenacity, no size or oil.
Type 300--bright, high-tenacity, no size or oil.

B. Presentation and Analysis of Experimental Data

1. Twist Determinations

Twist determinations for the nylon yarns are given in Table XIV.

TABLE XIV

TWIST MEASUREMENTS ON NYLON YARNS

Approximate Twist Added (TPI)	Measured Twist (TPI)				
	20- 7-0.5Z Type 200	30-10-0.5Z Type 200	40-13-0.5Z Type 200	40-34-0.5Z Type 200	70-34-0.5Z Type 100
As-Received	0.3	0.3	0.5	0.6	0.4
7.0	7.8	7.8	7.3	8.4	7.7
13.1	14.3	13.5	13.3	13.6	13.9
22.7	23.2	22.6	22.7	22.8	22.7
35.3	34.3	34.8	34.2	33.7	34.4
46.7	43.9	45.8	43.8	45.1	45.3
70.0	66.7	65.6	66.7	66.3	67.2
100.2	97.8	96.9	96.7	97.3	—

	70-34-0.5Z Type 200	70-34-0.5Z Type 300	100-34-0.5Z Type 300	210-34-1.0Z Type 300	260-17-1.0Z Type 300
As-Received	0.4	0.5	0.6	1.1	1.1
7.0	7.8	7.4	7.8	8.0	8.2
13.1	13.7	13.6	13.6	14.0	14.0
22.7	22.9	23.0	22.9	23.5	23.6
35.3	34.7	35.1	34.5	35.9	35.7
46.7	46.2	45.9	46.0	—	—
70.0	69.7	67.6	—	—	—
100.2	—	—	—	—	—

The measured twist of the as-received samples is in close agreement with the values specified by the manufacturer. The table shows that, when high twists were added, the measured twist was found to be slightly less than the calculated value.

2. Denier Determinations

The nylon denier determinations are presented in Table XV and shown graphically in Figure 19.

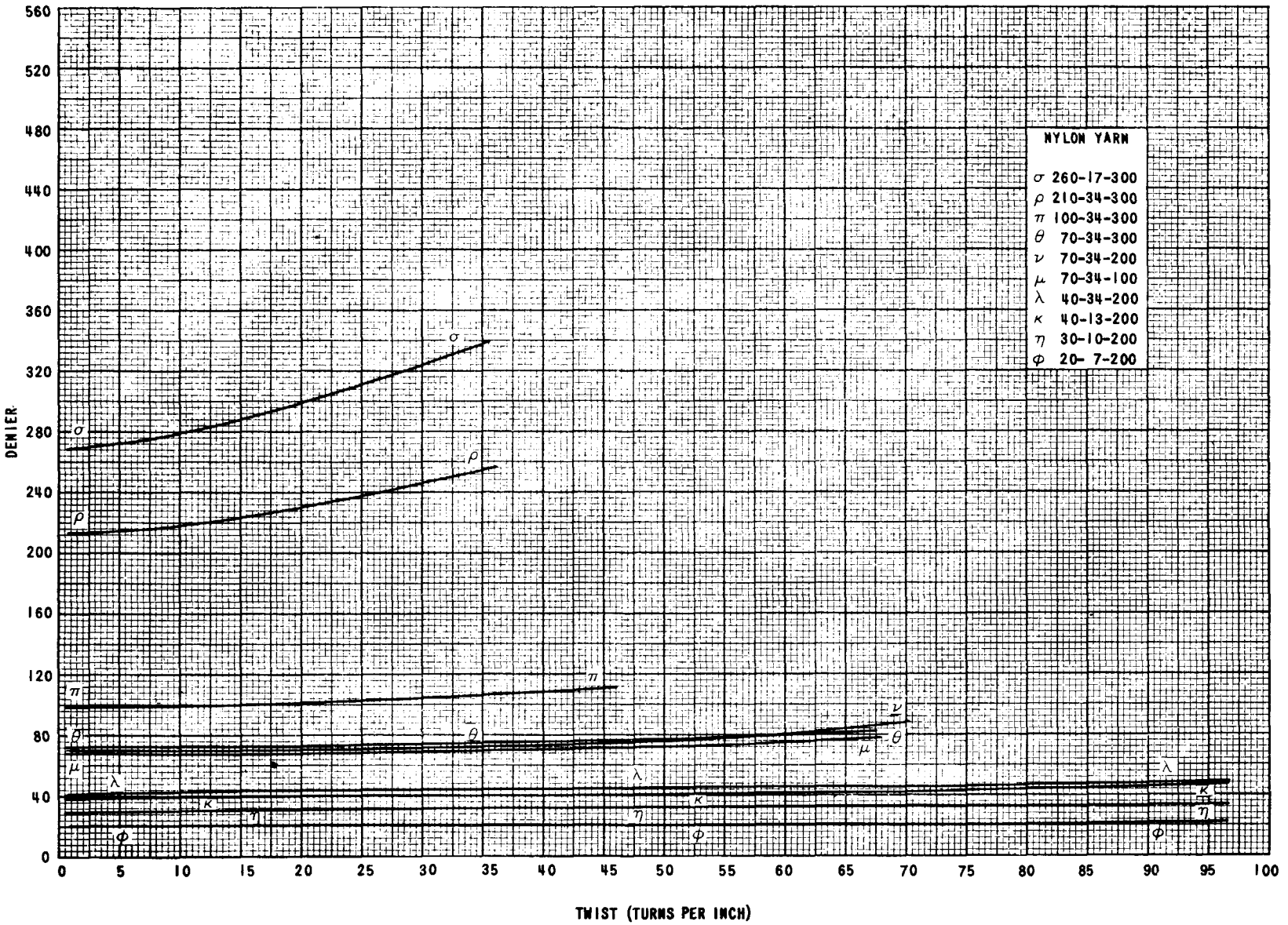


Figure 19. The Effect of Twist on the Denier of Nylon Yarns.

TABLE XV

DENIER MEASUREMENTS ON NYLON YARNS

Approximate Twist Added (TPI)	Denier				
	20- 7-0.5Z Type 200	30-10-0.5Z Type 200	40-13-0.5Z Type 200	40-34-0.5Z Type 200	70-34-0.5Z Type 100
As-Received	19.9	29.7	40.2	39.6	70.3
7.0	19.6	29.8	40.1	39.2	70.4
13.1	19.7	30.0	40.2	39.5	70.7
22.7	19.7	30.1	40.5	40.0	72.2
35.3	19.9	30.5	41.4	40.9	74.4
46.7	20.2	32.8	42.7	41.8	75.7
70.0	20.8	32.5	45.5	44.4	85.9
100.2	22.3	34.6	49.3	48.6	—

	70-34-0.5Z Type 200	70-34-0.5Z Type 300	100-34-0.5Z Type 300	210-34-1.0Z Type 300	260-17-1.0Z Type 300
As-Received	70.3	71.6	99.9	213.0	266.3
7.0	70.5	71.3	100.2	214.7	273.5
13.1	70.8	72.0	101.2	218.5	279.1
22.7.	72.1	73.8	103.5	230.1	299.3
35.3	74.4	76.1	108.8	251.0	334.0
46.7	75.9	77.6	113.9	—	—
70.0	84.7	—	—	—	—
100.2	—	—	—	—	—

From an analysis of the denier results, the following observations were made:

a. For all the yarns, the denier increases as twist is added.

b. The higher denier yarns exhibit the greatest change and rate of change in denier with added twist.

c. The change in denier for a given increase in twist is the same for both the 40 denier yarns.

d. The change in denier for a given increase in twist is approximately the same for the three types of 70 denier yarns.

3. Diameter Determinations

Data for the nylon diameter tests are given in Table XVI and presented graphically in Figure 20.

TABLE XVI

DIAMETER MEASUREMENTS ON NYLON YARNS

Approximate Twist Added (TPI)	Diameter (Microns)				
	20-70-0.5Z Type 200	30-10-0.5Z Type 200	40-13-0.5Z Type 200	40-34-0.5Z Type 200	70-34-0.5Z Type 100
As-Received	71.9	97.4	106.6	123.6	156.1
7.0	57.3	72.5	85.3	87.5	112.5
13.1	55.0	68.9	83.1	83.4	110.4
22.7	54.4	69.3	81.6	80.4	109.8
35.3	54.9	69.4	80.7	80.6	110.8
46.7	53.3	71.4	80.3	81.0	110.0
70.0	55.0	70.1	80.6	82.3	112.4
100.2	54.6	74.8	86.2	84.9	—

	70-34-0.5Z Type 200	70-34-0.5Z Type 300	100-34-0.5Z Type 300	210-34-1.0Z Type 300	260-17-1.0Z Type 300
As-Received	151.7	155.5	173.0	211.2	224.0
7.0	114.4	121.8	141.0	196.8	213.4
13.1	111.3	113.0	133.7	189.8	207.7
22.7	110.6	111.9	133.4	189.5	212.9
35.3	109.8	111.9	137.0	202.9	219.6
46.7	108.2	112.5	139.3	—	—
70.0	113.7	116.7	—	—	—
100.2	—	—	—	—	—

Data on diameter measurements show the following:

a. For all the yarns there is a noticeable decrease in the initial diameter with added twists up to 10-15 TPI. For twists above this range, the minimum diameter remains constant over a range of twist. Finally, the diameter increases (with the exception of the 20-7 yarn), usually with the last ten TPI of twist added.

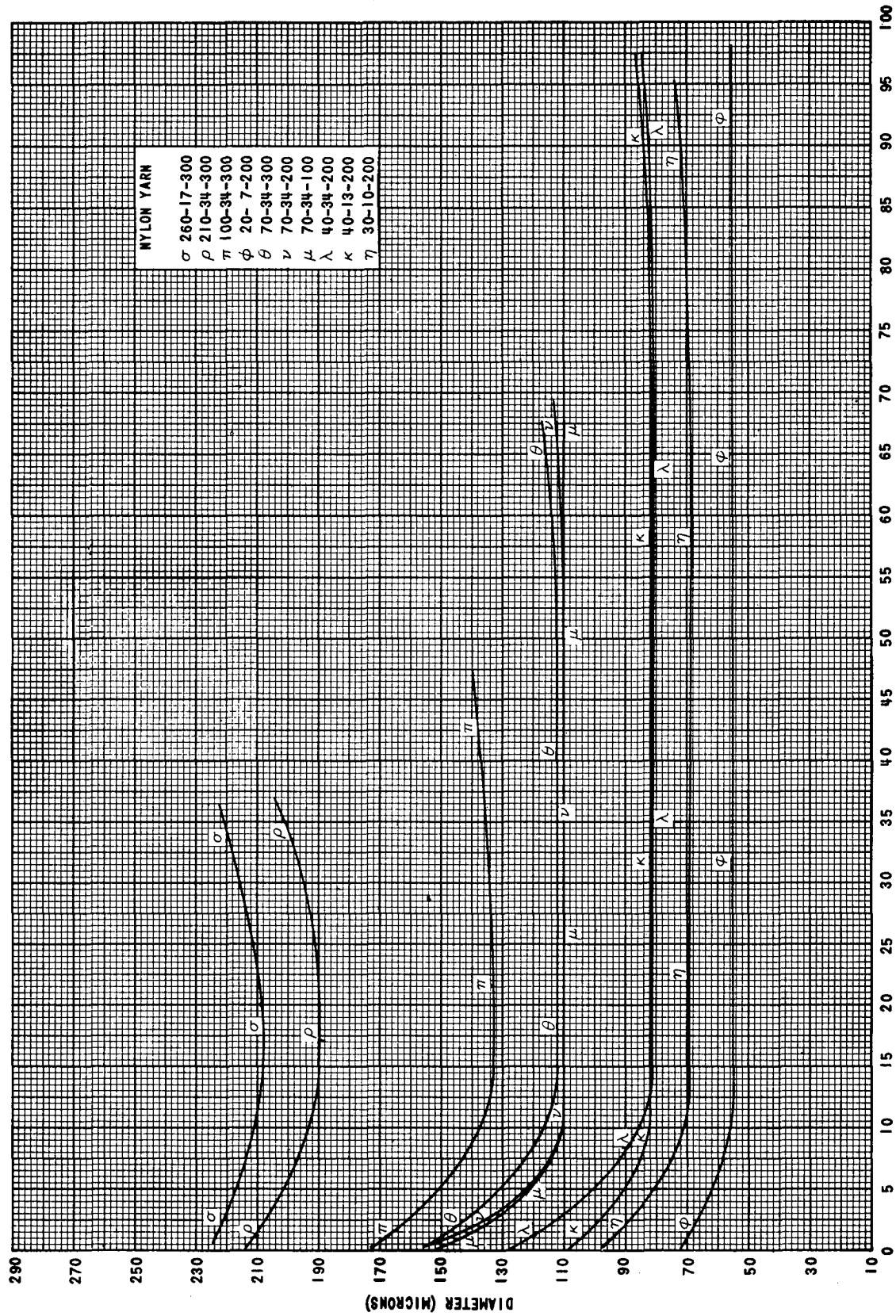


Figure 20. The Effect of Twist on the Diameter of Nylon Yarns.

b. The length of the constant range is an inverse function of the denier.

c. A comparison of the two 40 denier yarns shows that the softer 40-34 yarn has the larger initial diameter. However, the minimum diameter and the increase in diameter at high twists are approximately the same for both yarns.

d. A comparison of the 70 denier yarns shows that all three yarns have very nearly the same initial diameter. The type 100 and 200 yarns follow the same curve. However, the type 300 yarn does not exhibit as much decrease in diameter as do the other type yarns.

4. Breaking Strength and Elongation Determinations

A number of difficulties were encountered in testing the effect of twist on the breaking strength and elongation of nylon yarns. Originally, tests were made on the yarns with both the IP-2 and Suter testers as soon as possible after the twisting operations were completed. Although the breaking strength of the yarn was only slightly affected, the elongation appeared to be changed considerably by the added twist. In many instances the elongation results were erratic, and it became necessary to check the data frequently. The checks indicated that the relaxation time (the time the twisted yarn was allowed to remain on the spool before it was tested) had a direct effect on the elongation. This was particularly true of the lower denier yarns. After the above characteristics of the yarns were observed, an effort was made to determine an optimum yarn relaxation period. The limitation of time prevented this study for each individual yarn; so observations were made on the more critical yarns of low denier.

After the effect of relaxation for 144 hours was studied on one yarn, it was decided that each yarn would be stored on the twister spool for a period of two weeks before testing. This period made it possible for all tests to be based on a common time of relaxation, with a major portion of relaxation achieved. It was not assumed, however, that any yarn was completely relaxed.

Figures 21 and 22 show elongation and breaking strength curves for the 40-13 and 70-34 type 200 yarns respectively, before and after two weeks storage on twister spools. There appears to be a considerable change in the elongation, particularly at the higher twists of the smaller yarn. The breaking strength appears to be only slightly affected. Due to the large quantity of twisted yarn consumed in running and rerunning relaxation tests on the first five yarns in the series, there was not a sufficient amount of relaxed yarn to complete both IP-2 and Suter tests. Therefore, it was decided to use the IP-2 tester, since it is believed to be the more accurate one for testing smaller yarns.

It should also be noted that no data are given in the tables and graphs for the breaking strength, elongation, energy absorption, elastic recovery, and tenacity of the 40-34-200 yarn. The results of tests on this yarn at three different relaxation periods appeared to be erratic and anomalous and were omitted.

a. Breaking Strength Determinations. The breaking strength measurements for the nylon yarns are given in Table XVII and presented graphically in Figures 23 and 24.

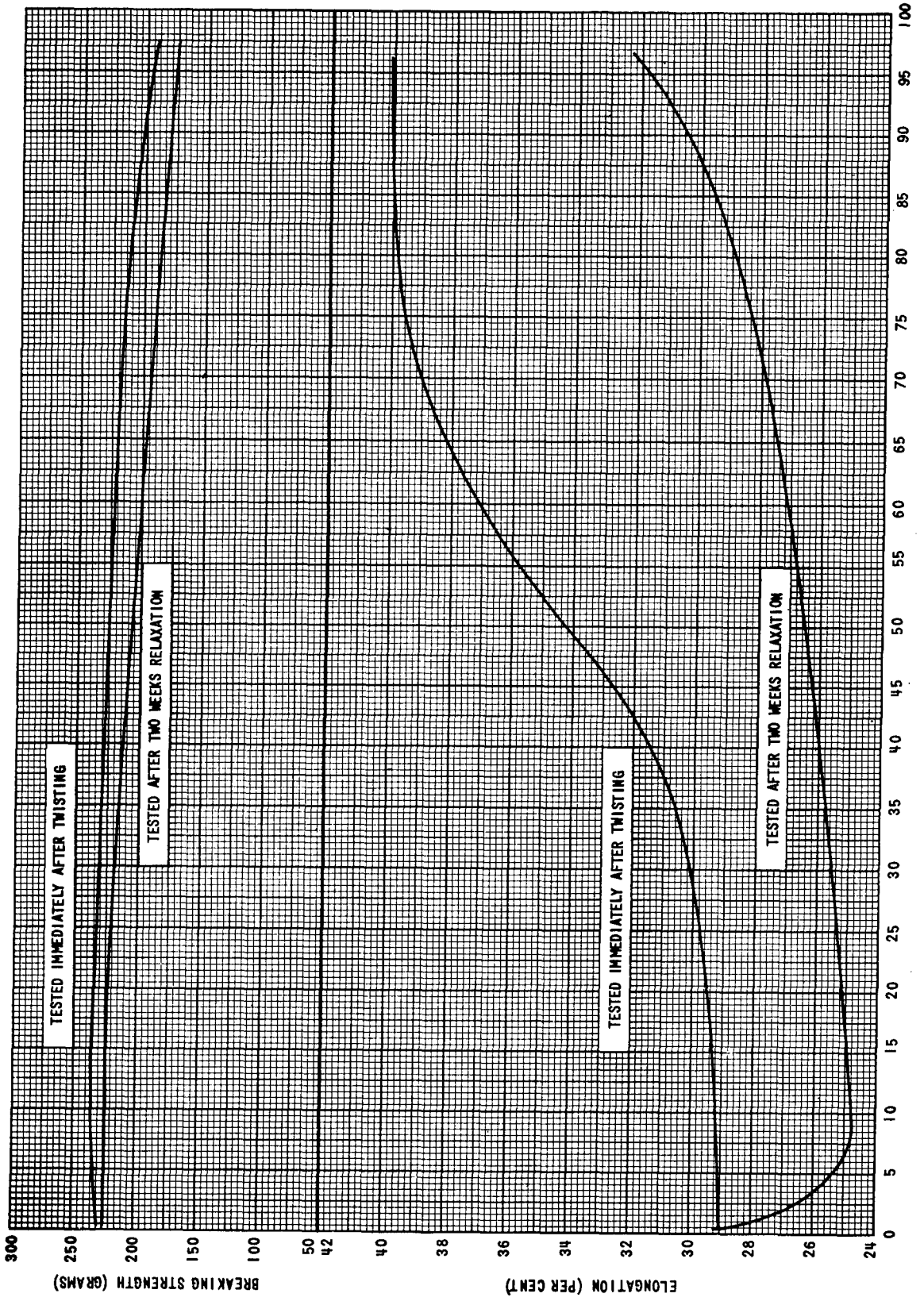


Figure 21. Effects of Relaxation on Nylon Yarn; κ, 40-13-200 (IP-2 Machine).

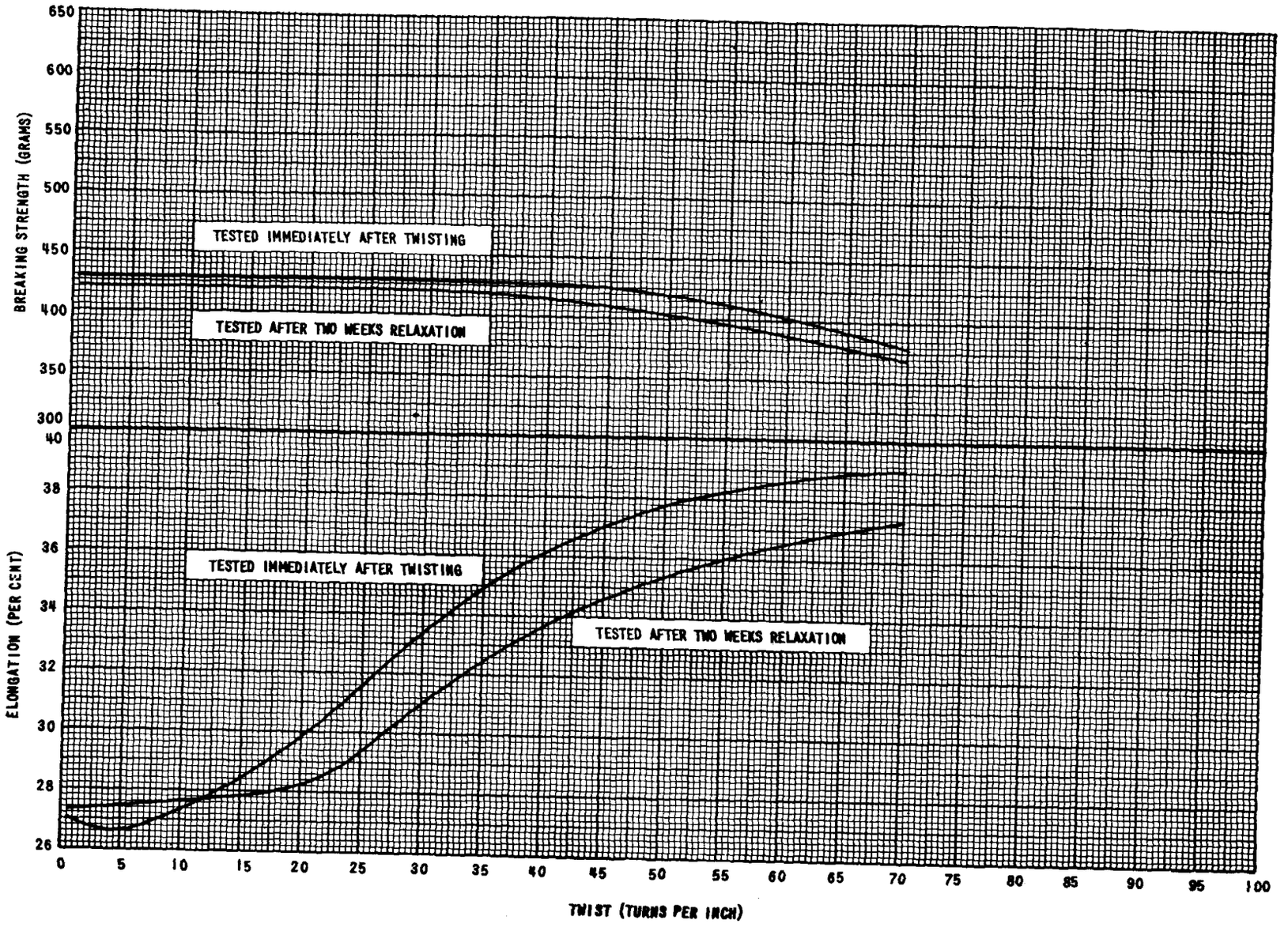


Figure 22. Effects of Relaxation on Nylon Yarn; ν, 70-34-200 (IP-2 Machine).

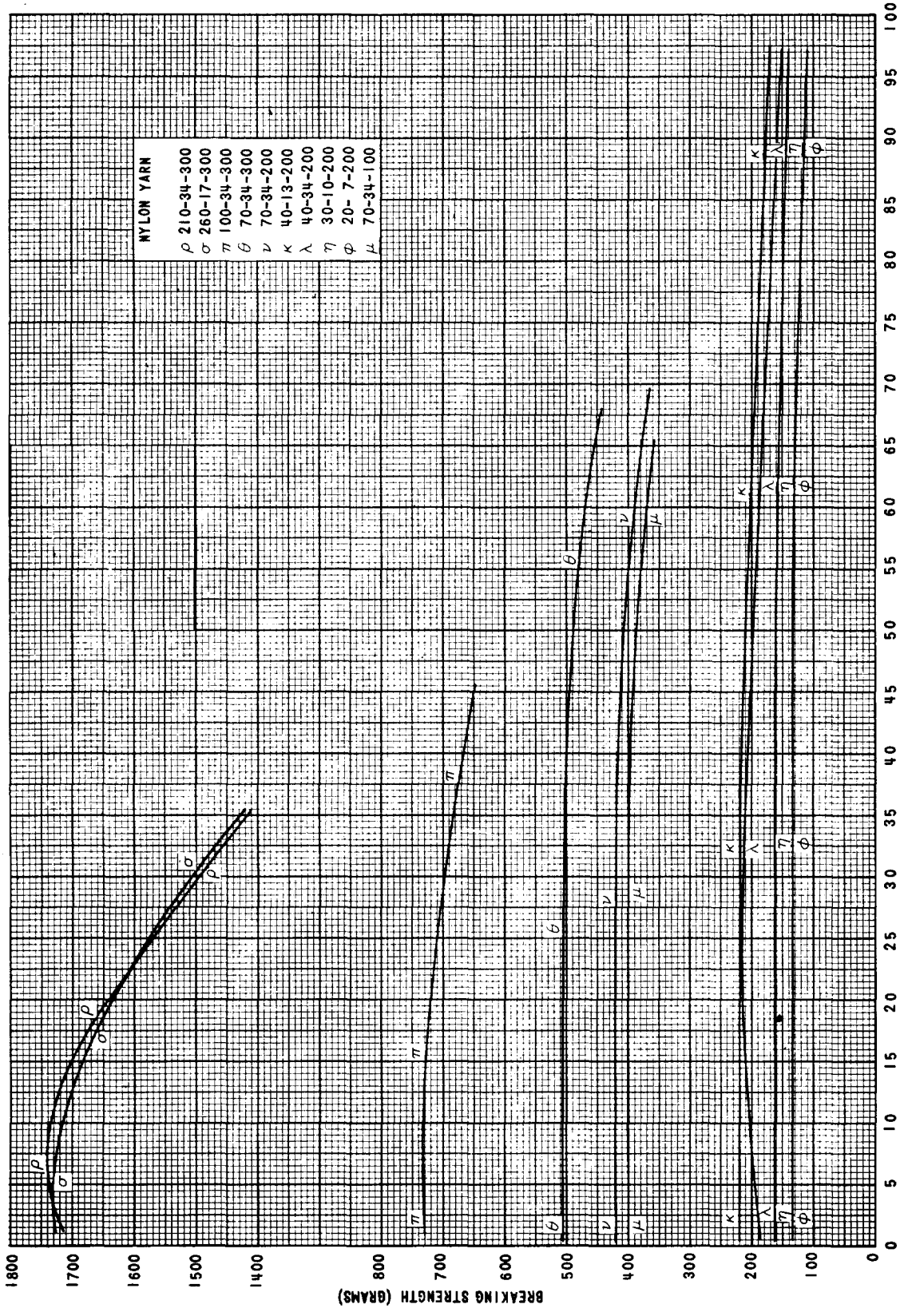


Figure 23. The Effect of Twist on the Breaking Strength of Nylon Yarns (IP-2 Machine).

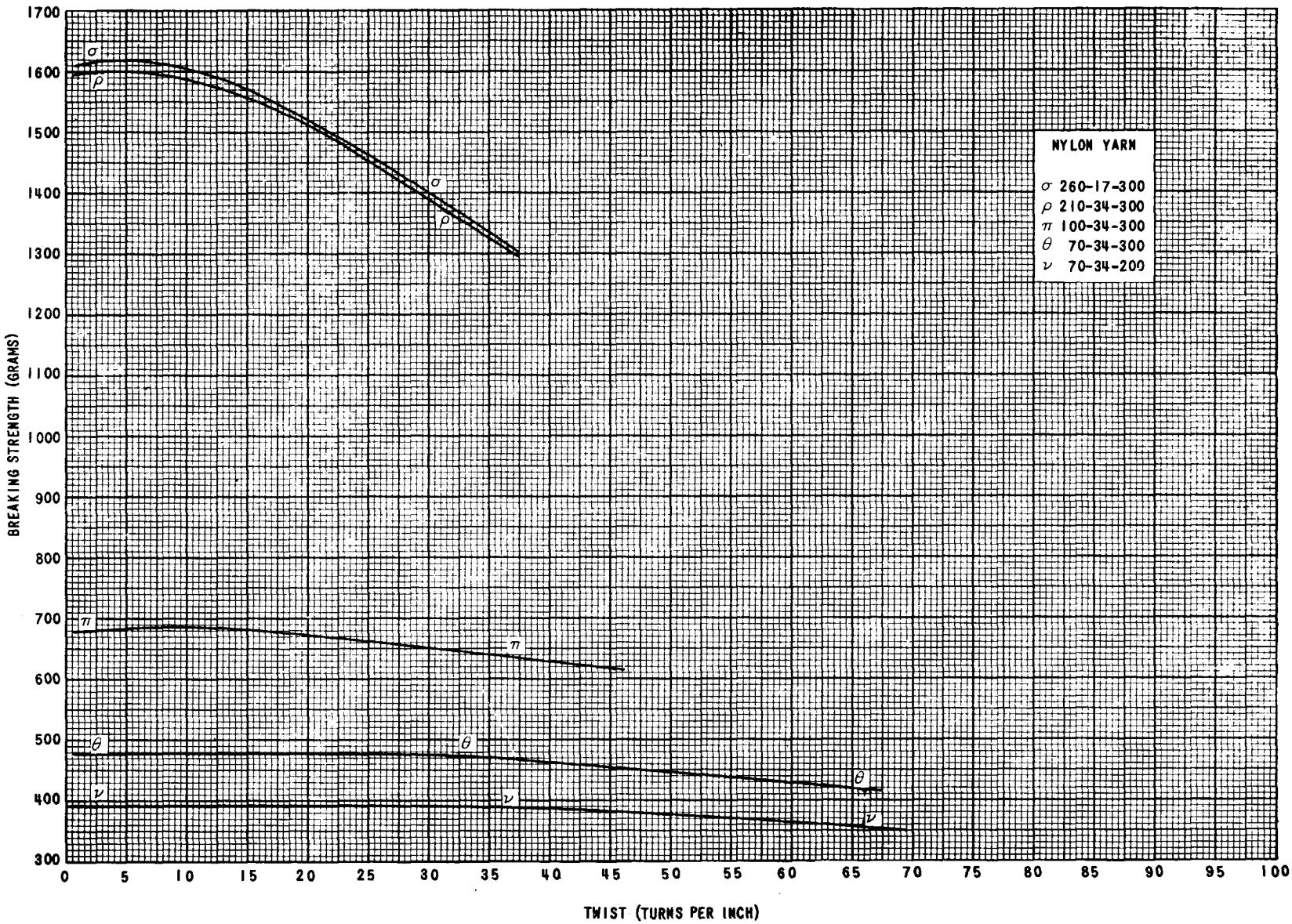


Figure 24. The Effect of Twist of the Breaking Strength of Nylon Yarns (Suter Single Strand Tester).

TABLE XVII

BREAKING STRENGTH MEASUREMENTS ON NYLON YARNS

Approximate Twist Added (TPI)	Breaking Strength (Grams) 20- 7-0.5Z Type 200 IP-2	30-10-0.5Z Type 200 IP-2	40-13-0.5Z Type 200 IP-2	70-34-0.5Z Type 100 IP-2
As-Received	134	166	266	395
7.0	134	167	222	407
13.1	134	169	224	404
22.7	134	168	224	403
35.3	133	167	215	403
46.7	132	163	212	383
70.0	127	155	196	354
100.2	112	143	174	---

	70-34-0.5Z Type 200		70-34-0.5Z Type 300		100-34-0.5Z Type 300		210-34-1.0Z Type 300		260-17-1.0Z Type 300	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	407	381	504	474	730	676	1715	1595	1727	1614
7.0	420	395	509	477	738	686	1736	1581	1729	1597
13.1	426	389	508	481	731	682	1727	1582	1692	1583
22.7	414	398	505	473	714	667	1568	1435	1581	1484
35.3	423	385	500	460	675	634	1411	1344	1418	1336
46.7	407	380	497	459	653	621	---	---	---	---
70.0	367	352	447	417	---	---	---	---	---	---
100.2	---	---	---	---	---	---	---	---	---	---

An analysis of these data shows that twist affects the breaking strength of nylon yarn as follows:

(1) The low denier yarns (20-70) show very little change in breaking strength below 40 TPI of twist, after which there is a gradual decrease in breaking strength up to 100 TPI.

(2) The breaking strength of the 100 denier yarn is unaffected by added twist up through 22 TPI.

(3) The breaking strength of the higher denier yarns decreases at much lower twists, and the rate of decrease is greater.

b. Elongation Determinations

The elongation measurements were recorded simultaneously with the breaking strength data. The measurements for all nylon yarns tested are presented in Table XVIII and are shown graphically in Figures 25 and 26.

TABLE XVIII

ELONGATION MEASUREMENTS AT BREAKING LOAD ON NYLON YARNS

Approximate Twist Added (TPI)	Elongation (Per Cent) 20- 7-0.5Z Type 200 IP-2	30-10-0.5Z Type 200 IP-2	40-13-0.5Z Type 200 IP-2	70-34-0.5Z Type 100 IP-2
As-Received	24.4	25.5	29.2	24.2
7.0	23.5	24.7	24.5	24.6
13.1	24.3	25.6	24.8	25.1
22.7	23.9	25.7	26.5	26.6
35.3	23.4	26.3	26.0	30.4
46.7	24.1	25.6	26.4	31.5
70.0	22.9	26.6	27.8	35.9
100.2	21.2	32.6	33.2	—

	70-34-0.5Z Type 200		70-34-0.5Z Type 300		100-34-0.5Z Type 300		210-34-1.0Z Type 300		260-17-1.0Z Type 300	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	27.2	26.9	21.9	22.6	21.2	20.5	18.0	16.9	24.5	26.7
7.0	27.5	24.6	22.4	19.1	19.7	17.9	18.7	16.3	25.2	20.9
13.1	28.1	25.4	22.4	19.7	19.9	17.7	20.1	17.2	25.5	22.2
22.7	28.6	27.4	22.2	22.5	20.7	19.5	20.1	18.8	27.8	23.6
35.3	32.5	28.4	24.4	22.0	21.9	20.7	25.8	25.9	35.6	30.2
46.7	34.5	34.7	27.9	26.3	26.4	24.3	—	—	—	—
70.0	37.4	36.8	34.2	32.2	—	—	—	—	—	—
100.2	—	—	—	—	—	—	—	—	—	—

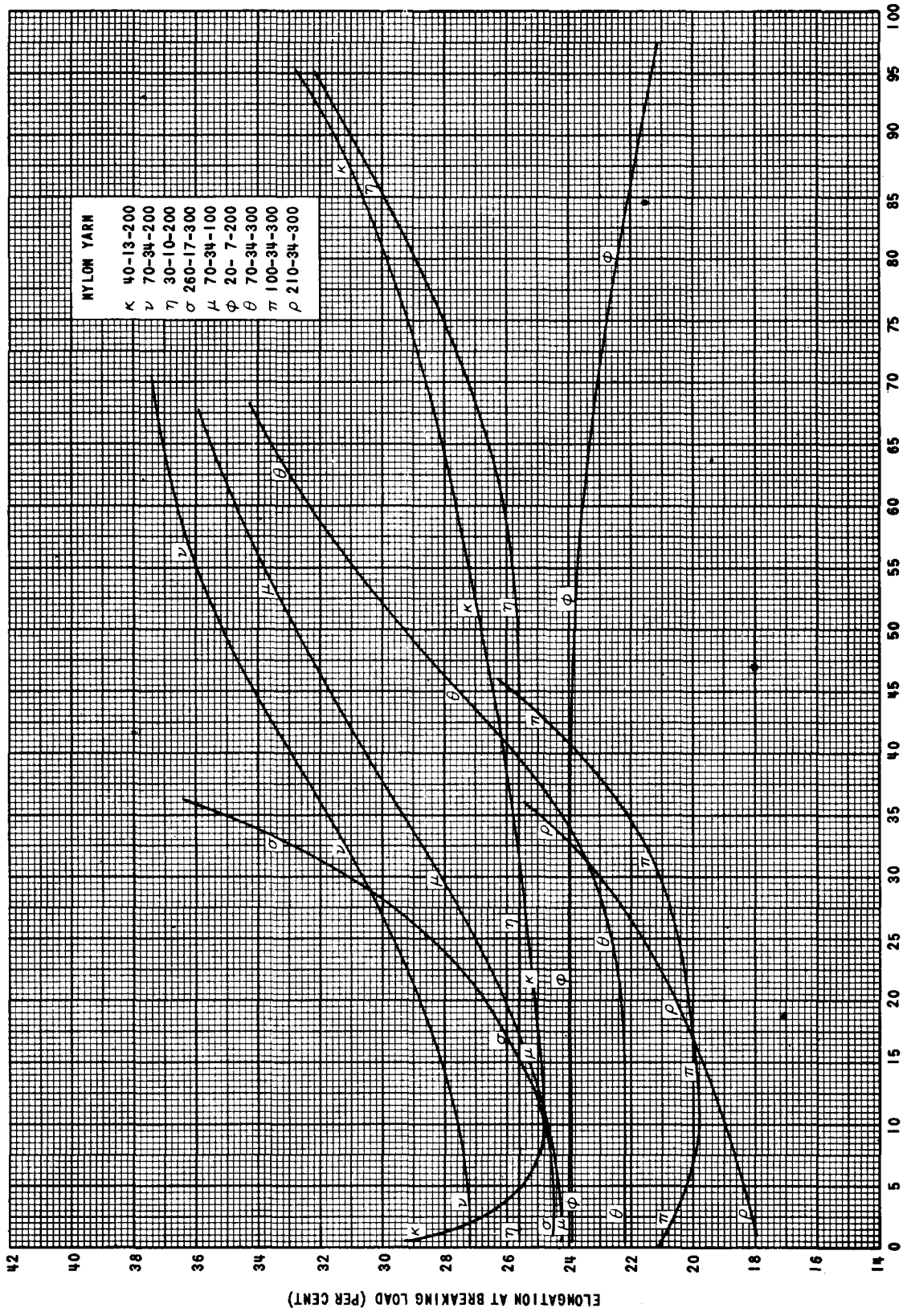


Figure 25. The Effect of Twist on the Elongation of Nylon Yarns (IP-2 Machine).

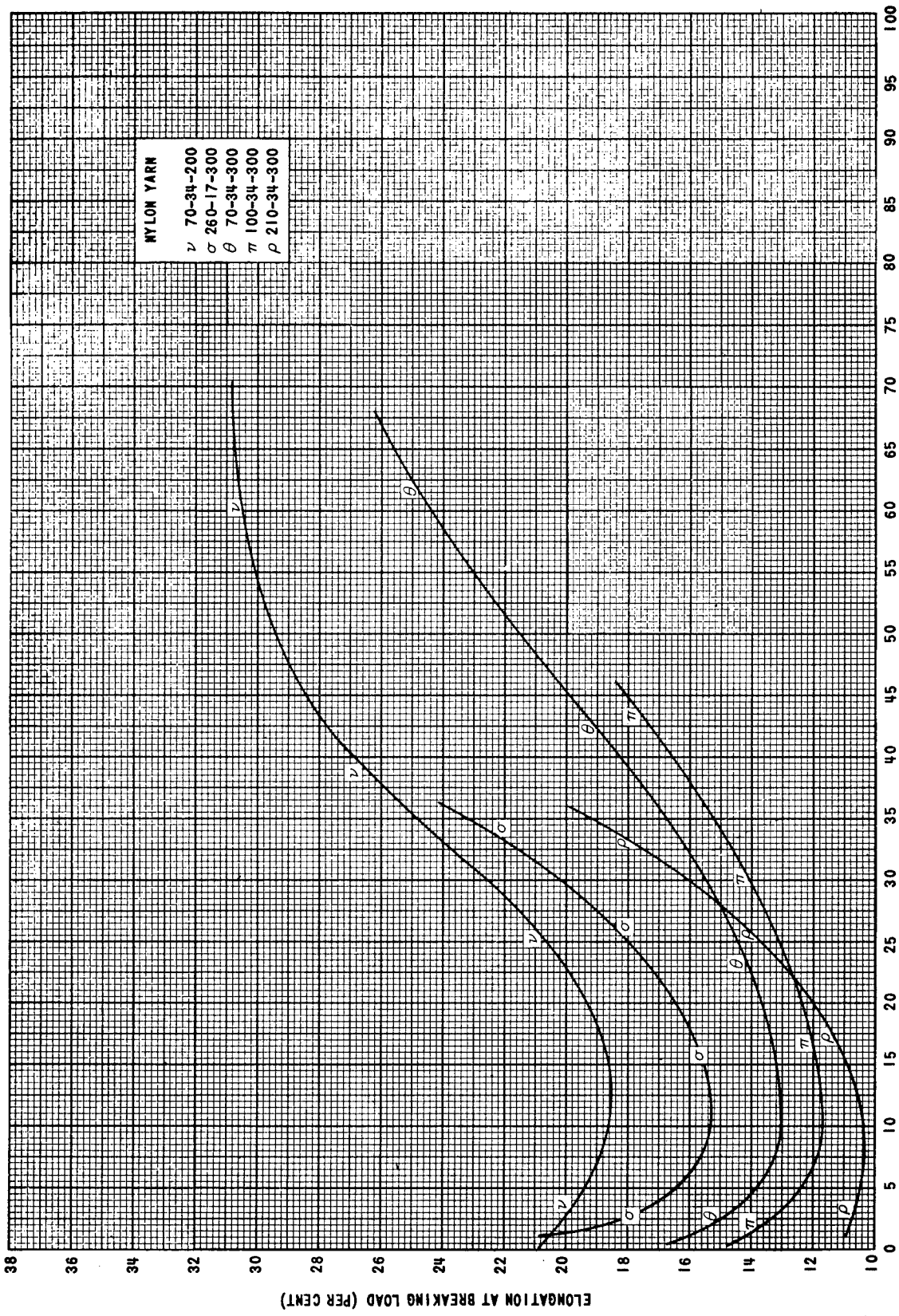


Figure 26. The Effect of Twist on the Elongation of Nylon Yarns (Suter Single Strand Tester).

An analysis of the elongation data indicates the following:

(1) The elongation of the lower denier yarns is affected the least by a given amount of added twist.

(2) In general, there is an increase in elongation of yarn with the addition of twist beyond 12 TPI.

5. Energy Absorption Values

Energy absorption values were calculated from the breaking strength and elongation data at breaking load and 85 per cent of breaking load for each yarn. Because of this, any errors in elongation values are manifested in energy absorption results. The data are given in Table XIX and Figures 27, 28, 29, and 30.

The data show that:

a. In general, added twist has very little effect on the energy absorbed by the low denier (20-40) yarns, until high twist is reached. This is indicated in values based on both the total break and 85 per cent measurements.

b. With the exception of the 100 denier yarn, the energy absorption at break of the higher denier yarns (70-260) increases up to a certain amount of twist, after which there is a decrease in energy absorption.

c. The energy absorption increases with increased twist in all yarns at 85 per cent break.

6. Elastic Recovery Values

Elastic recovery values which are presented in Table XX and Figure 31 were calculated from hysteresis curves.

TABLE XIX

ENERGY ABSORPTION VALUES FOR NYLON YARNS

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm.)									
	20- 7-0.5Z Type 200		30-10-0.5Z Type 200		40-13-0.5Z Type 200		70-34-0.5Z Type 100			
	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break		
As-Received	620.5	171.2	789.3	216.0	1215.0	391.1	1724.7	317.3		
7.0	597.7	150.0	776.0	184.6	971.5	285.1	1789.1	367.6		
13.1	619.7	151.6	805.0	208.1	998.2	287.5	1803.3	347.1		
22.7	615.8	168.9	804.2	199.5	1057.1	311.0	1900.7	384.8		
35.3	595.3	162.6	807.4	217.6	971.5	274.9	2191.3	520.0		
46.7	598.5	162.6	742.2	208.1	933.1	321.2	1982.0	620.5		
70.0	508.2	150.0	706.9	268.6	786.2	380.1	1859.8	860.0		
100.2	359.7	*	686.4	349.5	814.5	451.6	—	—		

	70-34-0.5Z Type 200		70-34-0.5Z Type 300		100-34-0.5Z Type 300		210-34-1.0Z Type 300		260-17-1.0Z Type 300	
	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break
As-Received	1968.8	389.6	1881.8	373.9	2585.5	556.1	4561.6	1218.9	7188.0	1702.7
7.0	2040.5	419.4	1960.4	383.3	2296.5	537.2	4750.1	1275.5	7307.4	1778.1
13.1	2111.2	505.8	1907.0	386.4	2305.9	527.8	5032.8	1451.4	6490.0	1885.0
22.7	2095.4	438.3	1803.3	436.7	2258.8	625.2	3952.0	1508.0	6409.0	2406.0
35.3	2351.5	728.9	1900.7	590.6	2104.9	879.6	4310.0	1972.9	6591.0	3286.0
46.7	2315.4	793.3	2070.3	794.8	2331.1	1083.9	—	—	—	—
70.0	1996.5	909.5	2095.4	1033.6	—	—	—	—	—	—
100.2	—	—	—	—	—	—	—	—	—	—

*Data Questionable

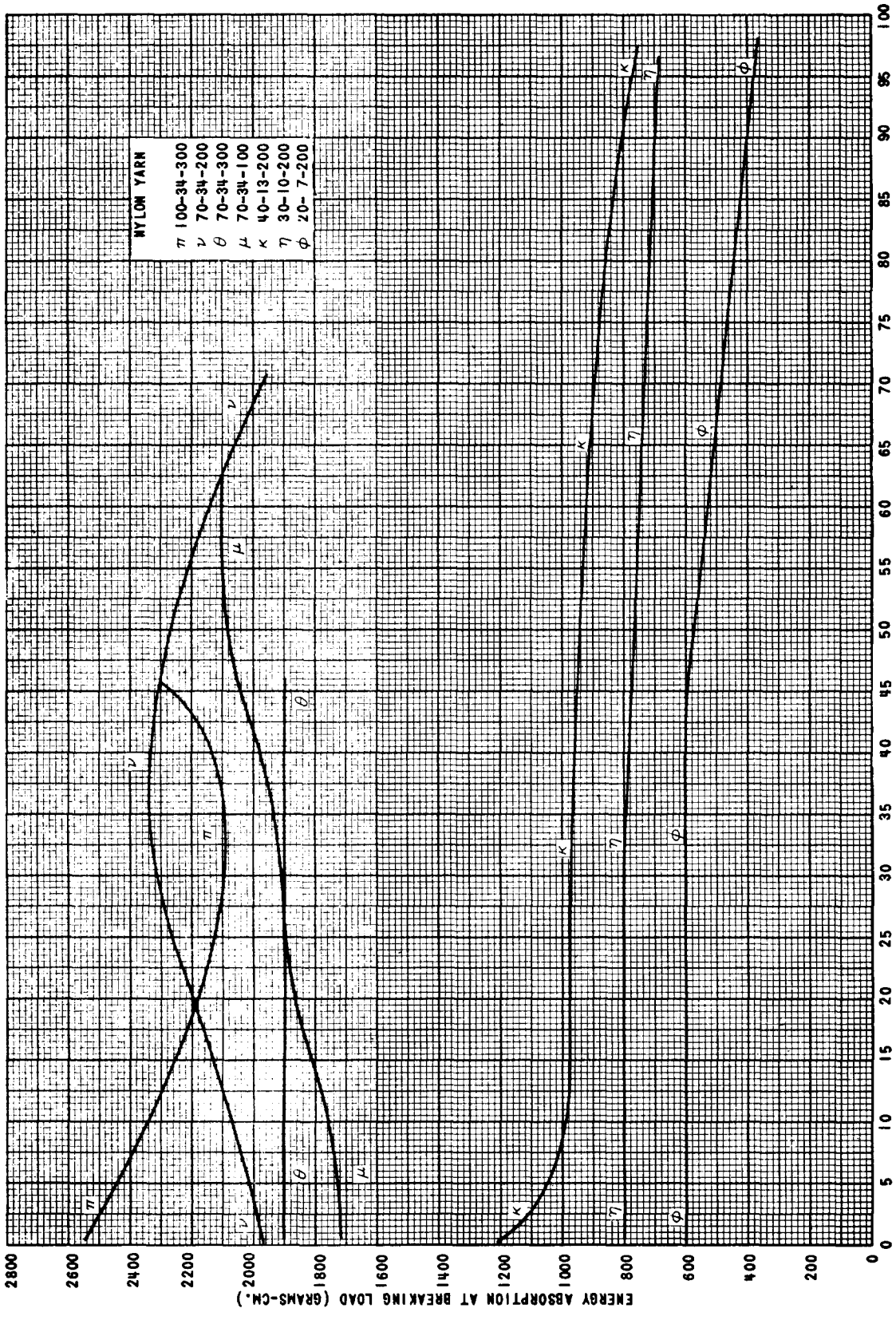


Figure 27. Energy Absorption Values at Breaking Load for Nylon Yarns.

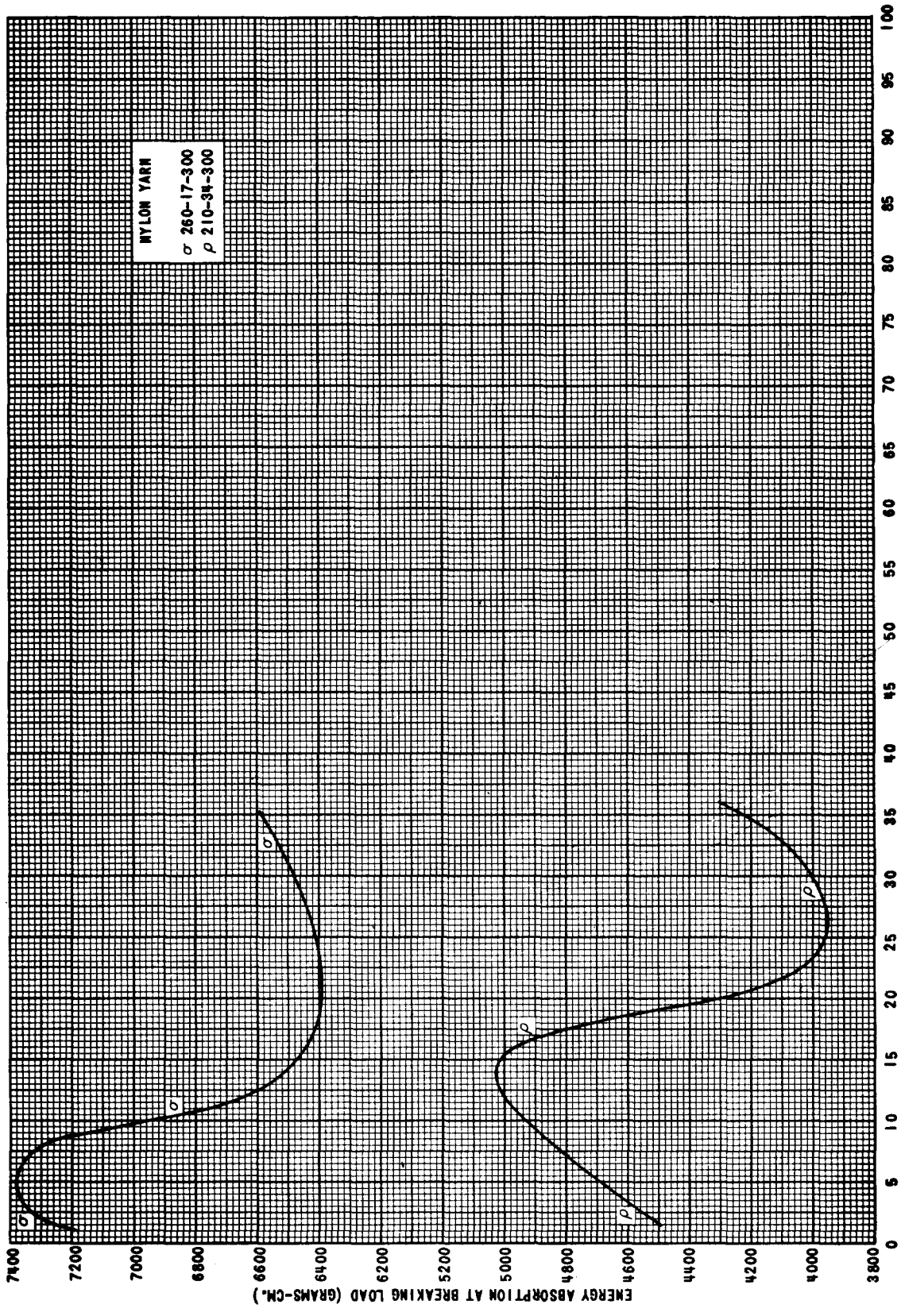


Figure 28. Energy Absorption Values at Breaking Load for Nylon Yarns.

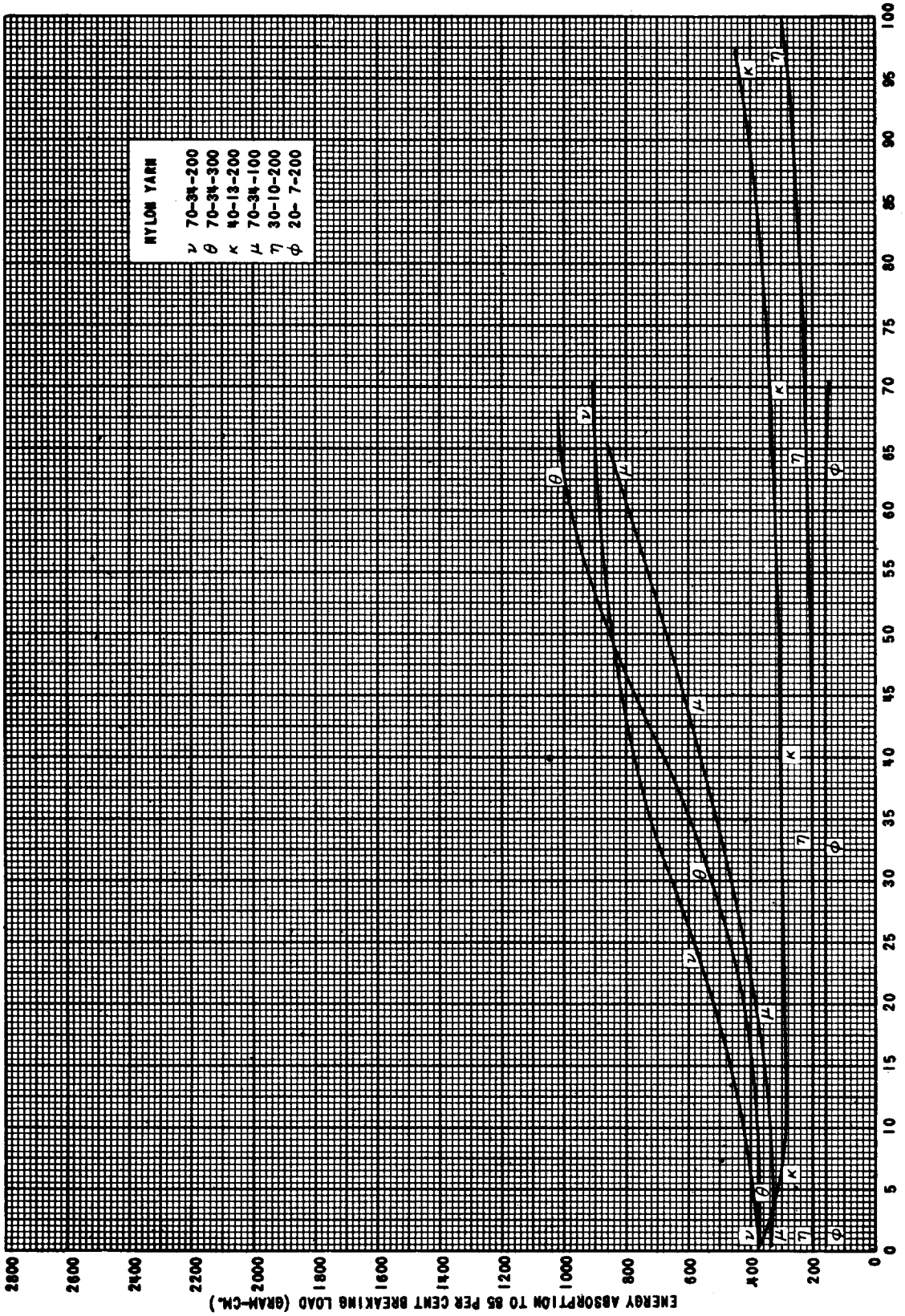


Figure 29. Energy Absorption Values at 85 Per Cent Breaking Load for Nylon Yarns.

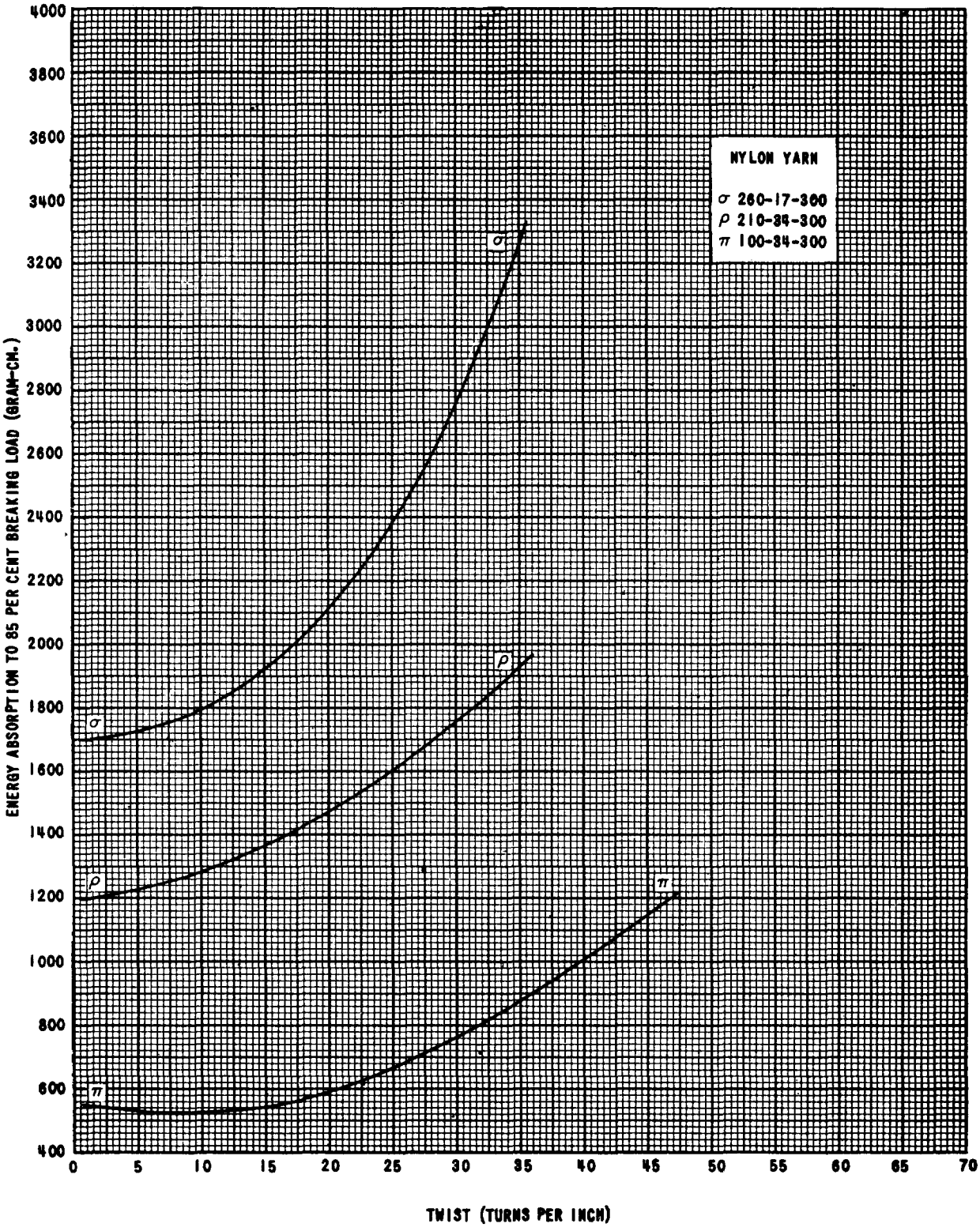


Figure 30. Energy Absorption Values at 85 Per Cent Breaking Load for Nylon Yarns.

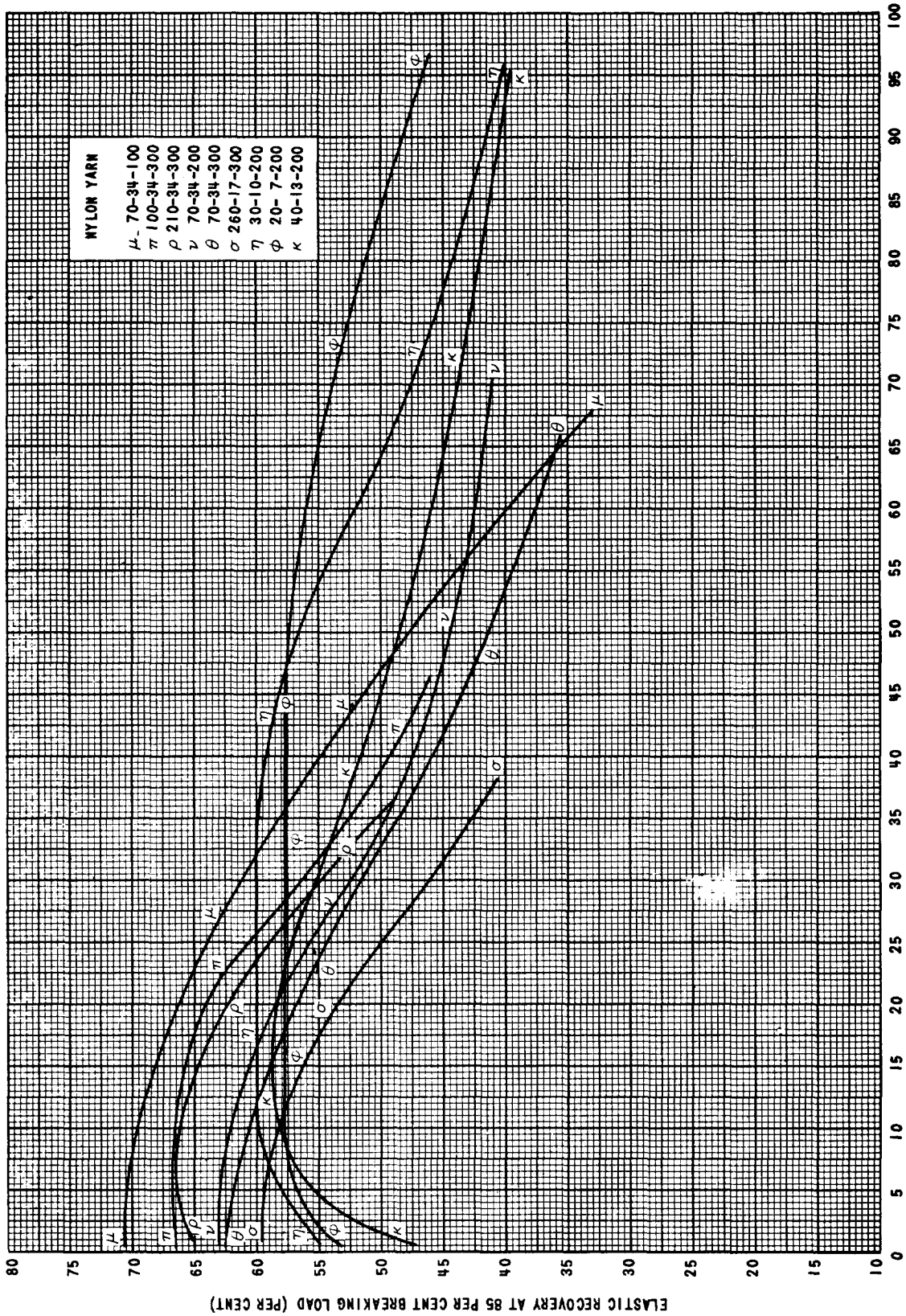


Figure 31. Elastic Recovery Values at 85 Per Cent Breaking Load for Nylon Yarns.

TABLE XX

ELASTIC RECOVERY VALUES AT 85 PER CENT
BREAKING LOAD FOR NYLON YARNS

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)			
	20- 7-0.5Z Type 200	30-10-0.5Z Type 200	40-13-0.5Z Type 200	70-34-0.5Z Type 100
As-Received	53.5	53.8	47.3	71.0
7.0	57.9	60.9	57.4	68.1
13.1	58.5	59.8	57.7	69.6
22.7	55.5	60.0	54.5	65.9
35.3	58.0	57.7	56.4	57.5
46.7	57.3	59.8	51.3	51.7
70.0	—	49.4	44.4	34.0
100.2	—	40.2	39.7	—

	70-34-0.5Z Type 200	70-34-0.5Z Type 300	100-34-0.5Z Type 300	210-34-1.0Z Type 300	260-17-1.0Z Type 300
As-Received	64.2	62.5	66.7	65.5	59.8
7.0	62.0	61.1	65.8	66.7	57.8
13.1	58.0	60.0	66.4	63.9	57.3
22.7	61.7	56.0	63.1	60.5	51.7
35.3	48.9	50.0	53.3	49.8	41.6
46.7	46.0	43.3	45.6	—	—
70.0	41.1	35.1	—	—	—
100.2	—	—	—	—	—

Examination of the data suggests the following conclusions:

a. Although the elastic recovery of low denier yarns appears to increase with the first increment of added twist, it definitely decreases for all yarns at higher twist, with the exception of the 20 denier.

b. The rate of decrease in elastic recovery is greater for the higher denier yarns.

7. Tenacity Values

Tenacities of the nylon yarns were calculated from the IP-2 breaking strength data and denier measurements. The results of the tenacity calculations are given in Table XXI and are presented graphically in Figure 32.

TABLE XXI

TENACITY VALUES FOR NYLON YARNS

Approximate Twist Added (TPI)	Tenacity (Grams/Denier)			
	20- 7-0.5Z Type 200	30-10-0.5Z Type 200	40-13-0.5Z Type 200	70-34-0.5Z Type 100
As-Received	6.73	5.59	5.62	5.62
7.0	6.84	5.60	5.54	5.78
13.1	6.80	5.63	5.57	5.71
22.7	6.80	5.58	5.53	5.58
35.3	6.68	5.48	5.19	5.42
46.7	6.53	4.97	4.96	5.06
70.0	6.11	4.77	4.31	4.12
100.2	5.02	4.13	3.53	—

	70-34-0.5Z Type 200	70-34-0.5Z Type 300	100-34-0.5Z Type 300	210-34-1.0Z Type 300	260-17-1.0Z Type 300
As-Received	5.79	7.04	7.31	8.05	6.49
7.0	5.96	7.14	7.37	8.09	6.32
13.1	6.02	7.06	7.22	7.90	6.06
22.7	5.74	6.84	7.00	6.81	5.28
35.3	6.04	6.57	6.20	5.62	4.25
46.7	5.81	6.40	5.73	—	—
70.0	5.24	5.10	—	—	—
100.2	—	—	—	—	—

From these values the following conclusions may be drawn.

a. The tenacities of all nylon yarns reach a maximum value at a relatively low twist and then decrease.

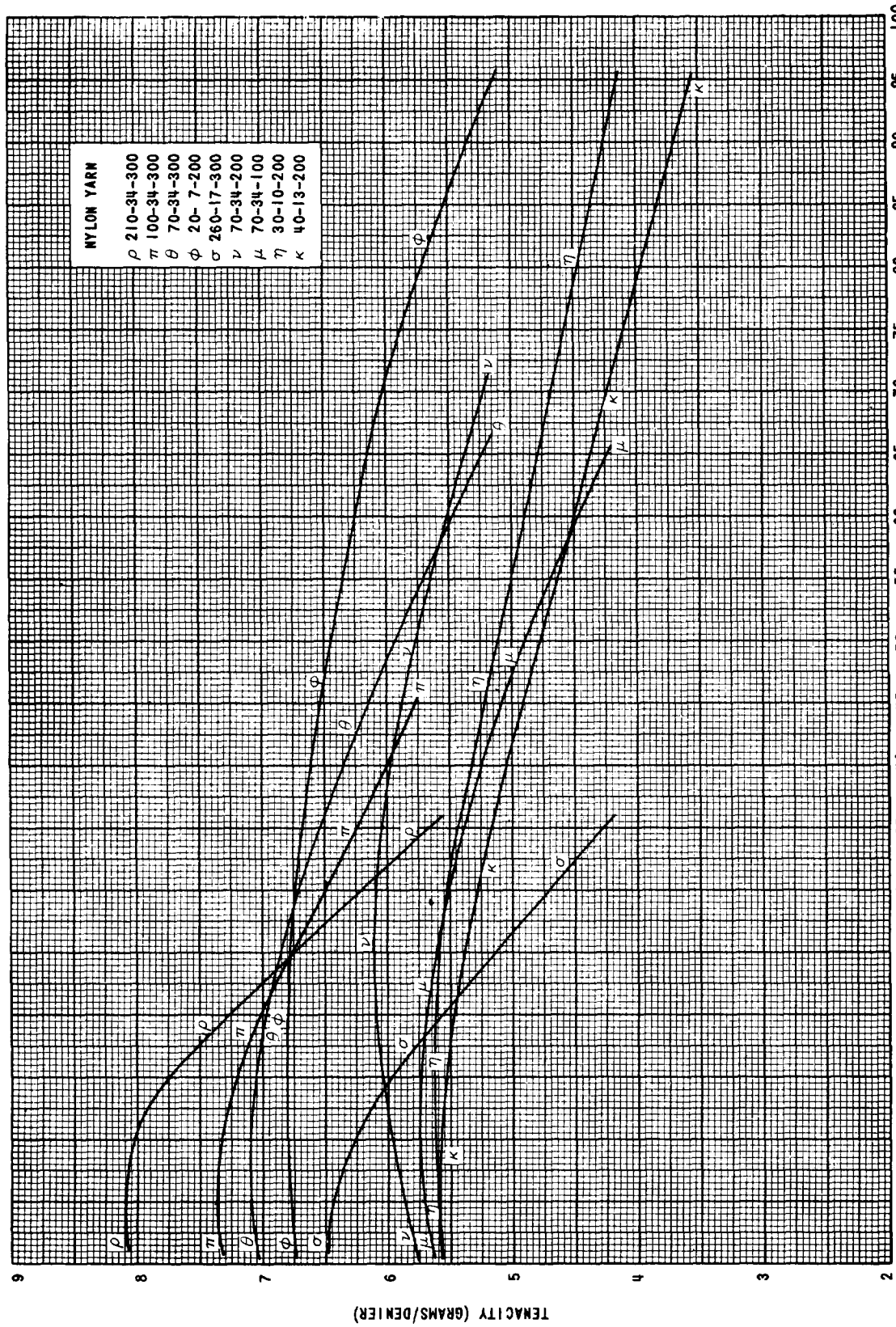


Figure 32. Tenacity Values for Nylon Yarns.

b. The maximum tenacity occurs at lower twist values for the higher denier yarns than it does for the lower denier yarns. The rate of decrease for added twist is greater for the higher denier yarns.

V. FIBER V YARNS

Studies of the effect of twist on yarn properties were made on three Fiber V filament yarns which were supplied by the E. I. duPont de Nemours & Co. Since Fiber V was being produced at the time of the research on an experimental basis only, a comparatively few yarns were available. These yarns are 40-34, 70-34, and 210-34 respectively. Neither the amount of twist nor the tenacity of the yarns as-received was specified by the manufacturer. Experimental data, however, showed the 40-34 and 70-34 denier yarns to be of normal tenacity and the 210-34 denier yarn to be of high tenacity. The yarns are, therefore, treated as such in the data analysis study.

A. Twisting

Twist was added to each of the Fiber V yarns until the yarns began to crepe. Creping occurred on the 70-34 yarn at twists above 49 TPI. Twists as high as 100 TPI, however, were added to the 40-34 yarn without the occurrence of creping. No shearing action took place on any of the yarns at high twists. The twists added to the respective Fiber V yarns follow in Table XXII. The percentage loss in the original breaking strength (as calculated from the IP-2 data) at the maximum added twist is also included.

TABLE XXII

TWISTING DATA FOR FIBER V YARNS

Yarn	Approximate Twist Added (TPI)	Per Cent Loss in Original Breaking Strength at Maximum Twist
40-34	7.0, 13.1, 22.7, 35.3, 46.7, 70.0, 100.2	16
70-34	7.0, 13.1, 22.7, 35.3, 46.7, 70.0	40
210-34	7.0, 13.1, 22.7, 35.3, 46.7	44

The desired 40 per cent loss in original breaking strength was obtained for all the yarns with the exception of the 40-34 yarn. Because of limitations of the twister, no more than 100 TPI could be added to the 40-34 yarn.

B. Presentation and Analysis of the Experimental Data

1. Twist Determinations

The twist measurements for each of the Fiber V yarns are given in Table XXIII.

TABLE XXIII

TWIST MEASUREMENTS ON FIBER V YARNS

Approximate Twist Added (TPI)	Measured Twist (TPI)		
	40-34	70-34	210-34
As-Received	1.0	0.9	1.4
7.0	7.8	8.1	8.4
13.1	13.3	13.5	14.5
22.7	23.1	23.0	23.8
35.3	35.0	34.6	36.5
46.7	45.7	45.2	47.8
70.0	67.5	67.4	—
100.2	97.9	—	—

2. Denier Determinations

Results of the denier measurements for the Fiber V yarns are given in Table XXIV and presented graphically in Figure 33.

TABLE XXIV

DENIER MEASUREMENTS ON FIBER V YARNS

Approximate Twist Added (TPI)	Denier		
	40-34	70-34	210-34*
As-Received	39.6	69.2	210.7
7.0	39.8	69.8	213.2
13.1	40.0	70.1	216.7
22.7	40.5	71.1	225.8
35.3	41.0	73.0	245.8
46.7	41.6	75.6	270.6
70.0	43.8	82.4	—
100.2	48.5	—	—

*High-tenacity yarn.

From the data obtained, the following conclusions were drawn:

a. For all the yarns, denier is an increasing function of the twist.

b. The larger the initial denier, the greater is the percentage increase in denier for a given increase in twist.

3. Diameter Determinations

The Fiber V yarn diameter measurements are presented in Table XXV, and graphs calculated from these data are given in Figure 34.

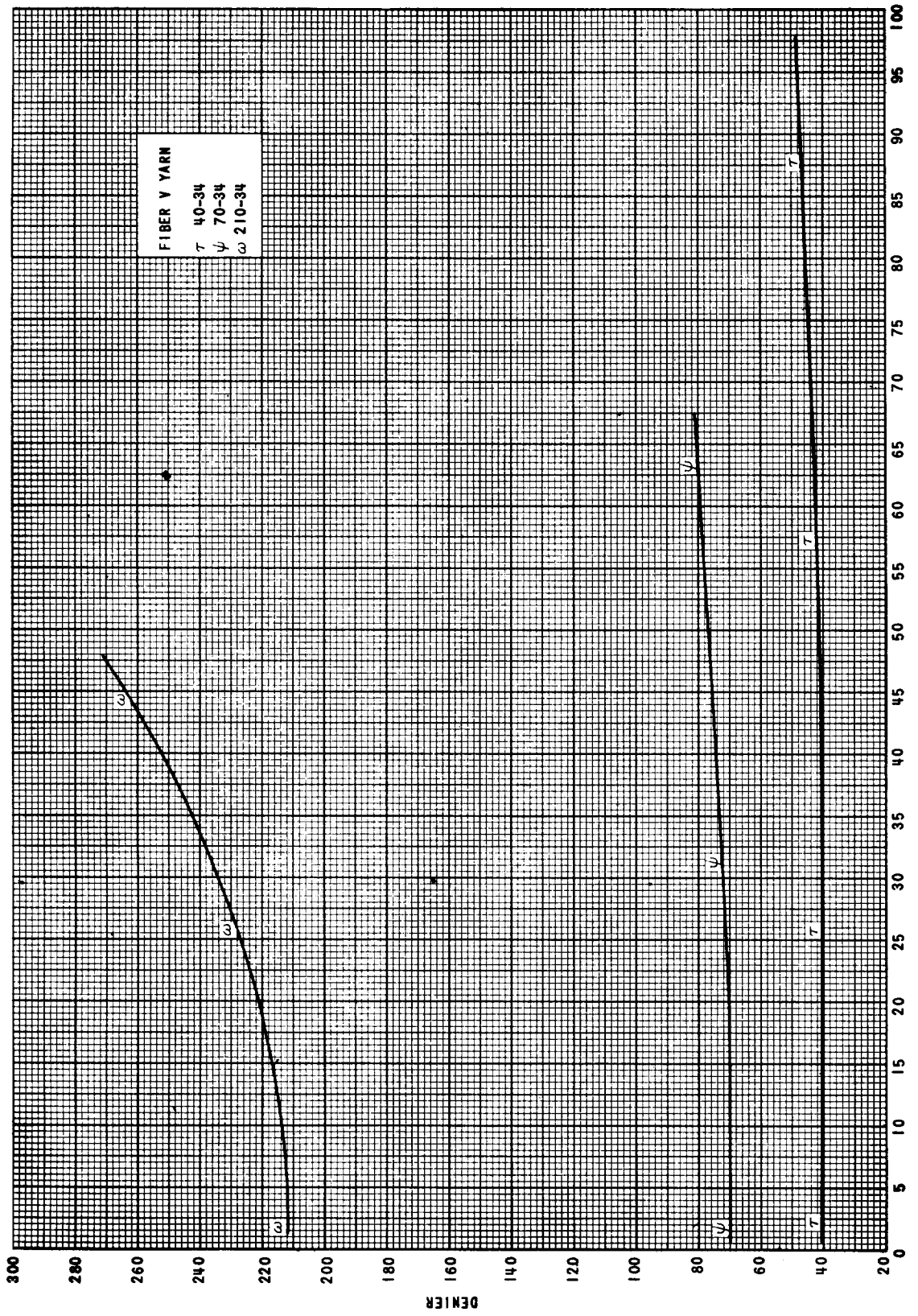


Figure 33. The Effect of Twist on the Denier of Fiber V Yarns.

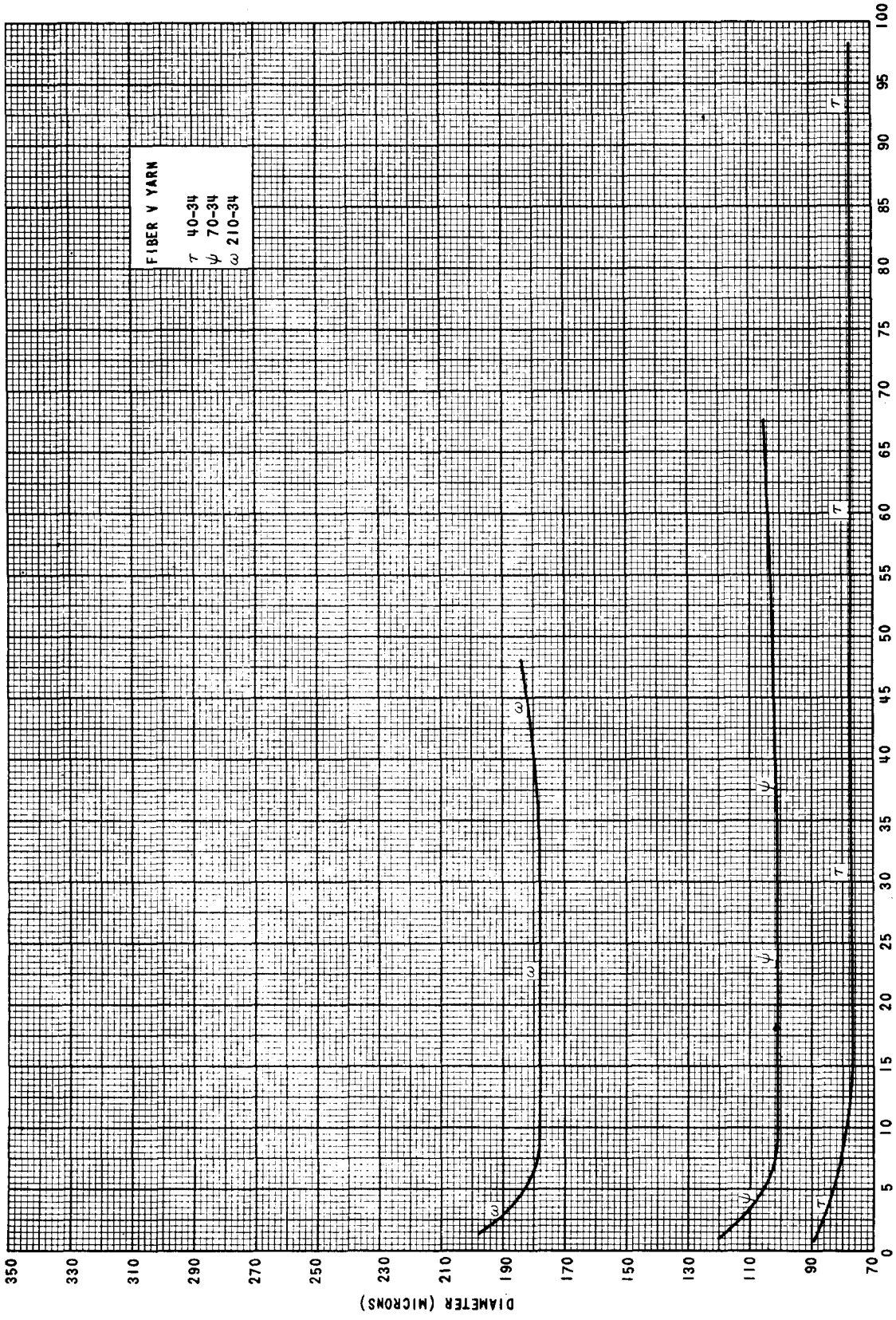


Figure 34. The Effect of Twist on the Diameter of Fiber V Yarns.

TABLE XXV

DIAMETER MEASUREMENTS ON FIBER V YARNS

Approximate Twist Added (TPI)	Diameter (Microns)		
	40-34	70-34	210-34*
As-Received	88.6	119.5	198.0
7.0	80.0	101.1	176.7
13.1	77.1	102.2	179.4
22.7	74.3	101.0	177.2
35.3	77.2	100.9	179.0
46.7	78.4	103.1	184.4
70.0	78.0	104.9	---
100.2	78.7	---	---

*High-tenacity yarn.

The data offer these conclusions:

a. For all yarns, the diameter decreases with small added twist, goes through a constant range, and then appears to increase at higher twists.

b. The length of the constant range is greater for lower denier yarns. The increase in diameter for the 40 denier does not appear in the twists covered.

4. Breaking Strength Determinations

Breaking strength determinations were made on both the Suter and IP-2 machines after a relaxation period of two weeks. The data obtained are given in Table XXVI and presented graphically in Figures 35 and 36.

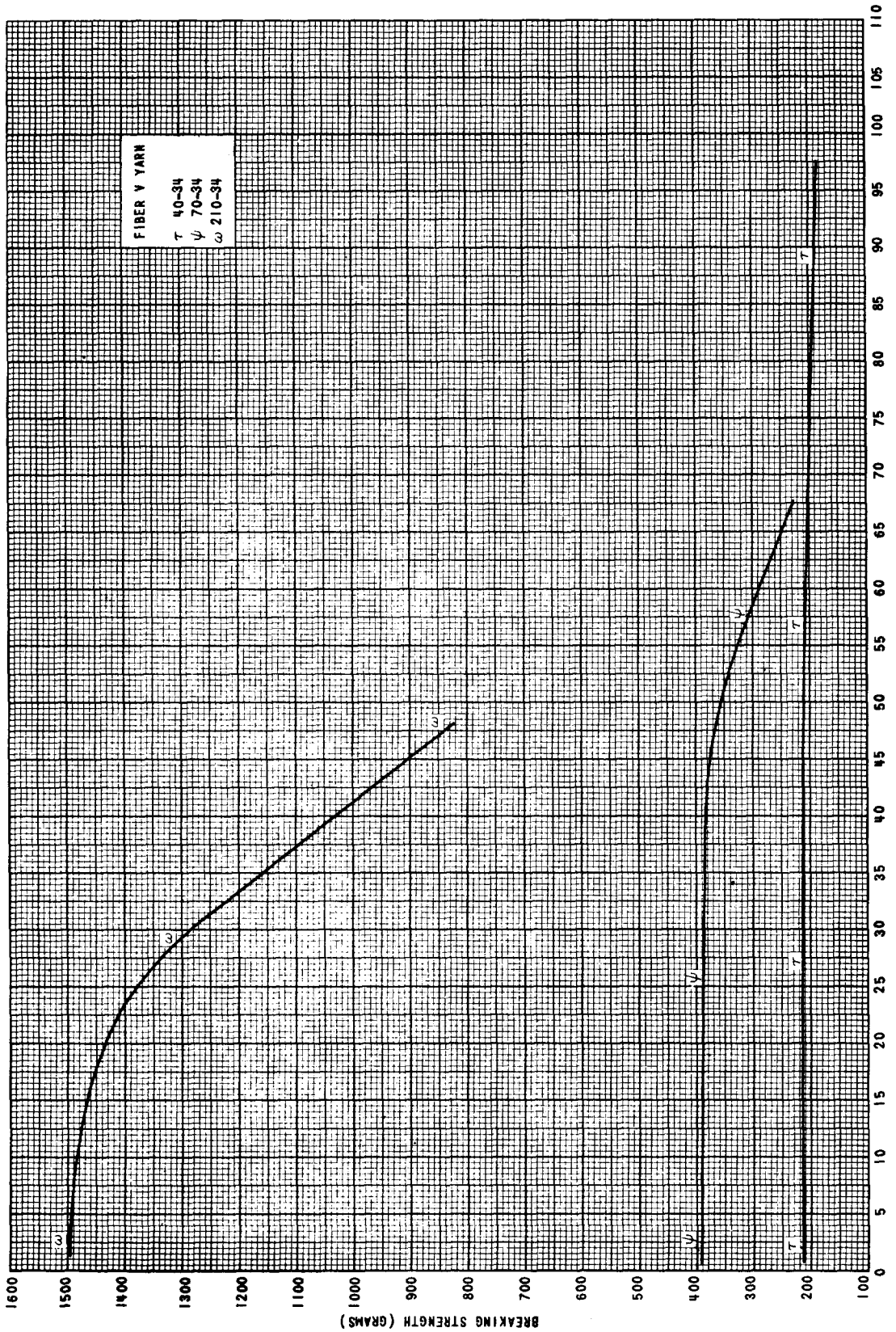


Figure 35. The Effect of Twist on the Breaking Strength of Fiber V Yarns (IP-2 Machine).

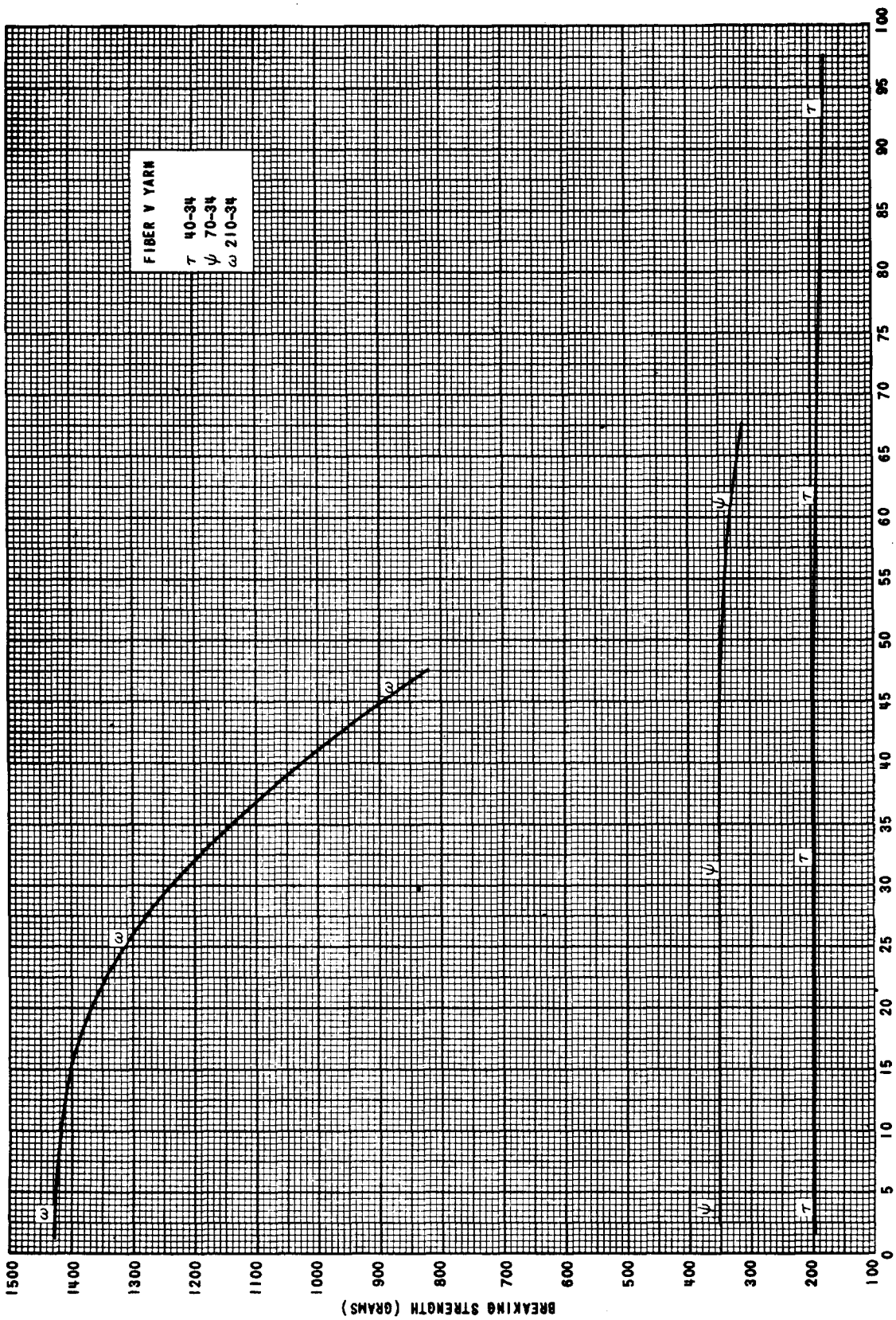


Figure 36. The Effect of Twist on the Breaking Strength of Fiber V Yarns (Suter Single Strand Tester).

TABLE XXVI

BREAKING STRENGTH MEASUREMENTS ON FIBER V YARNS

Approximate Twist Added (TPI)	Breaking Strength (Grams)					
	40-34		70-34		210-34*	
	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	217	198	390	346	1494	1413
7.0	211	192	389	354	1490	1428
13.1	211	192	392	355	1470	1411
22.7	218	197	388	356	1403	1337
35.3	219	199	384	344	1127	1103
46.7	213	197	376	344	834	818
70.0	198	188	228	314	—	—
100.2	182	171	—	—	—	—

*High-tenacity yarn.

The effects of twist on the breaking strength of the Fiber V yarns are as follows:

a. For all yarns, the breaking strength decreases with addition of twist, although the breaking strength of the 40 and 70 denier yarns are not affected appreciably until 45 TPI have been added.

b. The breaking strength of the 210-34 high-tenacity yarn begins to decrease immediately with the addition of twist, and the rate of decrease is greater than that of the other yarns.

5. Elongation Determinations

The elongation data and graphs about Fiber V are given in Table XXVII and Figures 37 and 38, respectively.

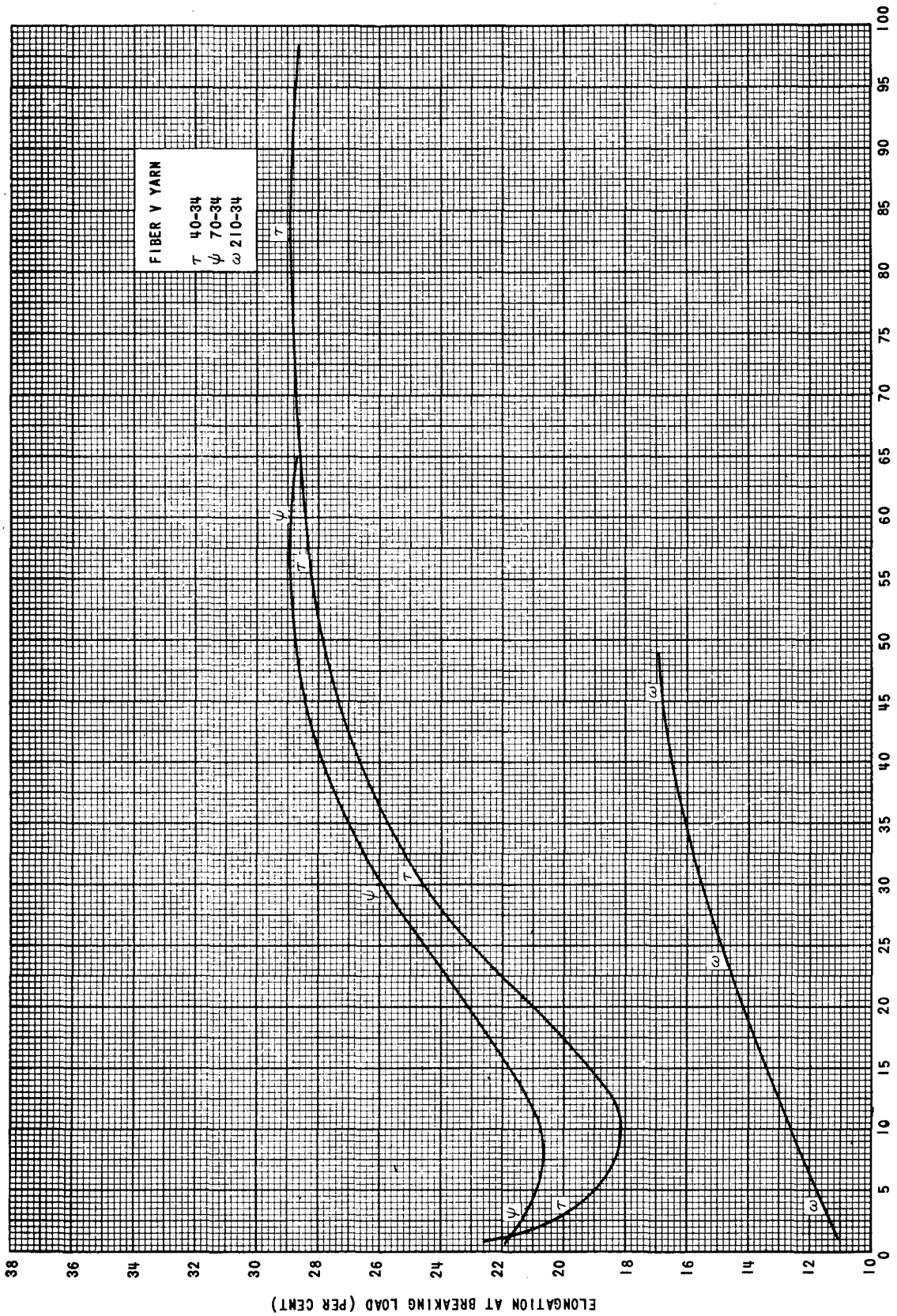


Figure 37. The Effect of Twist on the Elongation of Fiber V Yarns (IP-2 Machine).

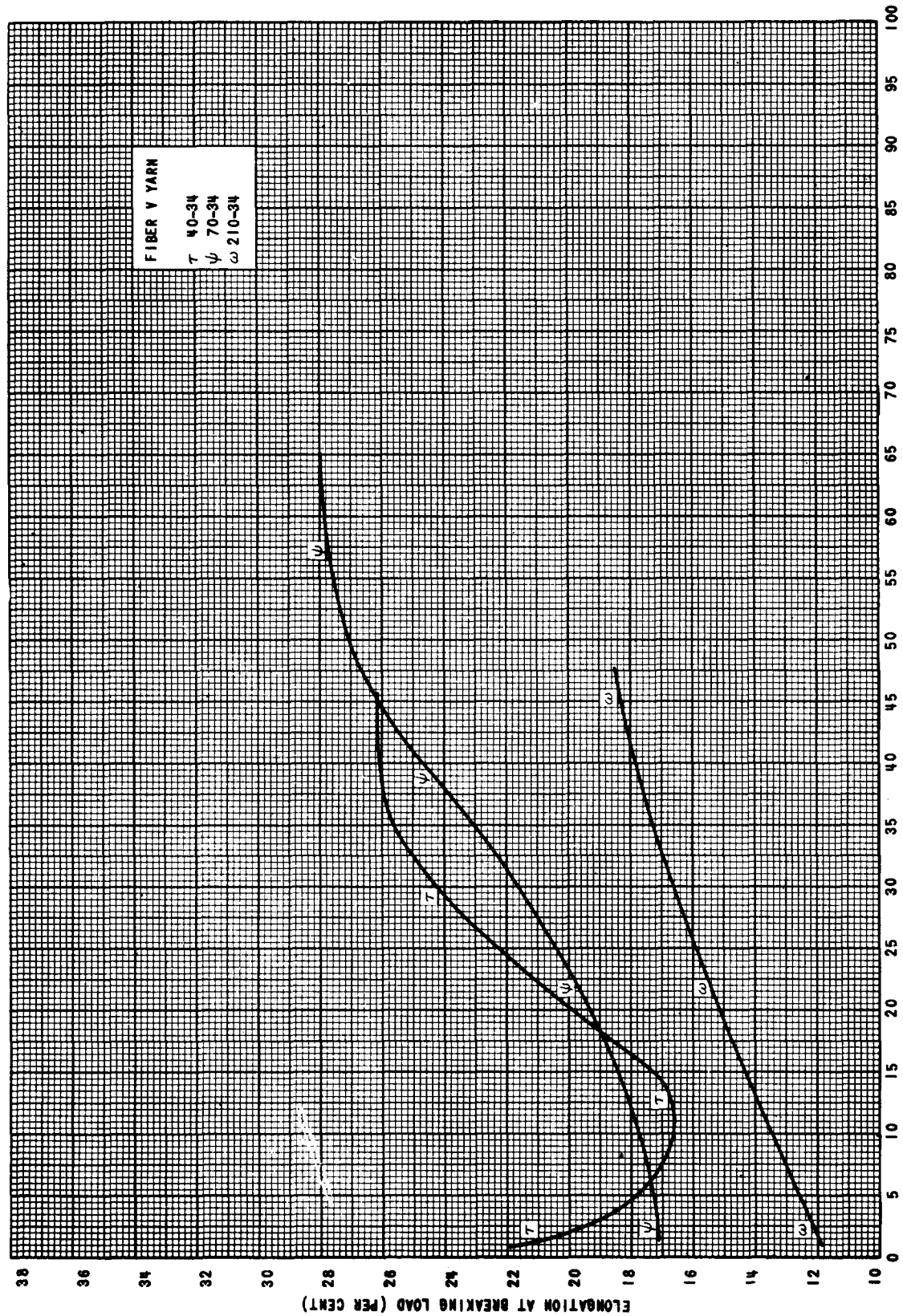


Figure 38. The Effect of Twist on the Elongation of Fiber V Yarns (Suter Single Strand Tester).

TABLE XXVII

ELONGATION MEASUREMENTS AT BREAKING LOAD
ON FIBER V YARNS

Approximate Twist Added (TPI)	Elongation (Per Cent)					
	40-34		70-34		210-34*	
	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	22.6	21.9	21.8	16.5	11.2	11.9
7.0	18.5	16.9	20.6	18.0	12.5	13.2
13.1	18.1	16.9	21.9	18.1	12.9	14.1
22.7	22.6	21.5	23.4	20.0	14.8	16.2
35.3	25.9	25.8	27.1	21.6	15.6	16.8
46.7	27.5	26.2	29.0	27.4	17.2	18.3
70.0	27.8	**	27.8	27.9	—	—
100.2	29.4	**	—	—	—	—

*High-tenacity yarn.
**Suter elongation data not considered valid at this twist

The following conclusions were drawn from a study of the elongation curves:

a. At all twists, the elongation of the high-tenacity 210 denier yarn is considerably lower than that of the normal-tenacity 40 and 70 denier yarns.

b. The elongation of the yarns increases rapidly as twists above 10 TPI are added. The increase continues to a twist of 40-50 TPI. Additional twist has little effect on elongation.

6. Energy Absorption Values

The amount of energy absorbed by the Fiber V yarns at break and at 85 per cent of the breaking load was calculated from stress-strain curves at break and from hysteresis curves at 85 per cent of

breaking load. The data are presented in Table XXVIII and given graphically in Figures 39 and 40.

TABLE XXVIII

ENERGY ABSORPTION VALUES
FOR FIBER V YARNS

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm.)					
	40-34		70-34		210-34*	
	Break	85% Break	Break	85% Break	Break	85% Break
As-Received	997.5	272.5	1709.0	554.5	2871.4	804.2
7.0	766.6	210.5	1584.9	454.0	3204.4	823.1
13.1	757.1	187.7	1704.3	603.2	3110.2	854.4
22.7	988.8	279.6	1781.3	540.4	3217.0	1237.8
35.3	1141.2	394.3	2004.3	678.6	2437.9	1294.3
46.7	1166.3	396.6	2016.9	881.2	1910.1	1200.1
70.0	972.3	418.6	911.1	270.2	—	—
100.2	887.5	482.2	—	—	—	—

*High-tenacity yarn.

The following general conclusions were reached in regard to the effect of twist on energy absorption properties of Fiber V:

a. The maximum in energy absorption at breaking load is attained in the range 10-20 TPI of added twist for the 210 denier yarns; however, it is about 40 TPI for both the 70 and 40 denier yarns.

b. The rate of decrease in energy absorption is greatest for the 210 denier high-tenacity yarn and least for the 40 denier yarn.

7. Elastic Recovery Values

The elastic recovery values calculated from yarns when stressed

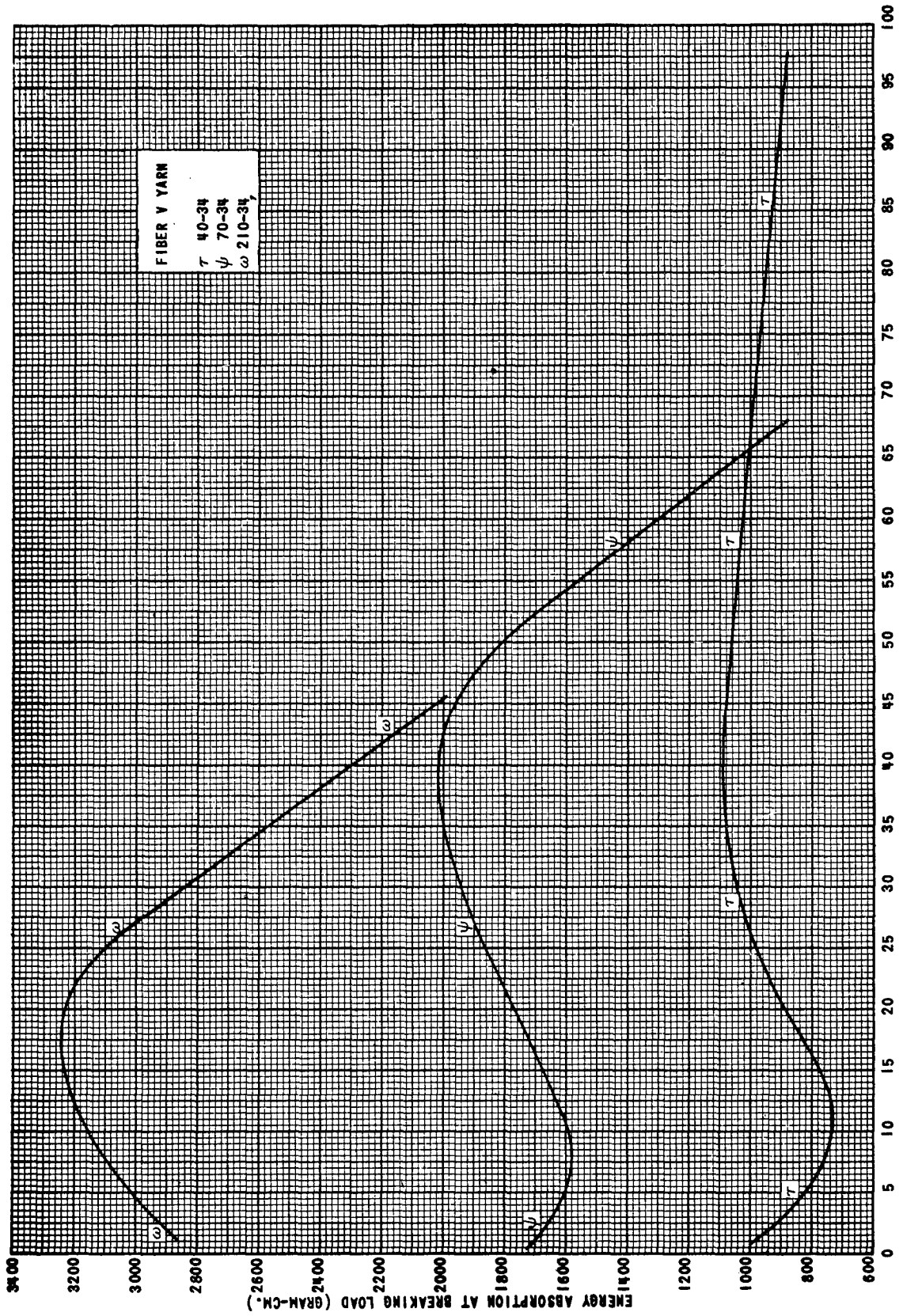


Figure 39. Energy Absorption Values at Breaking Load for Fiber V Yarns.

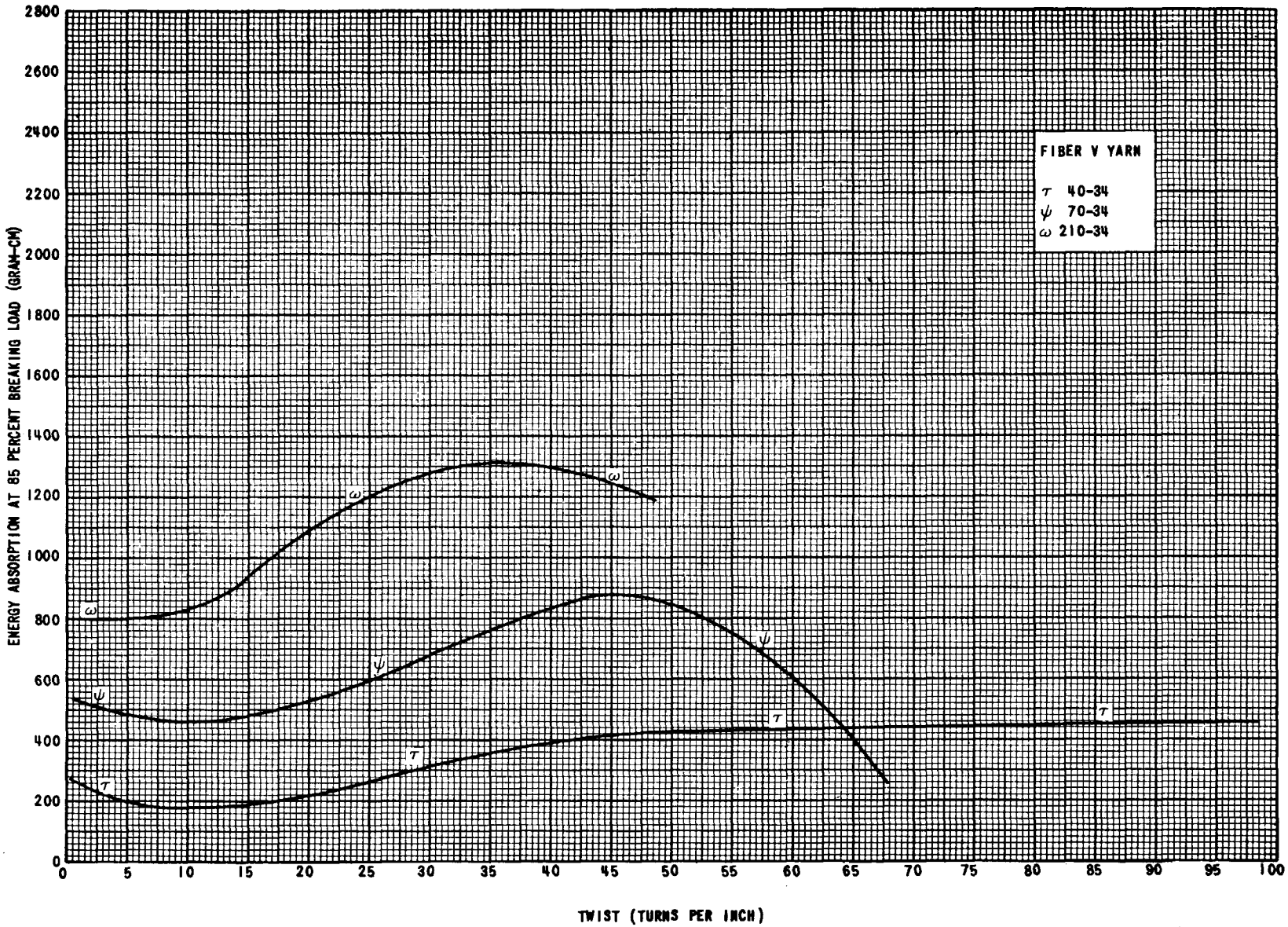


Figure 40. Energy Absorptions Values at 85 Per Cent Breaking Load for Fiber V Yarns.

to 85 per cent of the breaking load are given in Table XXIX and are presented graphically in Figure 41.

TABLE XXIX

ELASTIC RECOVERY VALUES AT 85 PER CENT BREAKING LOAD FOR FIBER V YARNS

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)		
	40-34	70-34	210-34*
As-Received	40.7	40.0	63.2
7.0	48.7	43.5	62.9
13.1	54.1	36.4	61.5
22.7	42.6	38.1	50.5
35.3	33.9	33.3	41.7
46.7	33.3	27.1	34.4
70.0	30.8	—	—
100.2	27.1	—	—

*High-tenacity yarn.

The data reveal these conclusions:

a. The maximum elastic recovery for all yarns is attained at twists below. 15 TPI.

b. The high-tenacity 210 denier yarn has the greatest elastic recovery.

8. Tenacity Values

Tenacity results are given in Table XXX and are presented graphically in Figure 42.

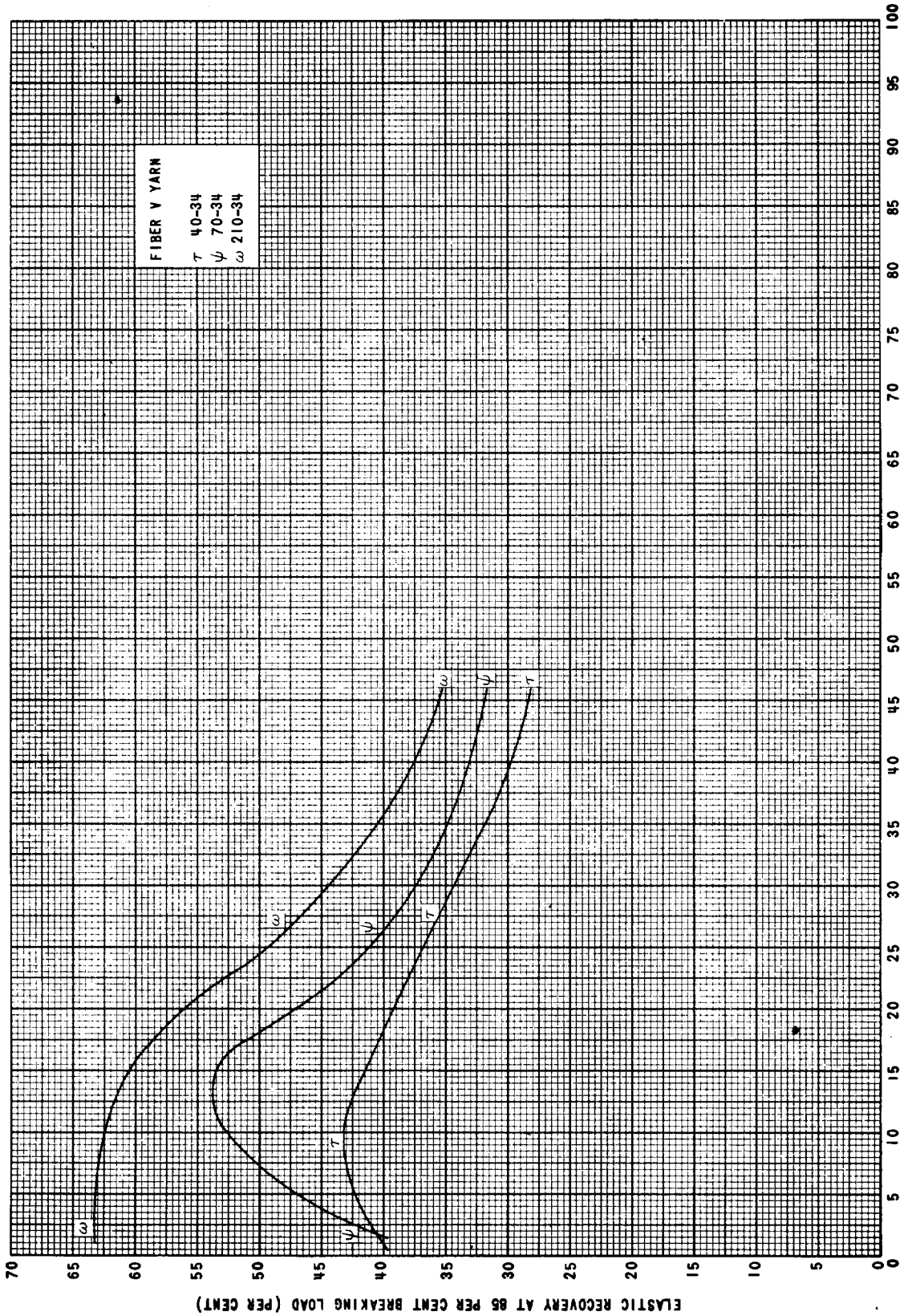


Figure 41. Elastic Recovery Values at 85 Per Cent Breaking Load for Fiber V Yarns.

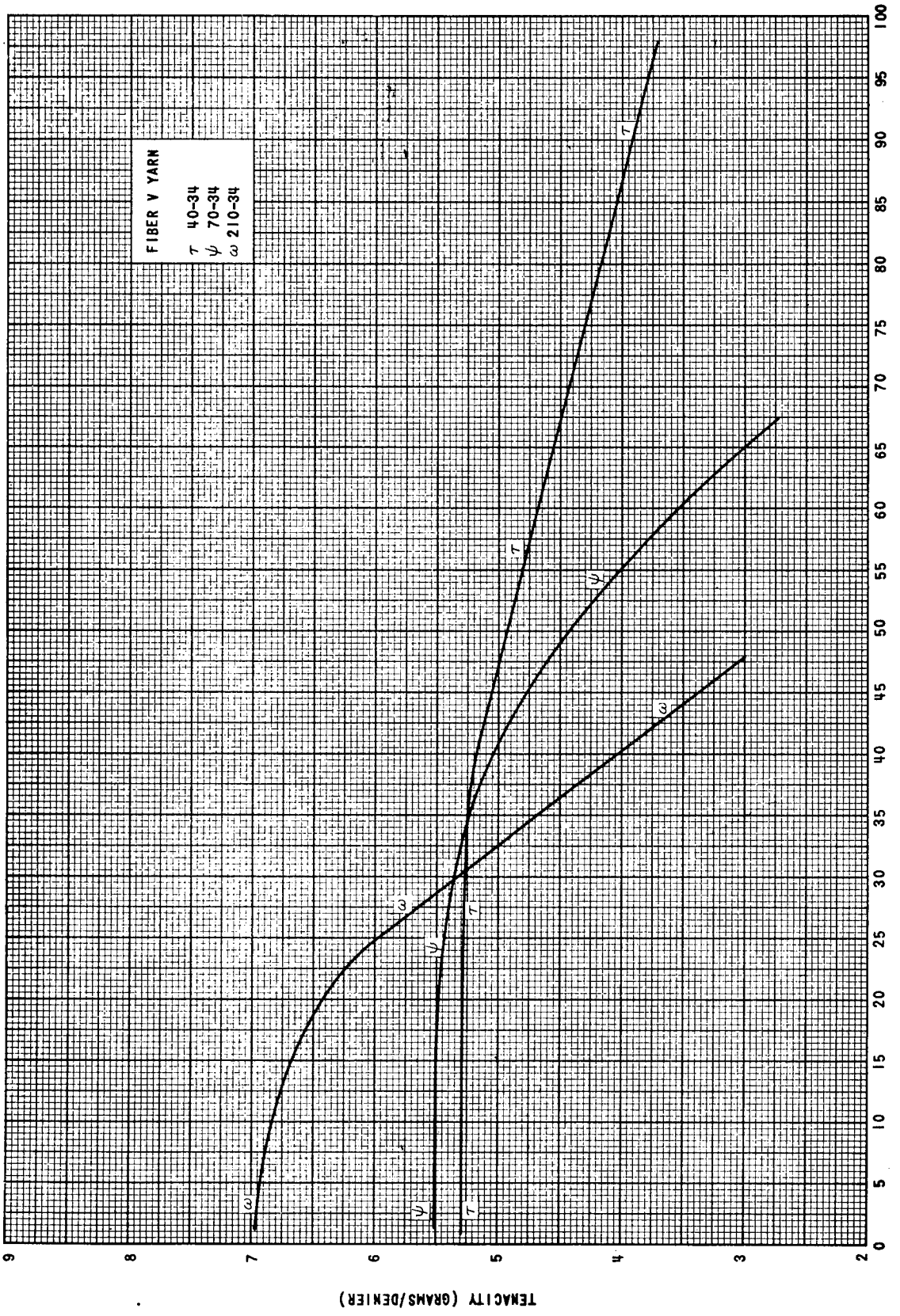


Figure 42. Tenacity Values for Fiber V Yarns.

TABLE XXX

TENACITY VALUES FOR FIBER V YARNS

Approximate Twist Added (TPI)	Tenacity (Grams/Denier)		
	40-34	70-34	210-34*
As-Received	5.40	5.56	6.99
7.0	5.24	5.48	6.89
13.1	5.21	5.51	6.69
22.7	5.30	5.38	6.13
35.3	5.26	5.19	4.52
46.7	5.06	4.91	3.04
70.0	4.46	2.73	—
100.2	3.70	—	—

*High-tenacity yarn.

The data offer the following conclusions:

a. The tenacities of all the yarns decrease with twists above 25 TPI.

b. The higher the denier of the yarn, the lower is the twist at which the decrease begins, and the greater is the rate of decrease.

c. The 210 denier yarn has a much greater initial tenacity than the 70 and 40 denier yarns.

VI. ORLON YARNS

The final phase of the experimental program was a study of the effect of twist on the properties of Orlon yarn. As in the case of Fiber V, the Orlon tested was produced on an experimental basis, and, as a result, only a limited number of yarns was available. The Orlon yarns were supplied by E. I. duPont de Nemours & Co., Inc., and are 75-30-0.3Z, 100-40-0.3Z, 200-80-0.3Z, and 400-160-0.3Z. Tenacities for the respective Orlon yarns were not specified by the manufacturer. However, calculations from the experimental data indicate that all the yarns were of normal tenacity, and they are treated as such in the analysis of the experimental results.

A. Twisting

Twists were added to the Orlon yarns as recorded in Table XXXI.

TABLE XXXI

TWISTING DATA FOR ORLON YARNS

Yarn	Approximate Twist Added (TPI)	Per Cent Loss in Original Breaking Strength at Maximum Twist
75-30-0.3Z	7.0, 13.1, 22.7, 35.3, 46.7, 70.0	58
100-40-0.3Z	7.0, 13.1, 22.7, 35.3, 46.7	38
200-80-0.3Z	7.0, 13.1, 22.7, 35.3,	44
400-160-0.3Z	7.0, 13.1, 22.7	37

In each case, twists higher than the maximum value given produced creping. The percentage loss in original breaking strength (as calculated from the

IP-2 data) at the maximum added twist is included.

After they were twisted, the yarns were allowed to relax on the twister spools for approximately two weeks before they were tested.

B. Results and Analysis of Experimental Data

1. Twist Determinations

Results of the twist measurements of Orlor yarns are presented in Table XXXII.

TABLE XXXII

TWIST MEASUREMENTS ON ORLON YARNS

Approximate Twist Added (TPI)	Measured Twist (TPI)			
	75-30-0.3Z	100-40-0.3Z	200-80-0.3Z	400-160-0.3Z
As-Received	0.2	0.3	0.3	0.3
7.0	7.5	7.1	7.5	7.5
13.1	12.9	13.2	13.6	13.5
22.7	22.4	22.4	23.1	23.0
35.3	34.1	34.7	35.2	—
46.7	45.1	46.3	—	—
70.0	68.5	—	—	—

The measured twist of the as-received samples agreed with the twist specified by the manufacturer. Other measured twist values were in good agreement with calculated values.

2. Denier Determinations

The Orlon denier measurements are given in Table XXXIII and are presented graphically in Figure 43.

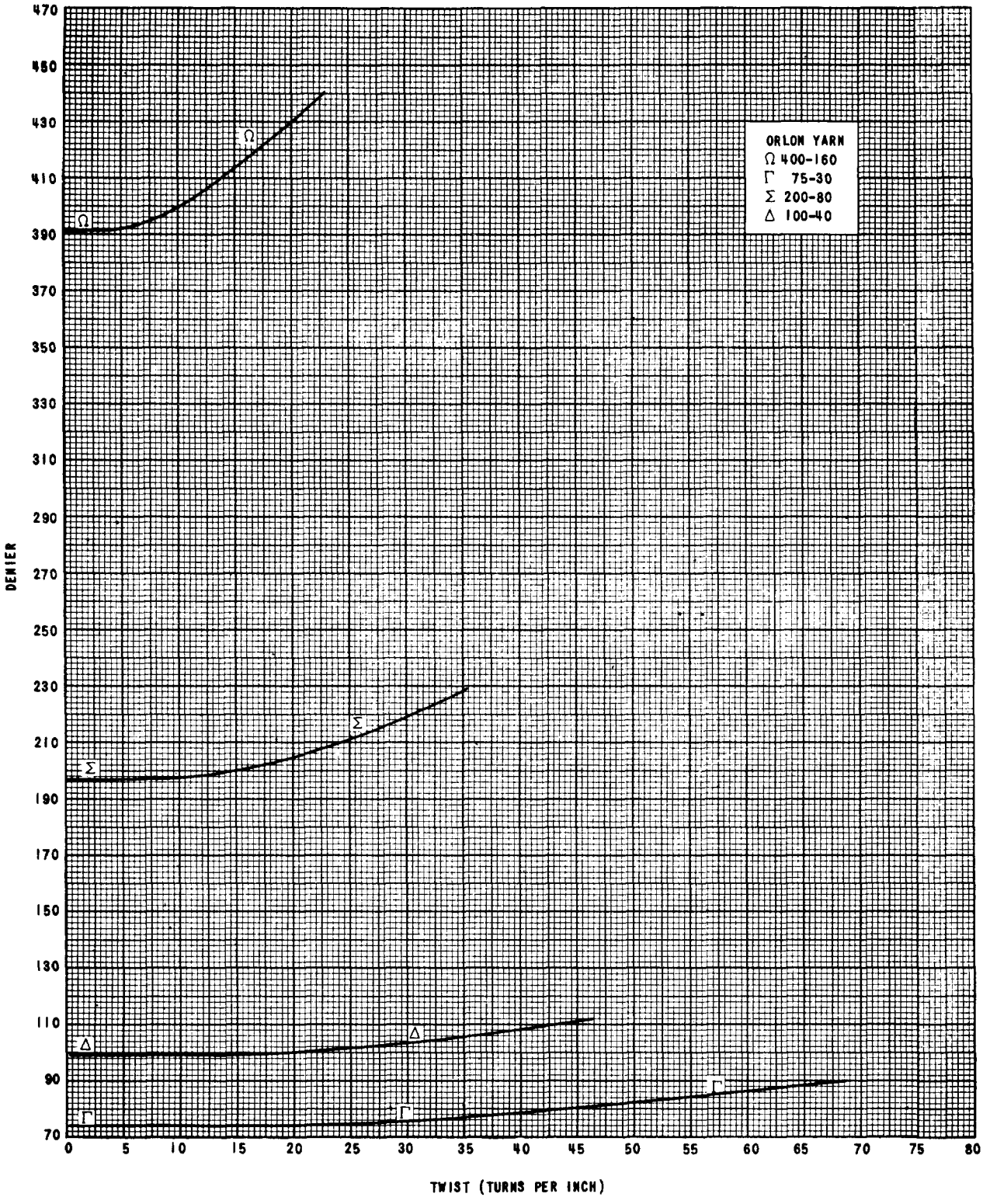


Figure 43. The Effect of Twist on the Denier of Orlon Yarns.

TABLE XXXIII

DENIER MEASUREMENTS ON ORLON YARNS

Approximate Twist Added (TPI)	Denier			
	75-30-0.3Z	100-40-0.3Z	200-80-0.3Z	400-160-0.3Z
As-Received	74.2	98.9	196.6	391.7
7.0	73.7	98.6	196.5	393.5
13.1	73.8	99.2	198.9	409.6
22.7	75.2	101.3	207.9	439.9
35.3	78.1	105.9	227.6	—
46.7	80.9	111.6	—	—
70.0	89.5	—	—	—

The effect of twist on the denier of the Orlon yarns tested is as follows:

a. For all the yarns, the denier is an increasing function of the twist.

b. The larger the initial denier size of the yarn, the lower is the twist at which the denier increases, and the greater is the rate of increase in denier.

3. Diameter Determinations

The diameter determinations of the Orlon yarns are given in Table XXXIV and are presented graphically in Figure 44.

TABLE XXXIV

DIAMETER MEASUREMENTS ON ORLON YARNS

Approximate Twist Added (TPI)	Diameter (Microns)			
	75-30-0.3Z	100-40-0.3Z	200-80-0.3Z	400-160-0.3Z
As Received	166.4	192.7	287.9	419.3
7.0	112.2	142.0	195.2	281.2
13.1	112.9	131.7	192.7	277.4
22.7	108.1	134.3	195.0	284.9
35.3	114.3	139.0	198.4	—
46.7	116.4	138.3	—	—
70.0	118.3	—	—	—

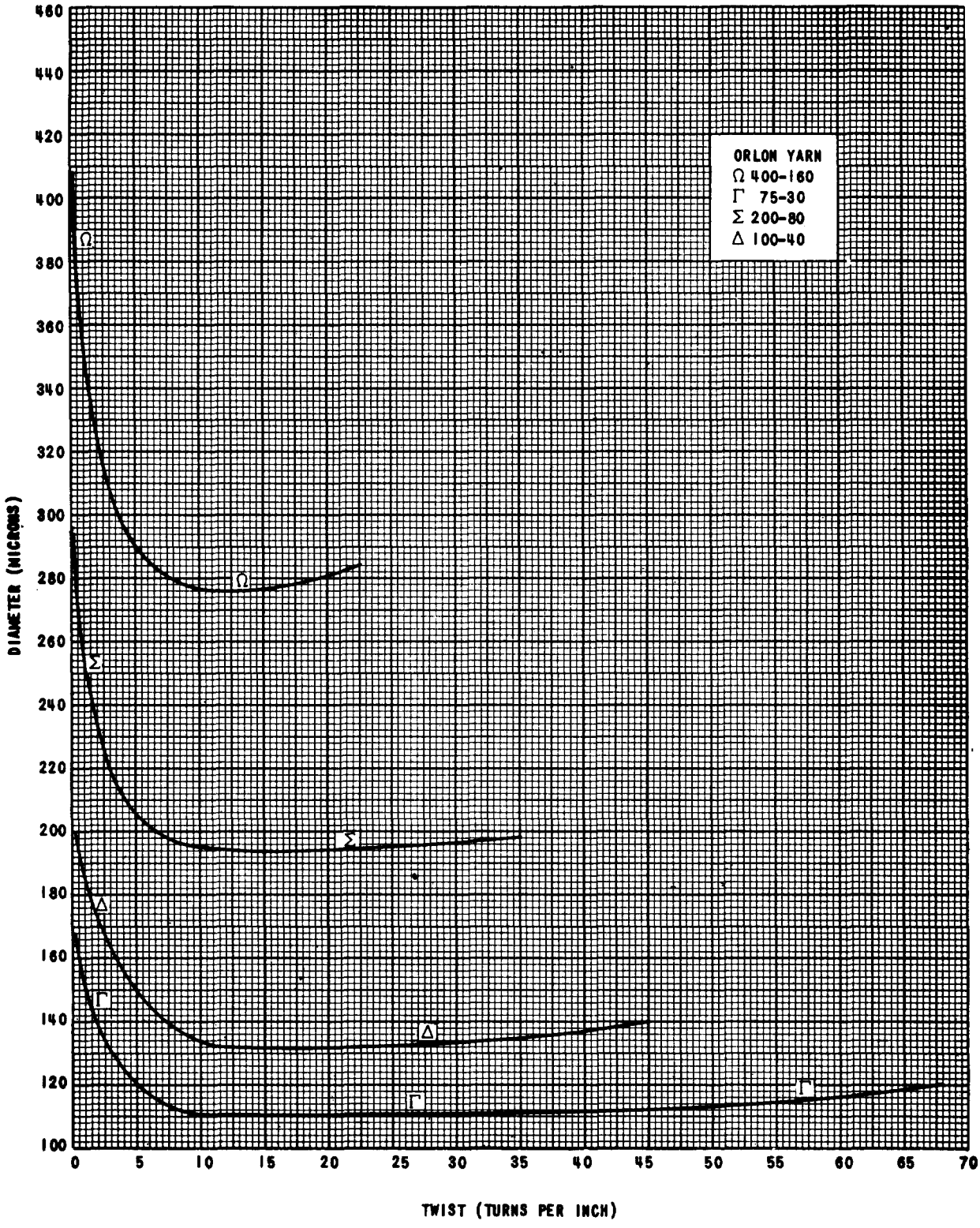


Figure 44. The Effect of Twist on the Diameter of Orlon Yarns.

The data show that:

a. For all the yarns there is a decided decrease in diameter with added twists up to 8-10 TPI.

b. At twists above the 8-10 TPI range, the diameter increases slowly, with the higher denier yarns having a greater rate of increase.

4. Breaking Strength Determinations

Breaking strength data obtained from IP-2 and Suter tests are given in Table XXXV and presented graphically in Figures 45 and 46.

TABLE XXXV

BREAKING STRENGTH MEASUREMENTS ON ORLON YARNS

Approximate Twist Added (TPI)	Breaking Strength (Grams)							
	75-30-0.3Z		100-40-0.3Z		200-80-0.3Z		400-160-0.3Z	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	353*	330	495	447	979	823	1714	1407
7.0	355*	342*	504*	441	971*	883	1886	1546
13.1	332*	343*	477*	453	978*	886	1539	1434
22.7	369*	345	483*	427	774	751	1078	1104
35.3	318	296*	392	341	546	519	—	—
46.7	244	237	308	288	—	—	—	—
70.0	147	140	—	—	—	—	—	—

*Majority of breaks at jaw.

Excessive jaw breaks were encountered when testing Orlon yarns. These were more numerous on the IP-2 tester than on the Suter. The greatest difficulty was experienced with the low denier yarns. However, after examination of all the breaking strength data, it is concluded that the jaw breaks did not seriously affect the over-all breaking strength of the yarn at a given increment of twist.

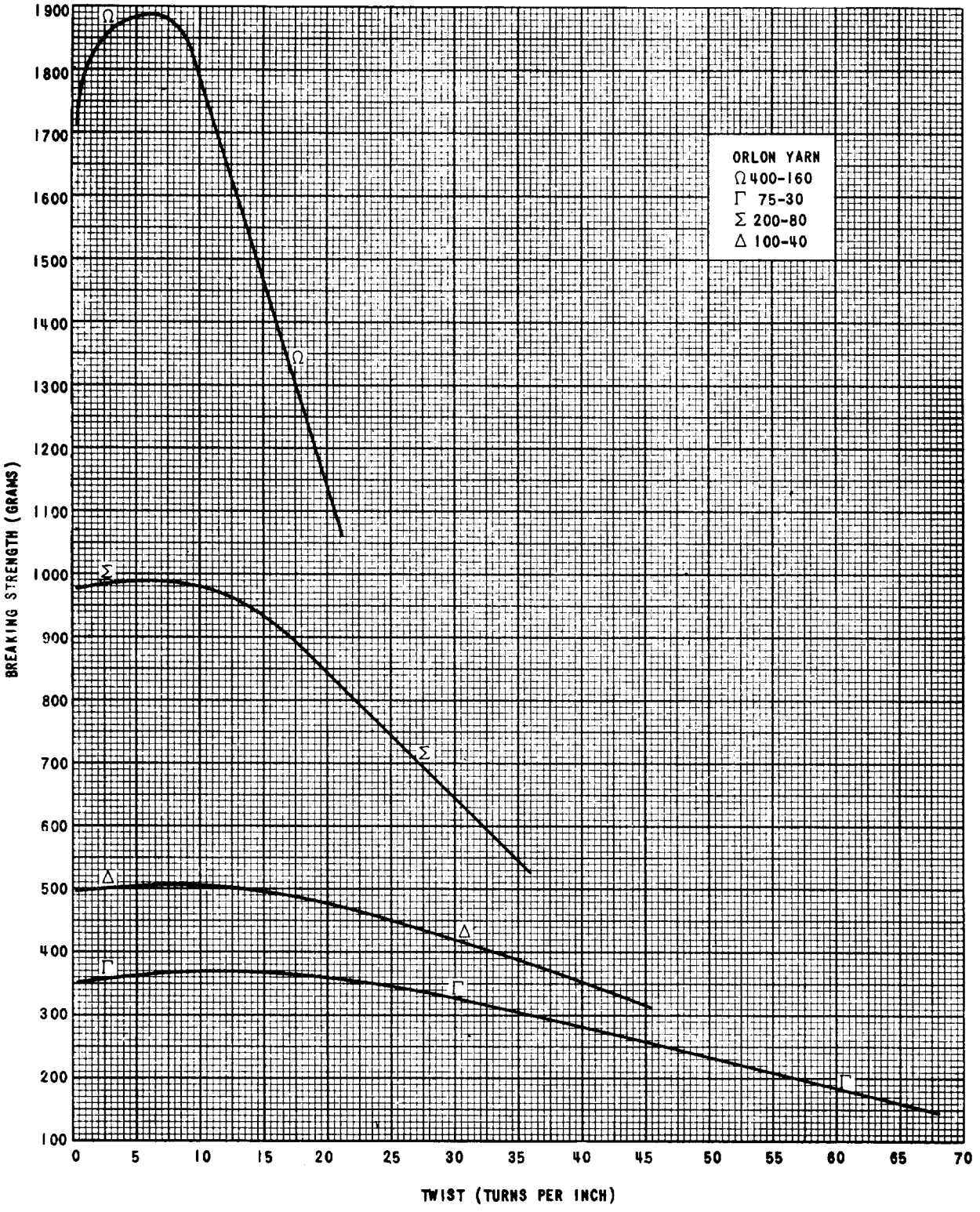


Figure 45. The Effect of Twist on the Breaking Strength of Orlon Yarns (IP-2 Machine).

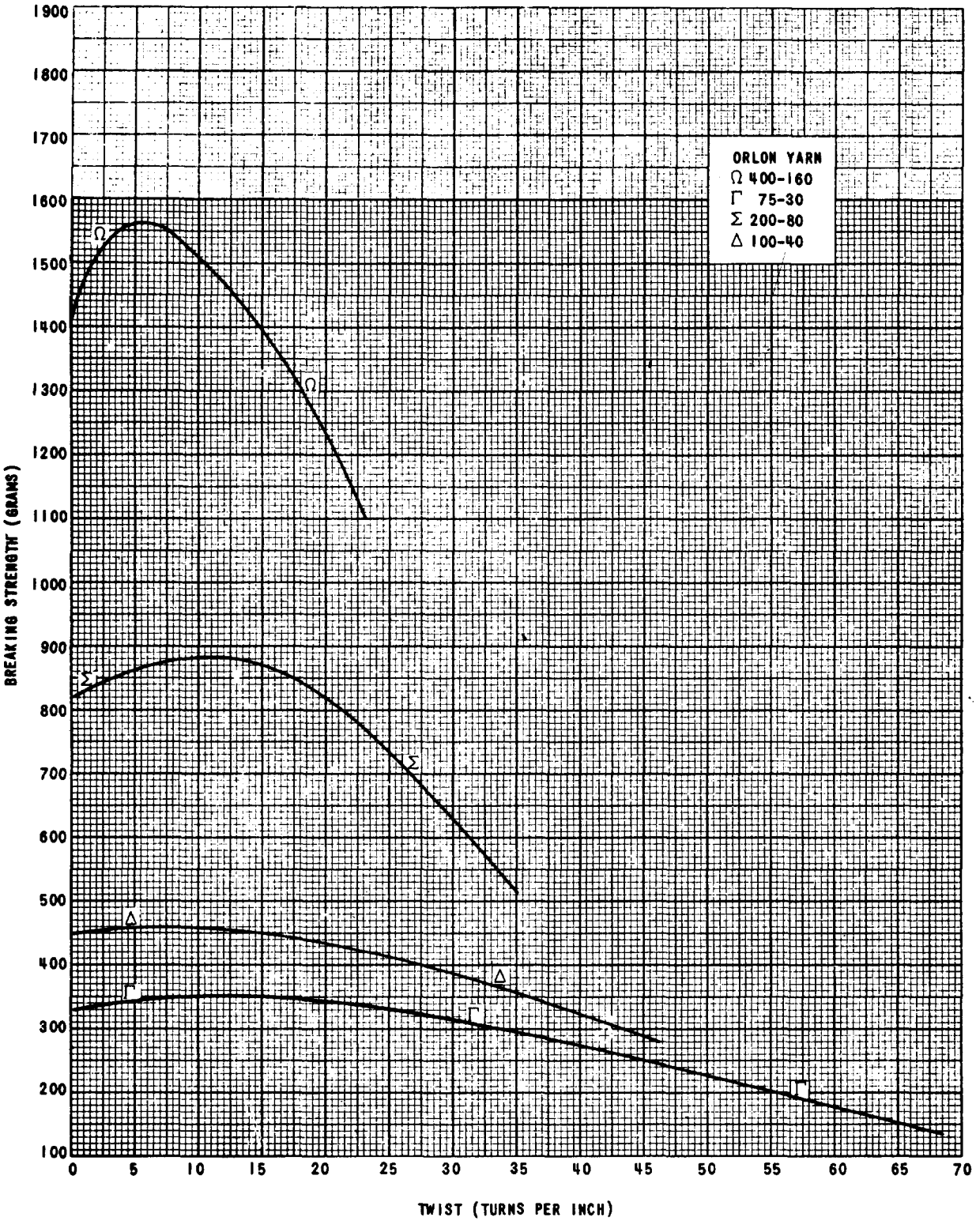


Figure 46. The Effect of Twist on the Breaking Strength of Orlon Yarns (Suter Single Strand Tester).

The effects of twist on the breaking strength of Orlon yarns are as follows:

a. The first increments of twist increase the breaking strength of all the yarns; further additions decrease the breaking strength.

b. The rate of increase and the rate of decrease in breaking strength are both greater for the higher denier yarns.

5. Elongation Determinations

The elongation results for the Orlon yarns are given in Table XXXVI and corresponding graphs are shown in Figures 47 and 48.

TABLE XXXVI

ELONGATION MEASUREMENTS AT BREAKING LOAD ON ORLON YARNS

Approximate Twist Added (TPI)	Elongation (Per Cent)							
	75-30-0.3Z		100-40-0.3Z		200-80-0.3Z		400-160-0.3Z	
	IP-2	Suter	IP-2	Suter	IP-2	Suter	IP-2	Suter
As-Received	17.3	16.1	16.8	16.4	16.8	16.1	15.7	15.0
7.0	16.2	15.3	16.4	15.7	16.2	16.1	16.4	14.5
13.1	15.5	15.5	15.8	16.2	16.9	16.2	15.7	15.3
22.7	17.1	16.8	17.3	16.2	16.2	16.2	15.3	15.6
35.3	16.6	16.3	16.0	15.6	16.2	16.3	—	—
46.7	15.9	15.6	15.4	16.0	—	—	—	—
70.0	13.8	13.5	—	—	—	—	—	—

The data show that added twists up to about 20 TPI do not affect elongation. Higher twists have some decreasing effect.

6. Energy Absorption Values

The energy absorption values at break and at 85 per cent of breaking load, as calculated from the breaking strength curves and

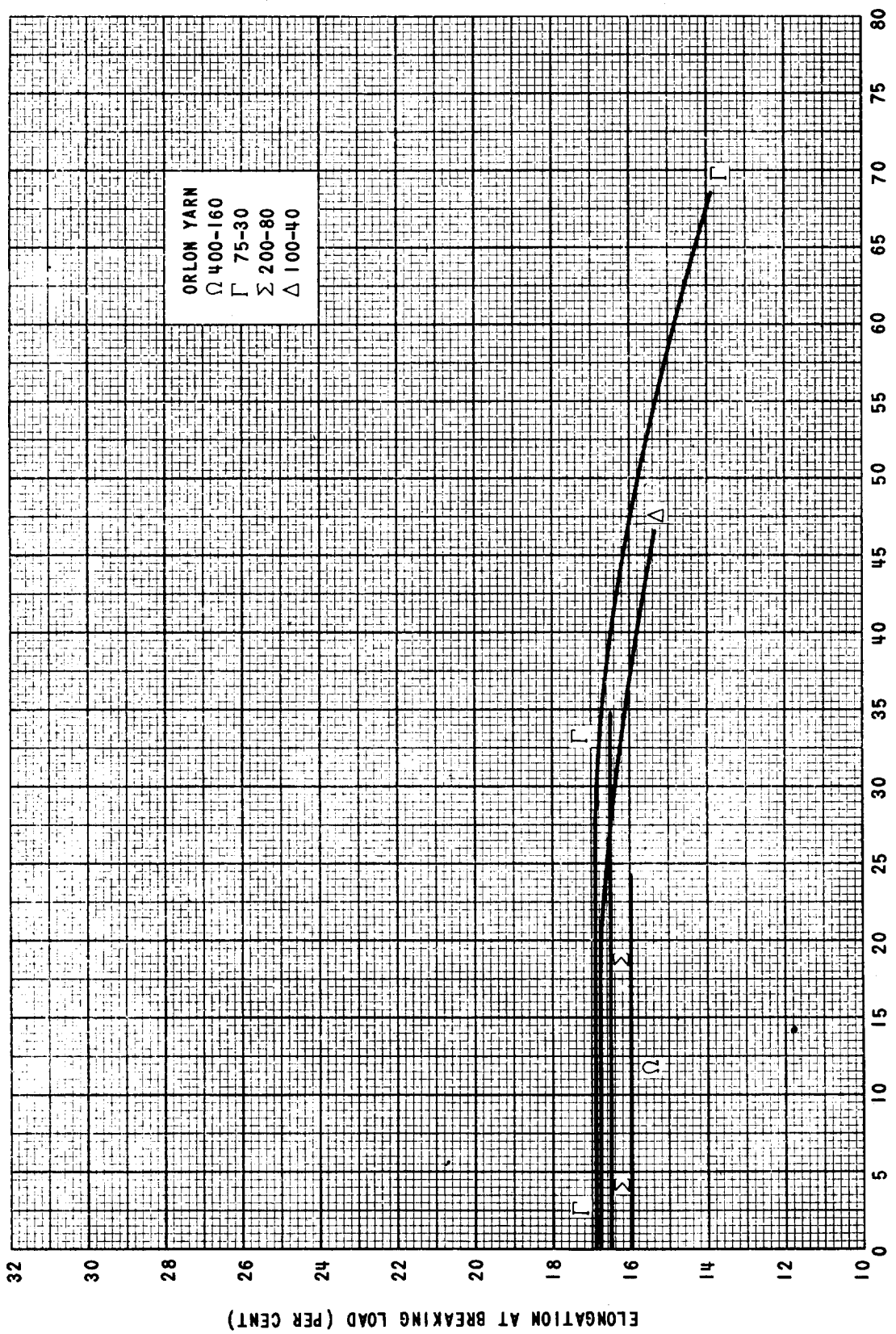


Figure 47. The Effect of Twist on the Elongation of Orlon Yarns (IP-2 Machine).

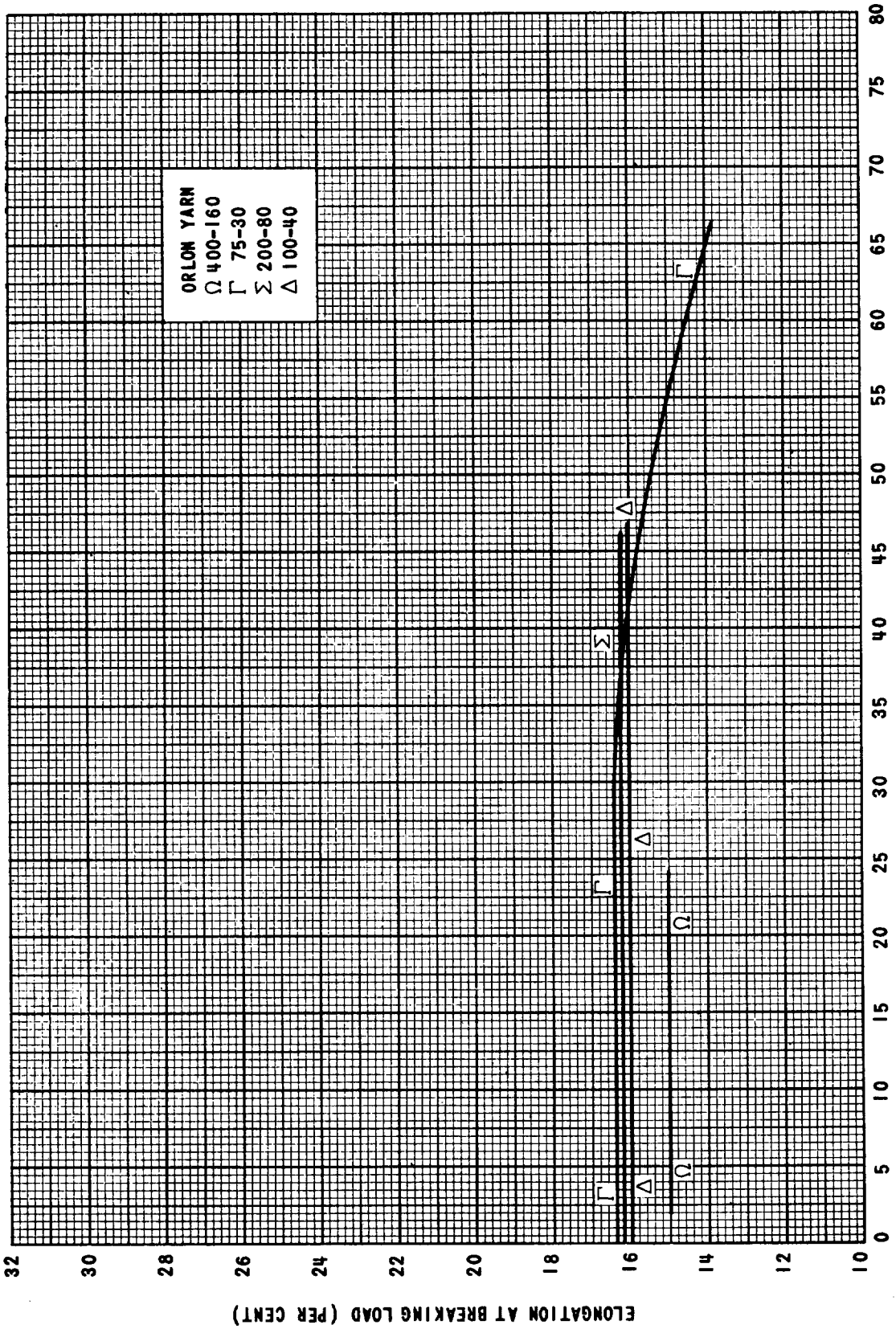


Figure 48. The Effect of Twist of the Elongation of Orlon Yarns (Suter Single Strand Tester).

hysteresis diagrams, respectively, are shown in Table XXXVII and are presented graphically in Figures 49 and 50.

TABLE XXXVII

ENERGY ABSORPTION VALUES
FOR ORLON YARNS

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm.)							
	75-30-0.3Z		100-40-0.3Z		200-80-0.3Z		400-160-0.3Z	
	Break	85% Break	Break	85% Break	Break	85% Break	Break	85% Break
As-Received	862.4	516.8	1153.0	741.4	2343.6	1508.0	3939.6	2331.1
7.0	765.0	479.1	1087.0	576.8	2136.3	1476.6	4071.5	2651.5
13.1	691.2	439.8	1005.3	662.9	2255.7	1508.0	3242.1	2155.1
22.7	834.1	541.9	1087.0	713.1	1740.4	1225.2	2393.9	1608.5
35.3	716.3	471.2	870.2	590.6	1332.0	955.0	—	—
46.7	552.9	344.0	694.3	474.4	—	—	—	—
70.0	333.0	194.8	—	—	—	—	—	—

From the values presented in the graphs and table, these observations may be made:

a. Curves showing the energy absorption values on the two bases have the same shape.

b. The higher denier yarns absorb the most energy.

c. The energy absorbed by the yarns at break is much higher than that at 85 per cent breaking load.

7. Elastic Recovery Values

Elastic recovery values for Orlon, as calculated from the hysteresis diagrams, are presented in Table XXXVIII and are given graphically in Figure 51.

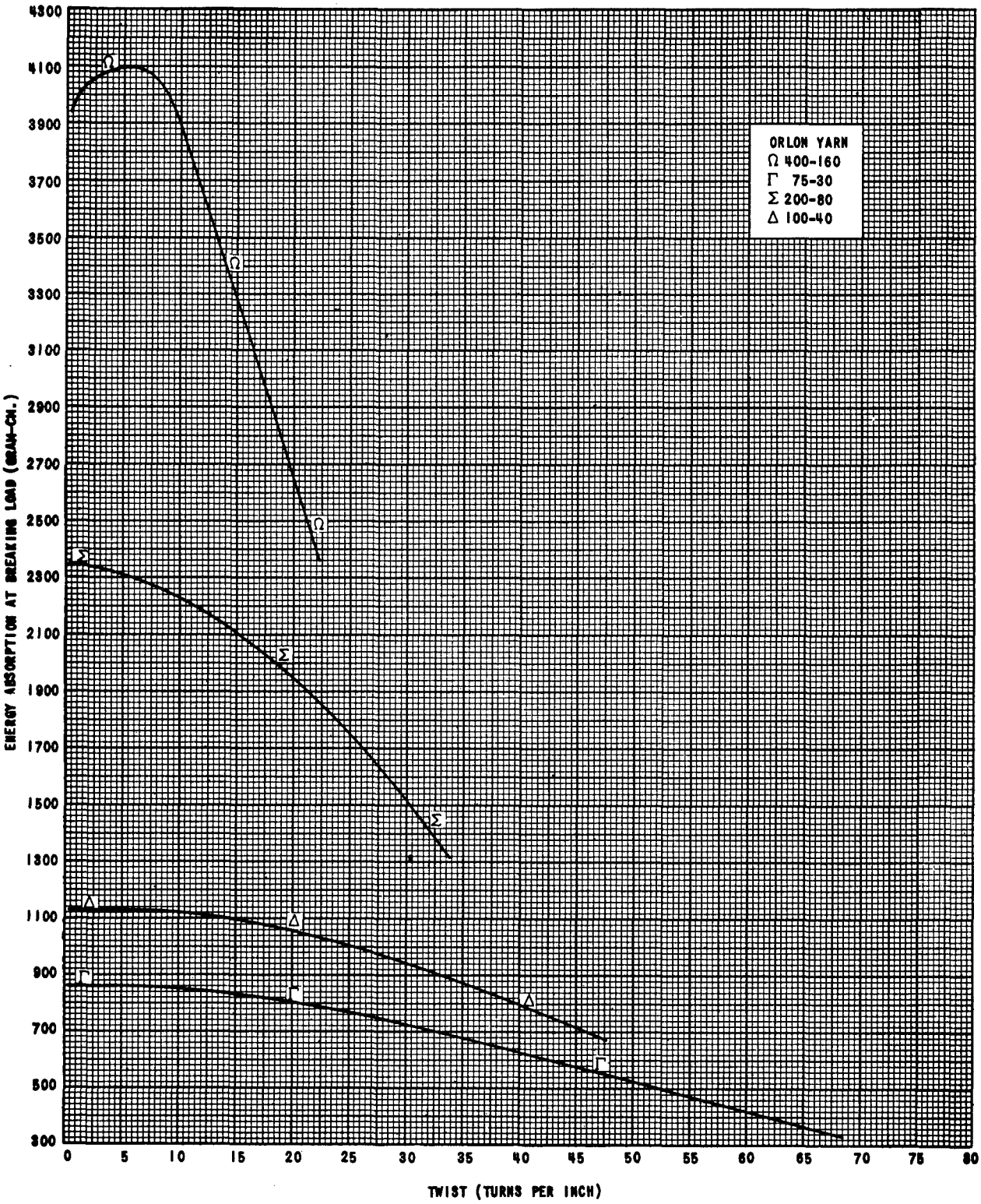


Figure 49. Energy Absorption Values at Breaking Load for Orlon Yarns.

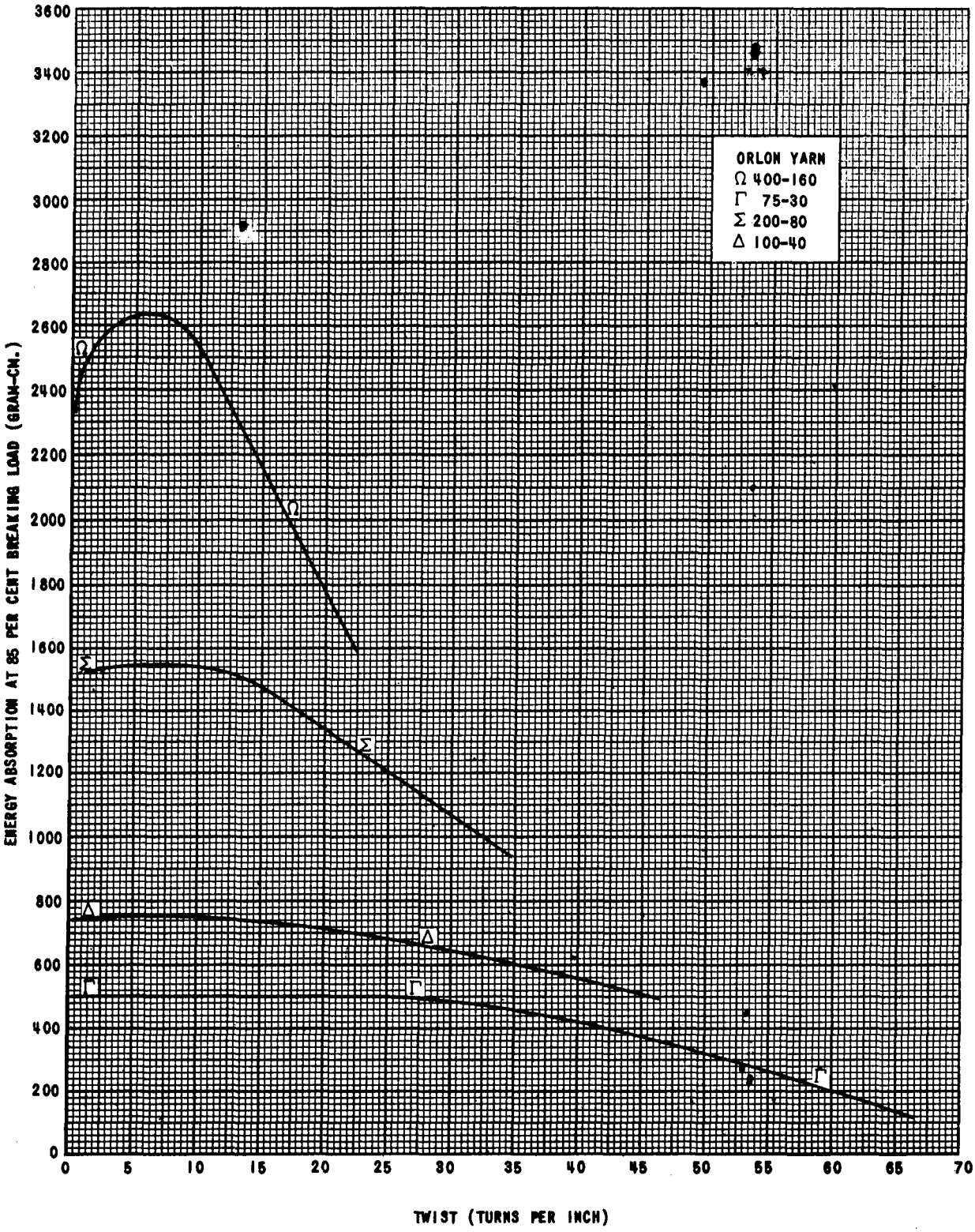


Figure 50. Energy Absorption Values at 85 Per Cent Breaking Load for Orlon Yarns.

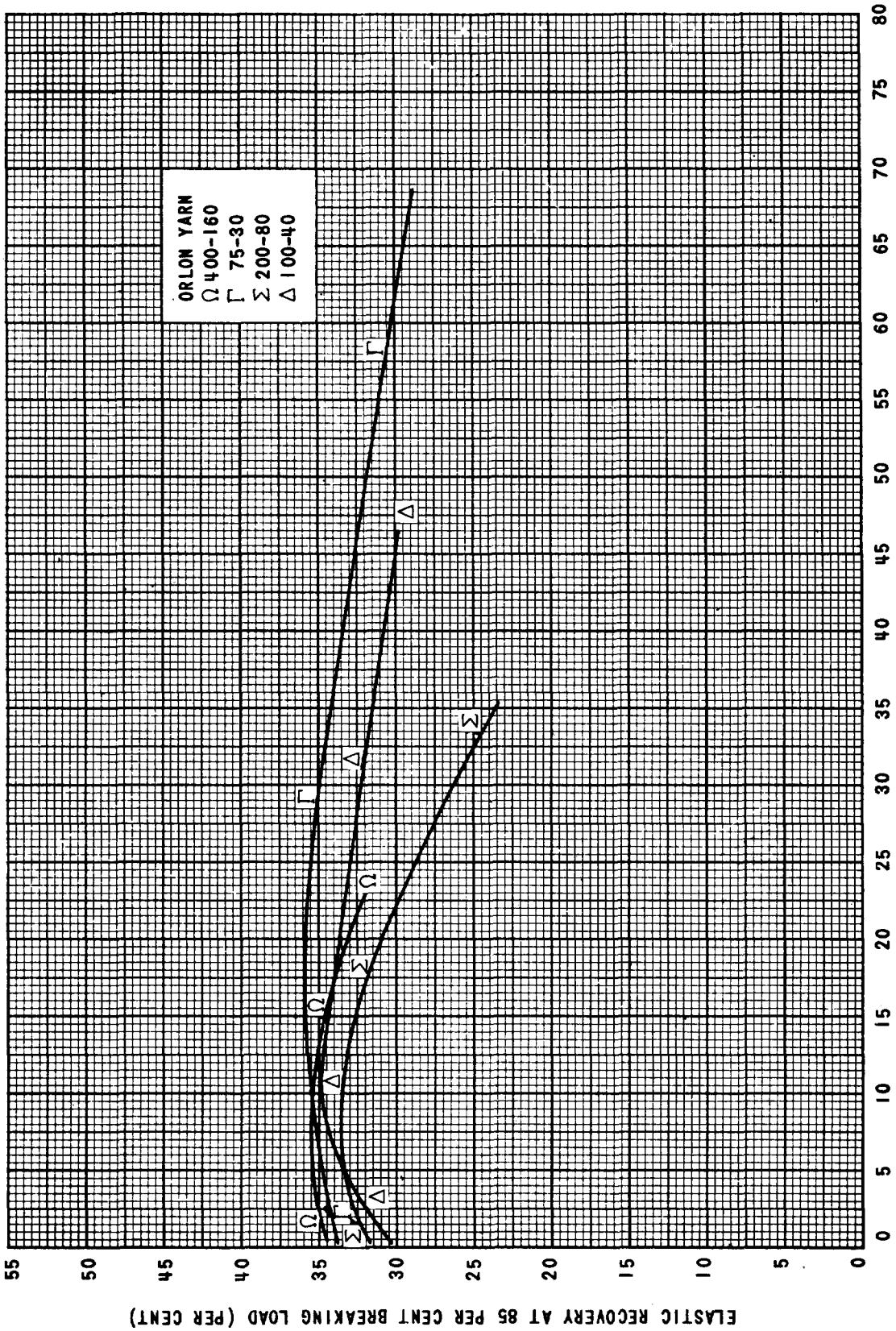


Figure 51. Elastic Recovery Values at 85 Per Cent Breaking Load for Orlon Yarns.

TABLE XXXVIII

ELASTIC RECOVERY VALUES AT 85 PER CENT
BREAKING LOAD FOR ORLON YARNS

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)			
	75-30-0.3Z	100-40-0.3Z	200-80-0.3Z	400-160-0.3Z
As-Received	33.8	30.2	31.9	34.6
7.0	35.4	34.5	32.4	35.4
13.1	34.6	34.5	33.8	35.0
22.7	35.9	33.1	28.6	31.8
35.3	34.2	31.5	24.1	—
46.7	32.6	29.9	—	—
70.0	28.6	—	—	—

The data show that:

a. The elastic recovery of all the Orlon yarns at low twists is very nearly the same.

b. The elastic recoveries reach a maximum value at relatively low twists.

c. The higher denier yarns have a greater rate of decrease in elastic recovery with added twist.

8. Tenacity Values

The tenacities of the Orlon yarns were calculated from the IP-2 breaking strength values and the denier determinations. The data obtained are given in Table XXXIX and are shown graphically in Figure 52.

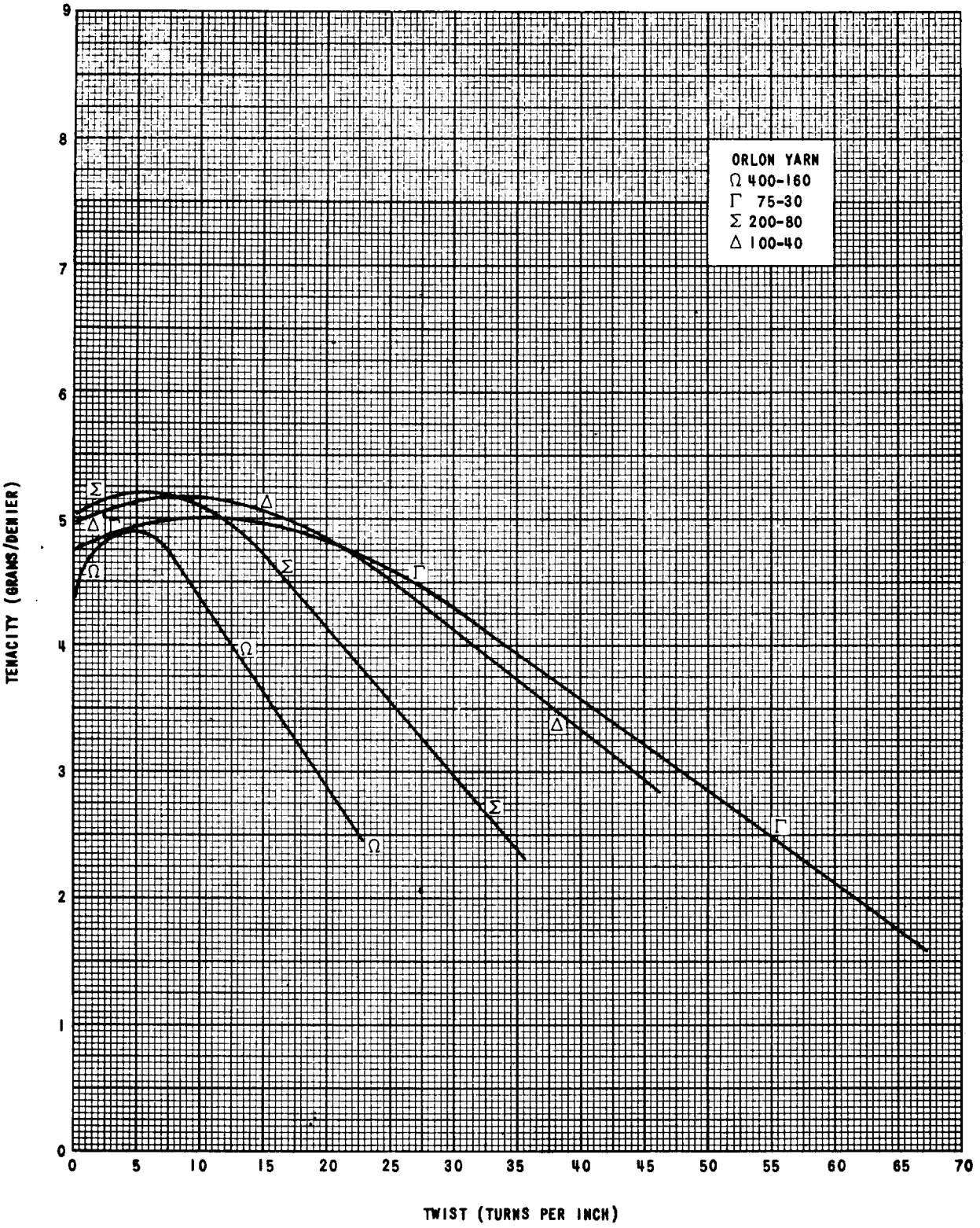


Figure 52. Tenacity Values for Orlon Yarns.

TABLE XXXIX

TENACITY VALUES FOR ORLON YARNS

Approximate Twist Added (TPI)	Tenacity (Grams/Denier)			
	75-30-0.3Z	100-40-0.3Z	200-80-0.3Z	400-160-0.3Z
As-Received	4.76	5.01	4.98	4.38
7.0	4.82	5.11	4.94	4.79
13.1	4.50	4.81	4.92	3.76
22.7	4.91	4.77	3.72	2.45
35.3	4.07	3.70	2.40	—
46.7	2.77	2.76	—	—
70.0	1.64	—	—	—

From these data it may be concluded that:

a. Tenacities of the yarns reach a maximum value at relatively low twists.

b. The higher denier yarns have greater rates of increase and decrease in tenacity with added twist.

VII. GENERAL CONCLUSIONS

The overall conclusions which may be drawn from the data given in the preceding sections are summarized below. However, attention is called to the comparative data in tables and graphs included in the Appendix.

1. In general, the effect of twist on any characteristic of a yarn is greater for high denier yarns than for low denier yarns.

2. Denier is an increasing function of twist for all yarns studied.

3. Diameter decreases with added twist up to 8-15 TPI; remains constant through a range, the length of which is an inverse function of the diameter; and then increases at higher twists. (This phenomenon is not demonstrated by all yarns.)

4. The breaking strength values of rayon and Orlon increase slightly over the initial values when small increments of twist are added; remain constant for a short range; and then decrease with added twist.

5. The breaking strength values of nylon and Fiber V are not affected by added twist until high twist has been added.

6. Elongation values of nylon and Fiber V increase at added twists above approximately 10-12 TPI. The elongation of rayon and Orlon is not affected by added twist.

7. Energy absorption values for nylon and Fiber V are greater and are affected less by twist than those for rayon and Orlon.

8. Maximum elastic recovery values at 85 per cent of breaking load are attained at relatively low twists for all yarns.

9. Tenacities of all the yarns except Fiber V have a maximum value at relatively low twists; they then decrease rapidly. Tenacities of Fiber V yarns are approximately constant up to 25 TPI and then decrease.

In addition to the summary of the effects of experimental procedures on yarns in general, the net effects of these procedures on the individual types of yarn may be mentioned. Nylon yarn is the least affected in its physical properties by the addition of twist. Fiber V yarn, although affected more than nylon yarn, shows smaller changes in its properties with added twist than do Orlon and rayon yarns.

VIII. APPENDIX

It should be pointed out that a parallel comparison among all the yarns, regardless of their varying polymeric nature, is of dubious technical validity; however, the comparison may have practical value. For that reason the following tables and graphs have been prepared. In order to compare the yarns more closely, breaking strength and energy absorption values have been converted to a per denier basis. Because of some change of scale in the graphs, it has been deemed advisable to follow points exactly in plotting the curves in this section. Since the increments of twist added to the rayon yarns differed slightly from those added to the others, the values for the rayon yarns in this section are interpolated from the graphs given in the third section.

Some division of the data must be made for convenience. The yarns, regardless of polymeric nature, were arbitrarily grouped in this manner:

a. Low denier (20-40)

b. Medium-low denier (70-75)

c. Medium denier (100-150)

d. Medium-high denier (200-210)

e. High denier (250-400).

Comparative values are tabulated in tables XL through XLIV and are presented graphically in Figures 53 to 72.

TABLE XL

SUMMARY OF YARN TENACITY VALUES

Approximate Twist Added (TPI)	Tenacity (Grams/Denier)			
	Nylon 20-7-200	Nylon 30-10-200	Nylon 40-13-200	Fiber V 40-34
As-Received	6.73	5.59	5.62	5.40
7.0	6.84	5.60	5.54	5.24
14.0	6.80	5.63	5.57	5.21
23.0	6.80	5.58	5.53	5.30
36.0	6.68	5.48	5.19	5.26
46.0	6.53	4.97	4.96	5.06
70.0	6.11	4.77	4.31	4.46
100.0	5.02	4.13	3.53	3.70

	Nylon 70-34-100	Nylon 70-34-200	Nylon 70-34-300	Fiber V 70-34	Orlon 75-30
As-Received	5.62	5.79	7.04	5.56	4.76
7.0	5.78	5.96	7.14	5.48	4.82
14.0	5.71	6.02	7.06	5.51	4.50
23.0	5.58	5.74	6.84	5.38	4.91
36.0	5.42	6.04	6.57	5.19	4.07
46.0	5.06	5.81	6.40	4.91	2.77
70.0	4.12	5.24	5.10	2.73	1.64
100.0	--	--	--	--	--

	Nylon 100-34-300	Orlon 100-40	AVisco 150-40	Ind. Ray. 150-40
As-Received	7.31	5.01	2.45	2.68
7.0	7.37	5.11	2.51	2.60
14.0	7.22	4.81	2.54	2.60
23.0	7.00	4.77	2.44	2.62
36.0	6.20	3.70	2.02	2.18
46.0	5.73	2.76	1.42	1.83
70.0	--	--	--	--
100.0	--	--	--	--

(Continued)

TABLE XL (Continued)

SUMMARY OF YARN TENACITY VALUES

Approximate Twist Added (TPI)	Tenacity (Grams/Denier)				
	Nylon 210-34-300	Fiber V 210-34	Orlon 200-80		
As-Received	8.05	6.99	4.98		
7.0	8.09	6.89	4.94		
14.0	7.90	6.69	4.92		
23.0	6.81	6.13	3.72		
36.0	5.62	4.52	2.40		
46.0	—	3.04	—		
70.0	—	—	—		
100.0	—	—	—		
	AVisco 250-60	AVisco 300-44	DuPont Rayon 300-120	Nylon 260-17-300	Orlon 400-160
As-Received	2.00	2.36	2.71	6.49	4.38
7.0	2.05	2.50	2.78	6.32	4.79
14.0	1.95	2.35	2.60	6.06	3.76
23.0	1.70	1.88	2.10	5.28	2.45
36.0	1.31	1.38	1.40	4.25	—
46.0	—	—	—	—	—
70.0	—	—	—	—	—
100.0	—	—	—	—	—

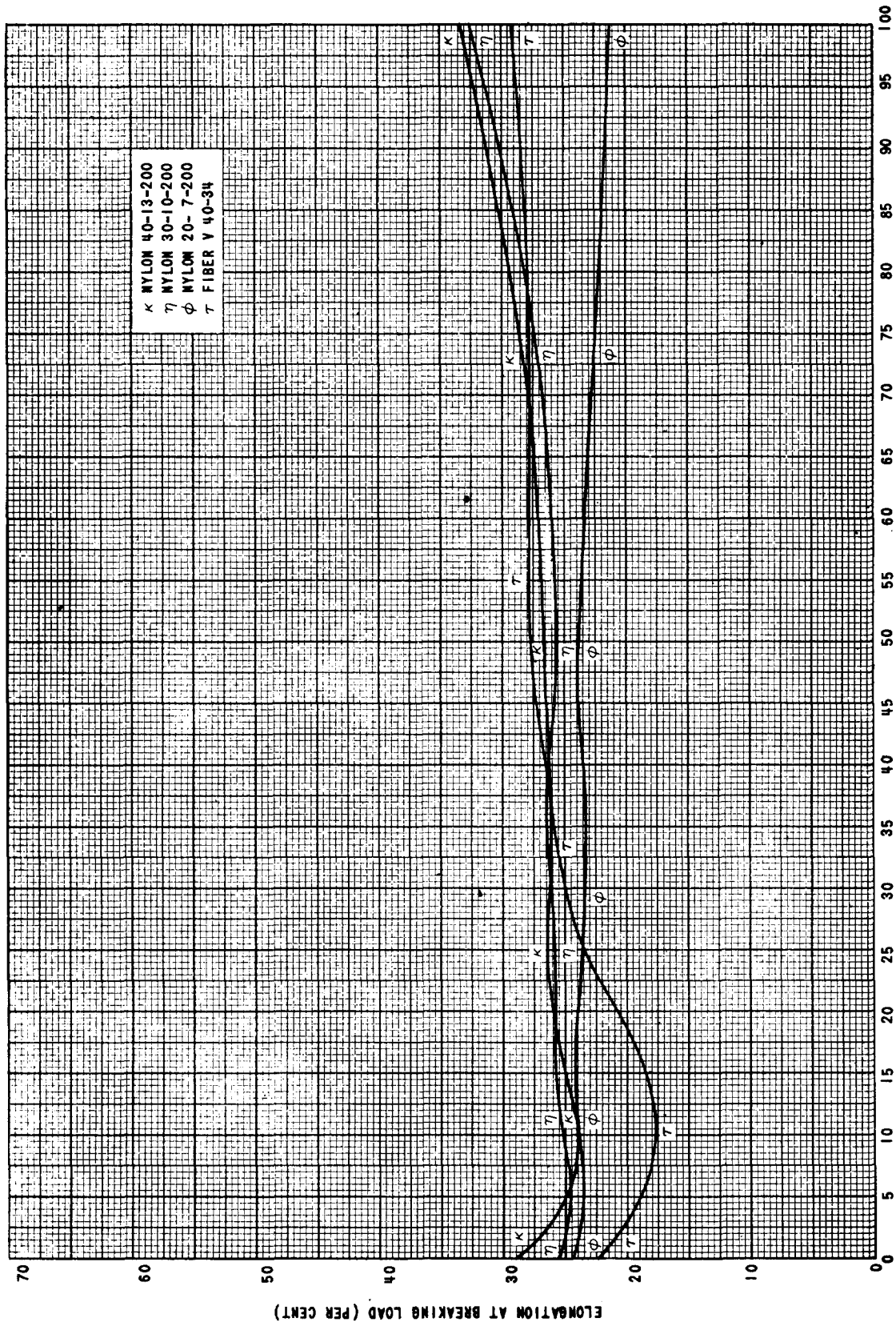


Figure 53. Summary of Yarn Elongations at Break.

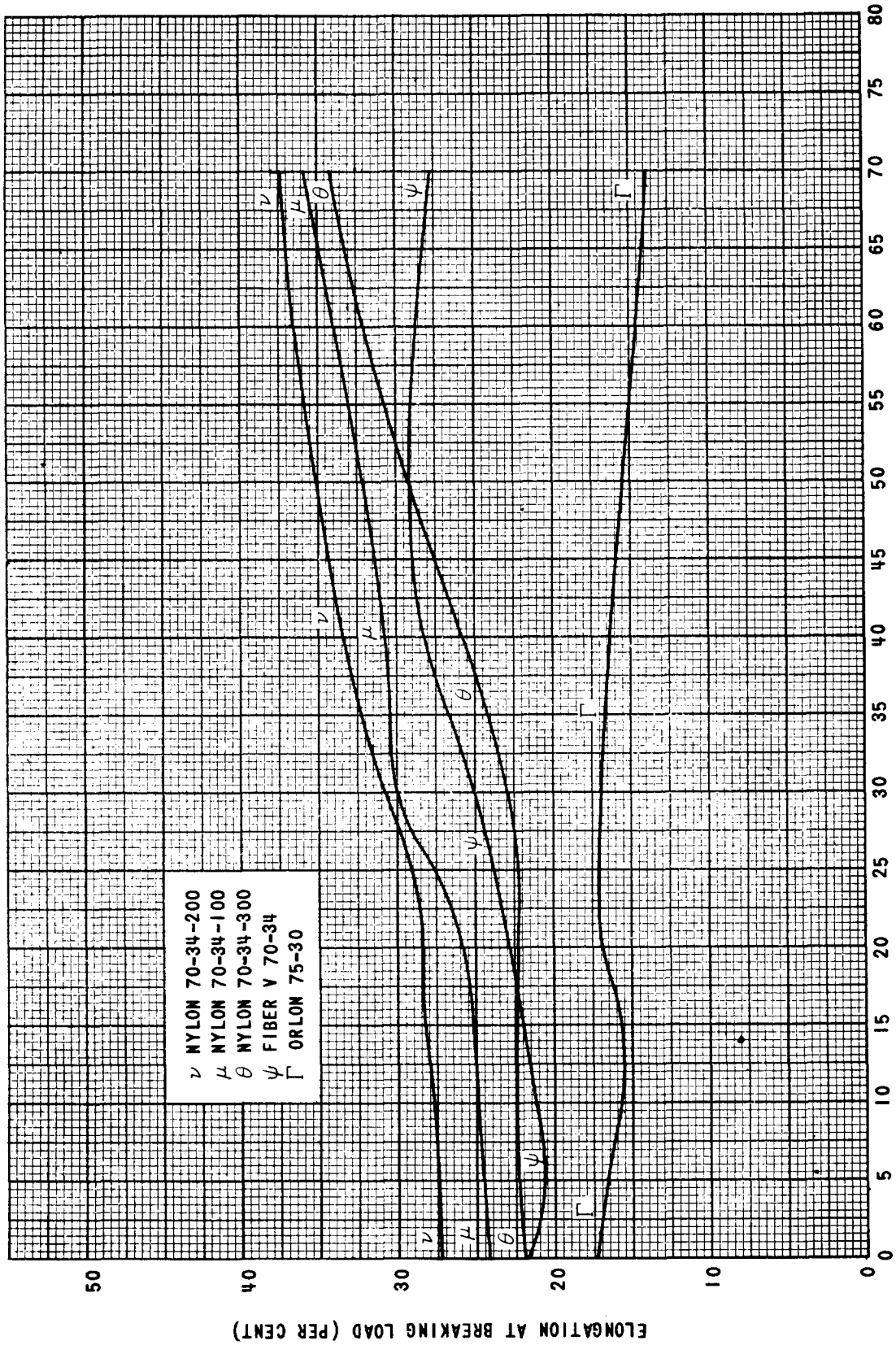


Figure 54. Summary of Yarn Elongations at Break.

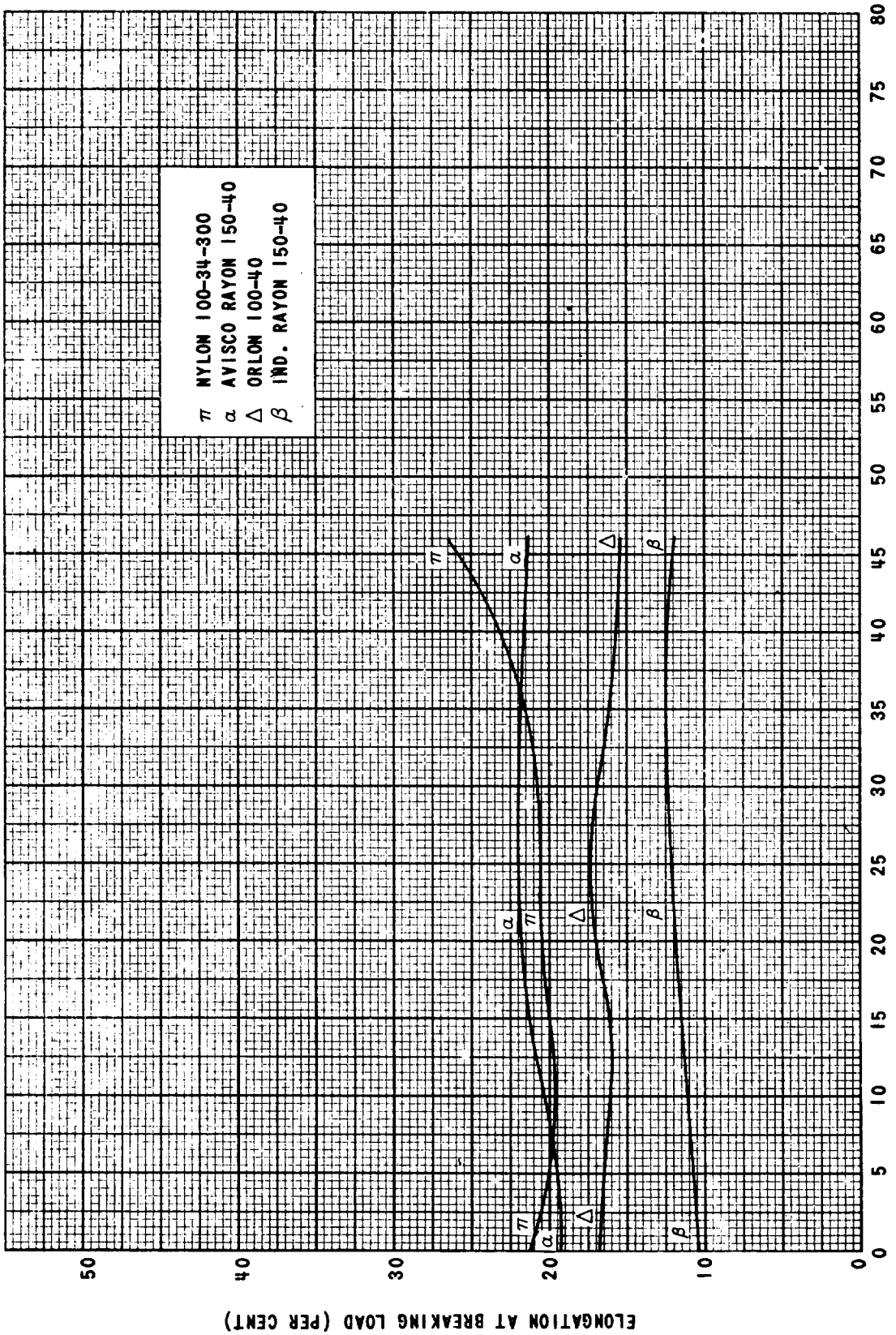


Figure 55. Summary of Yarn Elongations at Break.

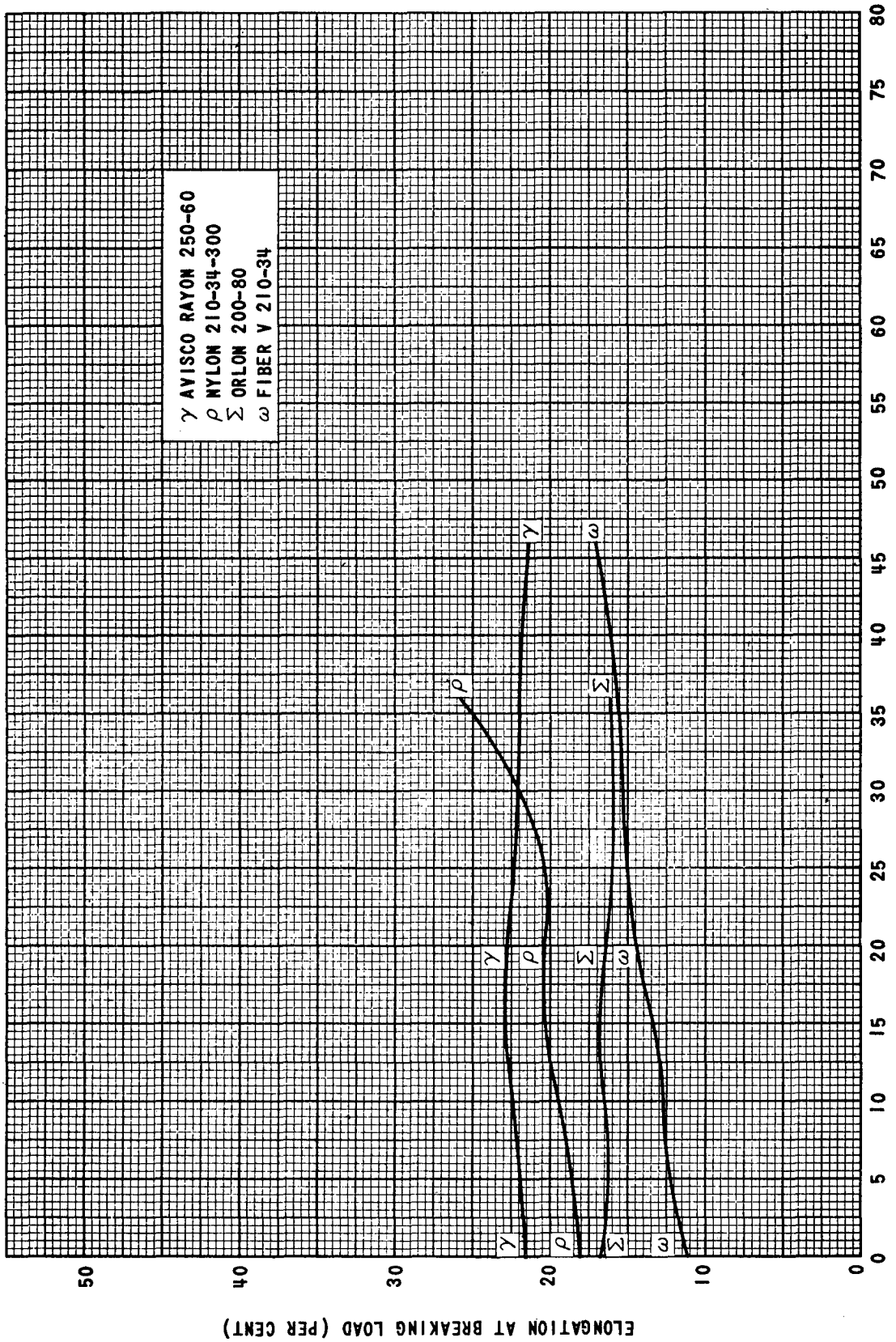


Figure 56. Summary of Yarn Elongations at Break.

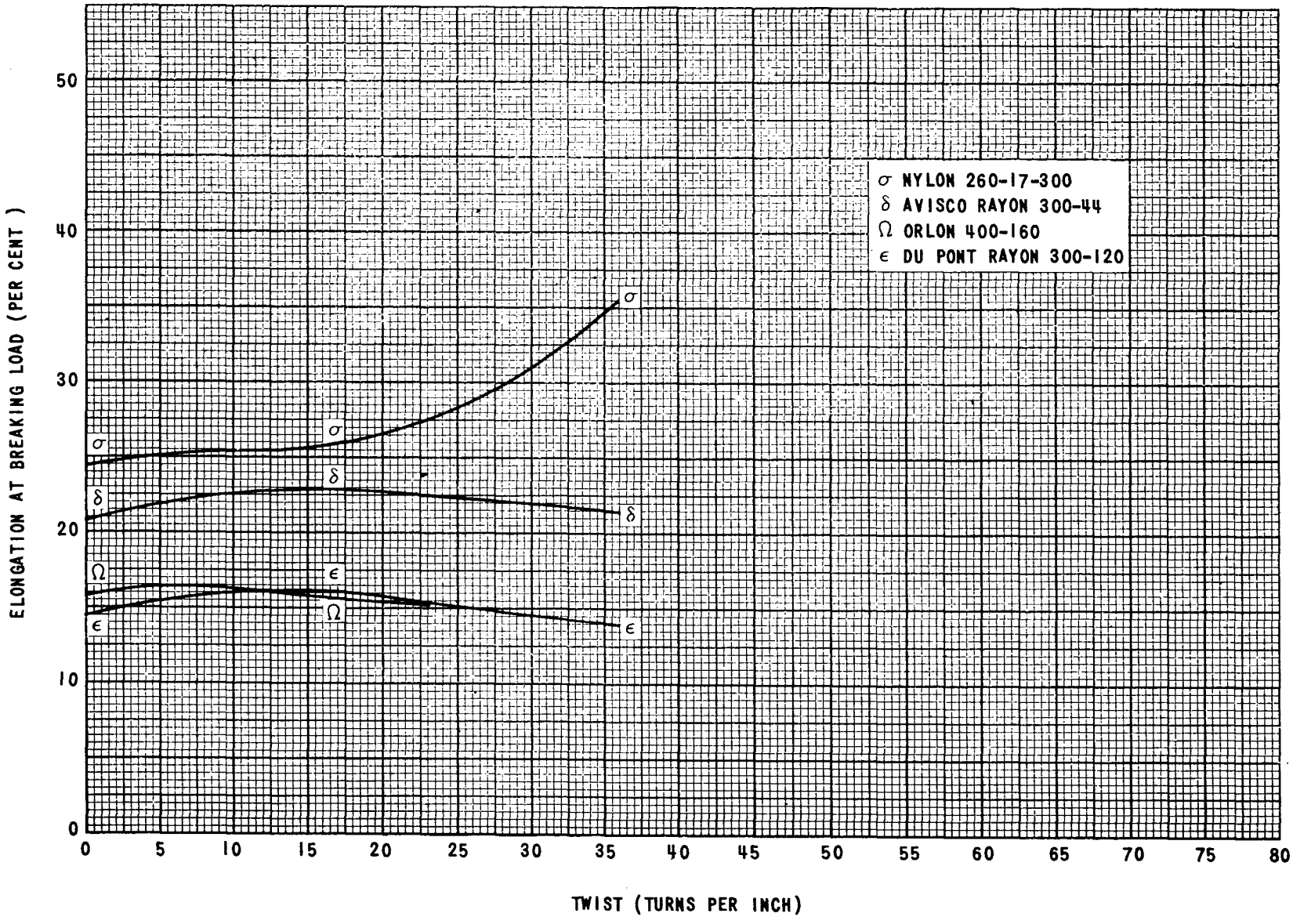


Figure 57. Summary of Yarn Elongations at Break.

TABLE XLI

SUMMARY OF ENERGY ABSORPTION VALUES
FOR YARNS AT BREAKING LOAD

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm./Denier)			
	Nylon 20-7-200	Nylon 30-10-200	Nylon 40-13-200	Fiber V 40-34
As-Received	31.2	26.6	30.2	25.2
7.0	30.5	26.0	24.2	19.2
14.0	31.5	26.8	24.8	18.9
23.0	31.3	26.7	26.1	24.4
36.0	29.9	26.5	23.4	27.8
46.0	29.6	22.6	21.8	28.0
70.0	24.4	21.7	17.3	22.2
100.0	16.1	19.8	16.5	18.3

	Nylon 70-34-100	Nylon 70-34-200	Nylon 70-34-300	Fiber V 70-34	Orlon 75-30
As-Received	24.5	28.0	26.3	24.7	11.6
7.0	26.4	28.9	27.5	22.7	10.4
14.0	26.5	29.8	26.5	24.3	9.4
23.0	26.3	29.0	24.4	25.0	10.9
36.0	29.5	31.6	25.0	27.5	9.2
46.0	26.2	30.5	26.7	26.7	6.8
70.0	21.6	23.6	—	11.1	3.7
100.0	—	—	—	—	—

	Nylon 100-34-300	Orlon 100-40	AVisco 150-40	Ind. Ray. 150-40
As-Received	25.9	11.7	7.9	4.8
7.0	22.9	11.0	8.4	5.5
14.0	22.8	10.2	8.7	5.7
23.0	21.8	10.8	8.7	5.3
36.0	19.4	8.2	7.0	4.2
46.0	20.4	6.2	5.8	3.4
70.0	—	—	—	—
100.0	—	—	—	—

(Continued)

TABLE XLI (Continued)

SUMMARY OF ENERGY ABSORPTION VALUES
FOR YARNS AT BREAKING LOAD

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm./Denier)		
	Nylon 210-34-300	Fiber V 210-34	Orlon 200-80
As-Received	21.6	13.6	11.9
7.0	22.1	15.0	10.8
14.0	23.0	14.3	11.3
23.0	17.2	14.2	8.4
36.0	17.2	9.9	5.8
46.0	—	7.0	—
70.0	—	—	—
100.0	—	—	—

	AVisco 250-60	AVisco 300-44	DuPont Rayon 300-120	Nylon 260-17-300	Orlon 400-160
As-Received	7.5	8.2	6.3	27.0	10.6
7.0	7.7	8.7	6.8	26.7	10.3
14.0	7.6	8.5	6.5	23.3	8.0
23.0	6.3	7.0	4.6	21.4	5.5
36.0	4.6	3.9	2.9	19.7	—
46.0	3.4	—	—	—	—
70.0	—	—	—	—	—
100.0	—	—	—	—	—

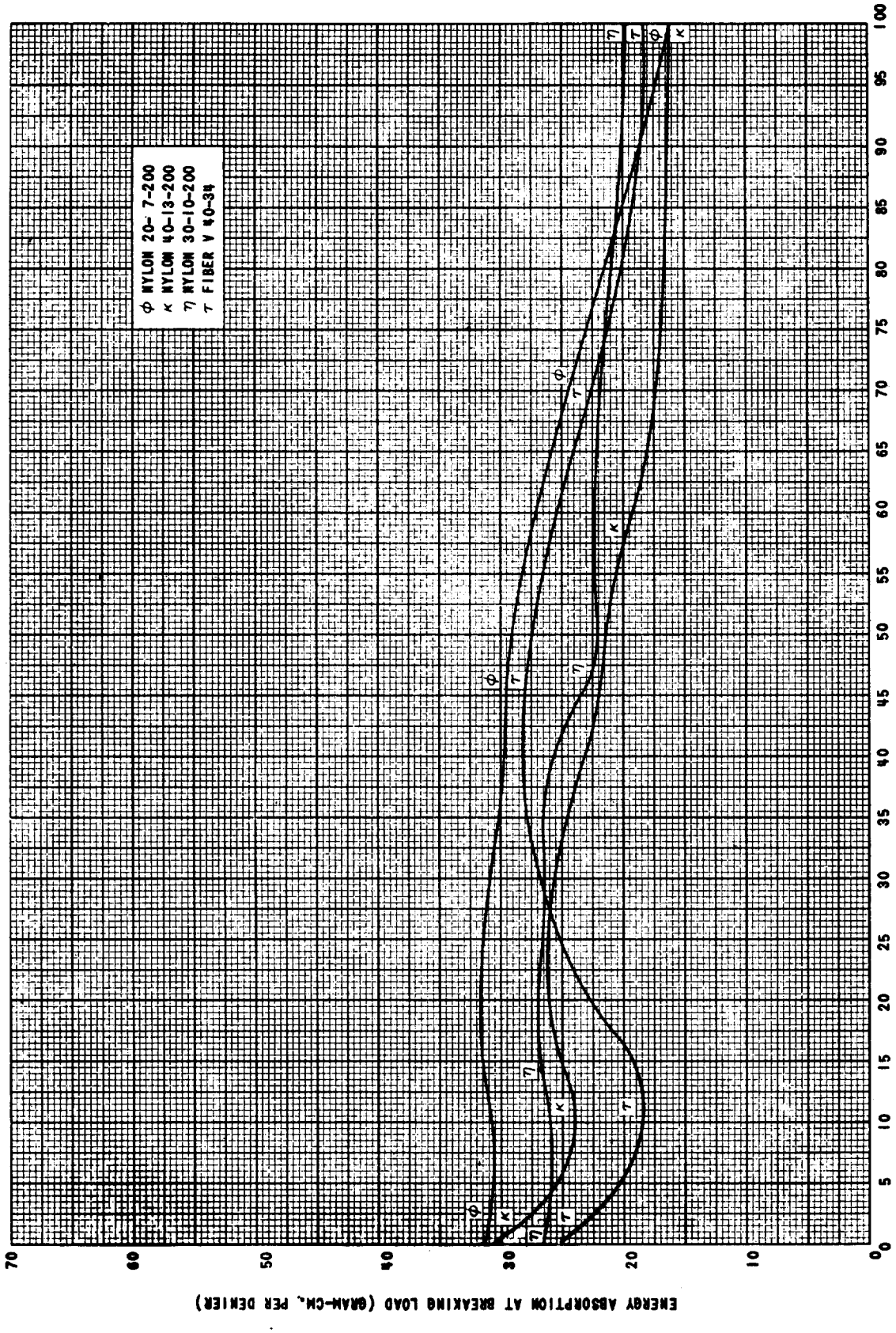


Figure 58. Summary of Energy Absorptions to Breaking Load.

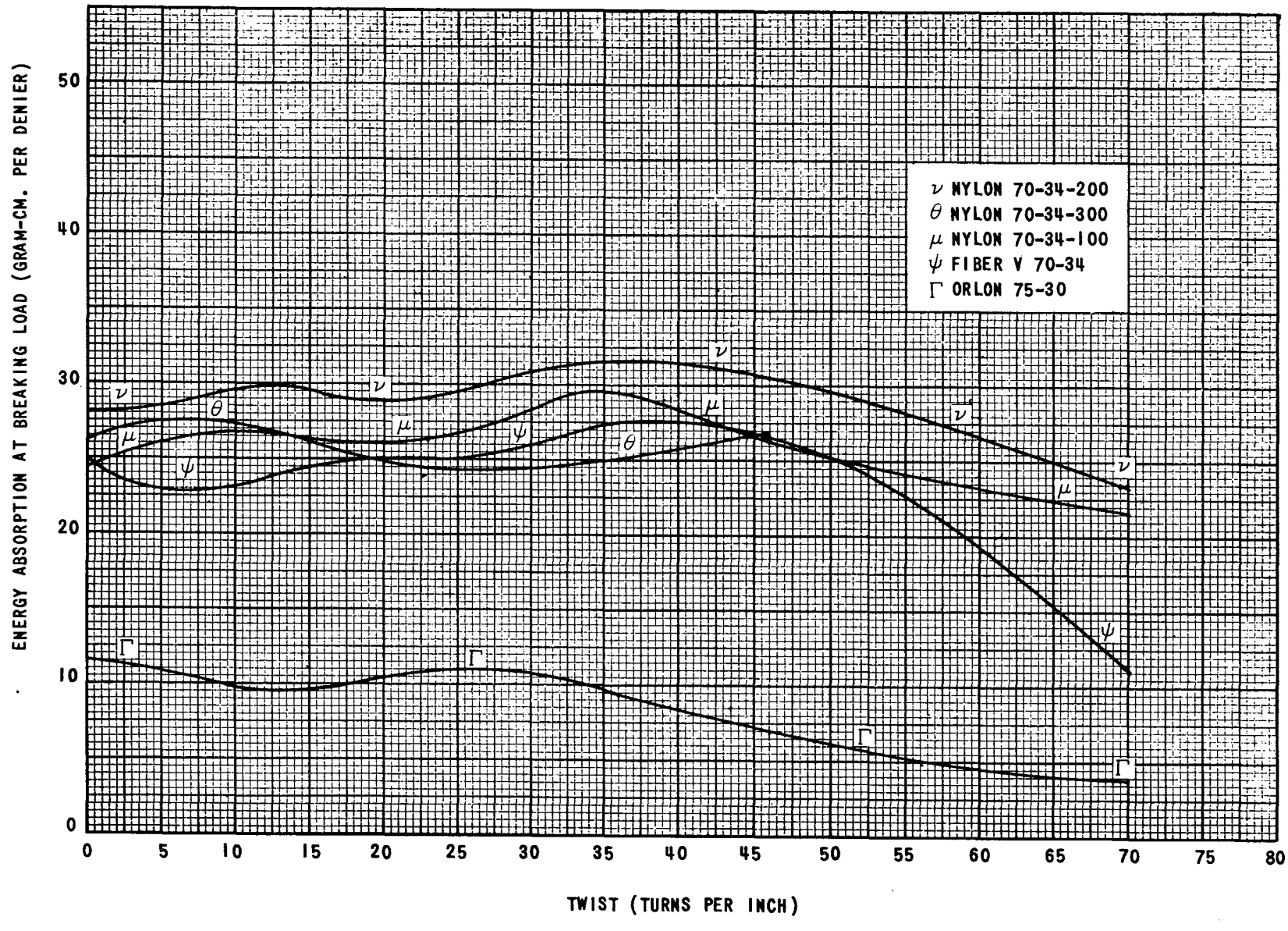


Figure 59. Summary of Energy Absorptions to Breaking Load.

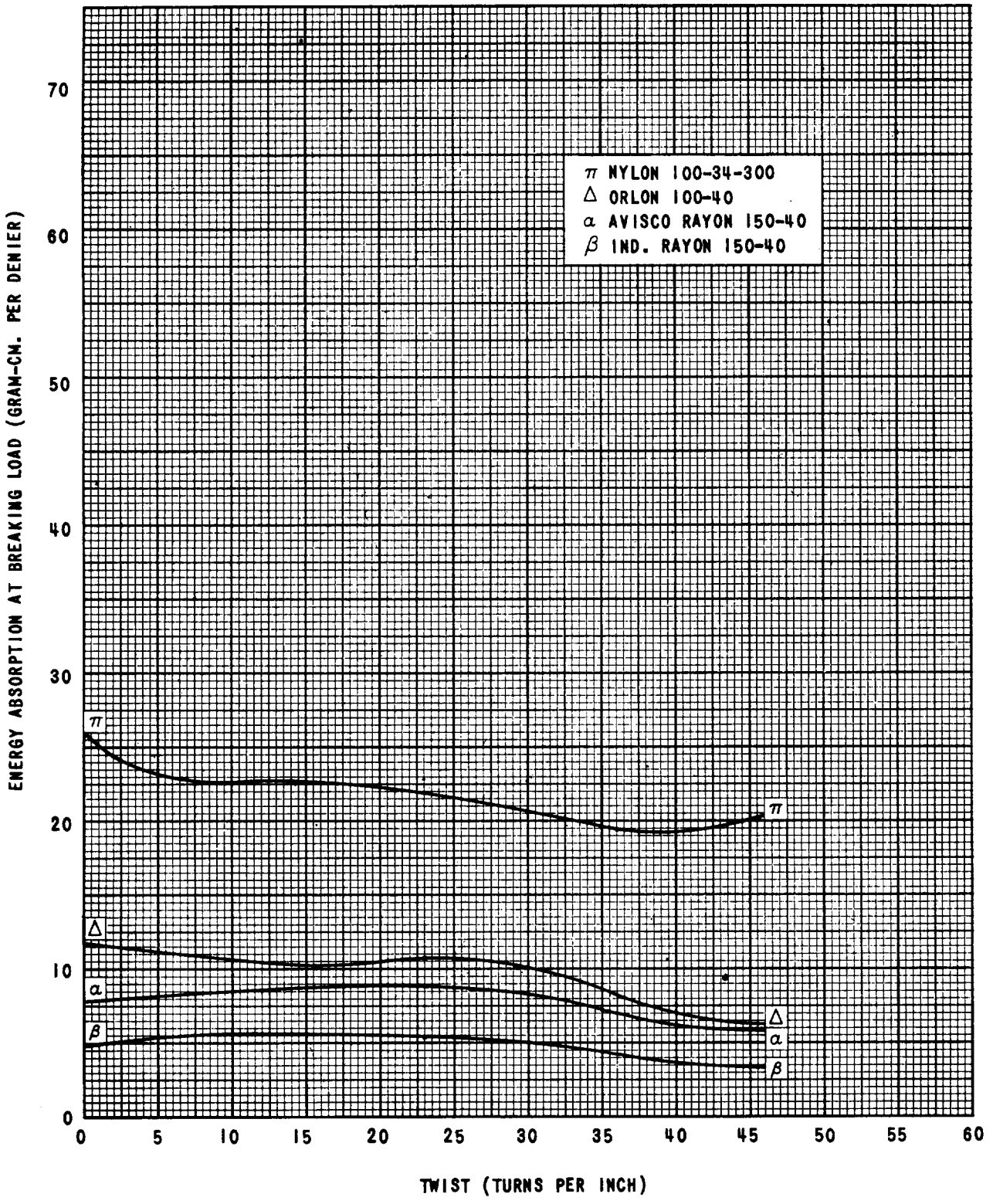


Figure 60. Summary of Energy Absorptions to Breaking Load.

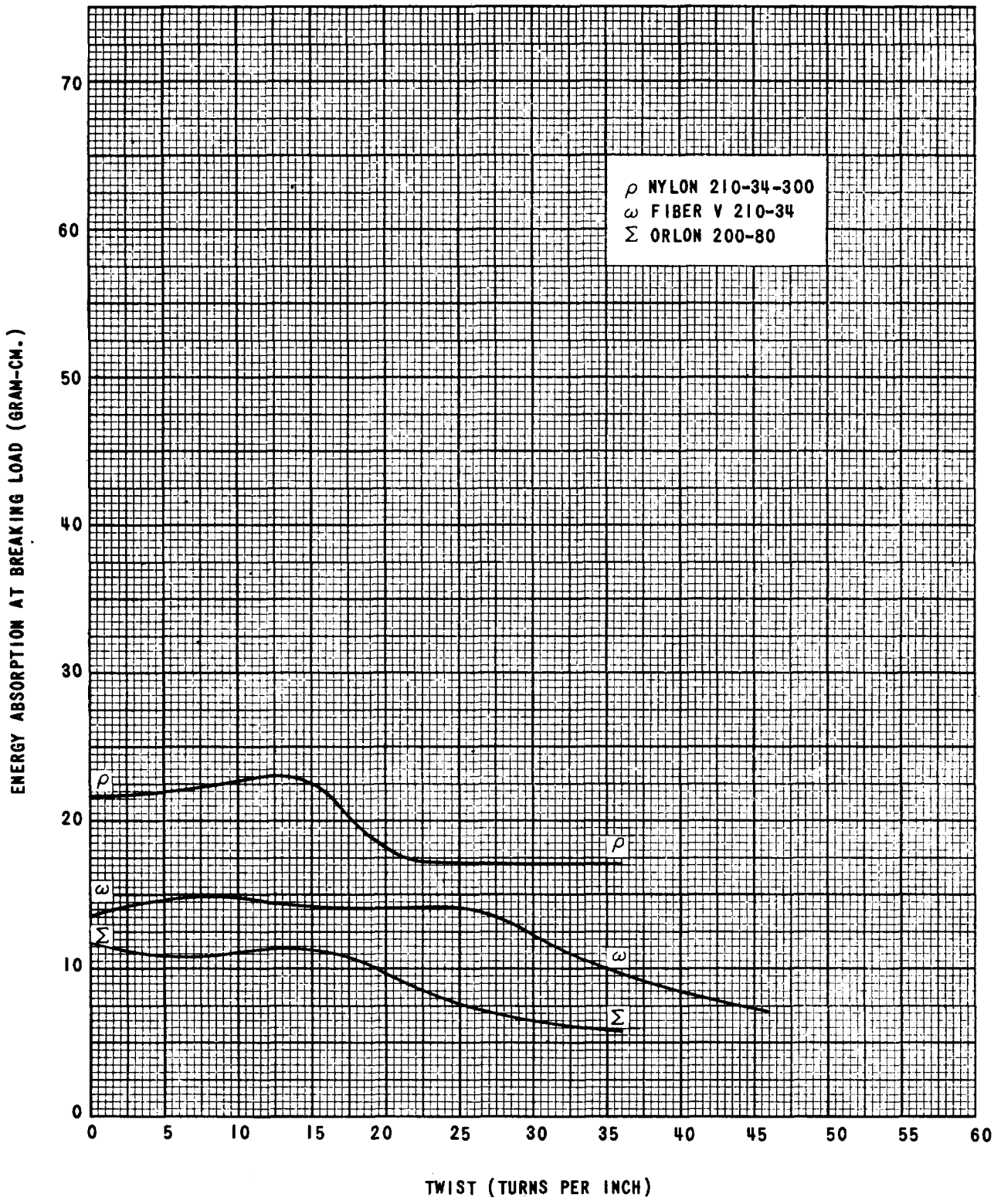


Figure 61. Summary of Energy Absorptions to Breaking Load.

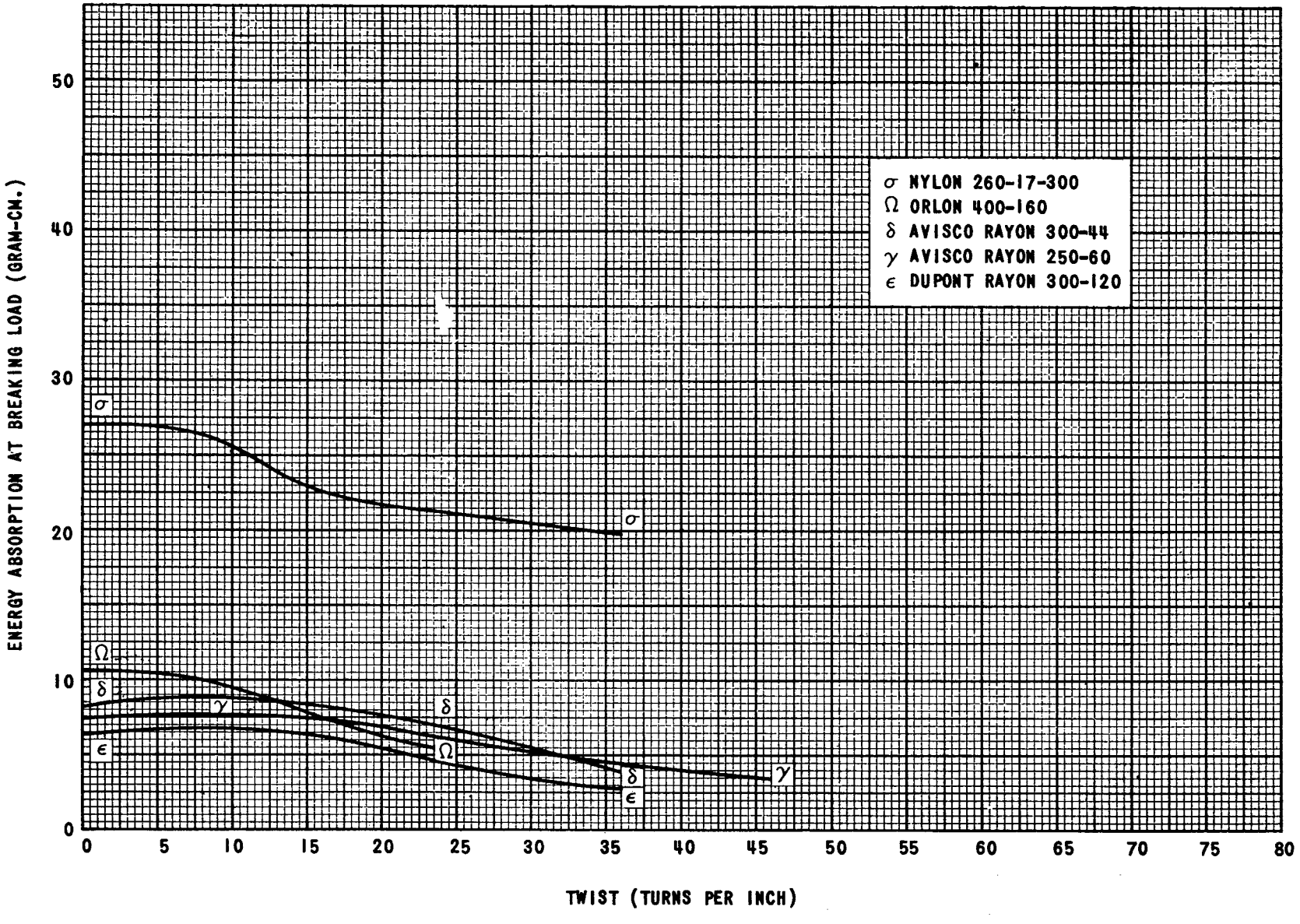


Figure 62. Summary of Energy Absorptions to Breaking Load.

TABLE XLII

SUMMARY OF ENERGY ABSORPTION VALUES
FOR YARNS AT 85 PER CENT BREAKING LOAD

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm./Denier)			
	Nylon 20-7-200	Nylon 30-10-200	Nylon 40-13-200	Fiber V 40-34
As-Received	8.59	7.27	9.72	6.89
7.0	7.65	6.27	7.10	5.30
14.0	7.71	6.93	7.13	4.70
23.0	8.57	6.51	7.67	6.91
36.0	8.19	7.14	6.64	9.60
46.0	8.06	6.34	7.51	9.54
70.0	7.21	8.24	8.35	9.56
100.0	—	10.08	9.14	9.93

	Nylon 70-34-100	Nylon 70-34-200	Nylon 70-34-300	Fiber V 70-34	Orlon 75-30
As-Received	4.50	5.54	5.22	8.02	6.96
7.0	5.21	5.94	5.37	7.93	6.49
14.0	4.90	7.14	5.36	8.60	5.96
23.0	5.31	6.06	5.90	7.59	7.20
36.0	6.98	9.78	7.75	9.30	6.03
46.0	8.19	10.44	10.24	11.65	4.25
70.0	10.01	10.73	—	3.27	2.17
100.0	—	—	—	—	—

	Nylon 100-34-100	Orlon 100-40	AVisco 150-40	Ind. Ray. 150-40
As-Received	5.56	7.50	4.94	2.48
7.0	5.35	5.85	5.10	2.82
14.0	5.20	6.68	5.61	3.00
23.0	6.03	7.03	5.62	3.13
36.0	8.08	5.58	4.90	2.84
46.0	9.51	4.25	4.00	2.27
70.0	—	—	—	—
100.0	—	—	—	—

(Continued)

TABLE XLII (Continued)

SUMMARY OF ENERGY ABSORPTION VALUES
FOR YARNS AT 85 PER CENT BREAKING LOAD

Approximate Twist Added (TPI)	Energy Absorbed (Gram-Cm./Denier)		
	Nylon 210-34-300	Fiber V 210-34	Orlon 200-80
As-Received	5.72	3.81	7.67
7.0	5.93	3.86	7.51
14.0	6.64	3.94	7.58
23.0	6.55	5.48	5.89
36.0	7.86	5.27	4.19
46.0	—	4.43	—
70.0	—	—	—
100.0	—	—	—

	AVisco 250-60	AVisco 300-44	DuPont Rayon 300-120	Nylon 260-17-300	Orlon 400-160
As-Received	4.93	5.19	4.02	6.39	5.95
7.0	5.11	5.37	4.42	6.50	6.73
14.0	5.24	5.24	4.56	6.75	5.26
23.0	4.40	4.65	3.15	8.03	3.65
36.0	3.38	3.20	2.32	9.83	—
46.0	2.57	—	—	—	—
70.0	—	—	—	—	—
100.0	—	—	—	—	—

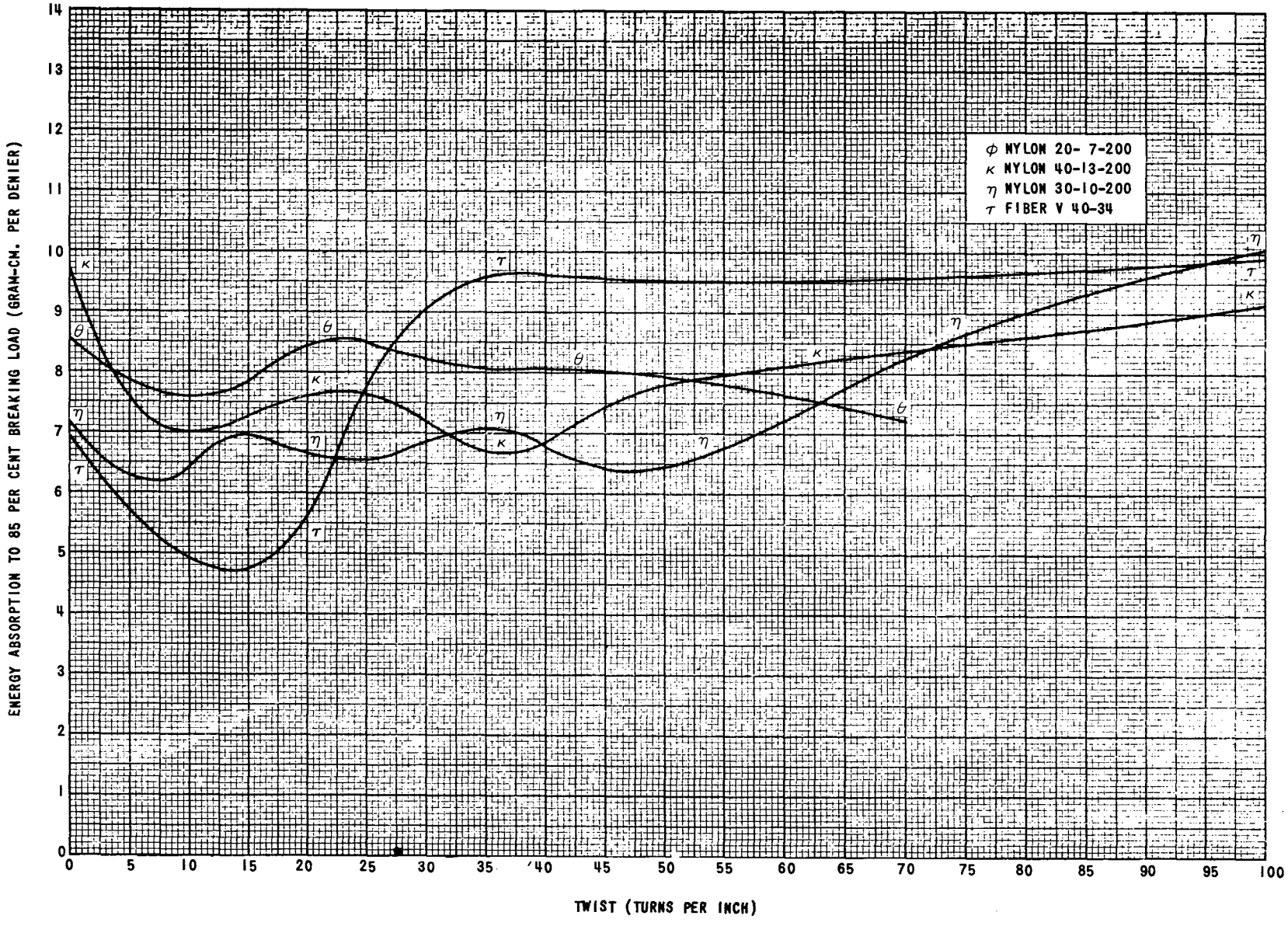


Figure 63. Summary of Energy Absorptions to 85 Per Cent Breaking Load.

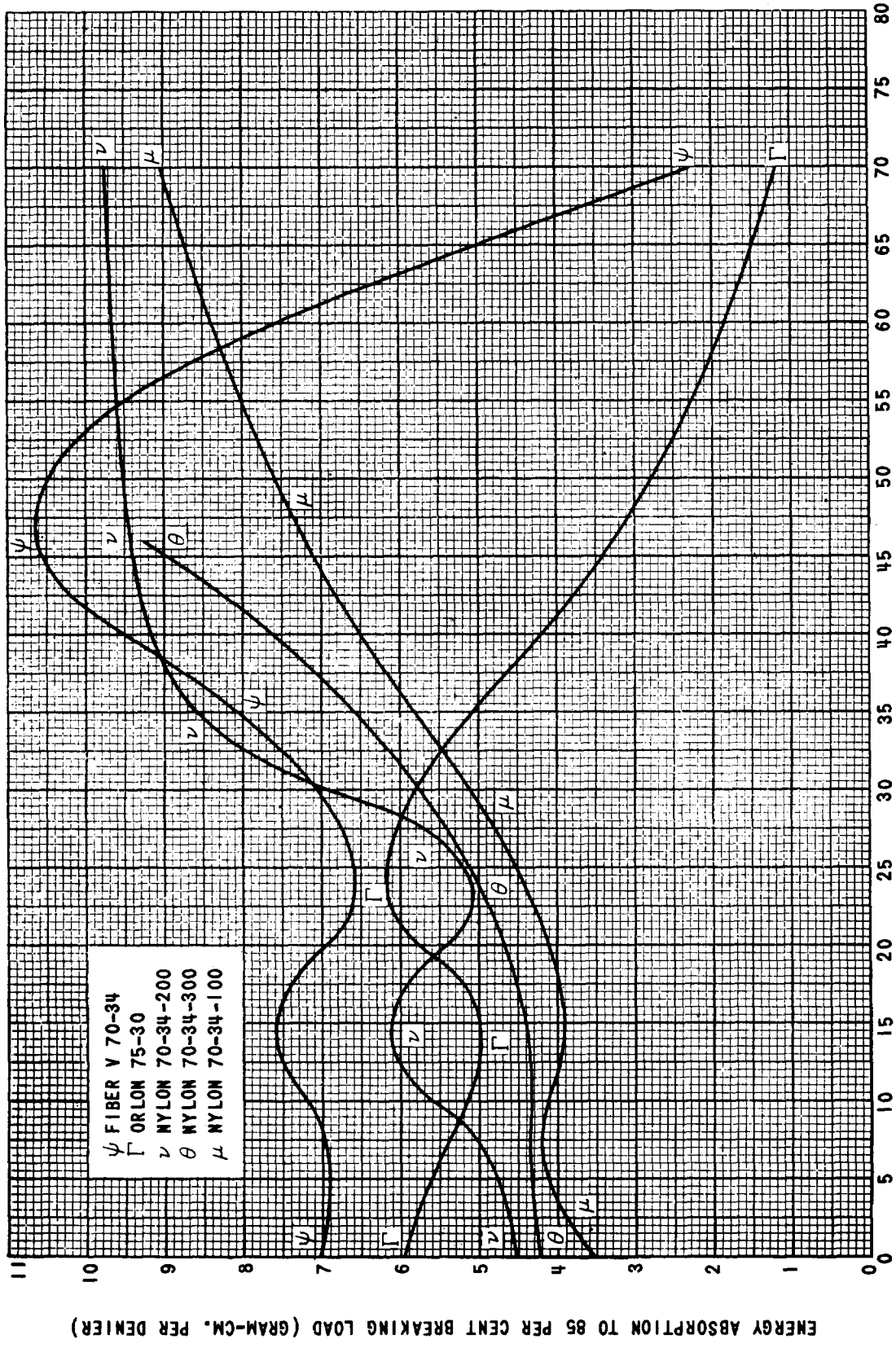


Figure 64. Summary of Energy Absorptions to 85 Per Cent Breaking Load.

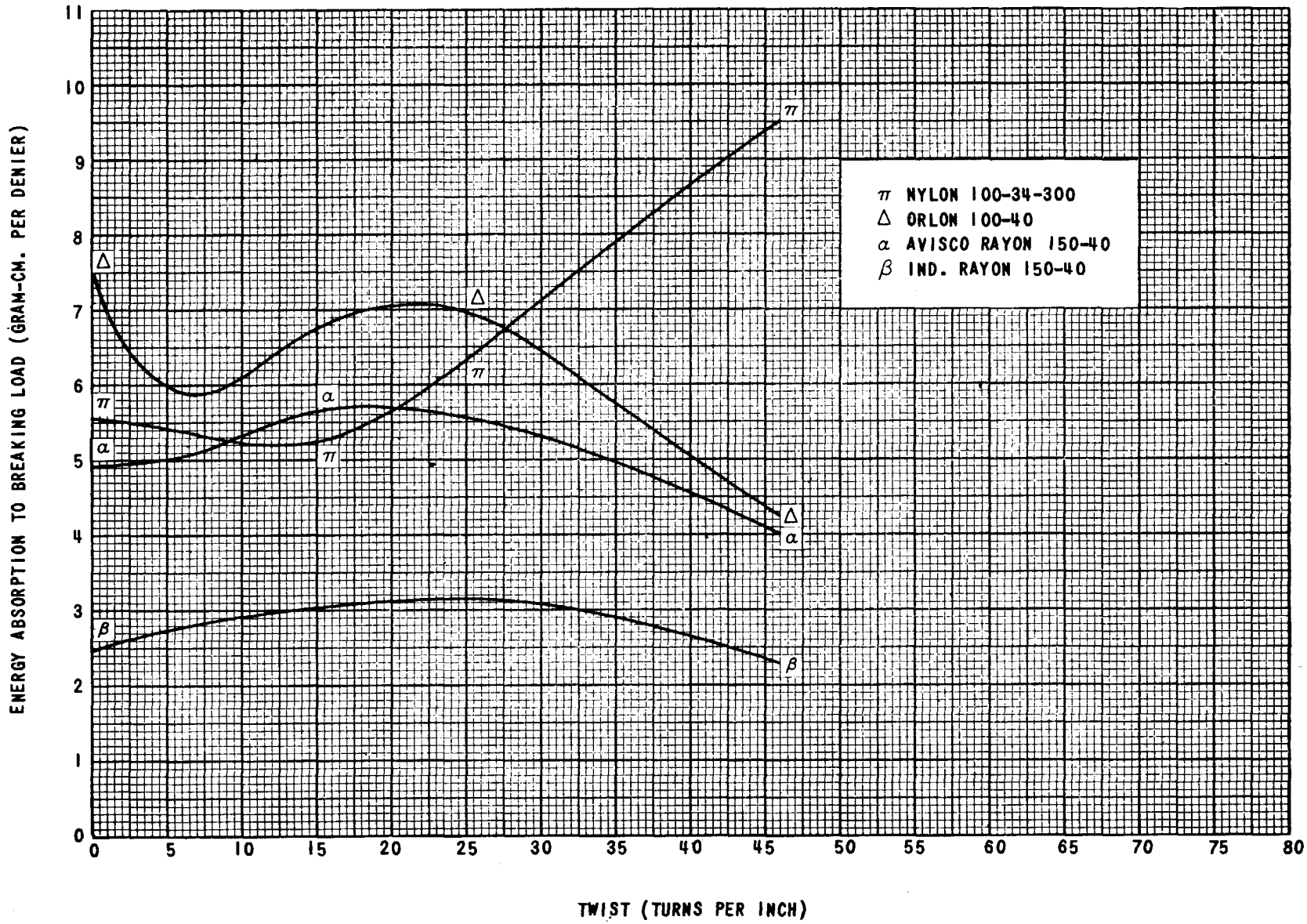


Figure 65. Summary of Energy Absorptions to 85 Per Cent Breaking Load.

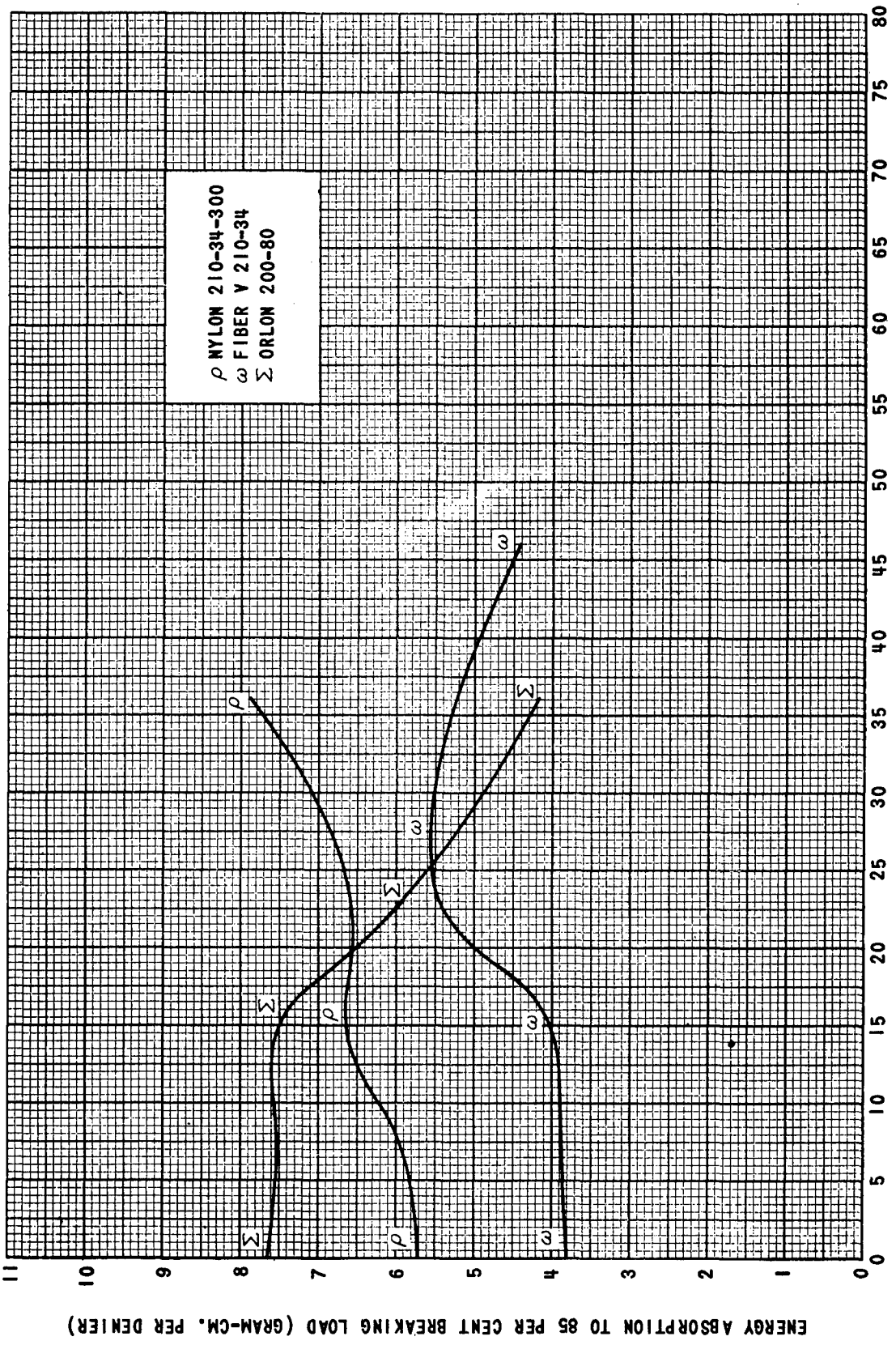


Figure 66. Summary of Energy Absorptions to 85 Per Cent Breaking Load.

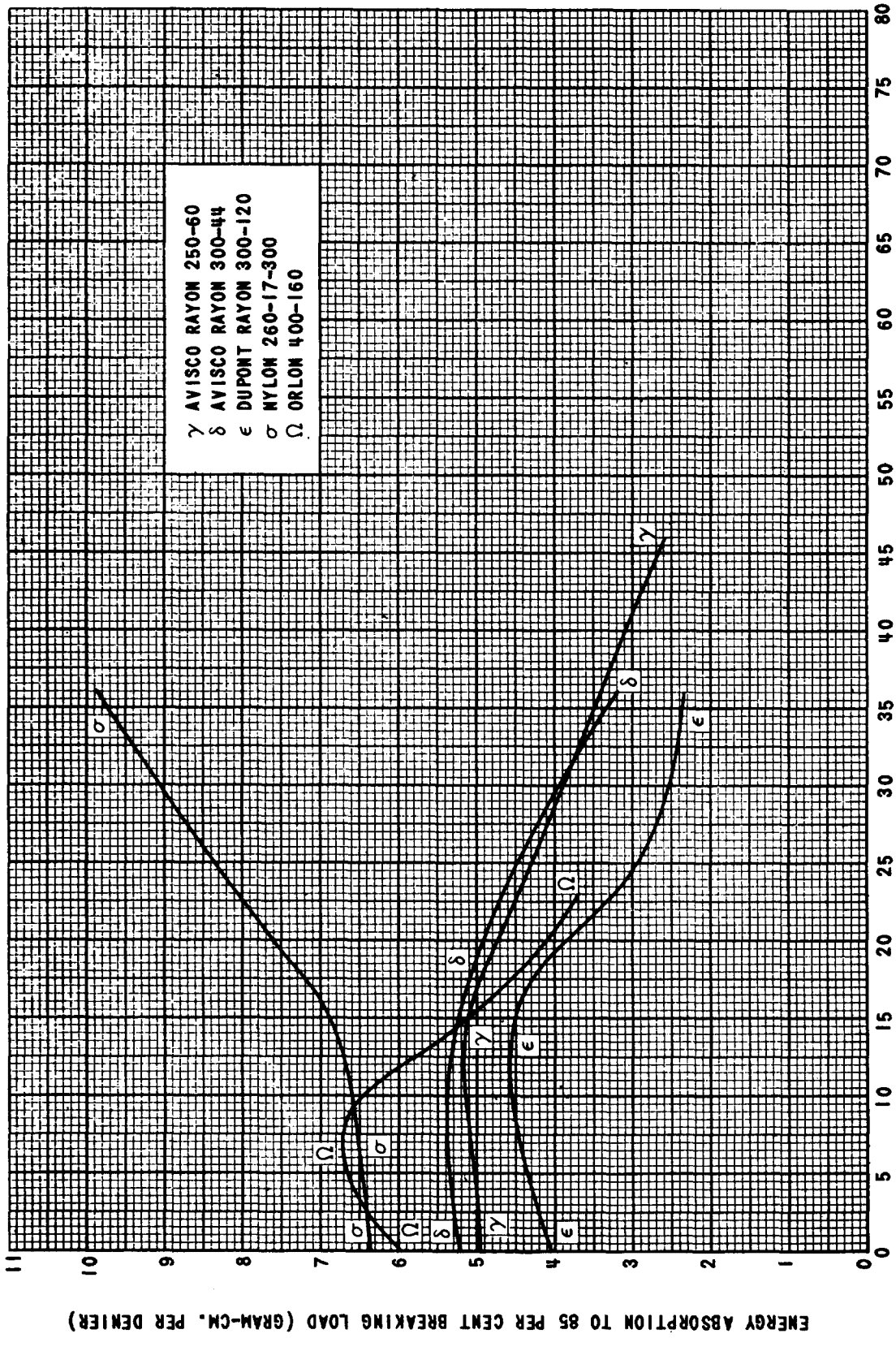


Figure 67. Summary of Energy Absorptions to 85 Per Cent Breaking Load.

TABLE XLIII

SUMMARY OF ELASTIC RECOVERY VALUES
FOR YARNS AT 85 PER CENT BREAKING LOAD

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)			
	Nylon 20-7-200	Nylon 30-10-200	Nylon 40-13-200	Fiber V 40-34
As-Received	53.5	53.8	47.3	40.7
7.0	57.9	60.9	57.4	48.7
14.0	58.5	59.8	57.7	54.1
23.0	55.5	60.0	54.5	42.6
36.0	58.0	57.7	56.4	33.9
46.0	57.3	59.8	51.3	33.3
70.0	—	49.4	44.4	30.8
100.0	—	40.2	39.7	27.1

	Nylon 70-34-100	Nylon 70-34-200	Nylon 70-34-300	Fiber V 70-34	Orlon 75-30
As-Received	71.0	64.2	62.5	40.0	33.8
7.0	68.1	62.0	61.1	43.5	35.4
14.0	69.6	58.0	60.0	36.4	34.6
23.0	65.9	61.7	56.0	38.1	35.9
36.0	57.5	48.9	50.0	33.3	34.2
46.0	51.7	46.0	43.3	27.1	32.6
70.0	34.0	41.1	35.1	42.2	28.6
100.0	—	—	—	—	—

	Nylon 100-34-300	Orlon 100-40	AVisco 150-40	Ind. Ray. 150-40
As-Received	66.7	30.2	18.6	32.4
7.0	65.8	34.5	17.9	30.7
14.0	66.4	34.5	17.1	33.8
23.0	63.1	33.1	17.2	31.1
36.0	53.3	31.5	17.3	29.7
46.0	45.6	29.9	15.7	28.1
70.0	—	—	—	—
100.0	—	—	—	—

(Continued)

TABLE XLIII (Continued)

SUMMARY OF ELASTIC RECOVERY VALUES
FOR YARNS AT 85 PER CENT BREAKING LOAD

Approximate Twist Added (TPI)	Elastic Recovery (Per Cent)				
	Nylon 210-34-300	Fiber V 210-34	Orlon 200-80		
As-Received	65.5	63.2	31.9		
7.0	66.7	62.9	32.4		
14.0	63.9	61.5	33.8		
23.0	60.5	50.5	28.6		
36.0	49.8	41.7	24.1		
46.0	—	34.4	—		
70.0	—	—	—		
100.0	—	—	—		
	AVisco 250-60	AVisco 300-44	DuPont Rayon 300-120	Nylon 260-17-300	Orlon 400-160
As-Received	14.5	13.5	23.3	59.8	34.6
7.0	13.8	14.6	25.7	57.8	35.4
14.0	13.8	14.4	20.4	57.3	35.0
23.0	15.7	14.0	16.1	51.7	31.8
36.0	14.6	14.0	19.0	41.6	—
46.0	15.9	—	—	—	—
70.0	—	—	—	—	—
100.0	—	—	—	—	—

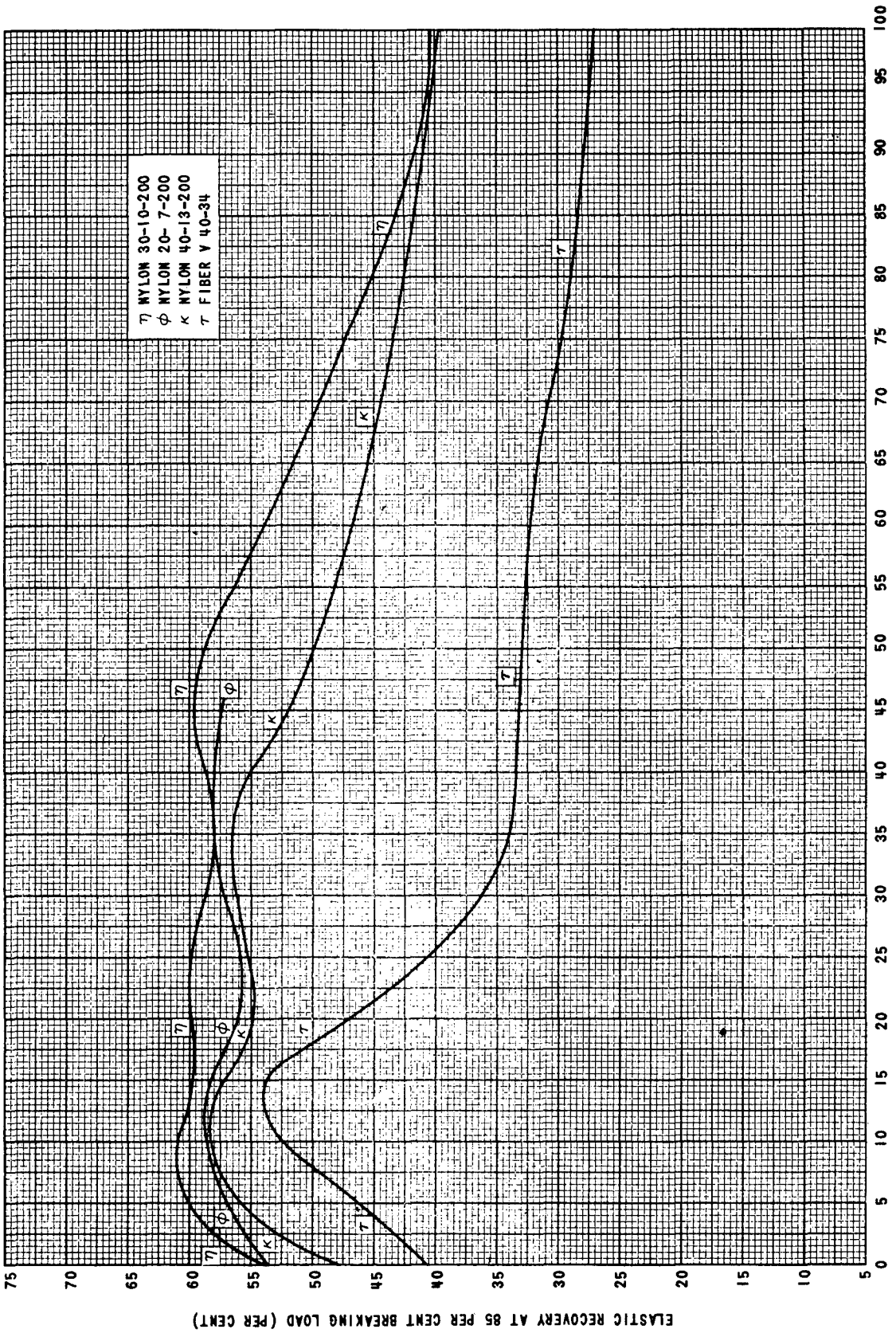


Figure 68. Summary of the Elastic Recovery of Yarns at 85 Per Cent Breaking Load.

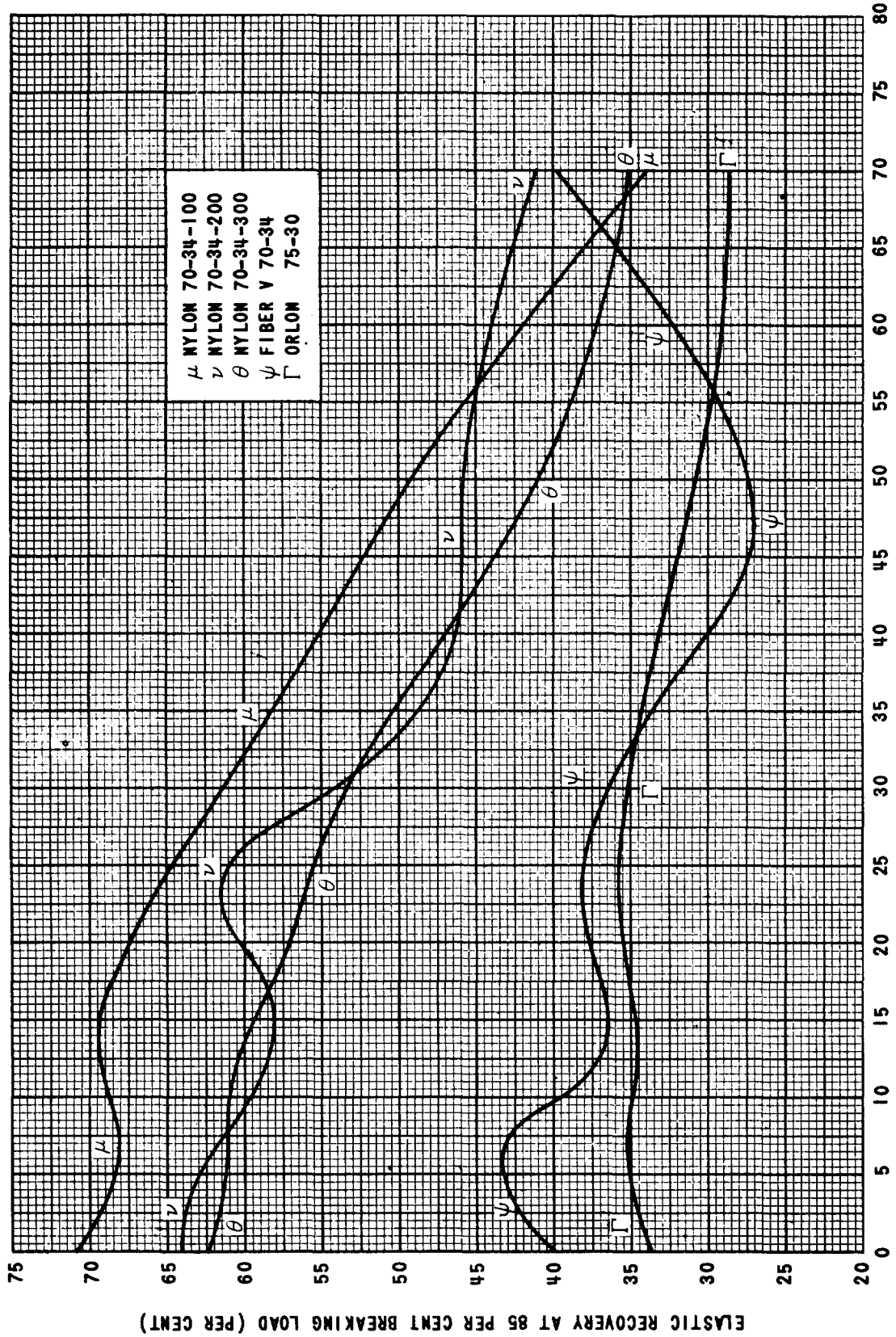


Figure 69. Summary of the Elastic Recovery of Yarns at 85 Per Cent Breaking Load.

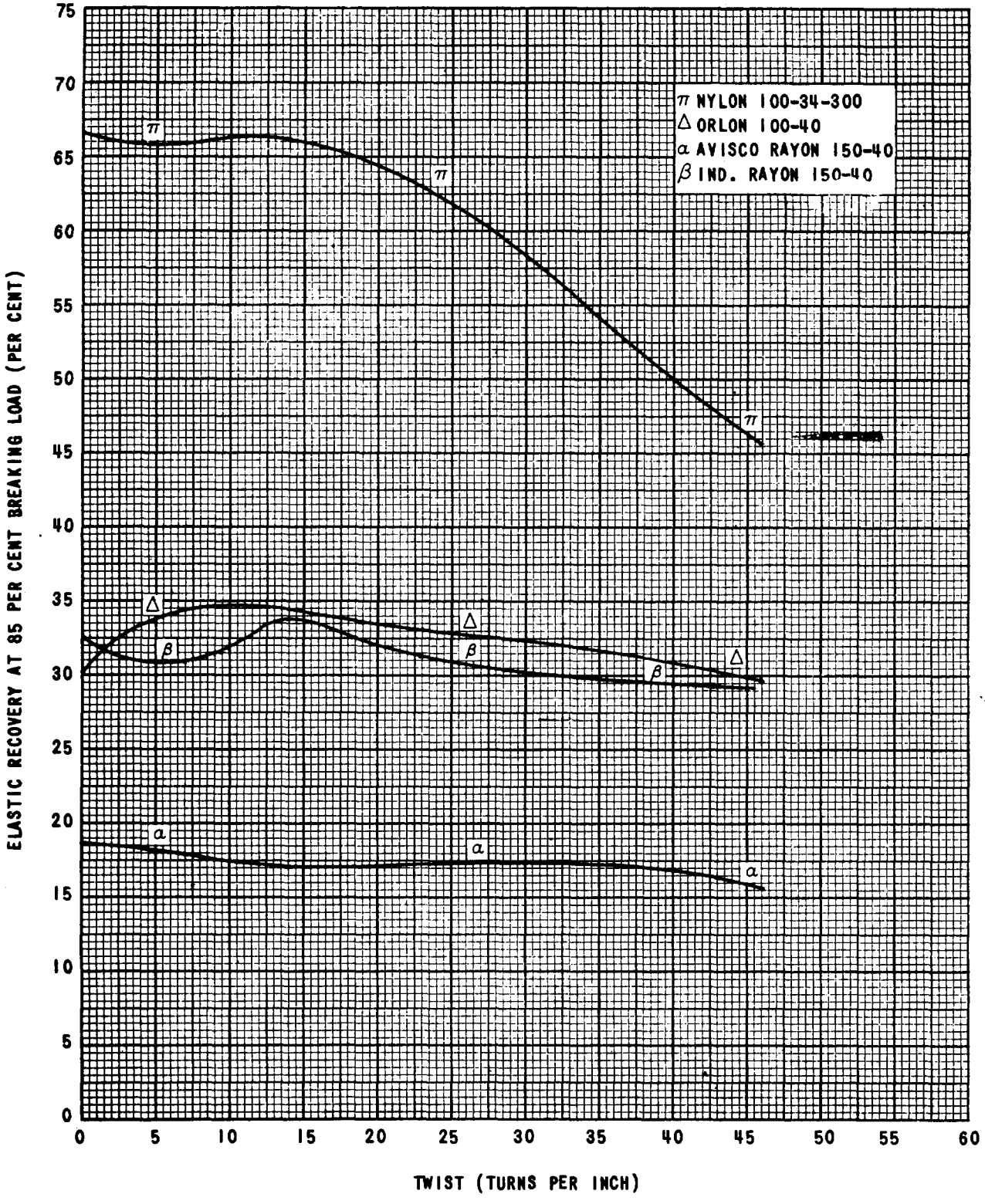


Figure 70. Summary of the Elastic Recovery of Yarns at 85 Per Cent Breaking Load.

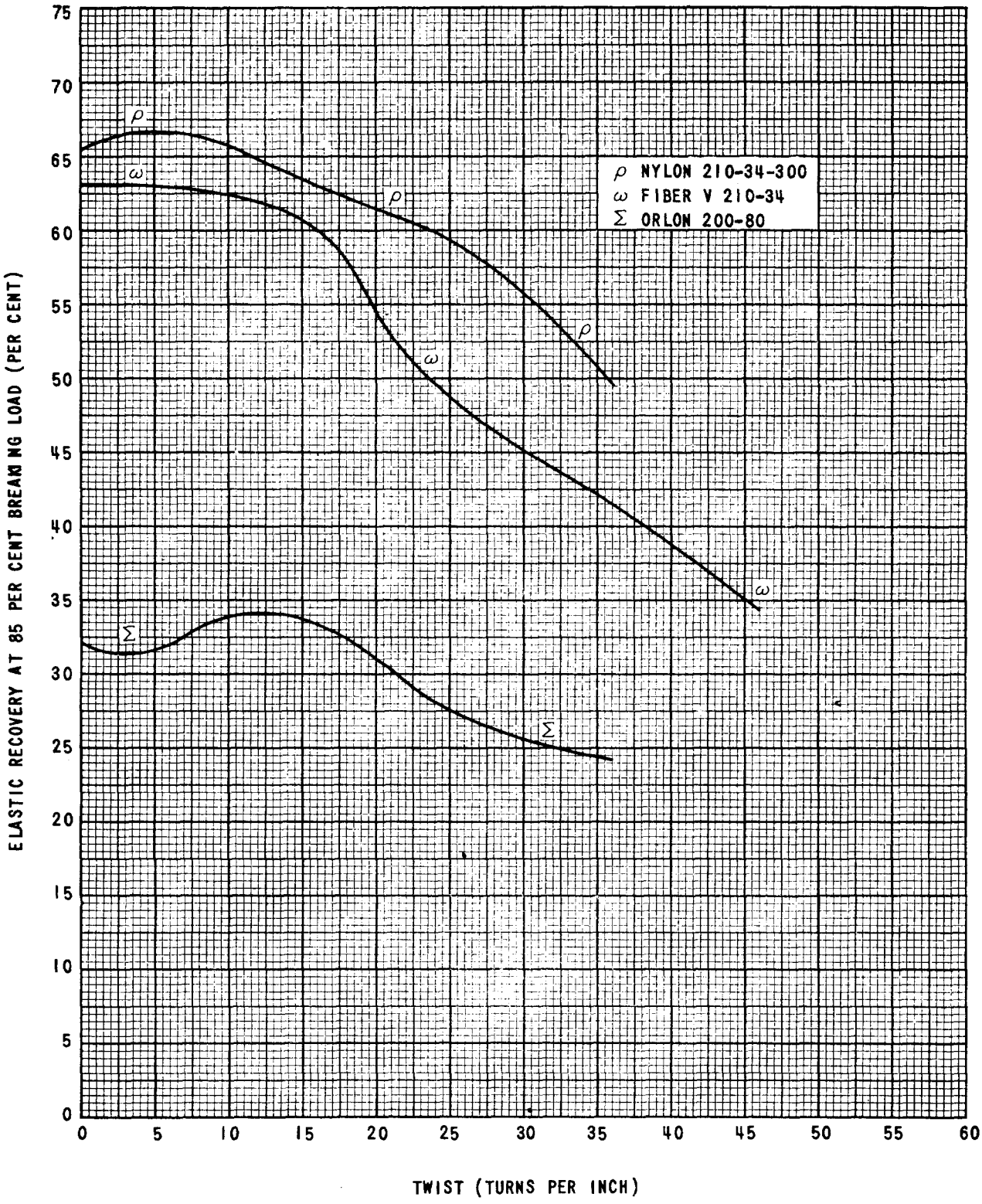


Figure 71. Summary of the Elastic Recovery of Yarns at 85 Per Cent Breaking Load.

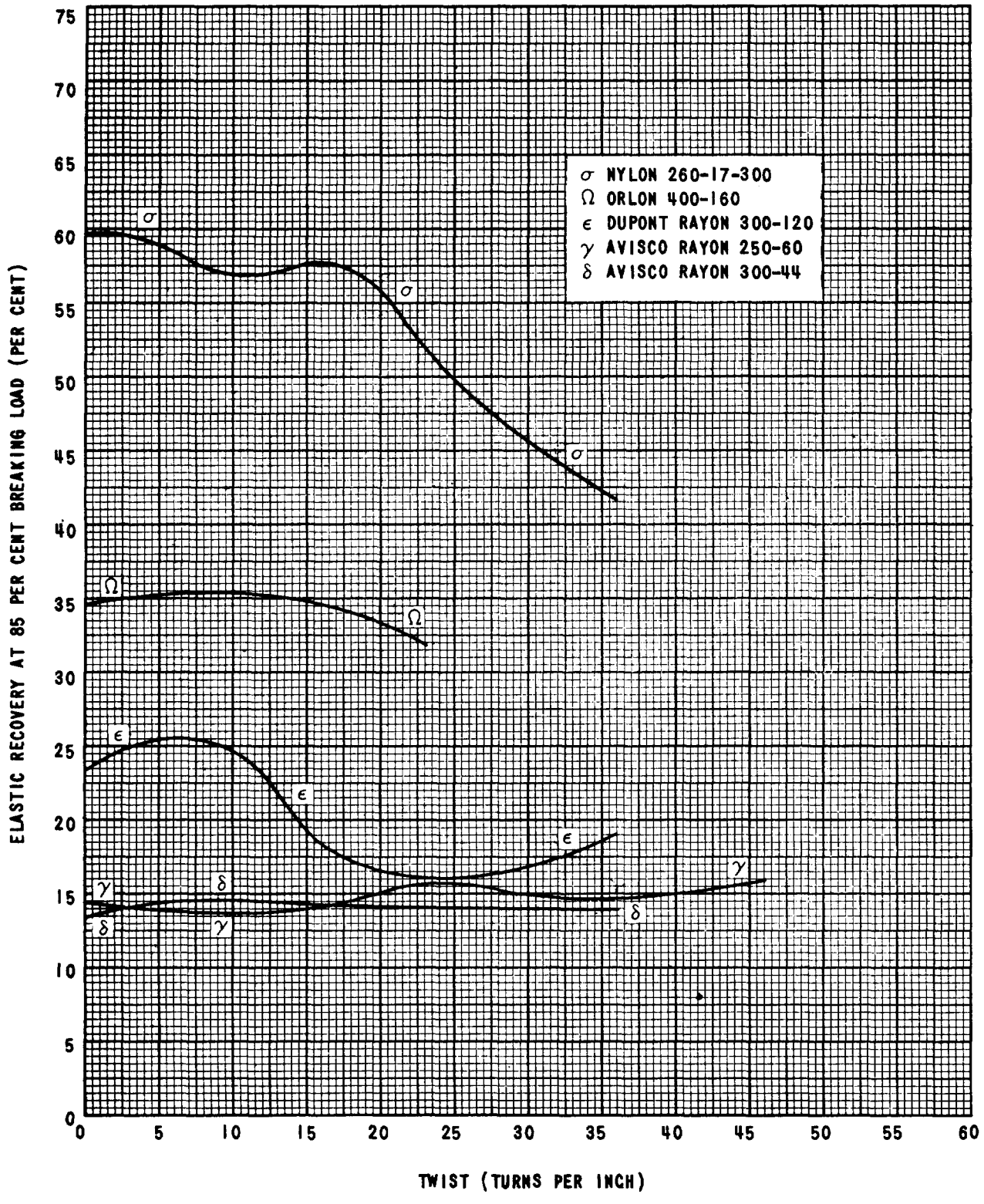


Figure 72. Summary of the Elastic Recovery of Yarns at 85 Per Cent Breaking Load.

TABLE XLIV

SUMMARY OF ELONGATION MEASUREMENTS
ON YARNS AT BREAKING LOAD

Approximate Twist Added (TPI)	Elongation (Per Cent)			
	Nylon 20-7-200	Nylon 30-10-200	Nylon 40-13-200	Fiber V 40-34
As-Received	24.4	25.5	29.2	22.6
7.0	23.5	24.7	24.5	18.5
14.0	24.3	25.6	24.8	18.1
23.0	23.9	25.7	26.5	22.6
36.0	23.4	26.3	26.0	25.9
46.0	24.1	25.6	26.4	27.5
70.0	22.9	26.6	27.8	27.8
100.0	21.2	32.6	33.2	29.4

	Nylon 70-34-100	Nylon 70-34-200	Nylon 70-34-300	Fiber V 70-34	Orlon 75-30
As-Received	24.2	27.2	21.9	21.8	17.3
7.0	24.6	27.5	22.4	20.6	16.2
14.0	25.1	28.1	22.4	21.9	15.5
23.0	26.6	28.6	22.2	23.4	17.1
36.0	30.4	32.5	24.4	27.1	16.6
46.0	31.5	34.5	27.9	29.0	15.9
70.0	35.9	37.4	34.2	27.8	13.8
100.0	—	—	—	—	—

	Nylon 100-34-300	Orlon 100-40	AVisco 150-40	Ind. Ray. 150-40
As-Received	21.2	16.8	19.1	10.3
7.0	19.7	16.4	20.0	10.8
14.0	19.9	15.8	21.3	11.4
23.0	20.7	17.3	22.0	12.0
36.0	21.9	16.0	21.8	12.4
46.0	26.4	15.4	21.4	12.0
70.0	—	—	—	—
100.0	—	—	—	—

(Continued)

TABLE XLIV (Continued)

SUMMARY OF ELONGATION MEASUREMENTS
ON YARNS AT BREAKING LOAD

Approximate Twist Added (TPI)	Elongation (Per Cent)		
	Nylon 210-34-300	Fiber V 210-34	Orlon 200-80
As-Received	18.0	11.2	16.8
7.0	18.7	12.5	16.2
14.0	20.1	12.9	16.9
23.0	20.1	14.8	16.2
36.0	25.8	15.6	16.2
46.0	—	17.2	—
70.0	—	—	—
100.0	—	—	—

	AVisco 250-60	AVisco 300-44	DuPont Rayon 300-120	Nylon 260-17-300	Orlon 400-160
As-Received	21.5	21.0	14.6	24.5	15.7
7.0	22.2	22.3	15.7	25.2	16.4
14.0	22.8	22.8	16.2	25.5	15.7
23.0	22.5	22.5	15.4	27.8	15.3
36.0	22.0	21.4	13.9	35.6	—
46.0	21.4	—	—	—	—
70.0	—	—	—	—	—
100.0	—	—	—	—	—

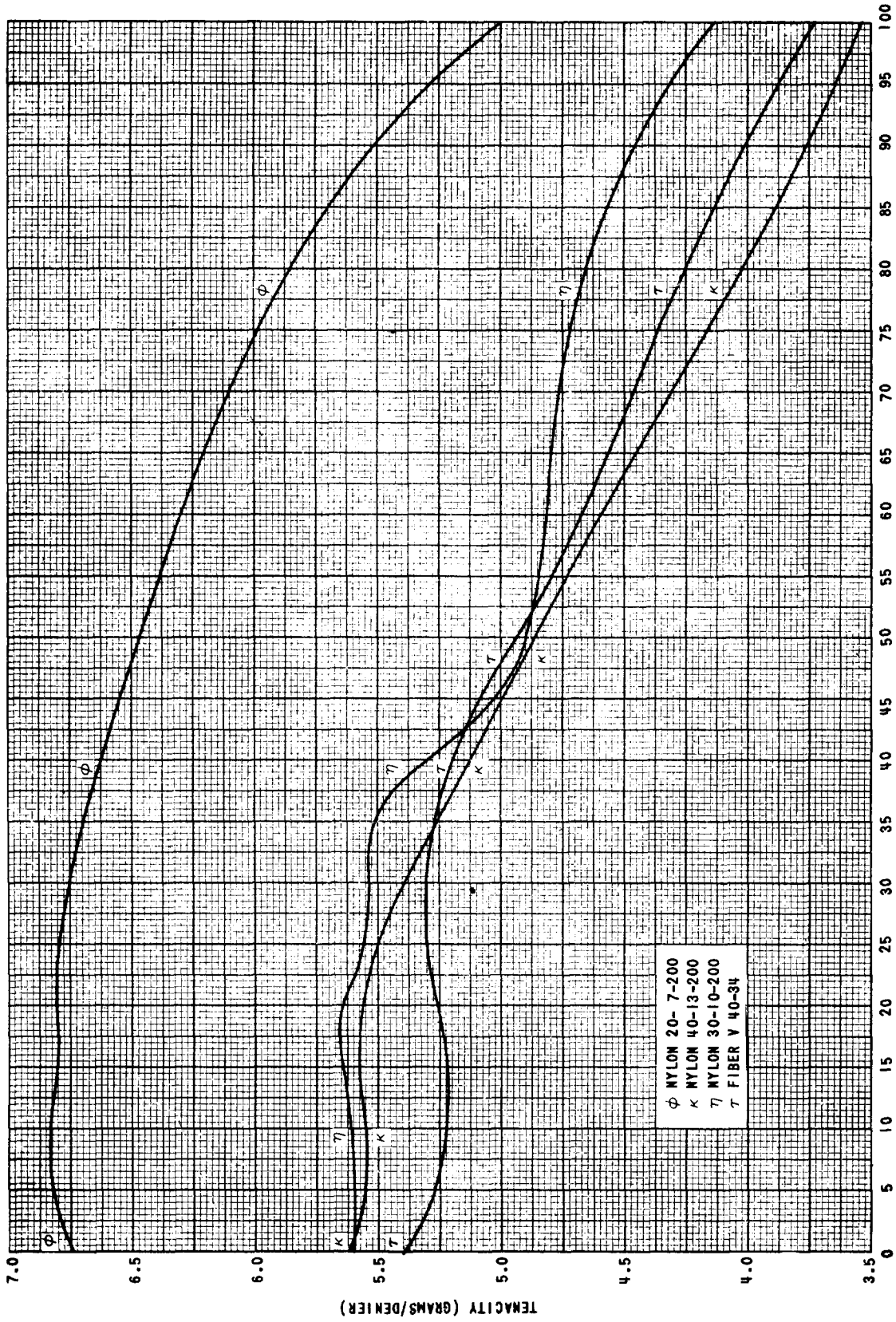


Figure 73. Summary of Yarn Tenacities.

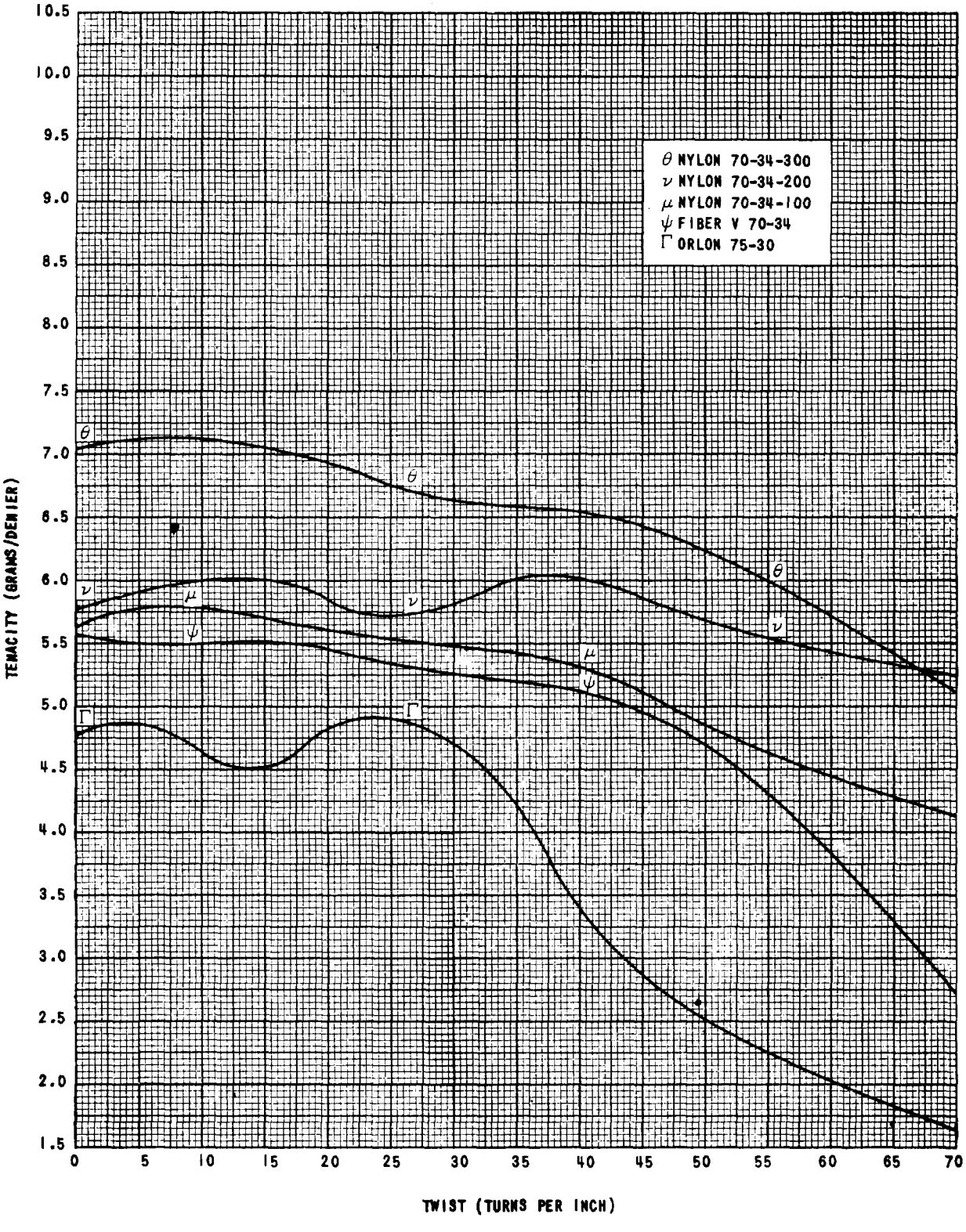


Figure 74. Summary of Yarn Tenacities.

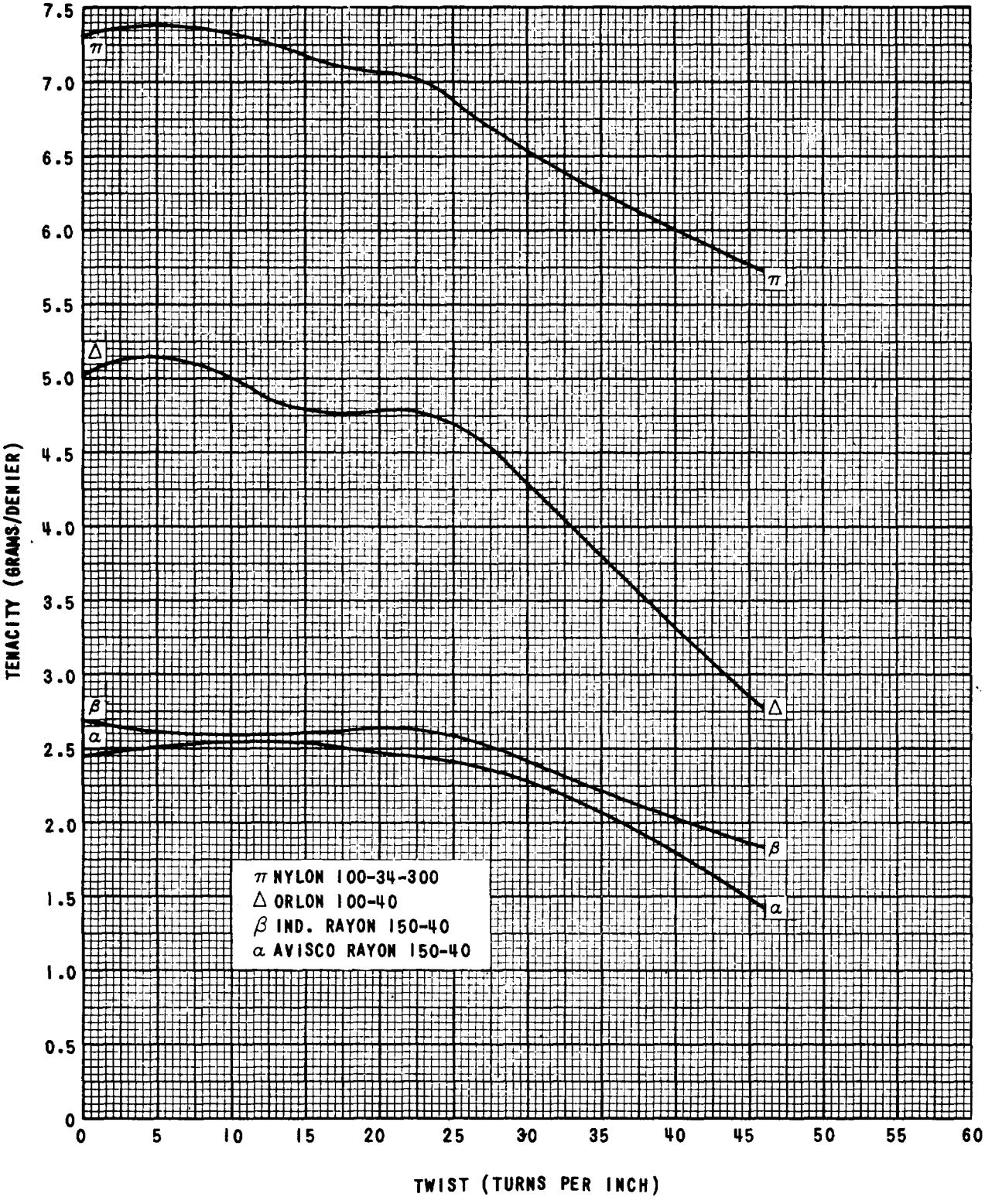


Figure 75. Summary of Yarn Tenacities.

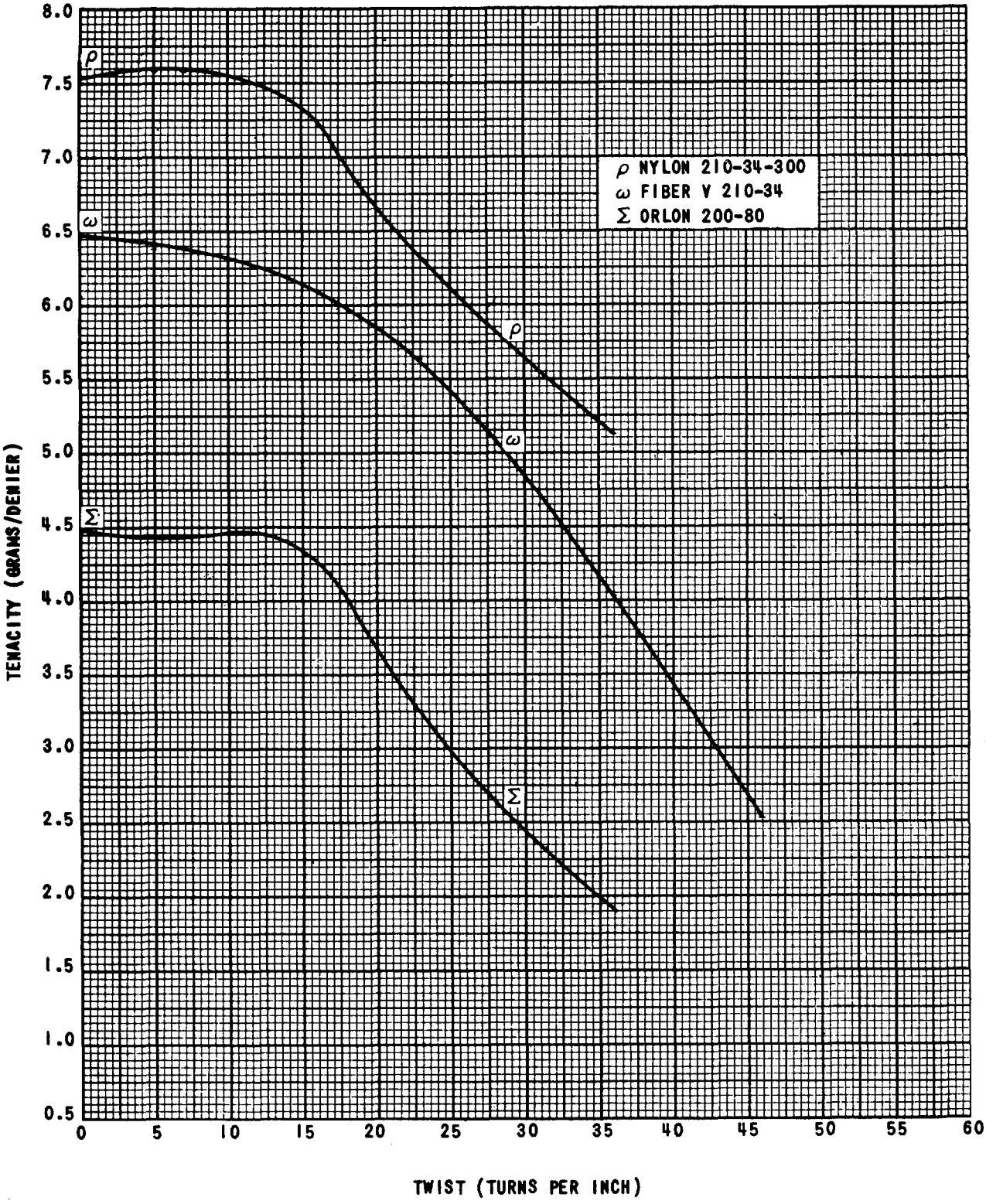


Figure 76. Summary of Yarn Tenacities.

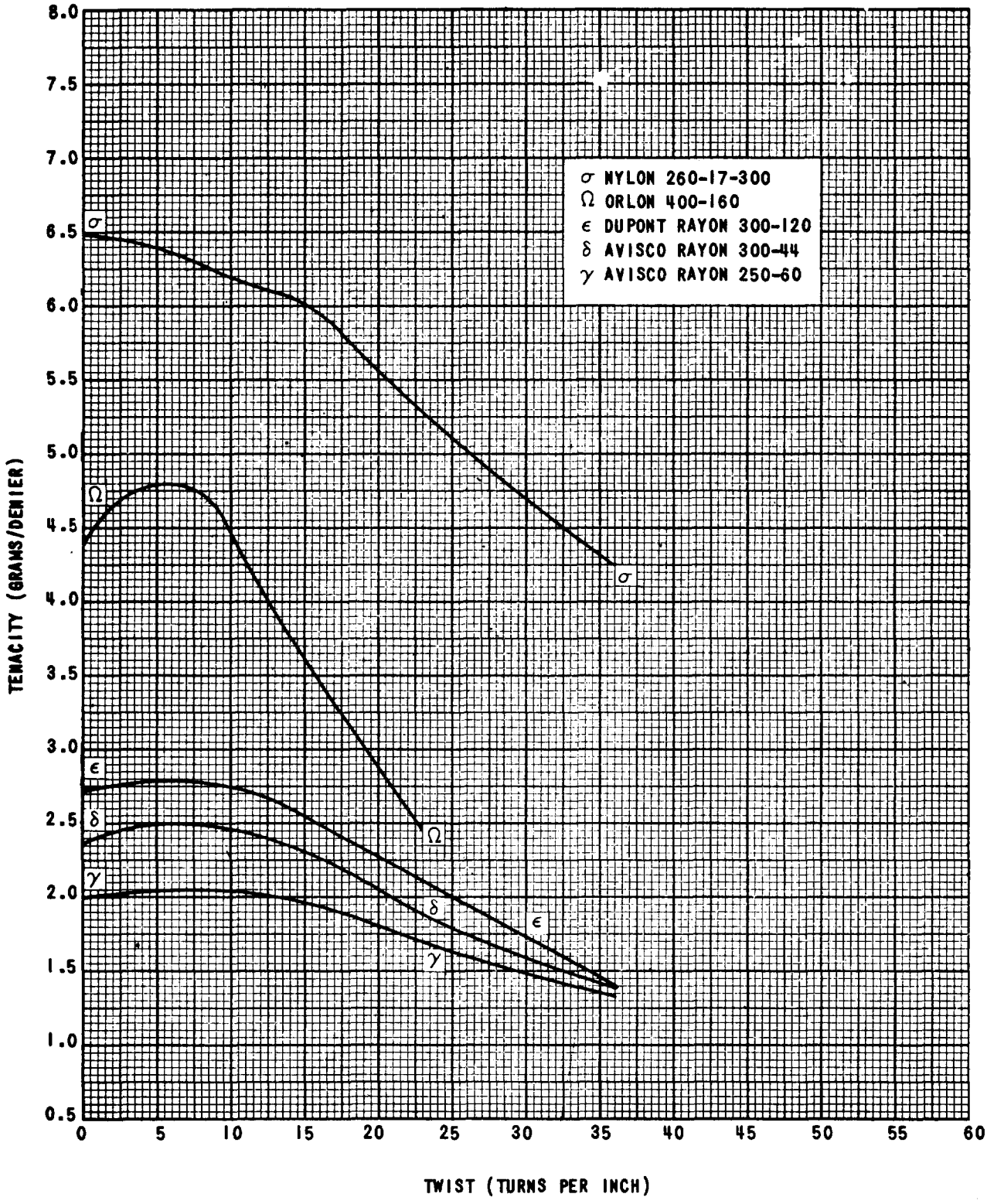


Figure 77. Summary of Yarn Tenacities.