1997

ANNUAL BOOK OF ASTM STANDARDS

SECTION 7

Textiles

ASTM

VOLUME 07.01 Textiles (I): D 76—D 3218

Revision issued annually

DMU 0406900 01 2
DE MONTFORT UNIVERSITY LIBRARY

1997 ANNUAL BOOK OF ASTM STANDARDS

SECTION 7

Textiles

ASTM

VOLUME 07.01

Textiles—Yarns, Fabrics, and General Test Methods

Includes standards of the following committee:

D-13 on Textiles

Publication Code Number (PCN): 01-070197-18

ASTM 100 Barr Harbor Drive, West Conshohocken, PA 19428 ■ (610) 832-9500 ■ FAX: 610-832-9555

dmu.ac.uk
DE MONTFORT UNIVERSITY
LEICESTER
LIBRARY

Editorial Staff

Director, Editorial Services:
Roberta A. Storer

Manager, Standards Publications:
Joan L. Cornillot
Paula C. Fazio-Fluehr

Senior Indexer:
H. Joel Shupak

Editors:
Jennifer C. Azara
Nicole C. Baldini
Lisa Bernhardt
Elizabeth L. Gutman
Joanne G. Kramer
Christine Leinweber
Vernice A. Mayer
Patricia A. McGee
Todd J. Sandler
Richard F. Wilhelm

Editorial Assistants:
Audrey Lewandowski
Karen L. Riley

DE MONTFORT UNIVERSITY LIBRARY
Acc. No.
Date 6/8/98
Loc./Form REF
Class 669.0218
Ann

Library of Congress Catalog Card Number: 83-641658

ISBN 0-8031-2468-6 (set)
ISBN 0-8031-2426-0 (section)
ISBN 0-8031-2427-9 (volume)

Copyright © 1997 AMERICAN SOCIETY FOR TESTING AND MATERIALS, West Conshohocken, PA. Prior editions copyrighted 1996 and earlier, by the American Society for Testing and Materials. All rights reserved. This material may not be reproduced or copied, in whole or in part, in any printed, mechanical, electronic, film, or other distribution and storage media, without the written consent of the publisher.

Photocopy Rights

Authorization to photocopy items for internal, personal, or educational classroom use, or the internal, personal, or educational classroom use of specific clients, is granted by the American Society for Testing and Materials (ASTM) provided that the appropriate fee is paid to the Copyright Clearance Center, 222 Rosewood Drive, Danvers, MA 01923, Tel: 508-750-8400; online: http://www.copyright.com/

Printed in Easton, MD, U.S.A.

Foreword

Organized in 1898, ASTM has grown into one of the largest voluntary standards development systems in the world. ASTM is a not-for-profit organization which provides a forum for producers, users, ultimate consumers, and those having a general interest (representatives of government and academia) to meet on common ground and write standards for materials, products, systems, and services.

From the work of 132 standards-writing committees, ASTM publishes more than 9,800 standards each year. These standards and other related technical information are sold throughout the world.

ASTM Headquarters has no technical research or testing facilities; such work is done voluntarily by 33,300 technically qualified ASTM members located throughout the world. Membership in the Society is open to all concerned with the fields in which ASTM is active. A membership application may be found at the back of this volume. Additional information may be obtained from Member and Committee Services, ASTM, 100 Barr Harbor Drive, West Conshohocken, PA 19428; tel. (610) 832-9693.

1997 Annual Book of ASTM Standards

The 1997 *Annual Book of ASTM Standards* consists of 72 volumes, divided among 16 sections, of which this volume is one. It contains approved ASTM standards, provisional standards, and related material. These terms are defined as follows in the *Regulations Governing ASTM Technical Committees:*

Categories:

standard—as used in ASTM, a document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations.
Discussion—The term "standard" serves in ASTM as an adjective in the title of documents, such as test methods or specifications, to connote specified consensus and approval. The various types of standard documents are based on the needs and usages as prescribed by the technical committees of the Society.

provisional standard—a document published for a limited period of time by the Society to meet a demand for more rapid issuance of specific documents, such as an emergency situation, regulatory requirements, or other special circumstances.
Discussion—Provisional standards are not full consensus documents because they require subcommittee consensus only. (These documents replace emergency standards and proposals.)

Types:

The various types of ASTM documents are to provide a flexibility of form, communication, and usage for both the technical committees and the myriad users of ASTM documents. The type of ASTM document that is developed and titled is based on the technical content and intended use, not on the degree of consensus achieved. The two categories of ASTM documents (standard and provisional standard) can be of the following forms and types:

classification—a systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use.

guide—a series of options or instructions that does not recommend a specific course of action.
Discussion—Whereas a practice prescribes a general usage principle, a guide only suggests an approach. The purpose of a guide is to offer guidance, based on a consensus of viewpoints, but not to establish a fixed procedure. A guide is intended to increase the awareness of the user to available techniques in a given subject area and to provide information from which subsequent evaluation and standardization can be derived.

Hyosung Ex. 1033, Page 3 of 31

LISTED BY SUBJECTS

SUBJECTS	VOLUME
Temperature Measurement	14.03
Textiles	07.01, 07.02
Thermal Insulation	04.06
Thermal Measurements	14.02
Thermocouples	14.03
Thermostats, Electrical Heating and Resistance, Contacts, and Connectors	03.04
Tires	09.02
Traveled Surface Characteristics	04.03
Vacuum Cleaners	15.07
Vehicle-Pavement Systems	04.03
Vitrified clay Pipe	04.05
Waste Management	11.04
Water	11.01, 11.02
Wear and Erosion	03.02
Wood	04.10

Contents

1997 ANNUAL BOOK OF ASTM STANDARDS, VOLUMES *07.01* AND 07.02

STANDARDS RELATING TO TEXTILES—YARNS, FABRICS, AND GENERAL TEST METHODS, FIBERS AND ZIPPERS

A complete Subject Index begins on p. 879

This contents includes only those standards included in Volumes 07.01 and 07.02 and those standards that appeared previously that have been superseded or discontinued within the past five years.[1] Since the standards in this book are arranged in alphanumeric sequence, no page numbers are given in this contents.

In the serial designations prefixed to the following titles, the number following the dash indicates the year of original adoption as standard or, in the case of revision, the year of last revision. Thus, standards adopted or revised during the year 1997 have as their final number, 97. A letter following this number indicates more than one revision during that year, that is, 97a indicates the second revision in 1997, 97b the third revision, etc. Standards that have been reapproved without change are indicated by the year of last reapproval in parentheses as part of the designation number, for example, (1997). A superscript epsilon indicates an editorial change since the last revision or reapproval—ε1 for the first change, ε2 for the second change, etc.

Volume 07.01

D 76 – 93	Specification for Tensile Testing Machines for Textiles
D 123 – 96a	Terminology Relating to Textiles
D 204 – 97	Methods of Testing Sewing Threads
§D 276 – 87 (1993)ε1	Test Methods for Identification of Fibers in Textiles
§D 418 – 93	Methods of Testing Pile Yarn Floor Covering Construction
§D 434 – 95	Test Method for Resistance to Slippage of Yarns in Woven Fabrics Using a Standard Seam
D 461 – 93	Test Methods for Felt
D 519 – 90 (1995)	Test Method for Length of Fiber in Wool Top
D 541 – 87ε1	Specification for Single Jute Yarn (Discontinued 1996†)
D 578 – 96	Specification for Glass Fiber Strands
D 579 – 97	Specification for Greige Woven Glass Fabrics
D 580 – 94	Specification for Greige Woven Glass Tapes and Webbing
D 581 – 94	Specification for Glass Fiber Greige Braided Tubular Sleeving
D 584 – 96	Test Method for Wool Content of Raw Wool—Laboratory Scale
§D 629 – 95	Test Methods for Quantitative Analysis of Textiles
D 681 – 87 (1993)ε1	Specification for Jute Rove and Plied Yarn for Electrical and Packing Purposes
D 737 – 96	Test Method for Air Permeability of Textile Fabrics
D 861 – 95	Practice for Use of the Tex System to Designate Linear Density of Fibers, Yarn Intermediates, and Yarns
D 885 – 94	Methods of Testing Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made from Man-Made Organic-Base Fibers
D 885M – 94	Methods of Testing Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made from Man-Made Organic-Base Fibers [Metric]
D 1059 – 97	Test Method for Yarn Number Based on Short-Length Specimens
D 1060 – 96	Practice for Core Sampling of Raw Wool in Packages for Determination of Percentage of Clean Wool Fiber Present
D 1113 – 90a (1995)	Test Method for Vegetable Matter and Other Alkali-Insoluble Impurities in Scoured Wool
D 1117 – 97	Methods of Testing Nonwoven Fabrics
D 1230 – 94	Test Method for Flammability of Apparel Textiles
D 1233 – 88 (1993)ε1	Specification for Twine Made from Bast and Leaf Fibers
D 1234 – 85 (1995)	Method of Sampling and Testing Staple Length of Grease Wool
D 1244 – 81 (1996)ε1	Practice for Designation of Yarn Construction
D 1282 – 96	Test Method for Resistance to Airflow as an Indication of Average Fiber Diameter of Wool Top, Card Sliver, and Scoured Wool
D 1283 – 85 (1995)ε1	Test Method for Alkali-Solubility of Wool
D 1294 – 95a	Test Method for Tensile Strength and Breaking Tenacity of Wool Fiber Bundles—1-in. (25.4-mm) Gage Length
D 1334 – 96	Test Method for Wool Content of Raw Wool—Commercial Scale
§D 1335 – 67 (1972)	Test Method for Tuft Bind of Pile Floor Coverings (Discontinued 1995†)

[1] For a list of all former standards on textile materials published by the Society, see Volume 07.01, p. 865.

† Although this standard has been officially withdrawn from Society approval, a brief description is included for information only.

§ Approved for use by agencies of the Department of Defense and, if indicated on the standard, replaces corresponding federal or military document. Consult the DoD Index of Specifications and Standards for the specific year of issue which has been adopted by the Department of Defense.

Hyosung Ex. 1033, Page 4 of 31

Designation: D 885 – 94

Standard Test Methods for Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made from Man-Made Organic-Base Fibers[1]

This standard is issued under the fixed designation D 885; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the testing of industrial filament yarns made wholly of man-made organic-base fibers, cords twisted from such yarns, and fabrics woven from such cords, products that are made specifically for use in the manufacture of pneumatic tires. If desired, these test methods may be applied to similar yarns and cords used for reinforcing other rubber goods and for other industrial applications. These test methods apply to nylon, polyester, rayon, and high-modulus aramid yarns and tire cords twisted from such yarns and to fabrics made from such cords. The yarn or cord may be wound on cones, tubes, bobbins, spools, or beams, woven into fabric or in other forms. These test methods include testing procedures only. These test methods do not include specification or tolerances.

1.2 No procedure is included for the determination of fatigue resistance of cord, but several commonly used procedures for the measurement of fatigue resistance of cords in rubber were published in the appendix of these test methods in the *1967 Book of ASTM Standards*, Part 24, and in earlier issues of Test Methods D 885.

NOTE 1—For tolerances on tire cords and tire cord fabrics, refer to the issue of Methods D 885 published in the *1984 Annual Book of ASTM Standards*, Vol 07.01, and in earlier issues. For tolerances on industrial yarns, tire cords, and tire cord fabrics made from man-made organic-base fibers, see Tolerances D 3219, for Industrial Filament Yarns, Tire Cords, and Tire Cord Fabrics Made from Man-Made Organic-Base Fibers.[2] For tolerances on other textile materials used in tires, refer to Tolerances D 122, for Tire Fabrics Other Than Tire Cord Fabrics.[2] For methods of test for glass cords refer to Methods D 2970, Testing Tire Cords, Tire Cord Fabrics, and Industrial Yarns Made from Glass Filaments;[2] for wire cords refer to Methods D 2969, Testing Filaments, Strands, Cords, and Fabrics Made from Steel.[2]

1.3 These test methods include the following sections:

	Section
Adhesion of Cord to Elastomers	36
Bibliography of Tire Cord Test Methods	X1
Breaking Strength (Load) of Yarns and Cords at Elevated Temperature	30.2
Breaking Strength (Load) of Conditioned Yarns and Cords	15
Breaking Strength (Load) of Oven-Dry Rayon Yarns and Cords	22
Breaking Strength (Load) of Rayon Yarns and Cords Adjusted to a Specific Moisture Regain Level	16
Breaking Tenacity of Conditioned Yarns and Cords	17
Breaking Tenacity of Oven-Dry Rayon Yarns and Cords	23
Breaking Toughness of Yarns and Cords	27
Commercial Mass (Note 2)	9
Conditioning	7
Contraction of Wet Yarns and Cords	31.2
Count of Fabric	37.3
Dip Adhesives Solids Pickup on Yarns and Cords	35
Elongation at Break of Conditioned Yarns and Cords	18
Elongation at Break of Oven-Dry Rayon Yarns and Cords	24
Elongation of Rayon Yarns and Cords Adjusted to a Specific Moisture Regain Level	19
Extractable Matter in Yarns and Cords	34
Fabric Properties, Count, Weight, and Width	37
Growth of Conditioned Yarns and Cords	29
Identification of Fibers	8
Linear Density of Yarns and Cords	11
Load at Specified Elongation (LASE) of Conditioned Yarns and Cords	20
Load at Specified Elongation (LASE) of Oven-Dry Rayon Yarns and Cords	25
Weight of Fabric (Note 2)	37.2
Modulus of Conditioned Yarns and Cords	21
Moisture Regain for Adjustment of Tensile Properties of Rayon Yarns and Cords	10
Precision and Bias of Certain Cord Tests	39
Sampling	6
Shrinkage Force of Conditioned Yarns and Cords at Elevated Temperature	30.4
Shrinkage of Conditioned Yarns and Cords at Elevated Temperature	30.3
Stiffness of Fabric	38
Tensile Properties of Yarns and Cords	12 to 29
Terminology	3
Thickness of Cords	33
Twist in Yarns and Cords	32

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of whoever uses this standard to consult and establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

NOTE 2—The technically correct term "mass" is used in these test methods instead of "weight."

2. Referenced Documents

2.1 *ASTM Standards:*

D 76 Specification for Tensile Testing Machines for Textiles[2]
D 123 Terminology Relating to Textiles[2]
D 276 Test Methods for Identification of Fibers in Textiles[2]
D 1423 Test Method for Twist in Yarns by the Direct Counting Method[2]
D 1777 Method for Measuring Thickness of Textile Materials[2]
D 1907 Test Method for Yarn Number by the Skein Method[2]
D 1909 Table of Commercial Moisture Regains for Textile Fibers[2]
D 2138 Test Method for Rubber Property—Adhesion to Textile Cord[3]
D 2256 Test Method for Tensile Properties of Yarns by the Single Strand Method[2]
D 2257 Test Method for Extractable Matter in Yarns[2]
D 2258 Practice for Sampling Yarn for Testing[2]
D 2494 Test Method for Commercial Mass of a Shipment of Yarn or Man-Made Staple Fiber or Tow[2]
D 2654 Test Methods for Moisture Content and Moisture Regain of Textiles[2]
D 3774 Test Methods for Width of Woven Fabric[4]
D 3775 Test Method for Count of Woven Fabric[4]
D 3776 Test Method for Mass per Unit Area (Weight) of Woven Fabric[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *atmosphere for testing textiles, n*—for tire cords and industrial yarns, air maintained at a relative humidity of 55 ± 2 % and at a temperature of 75 ± 2°F.[5]

3.1.2 *breaking load, n*—the maximum force applied to a specimen in a tensile test carried to rupture. (See also *tensile strength.*)

3.1.2.1 *Discussion*—Breaking load commonly is expressed as pounds-force (lbf).

3.1.3 *breaking strength, n*—the ability or capacity of a specific material to withstand the ultimate tensile load or force required for rupture. (See also *tensile strength*)

3.1.3.1 *Discussion*—Breaking strength is particularly significant as the characteristic of a sample as distinct from a specimen and usually is expressed as pounds-force (lbf).

3.1.4 *breaking tenacity, n*—the maximum resistance per unit size of material to deformation in a tensile test carried to rupture; that is, the breaking load, or force, per unit linear density of the unstrained specimen. (See also *tensile strength*)

3.1.4.1 *Discussion*—Customarily, breaking tenacity is expressed as grams-force per denier (gf/den).

3.1.5 *breaking toughness, n*—the actual work per unit volume or per unit mass of material that is required to rupture the material. Breaking toughness is calculated from work-to-break, length, and linear density of a specimen or by dividing specific work-to-break by linear density.

3.1.5.1 *Discussion*—Breaking toughness usually is expressed as inch-pounds per denier-inch.

3.1.6 *cord twist, n.*—the amount of twist in a cord made from two or more single or plied yarns.

3.1.6.1 *Discussion*—Cord twist is based on the initial length of a cord specimen.

3.1.7 *dip, n*—a material applied to cords or fabric designed to improve the adhesion of the textile material to an elastomer.

3.1.8 *dip pickup, n—in a textile cord or fabric*, the amount of dip or dip components present after processing, including drying, as determined by prescribed methods, and expressed as a percentage of the mass of the oven-dry, dip-free material.

3.1.9 *elongation, n*—the ratio of the extension of a material to the length of the material prior to stretching, expressed as a percent.

3.1.9.1 *Discussion*—Elongation may be measured at any specified force or at rupture.

3.1.10 *growth, n*—the increase in length of a specimen caused by the application of a continuing load or force under specified conditions. (See also *delayed deformation*; *creep* in Terminology D 123.)

3.1.11 *industrial yarn, n*—a yarn composed of continuous filaments, usually of high breaking tenacity, produced with or without twist, and intended for applications in which functional properties are of primary importance; for example in reinforcing material in elastomeric products (tires, hose, belting), in protective coverings, and in cordage and webbing, etc.

3.1.12 *initial modulus, n*—the slope of the initial straight portion of a stress-strain (or load-elongation) curve.

3.1.12.1 *Discussion*—Modulus is the ratio of the change in stress, expressed grams-force per denier (gf/den.) to the change in strain, expressed as a fraction of the original length. When stress is expressed as tenacity and strain as percent elongation, for the straight-line portion of the load-elongation curve, it is convenient to calculate the initial modulus using the following equation:

$$\text{initial modulus} = (\text{tenacity/percent elongation}) \times 100$$

3.1.13 *load at specified elongation (LASE), n*—the load or force required to produce a specified or predetermined percentage elongation of a yarn or tire cord.

3.1.13.1 *Discussion*—The LASE usually is expressed as pounds-force (lbf).

3.1.14 *moisture equilibrium for testing, n—for industrial yarns and tire cords*, the condition reached when, after free exposure to a test atmosphere (see 3.1.1) which is in motion, two successive weighings not less than 4 h apart show not more than 0.1 % progressive change in mass of the specimen or sample.

3.1.15 *single twist, n*—the amount of twist in each individual single yarn element in a tire cord structure based on the length of the element after twist has been removed from the cord.

3.1.16 *tabby sample, n*—the section of tire cord fabric between two tabbies that have been woven separately with a distance of 18 to 36 in. between them.

3.1.16.1 *Discussion*—A tabby usually is woven 6 to 8 in. in length using cotton filling yarn in the range from No. 3 to No. 8 cotton count and 8 to 12 picks/in.

3.1.17 *tensile strength, n*—the maximum resistance of material to deformation in a tensile test carried to rupture; that is , the breaking load, or force, per unit cross-sectional area of the unstrained specimen.

3.1.17.1 *Discussion*—Customarily, tensile strength is expressed as pounds-force per square inch (psi).

NOTE 3—There has been considerable confusion and misuse of the terms breaking load, breaking strength, breaking tenacity, and tensile strength as they have been applied to industrial yarns and tire cords. Breaking load refers to an external force applied to an individual specimen or a specific piece of material to produce rupture, whereas breaking strength preferably is restricted to the characteristic average force required to rupture several specimens of a sample. It has been the

[1] These test methods are under the jurisdiction of ASTM Committee D-13 on Textiles and are the direct responsibility of Subcommittee D13.19 on Tire Cord and Fabrics.

Current edition approved Dec. 15, 1994. Published July 1995. Originally published as D 885 – 46 T. Last previous edition D 885 – 85 (1992).

Methods D 885M is an SI companion to Methods D 885 using SI units only; therefore SI equivalents for metric and nonmetric units are not included in Methods D 885.

[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 09.01.

[4] *Annual Book of ASTM Standards*, Vol 07.02.

[5] The test atmosphere is under continued study by the committee due to possible incompatibility with standard regains.

Hyosung Ex. 1033, Page 5 of 31

usual practice in the rubber industry for many years to use the term breaking strength to characterize yarn and cord of a specified size and type without any reduction to unit size. Numerically, breaking strength is equal to breaking load for the same specimen. The average of the breaking loads observed on two or more specimens of a specific sample is referred to as the sample breaking strength which is the property used in engineering calculations for a specific textile material. Breaking tenacity and tensile strength, on the other hand, are derived, or calculated, values that characterize a type or class of material reduced to unit size. These terms can be used to compare intrinsic strengths of yarns and cords of different sizes or different materials. The term tensile strength in psi is not synonymous with either breaking load or breaking strength, lbf or breaking tenacity, gf/den.

3.1.18 *tire cord, n*—a twisted or formed structure composed of two or more single or plied industrial yarn elements having the same nominal twist, direction of twist, length, and tension.

3.1.18.1 *Discussion*—The direction of twist used to combine the single or plied yarn elements into a cord structure is in a direction opposite to that used in the yarns.

3.1.19 *tire cord fabric, n*—a fabric consisting of tire cord warp with widely spaced (usually 1 to 5 picks/in.) single yarn filling.

3.1.20 *work-to-break, n*—the total energy required to rupture a specimen to the breaking load during a tensile test. Work-to-break is proportional to the area under the load-elongation curve from the origin to the breaking point and commonly is expressed in inch-pounds.

3.1.20.1 *Discussion*—Specific work-to-break is total work-to-break divided by gage length and is expressed as inch-pounds per inch units.

3.1.21 For definitions of tensile test and other textile terms used in these test methods, refer to Terminology D 123.

3.2 *Description of Term Specific to This Standard:*

3.2.1 *high-modulus aramid, n*—for the purpose of these test methods, those aramid yarns with an initial modulus of at least 400 gf/den.

4. Summary of Test Methods, General

4.1 A summary of the directions prescribed for the determination of specific properties is stated in the appropriate sections of specific test methods.

5. Significance and Use

5.1 The procedures in these test methods should be used with caution for acceptance of commercial shipments owing to the absence of factual information on the between-laboratory precision of many of the procedures included in these test methods. It is recommended that any program of acceptance testing be preceded by an interlaboratory check in the laboratory of the purchaser and the laboratory of the seller on replicate specimens of the materials to be tested for all property (or properties) to be evaluated.

5.1.1 In case of a dispute arising from differences in reported test results when using one of the procedures in these test methods for acceptance testing of commercial shipments, the purchaser and the supplier should conduct comparative tests to determine if there is a statistical bias between their laboratories. Competent statistical assistance is recommended for the investigation of bias. As a minimum, the two parties should take a group of test specimens that are as homogeneous as possible and that are from a lot of material of the type in question. The test specimens should then be randomly assigned in equal numbers to each laboratory for testing. The average results from the two laboratories should be compared using Students *t*-test for unpaired data and an acceptable probability level chosen by the two parties before the testing is begun. If a bias is found, either its cause must be found and corrected or the purchaser and the supplier must agree to interpret future test results in the light of the known bias.

5.2 The significance and use of particular properties are discussed in the appropriate sections of specific test methods.

6. Sampling

6.1 *Yarn*—Separate all acceptance sampling lots of yarn, sample each lot, and determine the number of specimens to be tested as directed in Practice D 2258, except that when sampling yarn from beams, the sample may be wound on a tube or spool by means of a winder using a tension of 0.05 ± 0.01 gf/den. Take samples from the outside of the beam, unless there is a question or disagreement regarding a shipment; in this case, take a sample only after yarn has been removed from a beam to a radial depth of ¼ in. or more in order to minimize the effects of handling and atmospheric changes which may have occurred during shipment or while in storage. Place the sample in a moistureproof polyethylene bag or other moistureproof container to protect it from atmospheric changes until it is desired to condition the sample in the atmosphere for testing industrial yarns and tire cords.

6.2 *Cord:*

6.2.1 *Number of Samples*—The size of an acceptance sampling lot of tire cord shall be not more than one truck or rail car load or as determined by agreement between the purchaser and the seller. Take samples at random from each of a number of cones, tubes, bobbins, or spools within a lot so that they are as representative as possible within practical limitations. Make only one observation on an individual package for each physical property determination. Take the number of samples, therefore, that will be sufficient to cover the total number of specimens required for the determination of all physical properties of the tire cord. The recommended number of specimens is included in the appropriate sections of specific test methods covered below.

6.2.1.1 If the observed level of the coefficient of variation, is found to be v_1, and is greater than v, calculate the number of specimens required, n_1, using Eq. 1.

$$n_1 = (v_1^2/v^2) \times n \quad (1)$$

where:

n and v are the number of specimens and coefficient of variation, respectively as stated in each applicable section. In no test shall n_1 be less than n specimens.

6.2.2 *Preparation of Samples*—Remove and discard a minimum of 25 yd of cord from the outside of the package before taking the sample or any specimens. If specimens are not taken directly from the original package, it is desirable to wind the sample on a tube or spool by means of a winder using a tension of 0.05 ± 0.01 gf/den. If the sample is collected as a loosely wound package, or in the form of a skein, some shrinkage invariably will occur, in which case, report that the observed results were determined on a relaxed sample. Use care in handling the sample. Discard any sample subjected to any change of twist, kinking, or making any bend with a diameter less than ¼ in. Place the sample in a moistureproof polyethylene bag or other moistureproof container to protect it from atmospheric changes until it is desired to condition the sample in the test atmosphere for industrial yarns and tire cords.

6.3 *Tire Cord Fabric:*

6.3.1 *Number of Samples and Specimens*—The sizes of an acceptance sampling lot or tire cord fabric shall be one loom creel of cord or as determined by agreement between the purchaser and the seller. Take a sample from at least one roll of fabric per lot. From each roll of tire cord fabric take the number of specimens prescribed in each applicable section.

6.3.2 *Size of Sample*—Take a sample equal to the length of cord between the regular tabby woven at the end of the roll and a special tabby woven a short distance from the end when the roll of fabric is manufactured. For rolls that do not have a special woven tabby, improvise a tabby by the use of gummed tape or strips of cemented fabric applied across a section of the cord fabric. The length of the tabby sample shall be as agreed upon between the purchaser and the seller, but it shall be at least 18 in. The width of the sample shall be at least one tenth of the roll width.

6.3.3 *Preparation of Samples*—Cut the warp cords of the fabric along the center line of the special tabby across for a distance equal to the width of the desired sample. If this distance is less than the full width of the fabric, cut the filling yarns of the sample and of the special and regular tabbies in the direction parallel with the warp cords. The resulting section of cord fabric is the tabby sample. Attach the tabby sample to a piece of cardboard or fiberboard, the length of which shall be equal to at least the length of the cord warp between tabbies. Fold the tabby portions of the sample over each end of the board, and secure the sample to the board with pressure-sensitive tape or staples. Use care to avoid contact of tape or staples with the area to be tested. Handle the sample carefully and hold it under sufficient tension in the warp direction to prevent the cords from kinking. Discard any specimen subjected to change of twist, kinking, or making any bend with a diameter less than ¼ in. The board with the sample may be folded lengthwise and parallel with the warp for convenience. Place the board with the fabric sample in a polyethylene bag, or wrap it with several layers of polyethylene film to protect the sample from changes in atmospheric moisture content until it is desired to condition the sample in the atmosphere for testing industrial yarns and tire cords. Use care during subsequent handling of the sample to prevent any change in the cord twist and to avoid kinking the cords.

6.4 *Cord from Cured Tires:*

6.4.1 *Number of Samples and Specimens*—A minimum of ten cords shall be tested from each location or ply of each tire.

6.4.2 *Preparation of Samples*—Obtain a tire section comprising approximately one sixth of the whole tire. Smaller sections may be used, particularly for carcass cord samples of radial tires. If it is suspected that cords may be damaged in pulling them from the tire, immerse the section in a solvent[6] for 1 to 3 days to swell and soften the rubber. For convenience, turn the section inside out, if possible; clamp one of the beads in a vise. Mark a line along the inside of the section approximating the cord path of the first ply. Make a shallow cut down to the first ply along this line. Make an incision adjoining and perpendicular to this first cut at sufficient depth to sever several first ply-cords. Carefully cut and pull these cords from the tire from bead to bead following the cord path. Discard these initial cords. After initial cords are removed, remove bands of cords for testing by cutting near the bead through Ply 1 cords adjacent to the trough formed in initial cord removal. Carefully pull several cord bands approximately ¾ in. in width from the tire. Identify bands by tire number, ply number, and so forth. Remove the remainder of Ply 1 to uncover Ply 2. Proceed with Ply 2 or additional plies as directed for Ply 1.

6.4.3 *Preparation of Specimens for Testing from a Ply Band*—Make a cut approximately ¾ in. long between each cord at one end of the ply band. Strip every other cord from the band to a length sufficient for testing; leave a small unstripped cord portion attached to the band to facilitate handling. Cut individual ends from band for testing.

6.4.4 Large variations in properties can occur within the same cord depending on its location within the tire. Select the location in the tire to be sampled and take a length of cord from this location for subsequent testing. Use a gage length appropriate for the length of the specimen to obtain data that reflect the relationship between the cord properties and the location in the tire.

7. Conditioning

7.1 Bring all specimens of yarn and cord to moisture equilibrium for testing in the atmosphere for testing industrial yarns (see 3.1.1 and 3.1.13). Moisture equilibrium of rayon samples shall be approached from the dry side but not from a moisture-free condition.

NOTE 4—The moisture equilibrium of conditioned high-modulus aramid yarns and tire cords made from such yarns can be affected by heat and humidity conditions to which the samples have been previously exposed, hence care must be taken when conditioning samples to ensure that equilibrium moisture regain is not influenced by extreme preconditioning atmospheres.

8. Identification

8.1 Identify the common types of man-made organic-base fibers as directed in Test Methods D 276.

9. Commercial Mass (Note 2)

9.1 *Yarn*—Determine the commercial mass of a yarn shipment as directed in Option II of Test Method D 2494. Take samples of yarn from the outside of beams unless there is a question or disagreement regarding a shipment; in this case, take a sample of yarn only after yarn has been removed from a beam to a radial depth of ¼ in. or more (see 5.1). Take a sample 15 to 20 yd (15 to 20 m) long which is composed of all ends of yarn on the beam, and cut this sample crosswise to obtain two specimens of approximately

[6] Heptane, 1,1,1-trichloroethane, and a mixture of 50/50 Freon 113 and Stoddard Solvent have been used for this purpose.

Hyosung Ex. 1033, Page 6 of 31

equal mass (Note 2). Place the specimens in moistureproof polyethylene bags or other moistureproof containers until it is desired to begin the analysis.

9.2 *Cord and Tire Cord Fabric*—Determine the commercial mass (Note 2) of tire cord and tire cord fabric as agreed upon between the purchaser and the seller.

10. Moisture Regain, Actual

10.1 *Summary of Test Method*—Specimens of rayon yarn or cord, which are taken at the tensile testing machine at the time that tensile tests are being made, are weighed and dried in an oven until they reach a constant mass (Note 2). The observed moisture regain is calculated and reported as percent regain.

10.2 *Significance and Use*—This test method is used not only to determine moisture regain of the original sample but is also used to develop data which may be used to correct observed tensile properties of rayon yarns and cords to a standard regain basis. Since the moisture regain level of different specimens varies even after conditioning in a test atmosphere and since tensile properties are affected by moisture regain, it is desirable to correct observed tensile values when there is substantial variation from a standard moisture regain level. Directions for making such corrections are included in Section 11, Linear Density, and Sections 16 for breaking strength and Section 19 for elongation. It is assumed that no significant amount of nonaqueous volatile matter is present and that all loss in weight is moisture. If such materials are present, apply a suitable correction, or determine the true amount of moisture by the toluene distillation method as directed in Procedure 3 of Test Method D 2654.

10.3 *Apparatus:*

10.3.1 *Drying Oven,* with circulating air maintained at a temperature of 221 ± 6°F. The specimens shall not be subject to direct radiation from the heating units. The air shall pass freely through and around the specimens. The oven may be combined with a balance, in which case the design must prevent disturbance of the balance due to circulating air during the weighing operation.

10.4 *Preparation of Specimen*—Take a single specimen of yarn or cord weighing approximately 10 g, but in no case less than 5 g, from the original sample at the testing machine at the time that tensile properties are being determined (Note 5). Place this specimen in a covered weighing bottle. Do not touch the specimen with the bare hands.

NOTE 5—The determination of moisture regain can be combined with the determination of linear density (Section 11 Linear Density) if the specimen is long enough to meet the length and weight tolerances and if the skein is exposed to the same atmosphere as the sample to be used for determination of tensile properties.

10.5 *Procedure*—Weigh the yarn or cord specimen to 0.01 g and dry it in the ventilated oven at a temperature of 221 ± 6°F. Dry the specimen to constant mass (Note 2), that is, until it loses no more than 0.1 % of its weight at 15-min intervals if weighed in the oven or at 30-min intervals if weighed outside the oven. For specimens that are weighed outside the oven, use a weighing bottle with tight-fitting cover, and cool the specimen and container to room temperature in a desiccator before weighing.

10.6 *Calculation*—Calculate the moisture regain of the specimen using Eq 2:

$$\text{Moisture regain, \%} = [(W - D)/D] \times 100 \quad (2)$$

where:

W = original weight of specimen, g, and
D = oven-dry weight of specimen, g.

10.7 *Report*—Report the average moisture regain for the specimen and use this value for determining the amount of adjustments to make in Sections 16 and 19 to the observed breaking load and elongation of yarn or cord.

10.8 *Precision and Bias:*

10.8.1 *Precision*—The precision of this test method is being studied. (See also Test Methods D 2654.)

10.8.2 *Bias*—See 39.3.

11. Linear Density

11.1 *Number of Specimens*—Test five specimens of yarn or cord. This number is based on the assumption that the applicable coefficient of variation is 1.0 % and the allowable variation is 0.9 % of average with a probability level of 95 %.

11.2 *Procedure for Yarn*—Determine the linear density of yarn as directed in Option 1 of Test Method D 1907, except condition the yarn as specified in Section 7. Use Option 3 for rayon. If the finish-free linear density is desired, use Option 6.

11.3 *Procedure for Cord*—Determine the linear density of cord on packages or removed from a tabby sample of fabric by the procedures prescribed as follows for either conditioned cords or oven-dry cords (11.3.2) or as determined by agreement between the purchaser and the seller.

11.3.1 *Preparation of Specimens*—Take specimens having a minimum length of 9.8 yd from samples of cord on cones, tubes, bobbins, or spools. For tabby samples of fabric, use a sufficient number of ends to give a minimum length of 9 yd of cord for each specimen. Measure the length of the specimen to within 0.1 % while under a tension of 0.05 ± 0.01 gf/den. Weigh the conditioned cord specimen to the nearest 1 mg. If a balance of the required sensitivity (1 mg) for weighing the 9.8-yd specimen is not available, take a longer specimen or multiple ends.

NOTE 6—When arbitration is not involved, an approximation of the specified tension may be obtained by applying one of the weights (Note 2) listed as follows for the specified groups of yarn and cord sizes:

Linear Density of Specimen	Amount of Tension, ozf	Amount of Tension, gf
Below 3600 denier (400 tex)	4	113
3600 to 7200 denier (400 to 800 tex)	8	225
Above 7200 denier (800 tex)	12	340

11.3.2 *Procedure for Oven-Dry Specimens*—Using an oven with circulating air maintained at a temperature of 221 ± 6°F (see 10.3), dry the specimen to constant mass, that is, until it loses no more than 0.1 % of its weight at 15-min intervals if weighed to the nearest 1 mg in the oven or at 30-min intervals if weighed outside the oven. For specimens that are weighed outside the oven, use a weighing bottle with tight-fitting cover and cool the specimen and container to room temperature in a desiccator before weighing. Weigh the specimen of the oven-dry cord to the nearest 1 mg.

11.3.3 *Calculation*—Calculate the linear density of each specimen in denier or tex units using one of the Eqs 3 to 6:

Linear density:

in denier at a commercial moisture regain
$$= (9000 \times D \times K)/L \quad (3)$$

in tex at a commercial moisture regain = $(1000 \times D \times K)/L$ (4)

in denier at actual moisture regain = $(9000 \times C)/L$ (5)

in tex at actual moisture regain = $(1000 \times C)/L$ (6)

where:

D = mass (Note 2) of oven-dry specimen, g,
C = mass of conditioned specimen, g,
L = length of specimen, m (or yd ÷ 1.09) or (yd × 0.918), or both, and
K = factor for commercial regain.

11.3.3.1 Determine the factor K using Eq 7:

$$K = (100 + \text{commercial regain})/100 \quad (7)$$

For the commercial regain, see Table 1. See also Table D 1909.

Example for rayon:

$$K = (100 + 11)/100 = 1.11$$

11.3.3.2 For dipped cord, correct the observed linear density for dip solids pickup using Eqs 8 or 9:

Linear density corrected for dip pickup, denier (or tex)

$$= \frac{100}{100 + M} + \frac{Q}{100} \times \frac{100}{100 + Q} \times P \quad (8)$$

Linear density of dipped cord corrected for dip pickup and moisture regain, denier (or tex)

$$= \frac{100 + N}{100} \times \frac{100}{100 + Q} \times \frac{100P}{100 + M} \quad (9)$$

where:

M = percentage dip pickup,
N = percentage moisture regain of greige cord,
P = observed linear density of dipped cord, denier or tex, and
Q = percentage moisture regain of dipped cord.

11.3.4 *Report:*

11.3.4.1 State that the specimens were tested as directed in Section 11, of Test Methods D 885. Describe the material or product sampled and the method of sampling used.

11.3.4.2 Report the option or procedure used, the number of specimens tested, and the average value of linear density in denier or tex.

11.3.4.3 Report the basis on which linear density is being reported (for gage, dipped, etc.).

11.3.5 *Precision and Bias:*

11.3.5.1 *Precision*—The precision of this method is being studied. See also the section on Samples and Specimens of Test Method D 1907.

11.3.5.2 *Bias*—See 39.3.

TENSILE PROPERTIES OF YARNS AND CORDS

12. Summary of Test Method

12.1 A conditioned or oven-dry specimen of yarn or cord is clamped in a tensile testing machine and then stretched or loaded until broken. Breaking load (Note 3), elongation, and LASE are determined directly. Modulus and work-to-break are calculated from the load-elongation curve. In some laboratories, the output of a CRE type of tensile testing machine (see 14.1) is connected with electronic recording and computing equipment which may be programmed to calculate and print the results of tests for each desired tensile property. Because of the variety of electronic equipment available and the various possibilities for recording test data, use of this type of equipment is not covered in this test method.

13. Significance and Use

13.1 The levels of tensile properties obtained when testing industrial yarns and tire cords are dependent to a certain extent on the age and history of the specimen and on the specific conditions used during the test. Among these conditions are rate of loading, type of clamps, gage length of specimen, temperature and humidity of the atmosphere, rate of airflow across the specimen, and temperature and moisture content of the specimen. The relative importance of these factors varies with each type of fiber. Testing conditions accordingly are specified precisely in order that test results on a specific sample will be reproducible.

13.2 Since the load-bearing ability of a reinforced rubber product is related to the strength of the yarn or cord used as a reinforcing material, breaking strength (Note 3) is used in engineering calculations when designing various types of textile reinforced rubber products. When it is desirable to compare intrinsic strength characteristics of yarns or cords of different sizes or different types of fiber, breaking tenacity (Note 3) is very useful, because, for a given type of fiber, breaking load is approximately proportional to linear density.

13.3 Elongation of yarn or cord is taken into consideration in the design and engineering of reinforced rubber products because of its effect on uniformity of the finished product and its dimensional stability during service.

13.4 The LASE is used to monitor changes in characteristics of the textile material during the various stages involved in the processing and incorporation of yarn or cord into a rubber product.

13.5 Modulus is a measure of the resistance of yarn or cord to extension as a load is applied. It is useful for estimating the response of a textile reinforced structure to the application of varying loads and rates of loading. Although modulus may be determined at any specified load, initial modulus is the value most commonly used.

13.6 Work-to-break is dependent on the relationship of load to elongation. It is a measure of the ability of a textile structure to absorb mechanical energy. Toughness is work-to-break per unit length and per unit linear density.

13.7 It should be emphasized that, although the preceding parameters are related to the performance of a textile-reinforced product, the actual configuration of the product is significant. Shape, size, and internal construction also can have appreciable effect on product performance. It is not possible, therefore, to evaluate the performance of a textile reinforced product in terms of the reinforcing material alone.

14. Apparatus

14.1 *Tensile Testing Machine*—A single-strand tensile testing machine of one of the following types:

Hyosung Ex. 1033, Page 7 of 31

Type	Principle of Operation
CRE	constant-rate-of-specimen extension
CRL	constant-rate-of-load (inclined plane type)
CRT	constant-rate-of-traverse (pendulum type)

The specifications and methods of calibration and verification of these machines shall conform to Specification D 76. The testing machine shall be equipped with an autographic recorder (rectilinear coordinates preferred) and clamps of the cam or pneumatic type having fixed snubbing surfaces which are integral with one of the clamping surfaces. The snubbing surfaces may be circular with a diameter not less than 0.5 in., or semi-involute. It is permissible to use tensile testing machines that have a means for calculating and displaying the required results without the use of an autographic recorder. (Note 12)

15. Breaking Strength (Load) of Conditioned Yarns and Cords

15.1 *Number of Specimens*—Test ten specimens. This number is based on the data for cords in Table 4 which shows precision to be expected at the probability level of 95 % on various cords.

15.2 *Procedure*—Select a load scale such that the estimated breaking load of the specimen will fall in the range from 10 to 90 % of the full-scale load of the testing machine. Adjust the distance between the clamps on the testing machine so that the nominal gage length of the specimen, measured from nip to nip of the jaws of the clamps, is 10 ± 0.05 in. (alternate 20 ± 0.10 in. upon agreement by all parties). Use a tension device that applies a pre-tension load of 0.05 ± 0.01 gf/den (calculated from the nominal linear density) to the specimen in the test zone between clamps. (This tension device may be a dead load, a spring, or an air-actuated mechanism.) (See Notes 7 and 8.) Make all tests on conditioned yarns and cords in the atmosphere for testing industrial yarns and tire cords (see 3.1.1 and 3.1.13) (Notes 9 and 10). Remove the specimen of yarn or cord from the sample and handle it in such a manner that no change in twist can occur prior to closing the jaws of the clamps on the specimen. Do not touch with the bare hand that portion of the specimen which will be between the clamps. Thread one end of the specimen between the jaws of one of the clamps and close it. Place the other end through the jaws of the second clamp and apply to the unclamped end a pretension load that will result in the specified pretension in the test specimen. Close the second clamp and operate the testing machine at the rate specified in Table 2. When the specimen breaks, read the breaking load (Note 3) in pounds-force from the load-elongation curve on the chart, from the dial, or by electronic means (Note 11). Discard specimens that break in the jaws or within ⅛ in. of the nips of the jaws. If the clamps are of the air-actuated type, adjust the air pressure so that specimens will not slip in the jaws, but keep air pressure below the level that will cause specimens to break at the edge of the jaws.

NOTE 7—When arbitration of test data is involved, use care in the application of the pretension-load that may be specified since the actual pretension in the specimen commonly is different from the amount applied externally because of losses due to friction in the clamp. The actual pretension load can be measured by strain gages. Other tension-measuring instruments with sufficient accuracy may be used, provided that the specimen is threaded through the instrument prior to being placed in the second clamp. This procedure is necessary, because many instruments require appreciable displacement of the specimen.

NOTE 8—When arbitration is not involved, one of the following approximations of the specified pretension may be used. Either attach a load of 120 % of the nominal pretension to the unclamped end of the specimen prior to closing the second clamp or apply one of the loads listed as follows for the specified groups of yarn and cord sizes to secure the desired pretension.

Linear Density of Specimen	Amount of Pretension, ozf	Amount of Pretension, gf
Below 3600 denier (400 tex)	4	113
3600 to 7200 denier (400 to 800 tex)	8	225
Above 7200 denier (800 tex)	12	340

When using a CRE-type machine, a third technique is to close the upper clamp, then apply pretension by pulling the specimen taut until the recorder pen moves approximately ½ chart division from the zero line on the chart when using a load scale that is the same as that used for determining the breaking load.

NOTE 9—Because of the difficulty of securing the same tension in all the filaments and because of slippage in the clamps, variable results may be obtained when testing zero-twist multifilament yarns unless a small amount of twist is inserted prior to testing. For the amount of twist to be inserted in yarns of different sizes, refer to Note 6 of Test Method D 2256, which regards the addition of twist to zero twist fibers for tensile determinations and is especially significant for high-modulus aramids and rayon.

NOTE 10—The velocity of conditioned air flowing across a specimen while determining tensile properties can have a measurable effect on the breaking load and elongation at break because of the Gough-Joule effect. The magnitude of this effect depends on the type of fiber, air velocity, and sample history. Round-robin testing of nylon, polyester, and rayon cords indicates that air velocities of less than 50 ft/min across the specimen will not significantly bias the comparison of cord properties between laboratories.[7]

NOTE 11—As diameters and strengths of cords increase, clamps with larger snubbing surfaces and greater holding power or capacity may be required to prevent slippage of cords in testing machine clamps or an excessive number of jaw breaks. The levels of cord size and strength at which such higher capacity clamps are required must be determined by experiment, since they will vary with the type of fiber and construction. Examples of higher capacity clamps which have been found suitable for large cords are Instron Types 2714-004 (formerly 4C), and 2714-006 (formerly 4D), Scott Type "400," and Scott Type "Callaway-400."[8] The first three types of clamps are air-actuated with a lever system of closure and a mechanical advantage that accentuates and maintains greater pressure on the specimen than regular types of clamps. These clamps are of greater capacity than the last type which has a manually actuated cam system.

If slippage of cords cannot be prevented with the highest capacity clamps available to the user, it has been found useful to apply powdered rosin to the two portions of the cord which will be held between the snubbing surfaces. Use of rosin has been found particularly useful in testing organic cords that have been adhesive treated.

15.3 *Calculation and Report*—Calculate the average breaking load from the observed breaking loads of specimens read from the testing machine chart or dial. Report the average breaking load to the nearest 0.1 lbf as the breaking strength (Note 3) of the sample and the number of specimens tested.

15.4 *Precision and Bias*—See Section 39 for cord only.

[7] See Jones, R. E., and Desson, M. J., "Adiabatic Effects on Tensile Testing," *Journal of the I.R.I.*, June 1967.

[8] The Instron clamps may be obtained from Instron Engineering Corp., Canton, MA, and The Scott clamps from Scott Testers, by Precision Scientific, Chicago, IL 60647.

16. Adjustment of Observed Breaking Strength (Load) of Rayon Yarns and Cords to a Specified Moisture Regain Level

16.1 If the moisture regain of a rayon sample at the time of testing is within ±0.3 % of the regain level agreed upon between the purchaser and the seller, report the average observed breaking load as the breaking strength (Note 3). If the moisture regain is outside the ±0.3 % limit, adjust the observed breaking strength (load) to the agreed upon regain basis using a suitable adjustment factor. Establish this factor for a specific material by making breaking tests at a sufficient number of different moisture regain levels to determine the slope of the "breaking strength (load) versus regain" curve. Apply the factor using Eq 10:

$$\text{Breaking strength (load) (adjusted to specific regain level)} = S \times F \quad (10)$$

where:

S = observed average breaking load, and
F = factor for adjusting observed breaking loads to a specified moisture regain level.

17. Breaking Tenacity of Conditioned Yarns and Cords

17.1 *Calculation*—Calculate the breaking tenacity (Note 3) of the sample in terms of gf/den, or gf/tex, from the breaking strength and the linear density using Eq 11:

$$\text{Breaking tenacity, gf/den, or gf/tex} = S/D \text{ or } T \quad (11)$$

where:

S = average breaking load, g, at the optimum, moisture regain specified,
D = linear density, den, at commercial regain (see Section 11 and Table 1), and
T = linear density, tex, at commercial regain (see Section 11 and Table 1).

17.2 *Report*—Report the average breaking tenacity to the nearest 0.1 gf/den, or 1.0 gf/tex and the number of specimens tested.

18. Elongation at Break of Conditioned Yarns and Cords

18.1 Determine the elongation at break of each conditioned specimen when determining its breaking load (Section 15). Read the elongation from the autographic recorder chart, or by electronic means, at the breaking load.

NOTE 12—Elongation also may be determined from the load-elongation curve at any part-load that has been agreed upon between the purchaser and the seller.

18.2 *Calculation and Report*—Calculate the observed elongation of each specimen as a percentage of its nominal gage length. Calculate the average elongation of the sample. Report the average elongation at break to the nearest 0.1 % and the number of specimens tested.

18.3 *Precision and Bias*—See Section 39 for cord only.

19. Adjustment of Observed Elongation of Rayon Yarns and Cords to a Specified Moisture Regain Level

19.1 If the moisture regain of a rayon specimen at the time of testing is within ±0.3 % of the regain level agreed upon between the purchaser and the seller, report the average observed elongation at break. If the moisture regain is outside the ±0.3 % limit, adjust the observed elongation to the agreed upon regain basis using a suitable adjustment factor. Establish this factor for a specific material by making elongation tests at a sufficient number of different moisture regain levels to determine the slope of the "elongation at break versus regain" curve. Apply the factor using Eq 12:

$$\text{Elongation, \% (adjusted to specified regain level)} = E \times F \quad (12)$$

where:

E = observed elongation, and
F = factor for adjusting observed elongation to an elongation at a specified moisture regain.

20. Load at Specified Elongation (LASE) of Conditioned Yarns and Cords

20.1 *Procedure:*

20.1.1 *Nylon, Polyester, or Rayon Yarns and Cords*—Determine the LASE of each conditioned specimen when determining its breaking load (Section 15). Read the load directly from the autographic recorder chart, or by electronic means, at the specified value of elongation for the fiber types listed as follows:

Fiber	Elongation, % of Nominal Gage Length, Greige	Elongation, % of Nominal Gage Length, Adhesive Processed
Rayon	6	3
Nylon	14	7
Polyester	10	5
High-modulus aramid	2	1

20.1.2 *High-Modulus Aramid Yarns and Cords*—Determine the LASE of each conditioned specimen from the load-elongation curve on the autographic recorder chart from the tensile testing machine (Note 13 and Table 2). The load elongation curve will be generated as described in 15.2 with the exception that it will be run without pretension and with an operating rate of 50 % of the nominal gage length of the specimen per minute. Locate Point A on the ordinate (load axis) at a load equal to 4 gf/den nominal linear density of specimen) (see Fig. 2). Draw a line from Point A perpendicular to the load axis to its intersection with the load-elongation curve (Point B). Draw a line parallel to Line AB at a distance equal to 5.0 % full-scale load below Point A, intersecting the load elongation curve (Point C). Connect these two points and establish Line BC, extending it to the elongation axis (Point D) and upwards to the full-scale load line (Point L). The zero elongation point (Point D) is defined as the intersection of the extended modulus tangent line with the abscissa. The specified elongation will be measured from Point D to the specified elongation level with the load being obtained from the stress/strain curve (Point F).

20.2 *Calculation and Report*—Calculate the average LASE to the nearest 0.1 lbf, and report this average value and the number of specimens tested.

20.3 *Precision and Bias*—See Section 39 for cord only.

21. Initial Modulus of Conditioned Yarns or Cords

21.1 *Procedure:*

Hyosung Ex. 1033, Page 8 of 31

TABLE 1 Commercial Moisture Regains of Man-Made Organic-Base Fibers Used in Tire Cords [A]

	%
Rayon	11.0
Nylon	4.5
Polyester	0.4
High-modulus aramid	7.0

[A] Commercial moisture regain of fibers not listed in this table shall be as agreed upon between the purchaser and the seller.

21.1.1 *Nylon, Polyester, or Rayon Yarns and Cords*—Determine the initial modulus of each conditioned specimen when determining its breaking load (Section 15). Using the load-elongation curve (Fig. 1) on the autographic recorder chart from the tensile testing machine, draw a tangent to the initial straight-line portion of the curve (Note 13). Extend this tangent to the abscissa (elongation axis), and upwards to a point which corresponds to slightly more than 10 % elongation. On the abscissa, measure and mark a distance equal to 10 % elongation of the specimen gage length beginning at the point of intersection of the tangent with the abscissa. At the 10 % mark, draw a line perpendicular to the abscissa and extend it upwards until it intersects the tangent to the curve. This point of intersection represents the load required for 10 % elongation of the specimen at the rate represented by the straight portion of the load-elongation curve (Note 14). When electronic means are used, determine the modulus of the initial straight-line portion of the above curve. Calculate the modulus of a specimen using Eq 13:

$$\text{Modulus, gf/den} = (10 \times L)/K \quad (13)$$

where:
L = load for 10 %, and
K = nominal linear density, den.

NOTE 13—The CRL type of tester (14.1) is not suited for the test due to the fact that the initial portion of the load-elongation curve is somewhat distorted.

NOTE 14—Equations 13 and 14 are a special case of the general equation in 3.1.11.1 and are chosen to simplify the required calculation.

21.1.2 *High-Modulus Aramid Yarns and Cords*—Determine the modulus of each conditioned high-modulus aramid specimen from the load-elongation curve on the autographic recorder chart from the tensile testing machine (Note 13 and Table 2). Locate Point A on the ordinate (load axis) at a load equal to 4 gf/den of specimen (see Fig. 2). Draw a line from Point A perpendicular to the load axis to its intersection with the load-elongation curve (Point B). Draw a line parallel to Line AB at a distance equal to 5.0 % full-scale load below Point A, intersecting the load-elongation curve (Point C). Connect these two points and establish Line BC, extending it to the elongation axis (Point D) and upwards to the full-scale load line (Point L). Draw a line parallel to the ordinate from Point L until it intercepts the abscissa (elongation axis Point E). This segment DE represents the elongation required for a load equal to the full-scale load of the specimen at the rate represented by the slope of the segment BC of the load-elongation curve. When electronic means are used, determine the modulus of this same segment of the load-elongation curve. Calculate the modulus of a specimen using Eq 14.

$$\text{Modulus, gf/den} = (100 \times L)/(I)\,(K) \quad (14)$$

where:
I = elongation interval (Point E minus Point D), %,
L = full-scale load, gf, and
K = linear density, den.

21.2 *Report*—Report the number of specimens tested and the average initial modulus of the sample to the nearest 0.1 gf/den.

21.3 *Precision and Bias*—See Section 39 for cord only.

22. Breaking Strength (Load) of Oven-Dry Rayon Yarns and Cords

22.1 *Apparatus*—In addition to the tensile testing machine (Section 14), the following accessory equipment is required:

22.1.1 *Sample Holder*—For continuous length samples, use spools with tapered cores of corrosion-resistant metal or plastic and containers made of corrosion-resistant material that are large enough to hold the spools. Each container shall have a shallow, tight-fitting cover provided with a spindle mounted on the under side on which the spool can be placed and on which it will rotate freely. In the side of the container, at the upper edge, there shall be a narrow slit which terminates in a porcelain guide.[9] For tabby samples of tire cord fabric or other short-length samples, use racks of suitable design that will prevent any change in twist in specimens during drying and handling and that will facilitate rapid removal of specimens for testing.

22.1.2 *Oven*—An oven large enough to handle the required number of spools or racks as specified in 10.3.1.

22.1.3 *Source of Desiccated Air.*

22.2 *Preparation of Specimens:*

22.2.1 *Tapered Spools*—Place a strip of paper around the tapered core of a spool in such a manner that only the larger half of the core is covered. Wind the necessary length of sample on the core over the paper. Move the paper with the sample laterally on the spool to the small end of the core using care to preserve the sample structure as wound on the spool and to avoid tuckunders. Place the spool with the sample on the spindle attached to the cover of the container with the smallest diameter of the core adjacent to the cover and place the assemblage in the oven. Dry the sample for a sufficient length of time so that loss in mass on heating for an additional 15-min period is less than 0.1 % of the original mass of the sample. Quickly cover the oven-dry sample on the spool, which is on the spindle of the cover, with the inverted container in such a manner that the free end of the sample protrudes through the guide in the side of the container. Place the closed container in a desiccator or in a cabinet through which desiccated (predried) air is passed and cool to room temperature. Test specimens directly from the container with a minimum of elapsed time after removal from the cooling cabinet or desiccator.

22.2.2 *Short Specimens*—When it is desired to determine the breaking load and elongation under oven-dry conditions on short-length specimens of cord by the tapered spool procedure described in 22.2.1, tie a series of specimens (long enough to permit clamping in both clamps of the tensile testing machine) together or join them with sewn splices, and treat the resulting strand as a single cord. If the specimens are less than 1 m in length, space them between other lengths of cord which have identical twist construction and which can be discarded. Make all knots or splices in such a way as to prevent any change in twist and small enough to pass through the porcelain guide in the side of the drying can.

22.2.3 *Racks*—Place in racks a number of short lengths of cord removed from a tabby sample or from other sources. Mount them without tension and in such a manner that there is no change in twist. Allow sufficient slack to prevent development of any tension during the drying operation. Place the rack with the specimens along with unracked control specimens in the oven and dry for a sufficient length of time so that the loss in weight in heating of the control specimens for an additional 15-min period is less than 0.1 % of the original weight of the sample. Quickly remove the rack with the oven-dry specimens from the oven and place it in a desiccator or cabinet through which desiccated air is passed. Cool the sample to room temperature. If the rack is equipped with a tight-fitting cover which will prevent exposure to the laboratory atmosphere, it may be placed close to the testing machine. If there is no cover on the rack, provision must be made to protect specimens remaining in the rack from the laboratory atmosphere during the testing operation.

22.3 *Procedure:*

22.3.1 *Tapered Spools*—Place the unopened container with the cooled sample in a convenient position at the tensile testing machine. Pull approximately 2 yd of the sample through the guide from the container and discard the length. Pull another length of the sample from the container, quickly place it in the clamps of the testing machine, and determine the breaking load as directed in 15.2. If, for any reason, more than 25 s are required to place a particular test specimen in the machine and to break it, discard the results from that specimen. After breaking a specimen, discard the portion of the sample between the clamp and the container. Withdraw a length of unexposed sample from the container for the next specimen.

22.3.2 *Racks*—With the rack of cooled specimens protected from the laboratory atmosphere and close to the tensile testing machine, remove one specimen from the rack, quickly place it in the clamps of the testing machine and determine the breaking load as directed in 15.2. If, for any reason, more than 25 s are required to place a particular test specimen in the apparatus and to break it, discard the results for that specimen.

22.4 *Calculation and Report*—Calculate the average breaking load of the oven-dry rayon sample from the observed breaking loads of specimens read from the testing machine chart or dial. Report the average breaking load to the nearest 0.1 lbf as the breaking strength (Note 3) of the sample and the number of specimens tested.

22.5 *Precision and Bias*—See Section 39 for cord only.

23. Breaking Tenacity of Oven-Dry Rayon Yarns and Cords

23.1 Calculate the breaking tenacity (Note 3) of the oven-dried rayon sample as directed in Section 17 using the average breaking load in grams-force of the oven-dry sample and the linear density based on the commercial regain (see Section 11).

24. Elongation at Break of Oven-Dry Rayon Yarns and Cords

24.1 Determine the elongation at break of each oven-dry rayon specimen when determining its breaking load (22.3). Read the elongation from the autographic recorder chart, or by electronic means, at the breaking load. Express the observed elongation of each oven-dry specimen as a percentage of its nominal gage length.

24.2 *Calculation and Report*—Calculate the average elongation at break to the nearest 0.1 %. Report this value as the elongation at break for the oven-dry sample, and report the number of specimens tested.

24.3 *Precision and Bias*—See Section 39 for cord only.

25. Load at Specified Elongation (LASE) of Oven-Dry Rayon Yarns and Cords

25.1 Determine the LASE of each oven-dry rayon specimen when determining its breaking load (22.3). Read the load directly from the autographic recorder chart, or by electronic means, at the appropriate value of elongation for the product listed as follows:

	Elongation, % of Nominal Gage Length	
Fiber	Griege	Adhesive Processed
Rayon	6	3

25.2 *Calculation and Report*—Calculate the average LASE to the nearest 0.1 lbf, and report this average value and the number of specimens tested.

25.3 *Precision and Bias*—See Section 39 for cord only.

26. Work-to-Break of Yarns and Cords

26.1 *Procedure*—Using the load-elongation curves obtained as directed in Sections 16, 22, or 30, draw a line from the point of breaking load of each specimen perpendicular to the elongation axis. Measure the area bound by the curve, the perpendicular, and the elongation axis. This area may be estimated by counting squares, measured with a planimeter, or determined by electronic means.

26.2 *Calculation*—Calculate the work-to-break for each specimen using Eq 15, or specific work-to-break using Eq 16:

$$\text{Work-to-break, in.·lbf} = A \times F \times E \quad (15)$$

$$\text{Specific work-to-break, in.·lbf/in.} = (A \times F \times E)/L \quad (16)$$

where:
A = area under the load-elongation curve, in.^{2},
F = load scale factor, lbf/in., of chart,
E = elongation scale factor, in., of specimen elongation per inch of chart, and
L = gage length of specimen, in.

26.3 *Report*—Report the average work-to-break or average specific work-to-break of the sample and the number of specimens tested.

26.4 *Precision*—See Section 39 for cord only.

27. Breaking Toughness of Yarns and Cords

27.1 *Procedure*—Use the information developed in Sec-

[9] A suitable guide designated as No. 900 Worsted is available from Page-Madden Co., Inc., Mineola, Long Island, NY.

Hyosung Ex. 1033, Page 9 of 31

TABLE 2 Rates of Operation of Tensile Testing Machines

NOTE: **Caution**—If there exists any reason to doubt the validity of test results of high-modulus aramids at the specified rate of operation on CRE- and CRT-type testing machines, a referee operation rate of 50 % of the nominal gage length per minute shall be used. The 50 % rate has been used for aramid LASE data (Tables 3 and 4). The rate of loading for high-modulus aramids on CRL machines has not been established. All high-modulus aramid testing has been limited to 4D clamps and a 500-mm gage length. Testing differences have been found with alternate clamps and gage lengths.

CRE-Type Testing Machines:	
For all fiber types use a rate of crosshead travel in in./min of 120 ± 6 % of the nominal gage length of the specimen.	
CRL-Type Testing Machines:	
Use the following rates of loading:	
For rayon	18 ± 2 gf/den/min
For nylon and polyester	35 ± 5 gf/den/min
CRT-Type Testing Machines:	
For all fiber types, use a rate of traverse of 12 ± 0.5 in./min	

tion 11, and in 26 to calculate the breaking toughness of a yarn or cord sample.

27.2 *Calculation*—Calculate the breaking toughness of each specimen using Eq 17 or 18;

$$\text{Breaking toughness, in.·lbf/in.·den} = (A \times F \times E)/(L \times D) \quad (17)$$

$$= W/D \quad (18)$$

where:

A = area under the load-elongation curve, in.^{2},
F = load scale factor, lbf/in., of chart,
E = elongation scale factor, in., of specimen elongation per inch of chart,
L = gage length of specimen, in.,
D = linear density of specimen, den, and
W = specific work-to-break of specimen, in.·lbf/in.

27.3 *Report*—Report the average breaking toughness of the sample and the number of specimens tested.

27.4 *Precision and Bias:*

27.4.1 *Precision*—The precision of this test method is being studied.

27.4.2 *Bias*—See 39.3.

28. Reports, General

28.1 State that all specimens were tested as directed in Test Methods D 885, Sections 12 to 29. Describe the material or product sampled and the methods of sampling used.

28.2 Report the following information:

28.2.1 Type of tensile testing machine and type of clamp used,

28.2.2 Number of specimens tested per sample,

28.2.3 Average value of each property determined or calculated, and

28.2.4 Coefficient of variation, if calculated.

29. Growth of Conditioned Yarns and Cords

29.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord that has been permitted to relax in a conditioned atmosphere is determined while under a specified pretension load. A load of 1.0 ± 0.001 gf/den is then applied to the specimen and its length again measured after the length of the loaded specimen becomes constant. The amount of growth is calculated from the differences in observed specimen lengths.

29.2 *Significance and Use*—The growth of a yarn or cord is a factor in the dimensional stability under load, of a product which is reinforced with a specific textile material.

29.3 *Apparatus*—A length measuring device upon which test specimens at least 10 in. long can be mounted with one end of each specimen in a fixed position. The apparatus shall be equipped with a means for measuring the initial length and the final length of each specimen during the test period. This device shall be designed so that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

29.4 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to relax without kinking in the test atmosphere (see 3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

29.5 *Procedure*—Secure one end of a specimen at least 10 in. long in the clamp of the apparatus, and apply a pretension load of 0.05 ± 0.01 gf/den to the other end of the specimen in such a manner that there is no change in twist. Observe and record the initial length of the specimen. Apply an additional load to the specimen so that the total load is 1.0 ± 0.01 gf/den. When the increase in amount of growth is no more than 5 % (based on change in length of a specimen) during a 1-min interval, observe and record the final length of the specimen.

29.6 *Calculation*—Calculate the percentage growth of each specimen using Eq 19:

$$\text{Growth, \%} = [(B - A)/A] \times 100 \quad (19)$$

where:

A = initial length of specimen, and
B = final length of specimen.

Calculate the average growth of all specimens.

29.7 *Report*—State that the specimens were tested as directed in Section 29 of Test Methods D 885 and report the average growth of all specimens as the growth of the sample together with the number of specimens tested.

29.8 *Precision and Bias:*

29.8.1 *Precision*—The precision of this test method is being studied.

29.8.2 *Bias*—See 39.3.

30. Properties of Yarns and Cords at Elevated Temperature

30.1 *Significance and Use*—Since textile materials often are subjected to elevated temperatures during their processing and use, it is desirable to know the tensile properties and behavior at such temperatures. Such information is used in engineering calculations and in process specifications.

30.2 *Breaking Load of Yarns and Cords at Elevated Temperatures:*

30.2.1 *Summary of Test Method*—The breaking load of yarn or cord is determined while the specimen is at an elevated temperature. Elongation usually is not determined. This test is not a heat-aging test.

30.2.2 *Apparatus*—A tensile testing machine as specified in Section 14 except that the machine shall be equipped with an oven or elevated temperature chamber which completely encloses the testing clamps and specimen. The oven shall be such that it will maintain the desired temperature ±3°F.

TABLE 3 Components of Variance Expressed as Coefficients of Variation (Except as Noted)

NOTE—Between-laboratory coefficients of variation of high-modulus aramids are undesirably high and may warrant interlaboratory correlations in specific applications between the purchaser and the seller.

Property Measured	Number of Laboratories	Number of Observations in Each Laboratory	Degrees of Freedom: Within Laboratory	Degrees of Freedom: Between Laboratory	Coefficient of Variations: Within-Laboratory Component	Coefficient of Variations: Between-Laboratory Component
Table 3a 840/2 Nylon Cord (12 × 12 twist):[A]						
Breaking strength, lbf	8	10	152	7	1.61	1.57
Elongation at break, %	6	10	114	7	5.13	4.63
Load at specified elongation (LASE) (reported at 14 % *E*), lbf	7	10	133	6	5.67	7.25
Modulus, gf/den	2	10	38	1	5.76	2.38
Work-to-break, in.·lbf/in.	4	10	76	2	7.63	2.88
Thickness of cords, mils	4	10	76	3	0.64[B]	0.49[B]
Twist, tpi: Cord	5	10	114	5	0.31[B]	0.12[B]
Twist, tpi: Singles	5	10	95	4	0.14[B]	0.07[B]
Linear density, den:[A]						
From bobbin	8	9 to 15	105	7	1.92	1.24
From tabby	8	9 to 15	71	7	0.73	1.49
Table 3b 1000/3 Polyester Cord (10 × 10 twist):						
Breaking Strength, lbf	5	10	95	4	1.96	1.56
Elongation at break, %	6	10	114	5	3.03	3.46
Load at specified elongation (LASE) (reported at 10 % E), lbf	6	10	114	5	5.88	5.31
Modulus, gf/den	2	10	38	1	5.42	0.00[C]
Work-to-break, lbf/in.	4	10	76	3	5.51	5.53
Thickness of cords, mils	3	10	57	2	0.59[B]	0.16[B,C]
Twist, tpi: Cord	6	10	54	5	0.23[B]	0.15[B]
Twist, tpi: Singles	5	10	95	4	0.13[B]	0.10[B]
Linear Density, den:						
From bobbin	8	9 to 15	107	7	0.86	0.50
From tabby	8	9 to 15	79	7	1.17	0.79
Table 3c 1650/3 Rayon Cord (11 × 10 twist):[D]						
Breaking strength, lbf	6	10	114	5	3.12	1.77
Elongation at break, %	6	10	114	5	3.47	2.07
Load at specified elongation (LASE) (reported at 6 % *E*), lbf	5	10	95	4	5.33	6.72
Thickness of cords, mils	3	10	57	2	0.75[B]	0.71[B]
Twist, tpi: Cord	4	10	76	3	0.28[B]	0.16[B]
Twist, tpi: Singles	3	10	57	2	0.16[B]	0.09[B]
Linear density, den:						
From bobbin	9	9 to 15	114	8	0.66	0.94
From tabby	9	9 to 15	94	8	0.73	0.78
Table 3d 1500/2 High-Modulus Aramid Cord (4 × 4 twist):						
Breaking strength, lbf	8	10	72	7	1.21	2.38
Elongation at break, %	8	10	72	7	2.58	7.46
Modulus, gf/den	5	10	45	4	3.67	7.01
Work-to-break, in.·lbf/in.	6	10	54	5	4.44	17.62
Thickness of cords, mils	6	10	54	5	0.88[B]	3.86[B]
Twist, tpi: Cord	7	10	63	6	0.10[B]	0.12[B]
Twist, tpi: Singles	7	10	63	6	0.10[B]	0.08[B]
Table 3e 1500/2 High-Modulus Aramid Cord (7.5 × 7.5 twist):						
Breaking strength, lbf	8	10	72	7	2.41	3.45
Elongation at break, %	8	10	72	7	2.49	9.60
Modulus, gf/den	5	10	45	4	2.43	12.76
Work-to-break, in.·lbf/in.	6	10	54	5	9.60	15.50
Thickness of cords, mils	6	10	54	5	0.88[B]	3.05[B]
Twist, tpi: Cord	7	10	63	6	0.10[B]	0.20[B]
Twist, tpi: Singles	7	10	63	6	0.10[B]	0.20[B]
Load at specified elongation (LASE) without Rosin (reported at 2 % E), lbf	9	10	81	8	1.59	5.79
Table 3f 1500/1 High-Modules Aramid Yarn:						
Breaking strength, lbf	6	10	9	5	1.52	3.38
Elongation at break, %	5	10	9	4	2.91	8.39
Modulus, gf/den	3	10	9	2	5.06	5.05

[A] 1260/2 nylon cord for linear density.
[B] Properties that have components of variance as standard deviations in the units shown are noted in the table.
[C] The F-ratio indicates not significant at 95 % probability level.
[D] Rayon data, except thickness, twist, and linear density, are from oven-dry cords.

Hyosung Ex. 1033, Page 10 of 31

TABLE 4 Critical Differences, Expressed as Percent of Observed Average (Except as Noted)[A,B]

Property Measured	Number of Observations in Each Average	Critical Differences: Single-Operator Precision	Critical Differences: Between-Laboratory Precision
Table 4a 840/2 Nylon Cord (12 × 12 twist):[C]			
Breaking strength, lbf	10	1.41	4.57
Elongation at break, %	10	4.50	13.60
Load at specified elongation (LASE) (reported at 14 % E), lbf	10	4.97	20.70
Modulus, gf/den	10	5.05	8.31
Work-to-break, in.·lbf/in.	10	6.69	10.41
Thickness of cords, mils	10	0.56[D]	1.46[D]
Twist, tpi: Cord	10	0.27[D]	0.43[D]
Singles	10	0.12[D]	0.25
Linear density, den:[C]			
From bobbin	5	1.07	4.49
From tabby	5	0.40	4.54
Table 4b 1000/3 Polyester Cord (10 × 10 twist):			
Breaking Strength, lbf	10	1.72	4.65
Elongation at break, %	10	2.66	9.95
Load at specified elongation (LASE) (reported at 10 % *E*), lbf	10	5.15	5.59
Modulus, gf/den	10	4.75	4.75
Work-to-break, in.·lbf/in.	10	4.83	16.07
Thickness of cords, mils	10	0.52[D]	0.52[D]
Twist, tpi: Cord	10	0.21[D]	0.47[D]
Singles	10	0.11[D]	0.29[D]
Linear density, den:			
From bobbin	5	0.47	1.86
From tabby	5	0.65	2.83
Table 4c 1650/3 Rayon Cord (11 × 10 twist):[E]			
Breaking strength, lbf	10	2.73	5.62
Elongation at break, %	10	3.04	6.49
Load at Specified Elongation (LASE) (reported at 6 % E), lbf	10	4.67	19.20
Thickness of cords, mils	10	0.66[D]	2.07[D]
Twist, tpi: Cord	10	0.24[D]	0.51[D]
Singles	10	0.14[D]	0.30[D]
Linear density, den:			
From bobbin	5	0.37	2.98
From tabby	5	0.41	1.58
Table 4d 1500/2 High-Modulus Aramid Cord (4 × 4 twist):			
Breaking strength, lbf	10	1.06	6.68
Elongation at Break, %	10	2.26	20.80
Modulus, gf/den	10	3.22	19.69
Work-to-break, in.·lbf/in.	10	3.89	48.99
Thickness of cords, mils	10	0.77[D]	10.73[D]
Twist, tpi: Cord	10	0.09[D]	0.34[D]
Singles	10	0.09[D]	0.24[D]
Table 4e 1500/2 High-Modulus Aramid Cord (7.5 × 7.5 twist):			
Breaking strength, lbf	10	2.11	9.79
Elongation at break, %	10	2.18	26.70
Modulus, gf/den	10	2.13	35.43
Work-to-break, in.·lbf/in.	10	8.41	43.77
Thickness of cords, mils	10	0.77[D]	8.49[D]
Twist, tpi: Cord	10	0.09[D]	0.40[D]
Singles	10	0.09[D]	0.56[D]
Load at specified elongation (LASE) without Rosin (reported at 2 % E), lbf.	10	1.12	13.00
Table 4f 1500/1 High-Modulus Aramid Yarn:			
Breaking strength, lbf	10	1.33	9.46
Elongation at break, %	10	2.55	23.39
Modulus, gf/den	10	4.43	14.68

[A] The critical differences were calculated using $t = 1.960$ which is based on infinite degrees of freedom.

[B] To convert the values of the critical difference expressed as a percent of the grand average to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as a decimal fraction.

[C] 1260/2 nylon cord for linear density.

[D] Properties noted in this table have critical differences in the units shown rather than as a percent of the grand average.

[E] Rayon data, except thickness, twist, and linear density, are for oven-dry cord.

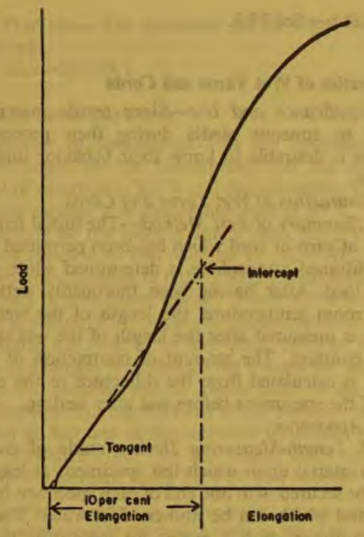


FIG. 1 Load-Elongation Curve

NOTE 15—The temperature to be used and the rate of temperature recovery by the oven shall be as agreed upon between the purchaser and the seller.

NOTE 16—Air-actuated testing machine clamps as usually supplied are not suitable for use in ovens at high temperature without modification. Such modification consists of increasing the diameter of the cylinder to compensate for thermal effects and the use of rings of heat-resistant material on the pistons.

30.2.3 *Procedure*—Place a conditioned specimen of yarn or cord (for rayon on oven-dried specimen prepared as directed in 22.2) in the clamps of the testing machine, enclose it in the oven and expose it to the specified temperature (Note 15). When the specimen reaches the temperature of the oven, immediately determine its breaking load as directed in Section 15.

30.2.4 *Calculation and Report*—Calculate the average breaking load of the sample from the observed breaking loads of the specimens. Report the average breaking load to the nearest 0.1 lbf as the breaking strength (Note 3) of the sample at the specified temperature and the number of specimens tested.

30.2.5 *Precision*—The precision of this test method is being studied.

30.2.6 *Bias*—See 39.8.

30.3 *Shrinkage of Conditioned Yarns and Cords at Elevated Temperature:*

30.3.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord that has been permitted to relax in a conditioned atmosphere is determined while under a specified load. After exposure of the loaded specimen to a specified temperature until its length becomes constant, the final length is measured and the amount of shrinkage is calculated from the difference in observed specimen lengths.

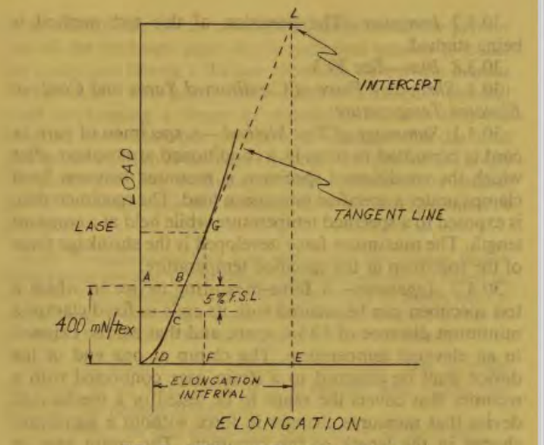


FIG. 2 HMO Load-Elongation Curve

30.3.2 *Apparatus*—A length-measuring device designed so that it can be exposed to an elevated temperature and upon which test specimens at least 10 in. long can be mounted with one end of each specimen in a fixed position. The device shall be equipped with a means for measuring the initial length and the final length of each specimen during the test period. This device shall be such that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

30.3.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

30.3.4 *Procedure*—Secure one end of the specimen in the apparatus, and apply a load of 0.05 ± 0.01 gf/den to the other end of the specimen in such a manner that there is no change in twist. Record the initial length of the specimen to the nearest 0.02 in. Place the apparatus with the specimen and load in an oven controlled within ±3°F of the agreed upon temperature (Note 15). Expose the specimen until the rate of shrinkage of the specimen is less than 5 %/min. Record the final length of the loaded specimen to the nearest 0.02 in. before removing it from the oven.

30.3.5 *Calculation*—Calculate the shrinkage at the specified temperature of each specimen using Eq 20:

$$\text{Shrinkage, \%} = [(I - F)/I] \times 100 \quad (20)$$

where:

I = initial length of specimen, and

F = final length of specimen.

Calculate the average shrinkage of all specimens.

30.3.6 *Report*—State that the specimens were tested as directed in 30.3 of Test Methods D 885 and report the average shrinkage of all specimens as the shrinkage of the sample at the specified temperature together with the number of specimens tested.

Hyosung Ex. 1033, Page 11 of 31

30.3.7 *Precision*—The precision of this test method is being studied.

30.3.8 *Bias*—See 39.3.

30.4 *Shrinkage Force of Conditioned Yarns and Cords at Elevated Temperature:*

30.4.1 *Summary of Test Method*—A specimen of yarn or cord is permitted to relax in a conditioned atmosphere after which the conditioned specimen is mounted between fixed clamps under a specified pretension load. The specimen then is exposed to a specified temperature while held at a constant length. The maximum force developed is the shrinkage force of the specimen at the specified temperature.

30.4.2 *Apparatus*—A force-measuring device in which a test specimen can be secured with its ends in fixed clamps a minimum distance of 10 in. apart, and that can be exposed to an elevated temperature. The clamp at one end of the device shall be attached to a strain gage connected with a recorder that covers the range to be tested or a mechanical device that measures changes in force without a significant change in the length of the specimen. The strain gage or mechanical device shall permit less than 0.001-in. change in specimen length when used under the maximum tension developed. The device shall permit the attachment of a pretension load to the end of the specimen opposite the strain gage, without any change in twist, prior to tightening the clamp.

30.4.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

30.4.4 *Procedure*—Secure one end of the specimen in the clamp attached to the strain gage or mechanical tension device and apply a pretension load of 0.05 ± 0.01 gf/den to the other end of the specimen using care to avoid any change in twist. Secure the other end of the specimen in the other clamp while it is under the pretension load. Expose the mounted specimen to the agreed-upon temperature ±3°F (Note 15). Expose the specimen until the rate of increase in force exerted by the specimen is less than 5 %/min. Record to the nearest 1 g the maximum force developed by the specimen while it is in the oven.

NOTE 17—If a strain gage with recorder is used, a complete force-time curve may be obtained.

30.4.5 *Calculation*—Record the shrinkage force in pounds or calculate the tenacity in terms of grams-force per denier for each specimen using Eq 21:

$$\text{Shrinkage tenacity, gf/den} = F/D \quad (21)$$

where:

F = maximum force developed by the specimen, gf, and
D = linear density of the specimen, den.

Calculate the average shrinkage force of all specimens.

30.4.6 *Report*—State that the specimens were tested as directed in 30.4 of Test Methods D 885 and report the average shrinkage force of all specimens as the shrinkage force at the specified temperature together with the number of specimens tested.

30.4.7 *Precision*—The precision of this test method is being studied.

30.4.8 *Bias*—See 39.3.

31. Properties of Wet Yarns and Cords

31.1 *Significance and Use*—Since textile materials are subjected to aqueous media during their processing, it sometimes is desirable to know their behavior under such conditions.

31.2 *Contraction of Wet Yarns and Cords:*

31.2.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord which has been permitted to relax in a conditioned atmosphere is determined while under a specified load. After having been thoroughly wetted with water at room temperature, the length of the wet loaded specimen is measured after the length of the wet specimen becomes constant. The amount of contraction of the wet specimen is calculated from the difference in the observed lengths of the specimens before and after wetting.

31.2.2 *Apparatus:*

31.2.2.1 *Length-Measuring Device*, made of corrosion-resistant material upon which test specimens at least 10 in. long can be secured with one end of each specimen in a fixed position and which can be immersed in water. The device shall be equipped with a means for measuring the initial length and final length of each specimen. This device shall be such that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

31.2.2.2 *Tank*, made of corrosion-resistant material and of suitable dimensions for immersing in water the device described in 31.2.2.1 with the specimens of yarn or cord.

31.2.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of the cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

31.2.4 *Procedure*—Using the apparatus with dry clamps, secure one end of the specimen in one of the clamps, and apply a load of 0.05 ± 0.01 gf/den to the other end of the specimen in such a manner that there is no change in twist. Record the initial length of the specimen to the nearest 0.5 mm (0.02 in.). Immerse the apparatus with the specimen and load in the water at a temperature of 75 ± 2°F. Expose the specimen until the rate of contraction of the specimen is less than 5 % of the shrinkage/min. Record the final length of the loaded specimen to the nearest 0.5 mm (0.02 in.) while it is wet.

31.2.5 *Calculation*—Calculate the contraction of each wet specimen using Eq 22:

$$\text{Contraction of wet yarn or cord, \%} = [(I - F)/I] \times 100 \quad (22)$$

where:

I = initial length of specimen, and
F = final length of specimen.

Calculate the average contraction of all specimens tested to the nearest 0.1 %.

31.2.6 *Report*—State that the specimens were tested as directed in 31.2 of Test Methods D 885 and report the average contraction of all specimens as the contraction of the wet sample together with the number of specimens tested.

31.2.7 *Precision*—The precision of this test method is being studied.

31.2.8 *Bias*—See 39.3.

32. Twist in Yarns and Cords

32.1 *Number of Specimens*—Test ten specimens. This number is based on the assumption that the applicable coefficient of variation is 3.0 % and the allowable variation is 1.9 % of the average at a probability level of 95 %.

32.2 Determine the twist in single yarn, plied yarn, and tire cord as directed in Test Method D 1423, 10.2 through 10.5, except use a tension of 0.05 ± 0.01 gf/den based on the nominal yarn or cord linear density (Note 18). When all but one of the elements of the untwisted cord have been cut prior to determining the twist of an individual element, leave the total load unchanged even though the tension per unit linear density in the element will be higher than in the original cord. Before determining the twist of the element, record its length after all but one of the elements have been cut away from the untwisted cord. Use this length when calculating the twist in the element using Eq 8 of Test Method D 1423.

NOTE 18—For convenience in routine testing, an approximation of the specified tension may be obtained by applying one of the loads listed as follows for the specified groups of yarn and cord sizes.

Linear Density of Specimen	Amount of Tension, ozf	Amount of Tension, gf
Below 3600 denier (400 tex)	4	113
3600 to 7200 denier (400 to 800 tex)	8	225
Above 7200 denier (800 tex)	12	340

32.3 *Precision and Bias*—See Section 39 for cord only. The precision of this test method for yarn is being studied.

33. Thickness of Cords

33.1 *Summary*—The average thickness (gage) of a group of parallel tire cords resting on an anvil is determined when under a specified pressure applied by the pressor foot of a thickness gage.

33.2 *Apparatus*—The thickness gage shall conform with the requirements specified in 6.1 of Method D 1777. The gage shall be equipped with a pressor foot having a diameter of 0.375 in. and shall exert a pressure of approximately 3.4 psi (related to the presser foot area, or to the contact area between the cord and the presser foot).

33.3 *Number of Specimens*—Test 5 specimens. This number is based on the assumption that the applicable coefficient of variation is 1.0 % and the allowable variation is 1.5 % of the average at a probability level of 95 %.

33.4 *Procedure*—Take a specimen comprised of four cords from the sample and handle the cords in such a manner that no change of twist can occur. For tabby samples of tire cord fabrics, prior to removing each set of four cords, position the cords so that they are adjacent and parallel with no ends crossed. Grasp the four cords so that the length of the cords between the fingertips of the left hand and the right hand is approximately equal to the length of the anvil. Use care to avoid any change in twist if the hands are repositioned after the set of four cords are removed from the tabby sample. Inspect the top and bottom of the specimen to be sure that no knots, splices, or foreign protuberances are present on the lengths of cord to be gaged. Place the four cords side by side on the anvil and directly under the pressor foot of the thickness gage. Apply sufficient tension to make the cords taut (about 1 lbf (see Note 19). Lower the pressor foot gradually and gently (take about 5 s to apply the full load) by keeping a finger or thumb in contact with the lowering lever until the pressor is in contact with the cord specimen. Wait until the gage reading becomes stable (about 5 s), and record the thickness of the specimen to the nearest 0.0005 in. Make only one measurement of each specimen of four cords.

NOTE 19—Laboratory tests have shown that the average tension applied by an operator, to four parallel cords held between the fingertips, was about 1 lbf. Tensions considerably greater than 1 lbf usually result in cord slippage. Tests using a tension in the range from 0.5 to 1.5 lbf resulted in no significant change in cord thickness, as measured.

33.5 *Calculation and Report*—Calculate the average thickness of all specimens from a sample and report this value to the nearest 0.0005 in.

33.6 *Precision and Bias*—See Section 39 for cord only.

34. Extractable Matter in Yarns and Cords

34.1 Determine the amount of extractable matter present in yarns and cords as directed in Test Method D 2257.

35. Dip (Adhesive) Solids Pickup on Yarns and Cords

35.1 *Summary of Test Method*—Individual procedures are given for determining the amount of adhesive dip solids on nylon (35.4), polyester (35.5), and rayon (35.6) yarns or cords that have been treated with resorcinol-formaldehyde-latex (RFL) type of adhesive dip by dissolving the fiber in an appropriate solvent and recovering the residue of dip solids by filtration after which it is dried and weighed. The amount of adhesive solids on a sample is reported as percentage dip solids pickup based on the oven-dry weight of the dip-free sample. An acceptable solids pickup test for high-modulus aramids has not yet been established.

35.2 *Significance and Use:*

35.2.1 Textile yarns and cords are treated with an adhesive dip to improve the adhesion of elastomers to the textile materials. The amount of dip solids pickup on the yarns or cords is used for process control.

35.2.2 This test method for testing dip pickup is not recommended for acceptance testing of commercial shipments of dipped yarns or cords because of large between-laboratory variations.

35.3 *Apparatus and Materials:*

35.3.1 *Air Oven*, controlled at 221 ± 6°F.

35.3.2 *Erlenmeyer Extraction Flasks*, capacity 250 mL, borosilicate glass, with interchangeable ground-glass joints.

35.3.3 *Glass-Fiber Filter Disks*,[10]

35.3.4 *Glass Weighing Bottles*, with ground-glass stoppers, 40 mm in diameter and 80 mm in height.

35.3.5 *Gooch Crucible*, No. 4.

35.3.6 *Vacuum Flask*, capacity 1 L.

35.3.7 *Water-Cooled Condensers*, borosilicate glass, with interchangeable ground-glass joints.

35.4 *Nylon Yarns and Cords:*

[10] Glass Fiber Filter Disks, No. X-934-AH, made by Hurlbut Paper Co., Box 9, Green Bay, WI 54305, have been found to be satisfactory for this purpose.

Hyosung Ex. 1033, Page 12 of 31

35.4.1 *Apparatus and Reagents:*

35.4.1.1 Apparatus and materials as listed in 35.3.

35.4.1.2 *Formic Acid* (90 %), HCOOH.

35.4.2 *Safety Precautions*—Use extreme care, wear rubber gloves and goggles, and work in a hood with forced ventilation when handling concentrated formic acid.

35.4.3 *Procedure*—Cut approximately 3 g of dipped nylon yarn or cord into pieces no longer than ¼ in. and place the pieces in a weighing bottle. Dry this specimen in an oven at a temperature of 221 ± 6°F to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus the specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to a 500-mL beaker and add 250 mL of 90 % formic acid. Allow the specimen to dissolve at room temperature with occasional stirring. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible that contains a glass-fiber filter disk. Wash the beaker and residue with two 25-mL portions of formic acid and allow the acid to filter slowly through the residue each time. Wash the residue with four 25-mL portions of water in the same manner as above. Dry the residue and crucible at a temperature of 221 ± 6°F to a constant mass. Cool in a desiccator and weigh to the nearest 1 mg.

35.4.4 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 23:

$$\text{Dip pickup, \%} = [R/(S - R)] \times 100 \quad (23)$$

where:

R = mass of oven-dry residue, g, and

S = mass of oven-dry specimen, g.

Calculate the average pickup of all specimens and report this value as the adhesive dip solids pickup of the sample together with the number of specimens tested.

35.4.5 *Report*—The average adhesive dip solids pickup of the sample together with the number of specimens tested.

35.4.6 *Precision:*

35.4.6.1 *Interlaboratory Test Data*—An interlaboratory test was run in 1968 in which three laboratories each tested dipped cord specimens from a single sample. A single nylon cord at a dip pickup level of approximately 5 % was wound on a drum, cut off the drum, and the resulting 10 to 12-in. lengths of cord were thoroughly mixed. Each participating laboratory was supplied a bundle of these short cords taken at random from the sample described. Each laboratory made five determinations on two different occasions. The components of variance for dip pickup results expressed as coefficients of variation were calculated to be as follows:

Within-laboratory component	2.13 % of the average
Between-laboratory component	6.14 % of the average

35.4.6.2 *Precision*—For the components of variance reported in 35.4.6, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed as follows:

DIP PICKUP

Number of Observations in Each Average	Critical Difference, % of Grand Average, for the Conditions Noted[A,B]: Single-Operator Precision	Between-Laboratory Precision
1	5.90	18.01
5	2.64	17.22
10	1.87	17.12

[A] The critical differences were calculated using $t = 1.960$, which is based on the infinite degrees of freedom.

[B] To convert the values of the critical differences to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as a decimal fraction.

NOTE 20—The within-laboratory component of variance is the sum of all the individual components of variance, except the single-operator component of variance, that contribute to the variability of observations within a single laboratory. Included are such components of variance as those for days of testing, units of apparatus, and different operators within a single laboratory. If the within-laboratory component of variance is not calculated separately, all sources of variability except the single-operator component are included in the between-laboratory component. Under these condition, calculate the standard error (between-laboratory) using zero for the within-laboratory component.

35.5 *Polyester Yarns and Cords:*

35.5.1 *Apparatus and Reagents:*

35.5.1.1 Apparatus and materials as listed in 35.3.

35.5.1.2 *Methylene Chloride*, CH_2Cl_2, reagent grade.

35.5.1.3 *Trichloroacetic Acid*, Cl_3CCOOH, reagent grade.

35.5.1.4 *Trichloroacetic Acid, Methylene Chloride Solution* (30 % (w/v))—Dissolve 300 g of trichloroacetic acid crystals in 1000 mL of methylene chloride.

35.5.2 *Procedure*—Cut approximately 2 g of dipped polyester yarn or cord into pieces no longer than ¼ in. and place the pieces in a weighing bottle. Dry this specimen in an oven at a temperature of 221 ± 6°F to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to the 250-mL Erlenmeyer extraction flask and add about 75 mL of the trichloroacetic acid-methylene chloride solution. Attach the flask to the condenser and reflux for 15 min or until the specimen appears to be dissolved. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible that contains a glass-fiber filter disk. Wash the flask and residue on the filter disk with three successive 25-mL portions of methylene chloride. Dry the Gooch crucible and filter disk with the dip solids residue at a temperature of 221 ± 6°F to constant mass. Cool in a desiccator and weigh to the nearest 1 mg.

35.5.3 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 23. Calculate the average pickup of all specimens and report this value as the adhesive dip solids pickup of the sample, together with the number of specimens tested.

35.5.4 *Precision:*

35.5.4.1 *Interlaboratory Test Data*—Data on components of variance are not available.

35.5.4.2 *Within-Laboratory Precision*—The uncertainty (0.95 level) of single measurements made in one laboratory has been found to be ±10 % of the average dip solids pickup.

35.5.4.3 *Between-Laboratory Precision*—The uncertainty (0.95 level) in the difference between two laboratories, each making five measurements, has been found to be ±15 % of the average dip solids pickup.

35.6 *Rayon Yarns and Cords:*

35.6.1 *Apparatus and Reagents:*

35.6.1.1 Apparatus and materials as listed in 35.3.

35.6.1.2 *Sulfuric Acid* (71 ± 1 %)—Pour slowly with constant stirring 420 mL of concentrated sulfuric acid (sp gr 1.84) into 260 mL of distilled water.

35.6.2 *Procedure*—Cut approximately 3 g of dipped rayon yarn or cord into pieces no longer than ¼ in. and place in a weighing bottle. Dry this specimen in an oven at a temperature of 221 ± 6°F to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to a 250-mL beaker. Add 150 mL of the H_2SO_4 (71 %), which has been heated to a temperature of 86 ± 9°F, to the specimen in the beaker with stirring. Maintain the mixture at the above temperature and stir continuously until the fibers appear to be completely dissolved, then stir for an additional 20 min. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible which contains a glass fiber filter disk. Wash the beaker and residue with successive 25-mL portions of water until the wash water is acid-free when tested with methyl red. Dry the residue and crucible at a temperature of 221 ± 6°F to a constant mass, cool in a dessicator, and weigh the residue to the nearest 1 mg.

35.6.3 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 23. Calculate the average pickup of all specimens and report this value as the adhesive dip solids pickup of the sample together with the number of specimens tested.

35.6.4 *Precision:*

35.6.4.1 *Interlaboratory Test Data*—The values of precision are based on interlaboratory testing by eight laboratories of a standard sample that contained about 5 % adhesive dip solids pickup. Components of variance are not available.

35.6.4.2 *Within-Laboratory Precision*—The uncertainty (0.95 level) of single measurements made in one laboratory has been found to be ±10 % of the average dip solids pickup.

35.6.4.3 *Between-Laboratory Precision*—The uncertainty (0.95 level) in the difference between two laboratories, each making five measurements, has been found to be ±15 % of the average dip solids pickup.

35.7 *Bias*—No justifiable statement on the accuracy of Test Methods D 885 for the Measurement of Dip Pickup can be made since the true value of this property cannot be established by a referee method.

36. Adhesion of Cord to Elastomers

36.1 Determine the adhesion of tire cords to elastomers as directed in Test Method D 2138.

NOTE 21—Other tire cord adhesion tests currently are being studied jointly by ASTM Committee D-11 on Rubber and Rubber-Like Products and Committee D-13.

37. Properties of Tire Cord Fabric

37.1 *Width*—Determine the width of tire cord fabric as directed in Test Methods D 3774.

37.2 *Mass*—Determine the mass of tire cord fabric as directed in Test Method D 3776.

37.3 *Count*—Determine the count of tire cord fabric as directed in Test Method D 3775 except count the filling yarns in a specimen of fabric having a length of at least 10 in.

38. Stiffness of Fabric

38.1 *Summary of Test Method*—Specimens of tire fabric are analyzed for stiffness using a CRE-type tensile testing machine, having normal jaws replaced with a holder or rack which allows the sample to rest across a 1-in. span opening. The specimen is deflected by a depressor applied in the center of the span and the load in grams-force (millinewtons) required to depress the sample is recorded and averaged.

38.2 *Significance and Use*—Stiffness of treated fabric is a factor influencing the handling, fabrication, and performance of the finished product. This test method may be used to determine the stiffness. Specified stiffness values will not be set forth because various applications, equipment for fabricating, condition of materials, and so forth. play an important part on the degree of stiffness desired or that can be tolerated.

38.3 *Apparatus:*

38.3.1 *CRE-Type Tensile Testing Machine.*

38.3.2 *Load Cell*, 2000-gf.

38.3.3 *Shears.*

38.3.4 *Specimen Holder*—A square frame made of 3/16-in. diameter steel rod. It is 3⅜-in. square. In the middle of one side is a hook made of ⅛-in. diameter rod for connecting the holder to the load cell. In the middle of the opposite side, there is a ⅞-in. rod fastened at midpoint and at right angles to the side of the frame. These two "*T*'s," 1 in. apart, form a rack on which the test specimens lay so that they are across the 1-in. opening (see Fig. 3).

38.3.5 *Specimen Depressor*, 3⅜-in. square frame, made of 3/16-in. diameter steel rod, rigidly fastened with a threaded connector to the lower crosshead. The side opposite the crosshead connection is covered with a ¼-in. diameter piece of steel tubing. This forms a bar which presses against specimens to bend them during the test (see Fig. 3).

38.4 *Number of Specimens:*

38.4.1 Unless otherwise agreed upon, as when specified in an applicable material specification, take a number of specimens such that the user may expect at the 95 % probability level that the test result is no more than 3.50 % of the average above or below the true average (that is, a theoretical average obtained from an infinite number of observations). Determine the number of specimens (in accordance with Practice D 2258) as follows:

38.4.2 *Reliable Estimate of v*—When there is a reliable estimate of v based upon extensive past records for similar materials tested in the user's laboratory as directed in the test method, calculate the number of specimens using Eq 24:

$$n = (t^2 \times v^2)/A^2 = 0.314 \times v^2 \quad (24)$$

where:

n = number of specimens (rounded upward to a whole number),

v = reliable estimate of the coefficient of variation of individual observations on similar materials in the user's laboratory under conditions of single-operator precision,

t = 1.960, the value of Student's t for infinite degrees of freedom, for two-sided limits, and a 95 % probability level (t^2 = 3.842),

A = 3.50 % of the average, the value of the allowable variation, and

0.314 = value calculated from t^2/A^2.

38.4.3 *No Reliable Estimate of v*—When there is no reliable estimate of v for the user's laboratory, Eq 24 should not be used directly. Instead, specify the fixed number of five specimens. This number of specimens is calculated using v = 3.71 % of the average, which is a somewhat larger value of v than is usually found in practice. When a reliable estimate of v for the user's laboratory becomes available, Eq 24 will usually require fewer than five specimens.

38.5 *Sample Preparation:*

38.5.1 *Fabric Sample*—Cut the required number of 2-in. long specimens of fabric, each containing 16 ends. Select specimens as straight as possible. Do not preflex samples before testing. Remove three ends from each edge of each specimen, leaving ten ends and all the filling in the sample.

38.6 *Procedure:*

38.6.1 Mount the specimen holder and depressor in the testing machine, calibrate, and set the tester at zero.

38.6.2 Adjust the crosshead so that the pressor bar of the depressor is approximately ¼ in. above the opening in the specimen rack.

38.6.3 Set the crosshead speed at 1 in./min and the chart speed at 5 in./min. Set the load selector for the minimum scale load to accommodate the sample and for the bending force to occur between 10 and 90 % of full-scale load, preferably at mid-scale.

38.6.4 Place the specimen on the rack with the middle of the specimen at the midpoint of the rack and the longitudinal axis of the specimen parallel to the 1-in. opening.

38.6.5 Start the tester so that the crosshead is lowered and the pressor bar is pulled down onto the specimen and through the opening in the specimen rack.

38.6.6 Record the maximum force to the nearest 0.1 gf required to pull the specimen through the opening.

38.6.7 Repeat 38.6.1 to 38.6.6, and average the stiffness results of all of the samples.

38.7 *Report:*

38.7.1 State that the specimens were tested as directed in Section 38 of Test Methods D 885. Describe the material or product sampled and the method of sampling used.

38.7.2 Report the average of the results of all of the specimens to the nearest 0.1 gf and the number of specimens tested.

38.8 *Precision and Bias:*

38.8.1 *Interlaboratory Test Data*[11]—An interlaboratory test was run in 1974 in which randomly drawn samples of one material were tested in each of five laboratories. The operator in each laboratory tested five specimens of each material. The components of variance for stiffness property results expressed as coefficients of variation were calculated to be:

Single-operator component	2.65 % of the average
Between-laboratory component	3.36 % of the average

38.8.2 *Precision*—For the components of variance reported in 38.8.1, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed as follows:

Number of Observations in Each Average	Critical Differences,[A,B] % of the Grand Average for the Conditions Noted: Single-Operator Precision	Between-Laboratory Precision
1	7.34	11.9
5	3.28	9.87
10	2.32	9.60

[A] The critical differences were calculated using t = 1.960, which is based on infinite degrees of freedom.

[B] To convert the tabulated values of the critical differences to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as decimal fractions.

NOTE 22—The tabulated values of the critical differences should be considered to be a general statement, particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias, if any, between them must be established, with each comparison being based on recent data obtained on randomized specimens from one sample of the material to be tested.

38.8.3 *Bias*—No justifiable statement on the bias of Test Methods D 885 for measuring the stiffness of fabric can be made since the true value of the property cannot be established by an accepted referee method.

39. Precision and Bias of Certain Cord Tests

39.1 *Interlaboratory Test Data*—An interlaboratory test was run in 1969 in which replicate samples from three tire cord materials were sent to eight laboratories. The samples were tested on two different occasions in each laboratory. These materials were greige 840/2 nylon; 1000/3 polyester; and 1650/3 rayon. Each laboratory received a small spool from a single lot of each material. Cord spools of all three materials were prepared in a single laboratory and sent to each laboratory participating in the interlaboratory test. Similar specimen preparation and interlaboratory tests were completed on 1500/1 high-modulus aramid yarn in 1973 and on two constructions of 1500/2 high-modulus aramid cords in 1974. In each interlaboratory test, a variety of properties were determined on each specimen. The load at specified elongation (LASE) results were initially withheld from Tables 3 and 4 because of excessive variation and a separate aramid LASE interlaboratory test program was completed in 1983 on greige and treated 1500/1/2 cord with and without the use of rosin to reduce clamp slippage. Rosin use altered results without reducing variation, providing higher LASE values when the entire sample was treated and intermediately high values when only clamp areas were treated. The LASE values shown are for non-rosin treated specimens. In 1974, a separate interlaboratory test was run on linear density in which other replicate samples in two forms, bobbin and tabby, from three tire cord materials were sent to nine laboratories. Five linear density determinations were made on three occasions in each laboratory. The components of variance expressed as coefficients of variation were calculated and are listed in Table 3. Facilities for measurement of a given property varied among laboratories; therefore, the listing in Table 3 does not always show the same number of participating laboratories for each property measurement.

39.2 *Precision*—For the components of variance reported in Table 3, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences shown in Table 4.

39.3 *Bias*—No justifiable statement on the bias of the procedures in Test Methods D 885 for measuring various properties of tire cords can be made since the true value of the properties cannot be established by referee methods.

40. Keywords

40.1 tire cord; tire fabric; industrial yarn; man-made fibers, cellulose base; man-made fibers, synthetic base; commercial mass; moisture regain; yarn number; tension (tensile) properties/tests; elongation; strand toughness; dimensional change; twist; extractable matter; dip-pickup; adhesion; width; length; mass-per-unit-area; breaking strength; and strand.

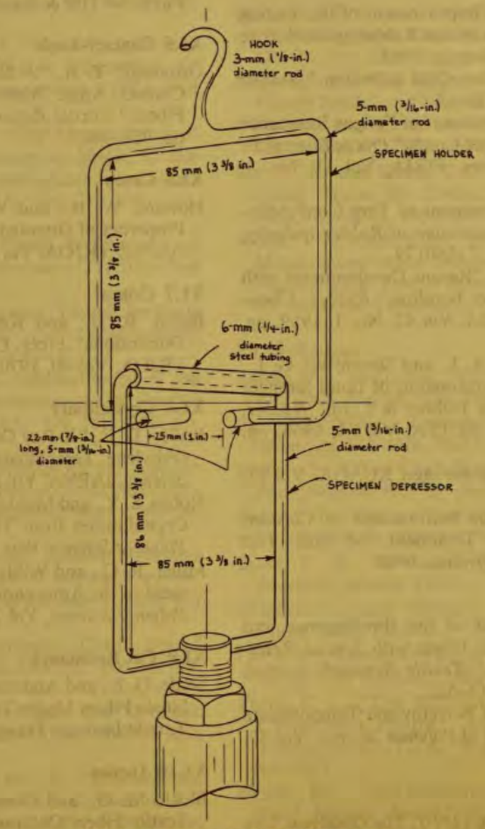


FIG. 3 Specimen Holder and Depressor

[11] ASTM Research Report No. RR:D13-1040. A copy is available on loan from ASTM Headquarters, 1916 Race St., Philadelphia, PA 19103.

Hyosung Ex. 1033, Page 14 of 31

APPENDIX

(Nonmandatory Information)

X1. BIBLIOGRAPHY OF TIRE CORD TEST METHODS

NOTE—The Bibliography of Tire Cord Test Methods covers the following journals: (1) Journal of Applied Polymer Science, January 1959–August 1970, (2) Journal of Polymer Science, January 1950–December 1963, General Papers, January 1963–December 1965, Polymer Physics Part A-2, January 1965–September 1970, Polymer Symposia Part C, January 1963–August 1970, (3) Journal of The Textile Institute Transactions, January 1950–August 1970, (4) Textile Research Journal, January 1950–September 1970, and (5) Other journals at random.

X1.1 Adhesion

Eccher, S., and Canevari, C., "Improvement of the Testing Method for Adhesion of Vulcanized Rubber to Steel Wire Cords," *D.K.G. Rubber Conference*, 1968.

Igengar, "Factors in Rubber Tire Cord Adhesion," *Rubber World*, RUBWA, 1963, pp. 39–42.

Kenyon, D., "Laboratory Assessments of Fatigue Resistance and Dynamic Adhesion of Tyre Cords," *Proceedings of the Institution of Rubber Industry*, PIRIA, Vol 11, No. 3, 1964, pp. 67–93.

Kenyon, D., "Laboratory Assessment of Tyre Cord Adhesion," *Transactions of the Institution of Rubber Industry*, TIRIA, Vol 38, No. 4, 1962, T1650179.

Takeyama, J., and Matsui, J., "Recent Developments with Tire Cords & Cord to Rubber Bonding," *Rubber, Chemistry, and Technology*, RCTEA, Vol 42, No. 1, 1969, pp. 159–256.

Tsydzik, M. A., Lukomskaya, A. I., and Slonimskii, G. L., "Dynamic Methods for Determination of Bond Strength Between Rubbers & Between Rubber & Cord," *Rubber, Chemistry, and Technology*, RCTEA, Vol 33, 1960, pp. 42–50.

"U-Adhesion Test Fixture," *Rubber Age*, RUAGA, Vol 91, No. 4, 1962, p. 676.

Wijngaarden, J. K., Van, "The Performance of Cord-in-Rubber Tests and the Treatment of the Test Results," *D.K.G. Rubber Conference*, 1960.

X1.2 Birefringence

Heyn, A. N. J., "Observations of the Birefringence and Refractive Index of Synthetic Fibers with Special Reference to Their Identification," *Textile Research Journal*, TRJOA, Vol 22, 1952, pp. 513–522.

Sakajiri, S., "The Transition of Polyethylene Terephthalate Fiber Birefringence," *Journal of Polymer Science*, Vol 35, No. 129, 1959, pp. 543–546.

X1.3 Breaking Time

"Hot Load Test," Test Procedure FD9-1, The Goodyear Tire & Rubber Co., Akron, OH, 1964.

Warburton, F. L., James, J. F. P., and Hother-Lushington, "Some Visco-Elastic Properties of Nylon," *British Journal of Applied Physics*, BJAPA, Vol 12, 1961, p. 230.

X1.4 Compression Testing

Bhakuni, R. S., Gingo, J. M., and Causa, A. G., *Tire Fiber Rheology*, The Goodyear Tire & Rubber Co., Akron, OH 1970.

Bobeth, W., "Automatic Textile Testing by Electronic Data Scanning and Evaluation by an Axial Pressure Tester," *Fasserforschung Und Textitechnik*, FSTXA, Vol 21, No. 11, 1970, pp. 453–459.

Friedemann, W., "Simple Method for Measuring the Stress in Compressed Cord Yarns," *Faserforschung Und Textiltechnik*, FSTXA, Vol 9, No. 8, 1958, pp. 334–337.

Wolf, B. M., and Armstrong, R. R., *Testing Cord Fabric*, Firestone Tire & Rubber Co., U.S.P. 1954, 2665582.

X1.5 Contact-Angle

Grindstaff, T. H., "A Simple Apparatus and Technique for Contact Angle Measurements on Small-Denier Single Fibers," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 958–962.

X1.6 Creep

Howard, W. H., and Williams, M. L., "The Viscoelastic Properties of Oriented Nylon 66 Fibers," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 689–698.

X1.7 Crimp

Brand, R. H., and Kende, P., "Measurement of Three-Dimensional Fiber Crimp," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 169–177.

X1.8 Crystallinity

Bosley, D. E., "X-Ray Determination of Crystallinity in Poly (Ethylene Terephthalate)," *Journal of Applied Polymer Science*, JAPNA, Vol 8, 1964, pp. 1521–1529.

Hobbs, S. Y., and Mankin, G. I., "Determination of Polymer Crystallinities from Thermal Measurements," *Journal of Polymer Science*, Part A-2, No. 9, 1971, pp. 1907–1910.

Miller, R. G., and Willis, H. A., "An Independent Measurement of the Amorphous Content of Polymers," *Journal of Polymer Science*, Vol 19, 1956, pp. 485–494.

X1.9 Cut Resistance

Settle, G. E., and Anderson, S. L., "Resistance to Rupture of Single Fibers Under Transverse Pressure," *Journal of The Textile Institute Transactions*, JTITA, Vol 54, T28, 1963.

X1.10 Denier

Bloch, M. G., and Gusack, J. A., "Denier Distribution of Textile Fibers Obtained with an Electrical Sensing Zone Particle Analyzer (Coulter Counter)," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 224–233.

X1.11 Differential Thermal Analysis

Keavney, J. J., and Eberlin, E. C., "The Determination of Glass Transition Temperatures by Differential Thermal Analysis," *Journal of Applied Polymer Science*, JAPNA, Vol 3, No. 7, 1960, pp. 47–53.

Schwenker, R. F., Jr., and Zuccarello, R. K., "Differential Thermal Analysis of Synthetic Fibers," *Journal of Polymer Science*, Part C, No. 6, 1964, pp. 1–16.

Strella, S., "Differential Thermal Analysis of Polymers," *Journal of Applied Polymer Science*, JAPNA, Vol 7, 1963, pp. 569–579.

X1.12 Dip Pickup

Todd, H. E., and Tramutt, H. M., "Flame Photometric Determination of Rubber Solids Deposited on Cords & Fabrics," *Rubber Age*, RUAGA, New York, Vol 73, 1953, p. 501.

X1.13 Dynamic Modulus

Ballow, J. W., and Smith, J. C., "Dynamics Measurements of Polymer Physical Properties," *Journal of Applied Physics*, JAPIA, Vol 20, 1949, pp. 493–502.

Chaikin, M., and Chamberlain, N. H., "The Propagation of Longitudinal Stress Pulses in Textile Fibers-Part I," *Journal of the Textile Institute Transactions*, JTITA, Vol 46, 1955, T25–43.

Dunell, B. A., and Dillon, J. H., "The Measurement of Dynamic Modulus & Energy Losses in Single Textile Filaments Subjected to Forced Longitudinal Vibrations," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 393–403.

Hamburger, W. J., "Mechanics of Elastic Performance of Textile Materials," *Textile Research Journal*, TRJOA, Vol 18, 1948, pp. 705–743.

Kainradl, P., and Handler, F., "Dynamic Testing Methods for Tyre Cord," *Faserforschung Und Textiltechnik*, FSTXA, Vol 11, No. 9, 1960, pp. 408–427.

Lyons, W. J., and Prettyman, I. B., "Measurement of the Dynamic Stretch-Modulus and Hysteresis of Tire Cords," *Journal of Applied Physics*, BJAPA, Vol 18, 1947, pp. 586–587.

Lyons, W. J., and Prettyman, I. B. "Method for the Absolute Measurement of Dynamic Properties of Linear Structures at Sonic Frequencies," *Journal of Applied Physics*, Vol 19, 1948, pp. 473–480.

Meredith, R., and Hsu, B. S., "Dynamic Bending Properties of Fibers: Effect of Temperature on Nylon 66, Terylene, Orlon, & Viscose Rayon," *Journal of Polymer Science*, Vol 61, 1962, pp. 271–292.

Mieck, et al, "Static and Dynamic Cord Tests," *Faserforschung Und Textiltechnik*, FSTXA, Vol 13, No. 11, 1962, pp. 502–511.

Palandri, G., "Measurement of Hysteresis and Dynamic Elastic Modulus of Textile Yarns and Cords," *Rubber Age*, 64, 1948, pp. 45–52.

Sakurada, I., Nukushina, Y., and Ito, T., "Experimental Determination of the Elastic Modulus of Crystalline Regions in Oriented Polymers," *Journal of Polymer Science*, Vol 57, 1962, pp. 651–660.

Smith, H. D., and Jenkins, R. C., "Cord Modulus: New Cord Extension System," *Rubber Age*, RUAGA, 95, No. 4, 1964, p. 575. *Rubber World*, RUBWA, Vol 95, No. 4, 1964, p. 90.

Tipton, H., "The Dynamic Tensile Mechanical Properties of Textile Filaments and Yarns," *Journal of the Textile Institute Transactions*, Vol 46, 1955, pp. T322–361.

Tokita, N., "The Effects of Crystallization and Drawing on the Viscoelastic Properties of Fibers," *Journal of Polymer Science*, Vol 20, 1956, pp. 515–536.

Van der Meer, S. J., "Dynamic Measurement on Textile Yarns, Industrial Yarns and Tire Cords," AKU Research Report No. R1209, 1965, AKU, Arnhem, Netherlands.

"Modulus Tester," *Rubber World*, RUBWA, Vol 148, No. 2, 1963, p. 22.

X1.14 Elastic Recovery

Hearle, J. W. S., and Plonsker, H. R., "Behavior of Fibers in Cumulative Extension Cycling," *Journal of Applied Polymer Science*, Vol 10, 1966, pp. 1949–1971.

X1.15 Elongation

Breazeale, F. B., and Irvin, H. D., "An Automatic Yarn Load-Elongation Recorder," *Textile Research Journal*, TRJOA, Vol 22, 1952, pp. 549–552.

Meredith, R., "The Effect of Rate of Extension on the Tensile Behavior of Viscose and Acetate Rayons, Silk and Nylon," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T30–43.

Orr, R. S., and Grant, J. N., "A Single-Fiber Load-Elongation Tester for Cotton," *Textile Research Journal*, TRJOA, Vol 23, 1953, pp. 505–509.

Wood, J. O., and Kilby, W. F., "An Apparatus for the Measurement of the Delayed Elongation of Tyre Cords," *Journal of the Textile Institute Transactions*, JTITA, Vol 49, 1958, pp. T89–94.

X1.16 Fatigue

Bartha, Z., "Evaluating Tyre Cords," *Man-Made Textiles*, MMTXA, Vol 38, May 1961, p. 57.

Bartha, Z., "Fatigue Testing of Tyre Cord Yarns in Rubber," *Muanyag*, MUANA, Vol 1, No. 7, 1964, pp. 212–215.

Bartha, Z., "Tyre Cord Fatigue Tests," *Rev. Gen. Caout. Plast.*, Vol 44, No. 10, 1967, pp. 1205–1212.

Buchan, J., "Fatigue Testing of Tyre Cords in Rubber," *Textile Weekly*, TEWEA, Vol 58, 1958, pp. 315–316.

Budd, C. B., "A Fatigue Test for Tire Cord," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 174–179.

Dischka, G., and Hajmasy, T., "Fatigue Tests on Tyre Cords," *Acta Technica*, Vol 38, 1962, pp. 235–257.

Falch, W., "Dynamic Fatigue Tests on Tyre Cord in Combination with Rubber," *DKG Rubber Conference*, 1956.

Floyd, K. L., "The Behavior of Rayon Tyre Cords Under Compressive Flexing," *Journal of the Textile Institute Transactions*, JTITA, Vol 53, No. 10, 1962, pp. T 449–463.

Forster, M. J., and Prettyman, I. D., "New Improved Tyre Cord Fatigue Tester," *Rubber, Chemistry, and Technology*, RUAGA, Vol 42, No. 4, 1969, pp. 1000–1008.

Frank, F., and Singleton, R. W., "A Study of Factors Influencing the Tensile Fatigue Behavior of Yarns," *Textile Research Journal*, Vol 34, 1964, pp. 11–19.

Gibson, E. C., "Tyre Cord Testing Machine," American Viscose Corp., U. S. Patent 2916912, 1959.

Hannell, J. W., "Tire Testing," *ASME Publications*, 59-SA-48, New York, 1959.

Hyosung Ex. 1033, Page 15 of 31

Hofferberth, W., "Static and Dynamic Testing of Textiles and Its Practical Importance," *DKG Rubber Conference*, 1954.

Kemmnitz, "A Study of the Compression Fatigue and the Damping Phenomena of Tire Cord," *Journal of Applied Polymer Science*, TAPNA, Vol 32, 1962, pp. 373–392.

Kenyon, D., "Laboratory Assessments of Fatigue & Dynamic Adhesion of Tyre Cords," Proc. I.R.I., Vol 11, No. 3, 1964, pp. 67–93.

Kenyon, D., "Tyre Cord Fatigue Testers," *British Nylon Spinners Outlook*, No. 13, 1964.

Lincoln, B., "Flexural Fatigue and Visco-Elastic Properties of Wool Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 43, 1952, pp. T 158–172.

Lockwood, P. A., Edmunds, W. M., and Grimm, G. W., "Fatigue Performance of Tire Belt Cords, *Rubber, Chemistry, and Technology*, RCTEA, Vol 44, No. 4, 1971, pp. 946–951.

Lyons, W. J., "Fatigue in Textile Fibers, Part I," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 448–459.

Lyons, W. J., "Fatigue in Textile Fibers, Part III," *Textile Research Journal*, TRJOA, 1962, pp. 750–761.

Lyons, W. J., "Fatigue in Textile Fibers, Part IX," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 1106–1109.

Lyons, W. J., "Fatigue in Textile Fibers, Part XI," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 60–68.

Lyons, W. J., "Fatigue in Textile Fibers, Part XII," *Textile Research Journal*, TRJOA, Vol 20, 1970, pp. 836–843.

Mieck, K. P., "Testing the Fatigue Behavior of Tyre Cord Vulcanized into Rubber," *Faserforschung Und Textiltechnik*, FSTXA, Vol 10, No. 12, 1959, pp. 578–587.

Ono, et al, "On the Fatigue Mechanism of Tire Cord," *Journal of the Society of Textile and Cellulose Industries of Japan*, SENGA, Vol 18, 1962, pp. 955–962.

Prevorsek, D. C., and Lyons, W. J., "Endurance of Polymeric Fibers in Cyclic Tension," *Rubber, Chemistry, and Technology*, RCTEA, Vol 44, No. 1, 1971, pp. 271–293.

Rhodes, T. J., "Apparatus for Testing Cord Fatigue," *U. S. Rubber Co.*, U.S. Patent 2612040, 1952.

Shirakashi, K., and Ishikawa, K., "Study on Tyre Cords," *Journal of the Society of Textile and Cellulose Industries of Japan*, SENGIA, Vol 12, 1956, pp. 392–397.

Stroenov, U. B., Denisenko, N. V., and Nemchenko, E. A., "Determination of the Fatigue Properties of (Tire) Cord Subjected to Repeated Deformation of Modernized Apparatus of the 5-24-1-Tyre," *Khim. Volok.*, No. 6, 1962, pp. 31–34.

Wegener, W., "Apparatus for Testing Dynamic Fatigue with Superimposed Alternating Load," *Melliand Textilberichte*, MTEEA, Vol 35, 1954, pp. 371–374.

Wegener, W., "Fatigue Testing Devices for Yarns and Fabrics," *Melliand Textilberichte*, MTEEA, Vol 39, No. 1, 1958, pp. 17–21.

Wilson, M. W., "Tire-Cord Compression Fatigue," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 47–54.

"Apparatus for Testing the Flexing Fatigue of Tyre Cords," Japanese Patent 5398159.

"B. F. Goodrich Disc. Compression Cord Tester," *Rubber Age*, RUAGA, Vol 78, 1955, p. 299.

"Fatigue Tester for Cord," *Rubber Age*, RUAGA, Vol 102, No. 5, 1970, pp. 125–128.

"Tire Cord Tester," *Rubber World*, RUBWA, Vol 144, No. 5, 1961, p. 62; *Rubber Age*, RUAGA, Vol 90, No. 1, 1961, p. 154.

X1.17 Flatspotting

Claxton, W. E., Forster, M. J., Robertson, J. J., and Thurman, G. R., "Correlation of Nylon Tire Cord Properties with Tire Flatspotting," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 903–914.

Jonson, C. A., "Apparatus for Measuring Elastic Properties," U.S. Patent 3,062,044, 1962.

Oswald, H. J., Papero, P. V., and Wincklhofer, R. C., "The Mechanism of Flatspotting and Its Relation to Fiber Properties," *Rubber, Chemistry, and Technology*, RCTEA, Vol 38, No. 4, November 1965.

Rye, G. W., and Martin, J. E., "Lab Test to Predict Flatspotting Behavior of Tyre Cord," *Rubber World*, Vol 148, No. 1, 1963, p. 76.

X1.18 Friction

Grosberg, P., and Plate, D. E. A., "Capstan Friction for Polymer Monofilaments with Rigidity," *Journal of the Textile Institute Transactions*, JTITA, Vol 60, 1969, pp. 268–283.

Guthrie, J. C., and Oliver, P. H., "Inter-Fiber Friction of Viscose Rayon," *Journal of the Textile Institute Transactions*, JTITA, Vol 43, pp. T579–594.

Hadley, D. W., "The Resistance to Abrasion Against Fine India Stone of Single Filaments of Polyethylene Terephthalate and Polypropylene," *Journal of the Textile Institute Transactions*, JTITA, Vol 54, 1963, pp. T409–419.

Howell, H. G., "Inter-Fiber Friction," *Journal of the Textile Institute Transactions*, JTITA, Vol 42, 1951, pp. T521–533.

King, G., "Some Frictional Properties of Wool and Nylon Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 41, 1950, pp. T135–144.

Lyons, W. J., and Scheier, S. C., "Measurement of the Surface Friction of Fibers by an Electro-Mechanical Method," *Textile Research Journal*, Vol 35, 1965, pp. 385–394.

Olsen, J. S., "Frictional Behavior of Textile Yarns," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 31–37.

Schlatter, C., and Demas, H. J., "Friction Studies on Caprolan Filament Yarn," *Textile Research Journal*, TRJOA, Vol 32, 1962, p. 8798.

Susich, G., "Abrasion Damage of Textile Fibers," *Textile Research Journal*, TRJOA, Vol 24, 1954, pp. 210–228.

X1.19 Gage

VanGijzen, A., "Tyre Cord Gauge Measurement," *Rayon Revue*, RYSIA, Vol 10, No. 5, 1956, pp. 189–192.

VanIssum, B. E., and Chamberlain, N. H., "The Free Diameter and Specific Volume of Textile Yarns," *Journal of the Textile Institute Transactions*, JTITA, Vol 50, 1959, p. T599.

X1.20 Hardness

Chakravarty, A. C., "Measurement of Hardness of Textile Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T723-729.

X1.21 Hysteresis

Wakeham, H., and Honold, E., "Mechanical Hysteresis Properties of Single Fibers & Cords," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 1–5.

X1.22 Impact Resistance

Ballou, J. W., and Roetling, J. A., "High Speed Tensile Testing of Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 631–646.

Cross, M. M., and Garrett, D. A., "High-Speed Fibre Extensometer," *Journal of the Textile Institute Transactions*, TRJOA, Vol 47, 1956, pp. T222–231.

Dickson, J. B., and Davieau, L. A., "Impact Tester for Textiles," *ASTM Bulletin*, No. 198, 1954, p. 85.

Hall, I. H., "The Tensile Properties of Textile Yarns at Very High Strain Rates," *Journal of Applied Polymer Science*, JAPNA, Vol 8, 1964, pp. 237–256.

Hamburger, W. J., "Time Effects on Textile Fibers," *SPE Trans.*, 1964, p. 208.

Holden, G., "Tensile Properties of Textile Fibers at Very High Rates of Extension," *Transactions*, JTITA, Vol 50, 1959, pp. T41–54.

Jameson, J. W., Stewart, G. M., Petterson, D. R., and Odell, F. A., "Dynamic Distribution of Strain in Textile Materials Under High-Speed Impact Part III," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 858–860.

Kerawalla, J. N., "Role of Cord Properties in Tire Impact Resistance," *Materials Research and Standards*, MTRSA, Vol 10, No. 6, June 1970, pp. 15–19.

Lang, W. R., "Ballistic Determination of Work of Rupture of Short Textile Samples," *Journal of the Textile Institute Transactions*, Vol 42, 1951, pp. T314–328.

Lothrop, E. W., "Tensile Properties of Yarns and Cords at High Rates of Extension," FMC Corp., American Viscose Division, 1965.

Lothrop, E. W., "Stress-Strain Properties of Tire Cords as a Function of Temperature and Rate of Extension," *Applied Polymer Symposia*, APPSA, Vol 1, 1965, pp. 111–124.

Lyons, W. J., "Impact Phenomena in Textiles," 1963, M.I.T. Press, Cambridge, MA, pp. 21–71.

Lyons, W. J., and Prettyman, I. B., "Use of the Ballistic Pendulum for Impact Testing of Tire Cord," *Textile Research Journal*, TRJOA, Vol 23, 1953, pp. 917–925.

Meredith, R., "The Effect of Rate of Extension on the Tensile Behavior of Viscose and Acetate Rayons, Silk, and Nylon," *Journal of the Textile Institute Transactions*, Vol 45, 1954, p. T30.

O'Neil, K. B., Dague, M. F., and Kimmel, J. E., "High Speed Tensile Testing of Tire Textiles," *Rubber, Chemistry, and Technology*, RCTEA, Vol 41, No. 4, 1968, pp. 1045–1050.

Parker, J. P., and Kemic, C. S., "A Flywheel Impact Test for Measuring Physical Properties of Tire Cords," *Journal of Applied Polymer Science*, JAPNA, Vol 6, No. 21, 1962, pp. 255–263.

Parker, J. P., and Kemic, C. S., "Impact Resistance of Rayon & Nylon Tire Cords," *Rubber World*, RUBWA, Vol 138, 1958, p. 116.

Parker, J. P., and Kemic, C. S. "Flywheel Impact Test for Measuring Physical Properties of Tire Cords," *High Speed Testing*, HSPT, Vol III, 1962, pp. 3–11.

Pavlov, N. N., Yaminskaya, E. Y., and Krymon, B. M., "Application of Strain Gages to the Study of (Tire) Cord at High Elongation Rates," *Rubber, Chemistry and Technology*, RCTEA, Vol 32, 1959, pp. 907–914.

Petterson, D. R., Stewart, G. M., Odell, F. A., and Maheux, R. C., "Dynamic Distribution of Strain in Textile Materials Under High Speed Impact Part I," *Textile Research Journal*, TRJOA, Vol 30, 1960, pp. 411–421.

Pilsworth, M. N., Jr., "Tension Impact on Rubber and Nylon," Quarter-Mast Research and Engineering Center, Natick, MA, Technical Report, PR-3, 1962.

Pilsworth, M. N., and Hoge, H. J., "Rate Dependent Response of Polymers to Tensile Impact," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 129–139.

Schiefer, H. F., Appel, W. D., Krasny, J. F., and Richey, G. C., "Impact Properties of Yarns Made From Different Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1953, p. 489.

Schulman, S., "Evaluation Techniques for Fibrous Materials," *Textile Research Journal*, Vol 36, 1966, pp. 673–681.

Selwood, A., "A Catapult Method for Extending Textile Filaments at High Rates," *Journal of the Textile Institute Transactions*, JTITA, 1964, p. T146–153.

Skelton, J., "Tensile Behavior of Fibrous Materials at High Rates of Strain & Sub Ambient Temperatures," *Materials, Research, and Standards*, MTRSA, Vol 10, No. 6, 1970, pp. 20–25.

Smith, J. C., Fenstermaker, C. A., and Schouse, P. J., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading, Part X," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 919–934.

Smith, J. C., Fenstermaker, C. A., and Schouse, P. J., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading, Part XI," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 743–756.

Smith, J. G., McCrakin, F. L., Schiefer, H. F., Stone, W. K., and Towne, K. M., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading, Part IV," *Textile Research Journal*, TRJOA, Vol 26, 1956, pp. 821–828.

Stone, W. K., Schiefer, H. F., and Fox, G., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading, Part I," *Textile Research Journal*, TRJOA, Vol 25, 1955, pp. 520–528.

"High Speed Tensile Properties of Tire Cord," Teijin, Ltd., 1965.

"Tyrex Test Measures Tyre Strength," *Chemical and Engineering News*, CENEA, Vol 44, No. 42, 1966, pp. 72–73.

X1.23 Infrared Analysis

Knight, J. A., Smoak, M. D., and Kirkland, W. E., "Direct Pressing of Fibers for Infrared Spectroscopic Studies," *Textile Research Journal*, Vol 37, 1967, pp. 924–927.

Hyosung Ex. 1033, Page 16 of 31

X1.24 Intrinsic Viscosity

Gramain, P. H., and Libeyre, R., "Automatic Recording Capillary Viscosimeter with Dilution," *Journal of Applied Polymer Science*, JAPNA, Vol 14, 1970, pp. 383–391.

X1.25 Moisture

Collins, J. B., "Producing Ripple-Free Direct Potential," US Patent 2849676.

Haase-Deyerling, et al, "New Dielectric Method for the Rapid Determination of the Moisture Content of Tire Cord," D. K. G. Rubber Conference, 1960.

Mess, E. and Mark, R. A., "Moisture Measuring Equipment," *Ind. Chem.*, Vol 38, No. 443, 1962, pp. 39–40.

X1.26 Orientation

Conrad, C. M., and Creely, J. J., "Apparatus for Use with the X-Ray Diffractometer to Determine the Degree of Crystallite Orientation in Fibers," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 863–866.

Farrow, G., and Bagley, Miss J., "The Measurement of Molecular Orientation in Polyethylene Terephthalate Filaments by X-Ray Diffraction," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 587–598.

X1.27 Reservoir

Jenkins, R. C., Meherg, J. W., and Linn, J. V., "The Cord Reservoir—A New Concept in the Mechanism of Tire Blows," The Goodyear Tire & Rubber Co., Akron, OH, 1963.

X1.28 Resilience

Hadley, D. W., "A Critical Comparison of Empirical Tests of the Extensional Resilience of Textile Fibers Part I," *Journal of the Textile Institute Transactions*, JTITA, Vol 60, 1969, pp. 301–311.

X1.29 Resonance Frequency

Hearle, J. W. S., and Turner, D. J., "A Preliminary Study of a Technique for Measuring Flexural Vibrations in Fabrics," *Textile Research Journal*, TRJOA, Vol 31, 1961, pp. 981–986.

X1.30 Solvation Resistance

"Solvation Resistance," Test Procedure FD14-1, The Goodyear Tire & Rubber Co., Akron, OH, 1964.

"Tensilizing Tire Fabric of Golden Caprolan Nylon," Allied Chemical Corp., Fibers Division, Hopewell, 1963.

X1.31 Specific Heat

Haly, A. R., and Snaith, J. W., "The Specific Heat of Polyethylene Terephthalate (PET) and the Fusion of its Absorbed Water," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 906–911.

X1.32 Staining

"Staining-Tire Cords," Test Procedure FD15-1, The Goodyear Tire and Rubber Co., Akron, OH, 1964.

X1.33 Stiffness

Abbott, G. M., and Grosberg, P., "Measurement of Fabric Stiffness and Hysteresis in Bending," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 928–930.

Chen, C. S., and Zorowski, C. F., "Cantilever Bending Behavior of Continuous Filament Cords," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 529–538.

Funsch, O. B., and Jenkins, R. C., "A New Technique for Measuring Tire Fabric Stiffness," The Goodyear Tire and Rubber Co., Akron, OH, 1965.

Kalkman, J. A., "Measuring the Flexural Rigidity of Woven Fabrics," *Enka and Breda Rayon Review*, EBREB, Vol 9, 1955, p. 9.

Livesay, R. G., and Owen, J. D., "Cloth Stiffness and Hystersis in Bending," *Journal of the Textile Institute Transactions*, JTITA, Vol 55, 1964, p. T516.

Noser, S., "Apparatus for Measuring Bending Stress in Tyre Cords," *Textile*, TXTIA, Vol 13, No. 6, 1958, pp. 221–222.

Owen, J. D., "The Application of Searles Single and Double Pendulum Methods to Single Fiber Rigidity Measurements," *Journal of the Textile Institute Transactions*, JTITA, Vol 56, 1965, pp. T329–339.

Scott, G. V., and Robbins, C. R., "A Convenient Method for Measuring Fiber Stiffness," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 975–976.

Stuart, I. M., and Baird, K., "A New Test for Bending Length," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 91–93.

X1.34 Stiffness (Dynamic Bending Modulus)

Wakayama, K. and Jinen, E., "An Automatic Vibroscope and How to Use It," *Journal of the Textile Machinery Society of Japan*, Vol 16, No. 2, 1970, pp. 59–67.

X1.35 Strain Recovery (Elastic Recovery)

Zurek, W. and Godon, J., "Strain Recovery of Twisted Viscose Rayon," *Textile Research Journal*, TRJOA, Vol 41, 1971, pp. 984–990.

X1.36 Stress Relaxation

Herwig, H. U., "The Influence of Stress Relaxation Interval on the Tensile Behavior of Industrial Yarns," *Textile Research Journal*, TRJOA, Vol 41, 1971, pp. 366–368.

Kuba, E. T., "The Stress Relaxation of Fibrous Materials I. Instrumentation and Preliminary Results," *Textile Research Journal*, TRJOA, Vol 22, 1952, p. 765.

Meredith, R., and Hsu, B., "Stress Relaxation in Nylon and Terylene: Influence of Strain, Temperature and Humidity," *Journal of Polymer Science*, Vol 61, 1962, p. 253.

X1.37 Tensile Strength

Brown, G. L., "Fabric Testing Machine, Inclined Plane Type," *Journal of the Textile Institute Transactions*, Vol 43, 1952, pp. T119–121.

Checkland, D. B., Bull, T. H., and Baker, E. J., "A Two-Dimensional Load-Extension Tester for Fabrics and Film," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 399–403.

Crane, R. A., and Wharff, P. C., Jr., "An Automatic Single Fiber Tensile Strength Tester," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 343–350.

Dent, R. W., and Hearle, J. W. S., "The Tensile Properties of Twisted Single Fibers," *Textile Research Journal*, TRJOA, Vol 30, 1960, pp. 805–826.

Frank, F. I., and Ruoff, A. L., "A Method of Measuring Poisson's Ratio of Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 213–217.

Frenzel, W., and Kittelman, W., "Tyre Cord Testing," *Faserforschung Und Textiltechnik*, FSTXA, Vol 8, No. 6, 1957, pp. 223–230.

Illingworth, J. W., and Kilby, W. F., "The Reversible Effect of Temperature on the Mechanical Properties of Tire Yarns and Cords," *Textile Research Journal*, TRJOA, Vol 26, 1956, pp. 243–254.

Klein, W. G., "Stress-Strain Response of Fabrics Under Two-Dimensional Loading, Part I," *Textile Research Journal*, TRJOA, Vol 29, 1959, pp. 816–821.

Klust, "The Knot-Tensile Strength of Ply Yarns and Cords Made of Synthetic Fibers," *Textil Praxis*, TEPRA, Vol 17, No. 9, 1962, pp. 881–884.

Phillipson, "Tyre Cord Testing," *Skinner's Silk and Rayon Record*, SSRRA, 1959, pp. 970–994.

Preusser, H. M., O'Connell, R. A., Yeiser, A. S., and Lungren, H. P., "Single Fiber Stress-Strain Apparatus," *Textile Research Journal*, TRJOA, Vol 24, 1954, pp. 118–122.

"Cord-Tensile Clamps," *Rubber World*, RUBWA, Vol 146, No. 3, 1962, p. 40, *Rubber Age*, RUAGA, Vol 92, No. 2, 1962, p. 315.

"Denison Tensile Test Machine," Dunlop-Rubber Co., Ltd., 1955.

"Scotomatic Model IP-4 Tester," *Textile, Mercury, and Argus*, TMARA, Vol 139, 1958, pp. 368–369.

X1.38 Thermal Conductivity

David, H. G., "A Simple Method of Measuring the Thermal Transmission of Fabrics," *Textile Research Journal*, Vol 33, 1963, p. 322.

X1.39 Thermal Shrinkage

Coe, A. B., Prevorsek, D. C., and Tobolsky, A. V., "A Microscopical Method for the Study of Free Thermal Shrinkage in Oriented Polymers," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 960–962.

Prevorsek, D., and Tobolsky, A. V., "Determination of Non-Flow Shrinkage Ratio in Oriented Fibers," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 798–802.

Ribnick, A., "Thermal Shrinkage of Oriented Nylon 66 Yarns as a Function of Time, Temperature, and Stress," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 428–434.

X1.40 Torsional Rigidity

Goodings, A. C., "A Method for the Measurement of the Rigidity of Fibers Immersed in Liquids: The Torsion Double Pendulum," *Textile Research Journal*, TRJOA, Vol 38, 1968, pp. 123–129.

Meredith, R., "The Torsional Rigidity of Textile Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T489–503.

Middelburg, P. H., "A Method for the Measurement of the Rigidity of Fibers Immersed in Liquids," *Textile Research Journal*, TRJOA, Vol 38, 1968, p. 1138.

Nordon, P., "Rotational Vibroscope for the Comparison of the Torsional Properties of Thin Fibers," *Journal of Scientific Instruments*, JSINA, Vol 38, 1961, pp. 349–354.

Skelton, J., "The Measurement of the Torsional Elastic Recovery of Filaments," *Journal of the Textile Institute Transactions*, JTITA, Vol 56, 1965, pp. T443–453.

X1.41 Twist

Batcheler, F. D., "Automatic Measurement of Folding Twist on Two-Ply Yarn," *Journal of the Textile Institute Transactions*, JTITA, Vol 61, 1970, pp. 221–231.

Denisora, et al, "Improving the Properties of Viscose Cord in the Twisting Process," *Khimicheskie Volokna*, KATRA, No. 6, 1962, pp. 25–27.

Frenzel, W., "Determination of Twist & Untwisted Length of Tyre Cord," *Faserforschung Und Textiltechnik*, FSTXA, Vol 2, No. 12, 1951, pp. 481–483.

Treloar, Mather, "Twisted Structures," *Journal of the Textile Institute, Proceedings*, JITPA, 1964, pp. P13–26.

Uno, and Shiomi, "Continuous Twist Irregularity Tester," *Textile Research Journal*, TRJOA, 1957, pp. 818–824.

X1.42 Uniformity

Prins, I., "Determination of the Irregularity of Filament Yarns," *Enka and Breda Rayon Review*, EBREB, Vol 9, 1965, p. 1.

Uno, M., Saito, H., Shiomi, A., and Hiramatu, T., "Photoelectric Twist Irregularity Tester," *Textile Research Journal*, TRJOA, Vol 29, 1959, pp. 550–557.

"A Twist Irregularity Meter for Tire Cord," *Enka Breda Rayon Revue*, EBREB, Vol 9, No. 3, 1955, pp. 81–87.

X1.43 Wettability

Dyba, R. V., and Miller, B., "Dynamic Measurements of the Wetting of Single Filaments," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 884–890.

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 1916 Race St., Philadelphia, PA 19103.

Hyosung Ex. 1033, Page 17 of 31

Designation: D 885M – 95
METRIC

Standard Test Methods for Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made From Man-Made Organic-Base Fibers [Metric][1]

This standard is issued under the fixed designation D 885M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 These test methods cover the testing of industrial filament yarns made wholly of man-made organic-base fibers, cords twisted from such yarns, fabrics woven from such cords, products that are made specifically for use in the manufacture of pneumatic tires. If desired, these test methods may be applied to similar yarns and cords used for reinforcing other rubber goods and for other industrial applications. These test methods apply to nylon, polyester, rayon, and high-modulus aramid yarns and tire cords twisted from such yarns and to fabrics made from such cords. The yarn or cord may be wound on cones, tubes, bobbins, spools, or beams, woven into fabric or in other forms. These test methods include testing procedures only. These test methods do not include specification or tolerances.

1.2 No procedure is included for the determination of fatigue resistance of cord, but several commonly used procedures for the measurement of fatigue resistance of cords in rubber were published in the appendix of these test methods in the *1967 Annual Book of ASTM Standards*, Part 24, and in earlier issues of Test Methods D 885.

NOTE 1—For methods of test for glass cords, refer to Test Method 2970, for wire cords, refer to Test Method D 2969.

1.3 These test methods include the following sections:

	Section
Adhesion of Cord to Elastomers	33
Bibliography of Tire Cord Test Methods	A1 pages. 48 to 55
Breaking Strength Load of Yarns and Cords at Elevated Temperature	X3.2
Breaking Strength (Load) of Conditioned Yarns and Cords	15
Breaking Strength (Load) of Oven-Dry Rayon Yarns and Cords	22
Breaking Strength (Load) of Rayon Yarns and Cords Adjusted to a Specific Moisture Regain Level	16
Breaking Tenacity of Conditioned Yarns and Cords	17
Breaking Tenacity of Oven-Dry Rayon Yarns and Cords	23
Breaking Toughness of Yarns and Cords	27
Commercial Mass (Note 3)	9
Conditioning	7
Contraction of Wet Yarns and Cords	X4.2
Count of Fabric	34.3
Dip (Adhesive) Solids Pickup on Yarns and Cords	32
Elongation at Break of Conditioned Yarns and Cords	18
Elongation at Break of Oven-Dry Rayon Yarns and Cords	24
Elongation of Rayon Yarns and Cords Adjusted to a Specific Moisture Regain Level	19
Extractable Matter in Yarns and Cords	31
Fabric Properties, Count, Mass, and Width	34
Growth of Conditioned Yarns and Cords	X2
Identification of Fibers	8
Keywords	37
Linear Density of Yarns and Cords	11
Load at Specified Elongation (LASE) of Conditioned Yarns and Cords	20
Load at Specified Elongation (LASE) of Oven-Dry Rayon Yarns and Cords	25
Mass of Fabric (Note 3)	34.2
Modulus of Conditioned Yarns and Cords	21
Moisture Regain for Adjustment of Tensile Properties of Rayon Yarns and Cords	10
Precision and Bias of Certain Cord Tests	36
Sampling	6
Shrinkage Force of Conditioned Yarns and Cords at Elevated Temperature	X3.3
Shrinkage of Conditioned Yarns and Cords at Elevated Temperature	X3.3
Significance and Use, General	5
Significance and Use, Tensile Properties	13
SI Calculations	X2
Stiffness of Fabric	38
Tensile Properties of Yarns and Cords	12 to 29
Terminology	3
Thickness of Cords	33
Twist in Yarns and Cords	32
Width of Fabric	34.1
Work-to-Break of Yarns and Cords	26

NOTE 2—These test methods are the counterparts of Methods D 885, and are compatible in technical content.

NOTE 3—The technically correct term "mass" is used in these test methods instead of "weight."

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific precautionary statements, see 35.4.2.

2. Referenced Documents

2.1 *ASTM Standards:*

D 76 Specification for Tensile Testing Machines for Textiles[3]

D 123 Terminology Relating to Textiles[3]

D 276 Test Methods for Identification of Fibers in Textiles[2]

D 1423 Test Method for Twist in Yarns by the Direct-Counting Method[2]

D 1777 Method for Measuring Thickness of Textile Materials[2]

D 1907 Test Method for Yarn Number by the Skein Method[2]

D 1909 Table of Commercial Moisture Regains for Textile Fibers[3]

D 2138 Test Methods for Rubber Property—Adhesion to Textile Cord[4]

D 2256 Test Method for Tensile Properties of Yarns by the Single-Strand Method[2]

D 2257 Test Method for Extractable Matter in Textiles[2]

D 2258 Practice for Sampling Yarn for Testing[2]

D 2494 Test Method for Commercial Mass of a Shipment of Yarn or Man-Made Staple Fiber or Tow[3]

D 2654 Test Methods for Moisture Content and Moisture Regain of Textiles[3]

D 2969 Test Method for Steel Tire Cords[2]

D 2970 Test Methods for Tire Cords, Tire Cord Fabrics, and Industrial Yarns Made from Glass Filaments[2]

D 3774 Test Methods for Width of Woven Fabric[2]

D 3775 Test Method for Count of Woven Fabric[2]

D 3776 Test Method for Mass per Unit Area (Weight) of Woven Fabric[2]

D 5591 Test Method for Thermal Shrinkage-Force of Yarn and Cord Using the Textile Thermal Shrinkage Force Tester[4]

3. Terminology

3.1 *Definitions:*

3.1.1 *atmosphere for testing textiles, n—for tire cords and industrial yarns*, air maintained at a relative humidity of 55 ± 2 % and at a temperature of 24 ± 1°C.[5]

3.1.2 *breaking force, n*—the maximum force applied to a material carried to rupture.

3.1.2.1 *Discussion*—Materials that are brittle usually rupture at the maximum force. Materials that are ductile usually experience a maximum force before rupturing. It has been the usual practice in the tire and related industries for many years to use the term *breaking strength* to characterize yarn and cord of a specified size and type without any reduction to unit size. Numerically, *breaking strength* is equal to breaking force for the same specimen. The average of the breaking force observed on two or more specimens of a specific sample is referred to as the sample breaking strength, which is the property used in engineering calculations for a specific textile material. *Tensile strength* and *breaking tenacity* are derived or calculated values that characterize a type or class of material reduced to unit size. These terms can be used to compare intrinsic strengths of yarns and cords of different sizes or different materials. The term *tensile strength*, in MPa, is not synonymous with either *breaking force* or *breaking strength* in N, *or breaking tenacity*, in Mn/tex.

3.1.3 *breaking strength, n*—strength expressed in terms of breaking force.

3.1.3.1 *Discussion*—Breaking strength is particularly significant as the characteristic of a sample as distinct from a specimen, and usually is expressed as newtons (N) (see 3.1.2.1).

3.1.4 *breaking tenacity, n*—the tenacity at the breaking force. See 3.1.2.1.

3.1.5 *breaking toughness, n*—toughness up to the breaking force of a material (Syn *toughness-at-break*).

3.1.5.1 *Discussion*—Breaking toughness is represented by the area under the stress-strain curve from the origin to the breaking force per unit length, and, in textiles is expressed as mass (joules per gram (J/g)).

3.1.6 *cord, n*—a twisted or formed structure composed of one or more single or plied filaments, strands, or yarns of organic polymer or inorganic materials.

3.1.6.1 *Discussion*—For the manufacturer of pneumatic tires or other industrial fabrics.

3.1.7 *cord twist, n*—the amount of twist in a cord made from two or more single or plied yarns.

3.1.7.1 *Discussion*—Cord twist is based on the initial length of a cord specimen.

3.1.8 *dip, n*—a chemical composition that is applied to a textile cord or fabric to improve its adhesion to rubber or other elastomer.

3.1.9 *dip pickup, n—in a textile cord or fabric*, the amount of dip or dip components present after processing, including drying, as determined by prescribed methods, and expressed as a percentage of the mass of the oven-dried, dip-free material.

3.1.10 *elongation, n*—the ratio of the extension of a material to the length of the material prior to stretching.

3.1.10.1 *Discussion*—Elongation may be measured at any specified force or at rupture and is usually expressed as percent.

3.1.11 *fabric, n*—in textiles, a planar structure consisting of yarns or fibers.

3.1.11.1 *Discussion*—For fabrics made of tire cord—consists of tire cord warp yarns with widely spaced filling yarn.

3.1.12 *force at specified elongation (FASE), n*—the force associated with a specific elongation on the force-extension or force-elongation curve.

3.1.13 *growth, n*—the increase in length of a specimen caused by the application of a continuing force under specified conditions.

3.1.14 *industrial yarn, n*—a yarn composed of continuous filaments, usually of high breaking tenacity, produced with or without twist, and intended for applications in which functional properties are of primary importance; for example in reinforcing material in elastomeric products (tires, hose, belting), in protective coverings, and in cordage and webbing, etc.

3.1.15 *initial modulus, n*—the slope of the initial straight portion of a stress-strain curve.

3.1.15.1 *Discussion*—Modulus is the ratio of the change in tenacity, expressed in millinewtons per tex (mN/tex) to the change in strain, expressed as a fraction of the original length. In the case of a tenacity elongation curve, the following equation is used to calculate the initial modulus:

$$\text{Initial modulus} = (\text{tenacity/percent elongation}) \times 100$$

3.1.16 *moisture equilibrium for testing, n—for industrial yarns and tire cords*, the condition reached when, after free

[1] These test methods are under the jurisdiction of ASTM Committee D-13 on Textiles and are the direct responsibility of Subcommittee D13.19 on Tire Cord and Fabrics.

Current edition approved August 15, 1995. Published February 1996. Originally published as D 885M – 79. Last previous edition D 885M – 94.

[2] *Annual Book of ASTM Standards*, Vol 07.01.

[3] *Annual Book of ASTM Standards*, Vol 07.02.

[4] *Annual Book of ASTM Standards*, Vol 09.01.

[5] The test atmosphere is under continued study by the committee due to assess difference, if any, in laboratory conditions on the physical properties of the various industrial fibers.

Hyosung Ex. 1033, Page 18 of 31

exposure to a test atmosphere which is in motion, two successive weighings, not less than 4 h apart, show not more than 0.1 % progressive change in mass of the specimen or sample.

3.1.17 *pneumatic tire, n*—a hollow tire that becomes load-bearing upon inflation with air, or other gas, to a pressure above atmospheric.

3.1.18 *single twist, n—in tire cord*, the amount of twist in each individual single yarn element in structures based on the length of the element such after twist has been removed from the cord (see 3.2.3).

3.1.19 *tabby sample, n*—the section of tire cord fabric between two tabbies that have been woven separately with a distance of 0.5 to 1.0 m between them.

3.1.19.1 *Discussion*—A tabby usually is woven 150 to 200 mm in length using cotton filling yarn in the range from 75 to 200 tex and 30 to 50 picks/dm.

3.1.20 *tensile strength, n*—the strength of a material under tension as distinct from compression, torsion or shear.

3.1.20.1 *Discussion*—Technically strength is a characteristic that is expressed in terms of force. Historically, however, tensile strength has been commonly expressed in terms of force per unit base, for example, the cross-sectional area of the unstrained material. Some common units are Pascal (Pa) which is newtons per square metre (N/m^2) and pounds-force per square inch (psi). See 3.1.2.1.

3.1.21 *tire, n*—a load-bearing ground-contacting circumferential attachment to a vehicle wheel.

3.1.22 *tire cord fabric, n*—a fabric consisting of tire cord warp with widely spaced single yarn filing.

3.1.23 *work-to-break, n*—the energy expended up to the breaking force.

3.1.23.1 *Discussion*—Work-to-break is proportional to the area under the stress-strain curve from the origin to the breaking force.

3.1.24 For definitions of terms related to force and deformation in textiles, refer to Terminology D 4848. For definitions of other terms related to textiles, refer to Terminology D 123.

3.2 *Description of Term Specific to This Standard:*

3.2.1 *high-modulus aramid, n*—for the purpose of these test methods, those aramid yarns with an initial modulus of at least 35 N/tex.

4. Summary of Test Methods, General

4.1 A summary of the directions prescribed for the determination of specific properties is stated in the appropriate sections of specific test methods.

5. Significance and Use

5.1 The procedures in these test methods should be used with caution for acceptance of commercial shipments owing to the absence of factual information on the between-laboratory precision of many of the test procedures included in the these test methods. It is recommended that any program of acceptance testing be preceded by an interlaboratory check in the laboratory of the purchaser and the laboratory of the supplier on replicate specimens of the materials to be tested for all property (or properties) to be evaluated.

5.1.1 In case of a dispute arising from differences in reported test results when using one of the procedures in Test Methods D 885M for acceptance testing of commercial shipments, the purchaser and the supplier should conduct comparative tests to determine if there is a statistical bias between their laboratories. Competent statistical assistance is recommended for the investigation of bias. As a minimum, the two parties should take a group of test specimens that are as homogeneous as possible and that are from a lot of material of the type in question. The test specimens should then be randomly assigned in equal numbers to each laboratory for testing. The average results from the two laboratories should be compared using Students *t*-test for unpaired data and an acceptable probability level chosen by the two parties before the testing is begun. If a bias is found, either its cause must be found and corrected or the purchaser and the supplier must agree to interpret future test results in the view of the known bias.

5.2 The significance and use of particular properties are discussed in the appropriate sections of specific test methods.

6. Sampling

6.1 *Yarn*—Separate all acceptance sampling lots of yarn, sample each lot as directed in Practice D 2258, and determine the number of specimens to be tested as specified in each specific property measurement in these test methods, except that when sampling yarn from beams, the sample may be wound on a tube or spool by means of a winder using a tension of 5 ± 1 mN/tex. Take samples from the outside of the beam, unless there is a question or disagreement regarding a shipment; in this case, take a sample only after yarn has been removed from a beam to a radial depth of 6 mm or more in order to minimize the effects of handling and atmospheric changes which may have occurred during shipment or while in storage. Place the sample in a moistureproof polyethylene bag or other moistureproof container to protect it from atmospheric changes until it is desired to condition the sample in the atmosphere for testing industrial yarns and tire cords.

6.2 *Cord:*

6.2.1 *Number of Samples*—The size of an acceptance sampling lot of tire cord shall be not more than one truck or rail car load or as determined by agreement between the purchaser and the supplier. Take samples at random from each of a number of cones, tubes, bobbins, or spools within a lot so that they are as representative as possible within practical limitations. Make only one observation on an individual package for each physical property determination. Take the number of samples, therefore, that will be sufficient to cover the total number of specimens required for the determination of all physical properties of the tire cord. The recommended number of specimens is included in the appropriate sections of specific test methods covered below. Where such is not specified, the number of specimens is as agreed between buyer and supplier.

6.2.1.1 If the observed level of the coefficient of variation, is found to be v_1, and is greater than v, calculate the number of specimens required, n_1, using Eq 1:

$$n_1 = (v_1^2/v^2) \times n \quad (1)$$

where: n and v are the number of specimens and coefficient of variation, respectively as stated in each applicable section.

In no test shall n_1 be less than n specimens.

6.2.2 *Preparation of Samples*—Remove and discard a minimum of 25 m of cord from the outside of the package before taking the sample or any specimens. If specimens are not taken directly from the original package, preferably wind the sample on a tube or spool by means of a winder using a tension of 5 ± 1 mN/tex. If the sample is collected as a loosely wound package, or in the form of a skein, some shrinkage invariably will occur, in which case, report that the observed results were determined on a relaxed sample. Use care in handling the sample. Discard any sample subjected to any change of twist, kinking, or making any bend with a diameter less than 10 times the yarn/cord thickness (or diameter). Place the sample in a moistureproof polyethylene bag or other moistureproof container to protect it from atmospheric changes until it is desired to condition the sample in the test atmosphere for industrial yarns and tire cords.

6.3 *Tire Cord Fabric:*

6.3.1 *Number of Samples and Specimens*—The sizes of an acceptance sampling lot of tire cord fabric shall be one loom creel of cord or as determined by agreement between the purchaser and the supplier. Take a sample from at least one roll of fabric per lot. From each roll of tire cord fabric take the number of specimens as specified in the test method for each property to be measured.

6.3.2 *Size of Sample*—Take a sample equal to the length of cord between the regular tabby woven at the end of the roll and a special tabby woven a short distance from the end when the roll of fabric is manufactured. For rolls that do not have a special woven tabby, improvise a tabby by the use of gummed tape or strips of cemented fabric applied across a section of the cord fabric. The length of the tabby sample shall be as agreed upon between the purchaser and the supplier, but it shall be at least 0.5 m. The width of the sample shall be at least one tenth of the roll width.

6.3.3 *Preparation of Samples*—Cut the warp cords of the fabric along the center line of the special tabby across for a distance equal to the width of the desired sample. If this distance is less than the full width of the fabric, cut the filling yarns of the sample and of the special and regular tabbies in the direction parallel with the warp cords. The resulting section of cord fabric is the tabby sample. Attach the tabby sample to a piece of cardboard or fiberboard, the length of which shall be equal to at least the length of the cord warp between tabbies. Fold the tabby portions of the sample over each end of the board, and secure the sample to the board with pressure-sensitive tape or staples. Use care to avoid contact of tape or staples with the area to be tested. Handle the sample carefully and hold it under sufficient tension in the warp direction to prevent the cords from kinking. Discard any specimen subjected to change of twist, kinking, or making any bend with a diameter less than 10 times the yarn/cord thickness (or diameter). The board with the sample may be folded lengthwise and parallel with the warp for convenience. Place the board with the fabric sample in a polyethylene bag, or wrap it with several layers of polyethylene film to protect the sample from changes in atmospheric moisture content until it is desired to condition the sample in the atmosphere for testing industrial yarns and tire cords. Use care during subsequent handling of the sample to prevent any change in the cord twist and to avoid kinking the cords.

6.4 *Cord from Cured Tires:*

6.4.1 *Number of Samples and Specimens*—A minimum of ten cords shall be tested from each location or ply of each tire.

6.4.2 *Preparation of Samples*—Obtain a tire section comprising approximately one sixth of the whole tire. Smaller sections may be used, particularly for carcass cord samples of radial tires. If it is suspected that cords may be damaged in pulling them from the tire, immerse the section in a solvent[6] for 1 to 3 days to swell and soften the rubber. For convenience, turn the section inside out, if possible; clamp one of the beads in a vise. Mark a line along the inside of the section approximating the cord path of the first ply. Make a shallow cut down to the first ply along this line. Make an incision adjoining and perpendicular to this first cut at sufficient depth to sever several first-ply cords. Carefully cut and pull these cords from the tire from bead to bead following the cord path. Discard these initial cords. After initial cords are removed, remove bands of cords for testing by cutting near the bead through Ply 1 cords adjacent to the trough formed in initial cord removal. Carefully pull several cord bands approximately 2 cm in width from the tire. Identify bands by tire number, ply number, and so forth. Remove the remainder of Ply 1 to uncover Ply 2. Proceed with Ply 2 or additional plies as directed for Ply 1. If the cords to be removed are from a tire having only one ply of reinforcement in the area to be sampled, for example, carcass ply of many radial tires reinforced with glass, aramid, or steel, it is preferable to remove cords for testing one at a time from the tire section itself. It is preferred that cord be removed in such a manner that it is not subjected to narrow-radius bending, such as a 180° bend back upon itself. This is accomplished by first removing and discarding a band of cords in the ply being sampled, then pulling the exposed cord at the edge of the ply (still in the tire section) by applying tension to this single cord as much within the plane of the ply as possible and in such a direction that the cord is subject to a bend of less than 60° at the tear point from its adjacent cord. The same principles just described also apply to areas of the tire (such as the tread) composed of multiple plies of high modulus cords.

6.4.3 *Preparation of Specimens for Testing from a Ply Band*—Make a cut approximately 2 cm long between each cord at one end of the ply band. Strip every other cord from the band to a length sufficient for testing; leave a small unstripped cord portion attached to the band to facilitate handling. Cut individual ends from the band for testing.

6.4.4 Large variations in properties can occur within the same cord depending on its location within the tire. Select the location in the tire to be sampled and take a length of cord from this location for subsequent testing. Use a testing length appropriate for the length of the specimen to obtain data that reflect the relationship between the cord properties and the location in the tire.

[6] Heptane, 1,1,1-trichloroethane, and a mixture of 50/50 Freon 113 trade and Stoddard Solvent have been used for this purpose.

Hyosung Ex. 1033, Page 19 of 31

7. Conditioning

7.1 Bring all specimens of yarn, cord, and fabric to moisture equilibrium for testing in the atmosphere for testing industrial yarns (see 3.1.1 and 3.1.6). Moisture equilibrium of rayon samples shall be approached from the dry side but not from a moisture-free condition.

NOTE 4—The moisture equilibrium of conditioned high-modulus aramid yarns and tire cords made from such yarns can be affected by heat and humidity conditions to which the samples have been previously exposed.

8. Identification of Fibers

8.1 Identify the common types of man-made organic-base fibers as directed in Test Methods D 276.

9. Commercial Mass

9.1 *Yarn*—Determine the commercial mass of a yarn shipment as directed in Option II of Test Method D 2494. Take samples of yarn from the outside of beams unless there is a question or disagreement regarding a shipment; in this case, take a sample of yarn only after yarn has been removed from a beam to a radial depth of 6 mm or more. Take a sample 15 to 20 m long which is composed of all ends of yarn on the beam, and cut this sample crosswise to obtain two specimens of approximately equal mass. Place the specimens in moistureproof polyethylene bags or other moistureproof containers until it is desired to begin the analysis.

9.2 *Cord and Tire Cord Fabric*—Determine the commercial mass (Note 3) of tire cord and tire cord fabric as agreed upon between the purchaser and the supplier.

10. Moisture Regain, Actual

10.1 *Summary of Test Method*—Specimens of rayon yarn or cord, which are taken at the tensile testing machine at the time that tensile tests are being made, are weighed and dried in an oven until they reach a constant mass. The observed moisture regain is calculated and reported as percent regain.

10.2 *Significance and Use*—This test method is used not only to determine moisture regain of the original sample but is also used to develop data which may be used to correct observed tensile properties of rayon yarns and cords to a standard regain basis. Since the moisture regain level of different specimens varies even after conditioning in a test atmosphere and since tensile properties are affected by moisture regain, it is desirable to correct observed tensile values when there is substantial variation from a standard moisture regain level. Directions for making such corrections are included in Section 11, Linear Density, and Sections 16 for breaking strength and Section 19 for elongation. It is assumed that no significant amount of nonaqueous volatile matter is present and that all loss in mass is moisture. If such materials are present, apply a suitable correction, or determine the true amount of moisture by the toluene distillation method as directed in Procedure 3 of Test Method D 2462.

10.3 *Apparatus:*

10.3.1 *Drying Oven*, with circulating air maintained at a temperature of 105 ± 3°C. The specimens shall not be subject to direct radiation from the heating units. The air shall pass freely through and around the specimens. The oven may be combined with a balance, in which case the design must prevent disturbance of the balance due to circulating air during the weighing operation.

10.4 *Preparation of Specimen*—Take a single specimen of yarn or cord weighing at least 10 g from the original sample at the testing machine at the time that tensile properties are being determined (Note 5). Place this specimen in a covered weighing bottle. Do not touch the specimen with the bare hands.

NOTE 5—The determination of moisture regain can be combined with the determination of linear density (Section 11 Linear Density) if the specimen is long enough to meet the length and mass tolerances and if the skein is exposed to the same atmosphere as the sample to be used for determination of tensile properties.

10.5 *Procedure*—Weigh the yarn or cord specimen to 0.01 g and dry it in the ventilated oven at a temperature of 105 ± 3°C. Dry the specimen to constant mass, that is, until it loses no more than 0.1 % of its mass at 15-min intervals if weighed in the oven or at 30-min intervals if weighed outside the oven. For specimens that are weighed outside the oven, use a weighing bottle with tight-fitting cover, and cool the specimen and container to room temperature in a desiccator before weighing.

10.6 *Calculation*—Calculate the moisture regain of the specimen using Eq 2:

$$MR = [(W - D)/D] \times 100 \quad (2)$$

where:

MR = moisture regain;
W = original mass of specimen, g, and
D = oven-dry mass of specimen, g.

10.7 *Report*—Report the average moisture regain for the specimens and use this value for determining the amount of adjustments to make in Sections 16 and 19 to the observed breaking load and elongation of yarn or cord.

10.8 *Precision and Bias:*

10.8.1 *Precision*—See also Test Method D 2654, Procedure 1.

10.8.2 *Bias*—See 36.3.

11. Linear Density

11.1 *Number of Specimens*—Test five specimens of yarn or cord. This number is based on the assumption that the applicable coefficient of variation is 1.0 % and the allowable variation is 0.9 % of average with a probability level of 95 %.

11.2 *Procedure for Yarn*—Determine the linear density of yarn as directed in Option 1 of Test Method D 1907, except condition the yarn as specified in Section 7. Use Option 3 for rayon. If the finish-free linear density is desired, use Option 6.

11.3 *Procedure for Cord*—Determine the linear density of cord on packages or removed from a tabby sample of fabric by the procedures prescribed as follows for either conditioned cords or oven-dry cords (11.3.2) or as determined by agreement between the purchaser and the supplier.

11.3.1 *Preparation of Specimens*—Take specimens having a minimum length of 10.0 m from samples of cord on cones, tubes, bobbins, or spools. For tabby samples of fabric, use a sufficient number of ends to give a minimum length of 9.0 m of cord for each specimen. Measure the length of the specimen to within 0.1 % while under a tension of corresponding with 5 ± 1 mN/tex. Weigh the conditioned cord specimen to the nearest 1 mg. If a balance of the required sensitivity (1 mg) for weighing the 10.0-m specimen is not available, take a longer specimen or multiple ends.

NOTE 6—When arbitration is not involved, an approximation of the specified tension may be obtained by applying one of the forces listed as follows for the specified groups of yarn and cord sizes:

Linear Density of Specimen	Amount of Force, N
Below 400 tex	1
400 to 600 tex	2
600 to 800 tex	3
Above 800 tex	4

11.3.2 *Procedure for Oven-Dry Specimens*—Using an oven with circulating air maintained at a temperature of 105 ± 3°C (see 10.3), dry the specimen to constant mass, that is, until it loses no more than 0.1 % of its mass at 15-min intervals if weighed to the nearest 1 mg in the oven or at 30-min intervals if weighed outside the oven. For specimens that are weighed outside the oven, use a weighing bottle with a tight-fitting cover and cool the specimen and container to room temperature in a desiccator before weighing. Weigh the specimen of the oven-dry cord to the nearest 1 mg.

11.3.3 *Calculation*—Calculate the linear density of each specimen in denier or tex units using Eq 3 or 4:

Linear density:

$$\text{in tex at a commercial moisture regain } LD, \text{ tex} = (1000 \times M_o \times K)/L_o \quad (3)$$

$$\text{in tex at actual moisture regain, } LD, \text{ tex} = (1000 \times M_c)/L \quad (4)$$

where:

M_o = mass of oven-dry specimen, g,
M_c = mass of conditioned specimen, g,
L_o = length of specimen, m, and
K = factor for commercial moisture regain, and
LD = linear density.

11.3.3.1 Determine the factor K using Eq 5:

$$K = (100 + \text{commercial } MR)/100 \quad (5)$$

For the commercial moisture regain, see Table 1. See also Table in D 1909.

Example for rayon:

$$K = (100 + 11)/100 = 1.11$$

11.3.3.2 For dipped cord, correct the observed linear density for dip solids pickup using Eqs 6 or 7:

Linear density corrected for dip pickup, tex

$$= \left[\frac{100}{100 + DPU} + \frac{MR_{dc}}{100}\right] \times \frac{100}{100 + MR_{dc}} \times LD_{dc} \quad (6)$$

Linear density of dipped cord corrected for dip pickup and moisture regain, tex

$$= \frac{100 + MR_{dc}}{100} \times \frac{100}{100 + MR_{dc}} \times \frac{100LD_{dc}}{100 + DPU} \quad (7)$$

TABLE 1 Commercial Moisture Regains of Man-Made Fibers Used in Tire Cords[A]

	%
Rayon	11.0
Nylon	4.5
Polyester	0.4
High-modulus aramid	7.0

[A] Commercial moisture regain of fibers not listed in this table shall be as agreed upon between the purchaser and the supplier.

where:

DPU = percentage dip pickup (see Section 35),
MR_{dc} = percentage commercial moisture regain of greige cord (as per Table 1),
LD_{dc} = observed linear density of dipped cord, tex, and
MR_{dc} = percentage moisture regain of dipped cord.

11.3.4 *Report:*

11.3.4.1 State that the specimens were tested as directed in Section 11 of Test Methods D 885M. Describe the material or product sampled and the method of sampling used.

11.3.4.2 Report the option or procedure used, the number of specimens tested, and the average value of linear density.

11.3.4.3 Report the bias on which linear density is being reported (for greige, dipped, etc.).

11.3.5 *Precision and Bias:*

11.3.5.1 *Precision*—See Section 36.

11.3.5.2 *Bias*—See 36.3.

TENSILE PROPERTIES OF YARNS AND CORDS

12. Summary of Test Method

12.1 A conditioned or oven-dry specimen of yarn or cord is clamped in a tensile testing machine and then stretched or loaded until broken. Breaking force (see 3.1.2.1), elongation, and force at specified elongation (FASE) are determined directly. Modulus and work-to-break are calculated from the load-elongation curve. The output of a constant-rate-of-extension (CRE) tensile testing machines can be connected with electronic recording and computing equipment which may be programmed to calculate and print the results of tests tensile properties of interest.

13. Significance and Use

13.1 The levels of tensile properties obtained when testing industrial yarns and tire cords are dependent to a certain extent on the age and history of the specimen and on the specific conditions used during the test. Among these conditions are rate of stretching, type of clamps, gage length of specimen, temperature and humidity of the atmosphere, rate of airflow across the specimen, and temperature and moisture content of the specimen. The relative importance of these factors varies with each type of fiber. Testing conditions accordingly are specified precisely in order that test results on a specific sample will be reproducible.

13.2 Since the load-bearing ability of a reinforced rubber product is related to the strength of the yarn or cord used as a reinforcing material, breaking strength (see 3.1.2.1) is used in engineering calculations when designing various types of textile reinforced rubber products. When it is desirable to compare intrinsic strength characteristics of yarns or cords of different sizes or different types of fiber, breaking tenacity (see 3.1.2.1) is very useful, because, for a given type of fiber, breaking load is approximately proportional to linear density.

13.3 Elongation of yarn or cord is taken into consideration in the design and engineering of reinforced rubber products because of its effect on uniformity of the finished product and its dimensional stability during service.

13.4 The FASE is used to monitor changes in characteristics of the textile material during the various stages involved

Hyosung Ex. 1033, Page 20 of 31

TABLE 2 Rates of Operation of Tensile Testing Machines

NOTE: **Caution**—If there exists any reason to doubt the validity of test results of high modulus aramids at the specified rate of operation on CRE and CRT type testing machines, a referee operation rate of 10 % of the nominal gage length per minute shall be used. The 50 % rate has been used for aramid LASE data (Tables 3 and 4). The rate of loading for high modulus aramids on CRL machines has not been established. All High Modulus Aramid testing has been limited to 4D clamps and a 500-mm gage length. Testing differences have been found with alternate clamps and gage lengths.

CRE Type Testing Machines:	
For all fiber types use a rate of crosshead travel in mm/s of 10 % of the nominal gage length in millimetres of the specimen	
CRL Type Testing Machines:	
Use the following rates of loading:	
For rayon	25 ± 3 (mN/tex)/s
For nylon and polyester	50 ± 7 (mN/tex)/s
CRT Type Testing Machines:	
For all fiber types, use a rate of traverse of 5 ± 0.2 mm/s	

in the processing and incorporation of yarn or cord into a rubber product.

13.5 Modulus is a measure of the resistance of yarn or cord to extension as a load is applied. It is useful for estimating the response of a textile reinforced structure to the application of varying loads and rates of stretching. Although modulus may be determined at any specified force, initial modulus is the value most commonly used.

13.6 Work-to-break is dependent on the relationship of force to elongation. It is a measure of the ability of a textile structure to absorb mechanical energy. Toughness is work-to-break per unit mass.

13.7 It should be emphasized that, although the preceding parameters are related to the performance of a textile-reinforced product, the actual configuration of the product is significant. Shape, size, and internal construction also can have appreciable effect on product performance. It is not possible, therefore, to evaluate the performance of a textile reinforced product in terms of the reinforcing material alone.

14. Apparatus

14.1 *Tensile Testing Machine*—A single-strand tensile testing machine of one of the following types:

Type	Principle of Operation
CRE	constant-rate-of-specimen extension
CRL	constant-rate-of-loading (inclined plane type)
CRT	constant-rate-of-traverse (pendulum type)

The specifications and methods of calibration and verification of these machines shall conform to Specification D 76. The testing machine shall be equipped with an autographic recorder (rectilinear coordinates preferred) and clamps of the cam or pneumatic type having fixed snubbing surfaces which are integral with one of the clamping surfaces. The snubbing surfaces may be circular with a diameter not less than 12.5 mm or semi-involute. It is also permissible to use tensile testing machines that have a means for calculating and displaying the required results without the use of an autographic recorder. CRE is the preferred type of test equipment to be used. Correlation of CRL and CRT results with CRE results is poor. Bias determination must be made for CRL, CRT, and CRE. For tensile testing of high modulus aramid fibers the CRL and CRT types of testing machines are considered to be not suitable and are not recommended (see also Note 10).

14.1.1 *CRE Type Testing Machines*—For all fiber types except high modulus aramid fibers use a crosshead travel rate in mm/min of 120 % (100 % alternate) of the nominal gage length in millimetres of the specimen. For high modulus aramid fibers use a crosshead travel rate in mm/min of 50 % of the nominal gage length in millimetres of the specimen.

14.1.2 *CRL Type Testing Machines*—Use the following rates of loading:

For rayon	25 ± 3 (mN/tex)/s
For nylon and polyester	50 ± 7 (mN/tex)/s

14.1.3 *CRT Type Testing Machines*—For all fiber types, except high modulus aramids (Note 10), use a rate of traverse in mm/min of 120 % (100 % alternate) of the nominal gage length in millimetres of the specimen.

15. Breaking Strength (Force) of Conditioned Yarns and Cords

15.1 *Number of Specimens*—Test ten specimens. This number is based on the data for cords in Table 4 which shows precision to be expected at the probability level of 95 % based on ten breaks from a single test spool of cord of each polymer type on various cords.

15.2 *Procedure*—Select a load cell and the settings of the tensile tester such that the estimated breaking force of the specimen will fall in the range from 10 to 90 % of the full-scale force range effective at the time of the specimen break. This selection of the full scale force range may be done manually by the operator before the start of the test or by electronic means or computer control during the test by automatically adjusting the amplification of the loadcell amplifer. Adjust the distance between the clamps on the testing machine so that the nominal gage length of the specimen, measured from nip to nip of the jaws of the clamps, is 250 ± 1 mm (alternate 500 ± 1 mm). Make all tests on the conditioned yarns and cords in the atmosphere for testing industrial yarns and tire cords (see 3.1.1 and 3.1.16) (Notes 6, 7, and 8 provide useful information in obtaining more consistent results in tensile testing). Remove the specimen of yarn or cord from the sample and handle it in such a manner that no change in twist can occur prior to closing the jaws of the clamps on the specimen. For essentially zero twist yarns, refer to Note 7. Do not touch with the bare hand that portion of the specimen which will be between the clamps. Depending on the equipment being used and the availability of on-line computer control and data processing, one of the two following procedures can be used:

a. the pretension-start procedure
b. the slack start procedure

15.2.1 *The Pretension-Start Procedure*—Use a tensioning device that applies a pretension corresponding to 20 ± 1 mN/tex for aramid fibers; use 5 ± 1 mN/tex for all other fibers. This device may be a dead mass, a spring, or an air-actuated mechanism. Thread one end of the specimen between the jaws of the clamp connected to the loadcell and close it. Place the other end through the jaw of the second clamp and fix a pretension mass to the unclamped end or pull the thread such that the specified pretension in the test specimen is applied. Close the second clamp and operate the testing machine at the rate specified in Section 14.1. When the specimen breaks (ruptures), read the breaking force

TABLE 3 Components of Variance Expressed as Coefficients of Variation (Except as Noted)

NOTE—Between-laboratory coefficients of variation of high-modulus aramids are undesirably high in most cases and may warrant interlaboratory correlations in specific applications between the purchaser and the seller.

Property Measured	Number of Laboratories	Number of Observations in Each Laboratory	Degrees of Freedom		Coefficients of Variations	
			Within-Laboratory	Between-Laboratory	Within-Laboratory Component	Between-Laboratory Component
Table 3a 93/2 tex Nylon Cord [A] (470 by 470 tpm): [A]						
Breaking strength, N	8	10	152	7	1.61	1.57
Elongation at break, %	6	10	114	7	5.13	4.63
Force at specified elongation (FASE) (reported at 14 % elongation), N	7	10	133	6	5.67	7.25
Modulus, mN/tex	2	10	38	1	5.76	2.38
Work-to-break, J/m	4	10	76	2	7.63	2.88
Thickness of cords, μm	4	10	76	3	16.3[B]	12.4[B]
Twist, tpm:						
Cord	5	10	114	5	12.2[B]	4.7[B]
Singles	5	10	95	4	5.5[B]	2.7[B]
Linear density, tex:[A]						
From bobbin	8	9 to 15	105	7	1.92	1.24
From tabby	8	9 to 15	71	7	0.73	1.49
Table 3b 111/3 tex Polyester Cord (390 by 390 tpm):						
Breaking strength, N	5	10	95	4	1.96	1.56
Elongation at break, %	6	10	114	5	3.03	3.46
Force at specified elongation (FASE) reported at 10 % elongation), N	6	10	114	5	5.88	5.31
Modulus, mN/tex	2	10	38	1	5.42	0.00[C]
Work-to-break, J/m	4	10	76	3	5.51	5.53
Thickness of cords, μm	3	10	57	2	15.0[B]	4.1[B,C]
Twist, tpm:						
Cord	6	10	114	5	9.1[B]	5.9[B]
Singles	5	10	95	4	5.1[B]	3.9[B]
Linear density, tex:						
From bobbin	8	9 to 15	107	7	0.86	0.50
From tabby	8	5 to 15	79	7	1.17	0.79
Table 3c 183/3 tex Rayon Cord (430 by 390 tpm): [D]						
Breaking strength, N	6	10	114	5	3.12	1.77
Elongation at break, %	6	10	114	5	3.47	2.07
Force at specified elongation (FASE) (reported at 6 % elongation), N	5	10	95	4	5.33	6.72
Thickness of cords, μm	3	10	57	2	19.0[B]	18.0[B]
Twist, tpm:						
Cord	4	10	76	3	11.0[B]	6.3[B]
Singles	3	10	57	2	6.3[B]	3.5[B]
Linear density, tex:						
From bobbin	9	9 to 15	114	8	0.66	0.94
From tabby	9	9 to 15	94	8	0.73	0.78
Table 3d 167/2 tex High-Modulus Aramid Cord (160 by 160 tpm):						
Breaking strength, N	8	10	72	7	1.21	2.38
Elongation at break, %	8	10	72	7	2.58	7.46
Modulus, mN/tex	5	10	45	4	3.67	7.01
Work-to-break, J/m	6	10	54	5	4.44	17.62
Thickness of cords, μm	6	10	54	5	22.3[B]	98.0[B]
Twist, tpm:						
Cord	7	10	63	6	3.9[B]	4.7[B]
Singles	7	10	63	6	3.9[B]	3.1[B]
Table 3e 167/2 tex High-Modulus Aramid Cord (300 by 300 tpm):						
Breaking strength, N	8	10	72	7	2.41	3.45
Elongation at break, %	8	10	72	7	2.49	9.60
Modulus, mN/tex	5	10	45	4	2.43	12.76
Work-to-break, J/m	6	10	54	5	9.60	15.50
Thickness of cords, μm	6	10	54	5	22.3[B]	77.5[B]
Twist, tpm:						
Cord	7	10	63	6	3.9[B]	5.5[B]
Singles	7	10	63	6	3.9[B]	7.9[B]
Force at specified elongation (FASE) without rosin (reported at 2 % elongation), N	9	10	81	8	1.59	5.79
Table 3f 167/1 tex High-Modulus Aramid Yarn:						
Breaking strength, N	6	10	9	5	1.52	3.38
Elongation at break, %	5	10	9	4	2.91	8.39
Modulus, mN/tex	3	10	9	2	5.06	5.05

[A] 140/2 tex nylon cord for linear density.
[B] Components of variance are expressed as standard deviations in the units shown.
[C] The F-ratio was not significant at the 5 % level of probability.
[D] Rayon data, except thickness, twist, and linear density are from oven-dry cords.

Hyosung Ex. 1033, Page 21 of 31

TABLE 4 Critical Differences Expressed as Percent of the Observed Average (Except as Noted) [A,B]

Property Measured	Number of Observations in Each Average	Critical Differences	
		Single-Operator Precision	Between-Laboratory Precision
Table 4a 93/2 tex Nylon Cord (470 by 470 tpm twist): [C]			
Breaking strength, N	10	1.41	4.57
Elongation at break, %	10	4.50	13.60
Force at specified elongation (FASE) (reported at 14 % elongation), N	10	4.97	20.70
Modulus, mN/tex	10	5.05	8.31
Work-to-break, J/m	10	6.69	10.41
Thickness of cords, µm	10	14.2[D]	37.1[D]
Twist, tpm:			
Cord	10	10.6[D]	16.9[D]
Singles	10	4.7[D]	9.8[D]
Linear density, tex			
From bobbin	5	1.07	4.49
From tabby	5	0.40	4.54
Table 4b 111/3 tex Polyester Cord (390 by 390 tpm twist):			
Breaking strength, N	10	1.72	4.65
Elongation at break, %	10	2.66	9.95
Force at specified elongation (FASE) (reported at 10 % elongation), N	10	5.15	15.59
Modulus, mN/tex	10	4.75	4.75
Work-to-break, J/m	10	4.83	16.07
Thickness of cords, µm	10	13.2[D]	17.4[D]
Twist, tpm:			
Cord	10	8.3[D]	18.5[D]
Singles	10	4.3[D]	11.4[D]
Linear density, tex:			
From bobbin	5	0.47	1.86
From tabby	5	0.65	2.83
Table 4c 183/3 tex Rayon Cord (430 by 390 tpm twist) [E]:			
Breaking strength, N	10	2.73	5.62
Elongation at break, %	10	3.04	6.49
Force at specified elongation (FASE) (reported at 6 % elongation)	10	4.67	19.20
Thickness of cords, µm	10	16.8[D]	52.6[D]
Twist, tpm:			
Cord	10	9.4[D]	20.1[D]
Singles	10	5.5[D]	11.8[D]
Linear density, tex:			
From bobbin	5	0.37	2.98
From tabby	5	0.41	1.58
Table 4d 167/2 tex High-Modulus Aramid Cord (160 by 160 tpm twist):			
Breaking strength, N	10	1.06	6.68
Elongation at break, %	10	2.26	20.80
Modulus, mN/tex	10	3.22	19.69
Work-to-break, J/m	10	3.89	48.99
Thickness of cords, µm	10	19.6[D]	272.5[D]
Twist, tpm:			
Cord	10	3.5[D]	13.4[D]
Singles	10	3.5[D]	9.4[D]
Table 4e 167/2 tex High-Modulus Aramid Cord (300 by 300 tpm twist):			
Breaking strength, N	10	2.11	9.79
Elongation at break, %	10	2.18	26.70
Modulus, mN/tex	10	2.13	35.43
Work-to-break, J/m	10	8.41	43.77
Thickness of cords, µm	10	19.6[D]	215.6[D]
Twist, tpm:			
Cord	10	3.5[D]	15.7[D]
Singles	10	3.5[D]	22.0[D]
Force at specified elongation (FASE) without rosin (reported at 2 % elongation), N	10	1.12	13.00
Table 4f 167/1 tex High-Modulus Aramid Yarn:			
Breaking strength, N	10	1.33	9.46
Elongation at break, %	10	2.55	23.39
Modulus, mN/tex	10	4.43	14.68

[A] The critical differences were calculated using $t = 1.960$, which is based on infinite degrees of freedom.

[B] To convert the values of the critical difference expressed as a percent of the observed average to units of measure (in terms of standard deviation), multiply the average of the two specific sets of data being compared by the critical difference given in the table for the property measured and then divide by 100.

[C] 140/2 tex nylon cord for linear density.

[D] Critical differences are expressed in the units shown rather than as a percent of the observed average.

[E] Rayon data, except thickness, twist, and linear density are for oven-dry cord.

(maximum force) (see 3.1.2.1) in newtons from the force-elongation (or force-extension) curve on the chart, from the dial, from the display or by electronic means. Discard specimens that break in the jaws or within 10 mm of the nip of the jaws. If the clamps are of the air-actuated type, adjust the air pressure so that specimens will not slip in the jaws, but keep air pressure below the level that will cause specimens to break at the edge of the jaws.

NOTE 7—When arbitration of test data is involved, use care in the application of the pretension load that may be specified since the actual pretension in the specimen commonly is different from the amount applied externally because of losses due to friction in the clamp. So check the pretension before starting the testing machine. The actual pretension can be measured by strain gages. Other tension-measuring instruments with sufficient accuracy may be used, provided that the specimen is threaded through the instrument prior to being placed in the second clamp. This procedure is necessary, because many instruments require appreciable displacement of the specimen.

NOTE 8—When arbitration is not involved, one of the following approximations of the specified pretension may be used. Either exert a force of 120 % of the nominal pretension to the unclamped end of the specimen prior to closing the second grip or apply one of the forces listed as follows for the specified groups of yarn and cord sizes to secure the desired pretension.

Linear Density of Specimen	Amount of Pretension, N
Below 400 tex	1
400 to 600 tex	2
600 to 800 tex	3
Above 800 tex	4

When using a CRE-type machine, a third technique is to close the upper clamp, then apply pretension by pulling the specimen taut until the recorder pen moves approximately ½ chart division from the zero line on the chart when using a force scale that is the same as that used for determining the breaking force.

15.2.2 *The Slack Start Procedure*—Thread one end of the specimen between the jaws of one of the clamps and close it. Place the other end of the specimen through the jaws of the second clamp and keep the specimen just slack (just zero tension) and close the clamp, taking care that the thread is positioned in the center-line of the jaws of the clamp. Operate the testing machine at the rate as specified in Section 14.1 and stretch the specimen until it ruptures. When the specimen breaks, read the breaking force (maximum force) (see 3.1.2.1) in newtons from the force-elongation curve, from the dial, from the display or by electronic means. Discard specimens that break in the jaws or within 10 mm of the nip of the jaws. If the clamps are of the air-actuated type, adjust the air pressure so that specimens will not slip in the jaws, but keep the air pressure below the level that will cause specimens to break at the edge of the jaws. This slack start procedure has the effect that the nominal gage length of the specimen is not exactly 250 (or 500) mm as specified in Section 15.2, but always will be somewhat more due to slack in the specimen after closing the clamps.

NOTE 9—Because of the difficulty of securing the same tension in all the filaments and because of slippage in the clamps, variable results may be obtained when testing zero-twist multifilament yarns unless a small amount of twist is inserted prior to testing. A twist of 60 t/m inserted into zero-twist yarns of different sizes has been found satisfactory for the purpose of tensile testing. Historically, twist up to 120 t/m have been used in some cases. For aramid yarns the amount of twist to be inserted shall be calculated with the equation:

$$\text{twist, (tpm)} = (1055 \pm 50)/\sqrt{LD}$$

LD = linear density, tex.

Inserting some twist in zero-twist yarns for tensile testing has the following effects on the test results:

a. modestly increases breaking force; too much twist reduces breaking force
b. increases elongation at break
c. reduces modulus (the slope of the force-elongation curve).

Manner of inserting the twist into the yarn, manually or with a twisting machine, can influence the test results, especially for the high modulus aramid yarns.

NOTE 10—The velocity of conditioned air flowing across a specimen while determining tensile properties can have a measurable effect on the breaking force and elongation at break because of the Gough-Joule effect. The magnitude of this effect depends on the type of fiber, air velocity, and sample history. Round-robin testing of nylon, polyester, and rayon cords indicates that air velocities of less than 250 mm/s across the specimen will not significantly bias the comparison of cord properties between laboratories.[7]

NOTE 11—As diameters and strengths of cords increase, clamps with larger snubbing surfaces and greater holding power or capacity may be required to prevent slippage of cords in testing machine clamps or an excessive number of jaw breaks. The levels of cord size and strength at which such higher capacity clamps are required must be determined by experiment, since they will vary with the type of fiber and construction. Examples of higher capacity clamps which have been found suitable for large cords are Instron Types "2714-004 (formerly 4C)" and "2714-006 (formerly 4D)," Scott Type "400," and Scott Type "Callaway-400."[8] The first three types of clamps are air-actuated with a lever system of closure and a mechanical advantage that accentuates and maintains greater pressure on the specimen than regular types of clamps. These clamps are of greater capacity than the last type which has a manually actuated cam system.

If slippage of cords cannot be prevented with the highest capacity clamps available to the user, it has been found useful to apply powdered rosin to the two portions of the cord which will be held between the snubbing surfaces. Use of rosin has been found particularly useful in testing organic cords that have been adhesive treated.

15.3 *Calculation and Report*—Calculate the average breaking force from the observed breaking loads of specimens read from the testing machine chart or dial. Report the average breaking force to the nearest 0.5 N as the breaking strength (see 3.1.2.1) of the sample, the procedure used, (15.2.1 or 15.2.2), the amount of twist, if any, inserted into the yarn for the tensile testing, and the number of specimens tested.

15.4 *Precision and Bias*—See Section 36 for cord only.

16. Adjustment of Observed Breaking Strength (Force) of Rayon Yarns and Cords to a Specified Moisture Regain Level

16.1 If the moisture regain of a rayon sample at the time of testing is within ±0.3 % of the regain level agreed upon between the purchaser and the supplier, report the average observed breaking force as the breaking strength (see 3.1.2.1). If the moisture regain is outside the ±0.3 % limit, adjust the observed breaking strength (force) to the agreed upon regain basis using a suitable adjustment factor. Establish this factor for a specific material by making breaking tests at a sufficient

[7] See Jones, R. E., and Desson, M. J., "Adiabatic Effects on Tensile Testing," *Journal of the I.R.I.*, June 1967.

[8] The Instron clamps may be obtained from Instron Corp., Canton, MA, and the Scott clamps from Scott Testers, by Precision Scientific, Chicago, IL 60647.

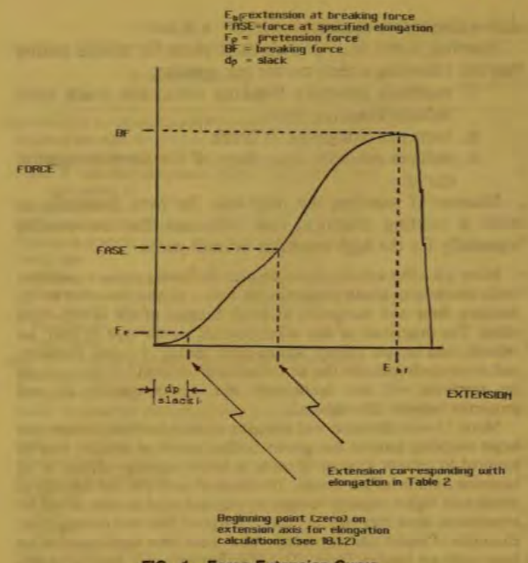


FIG. 1 Force-Extension Curve

number of different moisture regain levels to determine the slope of the "breaking strength (force) versus moisture regain" curve. Apply the factor using Eq 8:

$$\text{Breaking strength (force) (adjusted to specific moisture regain level)} = BF \times F \quad (8)$$

where:

BF = observed average breaking force, N, and
F = factor for adjusting observed breaking loads to a specified moisture regain level.

17. Breaking Tenacity of Conditioned Yarns and Cords

17.1 *Calculation*—Calculate the breaking tenacity (see 3.1.2.1) of the sample in terms of millinewtons per tex (mN/tex), from the breaking strength and the linear density using Eq 9:

$$\text{BF, mN/tex} = (BF \times 1000/LD) \quad (9)$$

where:

BF = average breaking force, N, and
LD = measured linear density, tex.

17.2 *Report*—Report the average breaking tenacity to the nearest 10 mN/tex and the number of specimens tested.

18. Elongation at Break of Conditioned Yarns and Cords

18.1 Determine the elongation at break of each conditioned specimen when determining its breaking force (Section 15). Read the extension at the breaking force from the autographic recorder or by electronic means:

The general formula for elongation at break is as follows using Eq 10:

$$\text{Elongation at break, \%} = \frac{E_{bf}}{L_o} \times 100 \quad (10)$$

where:

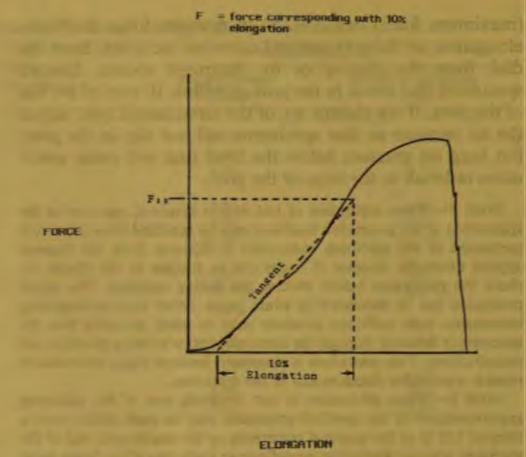


FIG. 2 Force Elongation Curve for the Determination of Initial Modulus

E_{bf} = extension of specimen in mm at the breaking force,
L_o = the length of the specimen in mm, under specified pretension measured from nip to nip of the holding clamps.

18.1.1 *Pretension Start Procedure*—Follow the procedure of 18.1 above.

18.1.2 *Slack Start Procedure*—The gage length (L_o) must be calculated to include the slack as follows in Eq 11:

$$L_o = L_s + dp \quad (11)$$

where:

L_o = gage length after clamping specimen (absolute distance nip-to-nip before movement of crosshead), and
dp = displacement of crosshead to reach the specified pretension of the specimen (see Fig. 1).

The pretension for aramid corresponds with 20 ± 1 mN/tex and for other yarns and cord to 5 ± 1 mN/tex.

The general formula for elongation at break in the case of slack start procedure is as follows in Eq 12:

$$\text{Elongation at break, \%} = \frac{E_{bf}}{L_s + d_p} \times 100 \quad (12)$$

NOTE 12—Elongation also may be determined from the load-elongation curve at any part-load that has been agreed upon between the purchaser and the seller.

18.2 *Calculation and Report*—Calculate the average elongation of the sample. Report the average elongation at break to the nearest 0.1 % and the number of specimens tested.

18.3 *Precision and Bias*—See Section 36 for cord only.

19. Adjustment of Observed Elongation of Rayon Yarns and Cords to a Specified Moisture Regain Level

19.1 If the moisture regain of a rayon specimen at the time of testing is within ±0.3 % of the regain level agreed upon between the purchaser and the supplier, report the average observed elongation at break. If the moisture regain is outside the ±0.3 % limit, adjust the observed elongation to the agreed upon regain basis using a suitable adjustment

TABLE 5 Elongation Values for Determination of FASE

Fiber	Greige	Adhesive Processed Cord
Rayon	6	3
Nylon	14	7
Polyester	10	5
High-modulus aramid	2	1

factor. Establish this factor for a specific material by making elongation tests at a sufficient number of different moisture regain levels to determine the slope of the "elongation at break versus regain" curve. Apply the factor using Eq 13:

$$\text{Elongation, \% (adjusted to specified moisture regain level)} = E \times F \quad (13)$$

where:

E = observed elongation, and
F = factor for adjusting observed elongation to an elongation at a specified moisture regain level.

20. Load at Specified Elongation (LASE) of Conditioned Yarns and Cords

20.1 *Procedure:*

20.1.1 *Nylon, Polyester, Rayon, and High Modulus Aramid Yarns and Cords*—Determine the force at specified elongation (FASE) of each conditioned specimen when determining its breaking load (Section 15 and Fig. 1). Read the force directly from the force-extension curve (Fig. 1) or by electronic means or with an on-line computer, at the specified value of elongation for the fiber types listed in Table 5.

Assure that the displacement (dp) of the crosshead to remove slack is taken into account when using slack start procedure. Follow same general procedure as for elongation at break (18.1.2 and Fig. 1).

Use Eq 14 in the case of slack start procedure to locate extension corresponding to specified elongation.

$$\text{Extension corresponding to specified elongation} = \frac{E_s L_s + dp}{100} \quad (14)$$

where:

E_s = specified elongation.

Extension is measured from the pretension point (see Fig. 1), where the slack is removed from the specimen. Read force, N, corresponding to above extension from the ordinate of the force-extension curve.

20.2 *Calculation and Report*—Calculate the average FASE to the nearest 0.5 N, and report this average value and the number of specimens tested.

20.3 *Precision and Bias*—See Section 36 for cord only.

21. Initial Modulus of Conditioned Yarns or Cords

21.1 *Procedure:*

21.1.1 *Nylon, Polyester, or Rayon Yarns and Cords*—Determine the initial modulus of each conditioned specimen when determining its breaking force (Section 15). Using the force-elongation curve (Fig. 2), draw a tangent to the initial straight-line portion of the curve. Extend this tangent to the abscissa (elongation axis), and upwards to a point which corresponds to slightly more than 10 % elongation. On the abscissa, measure and mark a distance equal to 10 % elongation of the specimen gage length beginning at the point of intersection of the tangent with the abscissa. At the 10 % mark, draw a line perpendicular to the abscissa and extend it upwards until it intersects the tangent to the curve. This point represents the force required for 10 % elongation of the specimen at the rate represented by the straight line portion of the force-elongation curve. When electronic means are used, determine the modulus of the initial straight-line portion of the above curve. Calculate the modulus of a specimen using Eq 11:

$$\text{Initial Modulus, mN/tex} = (10^4 \times F_{10})/LD \quad (15)$$

where:

F_{10} = force 10 % elongation, N, and
LD = nominal linear density, tex.

NOTE 13—The CRL and CRT type of tensile testing machines are not suited for modulus measurements; both types of testers tend to distort the slope of the force-elongation curve and do not guarantee the required accuracy for these tests.

TABLE 6 Lower and Upper Limit of the Chord Modulus Interval for the Different Types of Fibers

Type of Fiber	Lower Limit T_a, mN/tex	Upper Limit T_b, mN/tex
Rayon	30	60
Nylon	20	40
Polyester	30	60
High Modulus Aramid	300	400

21.1.2 *Chord-Modulus Aramid Yarns and Cords*—Determine the chord modulus of each conditioned specimen from the force-elongation curve (Fig. 3). Determine the chord modulus between the points A and B as specified in Table 6. Locate the points A and B on the ordinate at the forces equivalent to A mN/tex and B mN/tex respectively. Draw from each of these two points respectively a line perpendicular to the ordinate to the intersection with the force-elongation curve. From these intersection points determine the related elongation values by drawing perpendicular lines to the abscissa.

Calculate the chord modulus of a specimen using Eq 16:

$$\text{Chord modulus, mN/tex} = 100\,(T_b - T_a)/(E_b - E_a) \quad (16)$$

where:

T_b = upper limit in mN/tex,
T_a = lower limit in mN/tex,
E_b = elongation corresponding to T_b, and
E_a = elongation corresponding to T_a.

21.2 *Report*—Report the number of specimens tested and the average initial modulus and/or the average chord modulus of the sample to the nearest 10 mN/tex.

21.3 *Precision and Bias*—See Section 36 for non-aramid cord only.

22. Breaking Strength (Force) of Oven-Dry Rayon Yarns and Cords

22.1 *Apparatus*—In addition to the tensile testing machine (Section 14), the following accessory equipment is required:

[9] A suitable guide, designated as No. 900 Worsted, is available from Page-Madden Co., Inc., Mineola, Long Island, NY.

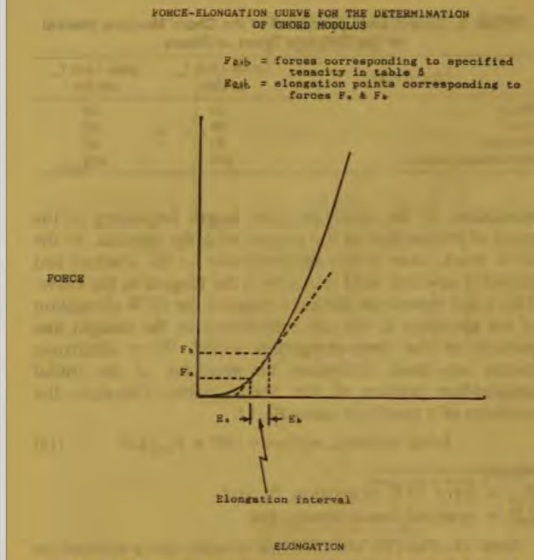


FIG. 3 Force-Elongation Curve for the Determination of Chord Modulus

22.1.1 *Sample Holder*—Use a yarn/cord support that will allow for tension-free contraction of the sample during the drying (for example, for continuous length samples a collapsible spool or reel, or a tapered spool, and for short specimens as from a tabby sample a special mounting rack). The holder has to be of a suitable design in order to prevent any change in twist, any buckling or crinkling or stretching of the specimen during handling and drying and to facilitate rapid removal of the specimen from the oven for testing.

22.1.2 *Oven*—An oven with circulating air maintained at a temperature of 105 ± 3°C and with fresh air replacement rate of 20 to 50 times the oven-volume per hour, the fresh air being taken from the standard atmosphere of 20 ± 2°C and 65 ± 2 % RH. The air shall pass freely through and around the specimens. The specimens must not be subjected to direct radiation from the heating unit. The oven has to be large enough to handle the required number of spools or racks and has to be equipped with suitable removable creels for placing the spools or reels in the oven and/or with supports for the special mounting racks for the same purpose.

22.2 *Preparation of Specimens*—For the drying process mount the yarn/cord without stretching, buckling or crinkling and without any change of twist on the yarn/cord support (see 22.1.1), which allows the specimen to contract during the drying. Dry the sample(s) at 105 ± 3°C for a sufficient length of time (for at least 2, but no longer than 6 hrs) so that the loss in mass on heating for an additional 15 min period is less than 0.1 % of the original mass of the sample. After drying, test the specimens in the tensile testing machine directly from the oven and start the tester 10 ± 1 s after the specimen leaves the oven. While moving the specimen from the oven to the tensile testing machine avoid any stretch, buckling, crinkling or change of twist of the specimen. Do not touch with bare hands that portion of specimen that will lie between the clamps of the tensile testing machine.

22.3 *Procedure*—Place the oven with the samples in a convenient position at the tensile testing machine, so that in a rapid way the specimen can be taken out of the oven and can be mounted in the prescribed way in the clamps of the testing machine (see Section 15.2). Take all the precautions mentioned already in 22.2. Make sure that the specimen being tested has stayed in the laboratory ambient atmosphere for just 10 ± 1 s at the moment the tensile tester is started. Determine the breaking force as directed in 15.2.

22.4 *Calculation and Report*—Calculate the average breaking force of the oven-dry sample from the observed breaking force of specimens read from the testing machine chart or dial. Report the average breaking load to the nearest 0.5 N as the breaking strength (see 3.1.2.1) of the sample and report the number of specimens tested.

22.5 *Precision and Bias*—See Section 36 for cord only.

23. Breaking Tenacity of Oven-Dry Rayon Yarns and Cords

23.1 Calculate the breaking tenacity (see 3.1.2.1) of the oven-dried rayon sample as directed in Section 17 using the average breaking force in newtons of the oven-dry sample and the linear density based on the commercial regain (see Section 11).

24. Elongation at Break of Oven-Dry Rayon Yarns and Cords

24.1 Determine the elongation at break of each oven-dry rayon specimen when determining its breaking force (22.3). Read the elongation from the autographic recorder chart, or by electronic means, at the breaking force. Express the observed elongation of each oven-dry specimen as a percentage of its nominal gage length.

24.2 *Calculation and Report*—Calculate the average elongation at break to the nearest 0.1 %. Report this value as the elongation at break for the oven-dry sample, and report the number of specimens tested.

24.3 *Precision and Bias*—See Section 36 for cord only.

25. Force at Specified Elongation (FASE) of Oven-Dry Rayon Yarns and Cords

25.1 Determine the FASE of each oven-dry rayon specimen when determining its breaking force (22.3). Read the force directly from the autographic recorder chart, or by electronic means, at the appropriate value of elongation for the product listed in Table 2.

25.2 *Calculation and Report*—Calculate the average FASE to the nearest 0.5 N, and report this average value and the number of specimens tested.

25.3 *Precision and Bias*—See Section 36 for cord only.

26. Work-to-Break of Yarns and Cords

26.1 *Procedure*—Using the force - elongation curves obtained as directed in Sections 15, 22, or 30, draw a line from the point of the breaking load of each specimen perpendicular to the elongation axis. Measure the area bounded by the curve, the perpendicular, and the elongation axis. This area may be estimated by counting squares, measured with a planimeter, or determined by electronic means.

26.2 *Calculation*—Calculate the work-to-break for each specimen using Eq 17, or specific work-to-break using Eq 18 (see Appendix X2):

$$\text{Work-to-break, } J = A \times F_{sf} \times E_{sf}\, 10^{-5} \times L_o \quad (17)$$

$$\text{Specific work-to-break, J/m} = A \times F_{sf} \times E_{sf} \times 10^{-2} \quad (18)$$

where:

A = area under the force - elongation curve, mm²,
F_{sf} = force scale factor, N/mm of chart,
E_{sf} = elongation scale factor, % of specimen elongation per mm of autographic chart, and
L_o = gage length of specimen, mm at specified pretension.

26.3 *Report*—Report the average work-to-break or average specific work-to-break of the sample and the number of specimens tested.

26.4 *Precision*—See Section 36 for cord only.

27. Breaking Toughness of Yarns and Cords

27.1 *Procedure*—Use the information developed in Section 11 and in Section 26 to calculate the breaking toughness of a yarn or cord sample.

27.2 *Calculation*—Calculate the breaking toughness of each specimen using Eq 19 or 20 (see Appendix X2):

$$\text{Breaking toughness, J/g} = (A \times F_{sf} \times E_{sf}) \times 10/(LD) \quad (19)$$

$$= (W \times 10^3)/LD \quad (20)$$

where:

A = area under the force - elongation curve, mm²,
F_{sf} = force scale factor, N/mm,
E_{sf} = elongation scale factor, % of specimen elongation per mm of autographic chart,
LD = measured linear density of specimen, tex, and
W = specific work-to-break of specimen, J/m.

27.3 *Report*—Report the average breaking toughness of the sample and the number of specimens tested.

27.4 *Precision and Bias:*

27.4.1 *Precision*—The precision of breaking toughness is derived from work-to-break and linear density. See Section 15.

27.4.2 *Bias*—See 36.3.

28. Reports, General

28.1 State that all specimens were tensile tested as directed in Test Methods D 885M, Sections 12 to 28. Describe the material or product sampled and the methods of sampling used.

28.2 Report the following information:

28.2.1 The test procedure used (15.2.1 or 15.2.2).

28.2.2 Type of tensile testing machine used and type of clamp used,

28.2.3 The amount of twist, if any, inserted into the yarn especially for the purpose of tensile testing the yarn (Note 7).

28.2.4 Number of specimens tested per sample,

28.2.5 Average value of each property determined or calculated, and

28.2.6 Coefficient of variation, if calculated.

29. Twist in Yarns and Cords

29.1 *Number of Specimens*—Test ten specimens. This number is based on the assumption that the applicable coefficient of variation is 3.0 % and the allowable variation is 1.9 % at a probability level of 95 %.

29.2 Determine the twist in single yarn, plied yarn, and tire cord as directed in Test Method D 1423, 9.2 through 9.5, except use a tension of 5 ± 1 mN/tex based on the nominal yarn or cord linear density (Note 14). When all but one of the elements of the untwisted cord have been cut prior to determining the twist of an individual element, leave the total load unchanged even though the tension per unit linear density in the element will be higher than in the original cord. Before determining the twist of the element, record its length after all but one of the elements have been cut away from the untwisted cord. Use this length when calculating the twist in the element using Eq 8 of Test Method D 1423.

NOTE 14—For convenience in routine testing, an approximation of the specified tension may be obtained by applying one of the forces listed as follows for the specified groups of yarn and cord sizes.

Linear Density of Specimen	Amount of Force, N
Below 400 tex	1
400 to 600 tex	2
600 to 800 tex	3
Above 800 tex	4

29.3 *Calculation and Report*—Calculate the twist of all specimens as directed in Test Method D 1423, Section 10.1 through 10.4.

29.4 *Precision and Bias*—See Section 36.

30. Thickness of Cords

30.1 *Summary of Test Method*—The average thickness (gage) of a group of parallel tire cords resting on an anvil is determined when under a specified pressure applied by the presser foot of a thickness gage.

30.2 *Apparatus*—The thickness gage shall conform with the requirements specified in 6.1 of Test Method D 1777. The gage shall be equipped with a presser foot having a diameter of 10 mm and shall exert a pressure of approximately 25 kPa (related to the presser foot area, or to the contact area between the cord and the presser foot).

30.3 *Number of Specimens*—Test five specimens. This number is based on the assumption that the applicable coefficient of variation is 1.0 % and the allowable variation is 1.5 % of the average at a probability level of 95 %.

30.4 *Procedure*—Take a specimen comprised of four cords from the sample and handle the cords in such a manner that no change of twist can occur. For tabby samples of tire cord fabric, prior to removing each set of four cords, position the cords so that they are adjacent and parallel with no ends crossed. Grasp the four cords so that the length of the cords between the fingertips of the left hand and the right hand is approximately equal to the length of the anvil. Use care to avoid any change in twist if the hands are repositioned after the set of four cords are removed from the tabby sample. Inspect the top and bottom of the specimen to be sure that no knots, splices, or foreign protuberances are present on the lengths of cord to be gaged. Place the four cords side by side on the anvil and directly under the presser foot of the thickness gage. Apply sufficient tension to make the cords taut (about 5 N) (see Note 15). Lower the presser foot gradually and gently (take about 5 s to apply the full load) by keeping a finger or thumb in contact with the lowering lever until the presser is in contact with the cord specimen. Wait until the gage reading becomes stable (about 5 s), and record the thickness of the specimen to the nearest

Hyosung Ex. 1033, Page 24 of 31

0.01 mm. Make only one measurement of each specimen of four cords.

NOTE 15—Laboratory tests have shown that the average tension applied by an operator, to four parallel cords held between the fingertips, was about 5 N. Tensions considerably greater than 5 N usually result in cord slippage. Tests using a tension in the range from 2 to 7 N resulted in no significant change in cord thickness, as measured.

30.5 *Calculation and Report*—Calculate the average thickness of all specimens from a sample and report this value to the nearest 0.01 mm.

30.6 *Precision and Bias*—See Section 36 for cord only.

31. Extractable Matter in Yarns and Cords

31.1 Determine the amount of extractable matter present in yarns and cords as directed in Test Method D 2257.

32. Dip (Adhesive) Solids Pickup on Yarns and Cords

32.1 *Summary of Test Method*—Individual procedures are given for determining the amount of adhesive dip solids on nylon (32.4), polyester (32.5), and rayon (32.6) yarns or cords that have been treated with resorcinol-formaldehyde-latex (RFL) type of adhesive dip by dissolving the fiber in an appropriate solvent and recovering the residue of dip solids by filtration after which it is dried and weighed. The amount of adhesive solids on a sample is reported as percentage dip solids pickup based on the oven-dry mass of the dip-free sample. An acceptable solids pickup test for high-modulus aramids has not yet been established.

32.2 *Significance and Use:*

32.2.1 Textile yarns and cords are treated with an adhesive dip to improve the adhesion of elastomers to the textile materials. The amount of dip solids pickup on the yarns or cords is used for process control.

32.2.2 This test method for testing dip pickup is not recommended for acceptance testing of commercial shipments of dipped yarns or cords because of large between-laboratory variations.

32.3 *Apparatus and Materials:*

32.3.1 *Air Oven*, controlled at 105 ± 3°C.

32.3.2 *Erlenmeyer Extraction Flasks*, capacity 250 mL, borosilicate glass, with interchangeable ground-glass joints.

32.3.3 *Glass-Fiber Filter Disks*.[10]

32.3.4 *Glass Weighing Bottles*, with ground-glass stoppers, 40 mm in diameter and 80 mm in height.

32.3.5 *Gooch Crucible*, No. 4.

32.3.6 *Vacuum Flask*, 1-L capacity.

32.3.7 *Water-Cooled Condensers*, borosilicate glass, with interchangeable ground-glass joints.

32.3.8 Water Bath.

32.3.9 Desiccator, with silica gel.

32.4 *Nylon Yarns and Cords:*

32.4.1 *Reagents:*

32.4.1.1 Apparatus and materials as listed in 32.3.

32.4.1.2 *Formic Acid* (HCOOH), 90 % for nylon extraction.

32.4.2 *Safety Precautions*—Use extreme care, wear rubber gloves and goggles, and work in a hood with forced ventilation when handling concentrated formic acid.

32.4.3 *Procedure*—Cut approximately 3 g of dipped nylon yarn or cord into pieces no longer than 10 mm and place the pieces in a weighing bottle. Dry this specimen in an oven at a temperature of 105 ± 3°C to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus the specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to a 500-mL beaker and add 250 mL of 90 % formic acid. Allow the specimen to dissolve at room temperature with occasional stirring. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible that contains a glass-fiber filter disk. Wash the beaker and residue with two 25-mL portions of formic acid and allow the acid to filter slowly through the residue each time. Wash the residue with four 25-mL portions of water in the same manner as above. Dry the residue and crucible at a temperature of 105 ± 3°C to a constant mass. Cool in a desiccator and weigh to the nearest 1 mg.

32.4.4 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 21:

$$DPU, \% = [M_{or}/(M_o - M_{or})] \times 100 \quad (21)$$

where:

DPU = dip pickup,
M_{or} = mass of oven-dry residue, g, and
M_o = mass of oven-dry specimen, g.

Calculate the average pickup of all specimens.

32.4.5 *Report*—The average adhesive dip solids pickup of the sample together with the number of specimens tested.

32.4.6 *Precision:*

32.4.6.1 *Interlaboratory Test Data*—An interlaboratory test was run in 1968 in which three laboratories each tested dipped cord specimens from a single sample. A single nylon cord at a dip pickup level of approximately 5 % was wound on a drum, cut off the drum, and the resulting 250 to 300-mm lengths of cord were thoroughly mixed. Each participating laboratory was supplied a bundle of these short cords taken at random from the sample described. Each laboratory made five determinations on two different occasions. The components of variance for dip pickup results expressed as coefficients of variation were calculated to be as follows:

Within-laboratory component	2.13 % of the average
Between-laboratory component	6.14 % of the average

32.4.6.2 *Precision*—For the components of variance reported in 32.4.6, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed as follows:

[10] Glass Fiber Filter Disks, No. X-934-AH, made by Hurlbut Paper Co., Box 9, Green Bay, WI 54305, have been found to be satisfactory for this purpose.

DIP PICKUP

Number of Observations in Each Average	Critical Difference, % of Grand Average, for the Conditions Noted[A,B] Single-Operator Precision	Between-Laboratory Precision
1	5.90	18.01
5	2.64	17.22
10	1.87	17.12

[A] The critical differences were calculated using $t = 1.960$, which is based on the infinite number of degrees of freedom.

[B] To convert the values of the critical differences to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as a decimal fraction.

NOTE 16—The within-laboratory component of variance is the sum of all the individual components of variance, except the single-operator component of variance, that contribute to the variability of observations within a single laboratory. Included are such components of variance as those for days of testing, units of apparatus, and different operators within a single laboratory. If the within-laboratory component of variance is not calculated separately, all sources of variability except the single-operator component are included in the between-laboratory component. Under these conditions, calculate the standard error (between-laboratory) using zero for the within-laboratory component.

32.5 *Polyester Yarns and Cords:*

32.5.1 *Reagents:*

32.5.1.1 Apparatus and materials as listed in 32.3.

32.5.1.2 *Methylene Chloride* (CH_2Cl_2) reagent grade.

32.5.1.3 *Trichloroacetic Acid* (Cl_3CCOOH) reagent grade.

32.5.1.4 *Trichloroacetic Acid, Methylene Chloride Solution* (30 % (w/v)) for polyester extraction—Dissolve 300 g of trichloroacetic acid crystals in 1000 mL of methylene chloride.

32.5.2 *Procedure*—Cut approximately 2 g of dipped polyester yarn or cord into pieces no longer than 10 mm and place the pieces in a weighing bottle. Dry this specimen in an oven at a temperature of 105 ± 3°C to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to the 250-mL Erlenmeyer extraction flask and add about 75 mL of the trichloroacetic acid-methylene chloride solution. Attach the flask to the condenser and reflux for 15 min or until the specimen appears to be dissolved. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible that contains a glass-fiber filter disk. Wash the flask and residue on the filter disk with three successive 25-mL portions of methylene chloride. Dry the Gooch crucible and filter disk with the dip solids residue at a temperature of 105 ± 3°C to constant mass. Cool in a desiccator and weigh to the nearest 1 mg.

32.5.3 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 21. Calculate the average pickup of all specimens and report this value as the adhesive dip solids pickup of the sample together with the number of specimens tested.

32.5.4 *Precision:*

32.5.4.1 *Interlaboratory Test Data*—Data on components of variance are not available.

32.5.4.2 *Within-Laboratory Precision*—The uncertainty (0.95 level) of single measurements made in one laboratory has been found to be ±10 % of the average dip solids pickup.

32.5.4.3 *Between-Laboratory Precision*—The uncertainty (0.95 level) in the difference between two laboratories, each making five measurements, has been found to be ±15 % of the average dip solids pickup.

32.6 *Rayon Yarns and Cords:*

32.6.1 *Reagents:*

32.6.1.1 Apparatus and materials as listed in 32.3.

32.6.1.2 *Sulfuric Acid* (H_2SO_4)—Pour slowly with constant stirring 420 mL of concentrated sulfuric acid (sp gr 1.84) into 260 mL of distilled water to achieve approximate 71 % H_2SO_4 for rayon extraction.

32.6.2 *Procedure*—Cut approximately 3 g of dipped rayon yarn or cord into pieces no longer than 6 mm and place in a weighing bottle. Dry this specimen in an oven at a temperature of 105 ± 3°C to a constant mass. Remove the specimen from the oven, close the weighing bottle, and cool in a desiccator. Weigh the bottle plus specimen to the nearest 1 mg and determine the mass of the specimen by difference. Transfer the specimen to a 250-mL beaker. Add 150 mL of the H_2SO_4 (71 %), which has been heated to a temperature of 30 ± 5°C, to the specimen in the beaker with stirring. Maintain the mixture at the above temperature and stir continuously until the fibers appear to be completely dissolved, then stir for an additional 20 min. When the solution of the specimen is complete, filter the solution through a tared Gooch crucible which contains a glass-fiber filter disk. Wash the beaker and residue with successive 25-mL portions of water until the wash water is acid-free when tested with methyl red. Dry the residue and crucible at a temperature of 105 ± 3°C to a constant mass, cool in a desiccator, and weigh the residue to the nearest 1 mg.

32.6.3 *Calculation and Report*—Calculate the amount of dip pickup for each specimen using Eq 21. Calculate the average pickup of all specimens and report this value as the adhesive dip solids pickup of the sample together with the number of specimens tested.

32.6.4 *Precision:*

32.6.4.1 *Interlaboratory Test Data*—The values of precision are based on interlaboratory testing by eight laboratories of a standard sample that contained about 5 % adhesive dip solids pickup. Components of variance are not available.

32.6.4.2 *Within-Laboratory Precision*—The uncertainty (0.95 level) of single measurements made in one laboratory has been found to be ±10 % of the average dip solids pickup.

32.6.4.3 *Between-Laboratory Precision*—The uncertainty (0.95 level) in the difference between two laboratories, each making five measurements, has been found to be ±15 % of the average dip solids pickup.

33. Adhesion of Cord to Elastomers

33.1 Determine the adhesion of tire cords to elastomers from among Test Methods D 4393, D 4776, D 4777, or as agreed upon between purchaser and supplier.

NOTE 17—Other tire cord adhesion tests currently are being studied by ASTM Committee D-11 on Rubber and Rubber-Like Products and Committee D-13.

Hyosung Ex. 1033, Page 25 of 31

34. Properties of Tire Cord Fabric

34.1 *Width*—Determine the width of tire cord fabric as directed in Test Methods D 3774.

34.2 *Mass*—Determine the mass of tire cord fabric as directed in Test Method D 3776 (Option A or B as appropriate).

34.3 *Count*—Determine the count of tire cord fabric as directed in Test Method D 3775 except count the filling yarns in a specimen of fabric having a length of at least 250 mm.

35. Stiffness of Fabric

35.1 *Summary of Test Method*—Specimens of tire fabric are analyzed for stiffness using a CRE-type tensile testing machine, having normal jaws replaced with a holder or rack which allows the sample to rest across a 25-mm span opening. The specimen is deflected by a depressor applied in the center of the span and the load in millinewtons required to depress the specimen is recorded and averaged.

35.2 *Significance and Use*—Stiffness of treated fabric is a factor influencing the handling, fabrication, and performance of the finished product. This test method may be used to determine the stiffness. Specified stiffness values will not be set forth because various applications, equipment for fabricating, condition of materials, and so forth, play an important part on the degree of stiffness needed or that can be tolerated.

35.3 *Apparatus:*

35.3.1 *CRE-Type Tensile Testing Machine.*

35.3.2 *Load Cell*, 20 N.

35.3.3 *Shears.*

35.3.4 *Specimen Holder*—An 85 mm square frame made of 5-mm diameter steel rod. In the middle of one side is a hook made of 3-mm rod diameter for connecting the holder to the load cell. In the middle of the opposite side, there is a 22 mm long, 5-mm diameter rod fastened at midpoint and at right angles to the side of the frame. These two "*T*'s," 25 mm apart, form a rack on which the test specimens lay so that they are across the 25-mm opening (see Fig. 3).

35.3.5 *Specimen Depressor*, 85-mm square frame, made of 5-mm diameter steel rod, rigidly fastened with a threaded connector to the lower crosshead. The side opposite the crosshead connection is covered with a 6-mm diameter piece of steel tubing. This forms a bar, which presses against specimens to bend them during the test (see Fig. 3).

35.4 *Number of Specimens:*

35.4.1 Unless otherwise agreed upon, as when specified in an applicable material specification, take a number of specimens such that the user may expect at the 95 % probability level that the test result is no more than 3.50 % of the average above or below the true average (that is, a theoretical average obtained from an infinite number of observations). Determine the number of specimens (in accordance with Practice D 2258) as follows:

35.4.2 *Reliable Estimate of v*—When there is a reliable estimate of v based upon extensive past records for similar materials tested in the user's laboratory as directed in the test method, calculate the number of specimens using Eq 22:

$$n = (t^2 \times v^2)/A^2 = 0.314 \times v^2 \quad (22)$$

where:

n = number of specimens (rounded upward to a whole number),

v = reliable estimate of the coefficient of variation of individual observations on similar materials in the user's laboratory under conditions of single-operator precision,

t = 1.960, the value of Student's t for infinite degrees of freedom, for two-sided limits, and a 95 % probability level ($t^2 = 3.842$),

A = 3.50 % of the average, the value of the allowable variation, and

0.314 = value calculated from t^2/A^2.

35.4.3 *No Reliable Estimate of v*—When there is no reliable estimate of v for the user's laboratory, Eq 22 should not be used directly. Instead, specify the fixed number of five specimens. This number of specimens is calculated using v = 3.71 % of the average, which is a somewhat larger value of v than is usually found in practice. When a reliable estimate of v for the user's laboratory becomes available, Eq 22 will usually require fewer than five specimens.

35.5 *Sample Preparations:*

35.5.1 *Fabric Sample*—Cut the required number of 50-mm specimens of fabric, each containing 16 ends. Select specimens as straight as possible. Do not preflex samples before testing. Remove three ends from each edge of each specimen, leaving ten ends and all the filling in the sample.

35.6 *Procedure:*

35.6.1 Mount the specimen holder and depressor in the testing machine, calibrate, and set the tester at zero.

35.6.2 Adjust the crosshead so that the pressor bar of the depressor is approximately 6 mm above the opening in the specimen rack.

35.6.3 Set the crosshead speed at 25 mm/min and the chart speed at 125 mm/min. Set the load selector for the minimum scale load to accommodate the specimen and for the bending force to occur between 10 and 90 % of full-scale load, preferably at mid-scale.

35.6.4 Place the specimen on the rack with the middle of the specimen at the midpoint of the rack and the longitudinal axis of the specimen parallel to the 25-mm opening.

35.6.5 Start the tester so that the crosshead is lowered and the pressor bar is pulled down onto the specimen and through the opening in the specimen rack.

35.6.6 Record the maximum force to the nearest 1 mN required to pull the specimen through the opening.

35.6.7 Repeat 35.6.1 to 35.6.6, and average the stiffness results of all of the specimens.

35.7 *Report:*

35.7.1 State that the specimens were tested as directed in Section 35 of Test Methods D 885M. Describe the material or product sampled and the method of sampling used.

35.7.2 Report the average of the results of all of the samples to the nearest 1 mN and report the number of specimens tested.

35.8 *Precision and Bias:*

35.8.1 *Interlaboratory Test Data*[11]—An interlaboratory test was run in 1974 in which randomly drawn samples of one material were tested in each of five laboratories. The operator in each laboratory tested five specimens of each material. The components of variance of stiffness property results expressed as coefficients of variation were calculated to be as follows:

Single-operator component	2.65 % of the average
Between-laboratory component	3.36 % of the average

35.8.2 *Precision*—For the components of variance reported in 35.8.1, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences listed as follows:

Number of Observations in Each Average	Critical Differences,[A,B] % of the Grand Average for the Conditions Noted	
	Single-Operator Precision	Between-Laboratory Precision
1	7.34	11.90
5	3.28	9.87
10	2.32	9.60

[A] The critical differences were calculated using t = 1.960, which is based on infinite degrees of freedom.

[B] To convert the tabulated values of the critical differences to units of measure, multiply the average of the two specific sets of data being compared by the critical differences expressed as decimal fractions.

NOTE 18—The tabulated values of the critical differences should be considered to be a general statement, particularly with respect to between-laboratory precision. Before a meaningful statement can be made about two specific laboratories, the amount of statistical bias, if any, between them must be established, with each comparison being based on recent data obtained on randomized specimens from one sample of the material to be tested.

35.8.3 *Bias*—No justifiable statement on the bias of Test Methods D 885M for measuring the stiffness of fabric can be made since the true value of the property cannot be established by an accepted referee method.

36. Precision and Bias of Certain Cord Tests

36.1 *Interlaboratory Test Data*—An interlaboratory test was run in 1969 in which replicate samples from three tire cord materials were sent to eight laboratories. The samples were tested on two different occasions in each laboratory. These materials were greige 93 tex Z 470 tpm/2 S 470 tpm, 186 tex nylon; 111 tex Z 390 tpm/3 S 390 tpm, 333 tex polyester; and 183 tex Z 430 tpm/3 S 390 tpm, 549 tex rayon. Each laboratory received a small spool from a single lot of each material. Cord spools of all three materials were prepared in a single laboratory and sent to each laboratory participating in the interlaboratory test. Similar specimen preparation and interlaboratory tests were completed on 167 tex/1 high-modulus aramid yarn in 1973 and on two constructions of 167 tex Z 300/2 S 300 tpm, 334 tex high-modulus aramid cords in 1974. In each interlaboratory test, a variety of properties were determined on each specimen. The FASE results were initially withheld from Tables 3 and 4 because of excessive variation, and a separate aramid FASE interlaboratory test program was completed in 1983 on greige and treated 167/2 tex cord with and without the use of rosin to reduce clamp slippage. Rosin use altered results without reducing variation, providing higher FASE values when the entire sample was treated, and intermediately high values when only clamp areas were treated. The FASE values shown are for non-rosin treated specimens. In 1974, a separate interlaboratory test was run on linear density in which other replicate samples in two forms, bobbin and tabby, from three tire cord materials were sent to nine laboratories. Five linear density determinations were made on three occasions in each laboratory. The components of variance expressed as coefficients of variation were calculated and are listed in Table 3. Facilities for measurement of a given property varied among laboratories; therefore, the listing in Table 3 does not always show the same number of participating laboratories for each property measurement.

36.2 *Precision*—For the components of variance reported in Table 3, two averages of observed values should be considered significantly different at the 95 % probability level if the difference equals or exceeds the critical differences shown in Table 4.

36.3 *Bias*—No justifiable statement on the bias of the procedures in Test Methods D 885M for measuring various properties of tire cords can be made since the true value of the properties cannot be established by referee methods.

37. Keywords

37.1 commercial mass; dip pickup; industrial yarn; linear density; man-made fibers; moisture regain; shrinkage; tensile properties/tests; tire cord; tire fabric; twist

APPENDIXES

(Nonmandatory Information)

X1. Additional Information

X1.1 The sections on "Growth of Conditioned Yarns and Cords," "Properties of Yarns and Cords at Elevated Temperature," and "Properties of Wet Yarns and Cords," have been moved to the Appendix as non-mandatory informational items in light of their very limited use by the industry. Because of their non-mandatory status precision and bias statements are not included.

[11] ASTM Research Report No. RR:D13-1040. A copy is available from ASTM Headquarters, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Hyosung Ex. 1033, Page 26 of 31

X2. GROWTH OF CONDITIONED YARNS AND CORDS

X2.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord that has been permitted to relax in a conditioned atmosphere is determined while under a specified pretension load. A load of 100 ± 1 mN/tex is then applied to the specimen and its length again measured after the length of the loaded specimen becomes constant. The amount of growth is calculated from the differences in observed specimen lengths.

X2.2 *Significance and Use*—The growth of a yarn or cord is a factor in the dimensional stability under load, of a product which is reinforced with a specific textile material.

X2.3 *Apparatus*—A length measuring device upon which test specimens at least 250 mm long can be mounted with one end of each specimen in a fixed position. The apparatus shall be equipped with a means for measuring the initial length and the final length of each specimen during the test period. This device shall be designed so that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

X2.4 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to relax without kinking in the test atmosphere (see 3.1.1 and 3.1.16) for a minimum of 48 h prior to testing.

X2.5 *Procedure*—Secure one end of a specimen at least 250 mm long in the clamp of the apparatus, and apply a pretension load of 5 ± 1 mN/tex to the other end of the specimen in such a manner that there is no change in twist. Observe and record the initial length of the specimen. Apply an additional load to the specimen so that the total load is 100 ± 1 mN/tex. When the increase in amount of growth is no more than 5 % (based on change in length of a specimen) during a 1-min interval, observe and record the final length of the specimen.

X2.6 *Calculation*—Calculate the percentage growth of each specimen using Eq X2.

$$\text{Growth, \%} = [(L_f - L_o)/L_o] \times 100 \qquad \text{(X2.1)}$$

where:
L_o = initial length of specimen, and
L_f = final length of specimen.
Calculate the average growth of all specimens.

X2.7 *Report*—State that the specimens were tested as directed in X2 of Test Methods D 885M and report the average growth of all specimens as the growth of the sample together with the number of specimens tested as agreed between buyer and supplier.

X3. PROPERTIES OF YARNS AND CORDS AT ELEVATED TEMPERATURE

X3.1 *Significance and Use*—Since textile materials often are subjected to elevated temperatures during their processing and use, it is desirable to know the tensile properties and behavior at such temperatures. Such information is used in engineering calculations and in process specifications.

X3.2 *Breaking Strength (Force) of Yarns and Cords at Elevated Temperatures:*

X3.2.1 *Summary of Test Method*—The breaking load of yarn or cord is determined while the specimen is at an elevated temperature. Elongation usually is not determined. This test is not a heat-aging test.

X3.2.2 *Apparatus*—A tensile testing machine as specified in Section 14, except that the machine shall be equipped with an oven or elevated temperature chamber which completely encloses the testing clamps and specimen. The oven shall be such that it will maintain the desired temperature ±2°C.

NOTE X1—The temperature to be used and the rate of temperature recovery by the oven shall be as agreed upon between the purchaser and the supplier.

NOTE X2—Air-actuated testing machine clamps as usually supplied are not suitable for use in ovens at high temperature without modification. Such modification consists of increasing the diameter of the cylinder to compensate for thermal effects and the use of rings of heat-resistant material on the pistons.

X3.2.3 *Procedure*—Place a conditioned specimen of yarn or cord (for rayon an oven-dried specimen prepared as directed in 22.2) in the clamps of the testing machine, enclose it in the oven and expose it to the specified temperature (Note X1). When the specimen reaches the temperature of the oven, immediately determine its breaking load as directed in Section 15.

X3.2.4 *Calculation and Report*—Calculate the average breaking force of the sample from the observed breaking loads of the specimens. Report the average breaking force to the nearest 0.5 N as the breaking strength (see 3.1.2.1) of the sample at the specified temperature and report the number of specimens tested.

X3.3 *Shrinkage of Conditioned Yarns and Cords at Elevated Temperature:*

X3.3.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord that has been permitted to relax in a conditioned atmosphere is determined while under a specified load. After exposure of the loaded specimen to a specified temperature until its length becomes constant, the final length is measured and the amount of shrinkage is calculated from the difference in observed specimen lengths (Note X3).

X3.3.2 *Apparatus*—A length-measuring device designed so that it can be exposed to an elevated temperature and upon which test specimens at least 250 mm long can be mounted with one end of each specimen in a fixed position. The device shall be equipped with a means for measuring the initial length and the final length of each specimen during the test period. This device shall be such that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

X3.3.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

X3.3.4 *Procedure*—Secure one end of the specimen in the apparatus, and apply a load of 5 ± 1 mN/tex to the other end of the specimen in such a manner that there is no change in twist. Record the initial length of the specimen to the nearest 0.5 mm. Place the apparatus with the specimen and load in an oven controlled within ±2°C of the agreed upon temperature (Note X1). Expose the specimen until the rate of shrinkage of the specimen is less than 5 % of the shrinkage/min. Record the final length of the loaded specimen to the nearest 0.5 mm before removing it from the oven.

X3.3.5 *Calculation*—Calculate the shrinkage at the specified temperature of each specimen using Eq X3.1:

$$\text{Shrinkage, \%} = [(L_o - L_f)/L_o] \times 100 \qquad \text{(X3.1)}$$

where:
L_o = initial length of specimen, and
L_f = final length of specimen.
Calculate the average shrinkage of all specimens.

X3.3.6 *Report*—State that the specimens were tested as directed in X3.3 of Test Methods D 885M and report the average shrinkage of all specimens as the shrinkage of the sample at the specified temperature together with the number of specimens tested.

X3.4 *Shrinkage Force of Conditioned Yarns and Cords at Elevated Temperature:*

X3.4.1 *Summary of Test Method*—A specimen of yarn or cord is permitted to relax in a conditioned atmosphere after which the conditioned specimen is mounted between fixed clamps under a specified pretension load. The specimen then is exposed to a specified temperature while held at a constant length. The maximum force developed is the shrinkage force of the specimen at the specified temperature (Note X5).

X3.4.2 *Apparatus*—A force-measuring device in which a test specimen can be secured with its ends in fixed clamps a minimum distance of 250 mm apart, and that can be exposed to an elevated temperature. The clamp at one end of the device shall be attached to a strain gage connected with a recorder that covers the range to be tested or a mechanical device that measures changes in force without a significant change in the length of the specimen. The strain gage or mechanical device shall permit less than 25-μm change in specimen length when used under the maximum tension developed. The device shall permit the attachment of a pretension load to the end of the specimen opposite the strain gage, without any change in twist, prior to tightening the clamp.

X3.4.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of tire cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

X3.4.4 *Procedure*—Secure one end of the specimen in the clamp attached to the strain gage or mechanical force-measuring device and apply a pretension load of 5 ± 1 mN/tex to the other end of the specimen using care to avoid any change in twist. Secure the other end of the specimen in the other clamp while it is under the pretension load. Expose the mounted specimen to the agreed-upon temperature ±2°C (Note 16). Expose the specimen until the rate of increase in force exerted by the specimen is less than 5 %/min. Record to the nearest 10 mN the maximum force developed by the specimen while it is in the oven.

NOTE X3—If a strain gage with recorder is used, a complete force-time curve may be obtained.

X3.4.5 *Calculation*—Calculate the tenacity in terms of millinewtons per tex for each specimen using Eq X3.2:

$$\text{Shrinkage tenacity, mN/tex} = F_m/LD \qquad \text{(X3.2)}$$

where:
F_m = maximum force developed by the specimen, mN, and
LD = linear density of the specimen, tex.
Calculate the average shrinkage force of all specimens.

X3.4.6 *Report*—State that the specimens were tested as directed in X3.4 of Test Methods D 885M and report the average shrinkage force of all specimens as the shrinkage force at the specified temperature together with the number of specimens tested.

X4. PROPERTIES OF WET YARNS AND CORDS

X4.1 *Significance and Use*—Since textile materials are subjected to aqueous media during their processing, it sometimes is desirable to know their behavior under such conditions.

X4.2 *Contraction of Wet Yarns and Cords:*

X4.2.1 *Summary of Test Method*—The initial length of a specimen of yarn or cord which has been permitted to relax in a conditioned atmosphere is determined while under a specified load. After having been thoroughly wetted with water at room temperature, the length of the wet loaded specimen is measured after the length of the wet specimen becomes constant. The amount of contraction of the wet specimen is calculated from the difference in the observed lengths of the specimens before and after wetting.

X4.2.2 *Apparatus:*

X4.2.2.1 *Length-Measuring Device*, made of corrosion-resistant material upon which test specimens at least 250 mm long can be secured with one end of each specimen in a fixed position and which can be immersed in water. The device shall be equipped with a means for measuring the initial length and final length of each specimen. This device shall be such that a tension load can be attached to the free end of each specimen in such a manner that there shall be no change in twist.

X4.2.2.2 *Tank*, made of corrosion-resistant material and of suitable dimensions for immersing in water the device described in X4.2.2.1 with the specimens of yarn or cord.

X4.2.3 *Preparation of Specimens*—Wind a skein sample of yarn or cord from a package or remove a tabby sample of the cord fabric from the board to which it may be attached. Permit the sample to condition while relaxed without kinking in the test atmosphere (3.1.1 and 3.1.13) for a minimum of 48 h prior to testing.

X4.2.4 *Procedure*—Using the apparatus with dry clamps, secure one end of the specimen in one of the clamps, and apply a load of 5 ± 1 mN/tex to the other end of the

specimen in such a manner that there is no change in twist. Record the initial length of the specimen to the nearest 0.5 mm. Immerse the apparatus with the specimen and load in the water at a temperature of 24 ± 2°C. Expose the specimen until the rate of contraction of the specimen is less than 5 % of the shrinkage/min. Record the final length of the loaded specimen to the nearest 0.5 mm while it is wet.

X4.2.5 *Calculation*—Calculate the contraction of each wet specimen using Eq X4.1:

$$\text{Contraction of wet yarn or cord, \%} = [(L_o - L_f)/L_o] \times 100 \quad \text{(X4.1)}$$

where:

L_o = initial length of specimen, and
L_f = final length of specimen.

Calculate the average contraction of all specimens tested to the nearest 0.1 %.

X4.2.6 *Report*—State that the specimens were tested as directed in X4.2 of Test Methods D 885M and report the average contraction of all specimens as the contraction of the wet sample together with the number of specimens tested.

X5. BIBLIOGRAPHY OF TIRE CORD TEST METHODS

NOTE—The Bibliography of Tire Cord Test Methods covers the following journals: (*1*) Journal of Applied Polymer Science, January 1959–August 1970, (*2*) Journal of Polymer Science, January 1950–December 1963, General Papers, January 1963–December 1965, Polymer Physics Part A-2, January 1965–September 1970, Polymer Symposia Part C, January 1963–August 1970, (*3*) Journal of the Textile Institute Transactions, January 1950–August 1970, (*4*) Textile Research Journal, January 1950–September 1970, and (*5*) Other journals at random.

X5.1 Adhesion

Eccher, S., and Canevari, C., "Improvement of the Testing Method for Adhesion of Vulcanized Rubber to Steel Wire Cords," *D.K.G. Rubber Conference*, 1968.

Iyengar, "Factors in Rubber Tire Cord Adhesion," *Rubber World*, RUBWA, 1963, pp. 39–42.

Kenyon, D., "Laboratory Assessments of Fatigue Resistance and Dynamic Adhesion of Tyre Cords," *Proceedings of the Institution of Rubber Industry*, PIRIA, Vol 11, No. 3, 1964, pp. 67–93.

Kenyon, D., "Laboratory Assessment of Tyre Cord Adhesion," *Transactions of the Institution of Rubber Industry*, TIRIA, Vol 38, No. 4, 1964, T1650179.

Takeyama, J., and Matsui, J., "Recent Developments with Tire Cords & Cord to Rubber Bonding," *Rubber, Chemistry, and Technology*, RCTEA, Vol 42, No. 1, 1969, pp. 159–256.

Tsydzik, M. A., Lukomskaya, A. I., and Slonimskii, G. L., "Dynamic Methods for Determination of Bond Strength Between Rubbers & Between Rubber & Cord," *Rubber, Chemistry, and Technology*, RCTEA, Vol 33, 1960, pp. 42–50.

"U-Adhesion Test Fixture," *Rubber Age*, RUAGA, Vol 91, No. 4, 1962, p. 676.

Wijngaarden, J. K., Van, "The Performance of Cord-in-Rubber Tests and the Treatment of the Test Results," *D.K.G. Rubber Conference*, 1960.

X5.2 Birefringence

Heyn, A. N. J., "Observations of the Birefringence and Refractive Index of Synthetic Fibers with Special Reference to their Identification," *Textile Research Journal*, TRJOA, Vol 22, 1952, pp. 513–522.

Sakajiri, S., "The Transition of Polyethylene Terephthalate Fiber Birefringence," *Journal of Polymer Science*, Vol 35, No. 129, 1959, pp. 543–546.

X5.3 Breaking Time

"*Hot Load Test*," Test Procedure FD9-1, The Goodyear Tire & Rubber Co., Akron, OH 1964.

Warburton, F. L., James, J. F. P., and Hother-Lushington, "Some Visco-Elastic Properties of Nylon," *British Journal of Applied Physics*, BJAPA, Vol 12, 1961, p. 230.

X5.4 Compression Testing

Bhakuni, R. S., Gingo, J. M., and Causa, A. G., *Tire Fiber Rheology*, The Goodyear Tire & Rubber Company, Akron, OH, 1970.

Bobeth, W., "Automatic Textile Testing by Electronic Data Scanning and Evaluation by an Axial Pressure Tester," *Fasserforschung Und Textiltechnik*, FSTXA, Vol 21, No. 11, 1970, pp. 453–459.

Friedemann, W., "Simple Method for Measuring the Stress in Compressed Cord Yarns," *Faserforschung Und Textiltechnik*, FSTXA, Vol 9, No. 8, 1958, pp. 334–337.

Wolf, B. M., and Armstrong, R. R., *Testing Cord Fabric*, Firestone Tire & Rubber Co., U.S.P. 1954, 2665582.

X5.5 Contact-Angle

Grindstaff, T. H., "A Simple Apparatus and Technique for Contact Angle Measurements on Small-Denier Single Fibers" *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 958–62.

X5.6 Creep

Howard, W. H., and Williams, M. L., "The Viscoelastic Properties of Oriented Nylon 66 Fibers," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 689–698.

X5.7 Crimp

Brand, R. H., and Kende, P., "Measurement of Three-Dimensional Fiber Crimp," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 169–177.

X5.8 Crystallinity

Bosley, D. E., "X-Ray Determination of Crystallinity in Poly (Ethylene Terephthalate)," *Journal of Applied Polymer Science*, JAPNA, Vol 8, 1964, pp. 1521–1529.

Hobbs, S. Y., and Mankin, G. I., "Determination of Polymer Crystallinities from Thermal Measurements," *Journal of Polymer Science*, Part A-2, No. 9, 1971, pp. 1907–1910.

Miller, R. G., and Willis, H. A., "An Independent Measurement of the Amorphous Content of Polymers," *Journal of Polymer Science*, Vol 19, 1956, pp. 485–494.

X5.9 Cut Resistance

Settle, G. E., and Anderson, S. L., "Resistance to Rupture of Single Fibers Under Transverse Pressure," *Journal of The Textile Institute Transactions*, JTITA, Vol 54, T28, 1963.

X5.10 Denier

Bloch, M. G., and Gusack, J. A., "Denier Distribution of Textile Fibers Obtained with an Electrical Sensing Zone Particle Analyzer (Coulter Counter)," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 224–233.

X5.11 Differential Thermal Analysis

Keavney, J. J., and Eberlin, E. C., "The Determination of Glass Transition Temperatures by Differential Thermal Analysis," *Journal of Applied Polymer Science*, JAPNA, Vol 3, No. 7, 1960, pp. 47–53.

Schwenker, R. F., Jr., and Zuccarello, R. K., "Differential Thermal Analysis of Synthetic Fibers," *Journal of Polymer Science*, Part C, No. 6, 1964, pp. 1–16.

Strella, S., "Differential Thermal Analysis of Polymers," *Journal of Applied Polymer Science*, JAPNA, Vol 7, 1963, pp. 569–579.

X5.12 Dip Pickup

Todd, H. E., and Tramutt, H. M., "Flame Photometric Determination of Rubber Solids Deposited on Cords & Fabrics," *Rubber Age*, RUAGA, New York, Vol 73, 1953, pp. 501.

X5.13 Dynamic Modulus

Ballow, J. W., and Smith, J. C., "Dynamic Measurements of Polymer Physical Properties," *Journal of Applied Physics*, JAPIA, Vol 20, 1949, pp. 493–502.

Chaikin, M., and Chamberlain, N. H., "The Propagation of Longitudinal Stress Pulses in Textile Fibers-Part I," *Journal of the Textile Institute Transactions*, JTITA, Vol 46, 1955, T25–43.

Dunell, B. A., and Dillon, J. H., "The Measurement of Dynamic Modulus & Energy Losses in Single Textile Filaments Subjected to Forced Longitudinal Vibrations," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 393–403.

Hamburger, W. J., "Mechanics of Elastic Performance of Textile Materials," *Textile Research Journal*, TRJOA, Vol 18, 1948, pp. 705–743.

Kainradl, P., and Handler, F., "Dynamic Testing Methods for Tyre Cord," *Faserforschung Und Textiltechnik*, FSTXA, Vol 11, No. 9, 1960, pp. 408–427.

Lyons, W. J., and Prettyman, I. B., "Measurement of the Dynamic Stretch-Modulus and Hysteresis of Tire Cords," *British Journal of Applied Physics*, BJAPA, Vol 18, 1947, pp. 586–587.

Lyons, W. J., and Prettyman, I. B., "Method for the Absolute Measurement of Dynamic Properties of Linear Structures at Sonic Frequencies," *Journal of Applied Physics*, Vol 19, 1948, pp. 473–480.

Meredith, R., and Hsu, B. S., "Dynamic Bending Properties of Fibers: Effect of Temperature on Nylon 66, Terylene, Orlon, & Viscose Rayon," *Journal of Polymer Science*, Vol 61, 1962, pp. 271–292.

Mieck, et al, "Static and Dynamic Cord Tests," *Faserforschung and Textiltechnik*, FSTXA, Vol 13, (11), 1962, pp. 502–511.

Palandri, G., "Measurement of Hysteresis and Dynamic Elastic Modulus of Textile Yarns and Cords," *Rubber Age*, 64, 1948, pp. 45–52.

Sakurada, I., Nukushina, Y., and Ito, T., "Experimental Determination of the Elastic Modulus of Crystalline Regions in Oriented Polymers," *Journal of Polymer Science*, Vol 57, 1962, pp. 651–660.

Smith, H. D., and Jenkins, R. C., "Cord Modulus: New Cord Extension System," *Rubber Age*, RUAGA, 95, No. 4, 1964, p. 575. *Rubber World*, RUBWA, Vol 95, No. 4, 1964, p. 90.

Tipton, H., "The Dynamic Tensile Mechanical Properties of Textile Filaments and Yarns," *Journal of the Textile Institute Transactions*, Vol 46, 1955, pp. T322–361.

Tokita, N., "The Effects of Crystallization and Drawing on the Viscoelastic Properties of Fibers," *Journal of Polymer Science*, Vol 20, 1956, pp. 515–536.

Van der Meer, S. J., "Dynamic Measurement on Textile Yarns, Industrial Yarns and Tire Cords," AKU Research Report No. R1209, 1965, AKU, Arnhem, Netherlands.

"Modulus Tester," *Rubber World*, RUBWA, Vol 148, No. 2, 1963, p. 22.

X5.14 Elastic Recovery

Hearle, J. W. S., and Plonsker, H. R., "Behavior of Fibers in Cumulative Extension Cycling," *Journal of Applied Polymer Science*, Vol 10, 1966, pp. 1949–1971.

X5.15 Elongation

Breazeale, F. B., and Irvin, H. D., "An Automatic Yarn Load-Elongation Recorder," *Textile Research Journal*, TRJOA, Vol 22, 1952, pp. 549–552.

Meredith, R., "The Effect of Rate of Extension on the Tensile Behavior of Viscose and Acetate Rayons, Silk and Nylon," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T30–43.

Orr, R. S., and Grant, J. N., "A Single-Fiber Load-Elongation Tester for Cotton," *Textile Research Journal*, TRJOA, Vol 23, 1953, pp. 505–509.

Wood, J. O., and Kilby, W. F., "An Apparatus for the Measurement of the Delayed Elongation of Tyre Cords," *Journal of the Textile Institute Transactions*, JTITA, Vol 49, 1958, pp. T89–94.

X5.16 Fatigue

Bartha, Z., "Evaluating Tyre Cords," *Man-Made Textiles*, MMTXA, Vol 38, May 1961, p. 57.

Bartha, Z., "Fatigue Testing of Tyre Cord Yarns in Rubber," *Muanyag*, MUANA, Vol 1, No. 7, 1964, pp. 212–215.

Bartha, Z., "Tyre Cord Fatigue Tests," *Rev. Gen. Caout. Plast.*, Vol 44, No. 10, 1967, pp. 1205–1212.

Buchan, J., "Fatigue Testing of Tyre Cords in Rubber," *Textile Weekly*, TEWEA, Vol 58, 1958, pp. 315–316.

Budd, C. B., "A Fatigue Test for Tire Cord," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 174–179.

Dischka, G., and Hajmasy, T., "Fatigue Tests on Tyre Cords," *Acta Technica*, Vol 38, 1962, pp. 235–257.

Falch, W., "Dynamic Fatigue Tests on Tyre Cord in Combination with Rubber," *DKG Rubber Conference*, 1956.
Floyd, K. L., "The Behavior of Rayon Tyre Cords Under Compressive Flexing," *Journal of the Textile Institute Transactions*, JTITA, Vol 53, No. 10, 1962, pp. T 449–663.
Forster, M. J., and Prettyman, I. D., "New Improved Tyre Cord Fatigue Tester," *Rubber, Chemistry, and Technology*, RUAGA, Vol 42, No. 4, 1969, pp. 1000–1008.
Frank, F., and Singleton, R. W., "A Study of Factors Influencing the Tensile Fatigue Behavior of Yarns," *Textile Research Journal*, Vol 34, 1964, pp. 11–19.
Gibson, E. C., "Tyre Cord Testing Machine," American Viscose Corp., U. S. Patent 2916912, 1959.
Hannell, J. W., "Tire Testing," *ASME Publications*, 59-SA-48, New York 1959.
Hofferberth, W., "Static and Dynamic Testing of Textiles and Its Practical Importance," *DKG Rubber Conference*, 1954.
Kemmnitz, "A Study of the Compression Fatigue and the Damping Phenomena of Tire Cord," *Journal of Applied Polymer Science*, TAPNA, Vol 32, 1962, pp. 373–392.
Kenyon, D., "Laboratory Assessments of Fatigue & Dynamic Adhesion of Tyre Cords," Proc. I.R.I., Vol 11, No. 3, 1964, pp. 67–93.
Kenyon, D., "Tyre Cord Fatigue Testers," *British Nylon Spinners Outlook*, No. 13, 1964.
Lincoln, B., "Flexural Fatigue and Visco-Elastic Properties of Wool Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 43, 1952, pp. T 158–172.
Lockwood, P. A., Edmunds, W. M., and Grimm, G. W., "Fatigue Performance of Tire Belt Cords," *Rubber, Chemistry, and Technology*, RCTEA, Vol 44, No. 4, 1971, pp. 946–951.
Lyons, W. J., "Fatigue in Textile Fibers, Part I," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 448–459.
Lyons, W. J., "Fatigue in Textile Fibers, Part III," *Textile Research Journal*, TRJOA, 1962, pp. 750–761.
Lyons, W. J., "Fatigue in Textile Fibers, Part IX," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 1106–1109.
Lyons, W. J., "Fatigue in Textile Fibers, Part XI," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 60–68.
Lyons, W. J., "Fatigue in Textile Fibers, Part XII," *Textile Research Journal*, TRJOA, Vol 20, 1970, pp. 836–843.
Mieck, K. P., "Testing the Fatigue Behavior of Tyre Cord Vulcanized into Rubber," *Faserforschung Und Textiltechnik*, FSTXA, Vol 10, No. 12, 1959, pp. 578–587.
Ono, et al, "On the Fatigue Mechanism of Tire Cord," *Journal of the Society of Textile and Cellulose Industries of Japan*, SENGA, Vol 18, 1962, pp. 955–962.
Prevorsek, D. C., and Lyons, W. J., "Endurance of Polymeric Fibers in Cyclic Tension," *Rubber, Chemistry, and Technology*, RCTEA, Vol 44, No. 1, 1971, pp. 271–293.
Rhodes, T. J., "Apparatus for Testing Cord Fatigue," *U. S. Rubber Co.*, U.S. Patent 2612040, 1952.
Shirakashi, K., and Ishikawa, K., "Study on Tyre Cords," *Journal of the Society of Textile and Cellulose Industries of Japan*, SENGIA, Vol 12, 1956, pp. 392–397.
Stroenov, U. B., Denisenko, N. V., and Nemchenko, E. A., "Determination of the Fatigue Properties of (Tire) Cord Subjected to Repeated Deformation of Modernized Apparatus of the 5-24-1-Tyre," *Khim. Volok.*, No. 6, 1962, pp. 31–34.
Wegener, W., "Apparatus for Testing Dynamic Fatigue with Superimposed Alternating Load," *Melliand Textilberichte*, MTEEA, Vol 35, 1954, pp. 371–374.
Wegener, W., "Fatigue Testing Devices for Yarns and Fabrics," *Melliand Textilberichte*, MTEEA, Vol 39, No. 1, 1958, pp. 17–21.
Wilson, N. W., "Tire-Cord Compression Fatigue," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 47–54.
"Apparatus for Testing the Flexing Fatigue of Tyre Cords," Japanese Patent 5398159.
"B. F. Goodrich Disc. Compression Cord Tester," *Rubber Age*, RUAGA, Vol 78, 1955, p. 299.
"Fatigue Tester for Cord," *Rubber Age*, RUAGA, Vol 102, No. 5, 1970, pp. 125–128.
"Tire Cord Tester," *Rubber World*, RUBWA, Vol 144, No. 5, 1961, p. 62; *Rubber Age*, RUAGA, Vol 90, No. 1, 1961, p. 154.

X5.17 Flatspotting

Claxton, W. E., Forster, M. J., Robertson, J. J., and Thurman, G. R., "Correlation of Nylon Tire Cord Properties with Tire Flatspotting," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 903–914.
Jonson, C. A., "Apparatus for Measuring Elastic Properties," U.S. Patent 3,062,044, 1962.
Oswald, H. J., Papero, P. V., and Wincklhofer, R. C., "The Mechanism of Flatspotting and Its Relation to Fiber Properties," *Rubber, Chemistry, and Technology*, RCTEA, Vol 38, No. 4, November 1965.
Rye, G. W., and Martin, J. E., "Lab Test to Predict Flatspotting Behavior of Tyre Cord," *Rubber World*, Vol 148, No. 1, 1963, p. 76.

X5.18 Friction

Grosberg, P., and Plate, D. E. A., "Capstan Friction for Polymer Monofilaments with Rigidity," *Journal of the Textile Institute Transactions*, JTITA, Vol 60, 1969, pp. 268–283.
Guthrie, J. C., and Oliver, P. H., "Inter-Fiber Friction of Viscose Rayon," *Journal of the Textile Institute Transactions*, JTITA, Vol 43, pp. T579–94.
Hadley, D. W., "The Resistance to Abrasion Against Fine India Stone of Single Filaments of Polyethylene Terephthalate and Polypropylene," *Journal of the Textile Institute Transactions*, JTITA, Vol 54, 1963, pp. T-409–419.
Howell, H. G., "Inter-Fiber Friction," *Journal of the Textile Institute Transactions*, JTITA, Vol 42, 1951, pp. T521–333.
King, G., "Some Frictional Properties of Wool and Nylon Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 41, 1950, pp. T135–144.
Lyons, W. J., and Scheier, S. C., "Measurement of the Surface Friction of Fibers by an Electro-Mechanical Method," *Textile Research Journal*, Vol 35, 1965, pp. 385–394.
Olsen, J. S., "Frictional Behavior of Textile Yarns," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 31–37.

Schlatter, C., and Demas, H. J., "Friction Studies on Caprolan Filament Yarn," *Textile Research Journal*, TRJOA, Vol 32, 1962, p. 8798.
Susich, G., "Abrasion Damage of Textile Fibers," *Textile Research Journal*, TRJOA, Vol 24, 1954, pp. 210–228.

X5.19 Gage

VanGijzen, A., "Tyre Cord Gauge Measurement," *Rayon Revue*, RYSIA, Vol 10, No. 5, 1956, pp. 189–192.
VanIssum, B. E., and Chamberlain, N. H., "The Free Diameter and Specific Volume of Textile Yarns," *Journal of the Textile Institute Transactions*, JTITA, Vol 50, 1959, p. T599.

X5.20 Hardness

Chakravarty, A. C., "Measurement of Hardness of Textile Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T723–729.

X5.21 Hysteresis

Wakeham, H., and Honold, E., "Mechanical Hysteresis Properties of Single Fibers & Cords," *Textile Research Journal*, TRJOA, Vol 21, 1951, pp. 1–5.

X5.22 Impact Resistance

Ballou, J. W., and Roetling, J. A., "High Speed Tensile Testing of Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 631–646.
Cross, M. M., and Garrett, D. A., "High-Speed Fibre Extensometer," *Journal of the Textile Institute Transactions*, JTITA, Vol 47, 1956, pp. T222–231.
Dickson, J.B., and Davieau, L. A., "Impact Tester for Textiles," *ASTM Bulletin*, No. 198, 1954, p. 85.
Hall, I. H., "The Tensile Properties of Textile Yarns at Very High Strain Rates," *Journal of Applied Polymer Science*, JAPNA, Vol 8, 1964, pp. 237–256.
Hamburger, W. J., "Time Effects on Textile Fibers," *SPE Trans.*, 1964, p. 208.
Holden, G., "Tensile Properties of Textile Fibers at Very High Rates of Extension," *Transactions*, JTITA, Vol 50, 1959, pp. T41–54.
Jameson, J. W., Stewart, G. M., Petterson, D. R., and Odell, F. A., "Dynamic Distribution of Strain in Textile Materials Under High-Speed Impact Part III," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 858–860.
Kerawalla, J. N., "Role of Cord Properties in Tire Impact Resistance," *Materials Research and Standards*, MTRSA, Vol 10, No. 6, June 1970, pp. 15–19.
Lang, W. R., "Ballistic Determination of Work of Rupture of Short Textile Samples," *Journal of the Textile Institute Transactions*, Vol 42, 1951, pp. T314–328.
Lothrop, E. W., "Tensile Properties of Yarns and Cords at High Rates of Extension," FMC Corp., American Vicose Division, 1965.
Lothrop, E. W., "Stress-Strain Properties of Tire Cords as a Function of Temperature and Rate of Extension," *Applied Polymer Symposia*, APPSA, Vol 1, 1965, pp. 111–124.
Lyons, W. J., "Impact Phenomena in Textiles," 1963, M.I.T. Press, Cambridge, MA, pp. 21–71.
Lyons, W. J., and Prettyman, I. B., "Use of the Ballistic Pendulum for Impact Testing of Tire Cord," *Textile Research Journal*, TRJOA, Vol 23, 1953, pp. 917–925.
Meredith, R., "The Effect of Rate of Extension on the Tensile Behavior of Viscose and Acetate Rayons, Silk, and Nylon," *Journal of the Textile Institute Transactions*, Vol 45, 1954, p. T30.
O'Neil, K. B., Dague, M. F., and Kimmel, J. E., "High Speed Tensile Testing of Tire Textiles," *Rubber, Chemistry, and Technology*, RCTEA, Vol 41, No. 4, 1968, pp. 1045–1050.
Parker, J. P., and Kemic, C. S., "A Flywheel Impact Test for Measuring Physical Properties of Tire Cords," *Journal of Applied Polymer Science*, JAPNA, Vol 6, No. 21, 1962, pp. 255–263.
Parker, J. P., and Kemic, C. S., "Impact Resistance of Rayon & Nylon Tire Cords," *Rubber World*, RUBWA, Vol 138, 1958, p. 116.
Parker, J. P., and Kemic, C. S. "Flywheel Impact Test for Measuring Physical Properties of Tire Cords," *High Speed Testing*, HSPT, Vol III, 1962, pp. 3–11.
Pavlov, N. N., Yaminskaya, E. Y., and Krymon, B. M., "Application of Strain Gages to the Study of (Tire) Cord at High Elongation Rates," *Rubber, Chemistry, and Technology*, RCTEA, Vol 32, 1959, pp. 907–914.
Petterson, D. R., Stewart, G. M., Odell, F. A., and Maheux, R. C., "Dynamic Distribution of Strain in Textile Materials Under High Speed Impact Part I," *Textile Research Journal*, TRJOA, Vol 30, 1960, pp. 411–421.
Pilsworth, M. N., Jr., "Tension Impact on Rubber and Nylon," Quarter-Mast Research and Engineering Center, Natick, MA, Technical Report, PR-3, 1962.
Pilsworth, M. N., and Hoge, H. J., "Rate of Dependent Response of Polymers to Tensile Impact," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 129–139.
Schiefer, H. F., Appel, W. D., Krasny, J. F., and Richey, G. C., "Impact Properties of Yarns Made From Different Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1953, p. 489.
Schulman, S., "Evaluation Techniques for Fibrous Materials," *Textile Research Journal*, Vol 36, 1966, pp. 673–81.
Selwood, A., "A Catapult Method for Extending Textile Filaments at High Rates," *Journal of the Textile Institute Transactions*, JTITA, 1964, pp. T146–153.
Skelton, J., "Tensile Behavior of Fibrous Materials at High Rates of Strain & Sub Ambient Temperatures," *Materials Research and Standards*, MTRSA, Vol 10, No. 6, 1970, pp. 20–25.
Smith, J. C., Fenstermaker, C. A., and Schouse, P. J., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading Part X," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 919–934.
Smith, J. C., Fenstermaker, C. A., and Schouse, P. J., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading Part XI," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 743–756.
Smith, J. G., McCrakin, F. L., Schiefer, H. F., Stone, W. K., and Towne, K. M., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading Part IV," *Textile Research Journal*, TRJOA, Vol 26, 1956, pp. 821–828.

Stone, W. K., Schiefer, H. F., and Fox, G., "Stress-Strain Relationships in Yarns Subjected to Rapid Impact Loading Part I," *Textile Research Journal*, TRJOA, Vol 25, 1955, pp. 520–528.

"High Speed Tensile Properties of Tire Cord," Teijin, Ltd., 1965.

"Tyrex Test Measures Tyre Strength," *Chemical and Engineering News*, CENEA Vol 44, No. 42, 1966, pp. 72–73.

X5.23 Infrared Analysis

Knight, J. A., Smoak, M. D., and Kirkland, W. E., "Direct Pressing of Fibers for Infrared Spectroscopic Studies," *Textile Research Journal*, Vol 37, 1967, pp. 924–927.

X5.24 Intrinsic Viscosity

Gramain, P. H., and Libeyre, R., "Automatic Recording Capillary Viscosimeter with Dilution," *Journal of Applied Polymer Science*, JAPNA, Vol 14, 1970, pp. 383–391.

X5.25 Moisture

Collins, J. B., "Producing Ripple-Free Direct Potential," US Patent 2849676.

Haase-Deyerling, et al, "New Dielectric Method for the Rapid Determination of the Moisture Content of Tire Cord," D.K.G. Rubber Conference, 1960.

Mess, E., and Mark, R. A., "Moisture Measuring Equipment," *Ind. Chem.*, Vol 38, No. 443, 1962, pp. 39–40.

X5.26 Orientation

Conrad, C. M., and Creely, J. J., "Apparatus for Use with the X-Ray Diffractometer to Determine the Degree of Crystallite Orientation in Fibers," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 863–866.

Farrow, G., and Bagley, Miss J., "The Measurement of Molecular Orientation in Polyethylene Terephthalate Filaments by X-Ray Diffraction," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 587–598.

X5.27 Reservoir

Jenkins, R. C., Meherg, J. W., and Linn, J. V., "The Cord Reservoir—A New Concept in the Mechanism of Tire Blows," The Goodyear Tire & Rubber Co., Akron, OH, 1963.

X5.28 Resilience

Hadley, D. W., "A Critical Comparison of Empirical Tests of the Extensional Resilience of Textile Fibers Part I," *Journal of the Textile Institute Transactions*, JTITA, Vol 60, 1969, pp. 301–311.

X5.29 Resonance Frequency

Hearle, J. W. S., and Turner, D. J., "A Preliminary Study of a Technique for Measuring Flexural Vibrations in Fabrics," *Textile Research Journal*, TRJOA, Vol 31, 1961, pp. 981–986.

X5.30 Solvation Resistance

"Solvation Resistance," Test Procedure FD14-1, The Goodyear Tire & Rubber Co., Akron, OH 1964.

"Tensilizing Tire Fabric of Golden Caprolan Nylon," Allied Chemical Corp., Fibers Division, Hopewell, 1963.

X5.31 Specific Heat

Haly, A. R., and Snaith, J. W., "The Specific Heat of Polyethylene Terephthalate (PET) and the Fusion of its Absorbed Water," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 906–911.

X5.32 Staining

"Staining-Tire Cords," Test Procedure FD15-1, The Goodyear Tire and Rubber Co., Akron, OH, 1964.

X5.33 Stiffness

Abbott, G. M., and Grosberg, P., "Measurement of Fabric Stiffness and Hysteresis in Bending," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 928–930.

Chen, C. S., and Zorowski, C. F., "Cantilever Bending Behavior of Continuous Filament Cords," *Textile Research Journal*, TRJOA, Vol 35, 1965, pp. 529–538.

Funsch, O. B., and Jenkins, R. C., "A New Technique for Measuring Tire Fabric Stiffness," The Goodyear Tire and Rubber Co., Akron, OH, 1965.

Kalkman, J. A., "Measuring the Flexural Rigidity of Woven Fabrics," *Enka and Breda Rayon Review*, EBREB, Vol 9, 1955, p. 9.

Livesay, R. G., and Owen, J. D., "Cloth Stiffness and Hysteresis in Bending," *Journal of the Textile Institute Transactions*, JTITA, Vol 55, 1964, p. T516.

Noser, S., "Apparatus for Measuring Bending Stress in Tyre Cords," *Textil*, TXTIA, Vol 13, No. 6, 1958, pp. 221–222.

Owen, J. D., "The Application of Searles Single and Double Pendulum Methods to Single Fiber Rigidity Measurements," *Journal of the Textile Institute Transactions*, JTITA, Vol 56, 1965, pp. T329–339.

Scott, G. V., and Robbins, C. R., "A Convenient Method for Measuring Fiber Stiffness," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 975–976.

Stuart, I. M., and Baird, K., "A New Test for Bending Length," *Textile Research Journal*, TRJOA, Vol 36, 1966, pp. 91–93.

X5.34 Stiffness (Dynamic Bending Modulus)

Wakayama, K., and Jinen, E., "An Automatic Vibroscope and How to Use It," *Journal of the Textile Machinery Society of Japan*, Vol 16, No. 2, 1970, pp. 59–67.

X5.35 Strain Recovery (Elastic Recovery)

Zurek, W., and Godon, J., "Strain Recovery of Twisted Viscose Rayon," *Textile Research Journal*, TRJOA, Vol 41, 1971, pp. 984–990.

X5.36 Stress Relaxation

Herwig, H. U., "The Influence of Stress Relaxation Interval on the Tensile Behavior of Industrial Yarns," *Textile Research Journal*, TRJOA, Vol 41, 1971, pp. 366–368.

Kuba, E. T., "The Stress Relaxation of Fibrous Materials I. Instrumentation and Preliminary Results," *Textile Research Journal*, TRJOA, Vol 22, 1952, p. 765.

Meredith, R., and Hsu, B., "Stress Relaxation in Nylon and Terylene: Influence of Strain, Temperature and Humidity," *Journal of Polymer Science*, Vol 61, 1962, p. 253.

X5.37 Tensile Strength

Brown, G. L., "Fabric Testing Machine, Inclined Plane Type," *Journal of the Textile Institute Transactions*, Vol 43, 1952, pp. T119–121.

Checkland, D. B., Bull, T. H., and Baker, E. J., "A Two-Dimensional Load-Extension Tester for Fabrics and Film," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 399–403.

Crane, R. A., and Wharff, P. C., Jr., "An Automatic Single Fiber Tensile Strength Tester," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 343–350.

Dent, R. W., and Hearle, J. W. S., "The Tensile Properties of Twisted Single Fibers," *Textile Research Journal*, TRJOA, Vol 30, 1960, pp. 805–826.

Frank, F. I., and Ruoff, A. L., "A Method of Measuring Poisson's Ratio of Fibers," *Textile Research Journal*, TRJOA, Vol 28, 1958, pp. 213–217.

Frenzel, W., and Kittelman, W., "Tyre Cord Testing," *Faserforschung Und Textiltechnik*, FSTXA, Vol 8, No. 6, 1957, pp. 223–230.

Illingworth, J. W., and Kilby, W. F., "The Reversible Effect of Temperature on the Mechanical Properties of Tire Yarns and Cords," *Textile Research Journal*, TRJOA, Vol 26, 1956, pp. 243–254.

Klein, W. G., "Stress-Strain Response of Fabrics Under Two-Dimensional Loading, Part I," *Textile Research Journal*, TRJOA, Vol 29, 1959, pp. 816–821.

Klust, "The Knot-Tensile Strength of Ply Yarns and Cords Made of Synthetic Fibers," *Textil Praxis*, TEPRA, Vol 17, No. 9, 1962, pp. 881–884.

Phillipson, "Tyre Cord Testing," *Skinner's Silk and Rayon Record*, SSRRA, 1959, pp. 970–994.

Preusser, H. M., O'Connell, R. A., Yeiser, A. S., and Lungren, H. P., "Single Fiber Stress-Strain Apparatus," *Textile Research Journal*, TRJOA, Vol 24, 1954, pp. 118–122.

"Cord Tensile Clamps," *Rubber World*, RUBWA, Vol 146, No. 3, 1962, p. 40, *Rubber Age*, RUAGA, Vol 92, No. 2, 1962, p. 315.

"Denison Tensile Test Machine," Dunlop-Rubber Co., Ltd., 1955.

"Scotomatic Model IP-4 Tester," *Textile, Mercury, and Argus*, TMARA, Vol 139, 1958, pp. 368–9.

X5.38 Thermal Conductivity

David, H. G., "A Simple Method of Measuring the Thermal Transmission of Fabrics," *Textile Research Journal*, Vol 33, 1963, p. 322.

X5.39 Thermal Shinkage

Coe, A. B., Prevorsek, D. C., and Tobolsky, A. V., "A Microscopical Method for the Study of Free Thermal Shrinkage in Oriented Polymers," *Textile Research Journal*, TRJOA, Vol 32, 1962, pp. 960–962.

Prevorsek, D., and Tobolsky, A. V., "Determination of Non-Flow Shrinkage Ratio in Oriented Fibers," *Textile Research Journal*, TRJOA, Vol 33, 1963, pp. 798–802.

Ribnick, A., "Thermal Shrinkage of Oriented Nylon 66 Yarns as a Function of Time, Temperature, and Stress," *Textile Research Journal*, TRJOA, Vol 39, 1969, pp. 428–434.

X5.40 Torsional Rigidity

Goodings, A. C., "A Method for the Measurement of the Rigidity of Fibers Immersed in Liquids: The Torsion Double Pendulum," *Textile Research Journal*, TRJOA, Vol 38, 1968, pp. 123–129.

Meredith, R., "The Torsional Rigidity of Textile Fibers," *Journal of the Textile Institute Transactions*, JTITA, Vol 45, 1954, pp. T489–503.

Middelburg, P. H., "A Method for the Measurement of the Rigidity of Fibers Immersed in Liquids," *Textile Research Journal*, TRJOA, Vol 38, 1968, p. 1138.

Nordon, P., "Rotational Vibroscope for the Comparison of the Torsional Properties of Thin Fibers," *Journal of Scientific Instruments*, JSINA, Vol 38, 1961, pp. 349–354.

Skelton, J., "The Measurement of the Torsional Elastic Recovery of Filaments," *Journal of the Textile Institute Transactions*, JTITA, Vol 56, 1965, pp. T443–453.

X5.41 Twist

Batcheler, F. D., "Automatic Measurement of Folding Twist on Two-Ply Yarn," *Journal of the Textile Institute Transactions*, JTITA, Vol 61, 1970, pp. 221–231.

Denisora, et al, "Improving the Properties of Viscose Cord in the Twisting Process," *Khimickeskie Volokna*, KATRA, No. 6, 1962, pp. 25–27.

Frenzel, W., "Determination of Twist & Untwisted Length of Tyre Cord," *Faserforschung Und Textiltechnik*, FSTXA, Vol 2, No. 12, 1951, pp. 481–483.

Treloar, Mather, "Twisted Structures," *Journal of the Textile Institute, Proceedings*, JITPA, 1964, pp. P13–26.

Uno, and Shiomi, "Continuous Twist Irregularity Tester," *Textile Research Journal*, TRJOA, 1957, pp. 818–824.

X5.42 Uniformity

Prins, I., "Determination of the Irregularity of Filament Yarns," *Enka and Breda Rayon Review*, EBREB, Vol 9, 1965, p. 1.

Uno, M., Saito, H., Shiomi, A., and Hiramatu, T., "Photoelectric Twist Irregularity Tester," *Textile Research Journal*, TRJOA, Vol 29, 1959, pp. 550–557.

"A Twist Irregularity Meter for Tire Cord," *Enka Breda Rayon Revue*, EBREB, Vol 9, No. 3, 1955, pp. 81–87.

X5.43 Wettability

Dyba, R. V., and Miller, B., "Dynamic Measurements of the Wetting of Single Filaments," *Textile Research Journal*, TRJOA, Vol 40, 1970, pp. 884–890.

X6. SI CALCULATION

X6.1 To explain the SI-units to be used preferably for breaking toughness, work-to-break, and specific-work to-break, the following example may be helpful:

X6.2 Using a linear load - elongation curve (for the simplicity of the calculations), let's suppose a specimen has the following properties:

	yarn	cord
Linear density, tex	100	400
Breaking load, N	80	320
Breaking tenacity, mN/tex	800	800
Breaking extension, %	10	30
Breaking extension, mm (based on 250-mm gage length)	25	75

X6.3 Calculate the three properties in X2.1 as follows:

X6.3.1 *Work-to-Break:*

for yarn: ½ × 80 N × 0.025 m = 1.00 N × m = 1.00 J

for cord: ½ × 320 N × 0.075 m = 12.0 N × m = 12.0 J

X6.3.2 *Specific-Work-to-Break* (work to break divided by the gage length):

for yarn: (1.00 J/0.25 m) = 4.00 J/m

for cord: (12.0 J/0.25 m) = 48.0 J/m

X6.3.3 *Toughness* (specific-work-to-break divided by the linear density):

for yarn: 4.00 J/m/100 tex = 4.00 J/m × 1000 m/100 g = 40 J/g

for cord: 48.0 J/m/400 tex = 48.0 J/m × 1000 m/400 g = 120 J/g

(1 tex = 1 g/1000 m = 1 g/1000 m)

X6.4 From this example, it is clear that the following units are preferred (see 3.20, 3.21, 26.2, and 27.2):

Work-to-break	J
Specific-work-to-break	J/m
Toughness	J/g

X6.5 To arrive at the specific units in X2.4, Eqs 13, 15, and 16 have been modified to:

$$\text{Work-to-break, J} = A \times F \times E \times 10^{-3} \quad (13)$$

$$\text{Breaking toughness, J/g} = 1000\,(A \times F \times E)/(L \times D) \quad (15)$$

$$= 1000\,W/D \quad (16)$$

The American Society for Testing and Materials takes no position respecting the validity of any patent rights asserted in connection with any item mentioned in this standard. Users of this standard are expressly advised that determination of the validity of any such patent rights, and the risk of infringement of such rights, are entirely their own responsibility.

This standard is subject to revision at any time by the responsible technical committee and must be reviewed every five years and if not revised, either reapproved or withdrawn. Your comments are invited either for revision of this standard or for additional standards and should be addressed to ASTM Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee, which you may attend. If you feel that your comments have not received a fair hearing you should make your views known to the ASTM Committee on Standards, 100 Barr Harbor Drive, West Conshohocken, PA 19428.

Designation: D 1059 – 97

Standard Test Method for Yarn Number Based on Short-Length Specimens[1]

This standard is issued under the fixed designation D 1059; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method covers the determination of the yarn number of all types of cotton, woolen, worsted, and man-made fiber yarns taken from packages; or from any textile fabrics in which the yarns are intact and can be removed in measurable lengths. The test method is not applicable to yarns taken from napped or cut pile fabrics. Because this method is based on short-length specimens, the results should only be considered as approximations of yarn number.

NOTE 1—For a more precise procedure for the determination of yarn number, refer to Test Method D 1907.

NOTE 2—The following additional methods for the determination of yarn number have been approved for yarns made from specific fibers: Specifications D 541, D 578, and D 681.

1.2 This test method is applicable to yarns which stretch less than 5 % when tension on yarn is increased from 0.25 to 0.75 cN/tex (0.25 to 0.75 gf/tex). By mutual agreement it may be adapted to yarns which stretch more than 5 % by use of tension lower than that specified in the method for elastomers or use of tension higher than that specified in the method to pull the crimp out of textured yarns.

1.3 The values stated in SI units are to be regarded as standard; the values in inch-pound units are reported as information only.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 123 Terminology Relating to Textiles[2]
D 541 Specification for Single Jute Yarn[3]
D 578 Specification for Glass Fiber Strands[2]
D 629 Test Methods for Quantitative Analysis of Textiles[2]
D 681 Specification for Jute Rove and Plied Yarn for Electrical and Packing Purposes[2]
D 1423 Test Method for Twist in Yarns by the Direct-Counting Method[2]
D 1776 Practice for Conditioning Textiles for Testing[2]
D 1907 Test Method for Yarn Number by the Skein Method[2]
D 2258 Practice for Sampling Yarn for Testing[2]

3. Terminology

3.1 *Definitions:*

3.1.1 *cotton count, n*—an indirect yarn numbering system generally in the cotton system equal to the number of 840-yd lengths of yarn per pound.

3.1.2 *cut, n—in asbestos and glass yarns,* the number of 100-yd lengths of yarn per pound; an indirect yarn numbering system.

3.1.3 *cut, n—in wool yarns,* the number of 300 yd lengths of yarn per pound; an indirect yarn numbering system.

3.1.4 *denier, n*—a unit of linear density, equal to the mass in grams per 9000 m of fiber yarn, or other textile strand that is used in direct yarn numbering system. (See also *linear density.*)

3.1.5 *direct yarn numbering system, n*—a system that expresses yarn linear density (number). (See also *denier, spyndle number,* and *tex.*)

3.1.6 *grex, n*—an obsolete direct numbering system for fiber yarn, or other textile strand equal to the mass in grams per 10 000 m. (See also *linear density.*)

3.1.7 *indirect yarn numbering system, n*—a system that expresses yarn as the reciprocal linear density (number). (See also *cotton count, metric count, worsted count, cut,* and *run.*)

3.1.8 *lea, n—in cotton yarns,* the number of 120-yd lengths of yarn per pound; an indirect yarn numbering system.

3.1.9 *lea, n—in linen yarns,* the number of 300-yd lengths of yarn per pound; an indirect yarn numbering system.

3.1.10 *linear density, n*—mass per unit length.

3.1.11 *metric count, n*—an indirect yarn numbering system for sliver roving, and yarn, equal to the number of 1000 m per kilogram.

3.1.12 *run, n—in the American woolen system,* the number of 1600-yd lengths of yarn per pound; an indirect yarn numbering system generally used for yarns spun on the woolen system.

3.1.13 *tex, n*—the unit of linear density, equal to the mass in grams of 1000 metres of fiber, or other textile strand that is used in a direct yarn numbering system. (See also *linear density and direct yarn numbering system.*)

3.1.14 *typp, n*—an obsolete indirect yarn numbering system equal to the number of 1000-yd lengths per pound.

3.1.15 *worsted count, n*—an indirect yarn numbering system in the worsted system equal to the number of 560-yd lengths per pound.

3.1.16 *yarn number, n*—the value, actual or nominal, of a yarn in a specific yarn numbering system.

[1] This test method is under the jurisdiction of ASTM Committee D-13 on Textiles and is the direct responsibility of Subcommittee D13.58 on Yarn Test Methods, General.

Current edition approved March 10, 1997. Published August 1997. Originally published as D 1059 – 49 T. Last previous edition D 1059 – 96.

[2] *Annual Book of ASTM Standards,* Vol 07.01.

[3] Discontinued; see *1996 Annual Book of ASTM Standards,* Vol 07.01.

Hyosung Ex. 1033, Page 31 of 31