



# Standard Test Method for Hot Air Thermal Shrinkage of Yarn and Cord Using a Thermal Shrinkage Oven<sup>1</sup>

This standard is issued under the fixed designation D 4974; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

## 1. Scope

1.1 This test method covers the measurement of shrinkage of yarns and cords when exposed in a thermal shrinkage oven.

1.2 This test method is applicable to yarns and cords made of nylon, polyester, and other polymers not detrimentally affected by the temperature used and with linear densities in the range from 20 to 700 tex (180 to 6300 denier).

1.2.1 Yarns or cords for testing may be taken from yarn or cord packages or from fabrics.

1.3 This test method shows values in both SI and inch-pound units. SI is the technically correct name for the system of units known as the International System of Units. Inch-pound units is the technically correct name for the customary units used in the United States. The values stated in either acceptable metric units or other units shall be regarded separately as standard. The values expressed in each system may not be exact equivalents; therefore, each system must be used independently of each other, without combining values in any way. Referee decisions are to use SI units.

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.* Specific hazard statements are given in Section 8.

## 2. Referenced Documents

### 2.1 ASTM Standards:

D 123 Terminology Relating to Textiles<sup>2</sup>

D 885 Methods of Testing Tire Cords, Tire Cord Fabrics, and Industrial Filament Yarns Made from Manufactured Organic-Base Fibers<sup>2</sup>

D 1776 Conditioning Textiles for Testing<sup>2</sup>

## 3. Terminology

### 3.1 Definitions of Terms Specific to This Standard:

3.1.1 *greige cord, n*—in tire cords, a cord that has been adhesive-treated, heat-treated, or otherwise treated before use (see *cord*).

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee D-13 on Textiles and is the direct responsibility of Subcommittee D13.19 on Tire Cord and Fabrics. Current edition approved Nov. 10, 1999. Published January 2000.

<sup>2</sup> *Annual Book of ASTM Standards*, Vol 07.01.

3.1.2 *standard atmosphere for testing textiles, n*—laboratory conditions for testing fibers, yarns, and fabrics in which air temperature and relative humidity are maintained at specific levels with established tolerances.

3.1.2.1 *Discussion*—for tire cord and yarns, a relative humidity of  $55 \pm 2\%$  and at a temperature of  $24 \pm 1^\circ\text{C}$  ( $75 \pm 2^\circ\text{F}$ ).

3.1.3 *thermal shrinkage, n*—of textile yarns and cords, contraction in length caused by heat.

3.1.4 *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.

3.1.4.1 *Discussion*—The direction of twist used to combine the single or plied yarn elements into a cord construction is in the direction opposite to that used in the yarns. Frequently, tire and other reinforcing cords consist of a single yarn strand having little or no twist. These cords are used synonymously with twisted and plied cords in this test method.

3.1.5 *yarn, n*—a generic term for a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric.

3.2 *Definitions*—For the definitions of other textile terms used in this test method, refer to Terminology D 123.

## 4. Summary of Test Method

4.1 A relaxed, conditioned specimen of yarn or cord is subjected to dry heat for a specified time while under a specified tension. The percent shrinkage is read directly from a scale or display on the instrument while the specimen is still under tension and exposed to heat.

## 5. Significance and Use

5.1 This test method may be used for the acceptance testing of commercial shipments of yarns and cords. Caution is advised because yarn and cord may contract in length over a period of time due to room temperature retraction. Thermal shrinkage values are reduced proportionately by the amount of room temperature retraction.

NOTE 1—Experience, especially with nylon, shows that yarn retraction, which may be observed directly as shortening of length (or indirectly as denier increase), will occur in unrestrained yarn or cord that is not at equilibrium (equilibrium in this case being defined as essentially zero thermal shrinkage yarn or fully relaxed yarn). Normally, retractive forces

are present in most wound packages of yarn and cord; thus, unrestrained yarn near the surface is likely, with time, to undergo some retraction. After retraction, such yarns exhibit lower thermal shrinkage values than yarn or cord deeper within the package. The opposite condition of yarn on the surface exists with yarn or cord wound against or near a rigid package core, such as a metal or hardwood wind-up spool. Such core yarn or cord cannot move against this restraint, and thus, will exhibit thermal shrinkage values even several weeks later near to those which were measured immediately from the surface of the freshly wound package. Elevated humidity will accelerate retraction of unrestrained yarn, but moisture content in itself will have little influence on thermal shrinkage. Exposure of untensioned skeins of yarn or cord to 95 to 100 % relative humidity at room temperature for two days and reconditioning under standard laboratory conditions will cause most of the room temperature retraction that is possible within a sample to occur.

5.1.1 In case of differences of practical significance in reported test results from two or more laboratories conduct comparative tests to determine if there is a statistical bias between them. Competent statistical assistance is recommended for the investigation of bias. As a minimum, the 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 then should be assigned randomly in equal numbers to each laboratory for testing. The average results from the two laboratories should be compared using Student's *t*-test for unpaired data and a probability level chosen by the parties before the testing is begun. If a bias is found, either its cause must be found and corrected, or future test results must be adjusted in consideration of the known bias.

5.2 Thermal shrinkage of nylon, polyester, and other fibers is related to the polymer of origin and its manipulation in processing. Thermal shrinkage measurement can be used to control product uniformity.

5.3 The level of thermal shrinkage is critical in the user's subsequent operations. For example it can affect the drumset (original length of cord) required in tire building to produce a finished, final tire of a particular size.

5.4 Thermal shrinkage is critical to final shape and size of fiber reinforced articles. For example, thermal shrinkage affects final size of V-belts and their ability to maintain tension while running.

5.5 This test method is similar to the procedures of Methods D 885 for the determination of thermal shrinkage of yarns and cords. Shrinkage is measured while the specimen is within an oven and tensioned as specified in Methods D 885; however, there are enough vagaries among different units of apparatus for measurement of thermal shrinkage that numerical equivalence between units of different design should not be assumed, even under the same nominal conditions.

## 6. Interferences

6.1 An effective draft shield on the thermal oven is critical. Because the chamber in which the specimen is heated is open on three sides, air drafts can effectively shorten the length of specimen experiencing the prescribed temperature environment. Results obtained without a shield generally are lower than with a shield.

6.2 The accurate control of temperature at any prescribed setting is of utmost importance. Bias between the set point temperature and the temperature that the specimen sees is a major cause of instrument bias. The temperature that the

specimen sees may be checked by attaching a small calibrated thermocouple to a piece of cord and suspending it in the specimen position such that the tip of the thermocouple is in the center of the oven cavity. The thermocouple must not touch the oven walls. Either correct any set point/sample temperature bias or determine the proper set point to give the specified specimen temperature.

6.3 The degree of room temperature length retraction, (for example, that which occurs in unrestrained skeins of yarn over time in the testing laboratory), of the laboratory sample or specimen affects the measurement of thermal shrinkage. Unrelaxed nylon, for example, shrinks much more than relaxed nylon. The amount of relaxation (retraction) occurring prior to testing of thermal shrinkage can affect the result.

6.4 Frictional forces against the pulley/indicator assembly cause measurement errors. Ensure that the indicator needle does not rub against the scale. Maintain the pulley bearings in good condition. The pulley wheel must be centered in the bearings. A force of 10 mN or less, applied to the tip of the indicator needle, should cause pulley rotation when the tester is in proper operating condition.

6.5 Thermal shrinkage increases as the exposure time increases. Check the exposure time with a stopwatch. Some thermal oven models have a timer installed. Compare this timer to a stopwatch and calibrate as necessary.

6.6 Center the threadline between the heating plates of the oven to obtain a correct measurement.

6.7 Specimens that are spun, textured, or crimped (as those removed from a fabric) may allow filaments to come in contact with interior surfaces of the thermal shrinkage oven. Such physical contact will cause inaccurate readings of thermal shrinkage.

6.8 Yarn or cords that are sufficiently sticky or tacky to prevent their free release from the pulley surface as it rotates will cause inaccurate readings of thermal shrinkage.

## 7. Apparatus

7.1 *Thermal Shrinkage Oven*<sup>3</sup>, consisting of a specimen heating cavity capable of heating up to 250°C (480°F), a means of accurately controlling the temperature of the cavity  $\pm 2^\circ\text{C}$  ( $\pm 4^\circ\text{F}$ ), and a means for measuring and displaying the amount of specimen shrinkage to the nearest 0.1 %. Fig. 1 shows the principle of operation of commercial thermal shrinkage ovens.

7.2 *Stopwatch or Timer.*

7.3 *Clip-On Masses.*

7.4 *Draft Shield*, if the oven does not have one provided.

## 8. Safety Hazards

8.1 The oven portion of the tester can reach temperatures over 200°C (390°F). Do not touch the oven.

8.2 Do not leave oven unattended if a specimen is installed.

## 9. Sampling and Test Specimens

9.1 *Primary Sampling Unit*—Consider shipping containers of cords or rolls of fabric to be the primary sampling unit, as applicable.

<sup>3</sup> Commercial thermal shrinkage ovens are available. Clip-on masses also are available from the manufacturer.

Operating Principle of Hot Air Shrinkage Tester

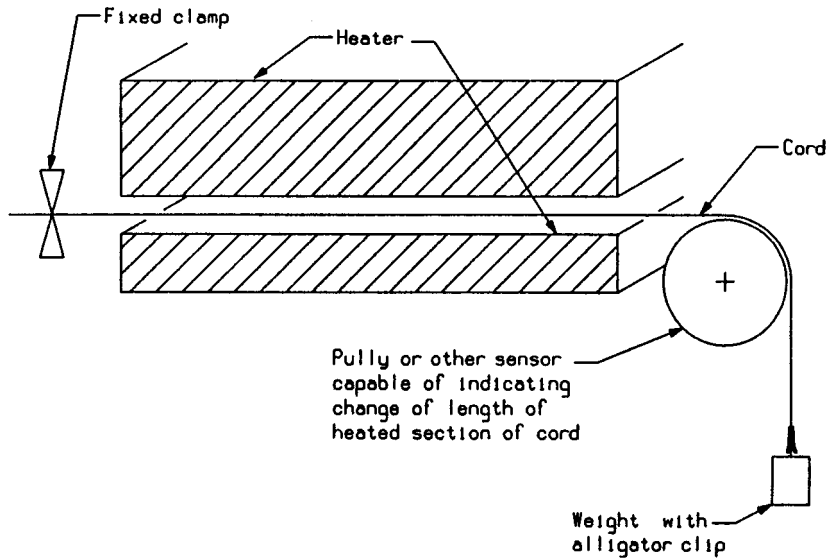


FIG. 1 Principle of Operation of a Thermal Shrinkage Oven

9.2 *Laboratory Sampling Unit*—As a laboratory sampling unit for acceptance testing, take material randomly from the primary sampling unit as follows:

9.2.1 For cords, take spools or packages per carton using the applicable procedure in Practice D 2258.

9.2.2 For fabric, take from rolls at least one full-width piece of fabric that is at least 1 m (1 yd) along the selvage (machine direction), after first discarding all fabric from the outside of the roll that contains creases, fold marks, disturbed weave, or contamination by foreign material.

9.3 *Test Specimens:*

9.3.1 For yarns and cords, strip at least 15 m (16 yd) from the outside of each package in the laboratory sampling unit. Inspect the outside of the package after stripping off the yarn. If there is visible damage, continue to strip off units of 15 m (16 yd) and reinspect until there is no visible damage. Take one specimen, 600 mm (24 in.) long, from each package in the laboratory sampling unit. Discard and replace specimens that are visibly damaged.

9.3.2 For fabrics, remove a minimum of three lengths of warp yarn or cord 600 mm (24 in.) long from each swatch in the laboratory sampling unit, with the specimens being taken at least 75 mm (3 in.) from the selvage of the swatch. For fabrics other than tire cord fabric, such as square-woven tire fabrics, also take from each swatch in the laboratory sampling unit a minimum of three lengths of filling yarn or cord 600 mm (24 in.) long after discarding those portions within 75 mm (3 in.) of the selvage of the swatch. In all cases, take warp specimens that are free of filling material and filling specimens that are free of warp material.

9.3.2.1 Instructions on the number of test specimens in 9.3.2 assume that a single valid thermal shrinkage result will adequately characterize the thermal shrinkage of the laboratory sampling unit from which the specimens are taken. The extra two specimens are taken to assure that a specimen free of handling damage is available after conditioning (see 10.1). If the applicable material specification or other agreement be-

tween the purchaser and the supplier specifies testing more than one specimen per laboratory sampling unit, an additional two specimens above the number to be tested should be taken from the laboratory sampling unit and conditioned.

10. *Conditioning Specimens and Preparation for Testing*

10.1 *Conditioning:*

10.1.1 Condition specimens as relaxed skeins or segments of untensioned fabric as directed in Practice D 1776 using the atmosphere specified for industrial yarns (see 3.1.2). Ensure that no change in yarn/cord twist occurs while carrying out this procedure.

10.1.2 Condition and relax yarn and greige cord specimens 12 to 28 h.

10.1.3 Condition and relax adhesive-treated cord samples 16 to 28 h, unless immediate testing (5 to 20 min after processing) is agreed upon between the buyer and the supplier. Immediate testing must be reported as an exception to this method (see Section 12).

10.2 *Preparation for Testing:*

10.2.1 With the draft shield in place, preheat the oven until the chamber has attained the specified temperature for a minimum of 5 min.

10.2.2 Test in standard atmosphere for testing industrial yarns (see 3.1.2).

10.2.3 Adjust the oven temperature controller set point to give a specimen temperature of  $177 \pm 2^\circ\text{C}$  ( $350 \pm 4^\circ\text{F}$ ). (See 6.2).

10.2.4 One may consult with the instrument vendor if calibration of the oven temperature is suspected to be in error.

11. *Procedure*

11.1 *Test Conditions* (Table 1):

11.1.1 For yarns or cords possessing low levels of shrinkage force, a tension loading of  $1.0 \pm 0.2\text{ mN/tex}$  ( $0.010 \pm 0.002\text{ gf/den}$ ) may be used. Use of this lower tension load should be noted in the report.

**TABLE 1 Test Conditions**

Temperature	Tension Load	Time, s	
		Specimen with Linear Mass up to 400 tex (3600 denier)	Specimen with Linear Mass Greater than 400 tex (3600 denier)
177 ± 2°C (350 ± 4°F)	5.0 ± 1.0 mN/tex (or 0.05 ± 0.01 gf/den)	120 ± 10	240 ± 10

11.2 Install one end of the specimen in the fixed clamp.

11.3 Bring the other end of the specimen over the pulley.

11.4 Set the indicator to zero and hold it on zero while performing the next step.

11.5 Attach a clip-on mass to the unclamped end of the specimen so that twist is not lost. Use a mass that creates a tension load as specified in 11.1. Table 2 shows the total mass needed to effect such tensions for typical yarns and cords.

NOTE 2—If the specimen is likely to untwist in the portion below the pulley, attach a toothpick or the equivalent (approximately 7.5 cm long) to the mass or clamp, perpendicular to the vertical threadline, so it will bear against the instrument case and prevent rotation of the mass.

11.6 Load specimen(s) into the oven. The specimen is centered automatically in the oven.

NOTE 3—In the case of highly-crimped yarns, typically those removed from tightly woven fabric, the initial dimensional change that occurs is usually growth, that is, an immediate elongating of the specimen as the specimen loses crimp and straightens. If the instrument allows, set the indicator to a shrinkage level in 11.4 sufficient to prevent the indicator from going below zero. Record positive shrinkage as the interval between the lowest and highest reading of the indicator during the test of that specimen. Note for the report (Section 12) the percent change in length due to crimp relaxation in the tester.

**TABLE 2 Tensioning Masses<sup>A,B</sup>**

A. Single-Strand Yarns		
d Tex	Denier	Tensioning Mass, g
235	210	10
940	840	42
1100	1000	50
1170	1050	53
1400	1260	63
1440	1300	65
1870	1680	84
2100	1890	95
B. Multiple Strands or Cords of Multiple Strands		
Construction		Tensioning Mass, g
940 × 2	840 × 2	84
1100 × 2	1000 × 2	100
1400 × 2	1260 × 2	126
1440 × 2	1300 × 2	130
1870 × 2	1680 × 2	168
2100 × 2	1890 × 2	189

<sup>A</sup>For yarns or cords not shown in Table 2, calculate clip-on mass required by multiplying total d Tex of specimen by 0.50 mN or total denier by 0.05 gf (for specimens expected to have low shrinkage tensions, the factors are 0.090 mN and 0.01 gf, respectively).

<sup>B</sup>If yarns or cords outside the linear density specified in this test method are tested on this type equipment, it may be necessary to use more mass in tensioning light yarns (to ensure sufficient friction to accurately move the pulley) or less mass in tensioning very heavy yarns or cords (to prevent overstressing of the pulley bearings). In such an event, show, in addition to the mass in grams in 12.1.2, the words *modified procedure*, immediately followed in parentheses by the calculated tension per unit of linear density, such as millinewtons per denier or grams per denier. For example, testing of a 10 000-denier cord with 100 g of tensioning mass will be reported in 12.1.2 as “100-g modified procedure (0.01 gf/denier).”

11.7 Lower the draft shield immediately after introducing the specimen.

11.8 Start the timer at the moment the draft shield is lowered.

11.9 At the end of 120 ± 10 s (240 ± 10 s for specimens equal to or greater than 400 tex or 3600 denier), read the percent shrinkage as indicated on the instrument output to the nearest 0.1 %.

11.10 Remove and discard the specimen.

## 12. Report

12.1 State that the specimens have been tested as directed in Test Method D 4974. Describe the material(s) or product(s) tested and the method of sampling used. Report the following information:

12.1.1 Individual thermal shrinkage results as indicated on the instrument output to the nearest tenth of a unit.

12.1.2 Mass, in g, used to apply tension force.

12.1.3 Measurements as “immediate testing” if not conditioned for standard period (see 10.1.2 and 10.1.3).

12.1.4 Measurements as “package testing” if specimens are not removed from package and relaxed prior to testing.

12.1.5 “Percent length increase prior to shrinkage” if such occurred during testing (see Note 3).

## 13. Precision and Bias

13.1 *Interlaboratory Test Data*—An interlaboratory test was conducted in 1989 using commercially available Testrite™ testers and involving twelve different tire cord materials, varying in polymeric structure (nylon and polyester), form (yarn, greige cord, and dipped cord), and linear density (840 denier yarn to 1260 × 3 cord). The type of materials chosen and their processing conditions produced an intentional thermal shrinkage difference among the specimens from less than 2 % to greater than 7 %. Replicate samples from the 12 tire cord materials were sent to 11 laboratories. Each laboratory received a small spool from a single lot of each material. Cord spools of all 12 materials were prepared in a single laboratory and sent to each laboratory participating in the interlaboratory test. Ultimately, the results from four laboratories were eliminated from the test data after discovery that testing was not performed precisely following the specified conditions in the test method; therefore, the precision data in this test method are based on results from seven laboratories. Each laboratory was requested to make three consecutive measurements on each material on four occasions by each of two operators in each laboratory, but to report the average of these three determinations as a single thermal shrinkage value for that occasion. This value was treated statistically as a single determination in Table 3 and Table 4. The components of variance expressed as standard deviations for each material are given in Table 3.

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

13.3 *Bias*—The procedure in this test method produces a test value that can be defined only in terms of a test method. There is no independent referee method by which bias may be

**TABLE 3 Components of Variance as Standard Deviations,  
Percentage Points**
**14. Keywords**

14.1 shrinkage; thermal; tire cord

Material Tested	Name of Property	Single Operator Component	Within Laboratory Component	Between Laboratory Component
Polyester yarn 1110 decitex Type 1W74	thermal shrinkage	0.110	0.010	0.278
Polyester yarn 1110 decitex 1X93DSP	thermal shrinkage	0.086	0.036	0.320
Nylon yarn 930 decitex T-728	thermal shrinkage	0.130	0.062	0.322
Nylon yarn 1400 decitex T-728	thermal shrinkage	0.105	0.051	0.219
Polyester greige cord 1110/1/2 394 × 394 tpm 1W74	thermal shrinkage	0.098	0.077	0.313
Polyester greige cord 1110/1/2 394 × 394 tpm 1X93	thermal shrinkage	0.250	0.064	0.185
Nylon greige cord 930/1/2 472 × 472 tpm T-278	thermal shrinkage	0.168	0.014	0.237
Nylon greige cord 1400/1/3 315 × 315 tpm T-728	thermal shrinkage	0.151	0.103	0.275
Polyester dipped cord 1110/1/2 394 × 394 tpm 1W74	thermal shrinkage	0.133	0.053	0.064
Polyester dipped cord 1110/1/2 394 × 394 tpm 1X93	thermal shrinkage	0.099	0.016	0.083
Nylon dipped cord 930/1/2 472 × 472 tpm T-728	thermal shrinkage	0.359	0.000	0.376
Nylon dipped cord 1400/1/3 315 × 315 tpm T-728	thermal shrinkage	0.152	0.000	0.147

determined. This test method has no known bias.

**TABLE 4 Critical Differences<sup>A</sup> for Conditions Noted, 95 % Probability Level, Percentage Points—Single Material Comparisons**

Material Tested	Name of Property	Number of Observations	Single Operator Precision	Within Laboratory Precision	Between Laboratory Precision
Polyester yarn	thermal shrinkage	1	0.305	0.306	0.830
1110 decitex		2	0.216	0.218	0.801
Type 1W74		4	0.153	0.155	0.787
(2.43) <sup>B</sup>		8	0.108	0.111	0.779
		16	0.076	0.081	0.775
Polyester yarn	thermal shrinkage	1	0.239	0.260	0.924
1110 decitex		2	0.169	0.197	0.909
1X93DSP		4	0.120	0.156	0.901
(5.99) <sup>B</sup>		8	0.085	0.132	0.897
		16	0.059	0.117	0.895
Nylon yarn	thermal shrinkage	1	0.360	0.400	0.977
930 decitex		2	0.255	0.308	0.943
T-728		4	0.180	0.250	0.926
(6.55) <sup>B</sup>		8	0.127	0.215	0.917
		16	0.090	0.195	0.913
Nylon yarn	thermal shrinkage	1	0.291	0.324	0.689
1400 decitex		2	0.206	0.250	0.657
T-728		4	0.146	0.203	0.641
(6.20) <sup>B</sup>		8	0.103	0.175	0.633
		16	0.072	0.159	0.629
Polyester greige cord	thermal shrinkage	1	0.272	0.345	0.934
1110/1/2		2	0.192	0.287	0.914
394 × 394 tpm		4	0.136	0.253	0.904
1W74		8	0.096	0.234	0.899
(2.19) <sup>B</sup>		16	0.067	0.223	0.897
Polyester greige cord	thermal shrinkage	1	0.693	0.716	0.880
1110/1/2		2	0.490	0.521	0.731
394 × 394 tpm		4	0.347	0.389	0.643
1X93		8	0.245	0.303	0.595
(6.13) <sup>B</sup>		16	0.173	0.248	0.569
Nylon greige cord	thermal shrinkage	1	0.466	0.468	0.807
930/1/2		2	0.329	0.332	0.737
472 × 472 tpm		4	0.233	0.236	0.699
T-728		8	0.165	0.169	0.679
(7.24) <sup>B</sup>		16	0.116	0.123	0.669
Nylon greige cord	thermal shrinkage	1	0.418	0.506	0.916
1400/1/3		2	0.295	0.410	0.867
315 × 315 tpm		4	0.209	0.353	0.841
T-728		8	0.148	0.321	0.828
(6.94) <sup>B</sup>		16	0.104	0.303	0.821
Polyester dipped cord	thermal shrinkage	1	0.367	0.390	0.434
1110/1/2		2	0.260	0.299	0.347
394 × 394 tpm		4	0.184	0.236	0.295
1W74		8	0.130	0.197	0.265
(1.27) <sup>B</sup>		16	0.091	0.174	0.248
Polyester dipped cord	thermal shrinkage	1	0.275	0.278	0.361
1110/1/2		2	0.194	0.199	0.305
394 × 394 tpm		4	0.137	0.144	0.272
1X93		8	0.097	0.106	0.254
(1.85) <sup>B</sup>		16	0.068	0.081	0.245
Nylon dipped cord	thermal shrinkage	1	0.996	0.996	1.44
930/1/2		2	0.704	0.704	1.26
472 × 472 tpm		4	0.498	0.498	1.15
T-728		8	0.352	0.352	1.10
(7.70) <sup>B</sup>		16	0.248	0.249	1.07
Nylon dipped cord	thermal shrinkage	1	0.421	0.421	0.585
1400/1/3		2	0.298	0.298	0.504
315 × 315 tpm		4	0.210	0.210	0.458
T-728		8	0.149	0.149	0.433
(3.29) <sup>B</sup>		16	0.105	0.105	0.420

<sup>A</sup> The critical differences were calculated using  $z = 1.960$ .

<sup>B</sup> Average % shrinkage for each material obtained by seven participating laboratories.

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