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WORKING GROUP  
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SUBJECT  
CATEGORY \_\_\_\_\_ Physical Properties \_\_\_\_\_

RELATED  
METHODS \_\_\_\_\_ See "Additional Information" \_\_\_\_\_

**TAPPI**

**CAUTION:**

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

# **Tensile properties of paper and paperboard (using constant rate of elongation apparatus) (Revision of T 494 om-01)**

(Underlines indicated changes/corrections since last draft)

## **1. Scope**

1.1 This test method describes the procedure, using constant-rate-of-elongation equipment, for determining four tensile breaking properties of paper and paperboard: tensile strength, stretch, tensile energy absorption, and tensile stiffness.

1.2 This procedure is applicable to all types of paper and paperboard within the limitations of the instruments used, whether the instruments perform horizontal or vertical tests or whether they are manually operated or computer controlled. It is also applicable to handsheets, with modifications, as specified in TAPPI T 220 "Physical Testing of Pulp Handsheets." It does not apply to combined corrugated board.

## 2. Definitions

2.1 *Tensile strength*, the maximum tensile force developed in a test specimen before rupture on a tensile test carried to rupture under prescribed conditions. Tensile strength (as used here) is the force per unit width of test specimen.

2.2 *Stretch*, the maximum tensile strain developed in the test specimen before rupture in a tensile test carried to rupture under prescribed conditions. The stretch (or percentage elongation) is expressed as a percentage, i.e., one hundred times the ratio of the increase in length of the test specimen to the original test span.

2.3 *Tensile energy absorption* (TEA), the work done when a specimen is stressed to rupture in tension under prescribed conditions as measured by the integral of the tensile strength over the range of tensile strain from zero to maximum strain. The TEA is expressed as energy per unit area (test span  $\times$  width) of test specimen.

2.4 *Tensile stiffness*, the ratio of tensile force per unit width to tensile strain within the elastic region of the tensile-strain relationship. The elastic region of the tensile-strain relationship is the linear portion of the load-elongation relationship up to the elastic limit. The elastic limit is the maximum tensile force above which the load-elongation relationship departs from linearity. (Tensile stiffness is numerically equivalent to  $E \cdot t$ , where  $E$  is the modulus of elasticity and  $t$  is sample thickness.)

2.5 *Breaking length*, the calculated limiting length of a strip of uniform width, beyond which, if such a strip were suspended by one end, it would break of its own weight.

2.6 *Tensile index*, the tensile strength in N/m divided by grammage.

**NOTE 1:** ISO/TC6 recommends the use of tensile index over breaking length. See TAPPI T 1210 or TIP 0800-01 "Units of Measurement and Conversion Factors."

## 3. Significance

3.1 Tensile strength is indicative of the strength derived from factors such as fiber strength, fiber length, and bonding. It may be used to deduce information about these factors, especially when used as a tensile strength index. For quality control purposes, tensile strength has been used as an indication of the serviceability of many papers which are subjected to a simple and direct tensile stress. Tensile strength can also be used as an indication of the potential resistance to web breaking of papers such as printing papers during printing on a web fed press or other web fed converting operations. When evaluating the tensile strength, the stretch and the tensile energy absorption for these parameters can be of equal or greater importance in predicting the performance of paper, especially when that paper is subjected to an uneven stress such as gummed tape, or a dynamic stress such as when a sack full of granular material is dropped.

3.2 Stretch (sometimes evaluated in conjunction with bending resistance) is indicative of the ability of paper to conform to a desired contour, or to survive nonuniform tensile stress. It should be considered important in all papers,

but is of particular importance in papers where stress-strain properties are being modified or controlled. This includes creped paper, pleated paper, air-dried paper, and paper that has been made extensible through mechanical compaction. Stretch may be used as an indication of the amount of crepe in tissues, towels, napkins, and similar grades. Stretch is evaluated in decorative papers and certain industrial grades such as paper tapes and packaging papers, both as an index of how well the paper will conform to irregular shapes and, along with tensile energy absorption, as an indication of the paper's performance under conditions of either dynamic or repetitive straining and stressing. Stretch has also been found important in reducing the frequency of breaks on high-speed web fed printing presses such as are used to print newspapers.

3.3 Tensile energy absorption is a measure of the ability of a paper to absorb energy (at the strain rate of the test instrument), and indicates the durability of paper when subjected to either a repetitive or dynamic stressing or straining. Tensile energy absorption expresses the "toughness" of the sheet. An example of this is a multi-wall sack that is subject to frequent dropping. In packaging applications such as multi-wall sacks, favorable drop tests and low failure rates have been found to correlate better with tensile energy absorption than with tensile strength.

3.4 Tensile stiffness tells of the stiffness of the sheet and often gives a better indication of the mechanical response of the sheet to converting forces than does failure criteria.

#### **4. Apparatus**

4.1 *Tensile testing machine*<sup>1</sup>, a constant-rate-of-elongation type (1), meeting the following requirements:

4.1.1 Two clamping jaws, each with a line contact for gripping the specimen, with the line contact perpendicular to the direction of the applied load and with means for controlling and adjusting the clamping pressure.

**NOTE 2:** "Line contact" describes the clamping zone resulting from gripping the specimen between a cylindrical and a flat surface or between two cylindrical surfaces whose axes are parallel (2).

**NOTE 3:** For certain grades of paper "line contact" jaws may not be appropriate and it may be necessary to substitute flat gripping surfaces. Certain grades are damaged by the "line contact" loading between cylindrical and flat surfaces. The use of emery cloth on flat gripping surfaces will help minimize slippage for some board grades.

4.1.2 The clamping surfaces of the two jaws shall be in the same plane and so aligned that they hold the test specimen in that plane throughout the test. The clamping lines shall be parallel to each other within an angle of  $\pm 1^\circ$ , and shall not change more than  $0.5^\circ$  during the test. The applied tensile force shall be perpendicular to the clamp lines within  $\pm 1^\circ$  throughout the test.

4.1.3 The distance between line contacts at the start of the test shall be adjustable and resettable to  $\pm 0.5$  mm (nominally 0.02 in.) for the specified initial test span (6.4). (See 11.3.)

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<sup>1</sup>Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list in the set of TAPPI Test Methods, or may be available from the TAPPI Quality and Standards Department.

4.1.4 The rate of separation of jaws shall be  $25 \pm 5$  mm/min (nominally 1.0 in. /min), or as otherwise noted (6.5) and once set shall be resettable and constant to  $\pm 4\%$ . (See 11.3.)

4.1.5 Recorder or indicator capable of indicating the actual force on the specimen within 1% or 0.1 N, whichever is greater.

4.1.6 Recorder speed or indicator shall be adjustable to provide a readability and accuracy of  $\pm 0.05\%$  stretch.

4.2 *Alignment jig* (optional) (2) to facilitate centering and aligning the specimen in the jaws, so that the clamping lines of contact are perpendicular to the direction of the applied force and the center line (long dimension) of the specimen coincides with the direction of applied force.

4.3 *Planimeter* or *integrator*, respectively, to measure the area beneath the load-elongation curve or to compute directly the work to rupture, with an accuracy of  $\pm 1\%$ .

4.4 *Specimen cutter*, for cutting specimens of the required width, with straight parallel sides (5.3).

4.5 *Magnifier and scale* or *optical comparator*, capable of measuring the specimen width to the nearest 0.1 mm (0.004 in.).

**NOTE 4:** Fully automated laboratory management and/or data acquisition systems are available which perform several functions such as: automatic calibration check, pre-setting and storing a variety of test programs, cutting the test strip, acquiring test data, and accurately determining the tensile breaking properties of paper and paperboard. These tests may be performed with the test strip horizontal or vertical by such equipment. Such equipment may be suitable for use in performing this method; however, the user is responsible for making independent assessment of this fact on the basis of data generated using specific equipment.

## 5. Sampling and test specimens

5.1 For sampling for acceptance of a lot of paper, paperboard, related product, without prior agreement between buyer and seller, use TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product."

5.2 For sampling for quality control and other purposes, use accepted and agreed upon company and laboratory sampling practices.

5.3 Precondition, then condition, the sample in accordance with TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products" prior to cutting the specimens.

**NOTE 5:** The exposure of the paper to a high relative humidity before preconditioning and conditioning can lead to erratic results varying from a decrease in stretch and tensile to a substantial increase (30% increase in stretch not uncommon) in these properties. Consequently, TEA is similarly affected. Careful protection of the sample from the time of sampling until testing is therefore very important.

5.4 Cut 10 test specimens from each test unit of the sample in each principal direction of the paper  $25 \pm 1$  mm (nominally 1.0 in.) wide with sides parallel within 0.1 mm (nominally 0.004 in.) and long enough to be clamped in the jaws when the test span is  $180 \pm 5$  mm (nominally 7.0 in.), leaving enough length so that any slack can be removed from

the strip before clamping. (See 11.3.) Insure that strips are free from abnormalities, creases, or wrinkles. In some cases, it may be impossible or impractical to obtain a test specimen having a length long enough to be clamped in the jaws having the test span specified here. In such cases, see Appendix A.3.1 for special considerations and procedures required for testing samples at smaller test spans.

## **6. Procedures**

6.1 Perform the test in the testing atmosphere specified in T 402.

6.2 If the test specimen width is not known to 0.1 mm (nominally 0.004 in.) (i.e., if a previously evaluated precision cutter is not used), determine width and parallelism using magnifier and scale. Lack of parallelism is indicated by a difference in width of the two ends of the specimen.

6.3 The testing machine shall be calibrated and adjusted as described in Appendixes A.1 and A.2.

6.4 Set the clamps to an initial test span (distance between line contacts) of  $180 \pm 5$  mm (nominally 7.0 in.). Determine and always reset this distance within  $\pm 0.5$  mm (nominally 0.02 in.). (See Appendix A.1.3.)

6.5 Set the controls for rate of separation of the jaws to  $25 \pm 5$  mm/min (nominally 1.0 in./min). (See 11.3.) In cases where the time required to break a single strip exceeds 30 s, a more rapid rate of jaw separation shall be used, such that the time to break a single strip will be between 15 and 30 s. In such cases, the speed of the instrument must be reported, along with the test data.

**NOTE 6:** For purposes of determining shipping sack and shipping sack paper TEA compliance with Carrier and Federal requirements, Uniform Freight Classification Rule 40, National Motor Freight Classification, Item 200, UUS 48 and Department of Transportation 178.236, 4.8 in. (122 mm) between the jaws and 1 in. (25 mm) per minute jaw separation should be used.

6.6 Select recorder speed or indicator to give a readability equivalent to 0.05% stretch.

6.7 Select the full-scale reading, if possible, so that breaking force can be read in the upper three-fourths of the scale. Make preliminary trial tests if necessary to determine full-scale load.

**NOTE 7:** If, for any reason, any of the testing conditions specified above (specimen length, rate of jaw separation, sample width, etc.) cannot be followed because of the small sample size or other reason, the method variance *must* be stated in the report.

6.8 Align and clamp the specimen first in one jaw and then, after carefully removing any noticeable slack, but without straining the specimen, in the second jaw. While handling the test specimen, avoid touching the test area between the jaws with the fingers. Use a clamping pressure determined to be satisfactory (Appendix A.1.4), i.e., so that neither slippage nor damage to the specimen occurs. Automated instruments for which both jaws close simultaneously are within the context of this method.

6.9 Test 10 specimens in each principal direction for each test unit.

6.10 Reject any value in which the test specimen slips in the jaws, breaks within the clamping area, or shows evidence of uneven stretching across its width. Also reject any values for test specimens which break within 5 mm of the

clamp area if further inspection indicates the break location is due to improper clamping conditions or misalignment. If more than 20% of the specimens for a given sample are rejected, reject all readings obtained for that sample, inspect the apparatus for conformance with specifications, and take any steps necessary to correct the trouble.

6.11 If determining tensile strength and stretch, read and record the breaking force to 0.5% of full scale and the elongation at break to the equivalent of 0.05% stretch.

6.12 If determining tensile energy absorption, record the integrator reading or use the planimeter to determine the area under the load-elongation curve from zero load to the breaking load.

**NOTE 8:** For the purpose of terminating integration, the specimen will be deemed broken when maximum tensile load has been reached and the tensile load has dropped no more than 0.25% of the full-scale load below the maximum load. This procedure is applicable in the determination of TEA as long as maximum strain occurs at rupture, which is usually the case.

6.13 If determining tensile stiffness, measure the strain at two force levels within the elastic region of the tensile force-strain relationship. The lower of the two force levels must be at least 5% of the apparent elastic limit, the higher not more than 75%, and the two force levels must be separated by at least 20% of the apparent elastic limit. For purposes of this measurement, the apparent elastic limit is defined as the point at which the tensile force-strain relationship departs from linearity. Alternately, the slope can be continuously monitored, and the maximum value taken as the measure of tensile stiffness. Determine the tensile stiffness,  $S_t$ , from:

$$S_t = (\Delta f \cdot L) / (w \cdot \Delta L)$$

where:

$S_t$  = Tensile stiffness, kN/m

$\Delta f$  = difference between two force levels, kN

$L$  = initial test length, m

$w$  = initial specimen width, m

$\Delta L$  = change in length corresponding to  $\Delta f$ , m

## 7. Calculations

7.1 For each test unit and in each principal direction, calculate from the recorded values the average breaking force, average elongation at break, average integrator or planimeter value, and the average elastic slope, as required. Correct the instrumental results, if necessary, according to the correction curve described in the Appendix (A.2.2). Corrections for instrumental deflection need to be applied to both the elongation and energy measurements. Determine the range or standard deviation in each case.

7.2 Divide the average breaking force by the specimen width (as determined in 6.2) to obtain the tensile strength. If this has been measured in pounds and inches, convert to kN/m by multiplying by 0.1751. If this has been measured in kg/mm, convert to kN/m by multiplying by 9.807.

**NOTE 9:** To calculate the breaking length (air dry) in meters use the following formula:

$$BL = 102,000 (T/R) = 3658 (T'/R')$$

To calculate the tensile index in newton meters per gram use the following formula:

$$TI = 1000 (T/R) = 36.87 (T'/R')$$

where

TI	=	tensile index, N • m/g
BL	=	breaking length, m
T	=	tensile strength, kN/m
T'	=	tensile strength, lbf/in.
R	=	grammage (air dry), g/m <sup>2</sup>
R'	=	mass per unit area (air dry), lb/1000 ft <sup>2</sup>

7.3 To calculate the percentage stretch, divide the average elongation at break by the initial test span (as determined in 6.4) and multiply by 100.

7.4 Multiply the average integrator or planimeter value by the appropriate factor for the equipment and settings used to obtain the area under the load-elongation curve (Note 8) in energy units, joules (preferred) or inch-pound force. Then calculate the tensile energy absorption, according to one of the following formulas (see Appendix A.4 for proof of constants):

$$TEA = 1 \times 10^6 A/LW \text{ or } 9.807 \times 10^4 A' / LW \text{ or } 175.1 a/lw$$

$$tea = 12 a/lw$$

where:

TEA	=	tensile energy absorption, J/m <sup>2</sup>
L	=	initial test span, mm
W	=	specimen width, mm
A	=	area under load-elongation curve, J
A'	=	area under load-elongation curve, kgf • cm
tea	=	tensile energy absorption, ft • lbf/ft <sup>2</sup>

- a = area under load elongation curve, lbf • in.  
 l = initial test span, in.  
 w = specimen width, in.

To convert tensile energy absorption in ft • lbf/ft<sup>2</sup> to J/m<sup>2</sup>, multiply by 14.60.

**NOTE 10:** The “area under the load-elongation curve” is the area between the curve and the elongation axis.

7.5 Divide the elastic slope by the specimen width to obtain the tensile stiffness. If the slope has been measured in pounds and inches, convert to kN/m by multiplying by 0.1751.

7.6 Determine the corresponding ranges or standard deviations from the ranges or standard deviations of the measured values (7.1).

**NOTE 11:** Hardware/software systems are available that will perform all calculations required in the desired units of measurements.

## 8. Report

- 8.1 Report for each test unit and in each direction to three significant figures:
- 8.1.1 The average tensile strength and the range or standard deviation in kN/m and (if desired) in lbf/in.
- 8.1.2 The average stretch and the range or standard deviation as a percentage.
- 8.1.3 The average tensile energy absorption and the range or standard deviation in J/m<sup>2</sup> and (if desired) in ft • lbf/ft<sup>2</sup>.
- 8.1.4 The average tensile stiffness and the range or standard deviation in kN/m and (if desired) in lbf/in.
- 8.2 Report, in each case, the number of tests rejected and the reasons for rejection.
- 8.3 Report any deviation in test procedure, as when a short specimen must be used, alternate clamping configurations are used, a wide or narrow strip was tested, or when the rate of jaw separation was varied from 25 ± 5 mm/min (nominally 1.0 in./min) as described in 6.5.

## 9. Precision

9.1 On the basis of studies (3) made in accordance with TAPPI T 1200 “Interlaboratory Evaluation of Test Methods,” two test results, each representing an average of 10 determinations, from the same or different samples as noted, are expected to agree within the amounts shown in Table 1. The interlaboratory study included 20 laboratories and 22 samples. The samples ranged in tensile strength from 2 to 12 kN/m, in stretch from 1 to 9%, and in TEA from 30 to 450 J/m<sup>2</sup>.

**Table 1.** 95% probability limits

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	<i>Tensile strength*</i>	<i>% Stretch* %</i>	<i>TEA* %</i>
Repeatability (same sample, operator and apparatus)	5	9	10-16
Reproducibility (same sample, different laboratories)	10	25	22-36

\*Percentage of the average of the two results

9.2 In each case, the coefficient of variation of a test result (average of 10 determinations) is expected to be about 0.36 times the value shown in Table 1.

9.3 The repeatability of tensile stiffness measurements, based on test results from a single laboratory, is estimated to be 7-8%.

## **10. Keywords**

Paper, Paperboard, Tensile tests, Tensile strength, Stretch, Rupture work, Stiffness, Tensile energy absorption

## **11. Additional information**

11.1 Effective date of issue: to be assigned.

11.2 This test method may be used in place of the similar method for tensile strength and stretch (T 404) which uses a different type tensile testing machine. These methods are not strictly comparable in that different instrument types are used, but when similar testing conditions are used, they may give similar results. This test method permits four tests (tensile breaking strength, tensile energy absorption, elongation at break, and tensile stiffness) to be run simultaneously on the same test specimen. This test method also gives more detailed requirements for the apparatus (standardizing on the constant-rate-of-elongation apparatus) and more detailed instructions for the procedure.

11.3 The intent of this method is to specify a specimen width of about 1 inch, a test length of about 7 inches, and a testing speed of about 1 inch per minute. The metric equivalents of these are about 25, 180, and 25 mm, respectively. These “rounded” numbers are specified in the method, with large enough tolerances to accommodate both English and metric cutters and testers. As discussed in the Appendix, the use of values at different levels within the tolerances given will not significantly affect the test result.

11.4 In the modernized metric system, or System International (SI), the units of force and energy are newton (N) and joule (J), respectively. The factors for conversion from the relevant customary units to SI units are as follows:

Force:

$$1 \text{ lbf} = 4.448 \text{ N}$$

$$1 \text{ kgf} = 9.807 \text{ N}$$

Energy:

$$1 \text{ N} \cdot \text{m} = 1.000 \text{ J}$$

$$1 \text{ ft} \cdot \text{lbf} = 1.356 \text{ J}$$

$$1 \text{ m} \cdot \text{kgf} = 9.807 \text{ J}$$

Tensile strength:

$$1 \text{ lbf/in.} = 0.175 \text{ kN/m}$$

$$1 \text{ kgf/15 mm} = 0.654 \text{ kN/m}$$

Tensile index:

The breaking length in meters is numerically equal to 102 times tensile index in newton meters per gram.

Tensile energy absorption:

$$1 \text{ ft} \cdot \text{lb/ft}^2 = 14.60 \text{ J/m}^2$$

Tensile stiffness:

$$1 \text{ lbf/in.} = 0.175 \text{ kN/m}$$

11.5 This method was first published in 1964 as a Suggested Method and became an Official Method in 1970.

Tensile stiffness was added to the 1996 revision of the method.

11.6 Related methods: ASTM D828 “Tensile Breaking Strength for Paper and Paperboard Using Constant Rate of Elongation Apparatus,” American Society for Testing and Materials, Philadelphia; AS1301.448S “Tensile Strength of Paper and Paperboard (Constant Rate of Elongation Method),” Technical Association of Australian and New Zealand Pulp and Paper Industry, Carlton, Victoria, Australia; D.34, “Tensile Breaking Strength of Paper and Paperboard (Constant Rate of Elongation Test),” Pulp and Paper Technical Association of Canada, Montreal, Canada; AFNOR QO 3-001, Association Francaise de Normalisation, Paris, France; VXPCI, V12, Zellcheming, Rheinstrasse, Germany; ISO 1924, “Paper and Board, Determination of Tensile Strength,” International Organization for Standardization, Geneva, Switzerland; SCAN P38, “Tensile Strength Stretch TEA and Tensile Stiffness of Paper and Paperboard,” Scandinavian Pulp, Paper, and Board Testing Committee, Stockholm, Sweden. ISO 1924, and other methods noted above, may differ from T 494 in required specimen dimensions, testing speed, or number of tests.

## **Appendix**

### *A.1 Adjustment and maintenance of testing machine*

A.1.1 Regularly inspect the machine for cleanliness and for faults such as wear, misalignment, loose parts, and damage. Clean the machine and rectify any faults.

A.1.2 Level the machine accurately in its two principal directions. Align the clamping jaws to hold the specimen in the plane of the applied load throughout the test.

A.1.3 Position the jaws so that the test span is as specified in 6.4. Verify by measuring the effective test span, e.g., by measuring the distance between the centers of the line clamp impressions produced on strips of thin foil.

A.1.4 Determine appropriate clamping pressure so that neither slippage nor specimen damage occurs.

**NOTE 12:** Papers prepared from the more highly hydrated or beaten stocks, such as tracing paper or glassine, present the most difficult gripping problem. Thus, it is recommended that the clamping pressure be adjusted by making a test with a strong tracing paper. The clamping pressure is adjusted to give satisfactory results with this wide variety of papers in the intermediate weight and strength range. The use of excessively high pressure is shown by straightline breaks in, and immediately adjacent to, the clamping zone; whereas the use of too low a pressure shows an abrupt discontinuity in the load-elongation curve, or failure of the specimen beyond the clamped zone, or, following the test, a wider-than-normal impression of the clamping line.

## A.2 *Calibration of testing machine*

A.2.1 After leveling the machine accurately, calibrate the load measuring mechanism with standard weights by the dead-weight method; i.e., obtain readings at about ten points evenly spaced throughout the scale, by applying known weights with increasing then decreasing increments to the clamp actuating the indicating or recording mechanism. Note the scale readings when the weights and mechanism come gently into the equilibrium position. If readings differ from the corresponding applied loads by more than 0.5%, construct a correction curve.

**NOTE 13:** This calibration procedure is only applicable for vertical tensile instruments. For horizontal instruments, follow recommended manufacturer's procedures.

A.2.2 Calibrate the extension measuring mechanism with inside vernier calipers or other appropriate means over the entire load range of interest (*l*). Read the elongation scale at a number of points evenly spaced over the range from about 1 to 20% strain. If readings are in error by more than 0.1% strain, construct a correction curve.

## A.3 *Modifications of procedure (and effects thereof)*

### A.3.1 *Test specimens*

A.3.1.1 If undersized specimens must be used (e.g., because of size of sample sheets), use 25 mm (preferred) or 15 mm width and lengths long enough to be clamped in jaws either  $100 \pm 5$  mm ( $4 \pm 0.2$  in.) or  $50 \pm 2$  mm ( $2 \pm 0.1$  in.) apart.

A.3.1.2 The shorter test spans will give higher readings, and it is difficult to measure the elongation accurately [see the Pierce weak-link theory (4, 5)]. For papers which have a poor formation, the difference between a test span of 100 mm and the standard span of 180 mm may amount to over 10% in tensile strength and TEA.

**NOTE 14:** The tensile breaking load, and consequently the breaking strain and TEA, is known to decrease as the test span increased. The decrease occurs because tensile specimens fail at the weakest part along their length, and because as the test length is increased the probability of including a still weaker part also increases.

The effect of test span on breaking load of paper has been found (4) to follow the Pierce (5) weak-link theory which states that:

$$F_{t1}/F_L = 1 - 4.2(1 - r^{-0.2})V/100$$

where:

- $F_L$  = breaking load at span  $L$
- $F_{rL}$  = breaking load at span  $rL$
- $V$  = coefficient of variation at span  $L$

Table 2 shows the predicted change in tensile breaking load at several test spans and levels of variability, relative to the breaking load at a test span of 200 mm (4, 5). For example, if a paper is tested for tensile strength using a test span of 50 mm, and the coefficient of variation is 6% of the average measured tensile, then that test result would be 8% higher than would be obtained had the test been made using a span of 200 mm.

A.3.1.3 The sample width is used in the calculation of tensile strength, TEA, and tensile stiffness. Studies have shown that lower results will be obtained for specimens having widths less than about 12 mm. For specimens having widths greater than 12 mm, test results per unit width are not significantly affected by specimen width.

#### A.3.2. Procedure

A.3.2.1 At shorter initial test spans, adjust the rate of jaw separation so that the strain rate matches that achieved with the test span and rate specified in 6.4 and 6.5. This strain rate (rate of jaw separation/test span) is  $0.14 \pm 0.04$  (mm/min / mm). For example, if only one-half (90 mm) of the specified test span were used, the test speed would be set at one-half (12.5 mm/min) of the specified speed.

A.3.2.2 Doubling the test speed (for same length specimen) will increase the apparent tensile strength and may increase TEA for some papers approximately 3%. In other cases stretch will be reduced, thus acting to keep TEA nearly constant.

A.4 Proof of constants:

$$\begin{aligned}
 \text{TEA (J/m}^2\text{)} &= \frac{A \text{ (J)}}{L \text{ (mm)} \mid W \text{ (mm)}} \mid \frac{(1000 \text{ mm})^2}{\text{m}^2} \\
 &= 1 \times 10^6 A/LW \\
 \text{TEA (J/m}^2\text{)} &= \frac{A' \text{ (kg}_f\text{)(cm)}}{L \text{ (mm)} \mid W \text{ (mm)}} \mid \frac{(1000 \text{ mm})^2}{\text{m}^2} \mid \frac{\text{m}}{100 \text{ cm}} \\
 &\times \frac{1 \text{ J}}{\text{Nm}} \mid \frac{\text{N} \cdot \text{S}^2}{(\text{kg}_m) \text{ (m)}} \mid \frac{9.807 \text{ (kg}_m) \text{ (m)}}{(\text{kg}_f)\text{S}^2} \\
 &= 9.807 \times 10^4 A'/LW \\
 \text{TEA (J/m}^2\text{)} &= \frac{a \text{ (lb}_f \cdot \text{in)}}{l \text{ (in)} \mid w \text{ (in)}} \mid \frac{\text{J}}{0.7376 \text{ ft} \cdot \text{lb}} \\
 &\times \frac{\text{ft}}{12 \text{ in}} \mid \frac{(39.37 \text{ in})^2}{\text{m}^2} \\
 &= 175.1 a/lw
 \end{aligned}$$

**Table 2.** Predicted change in tensile breaking load.

Coefficient of variation, %	Predicted change in breaking load, %				
	50 mm span	100 mm span	200 mm span	300 mm span	400 mm span
2	2.7	1.2	---	-0.7	-1.1
4	5.4	2.5	---	-1.3	-2.2
6	8.0	3.7	---	-2.0	-3.3
8	10.7	5.0	---	-2.6	-4.3
10	13.4	6.2	---	-3.3	-5.4

**Literature cited**

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*Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Director of Quality and Standards.* ■

WI \_\_\_\_\_ 050808.09 \_\_\_\_\_

T \_\_\_\_\_ 494 \_\_\_\_\_

DRAFT NO. \_\_\_\_\_ 1 \_\_\_\_\_

DATE \_\_\_\_\_ November 15, 2005 \_\_\_\_\_

**TAPPI**

WORKING GROUP  
CHAIRMAN \_\_\_\_\_ to be assigned \_\_\_\_\_

SUBJECT  
CATEGORY \_\_\_\_\_ Physical Properties \_\_\_\_\_

RELATED  
METHODS \_\_\_\_\_ See "Additional Information" \_\_\_\_\_

**CAUTION:**

This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

# **Tensile properties of paper and paperboard (using constant rate of elongation apparatus) (Five-year review of T 494 om-01)**

## **1. Scope**

1.1 This test method describes the procedure, using constant-rate-of-elongation equipment, for determining four tensile breaking properties of paper and paperboard: tensile strength, stretch, tensile energy absorption, and tensile stiffness.

1.2 This procedure is applicable to all types of paper and paperboard within the limitations of the instruments used, whether the instruments perform horizontal or vertical tests or whether they are manually operated or computer controlled. It is also applicable to handsheets, with modifications, as specified in TAPPI T 220 "Physical Testing of Pulp Handsheets." It does not apply to combined corrugated board.

1.3 TAPPI T 404 “Tensile Breaking Strength and Elongation of Paper and Paperboard (Using Pendulum-Type Tester)” describes a procedure for measuring tensile strength and stretch using constant rate of loading instruments.

## 2. Definitions

2.1 *Tensile strength*, the maximum tensile force developed in a test specimen before rupture on a tensile test carried to rupture under prescribed conditions. Tensile strength (as used here) is the force per unit width of test specimen.

2.2 *Stretch*, the maximum tensile strain developed in the test specimen before rupture in a tensile test carried to rupture under prescribed conditions. The stretch (or percentage elongation) is expressed as a percentage, i.e., one hundred times the ratio of the increase in length of the test specimen to the original test span.

2.3 *Tensile energy absorption* (TEA), the work done when a specimen is stressed to rupture in tension under prescribed conditions as measured by the integral of the tensile strength over the range of tensile strain from zero to maximum strain. The TEA is expressed as energy per unit area (test span  $\times$  width) of test specimen.

2.4 *Tensile stiffness*, the ratio of tensile force per unit width to tensile strain within the elastic region of the tensile-strain relationship. The elastic region of the tensile-strain relationship is the linear portion of the load-elongation relationship up to the elastic limit. The elastic limit is the maximum tensile force above which the load-elongation relationship departs from linearity. (Tensile stiffness is numerically equivalent to  $E \cdot t$ , where  $E$  is the modulus of elasticity and  $t$  is sample thickness.)

2.5 *Breaking length*, the calculated limiting length of a strip of uniform width, beyond which, if such a strip were suspended by one end, it would break of its own weight.

2.6 *Tensile index*, the tensile strength in N/m divided by grammage.

**NOTE 1:** ISO/TC6 recommends the use of tensile index over breaking length. See TAPPI T 1210 or TIP 0800-01 “Units of Measurement and Conversion Factors.”

## 3. Significance

3.1 Tensile strength is indicative of the strength derived from factors such as fiber strength, fiber length, and bonding. It may be used to deduce information about these factors, especially when used as a tensile strength index. For quality control purposes, tensile strength has been used as an indication of the serviceability of many papers which are subjected to a simple and direct tensile stress. Tensile strength can also be used as an indication of the potential resistance to web breaking of papers such as printing papers during printing on a web fed press or other web fed converting operations. When evaluating the tensile strength, the stretch and the tensile energy absorption for these parameters can be of equal or greater importance in predicting the performance of paper, especially when that paper is subjected to an uneven stress such as gummed tape, or a dynamic stress such as when a sack full of granular material is dropped.



3.2 Stretch (sometimes evaluated in conjunction with bending resistance) is indicative of the ability of paper to conform to a desired contour, or to survive nonuniform tensile stress. It should be considered important in all papers, but is of particular importance in papers where stress-strain properties are being modified or controlled. This includes creped paper, pleated paper, air-dried paper, and paper that have been made extensible through mechanical compaction. Stretch may be used as an indication of the amount of crepe in tissues, towels, napkins, and similar grades. Stretch is evaluated in decorative papers and certain industrial grades such as paper tapes and packaging papers, both as an index of how well the paper will conform to irregular shapes and, along with tensile energy absorption, as an indication of the paper's performance under conditions of either dynamic or repetitive straining and stressing. Stretch has also been found important in reducing the frequency of breaks on high-speed web fed printing presses such as are used to print newspapers.

3.3 Tensile energy absorption is a measure of the ability of a paper to absorb energy (at the strain rate of the test instrument), and indicates the durability of paper when subjected to either a repetitive or dynamic stressing or straining. Tensile energy absorption expresses the "toughness" of the sheet. An example of this is a multi-wall sack that is subject to frequent dropping. In packaging applications such as multi-wall sacks, favorable drop tests and low failure rates have been found to correlate better with tensile energy absorption than with tensile strength.

3.4 Tensile stiffness tells of the stiffness of the sheet and often gives a better indication of the mechanical response of the sheet to converting forces than does failure criteria.

#### **4. Apparatus**

4.1 *Tensile testing machine*<sup>1</sup>, a constant-rate-of-elongation type (1), meeting the following requirements:

4.1.1 Two clamping jaws, each with a line contact for gripping the specimen, with the line of contact perpendicular to the direction of the applied load and with means for controlling and adjusting the clamping pressure.

**NOTE 2:** "Line contact" describes the clamping zone resulting from gripping the specimen between a cylindrical and a flat surface or between two cylindrical surfaces whose axes are parallel (2).

**NOTE 3:** For certain grades of paper "line contact" jaws may not be appropriate and it may be necessary to substitute flat gripping surfaces. Certain grades are damaged by the "line contact" loading between cylindrical and flat surfaces. The use of emery cloth on flat gripping surfaces will help minimize slippage for some board grades.

4.1.2 The clamping surfaces of the two jaws shall be in the same plane and so aligned that they hold the test specimen in that plane throughout the test. The clamping lines shall be parallel to each other within an angle of  $\pm 1^\circ$ , and shall not change more than  $0.5^\circ$  during the test. The applied tensile force shall be perpendicular to the clamp lines within  $\pm 1^\circ$  throughout the test.

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<sup>1</sup>Names of suppliers of testing equipment and materials for this method may be found on the Test Equipment Suppliers list in the set of TAPPI Test Methods, or may be available from the TAPPI Quality and Standards Department.

4.1.3 The distance between line contacts at the start of the test shall be adjustable and resettable to  $\pm 0.5$  mm (nominally 0.02 in.) for the specified initial test span (6.4). (See 11.3.)

4.1.4 The rate of separation of jaws shall be  $25 \pm 5$  mm/min (nominally 1.0 in. /min), or as otherwise noted (6.5) and once set shall be resettable and constant to  $\pm 4\%$ . (See 11.3.)

4.1.5 Recorder or indicator capable of indicating the actual force on the specimen within 1% or 0.1 N, whichever is greater.

4.1.6 Recorder speed or indicator shall be adjustable to provide a readability and accuracy of  $\pm 0.05\%$  stretch.

4.2 *Alignment jig* (optional) (2) to facilitate centering and aligning the specimen in the jaws, so that the clamping lines of contact are perpendicular to the direction of the applied force and the center line (long dimension) of the specimen coincides with the direction of applied force.

4.3 *Planimeter* or *integrator*, respectively, to measure the area beneath the load-elongation curve or to compute directly the work to rupture, with an accuracy of  $\pm 1\%$ .

4.4 *Specimen cutter*, for cutting specimens of the required width, with straight parallel sides (5.3).

4.5 *Magnifier and scale* or *optical comparator*, capable of measuring the specimen width to the nearest 0.1 mm (0.004 in.).

**NOTE 4:** Fully automated laboratory management and/or data acquisition systems are available which perform several functions such as: automatic calibration check, pre-setting and storing a variety of test programs, cutting the test strip, acquiring test data, and accurately determining the tensile breaking properties of paper and paperboard. These tests may be performed with the test strip horizontal or vertical by such equipment. Such equipment may be suitable for use in performing this method; however, the user is responsible for making independent assessment of this fact on the basis of data generated using specific equipment.

## 5. Sampling and test specimens

5.1 For sampling for acceptance of a lot of paper, paperboard, related product, without prior agreement between buyer and seller, use TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product."

5.2 For sampling for quality control and other purposes, use accepted and agreed upon company and laboratory sampling practices.

5.3 Precondition, then condition, the sample in accordance with TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products" prior to cutting the specimens.

**NOTE 5:** The exposure of the paper to a high relative humidity before preconditioning and conditioning can lead to erratic results varying from a decrease in stretch and tensile to a substantial increase (30% increase in stretch not uncommon) in these properties. Consequently, TEA is similarly affected. Careful protection of the sample from the time of sampling until testing is therefore very important.

5.4 Cut 10 test specimens from each test unit of the sample in each principal direction of the paper  $25 \pm 1$  mm (nominally 1.0 in.) wide with sides parallel within 0.1 mm (nominally 0.004 in.) and long enough to be clamped in the jaws when the test span is  $180 \pm 5$  mm (nominally 7.0 in.), leaving enough length so that any slack can be removed from the strip before clamping. (See 11.3.) Insure that strips are free from abnormalities, creases, or wrinkles. In some cases, it may be impossible or impractical to obtain a test specimen having a length long enough to be clamped in the jaws having the test span specified here. In such cases, see Appendix A.3.1 for special considerations and procedures required for testing samples at smaller test spans.

## **6. Procedures**

6.1 Perform the test in the testing atmosphere specified in T 402.

6.2 If the test specimen width is not known to 0.1 mm (nominally 0.004 in.) (i.e., if a previously evaluated precision cutter is not used), determine width and parallelism using magnifier and scale. Lack of parallelism is indicated by a difference in width of the two ends of the specimen.

6.3 The testing machine shall be calibrated and adjusted as described in Appendixes A.1 and A.2.

6.4 Set the clamps to an initial test span (distance between line contacts) of  $180 \pm 5$  mm (nominally 7.0 in.). Determine and always reset this distance within  $\pm 0.5$  mm (nominally 0.02 in.). (See Appendix A.1.3.)

6.5 Set the controls for rate of separation of the jaws to  $25 \pm 5$  mm/min (nominally 1.0 in./min). (See 11.3.) In cases where the time required to break a single strip exceeds 30 s, a more rapid rate of jaw separation shall be used, such that the time to break a single strip will be between 15 and 30 s. In such cases, the speed of the instrument must be reported, along with the test data.

**NOTE 6:** For purposes of determining shipping sack and shipping sack paper TEA compliance with Carrier and Federal requirements, Uniform Freight Classification Rule 40, National Motor Freight Classification, Item 200, UUS 48 and Department of Transportation 178.236, 4.8 in. (122 mm) between the jaws and 1 in. (25 mm) per minute jaw separation should be used.

6.6 Select recorder speed or indicator to give a readability equivalent to 0.05% stretch.

6.7 Select the full-scale reading, if possible, so that breaking force can be read in the upper three-fourths of the scale. Make preliminary trial tests if necessary to determine full-scale load.

**NOTE 7:** If, for any reason, any of the testing conditions specified above (specimen length, rate of jaw separation, sample width, etc.) cannot be followed because of the small sample size or other reason, the method variance *must* be stated in the report.

6.8 Align and clamp the specimen first in one jaw and then, after carefully removing any noticeable slack, but without straining the specimen, in the second jaw. While handling the test specimen, avoid touching the test area between the jaws with the fingers. Use a clamping pressure determined to be satisfactory (Appendix A.1.4), i.e., so that neither slippage nor damage to the specimen occurs. Automated instruments for which both jaws close simultaneously are within the context of this method.

6.9 Test 10 specimens in each principal direction for each test unit.

6.10 Reject any value in which the test specimen slips in the jaws, breaks within the clamping area, or shows evidence of uneven stretching across its width. Also reject any values for test specimens which break within 5 mm of the clamp area if further inspection indicates the break location is due to improper clamping conditions or misalignment. If more than 20% of the specimens for a given sample are rejected, reject all readings obtained for that sample, inspect the apparatus for conformance with specifications, and take any steps necessary to correct the trouble.

6.11 If determining tensile strength and stretch, read and record the breaking force to 0.5% of full scale and the elongation at break to the equivalent of 0.05% stretch.

6.12 If determining tensile energy absorption, record the integrator reading or use the planimeter to determine the area under the load-elongation curve from zero load to the breaking load.

**NOTE 8:** For the purpose of terminating integration, the specimen will be deemed broken when maximum tensile load has been reached and the tensile load has dropped no more than 0.25% of the full-scale load below the maximum load. This procedure is applicable in the determination of TEA as long as maximum strain occurs at rupture, which is usually the case.

6.13 If determining tensile stiffness, measure the strain at two force levels within the elastic region of the tensile force-strain relationship. The lower of the two force levels must be at least 5% of the apparent elastic limit, the higher not more than 75%, and the two force levels must be separated by at least 20% of the apparent elastic limit. For purposes of this measurement, the apparent elastic limit is defined as the point at which the tensile force-strain relationship departs from linearity. Alternately, the slope can be continuously monitored, and the maximum value taken as the measure of tensile stiffness. Determine the tensile stiffness,  $S_t$ , from:

$$S_t = (\Delta f \cdot L) / (w \cdot \Delta L)$$

where:

$S_t$  = Tensile stiffness, kN/m

$\Delta f$  = difference between two force levels, kN

$L$  = initial test length, m

$w$  = initial specimen width, m

$\Delta L$  = change in length corresponding to  $\Delta f$ , m

## 7. Calculations

7.1 For each test unit and in each principal direction, calculate from the recorded values the average breaking force, average elongation at break, average integrator or planimeter value, and the average elastic slope, as required. Correct the instrumental results, if necessary, according to the correction curve described in the Appendix (A.2.2).

Corrections for instrumental deflection need to be applied to both the elongation and energy measurements. Determine the range or standard deviation in each case.

7.2 Divide the average breaking force by the specimen width (as determined in 6.2) to obtain the tensile strength. If this has been measured in pounds and inches, convert to kN/m by multiplying by 0.1751. If this has been measured in kg/mm, convert to kN/m by multiplying by 9.807.

**NOTE 9:** To calculate the breaking length (air dry) in meters use the following formula:

$$BL = 102,000 (T/R) = 3658 (T'/R')$$

To calculate the tensile index in newton meters per gram use the following formula:

$$TI = 1000 (T/R) = 36.87 (T'/R')$$

where

TI	=	tensile index, N • m/g
BL	=	breaking length, m
T	=	tensile strength, kN/m
T'	=	tensile strength, lbf/in.
R	=	grammage (air dry), g/m <sup>2</sup>
R'	=	mass per unit area (air dry), lb/1000 ft <sup>2</sup>

7.3 To calculate the percentage stretch, divide the average elongation at break by the initial test span (as determined in 6.4) and multiply by 100.

7.4 Multiply the average integrator or planimeter value by the appropriate factor for the equipment and settings used to obtain the area under the load-elongation curve (Note 8) in energy units, joules (preferred) or inch-pound force. Then calculate the tensile energy absorption, according to one of the following formulas (see Appendix A.4 for proof of constants):

$$TEA = 1 \times 10^6 A/LW \text{ or } 9.807 \times 10^4 A' / LW \text{ or } 175.1 a/lw$$

$$tea = 12 a/lw$$

where:

TEA	=	tensile energy absorption, J/m <sup>2</sup>
L	=	initial test span, mm
W	=	specimen width, mm
A	=	area under load-elongation curve, J

- $A'$  = area under load-elongation curve, kgf • cm  
tea = tensile energy absorption, ft • lbf/ft<sup>2</sup>  
a = area under load elongation curve, lbf • in.  
l = initial test span, in.  
w = specimen width, in.

To convert tensile energy absorption in ft • lbf/ft<sup>2</sup> to J/m<sup>2</sup>, multiply by 14.60.

**NOTE 10:** The “area under the load-elongation curve” is the area between the curve and the elongation axis.

7.5 Divide the elastic slope by the specimen width to obtain the tensile stiffness. If the slope has been measured in pounds and inches, convert to kN/m by multiplying by 0.1751.

7.6 Determine the corresponding ranges or standard deviations from the ranges or standard deviations of the measured values (7.1).

**NOTE 11:** Hardware/software systems are available that will perform all calculations required in the desired units of measurements.

## 8. Report

- 8.1 Report for each test unit and in each direction to three significant figures:
- 8.1.1 The average tensile strength and the range or standard deviation in kN/m and (if desired) in lbf/in.
  - 8.1.2 The average stretch and the range or standard deviation as a percentage.
  - 8.1.3 The average tensile energy absorption and the range or standard deviation in J/m<sup>2</sup> and (if desired) in ft • lbf/ft<sup>2</sup>.
  - 8.1.4 The average tensile stiffness and the range or standard deviation in kN/m and (if desired) in lbf/in.
- 8.2 Report, in each case, the number of tests rejected and the reasons for rejection.
- 8.3 Report any deviation in test procedure, as when a short specimen must be used, alternate clamping configurations are used, a wide or narrow strip was tested, or when the rate of jaw separation was varied from 25 ± 5 mm/min (nominally 1.0 in./min) as described in 6.5.

## 9. Precision

9.1 On the basis of studies (3) made in accordance with TAPPI T 1200 “Interlaboratory Evaluation of Test Methods,” two test results, each representing an average of 10 determinations, from the same or different samples as noted, are expected to agree within the amounts shown in Table 1. The interlaboratory study included 20 laboratories and 22 samples. The samples ranged in tensile strength from 2 to 12 kN/m, in stretch from 1 to 9%, and in TEA from 30 to 450 J/m<sup>2</sup>.

**Table 1.** 95% probability limits

	<i>Tensile strength*</i>	<i>% Stretch* %</i>	<i>TEA* %</i>
Repeatability (same sample, operator and apparatus)	5	9	10-16
Reproducibility (same sample, different laboratories)	10	25	22-36

\*Percentage of the average of the two results

9.2 In each case, the coefficient of variation of a test result (average of 10 determinations) is expected to be about 0.36 times the value shown in Table 1.

9.3 The repeatability of tensile stiffness measurements, based on test results from a single laboratory, is estimated to be 7-8%.

## **10. Keywords**

Paper, Paperboard, Tensile tests, Tensile strength, Stretch, Rupture work, Stiffness, Tensile energy absorption

## **11. Additional information**

11.1 Effective date of issue: to be assigned.

11.2 This test method may be used in place of the similar method for tensile strength and stretch (T 404) which uses a different type tensile testing machine. These methods are not strictly comparable in that different instrument types are used, but when similar testing conditions are used, they may give similar results. This test method permits four tests (tensile breaking strength, tensile energy absorption, elongation at break, and tensile stiffness) to be run simultaneously on the same test specimen. This test method also gives more detailed requirements for the apparatus (standardizing on the constant-rate-of-elongation apparatus) and more detailed instructions for the procedure.

11.3 The intent of this method is to specify a specimen width of about 1 inch, a test length of about 7 inches, and a testing speed of about 1 inch per minute. The metric equivalents of these are about 25, 180, and 25 mm, respectively. These “rounded” numbers are specified in the method, with large enough tolerances to accommodate both English and metric cutters and testers. As discussed in the Appendix, the use of values at different levels within the tolerances given will not significantly affect the test result.

11.4 In the modernized metric system, or System International (SI), the units of force and energy are newton (N) and joule (J), respectively. The factors for conversion from the relevant customary units to SI units are as follows:

Force:

$$1 \text{ lbf} = 4.448 \text{ N}$$

$$1 \text{ kgf} = 9.807 \text{ N}$$

Energy:

$$1 \text{ N} \cdot \text{m} = 1.000 \text{ J}$$

$$1 \text{ ft} \cdot \text{lbf} = 1.356 \text{ J}$$

$$1 \text{ m} \cdot \text{kgf} = 9.807 \text{ J}$$

Tensile strength:

$$1 \text{ lbf/in.} = 0.175 \text{ kN/m}$$

$$1 \text{ kgf/15 mm} = 0.654 \text{ kN/m}$$

Tensile index:

The breaking length in meters is numerically equal to 102 times tensile index in newton meters per gram.

Tensile energy absorption:

$$1 \text{ ft} \cdot \text{lb/ft}^2 = 14.60 \text{ J/m}^2$$

Tensile stiffness:

$$1 \text{ lbf/in.} = 0.175 \text{ kN/m}$$

11.5 This method was first published in 1964 as a Suggested Method and became an Official Method in 1970. Tensile stiffness was added to the 1996 revision of the method.

11.6 Related methods: ASTM D828 "Tensile Breaking Strength for Paper and Paperboard Using Constant Rate of Elongation Apparatus," American Society for Testing and Materials, Philadelphia; AS1301.448S "Tensile Strength of Paper and Paperboard (Constant Rate of Elongation Method)," Technical Association of Australian and New Zealand Pulp and Paper Industry, Carlton, Victoria, Australia; D.6H, "Tensile Breaking Strength of Paper and Paperboard (Using Constant Rate of Loading Apparatus)," Pulp and Paper Technical Association of Canada, Montreal, Canada; AFNOR QO 3-001, Association Francaise de Normalisation, Paris, France; VXPCI, V12, Zellcheming, Rheinstrasse, Germany; ISO 1924, "Paper and Board, Determination of Tensile Strength," International Organization for Standardization, Geneva, Switzerland; SCAN P38, "Tensile Strength Stretch TEA and Tensile Stiffness of Paper and Paperboard," Scandinavian Pulp, Paper, and Board Testing Committee, Stockholm, Sweden. ISO 1924, and other methods noted above, may differ from T 494 in required specimen dimensions, testing speed, or number of tests.

## Appendix

### A.1 *Adjustment and maintenance of testing machine*



A.1.1 Regularly inspect the machine for cleanliness and for faults such as wear, misalignment, loose parts, and damage. Clean the machine and rectify any faults.

A.1.2 Level the machine accurately in its two principal directions. Align the clamping jaws to hold the specimen in the plane of the applied load throughout the test.

A.1.3 Position the jaws so that the test span is as specified in 6.4. Verify by measuring the effective test span, e.g., by measuring the distance between the centers of the line clamp impressions produced on strips of thin foil.

A.1.4 Determine appropriate clamping pressure so that neither slippage nor specimen damage occurs.

**NOTE 12:** Papers prepared from the more highly hydrated or beaten stocks, such as tracing paper or glassine, present the most difficult gripping problem. Thus, it is recommended that the clamping pressure be adjusted by making a test with a strong tracing paper. The clamping pressure is adjusted to give satisfactory results with this wide variety of papers in the intermediate weight and strength range. The use of excessively high pressure is shown by straightline breaks in, and immediately adjacent to, the clamping zone; whereas the use of too low a pressure shows an abrupt discontinuity in the load-elongation curve, or failure of the specimen beyond the clamped zone, or, following the test, a wider-than-normal impression of the clamping line.

## A.2 *Calibration of testing machine*

A.2.1 After leveling the machine accurately, calibrate the load measuring mechanism with standard weights by the dead-weight method; i.e., obtain readings at about ten points evenly spaced throughout the scale, by applying known weights with increasing then decreasing increments to the clamp actuating the indicating or recording mechanism. Note the scale readings when the weights and mechanism come gently into the equilibrium position. If readings differ from the corresponding applied loads by more than 0.5%, construct a correction curve.

**NOTE 13:** This calibration procedure is only applicable for vertical tensile instruments. For horizontal instruments, follow recommended manufacturer's procedures.

A.2.2 Calibrate the extension measuring mechanism with inside vernier calipers or other appropriate means over the entire load range of interest (*I*). Read the elongation scale at a number of points evenly spaced over the range from about 1 to 20% strain. If readings are in error by more than 0.1% strain, construct a correction curve.

## A.3 *Modifications of procedure (and effects thereof)*

### A.3.1 *Test specimens*

A.3.1.1 If undersized specimens must be used (e.g., because of size of sample sheets), use 25 mm (preferred) or 15 mm width and lengths long enough to be clamped in jaws either  $100 \pm 5$  mm ( $4 \pm 0.2$  in.) or  $50 \pm 2$  mm ( $2 \pm 0.1$  in.) apart.

A.3.1.2 The shorter test spans will give higher readings, and it is difficult to measure the elongation accurately [see the Pierce weak-link theory (4, 5)]. For papers which have a poor formation, the difference between a test span of 100 mm and the standard span of 180 mm may amount to over 10% in tensile strength and TEA.

**NOTE 14:** The tensile breaking load, and consequently the breaking strain and TEA, is known to decrease as the test span increased. The decrease occurs because tensile specimens fail at the weakest part along their length, and because as the test length is increased the probability of including a still weaker part also increases.

The effect of test span on breaking load of paper has been found (4) to follow the Pierce (5) weak-link theory which states that:

$$F_{rl}/F_L = 1 - 4.2(1 - r^{-0.2})V/100$$

where:

- $F_L$  = breaking load at span  $L$
- $F_{rl}$  = breaking load at span  $rL$
- $V$  = coefficient of variation at span  $L$

Table 2 shows the predicted change in tensile breaking load at several test spans and levels of variability, relative to the breaking load at a test span of 200 mm (4, 5). For example, if a paper is tested for tensile strength using a test span of 50 mm, and the coefficient of variation is 6% of the average measured tensile, then that test result would be 8% higher than would be obtained had the test been made using a span of 200 mm.

A.3.1.3 The sample width is used in the calculation of tensile strength, TEA, and tensile stiffness. Studies have shown that lower results will be obtained for specimens having widths less than about 12 mm. For specimens having widths greater than 12 mm, test results per unit width are not significantly affected by specimen width.

#### A.3.2. Procedure

A.3.2.1 At shorter initial test spans, adjust the rate of jaw separation so that the strain rate matches that achieved with the test span and rate specified in 6.4 and 6.5. This strain rate (rate of jaw separation/test span) is  $0.14 \pm 0.04$  (mm/min / mm). For example, if only one-half (90 mm) of the specified test span were used, the test speed would be set at one-half (12.5 mm/min) of the specified speed.

A.3.2.2 Doubling the test speed (for same length specimen) will increase the apparent tensile strength and may increase TEA for some papers approximately 3%. In other cases stretch will be reduced, thus acting to keep TEA nearly constant.

A.4 Proof of constants:

$$\begin{aligned} \text{TEA (J/m}^2\text{)} &= \frac{A \text{ (J)}}{L \text{ (mm)} \mid W \text{ (mm)}} \mid \frac{(1000 \text{ mm})^2}{\text{m}^2} \\ &= 1 \times 10^6 A/LW \\ \text{TEA (J/m}^2\text{)} &= \frac{A' \text{ (kg}_f\text{)(cm)}}{L \text{ (mm)} \mid W \text{ (mm)}} \mid \frac{(1000 \text{ mm})^2}{\text{m}^2} \mid \frac{\text{m}}{100 \text{ cm}} \\ &\times \frac{1 \text{ J}}{\text{Nm}} \mid \frac{\text{N} \cdot \text{S}^2}{(\text{kg}_m) \text{ (m)}} \mid \frac{9.807 \text{ (kg}_m) \text{ (m)}}{(\text{kg}_f)\text{S}^2} \\ &= 9.807 \times 10^4 A'/LW \\ \text{TEA (J/m}^2\text{)} &= \frac{a \text{ (lb}_f \cdot \text{in)}}{l \text{ (in)} \mid w \text{ (in)}} \mid \frac{\text{J}}{0.7376 \text{ ft} \cdot \text{lb}} \\ &\times \frac{\text{ft}}{12 \text{ in}} \mid \frac{(39.37 \text{ in})^2}{\text{m}^2} \\ &= 175.1 a/lw \end{aligned}$$

**Table 2.** Predicted change in tensile breaking load.

Coefficient of variation, %	Predicted change in breaking load, %				
	50 mm span	100 mm span	200 mm span	300 mm span	400 mm span
2	2.7	1.2	---	-0.7	-1.1
4	5.4	2.5	---	-1.3	-2.2
6	8.0	3.7	---	-2.0	-3.3
8	10.7	5.0	---	-2.6	-4.3
10	13.4	6.2	---	-3.3	-5.4

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*Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Director of Quality and Standards.* ■