Designation: D 5803 – 97 (Reapproved 2002)

An American National Standard

Standard Test Method for Tensile Strength at Zero-Span ("Wet Zero-Span Tensile")[1]

This standard is issued under the fixed designation D 5803; 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.

INTRODUCTION

The determination of the tensile strength of paper and paperboard when dry or wet is described in Test Methods D 828 and D 829, respectively. In these procedures, the standard effective specimen length is defined by the tensile tester grip separation at the start of the test. This standard grip separation, sometimes called gage length or span, is 180 mm (7.1 in.). Other gage lengths are permitted for specific testing purposes and are described in the respective test methods.

At a gage length of 180 mm, the measured tensile strength of a sheet of paper or paperboard is heavily impacted by sheet structural characteristics such as formation, basis weight, fiber orientation, and other structural characteristics, and is essentially unchanged at gage lengths ranging from 50 to 200 mm. Sheet structural characteristics, in turn, are dependent upon fundamental properties of the individual fibers and the way these properties are impacted throughout the entire papermaking process. This is true whether the specimens for testing are taken from an early or intermediate point in the papermaking process, or are sampled after the finished paper material has been produced.

At a gage length of zero, however, tensile strength is highly dependent upon fundamental strength and other quality properties of individual fibers rather than sheet structural properties. Tensile data measured at a gage length of zero is typically higher than that measured using Test Method D 828, because the strength of individual fibers, as opposed to the cumulative effect of fiber properties (particularly bonding) on sheet characteristics is being measured.

Tensile strength data at a gage length of zero may be used to assess the retention of fiber strength and fiber quality parameters through the entire fiber processing chain, thereby providing opportunities to optimize fiber characteristics and utilization in various paper grades. Tensile strength values determined at a gage length of zero contribute to our understanding of finished sheet strength and are of increasing importance in measuring the impact of new pulping, bleaching, and papermaking processes on fiber quality characteristics. In turn, fiber quality characteristics impact fiber processing and utilization considerations, and of most importance, the overall finished paper or paperboard properties and quality.

For ease in communication, as well as theoretical considerations, very short-span measurement of fibers in sheeted form is generally done at "zero-span," that is, at an effective gage length of 0.00 mm (0.000 in.). When the specimen is tested in the dry state, this measurement is generally referred to as "zero-span tensile strength." When the specimen is tested after wetting, the measurement is described as "wet zero-span tensile strength."

1. Scope

1.1 This test method provides a quick, reliable means to measure the wet zero-span tensile strength of a specimen of sheeted material.

1.2 In cases where fibers are to be tested prior to finished production of paper or paperboard, a random standard aggregate of pulp fibers, or handsheet, produced using a standardized procedure, such as, TAPPI T 205 is required.

1.3 This test method requires specimens such as those described in 1.2.

1.4 While testing is possible on finished paper or paperboard, information on fiber quality from intermediate steps in the pulping or papermaking process, or both, is frequently

[1] This test method is under the jurisdiction of ASTM Committee D06 on Paper and Paper Products and is the direct responsibility of Subcommittee D06.92 on Test Methods.

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more useful for improving finished paper and paperboard quality or improving fiber utilization of recycled fibers, or fibers subjected to new pulping, bleaching, or finishing processes **(1, 2, 3, 4)**.[2]

1.5 The modifications of this test method required for testing finished paper is straightforward; however, testing shall be done in the two principle directions of the sheet, as required in Test Method D 829. The finished paper or paperboard will generally have nonrandom fiber orientation, resulting in different strength properties in the two principle directions of the finished sheet. Testing of sheets having a grammage greater than 100 g/m^2, which includes some paper materials described as paper and many paperboards, is difficult because of problems associated with clamping of individual fibers as the number of fibers per unit area increases.

1.6 Modifications such as those in 1.5 are not described in this test method. If modifications are made, they must be acknowledged and clearly described in the report as deviations from the standard procedure.

1.7 *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 586 Test Method for Ash in Pulp, Paper, and Paper Products[3]

D 828 Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-of-Elongation Apparatus[3]

D 829 Test Methods for Wet Tensile Breaking Strength of Paper and Paper Products[3]

D 1193 Specification for Reagent Water[4]

D 1968 Terminology Relating to Paper and Paper Products[3]

E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for Characteristic of a Lot or Process[5]

2.2 *TAPPI Standards:*

T 205 Forming handsheets for physical tests of pulp[6]

T 220 Physical testing of pulp handsheets[6]

3. Terminology

3.1 For definitions used in this test method, refer to Terminology D 1968 or the *Dictionary of Paper*.[6]

4. Summary of Test Method

4.1 A sample is selected and a handsheet is prepared using TAPPI T 205 or another agreed-upon procedure.

4.2 A specimen of the prepared handsheet is cut for testing such that the specimen width is approximately 5.6 mm wider than the zero-span jaws which will be used in the testing.

4.3 The specimen is wetted with reagent water using a sponge and wet roller.

4.4 The wet specimen is inserted into the jaws of a suitable tensile tester having grips which are adjusted to at an effective gage length of 0.00 mm or "zero-span".

4.5 The tensile tester is activated and the wet zero-span tensile strength is determined and reported in newtons per centimetre, or in other units of user choice.

5. Significance and Use

5.1 The wet zero-span tensile test measures the tensile strength at the moment of tensile failure of wet fibers, which are clamped in the two jaws of a suitable tensile tester. The wet zero-span tensile value may be used to assess the tensile strength of individual fibers in their length dimension when wet.

5.2 For unbeaten chemical pulps, the wet zero-span tensile test is a very sensitive measure of the loss in individual fiber strength in the length dimension (axial tensile strength of the individual fibers) due to pulping and bleaching.

5.3 For mechanical pulps, the wet zero tensile test is a very sensitive measure of quality and strength of the finished sheet in terms of fines content and particle size, because the absence of a harsh chemical environment over a significant time means that the strength of the individual fibers undergoes minimal change.

5.4 Wet zero-span tensile data may be used to indicate individual fiber strength and guide the best utilization of fibers of unknown history, such as recycled fiber material.

5.5 The relationship between the strength of a fibrous sheet is determined by methods such as Test Methods D 828 and D 829 fibers, and the strength of the individual fiber comprising the sheet is important to overall properties of the finished sheet and may be studied using this test method.

5.6 More theoretical interpretations of wet zero-span will be found in the early work of Van den Akker **(5)** and the later work of Boucai **(6)**. See Appendix X1.

6. Apparatus

6.1 *Clamping Jaws*, two adjacent, spatially aligned clamping jaws in initial intimate contact ("zero-span"), which reliably and reproducibly exert a very high, optimum, and uniform clamping pressure on fibers in a test specimen after the specimen has been wetted with reagent water using a defined procedure. The essential elements that shall be incorporated into any wet zero-span tester are shown in Fig. 1.

6.1.1 The clamping pressure required ensures a maximum clamping effect but cannot totally prevent the microslippage, whereby the tensile load transmitted in the clamped fibers is dissipated by frictional shear into the clamping jaws. This microslippage means that the ends of some fibers will slip out from beneath a clamping jaw, thereby diminishing the number of fibers carrying the load at tensile failure. For this reason, careful interpretation of the wet zero-span tensile strength value must be exercised in order to separate effects due to the relative number of fibers which are carrying the load at failure

[2] The boldface numbers in parentheses refer to the list of references at the end of this test method.

[3] *Annual Book of ASTM Standards*, Vol 15.09.

[4] *Annual Book of ASTM Standards*, Vol 11.01.

[5] *Annual Book of ASTM Standards*, Vol 14.02.

[6] Available from the Technical Association of the Pulp and Paper Industry (TAPPI), P.O. Box 105113, Atlanta, GA 30348.

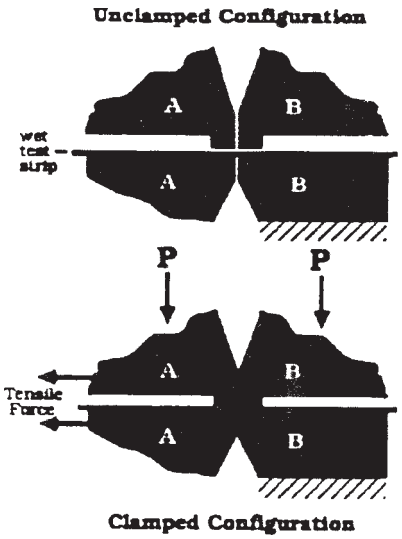


FIG. 1 Essential Elements for Any Wet Zero-Span Tester

and the effects due to the average tensile strength of the individual fibers present in the aggregate.

6.2 While firmly clamping the specimen, the clamps shall separate at a defined uniform rate of loading until the sample fails.

6.3 There are two adjacent clamping jaws which, in an unpressurized configuration, allow a wet test strip to be inserted between them. In the pressurized configuration, both jaws come together to apply a very high and uniform clamping pressure to the wet test strip. This securely clamps the wet fibers in the specimen that crosses the clamping line, defined by the intimate and very accurate spatial alignment of the two jaws at zero-span.

6.4 *Means to Apply Tensile Force*, tending to cause one jaw to move away from the other.

6.5 *Measuring System*, to record the tensile load carried by the specimen at the moment of the tensile failure.

6.6 *Clamping Arrangement*, suitable for either of the two clamping jaws is illustrated in Fig. 2. The required clamping dimensions include a clamping width of not less than 15.0 mm and a clamping length of not less than 0.060 mm. Clamping widths as great as 22.0 mm, and clamping lengths of 0.80 have been found satisfactory. It is extremely important that the clamping width be accurately determined to the ±0.01 mm, using a digital caliper or similar device with calibration accuracy traceable to NIST, or equivalent national standardizing body, and that the two clamps making up a pair have identical clamping widths to the same tolerance. The exact length of the clamp is not critical, but pairs of clamps shall have widths identical to the tolerance of ±0.01 mm. The clamping jaws should come together to provide a clamping pressure which is uniform across the clamping width to better than 1 part in 1000. The clamping jaws should be manufactured to ensure the maintenance of such precision over an extended period of repetitive high-pressure clamping in a wet environment (stainless steel or other rust-resistant alloy).

6.7 The spatial alignment of the two jaws is illustrated in Fig. 3. The top and bottom clamping surfaces of both sets of jaws shall come together in the clamped arrangement to create the two precision planes illustrated. When clamped, the horizontal surfaces of both jaws shall conform to Plane A, to a tolerance of 0.005 mm or less. The vertical surfaces which are in contact at zero-span shall, when clamped, conform to Plane B with a tolerance such that a light beam is completely interrupted when the jaws are in clamped zero-span contact.

6.8 The apparatus shall provide the capability to cause both clamping jaws to come together so as to induce an adjustable range of measurable clamping pressures sufficient to demonstrate optimum clamping of the wet fiber aggregate.

6.9 Increasing the jaw clamping pressure from a low value improves clamping efficiency, resulting in an increase in the observed zero-span tensile failure load of wet fiber aggregate. Such increases will continue until the clamping pressure reaches a level which causes fiber damage, after which the zero-span tensile failure load of the wet fiber aggregate will be observed to decline. The clamping pressure which maximizes the zero-span tensile failure load of the wet fiber aggregate is the optimum clamping pressure.

6.10 The apparatus must provide the means to exert and measure an in-plane tensile force within the clamped wet fiber aggregate and to increase this force at a controllable rate until tensile failure occurs. The increase in the tensile force is at a rate of 25 ± 2 N/s/cm of jaw width.

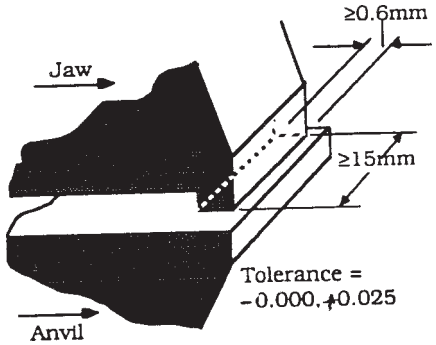


FIG. 2 Suitable Clamping Arrangement for Either of the Two Clamping Jaws

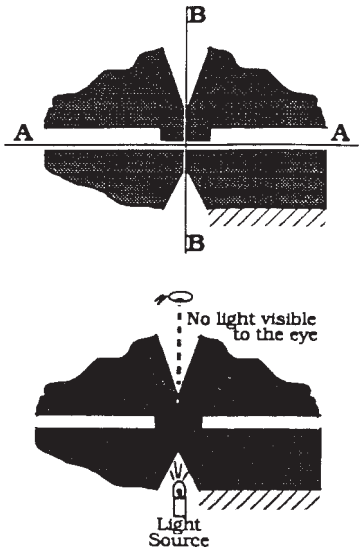


FIG. 3 Spatial Alignment of the Two Jaws

NOTE 1—There are at least three instrument systems complying with the requirements of Section 6. These are the specially designed zero-span jaws of Clark **(7)**, and those of Wink and Van Eperen **(8)**, either of which can be used with a conventional tensile testing instrument such as is described in Test Method D 828, and a self-contained unit comprised of a tensile measuring system and zero-span jaws.[7] For this test method, where the specimen is handled wet (and may be extremely fragile), a self-contained instrument is significantly easier to use than are the zero-span jaws of Clark or Wink and Van Eperen.

7. Reagents

7.1 *Distilled Water*—Any of the four grades of water described in Specification D 1193 are suitable for making the measurements described in this test method.

8. Sampling

8.1 The sampling and number of test specimens taken depends upon the purpose of the testing. Practice E 122 is recommended.

8.2 Take samples at various points in the production process, depending upon the information required or agreement of parties involved in the testing.

9. Preparation of Apparatus

9.1 Prepare the apparatus chosen for use in accordance with Section 6, following the manufacturer's instructions.

10. Calibration and Maintenance

10.1 *Calibration*—Use the calibration procedure that is specified by the manufacturer. If no procedure is specified, use the following: Calibrate load measuring mechanism. Zero-span jaws, mounted vertically, may be calibrated using a dead weight or force gage traceable to NIST (similar to a conventional tensile tester). It is preferable to use a force gage on zero-span jaws that are mounted horizontally. Obtain readings at six points throughout the usable range of the load measuring mechanism. Applied values should agree with measured values to within 0.5 %.

10.2 *Maintenance*—Make sure that light passing between the jaws is totally absent when the clamping jaws are brought to zero-span contact. Careful and regular cleaning of the jaws is required to maintain the jaws in this state. It is particularly important to prevent fibers or solid deposits from forming between the lower jaws, as their presence will affect jaw performance and test results.

11. Sample Preparation

11.1 Because this test method requires a random aggregate of fibers in sheeted form for testing, even when the sample is obtained in sheet form, it must be reformed into a fiber slurry and then reformed into a randomly oriented sheet following standardized procedures such as TAPPI T 205.

11.2 When the sample is a pulp slurry, use the pulp sample in dilute slurry form as received or with further dilution in reagent water.

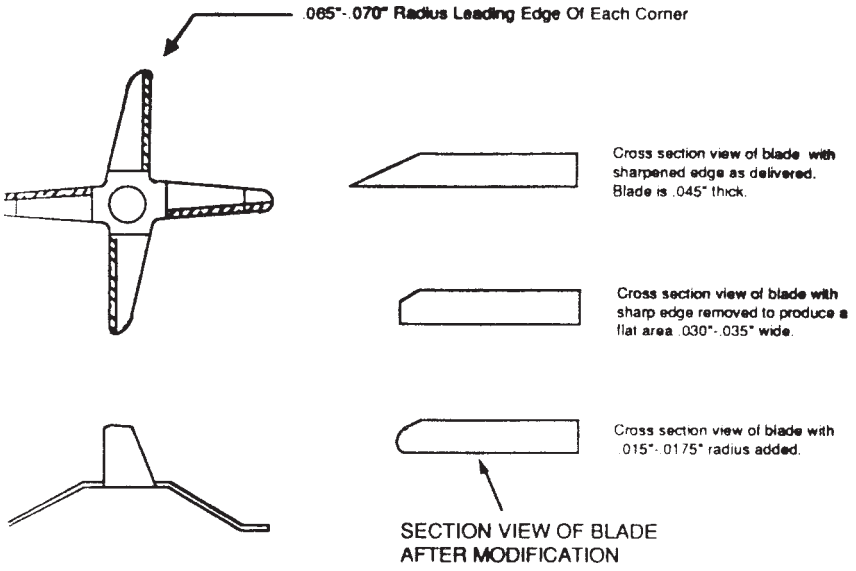
11.3 Reslurry a thickened pulp sample in reagent water in accordance with TAPPI T 205.

11.4 Soak in reagent water and disintegrate a dry pulp sample in accordance with TAPPI T 205.

11.5 Treat pulp samples derived as in 11.2 through 11.4 for 3 min at approximately 0.3 to 0.4 % fiber solids by weight in reagent water in a high-speed blender with dulled blades (Fig. 4).

11.5.1 The treatments described in 11.2 through 11.4 are applicable to the range of samples normally encountered. The treatment described in 11.5 for a wide range of sample types causes the wet zero-span tensile to reach a level which is constant over additional treatment for as much as 15 to 30 min and most samples of the types that will be tested are best compared using this treatment.

[7] Available from Pulmac Instruments, Montpelier, VT. An equivalent self-contained unit may be used.



NOTE 1—All four leading edges and corners must have 0.015 to 0.0175-in. (0.38 to 0.44-mm) radius added.

FIG. 4 Specifications for Blender

11.6 Using the fiber suspension from 11.5, prepare handsheets for testing using TAPPI T 205 or some other agreed-upon procedure.

11.7 As required in TAPPI T 205, the resulting handsheet will have a grammage of 60 g/m^2 with a tolerance of ±5 %. This is the grammage required in 12.1.

12. Procedure

12.1 Weigh each test handsheet to determine grammage in accordance with TAPPI T 220. As specified in 11.7, the grammage of the prepared handsheets must be 60 g/m^2 with a tolerance of + 5 %. Handsheets outside this tolerance range are not to be used.

12.2 Cut each test handsheet into test strips of a size to suit the wet zero-span tensile jaws which will be used (for example, 11 by 2 cm). Cut the test strip to a width which exceeds the width of the clamping jaws so that when a strip is located in the test position, it extends beyond the jaws in both directions by about 2.5 mm (for example, for a 15-mm jaw, the specimen width should be at least 20 mm).

12.2.1 The tensile measurement includes only the clamped fibers. The part of the test sheet outside of the clamping region will not affect the test result. This procedure guarantees that the fiber aggregate is uniformly clamped over the whole jaw width, with no edge effects.

12.3 Using a sponge and a wet roller, gently wet each strip uniformly before placing in the zero-span jaws of the tensile tester.

12.3.1 The sample is properly wetted when no "opaque" spots can be seen. Normal capillary action will readily draw sufficient water into the sheet to accomplish wetting, which will generally be instantaneous unless the sheet fibers have undergone extensive chemical or physical treatment prior to testing.

12.3.2 Place the rewet strip onto a sample inserter and place in the test position (Fig. 5). The wet sample inserter is used because of the tendency of wet test strips to fall apart when handled.

12.4 Activate the tester to conduct the zero-span tensile test and record the zero-span tensile load at failure, in Newtons, or units which can be converted to Newtons, or units as agreed upon by parties involved in the testing.

12.5 Make at least ten replicate determinations on each sample.

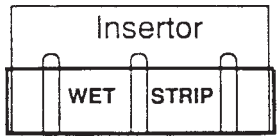


FIG. 5 Test Position

13. Calculations

13.1 Correct each of result to target grammage of 60 g/m^2(oven-dried equivalent: see TAPPI T 205), as follows:

$$\text{Corrected wet zero}-\text{span value} = \text{measured value} \times (60/\text{strip grammage}) \quad (1)$$

13.2 Calculate the wet zero-span tensile test value of each result corrected to 60 g/m^2 (oven-dried equivalent), in newtons per centimetre (to one significant figure after the decimal point) using Eq 2, as follows:

$$\text{Corrected wet zero}-\text{span value, N/cm} = \frac{\text{measured value} \times (60/\text{strip BW})}{\text{jaw width from 6.5, cm}} \quad (2)$$

13.3 Calculate the average wet zero-span tensile strength for each sample from all of the results from 13.3 for each sample tested.

13.4 If the original pulp sample contained filler or additive (typically from broke), or both, correct each wet zero-span tensile result to account for its presence (see Test Method D 586), as follows:

$$\text{Ash corrected wet zero}-\text{span value} = \text{uncorrected value} \times [100/(100 - \%\text{ash})] \quad (3)$$

14. Report

14.1 Report the following information:

14.1.1 The average wet zero-span tensile result from 13.3 or 13.4,

14.1.2 The range and standard deviation for results on specimens from each sample, and

14.1.3 Any deviations from the requirements of this test method.

15. Precision and Bias

15.1 *Precision*:

15.1.1 The estimated repeatability reported here was calculated on a total of 98 test determinations. These are twelve determinations per sample from three lots of material, each of which was sampled in triplicate. The three lots of material, bleach hardwood, bleached softwood, and neutral sulfite semi-chemical pulp, had test results ranging from 60 to 88 N/cm.

15.1.1.1 *Repeatability Standard Deviation (Within a Laboratory)*—1.5 % of the measured value.

15.1.1.2 *Repeatability Critical Limits, 95 % (Within a Laboratory)*—4.2 % of the measured value.

15.2 *Bias*—The procedure in the test method for zero-span tensile strength has no bias, because zero-span tensile strength is defined in terms of the specific testing conditions.

16. Keywords

16.1 fibers; paperboard; wet zero-span tensile; zero-span tensile

APPENDIX

(Nonmandatory Information)

X1. WET-ZERO SPAN EQUATION

X1.1 The wet zero-span equation is as follows:

$$Z_0 = (1 - f_f) f_0 N \phi t \quad \text{(X1.1)}$$

where:

Z_0 = observed wet zero-span tensile failure measurement, N/cm,
f_f = fraction of the sheet basis weight consisting of filler or fines,
f_0 = fraction of potentially active fibers (particles) which remain securely clamped and thus contribute to the wet zero-span failure load,
N = total number of fibers (particles) which cross the zero-span clamping line,
ϕ = coefficient in the wet zero-span equation, whose value reflects the degree of randomness of the fiber orientation in the specimen, and
t = average axial tensile strength of the individual fibers (particles) contained in the wet sheet.

X1.1.1 Particles below a certain size (approximately 200 µm) are too small to span the jaw separation present at zero-span failure. Such particles, qualitatively identified as fines and filler, cannot contribute to the wet zero-span failure load, but do contribute to basis weight. Thus, $(1 - f_f)$ expresses the fraction of the basis weight that can contribute to the wet zero-span failure load, that is, the fines and filler-free fraction of the basis weight.

X1.1.2 The magnitude of jaw separation at failure depends on the interaction of clamping pressure, surface friction, and wet fiber modulus which, for a given fiber type and constant clamping conditions, will be nominally constant. The probability that any particle will span this distance depends on particle length and orientation. For random orientation, the probability function will change only in response to changes in effective particle length. Thus, f_0 is in effect the average probability that fibers (particles) which are long enough to span the microslippage gap are securely clamped and thus carrying a load at wet zero-span failure.

X1.1.3 The number of (fibers) particles which cross a given clamping line is defined precisely by grammage, particle courseness (weight per unit length, w/l), and the length of the clamping line (ϕ) in accordance with the following equation:

$$N = \frac{\phi(grammage)}{w/l} \quad \text{(X1.2)}$$

X1.1.4 If all fibers were lined up in the direction of strain, the value would be 1.0. The theoretical value for randomly oriented fibers is 0.375.

X1.2 The wet zero-span measurement responds to two components. One of these is the quality of the wet sheet represented by the terms ($(1 - f_f) f_0 N$) where quality reflects fines content, effective fiber length, and fiber coarseness. The other component is determined by the average unit strength of the individual fibers in the wet aggregate (represented by the term ϕt).

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