T 569 pm-00

PROVISIONAL METHOD – 2000

Internal bond strength (Scott type)

1. Introduction

Printing, converting and many product applications subject paper and paperboard to impulses, impacts and shock loads into or out of the plane of the sheet. These can cause structural failures such as surface picks, blistering or delaminations within the interior of the sheet. The common denominators of these failures are a) the high velocity of the impact loads b) the short time period during which the material is stressed, frequently one to a few hundred milliseconds, and c) the planar nature of the resultant sheet failure. Test results from this method may correlate with product failures of this type.

2. Scope

2.1 This method defines a test that measures the energy required to rapidly delaminate a sheet-type specimen. The "Z" directional rupture is initiated by the impact of a pendulum having both a controlled mass and a controlled velocity that exceeds 6000 times the velocity of tensile strength and other dead-weight testers. The geometry of the apparatus causes the tensile stress to be rotational in nature with negligible shear stress on the specimen.

2.2 The method is suitable for both single and multi-ply paper and paperboard, including coated sheets and those that are laminated with synthetic polymer films.

2.3 Because sample preparation entails pressing double coated tape to both sides of the test specimen under relatively high pressures, this method may not be suitable for testing low basis weight, porous, soft or low density materials. Limitations include materials that permit significant migration of the tape's adhesive into the sample with potential tape-to-tape bonding, or materials that could be structurally damaged or collapse during the press cycle.

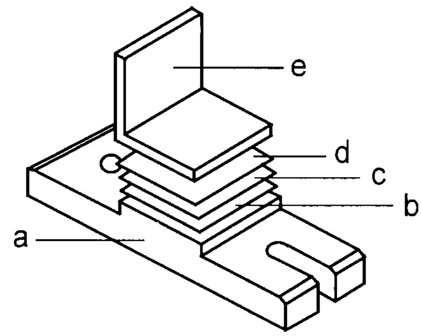
2.4 To determine the applicability of the test method, it is important to visually inspect both sides of a set of at least 10 delaminated samples. The ability to rupture a sample within the measurement range of the instrument is an insufficient criterion. For interpretations of observations, see Section 9.2.

2.5 Because energy is absorbed during the elongation and stretching of the sample's fiber network prior to rupture, this internal bond test responds to the semi-elastic nature of paper and paperboard. The test is a measurement of strain energy per unit sample area, which is proportional to the area under the stress-strain curve. Strength measurements by this method do not correlate with "Z" direction tensile strength tests (ZDT) that measure the maximum (peak) stress in a slow, constant rate of elongation or dead-weight rupture. Also, the constant rate of elongation specified in TAPPI T 541 "Internal Bond Strength of Paperboard (z-Direction Tensile)," (ZDT) and "X" and "Y" plane tensile tests per TAPPI T 494 "Tensile Breaking Properties of Paper and Paperboard (Using Constant Rate of Elongation Apparatus)," is several orders of magnitude less than the rate attained in this method.

3. Summary

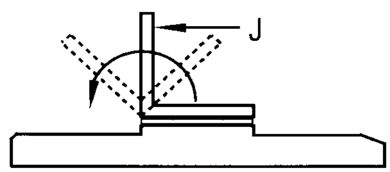
A sandwich consisting of double-coated tape, the paper specimen, and double-coated tape is pressed between a flat metal anvil and an aluminum platen as shown in Figure 1. A pendulum impacts the top inside surface of the platen, causing it to rotate and split the paper specimen in the thin, "Z" direction (see Figure 2). The energy absorbed in rupturing the sample is computed by measuring the peak excess swing of the pendulum. The strength equation parameters include a) the potential energy of the latched pendulum, b) the peak excess swing, c) the energy required to accelerate a bare sample angle away from the pendulum, d) frictional losses, and e) internal vibration losses within the pendulum.

Approved by the Physical Properties and Fiberboard Shipping Container Testing Committees
of the Process and Product Quality and Corrugated Containers Divisions
TAPPI



a steel anvil
b double coated tape
c specimen
d double coated tape
e aluminum platen

Figure 1



J = Pendulum Impact

Figure 2

4. Significance

4.1 Internal bond strength as defined in this method is indicative of the serviceability and processibility of many types of paper and paperboard. These include printing papers, cover, label, release, linerboard, carton, carrier, newsprint and others. Test results often correlate with high speed surface and internal structural failures encountered in both printing and converting operations.

4.2 Some fiber processing and papermaking characteristics can also be correlated with this type of internal bond strength test. These include extent of refining, machine speed, pressing, interply bonding in multiple headbox operations, and furnish composition such as long-to-short fiber mix, recycle content and the effect of dry strength additives. The test responds to both individual fiber strength characteristics and to the degree of interfiber bonding, but does not isolate and distinguish between these factors.

4.3 The combination of internal bond strength data with other TAPPI test methods can provide additional strength and processibility information. An example is the combination with porosity data derived from TAPPI T 460 “Air Resistance of Paper (Gurley Method)” or TAPPI T 547 “Air Permeance of Paper and Paperboard (Sheffield Method)” to predict blistering tendencies for coated web offset papers.

5. Apparatus and materials

5.1 A *multiple specimen preparation station* capable of pressing five 2.54 × 2.54 cm (1.0 inch × 1.0 inch) samples, the ability to accommodate specimens of varying caliper up to 1.25 mm (.050 inches) thick, with optional clamping pressures on the specimen from 345 kPa (50 psi) to 1034 kPa (150 psi) in at least 345 kPa (50 psi) increments. Pressure control shall be within ± 21 kPa (3 psi) at the most commonly used clamping pressure of 690 kPa (100 psi) and within ± 34 kPa at the 1034 kPa (± 5 at the 150 psi) level. A *strongback* is a component of the preparation station designed to temporarily retain and align the five aluminum platens and prevent their deflection during sample pressing.

5.2 A *pendulum* mounted on a pedestal, with an axle supported at two points on ball or similar low friction bearings, and whose center of gravity is located 127 ± 0.6 mm (5.00 ± .025 inches) from the centerline of the axle. The pendulum should be free to rotate from a horizontal position through at least a 180° swing and the impact ball on the pendulum shall strike the aluminum platen (see Section 5.4) when it reaches the vertical 90° point in its swing. The resultant 5.00-inch drop in the center of gravity thereby determines the velocity of the pendulum at impact. If weights are added to the pendulum to extend its range, they must be positioned so that the center of gravity is not altered. In addition, if adding weights alters the center of percussion of the pendulum, this factor must be reflected in the high range calibration for the instrument.

NOTE 1: See cautionary additional information in Section 13.3.

5.3 A means for holding the pendulum in a horizontal position with provision for instantaneous release.

5.4 A *stationary anvil (base) and a separable aluminum platen (sample angle)* that is a right angle in cross section. The specimen sandwich, anvil and platen are held stationary on a sample stage and positioned so that the pendulum strikes at the center of percussion of the platen when the center of oscillation (rotational axis) is at the outside corner of the right angle of the platen. See Figure 2.

5.5 A means of mechanically or electronically registering the peak angular swing of the pendulum after it is released and after it swings beyond the vertical (plumb) position.

5.6 A means to convert a measurement of the peak angular swing of the pendulum to internal bond strength and provide a visual display of this value. This non-linear calculation may be done with a mechanical scale and friction pointer or electronically with a digital computer. The minimum range of the instrument should be 525 joules/m^2 (0-250 ft. lbs. × 10^{-3}/sq. in.).

5.7 An *optional means to extend the range of the instrument*. This may be done by changing the complete pendulum, adding weights to the pendulum or reducing the surface area of the test specimen by a percentage not exceeding 40%.

5.8 A *specimen cutter* for cutting specimens 25.4 mm (1.00 inches) wide with straight parallel sides within 0.1 mm (.004 inches) and long enough for alignment in the specimen preparation station (see tolerances in Section 7.3).

5.9 A *knife or multi-blade cutting apparatus* for separating and trimming the five specimens to obtain edges without overlaps. The appropriate blade width is determined by the spacing of the anvils in the specimen preparation station and is specified by the apparatus manufacturer as either .025 or .038 cm (.010 or .015 in.).

5.10 *Double-coated paper tape* 2.54 ± .008 cm (1.00 ± .003 in.) wide with a creped release liner. The tape should exhibit a minimum adhesion to stainless steel of 45 oz./in. width when tested per ASTM D 3330, and should have a nominal thickness of 0.13 mm (see cautionary note in Section 8.5).

5.11 A *solvent such as isopropyl alcohol* for removing adhesive residue from the anvils and platens.

6. Calibration

6.1 For both mechanical and electronic instruments, it is important to mount the instrument on a rigid bench or table and carefully level it by means of its adjustable feet. Leveling is most accurately done with a 7.5 cm or longer machinist's level rather than relying on the limited resolution provided by the small circular levels mounted on commercial instruments. Level the instrument both side-to-side and front-to-rear using either the sample stage or the calibration weight slide as a reference surface in accordance with the instrument manufacturer's instructions.

6.2 Pendulums of multi-piece construction must be checked for structural integrity by gently attempting to twist the assembly along its length, perpendicular to its rotational axis (axle). If the lower portion of the pendulum is even slightly loose with respect to the main body, internal vibration losses can affect proper calibration and the entire pendulum assembly should be replaced.

6.3 Latch, then release the pendulum to establish a free swing calibration point in accordance with the instrument manufacturer's instructions. The angular difference between the “calibration” line and “zero” on the scale for mechanical instruments–or the specific "free swing number" and "zero" on the scale for the electronic instruments–represents the energy required to accelerate a bare aluminum platen away from the pendulum. This energy factor is thereby removed from the strength equation relating the pendulum's peak angular position to the energy required to rupture a sample.

6.4 For mechanical instruments, establishing a proper free swing by adjusting the pendulum friction nut completes the calibration procedure.

6.5 For electronic instruments, the readout for the plumb pendulum position should be adjusted in accordance with the manufacturer's instructions. The free swing value should then be re-checked and re-adjusted if necessary.

6.6 Calibration test weights, if provided with the instrument, should be tested by impacting with the pendulum in accordance with the manufacturer's instructions. Acceptable tolerances for the test weight readings are defined by the manufacturer. After impact, it is important to catch the flying test weights so that their surfaces are not damaged by falling on some hard surface.

7. Sampling and test specimens

7.1 Obtain a sample in accordance with TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard or Related Product."

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

NOTE 2: Exposure of the paper to a high relative humidity before preconditioning and conditioning can lead to erratic results. Careful protection of the samples from the time of sampling until testing is therefore very important.

7.3 From each test unit of the sample, accurately cut specimens 25.4 mm (1.00 inches) wide ± 0.1 mm (.004 inches) and 140 mm (5.5 inches) long. For accurate alignment in some specimen preparation stations, the specimens should be 178 mm (7.0 inches) long. Handle specimens by the extreme ends of the strip only. Ensure that strips are free from abnormalities, creases, or wrinkles.

8. Procedure

8.1 Perform the test in the testing atmosphere specified in TAPPI T 402.

8.2 Verify the width and parallelism of the samples. Lack of parallelism is indicated by a difference in width at the two ends of the specimen.

8.3 The testing apparatus shall be calibrated and adjusted as described in Sections 6.1 through 6.6.

8.4 Adjust and verify that the specimen preparation station exerts a pressure of 690 ± 21 kPa (100 ± 3 psi) at all positions and that semi-automatic types produce a clamp period of three seconds. The objective is to use the least pressure at or above 100 psi to avoid tape-to-metal separation at either the anvil or the aluminum platen.

NOTE 3: Excessive pressure and/or press time may result in migration of the adhesive into the specimen.

8.5 Load the tape dispenser with a roll of 25.4 mm (1.0 inch) ± 0.08 mm (0.10 inch) wide double-faced pressure sensitive tape (see Section 5.10).

NOTE 4: Although manufacturers quote a shelf life of one year for rubber based tapes, there can be a significant loss of tack after 6 months. Tape should be kept cool and dry by storing in an air-conditioned atmosphere, preferably at 70°F and *50%* relative humidity. Tapes with ridges and gaps that indicate a loosely wound roll will dry out rapidly and exhibit low tack. It may be necessary to strip back and discard two to three meters of an older or loosely wound roll to reach a layer of acceptable tape.

8.6 Lay the bottom steel anvils in their respective numbered positions on the preparation station with the locating holes on the front dowels and the slots toward the rear. Ensure that both the anvils and the aluminum platens are free of adhesive and fiber remnants from previous tests.

8.7 Pull out a strip of tape sufficient to extend across the anvils and beyond at least 2.5 cm. If wrinkles, dry spots or a noticeable lack of adhesion are apparent, that section of tape should be discarded. Bring the tape down on the anvils between the guide pins aligning the front edge carefully with the slot or ridge delineating the central, specimen area of the anvils. Avoid overlaps at the rear or front of the specimen area. Avoid air bubbles under the tape by keeping very slight tension on the tape during placement. Eliminate air entrapment and raised tape areas by tapping lightly with the back of the knife.

8.8 Place the strip of paper to be tested in exact position on this first layer of tape, being careful to hold the specimen by the ends only. Cut the tape and pull out a second strip of tape to extend between the guide pins, across the paper specimen and beyond at least 2.5 cm. Place the second strip of tape exactly on top of the paper specimen. Avoid overlapping the tape beyond the rear and front edges of the paper specimen to avert tape-to-tape bonding which can invalidate test results by restricting the paper rupture. Cut the tape-paper-tape sandwich with a knife.

8.9 Install the strongback loaded with five aluminum platens (angles) oriented with their vertical surfaces toward the front. The surface of each platen that contacts the tape must be flat, free of protrusions from nicks and have square edges.

NOTE 5: Worn and blemished platens can produce measurement errors of 15% and greater.

8.10 For mechanical sample presses, clamp the strongback in position with the knurled thumbscrews. Apply pressure by pulling the cam lever forward for two to three seconds. Clamping too long or at too high a pressure will cause adhesive to penetrate the specimen and invalidate the test results (see Section 9.3). Release pressure by returning the handle to its top position.

8.11 For pneumatic or hydraulic sample presses, follow the manufacturer's instructions to trigger the automatic press cycle. The clamp pressure should be set to 690 ± 14 kPa (100 ± 2 psi).

8.12 Unlock and remove the strongback carefully, leaving the aluminum platens adhered to the specimen sandwich. Separate each of the five specimens with a knife of appropriate blade thickness (see Section 5.9). Insert the knife between successive pairs of platens and anvils to cut through the sandwich of tape-paper-tape. On the end samples, trim the specimen carefully to avoid any overlaps or lips. Alternatively, follow the manufacturer's instructions when using multi-blade automatic cutting stations.

8.13 Swing the pendulum to the right until it latches. For mechanical instruments, swing the plastic pointer to this position also, ensuring that it touches the latch pin on the pendulum. Place the specimen on the sample stage with the slot of the anvil to the right and the vertical portion of the aluminum platen to the left. The anvil should be as far to the left as the locating pin will allow. Secure the assembly in place with the knurled thumbscrew on mechanical instruments or by activating the automatic clamp on electronic versions.

8.14 To make the test, release the pendulum, allowing it to rupture the sample. On mechanical instruments, depress the latch sharply and fully so that the pin does not drag on the lower latch. On electronic instruments use the index finger, not a thumb, to depress the drop switch and release the switch before the pendulum passes through the vertical position during its swing. Relatch the pendulum on its return swing. Read the results, reset the pointer on mechanical instruments, remove the first anvil from the sample stage, secure the next specimen assembly, etc.

8.15 Make at least five tests in each principal direction of the paper. For many grades there will be no statistically significant difference in machine direction versus cross direction test results. However, the direction of testing should be consistent and reported.

9. Calculations and interpretations of observations

9.1 Numerical results are obtained directly from the test apparatus and no calculations are necessary.

9.2 Examine both top and bottom surfaces of the specimen ruptures. Delamination near the mid-plane of the specimen, at any plane bounded completely by fibers, multi-ply ruptures, splits with pillowing of a second ply, or delaminations with clumps of fiber tufts on upper and lower plies indicate acceptable tests. Conversely, partial delaminations, an unsplit tongue torn from the specimen, evidence of tape-to-tape bonding or tape show-through of any type disqualify the test. Tape-to-metal peeling at the leading edge of the rupture invalidates that test sample. Tape-to-metal peeling at the trailing edge of the rupture may not invalidate the test if the results are within one standard deviation of other tests on the same paper.

9.3 At internal bond strength levels below 900 J/m^2 (450×10^{-3} ft. lbs./in.^{2}), tape-to-metal peeling should not occur if a) the tape is fresh and its tack is correct, b) the sample anvils and platens are flat and free of blemishes, and c) the sample press components are properly aligned to generate uniform and flat surface-to-surface contact. A clamp pressure of 690 kPa (100 psi) should be adequate for these tests. Above 900 J/m^2 it may be necessary to increase the clamp pressure to as much as 1035 kPa (150 psi). Do not increase the clamp pressure on low basis weight and low caliper printing grades because of the possibility of adhesive penetration into the specimen with areas of tape-to-tape bonding. Do not increase the clamp pressure on easily deformed specimens such as handsheets or linerboard. Excessive pressure produces abnormal test values. Increases in clamp pressure may be effective when testing heavier basis weight materials that are not easily crushed, such as core board and carrier.

10. Report

10.1 Report for each strip consisting of five test specimens, the direction of the test and:
10.1.1 The average internal bond strength in J/m^2 or (if desired) ft. lbs. $\times 10^{-3}/in.^2$, to three significant digits.
10.1.2 The standard deviation in the above units to two significant digits, or alternatively, as a percentage.
10.1.3 The number of tests rejected and the reason for the rejection.
10.1.4 The type of tape used and the clamp pressure.
10.2 Report any deviations in the test procedure such as clamp periods other than two to three seconds or clamp pressure other than 690 kPa (100 psi).
10.3 Report any anomalies in the ruptured surfaces as detailed in Section 9.2.
10.4 If the apparatus repeatedly fails to rupture specimens from a test strip, and means for increasing the instrument's range are not available, test results may be reported as "greater than (the upper range of the instrument in J/m^2 or ft. lbs. $\times 10^{-3}/in.^2$)."

11. Precision

11.1 Within a single laboratory, using one operator and fresh tape as specified in Sections 5.10 and 8.5, the percent repeatability is largely dependent upon the homogeneity of the material being tested. Table 1 illustrates the results of 10 replications for 4 different paper and board specimens; refer to TAPPI T 1206 "Precision Statement for Test Methods" for complete definitions of the statistical terms.

Table 1. Each test strip consisted of five 2.54 × 2.54 cm (1.00 × 1.00 in.) samples.
Samples were pressed at 690 kPa (100 psi) for 3 seconds
Tape: 3M Tape 406

Internal Bond Strength in J/m^2 (ft. lbs. $\times 10^{-3}/in.^2$).

Test Strip	Cover	Virgin Linerboard	Coated Cover	Coated Book
1	183(87)	212(101)	296(141)	393(187)
2	183(87)	216(103)	298(142)	395(188)
3	181(86)	206(96)	290(138)	383(187)
4	177(84)	198(94)	290(138)	399(190)
5	183(87)	219(104)	304(145)	399(190)
6	179(85)	221(105)	301(143)	414(197)
7	183(87)	233(111)	296(141)	380(181)
8	183(87)	221(105)	292(139)	412(196)
9	185(88)	208(99)	292(139)	395(188)
10	181(86)	210(100)	298(142)	397(189)
Average, $\bar{x}$	182(86.2)	214(102)	296(141)	397(189)
STD, Se	4.2(2.0)	14.(6.8)	9.0(4.3)	19(9.2)
STD, Sr	1.8(.87)	6.3(3.0)	4.0(1.9)	8.6(4.1)
Repeatability, r	5.0(2.4)	18(8.4)	11(5.3)	24(11.4)
Repeatability, %	2.8%	8.3%	3.8%	6.0%

11.2 Paper tends to exhibit increasing variance in strength characteristics as strength increases and caliper decreases. For grades where the specimen thickness approaches 3 fiber diameters and internal bond strength levels exceed 600 J/m^2 (286 ft. lbs. $\times 10^{-3}/in.^2$) the percent repeatability can exceed 10%. Also, high caliper-multi-ply materials formed with multiple headboxes tend to exhibit more variance in strength characteristics than single-ply specimens. For multi-ply boards with considerable recycle content, the repeatability in percent can exceed 10%, even at internal bond strength levels below 300 J/m^2(143 ft. lbs. $\times 10^{-3}/in.^2$).
11.3 The standard deviation and repeatability are improved by using the a) lowest instrument range that permits consistent sample ruptures, b) unblemished and unworn anvils and platens, and c) a sharp knife to avoid smearing the tape adhesive and tearing the specimens at the edges.

12. Keywords

Internal bond, Fiber bonding, Bonding strength, Z-direction, Tensile stress, Delamination, Blistering, Picking, Impact, Tensile energy absorption (TEA).

13. Additional information

13.1 Effective date of issue: March 3, 2000.

13.2 This test method is a revision and expansion of TAPPI UM 403 and the subsequent TAPPI T 833 pm-94 "Test for Interfiber Bond Using the Internal Bond Tester" to provide more detailed requirements of the apparatus, calibration, and test procedure, with further definition of the scope and limitations of the method. It eliminates references to "shear", "windage" and "dual range pendulum" for technical reasons and recognizes the use of recent electronic instrument designs with differing range extension techniques.

13.3 Comparisons of test data from the mechanical Scott Internal Bond Tester with data from later electronic versions pose two problems. First, the upper and lower ranges on earlier instruments that use removable weights to increase the range of the pendulum do not agree. The weight additions shift the pendulum's Center of Percussion, thereby affecting both its range and internal vibrational losses. To correct this problem, later electronic instruments use an extrapolated lower range scale when extending the range of the instrument. While correlations and agreement with low range scale (without additional pendulum weights) data are straightforward, it is not possible to correlate electronic instrument test results with data taken on a mechanical instrument that is in the high range configuration.

13.4 The standard deviations of tests run on groups of mechanical instruments versus electronic instruments are different. Statistically, the averages of tests with widely different standard deviations cannot be expected to be equal. Collaborative Testing data over a three year period indicates that the averages for tests made on electronic instruments have lower standard deviations and fall within approximately 1.0 to 1.4 standard deviations of tests on mechanical instruments.

References

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3. Huygen Corporation, "Instruction Manual - Huygen Internal Bond Tester" (AV-2, 1978 - 1991), (AV-3, 1994 -), Model 1314, 1992 -).
4. Testing Machines Inc., "Instruction Manual - Model 80-01-01 TMI Monitor/Internal Bond Test Station" and "I-Bond Prep-Station Instruction Manual."
5. Varlen Instruments, Inc., "Instructions for Installing and Using the Internal Bond Tester, Model B."

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Technical Operations Manager. ■