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T 549

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WORKING GROUP
CHAIRMAN Steve Berg

SUBJECT
CATEGORY Physical Properties

RELATED
METHODS See "Additional Information"

Coefficients of static and kinetic friction of uncoated writing and printing paper by use of the horizontal plane method

(Five-year review of Official Method T 549 om-13)

(changes from Draft 1 and editorial corrections incorporated)

1. Scope

1.1 This method describes a horizontal plane procedure for the determination of the coefficient of static and kinetic friction of paper measured when sliding against itself.

1.2 The horizontal instrument requires some means of movement of the specimen in relation to the surface upon which it rests. The coefficient of friction (COF) is measured directly from the resistance to tangential motion and the applied weight pressing two pieces of paper together.

1.3 Static COF relates to the force required to initiate movement between two surfaces while kinetic COF relates to the force required to cause continuation of the movement at uniform speed.

Approved by the Standard Specific Interest Group for this Test Method
TAPPI

1.4 The determinations of COF for packaging materials is described in TAPPI T 815 "Coefficient of Static Friction (Slide Angle) of Packaging and Packaging Materials (Including Shipping Sack Papers, Corrugated and Solid Fiberboard) (Inclined Plane Method)." In the method for testing packaging materials, the force measurement is often made on the third slip, while in this method the determination is made on the first slip.

2. Applicable documents

2.1 TAPPI Test Methods: TAPPI T 400 "Sampling and Accepting a Single Lot of Paper, Paperboard, Containerboard, or Related Product;" TAPPI T 402 "Standard Conditioning and Testing Atmospheres for Paper, Board, Pulp Handsheets, and Related Products;" TAPPI T 409 "Machine Direction of Paper and Paperboard;" TAPPI T 455 "Identification of Wire Side of Paper;" TAPPI T 494 "Tensile Properties of Paper and Paperboard (Using Constant Rate of Elongation Apparatus)."

3. Terminology

3.1 *Friction*, the resisting force that arises when a surface of one substance slides, or tends to slide, over an adjoining surface of itself or another substance. Between surfaces of solids in contact there are two kinds of friction: (1) the resistance opposing the force required to start to move one surface over another, and (2) the resistance opposing the force required to continue moving one surface over another at a constant speed.

3.2 *Coefficient of friction* (COF), the ratio of the frictional force resisting movement of the surface being tested to the force applied normal to that surface (the weight of the material above that surface).

3.3 *Coefficient of static or starting friction*, the ratio of the force resisting initial motion of the surfaces, to the normal force.

3.4 *Coefficient of kinetic or sliding friction*, the ratio of the force required to sustain the uniform relative movement of the surfaces, to the normal force.

4. Summary of method

One specimen of the paper sample is clamped to a horizontal plane surface, the other to a specimen sled. The sled is pulled across the surface, or the plane pulled under the stationary sled and the force required to do so is measured. The coefficients of both static and kinetic friction may be determined.

5. Significance and use

5.1 The coefficient of friction of printing and writing papers is an indicator of the ease with which the top or bottom sheets of a stack of paper will slide across the succeeding sheet, such as occurs on the infeed of a printing press or the sheet transport into a copier machine. A minimum value of coefficient of friction is required to prevent double-feeding of any sheets.

5.2 Since each sheet is removed from the stack only once, a single slide of each pair of specimens is performed and the value recorded.

6. Apparatus (Fig. 1)

6.1 *Horizontal plane and supporting base*, a horizontal plane surface of a smooth, incompressible material - metal, hardwood, plate glass or plastic, having a width at least 25 mm (1 in.) wider than the specimen sled (see 6.2). The plane is mounted on a supporting base provided with means of leveling in two directions. A constant rate-of-motion tester, as described in TAPPI T 494, has also been found suitable. If this type of tester is used, the horizontal plane and supporting base are one and the same.

6.2 *Specimen sled*, a sled or specimen block made of an incompressible 63.5-mm (2.5-in.) square metal block weighing 200 ± 5 g has been found satisfactory. The precision statement is based on a sled of that size. The lower surface of the specimen block shall be backed with a compressible backing made from a sheet of closed cell neoprene cellular rubber, with a thickness between 1.5 mm and 3.0 mm. The backing shall have a uniform thickness and shall be replaced if its edges become worn or its surface becomes damaged. A means for clamping the specimen to the sled may be provided, but it is not necessary if the lower surface is faced with 3-mm (0.12-in.) thick backing. A means for fastening the sled to the force measuring device, such as a wire cable or nylon filament line, is required. Take care in selecting a wire cable or nylon filament line to make certain that its ability to stretch does not interfere with the measurement of force. The sled may be directly connected to the load cell.

6.3 *Mechanical power unit*, means for moving the specimen sled horizontally along the plane surface, or the plane surface under the specimen sled at a uniform speed of 150 ± 30 mm/min (0.5 ± 0.1 ft/min). A constant rate-of-motion tester equipped with a load cell in its upper crosshead and a constant rate-of-motion lower crosshead has been found satisfactory (T 494).

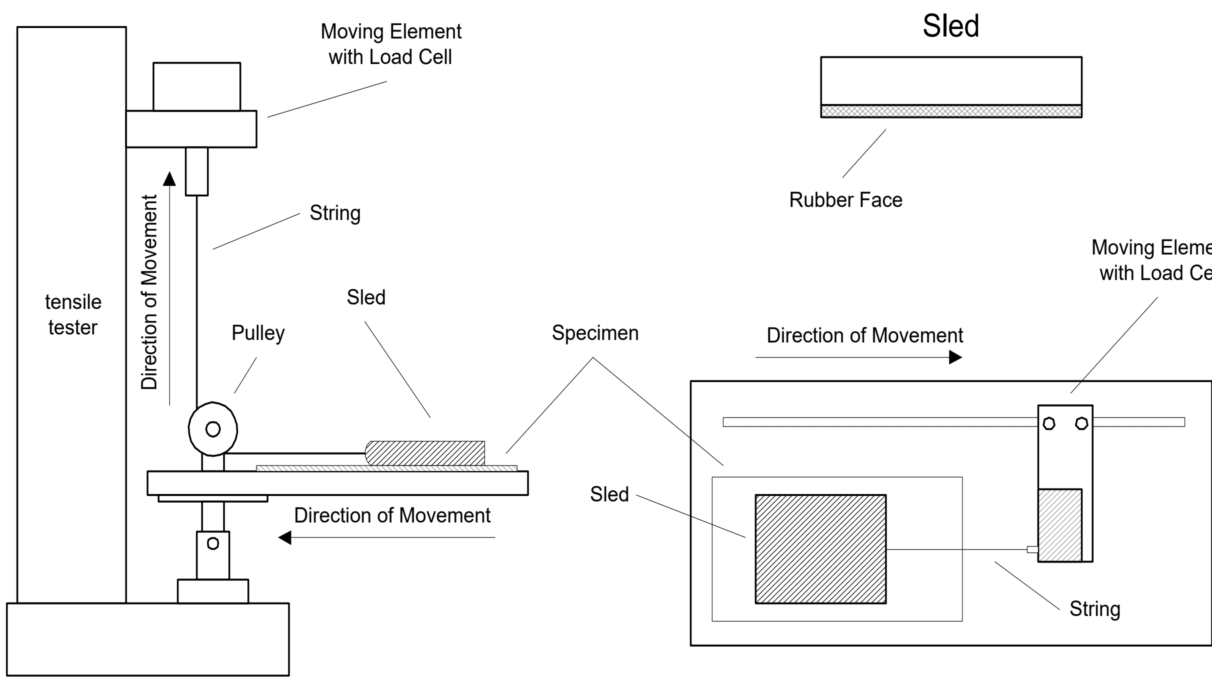

Fig. 1. Schematics for two horizontal plane instruments. A tensile tester fixture and a horizontal tester.

6.4 *Force measuring device*, means for measuring the force required to move or restrain the specimen sled to the nearest 5 gf (0.01 lbf). A force gauge or the load cell of a constant rate-of-motion tester have both been found suitable.

NOTE 1: Exercise care so that vibration from the drive motor or other sources does not affect measurements.

6.5 *Paper cutter*, to cut test specimens.

7. Sampling and test specimens

NOTE 2: See Appendix A.1.

7.1 If a lot of paper is being tested, select the sample in accordance with TAPPI T 400. The sample should be in the form of a finished ream or a "lift" sample from a roll. A lift is a stack of sheets about 1.3 cm (0.5 in.) cut from a roll.

7.2 Precondition, condition, and test in the atmospheres as described in TAPPI T 402.

7.3 Cut the sample into test specimen pairs as follows:

NOTE 3: Exercise care in cutting test pieces to avoid rough, damaged edges.

7.3.1 *Finished ream samples.*

7.3.1.1 With machine direction COF. Lift off a stack of six consecutive sheets, identify the machine direction (T 409) and the felt (or top) side (TAPPI T 455) of the top sheet, and cut two specimens from each sheet: one 100 × 215 mm (4 × 8.5 in.) and the other 75 × 130 mm (3 × 5 in.). Cut the specimens so that the machine direction is parallel to the long dimension. Stack the two sets of specimens in separate piles, maintaining the same order of sheets as in the ream. Take the top sheet off the pile of larger specimens and discard. Use the second large specimen with the first small specimen, the third large specimen with the second specimen, and so on, performing the test with five pairs of specimens from consecutive sheets. Discard the one leftover small specimen (sixth).

7.3.1.2 Across machine direction COF. Follow directions given in 7.3.1.1, except: Cut the specimens so that the machine direction is parallel to the shorter dimension.

7.3.2 *Lift sample.*

7.3.2.1 With machine direction COF. Lift off a stack of at least seven consecutive sheets, identify the machine direction and the felt (or top) side of the top sheet, and cut two specimens from each sheet: one 100 × 215 mm (4 × 8.5 in.) and the other 75 × 130 mm (3 × 5 in.). Cut the specimens so that the machine direction is parallel to the longer dimension. Discard the top sheet from each stack and test five pairs of specimens. Each pair is from the same sheet. Discard the bottom sheets.

7.3.2.2 Across machine direction COF. Follow directions given in 7.3.2.1, except: Cut the specimens so that the machine direction is parallel to the shorter dimension. Discard the top sheet from each stack and test five pairs of specimens. Each pair is from the same sheet. Discard the bottom sheets.

8. Procedure

8.1 Place the instrument on a solid and vibration-free table and level it. If a constant rate-of-motion tester is used, set it up according to its instructions for coefficient of friction determination. If necessary, adjust the force measuring device to zero.

8.2 With machine direction COF. Select the specimens cut with the grain direction parallel to the long dimension, 7.3.1.1 or 7.3.2.1. See Appendix A.2.

8.2.1 Place the longer of each specimen pair on the horizontal plane with the top (felt) side upward and clamp or otherwise attach the end farthest from the force measuring device to the plane.

8.2.2 Place the smaller specimen on top of the larger with the wire side facing down, and set the rubber-faced sled lightly atop it. Or attach the smaller specimen to the sled and position the sled atop the larger specimen.

NOTE 4: Exercise care in placing the sled on the lower test piece. Place the sled directly on the lower piece without any horizontal motion.

8.2.3 Attach the cable from the power unit or force gauge to the sled.

8.2.4 Start the power unit, making sure the cable remains taut (on instruments so equipped) as the drive takes up the load. No immediate relative motion may take place between the sled and the plane until the pull on the sled is equal to, or exceeds, the static frictional force acting at the contact surfaces. Record this initial, maximum reading, or note the maximum peak recorded on the strip chart recorder of the constant rate-of-motion tester, as the force component of the coefficient of static friction. Do not include the static value, 8.2.4, in the kinetic readings. It is recommended that the time between placing the sled on the sample surface and start of test motion be consistent.

8.2.5 Continue the motion of the two specimens for a distance of about 130 mm (5 in.). Record the average force reading during this period, or obtain the average force by integrating the recorded trace on the strip chart recorder of the constant rate-of-motion tester, as the force component of the coefficient of kinetic friction.

8.2.6 After the sled has traveled the required distance, stop the power unit, remove the specimens, and return the apparatus to starting positions. Continue to test the remaining specimen pairs in identical fashion. No specimen pairs shall be tested more than once unless such tests constitute one of the variables to be studied.

8.3 Across machine direction COF. Select the set of specimens cut with the machine direction parallel to the short dimension, 7.3.1.2 or 7.3.2.2. Repeat the procedure described in 8.2.1 through 8.2.6.

9. Calculations

9.1 Calculate for each specimen pair the coefficient of static friction as follows:

COF static = force required to initiate motion, in mN / (sled mass, grams × 9.80665 m/s^2)

9.2 Calculate for each specimen pair the coefficient of kinetic friction as follows:

COF kinetic = average force reading during uniform sliding, in mN / (sled mass in grams × 9.80665 m/s^2)

NOTE 5: COF static and COF kinetic, calculated using the 9.1 and 9.2 equations and units, are unitless coefficients. Hardware and software systems that will perform all calculations required are available.

10. Report

10.1 Report as coefficient of static friction, the average and standard deviation of the five determinations separately for each principal direction.

10.2 Report as coefficient of kinetic friction, the average and standard deviation of the five determinations separately for each principal direction.

10.3 Report whether the sample is taken from a finished ream or a lift.

11. Precision

11.1 The following estimates of repeatability and reproducibility are based on data from the CTS-TAPPI Interlaboratory Program from 1996 through 1999. The individual analyses on which this data is based can be found in reports 164G through 179G. All samples on which this data is based were uncoated printing and writing grades. Data is based on 32 different analyses for both static and kinetic results; using 19 different grades. Participants were asked to follow "TAPPI Official Test Method T 549 pm-90," revision of this method. Testing is based on 5 determinations per test result and 1 result per lab, per material. The second section shows results for individual analyses across the range of COF values offered in the program.

11.2 Although the method is basic in concept, the precision statement has been developed on uncoated writing and printing papers. While the use of the method is recommended for those grades only, it may be used with other types of paper given specific attention to special paper characteristics and with the understanding that the precision and accuracy may not be the same.

11.3 Repeatability and reproducibility are estimates of the maximum **difference** (at 95%) which should be expected when comparing **test results** for materials similar to those described above under similar test conditions. These estimates may not be valid for different materials or testing conditions.

Table 1: Coefficient of Friction Measurements

Method description	*Between lab standard dev.*	*Repeatability r and %r*		*Reproducibility R and %R*		*Labs Included*
Static COF	0.057	0.06	12%	0.12	24%	26
Kinetic COF	0.056	0.06	13%	0.12	27%	26

Table 2: Coefficient of Friction Measurements – Individual Analyses

Type of measure	*Material description*	*Grand mean*	*Between lab standard dev*	*Repeatability r and %r*		*Reproducibility R and %R*		*Labs included*
Static	74# Offset	0.59	0.06	0.05	8%	0.17	28%	27
Static	50# Book	0.57	0.04	0.04	6%	0.12	21%	22
Static	50# Offset	0.55	0.07	0.05	9%	0.19	35%	28
Static	24# Bond	0.31	0.03	0.03	10%	0.08	26%	22
Kinetic	74# Offset	0.53	0.05	0.05	9%	0.15	28%	29
Kinetic	24# Writing	0.49	0.04	0.04	9%	0.10	21%	27
Kinetic	60# Offset	0.45	0.05	0.05	12%	0.12	28%	27
Kinetic	24# Bond	0.25	0.04	0.02	9%	0.10	41%	27

12. Keywords

Friction, Friction factor, Kinetic friction, Horizontal plane method, Horizontal planes, Paper, Printing paper, Writing paper

13. Additional information

13.1 Effective date of issue: To be assigned.

13.2 Related methods: ISO 15359.

13.3 The 2008 version of this method included revisions to clarify the calculations. The revised equations 9.1 and 9.2 introduce to this method the millinewton unit, replacing the now deprecated gram-force unit used in all earlier versions of this method, for the forces required to initiate and to maintain sled motion. The revised equations 9.1 and 9.2 also correct an error in the 2001 and 2006 versions of this method, where the equations 9.1 and 9.2 result in a COF too high by a factor of 10^5.

Appendix

(Nonmandatory information)

A.1 Significance and interpretation of test method. Section 7.1 describes the procedure for selecting the sample in two manners depending upon the form of the paper to be tested. Section 7.3 describes the procedure for preparing test specimens depending upon the form of the paper to be tested. Sampling of a cut size ream of the type commonly used in sheet fed printing presses and copy machines is described in 7.3.1. Sampling paper from a roll is described in 7.3.2.

A.1.1 Ream sample. In the manufacturing process of converting paper from rolls to sheets, it is common practice to combine the webs of two or more rolls in the processing equipment. As a result, successive sheets in the stack of cut paper represent the combination of the several rolls that are processed together. By using the sampling procedure described in 7.3.1, the resulting COF values represent the relationships between successive sheets. This is comparable to the manner in which the sheets are fed into the press or copier.

A.1.1.1 If there is a need to determine the COF of an individual sheet in such a way as to avoid influence by the adjacent sheet from another roll, the operator may select a single sheet, prepare a test specimen pair, and test according to instructions given.

A.1.2 Roll sample. If the paper to be tested is in the form of a roll, the samples are selected as described in 7.3.2. The test results will not be influenced by other sheets.

A.2 Running direction effect. Running direction is the direction of flow on the paper machine as the paper is manufactured. There is evidence that the fibers on the surface experience some orientation due to the various forces exerted during the process and that this effects the frictional properties. Exercise care to orient the running directions of the top and bottom test pieces so that they are in the same direction.

A.3 The report, "Paper Friction-Influence of Measurement Conditions" by Johansson, Fellers, Gunderson and Haugen published in the TAPPI Journal vo. 81 No.5 May 1998 p. 175, describes the results of a study, conducted by STFI of Sweden and Forest Products Laboratory of the USA, of the variables affecting the measurement of COF.

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department. ■