
**Paper and board — Determination of the
static and kinetic coefficients of friction —
Horizontal plane method**

*Papier et carton — Détermination des coefficients de frottement statique et
cinétique — Méthode du plan horizontal*



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International Standard ISO 15359 was prepared by Technical Committee ISO/TC 6, *Paper, board and pulps*, Subcommittee SC 2, *Test methods and quality specifications for paper and board*.

Annexes A and B of this International Standard are for information only.

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Introduction

This International Standard describes a procedure for the determination of the static and kinetic coefficients of friction of paper or board by the horizontal plane method.

The condition of the surfaces of a paper depends on their history. Their frictional properties are largely determined by the static and kinetic coefficients of friction which are determined, in this International Standard, by sliding one sheet of paper over another sheet of the same paper, or another surface in the horizontal plane, with a downwards vertical force applied to the upper material. The friction property relates to the horizontal force required to initiate and maintain movement between the two surfaces.

The coefficients of friction are properties of two surfaces. The values obtained for the coefficients are influenced by test conditions. The condition of the two surfaces under the conditions specified in this International Standard may or may not relate to the condition of the surfaces in a specific end-use situation. Nevertheless, the test results are useful in determining the combined properties of the surfaces tested.

The coefficients of friction of a machine-made paper can be different when measured in the machine direction, MD, or in the cross direction, CD. Often there is a difference between the two sides of the paper.

For certain papers, e.g. copy paper, only the static coefficient of friction at the first slide, i.e. the coefficient obtained without any previous sliding of the surfaces across each other, between the lower surface of one sheet of paper and the upper surface of another paper of the same kind may be of interest.

For certain other paper grades, e.g. shipping sack paper, linerboard and solid fibreboard, the coefficients of friction after a given amount of wear between the surfaces may be of interest. In this International Standard, to determine the coefficients of friction of worn surfaces, one test piece is caused to slide with respect to the other test piece three times. The force required to initiate and maintain sliding on the third slide is measured.

The intended use of the paper grade determines the sides of the papers which are to be in contact, the direction of the paper test pieces with respect to the direction of sliding and the number and type of coefficients of friction to be evaluated.

Annex A provides a list of recommended symbols to indicate the directions and positions of the surfaces tested.

Annex B provides a summary of test conditions for some common standard methods for paper products and plastics.

A bibliography follows the annexes.

Paper and board — Determination of the static and kinetic coefficients of friction — Horizontal plane method

1 Scope

This International Standard specifies

- a friction-testing method based on the horizontal plane principle, and
- the procedure for the determination of the static coefficient of friction before, and static and kinetic coefficients of friction after, a specified amount of wear between the surfaces.

It is applicable to paper and board.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 186:1994, *Paper and board — Sampling to determine average quality*.

ISO 187:1990, *Paper, board and pulps — Standard atmosphere for conditioning and testing and procedure for monitoring the atmosphere and conditioning of samples*.

ISO 4046:1978, *Paper, board, pulp and related terms — Vocabulary*.

3 Terms and definitions

For the purposes of this International Standard, the following terms and definitions apply.

3.1 friction

resisting force that arises when a surface of one material tends to slide or slides over another surface of the same or some other material

3.2 static friction

force that resists initiation of movement of one surface sliding over another surface

NOTE The force required to initiate movement is equal to that which resists initiation of movement.

3.3 static coefficient of friction, μ_S

ratio of the static friction to the force applied perpendicularly to the two surfaces in a friction test

3.4

kinetic friction

force that resists maintained sliding of one surface over another surface

NOTE The force required to maintain sliding is equal to that which resists the maintenance of sliding.

3.5

kinetic coefficient of friction, μ_k

ratio of the kinetic friction to the force applied perpendicularly to the two surfaces in a friction test

3.6

ramp time

time required to increase the horizontal applied force from zero up to the static friction value

4 Principle

The surfaces to be tested are placed together in plane contact and under apparent uniform contact pressure. The forces needed to initiate sliding (the static friction force) and to slide the surface relative to each other (the kinetic friction force) are recorded.

5 Apparatus (see Figure 1)

5.1 Horizontal table, with a flat top surface of incompressible material (metal, hardwood, glass, etc.) wide enough to accommodate the sled with a margin of at least 5 mm on each side. The table shall be provided with means to prevent slippage between the test piece and the table during the test.

5.2 Sled, capable of producing a normal pressure of $2,2 \text{ kPa} \pm 0,6 \text{ kPa}$ on the test piece mounted onto its underside. This underside shall be flat, shall have dimensions of $(60 \text{ mm} \pm 5 \text{ mm}) \times (60 \text{ mm} \pm 5 \text{ mm})$ and shall be constructed of an incompressible material.

NOTE A sled having a mass of $(800 \pm 100) \text{ g}$, will produce the required nominal pressure by virtue of the gravitational force acting upon it. The sled mass should be measured and reported to an accuracy of at least $\pm 10 \text{ g}$. If means other than gravity are used to create the perpendicular force, the mass of the sled may be other than 800 g provided the equivalent pressure is developed.

5.3 Elevator, for lowering and lifting the sled with respect to the table. The elevator shall operate such that no sliding of the sled relative to the table shall occur as the sled comes into contact with the table and eventually rests upon it.

NOTE Even the slightest backslide motion can influence the result of the test.

5.4 Load cell, to measure the force F applied to the sled (or the table) by the driving mechanism, with an accuracy of 2 % of the reading.

5.5 Recording means, to record the force as a function of time.

NOTE The static friction peak is normally a transient event and recording means should be sufficiently fast to capture that event.

5.6 Device for connecting the load cell to the sled, to convey the force F between the sled and load cell. Figure 1 shows one example of a possible set-up. The device shall enable the force to be applied centrally with respect to the test area and in a direction parallel to the surface of the table.

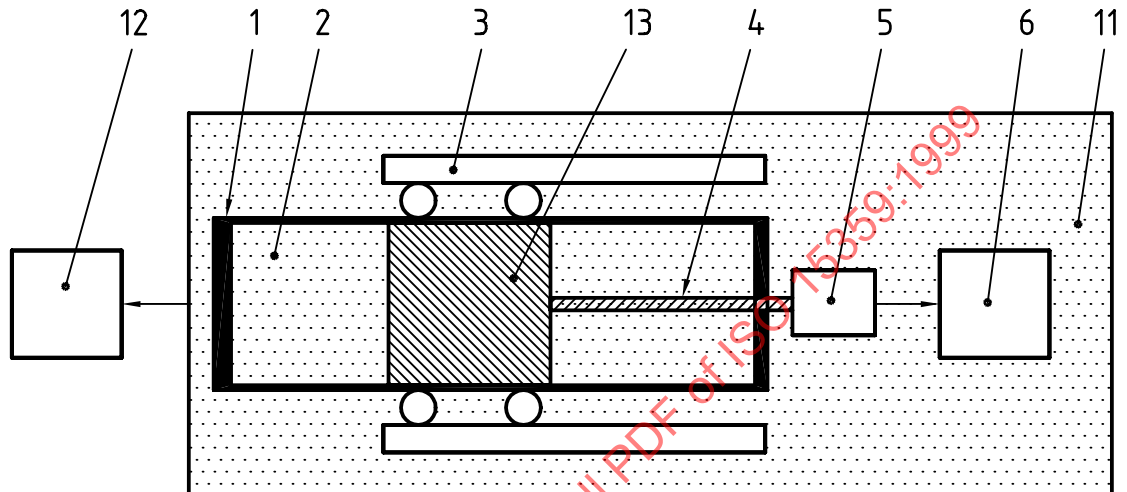
NOTE 1 The line of force connecting the sled and load cell can lie above, below, or coincident with the plane of contact between the two test pieces. The distance (10 in Figure 1) between the line of force and the plane of contact between the test pieces is not critical but should not exceed 10 mm.

NOTE 2 Some pieces of apparatus may employ a variable degree of elasticity in the mechanical construction for the purpose of altering the time from initial application of the pulling force to the moment at which sliding begins (the ramp time in Figure 2). In other apparatuses the degree of elasticity is not a variable. However, a rigid connection is preferable for measurements of kinetic friction.

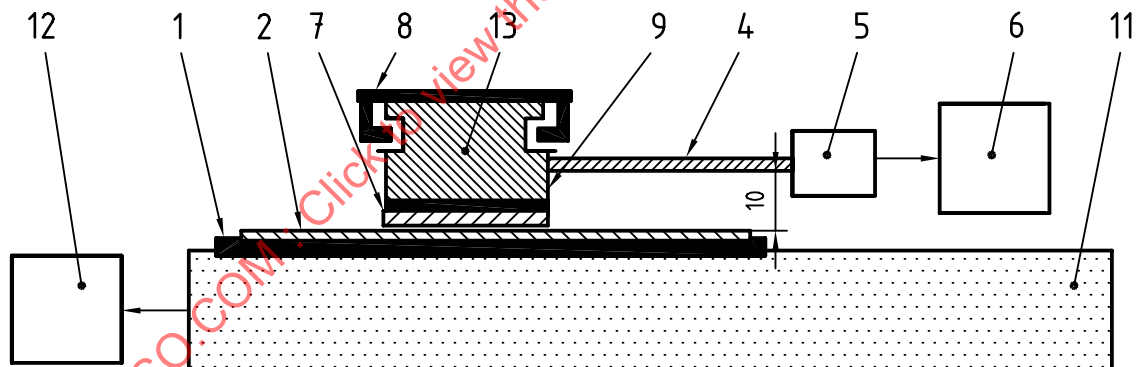
5.7 Drive mechanism, to first impart a vibration-free, gradually increasing force to the sled up to the time at which the first sliding motion between the sled and table is initiated, and subsequently to move the sled or table with respect to the other. The drive mechanism shall move the sled or the table or both.

5.8 Backing, to ensure a uniform pressure distribution. At least one of the test pieces shall be backed by 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.

Top view



Side view



Key

- 1 Backing of foam rubber on the table
- 2 Test piece for the table
- 3 Guidance system for the sled (shown schematically)
- 4 Device for connecting the load-cell to the sled
- 5 Load-cell
- 6 Driving mechanism for the sled
- 7 Test piece for the sled
- 8 Elevator for lowering and lifting the sled
- 9 Backing of foam rubber on the sled
- 10 Distance between the table and the plane of action of the force
- 11 Horizontal table
- 12 Driving mechanism for the table
- 13 Sled

Figure 1 — General layout of the apparatus

5.9 Guidance system for the sled, for keeping the orientation of the sled parallel to that of the table.

NOTE Even minor rotational motion of the sled in the plane of the table can produce lower measured values for the coefficients of friction.

6 Sampling

Ensure that the test pieces used are representative of the sample received. If the determination is to represent a lot of paper or board, the sampling procedure shall be carried out in accordance with ISO 186.

7 Conditioning

The sample material shall be conditioned in accordance with ISO 187. The test pieces shall be prepared, and testing carried out, in the same atmospheric conditions as those used to condition the samples.

8 Preparation of test pieces

The surfaces shall not be touched by the hands and shall not come into contact with, or be rubbed against, any surface which could alter the test pieces in any of the preparation stages.

NOTE 1 Friction test results are extremely sensitive to minute contamination of the surfaces to be tested. Friction tests may also be sensitive to wear of the surfaces. In some environments, it may also be necessary to protect the specimens against contamination by airborne matter.

NOTE 2 It is acknowledged that, in practical everyday work, it may not be possible to prevent contact with and rubbing of the sample materials. It is recommended, therefore, that the procedure for collection and handling of sample materials be evaluated to determine its effect on friction test results.

Two different test pieces are required for the test; one to be attached to the sled and one to be attached to the table.

Mark on both test pieces, if necessary, the machine direction, the manufacturing direction and the sides, i.e. wire and top side, printed or unprinted, marked or unmarked.

The size of the test pieces shall depend on the design and function of the friction apparatus. The test piece attached to the sled shall be at least 60 mm × 60 mm. The test piece attached to the table shall be at least 60 mm wide and as long as necessary to cover the length of the sled and to cover the actual sliding distance. If determination of the coefficient of friction at the third slide is required, the length of the table test piece shall be sufficient to allow a slide distance of at least 70 mm.

Prepare a sufficient number of test pieces to perform at least six valid tests for each configuration to be considered.

It is recommended that test pieces be individually cut, i.e. one test piece at a time.

Cutting shall be performed in a manner which produces a smooth level edge and does not contaminate the test surface of the test piece.

NOTE 3 The possible combinations for machine-made papers are listed in annex A.

NOTE 4 The combinations to be considered depend on the purpose of the test and should be agreed between the parties.

NOTE 5 Poor cutting which raises the edges of the test pieces is a potential source of error.

The cutting and mounting of the test piece onto the sled shall be done in such a way that the leading edge of the sled cannot interfere with the measurement.

NOTE 6 In heavier board, bending may cause unequal pressure distribution within the test area. Preferably, mounting of the test pieces of such boards should be carried out without bending or folding.

9 Procedure

9.1 General

9.1.1 Sled orientation

The orientation of the sled shall remain parallel to that of the table during the entire test.

9.1.2 Raising and lowering of the sled

Do not place the sled on the table or lift it from the table by hand.

NOTE 1 When lowering, it is desirable that the entire area of the two surfaces meet simultaneously.

The sled shall be lifted clear of the table before the relative horizontal motion of the sled and table stops.

After the sled has been lifted clear of the table, the drive mechanism shall be returned to its initial position within a tolerance of ± 2 mm.

NOTE 2 The static coefficient of friction is highly sensitive to even a minute reversal in the direction of the relative horizontal motion of sled and table. The potential for such a reversal is precluded by lifting the sled while the table is in forward motion.

9.2 Static coefficient of friction at the first slide

If only the static coefficient of friction at the first slide is of interest, carry out the test as follows.

Fasten the test pieces to the table and to the sled so that the sides to be tested are in contact and facing outwards. Ensure that the directions of the sheet materials of both table and sled are parallel to the pulling direction. The test pieces shall be oriented such that the sliding motion is, for example, in the machine direction of the test pieces for an MD/MD test (see Table A.2). If known, it may also be necessary to take note of the orientation of the forming and anti-forming directions of the test pieces with respect to the direction of motion.

Lower the sled onto the table slowly at a rate of $3,0 \text{ mm/s} \pm 2,0 \text{ mm/s}$ using the elevator (5.3), preferably so that the two surfaces meet simultaneously over the entire area which will be in contact during the test. The test pieces may be of different size, thus their entire surface area may never meet.

Do not move or reposition the sled even slightly once the two test pieces have been brought into contact. Allow the sled to rest for at least 1 s but not more than 20 s before initiating the linear increase of force.

Start the drive mechanism and check that the force reading increases so that the ramp time is between 0,5 s and 5 s and the ramp curve falls within the range indicated by the shading in Figure 2. Record the force, F_{S1} , required to initiate the first sliding motion. If the ramp time is not between 0,5 s and 5 s, the result is invalid. In this case, adjust the rate of force increase to bring the ramp time within the required range, replace the test pieces and repeat the test.

Discard the test pieces after the test.

Repeat the tests until a total of at least six valid results have been obtained.

9.3 Static coefficient of friction at the first slide, static coefficient of friction and kinetic coefficient of friction at the third slide

If the static coefficient of friction at the first slide, the static coefficient of friction and kinetic coefficient of friction at the third slide are of interest, carry out the test as follows.

Fasten the test pieces to the table and to the sled so that the sides to be tested are in contact and facing outwards. Ensure that the directions of the sheet materials of both table and sled are parallel to the pulling direction. The test pieces shall be oriented such that the sliding motion is, for example, in the machine direction of the test pieces for an MD/MD test (see Table A.2). If known, it may also be necessary to take note of the orientation of the forming and anti-forming directions of the test pieces with respect to the direction of motion.

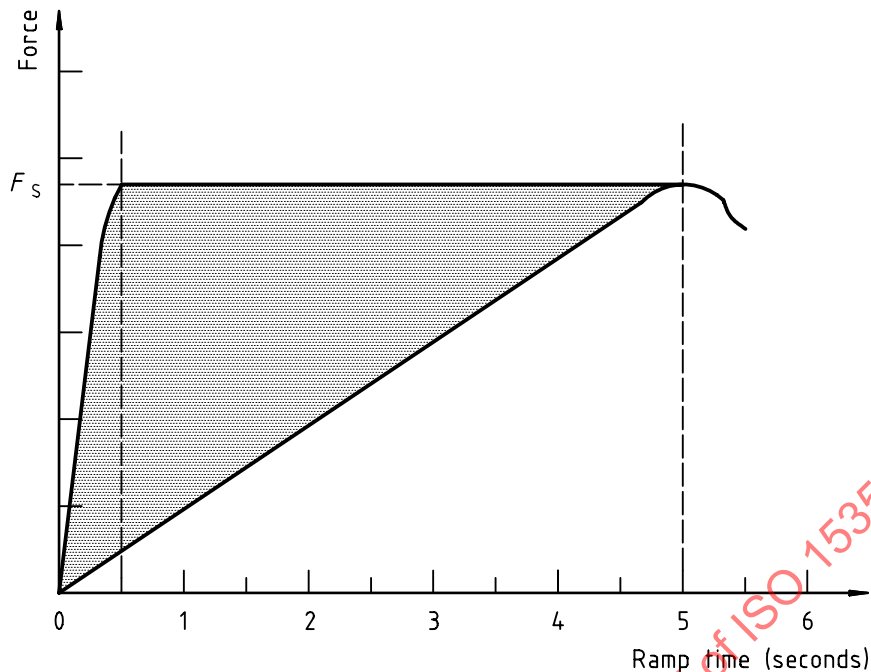


Figure 2 — The force-time curve

Lower the sled onto the table slowly at a rate of approximately $3,0 \text{ mm/s} \pm 2,0 \text{ mm/s}$ using the elevator (5.3), preferably so that the two surfaces meet simultaneously over the entire area which will be in contact during the test. The test pieces may be of different size, thus their entire surface area may never meet.

Do not move or reposition the sled even slightly once the two test pieces have been brought into contact. Allow the sled to rest for at least 1 s but not more than 20 s before initiating the linear increase of force.

Start the drive mechanism and check that the force reading increases so that the ramp time is between 0,5 s and 5 s and the ramp curve falls within the range indicated by the shading in Figure 2. Record the force, F_{S1} , required to initiate the first sliding motion. If the ramp time is not between 0,5 s and 5 s, the result is invalid. In this case, adjust the rate of force increase to bring the ramp time within the required range, replace the test pieces and repeat the test.

Once the sliding motion between sled and table has been initiated by the ramped force, this motion shall be controlled as follows:

- during the first 20 mm of travel, the relative speed between the sled and table shall increase to a rate of $(20 \pm 2) \text{ mm/s}$;
- during the next 40 mm of travel, the relative speed between the sled and table shall remain constant at $(20 \pm 2) \text{ mm/s}$;
- thereafter, travel shall continue for another $15 \text{ mm} \pm 6 \text{ mm}$ during which the relative speed between the sled and table may be reduced, and during which the sled shall be lifted clear of the table by the elevator.

Return the test pieces to their initial positions. Using the same pair and sides of the test pieces, repeat the sliding procedure a second time.

Return the test pieces to their initial positions. Using the same pair and sides of the test pieces, repeat this sliding procedure a third time.

Record the force, F_{S3} , required to initiate the third sliding motion.

Record the average friction force, F_K over the slide distance from 40 mm to 60 mm on the third sliding motion.

Discard the test pieces after the test.

Repeat the tests until a total of at least six valid results have been obtained.

The kinetic friction shall not be evaluated if stick-slip is observed.

NOTE Stick-slip is characterized by sequential build-up and release of stored energy in elastic components of the friction apparatus. It results in cyclical acceleration and deceleration of the sled. The phenomenon is apparent as a ragged force variation in the force-time diagram provided the true response has not been suppressed. As discussed by Johansson et al. [1, 2], it is not possible to evaluate kinetic friction if the test pieces are sliding relative to one another in a stick-slip mode. Stick-slip response is best controlled and eliminated by raising the mechanical stiffness of the test apparatus. If it cannot be controlled, evaluation of kinetic friction is not feasible.

Suppression of the dynamic record by a recording system with a slow response characteristic does not improve the situation. On the contrary, not only is the resulting record an erroneous indication of kinetic friction, but the system may mask the fact that stick-slip behaviour is occurring.

10 Calculation

10.1 Static coefficient of friction at the first slide

Calculate the static coefficient of friction at the first slide using the expression

$$\mu_{S1} = \frac{\bar{F}_{S1}}{mg}$$

where

μ_{S1} is the static coefficient of friction for the first slide;

$\bar{F}_{S1}$ is the mean force (from at least six replicate tests) required to initiate motion for the first slide, in newtons;

m is the mass of the sled, in kilograms;

g is 9,81 m/s².

10.2 Static coefficient of friction at the third slide

Calculate the static coefficient of friction at the third slide using the expression

$$\mu_{S3} = \frac{\bar{F}_{S3}}{mg}$$

where

μ_{S3} is the static coefficient of friction for the third slide;

$\bar{F}_{S3}$ is the mean force (from at least six replicate tests) required to initiate motion for the third slide, in newtons;

m is the mass of the sled, in kilograms;

g is 9,81 m/s².

10.3 Kinetic coefficient of friction

Calculate the kinetic coefficient of friction using the expression

$$\mu_K = \frac{\bar{F}_K}{mg}$$

where

μ_K is the kinetic coefficient of friction for the third slide;

$\bar{F}_K$ is the mean force (from at least 6 replicate tests) required to maintain motion over the slide distance from 40 mm to 60 mm for the third slide, in newtons;

m is the mass of the sled, in kilograms;

g is 9,81 m/s².

The kinetic friction shall not be evaluated if stick-slip, as described in the note in 9.3, is present.

11 Precision

The precision of this test method is not known because interlaboratory data are not available. Interlaboratory data are being obtained and a precision statement will be added with the next revision.

12 Test report

The test report shall include the following particulars:

- a) reference to this International Standard;
- b) date and place of testing;
- c) identification of the test piece;
- d) the results and the corresponding coefficients of variation and orientation of each test piece for each configuration tested;
- e) notice of any departure from this International Standard or any other circumstances that can have affected the results.

NOTE Symbols and a system of identification which may be used in the test report are suggested in annex A.

Annex A (informative)

Symbols and identification system for expression of results

A means of expressing, in symbol form, the particular coefficients of friction determined is given in Table A.1. A list of possible combinations is given in Table A.2.

The testing parameters may be expressed with symbols as follows.

KEY:

$\mu_{12}(34/56)$

Table A.1 — Symbols for test parameters

Position	Symbol	Comments
1	μ_S μ_K	Type of coefficient of friction: static coefficient of friction kinetic coefficient of friction
2	1 3	Sliding number: The first slide The third slide
3	MD CD I	Orientation of test piece on sled: Machine Direction Cross Direction Isotropic laboratory sheets
4	Examples: t, w, c, u	Side designation of test piece on sled: top side, wire side, coated side, uncoated side
5	MD CD I	Orientation of test piece on table: Machine Direction Cross Direction Isotropic laboratory sheets
6	Examples: t, w, c, u	Side designation of test piece on table: top side, wire side, coated side, uncoated side

NOTE In those instances where rewinding, converting or other operations have occurred, other symbols to identify the direction of the test pieces may have to be used. In some cases, it may be desirable to keep track of the forming and anti-forming directions for the MD orientation in the paper machine. In that case, it is recommended that MD+ be used to indicate the forming direction, and MD– to indicated the anti-forming direction.

EXAMPLE

The designation of “Static coefficient of friction from the first slide using a CD specimen with a coated side exposed on the sled and a MD specimen with an uncoated side exposed on the table” is as follows:

$\mu_{S1}(CDc/MDu)$

Table A.2 — Possible combinations of directions of machine-made paper

Sled	Table
CD	CD
CD	MD
MD	CD
MD	MD

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