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Rubber — Determination of frictional properties

Caoutchouc — Détermination des propriétés frictionnelles

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Contents

Page

Foreword

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International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 15113 was prepared by Technical Committee ISO/TC 45, *Rubber and rubber products*, Subcommittee SC 2, *Testing and analysis*.

This second edition cancels and replaces the first edition (ISO 15113:1999), of which it constitutes a minor revision, the main purpose of which was to update the normative references clause. It also incorporates Technical Corrigendum ISO 15113:1999/Cor. 1:2001.

Introduction

Various geometrical arrangements can be used when measuring friction, but each is likely to give a different value for μ, the coefficient of friction. Each may be appropriate in particular circumstances, but it is desirable that some standard method utilizing specified test conditions be employed when comparisons between materials are undertaken.

Rubber samples are most readily available in sheet form, and for many practical applications measurement between two planar surfaces most nearly approaches service behaviour. Consequently, this is the most widely used geometry. For this geometry, the apparatus used needs careful design in order to ensure reproducible contact between the surfaces, and this is discussed in Annex A.

Where rubber moulding facilities are available, some workers prefer to use a hemispherical rubber slider and a planar test track. This gives a more definable contact area and minimizes the errors involved if the friction plane does not contain both the line of action of the load cell and that of the towing force. However, when this geometry is used, the frictional force is not proportional to the normal load (see Annex B), and the contact area is estimated from a knowledge of the modulus of the rubber. Hence care should be taken when quoting values for coefficients of friction. The big disadvantage of the method is that special test pieces need to be moulded from unvulcanized rubber, and rubber products cannot be accommodated. Finally, since some degree of wear is inseparable from friction, extended testing will produce a “flat” on the hemispherical test piece. Frequent inspection of the test surface is recommended, therefore, to ensure that the initial contact geometry is maintained.

The alternative “ball-on-flat” geometry where a hard ball slides on a flat rubber surface is not an exact equivalent. The ploughing action of the ball through the rubber results in an energy loss by hysteresis which gives a higher measured coefficient of friction. However, in some circumstances this may be an appropriate test procedure.

Although there may be some uncertainty in the contact area using plane-on-plane geometry, this International Standard is based on this geometry because of its wide practical applicability. However, it is emphasized that it is necessary to have a well designed apparatus with the line of action of the load cell included in the plane of contact of the test pieces (see Annex A). The method can be adapted to cover other contact geometries to suit particular products, including the ball-on-flat geometry set out in Annex B.

This International Standard is based on linear motion, and guidance on the experimental arrangement is given in Annex A. Because friction generates heat, it is usual to restrict testing to velocities typically below 1 000 mm/min in order to avoid a large temperature rise at the interface. If service conditions involve high speeds, then an entirely different method based on rotary motion is more appropriate as discussed in Annex A. The method of test set out here enables kinetic friction to be measured at a number of fixed velocities. It can be arranged that the lowest velocity is such that movement is barely discernible, and this gives an approximation to frictional behaviour close to zero velocity (static friction). This may be different from the starting friction, which may involve some element of adhesion (stiction) as discussed in Annex C. This method is suitable for measuring the initial friction only if the machine has a constant-rate-of-load facility and a sufficiently compliant load cell. A discussion on static friction and the correct approach to its measurement is given in Annex C.

Rubber friction is complex, and the coefficient of friction is dependent on the contact geometry, normal load, velocity and temperature, as well as the composition of the rubber. A discussion of the influence of these parameters and some other factors which affect measurement is presented in Annex D.

Rubber — Determination of frictional properties

1 Scope

This International Standard outlines the principles governing the measurement of coefficient of friction and describes a method suitable for measuring the coefficient of friction of a rubber against standard comparators, against itself, or against any other specified surface.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 5893:2002, *Rubber and plastics test equipment — Tensile, flexural and compression types (constant rate of traverse) — Specification*

ISO 23529, *Rubber — General procedures for preparing and conditioning test pieces for physical test methods*

3 Terms and definitions

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

3.1
coefficient of friction
ratio of the frictional force opposing motion between two surfaces to the normal force between the surfaces under specified test conditions

NOTE Coefficient of friction is dimensionless and its value is not restricted to numbers less than unity.

3.2
area of contact
whole of the apparent area made between the two test surfaces (test track and test piece)

NOTE The real area of contact (see 3.3) may well be less than this.

3.3
real area of contact
sum total of the minute contact areas at which the two test surfaces touch

3.4
velocity of test
velocity with which one surface is driven relative to the other

NOTE If stick-slip (see 3.5) occurs, this will then be the mean velocity with which one surface moves relative to the other.

3.5
stick-slip
condition in which the actual velocity between the surfaces oscillates between two extremes about the test velocity, resulting in corresponding oscillations in the measured frictional force

3.6
test track
surface against which the rubber is to be tested

NOTE The test track may be made of the same material as the rubber under test or it may be different.

3.7
temperature of test
temperature of the test apparatus and its environment

NOTE Since friction generates heat, this may differ from the actual temperature of one or both of the test surfaces.

3.8
lubricant
substance introduced between two surfaces to lower the coefficient of friction

NOTE A lubricant is usually a liquid, but in some circumstances solid powders are used, e.g. talc. Usually, lubricants are introduced deliberately.

3.9
contaminant
any substance present on either test surface not of the same composition as that surface

NOTE A contaminant may act as a lubricant. Usually, in service, contaminants are introduced inadvertently.

3.10
stiction
force needed to move one surface over another when the external normal load is reduced to zero

NOTE This is an apparent frictional force, but no coefficient of friction can be calculated since the normal force is zero. See Annex C.

3.11
static friction
frictional force needed to start motion (i.e. the frictional force at zero velocity)

NOTE Where there is an external normal load, a coefficient of static friction can be calculated. Static friction often involves some element of stiction. See Annex C.

4 Principle

Two test surfaces are brought together under the action of a measured normal load. A mechanism slides one of the surfaces over the other at a measured velocity, and the force opposing motion is monitored and recorded. The ratio of this frictional force to the normal load at any instant is the coefficient of friction at that time. Since the test itself will alter the surfaces and may change the temperature at the interface, the measured coefficient of friction may change as the test proceeds.

In an ideal apparatus, the line of action of the force-measuring equipment will lie in the plane of the two contacting surfaces. This may be either a horizontal or a vertical plane.

5 Apparatus

5.1 Device, with provision for attaching two friction surfaces and capable of providing linear motion between the surfaces for a distance of typically 100 mm at a number of fixed velocities, typically between 0,5 mm/min and 1 000 mm/min. This may be a dedicated device or, alternatively, a tensile-testing machine may be adapted for the purpose.

5.2 Means of providing several measured normal loads between the surfaces within the range 1 N to 200 N. When the test track is horizontal, suitable weights may be used directly to provide the normal load, but on a machine with a vertical test track it will be necessary to use a bell crank lever system to convert the vertical gravitational force into a horizontal normal force.

5.3 Series of load cells or, alternatively, a **load cell with multiple ranging**, conforming to at least class 1 as defined in ISO 5893:2002, fitted with a means of recording the output and fastened to one of the friction surfaces, with ranging or other means of indicating the frictional force to an accuracy of ± 1% throughout the range of measurement.

NOTE Corresponding to the range of normal loads stated in 5.2, the measured frictional forces are likely to be within the range 0,1 N to 1 kN.

5.4 Environmental cabinet (if the effects of temperature are to be studied), to contain the apparatus and the two surfaces under test (but not the load cell), with a means of measuring and recording the temperature to an accuracy of ± 0,5 °C. The environmental chamber shall not make physical contact with any moving parts.

NOTE 1 The exclusion of a condensation-forming atmosphere from the test environment is extremely difficult, and the formation of ice crystals or particles or films on the test surfaces can only be assessed visually.

NOTE 2 To avoid the formation of ice when testing at temperatures at or below 0 °C, a very dry atmosphere (e.g. 5 % to 10 % r.h.) is needed.

5.5 Means of avoiding stick-slip, as the whole apparatus (including the load cell) needs to be as stiff as possible. All connections shall be made with rods and not with wire. Where an apparatus is designed to be attached to a tensile-testing machine, then a machine with a high degree of stiffness shall be chosen. In practice, this means a tensile-testing machine with a load capacity some 20 times greater than the maximum frictional force being measured.

5.6 Means of separating the surfaces under test, for use when the apparatus is reset to its initial position after each measurement. This is necessary because friction is very dependent on the history of the surfaces.

NOTE Separation of the surfaces may be carried out manually or automatically.

6 Test surfaces

6.1 General

For each test, two prepared surfaces shall be used, one manufactured from the rubber under test and the other (the test track) made either from this same rubber or, alternatively, from a specified material.

6.2 Test track

The test track shall be approximately planar but may have a patterned surface.

The material used to form the test track shall be larger in both linear dimensions than the test pieces (see 6.3). The longer dimension shall be sufficient to allow a linear travel of at least 50 mm.

The test track may be any surface agreed between the interested parties, but where comparisons have to be made it may be more appropriate to select one of the following:

a) The rubber under test with the surface moulded, split or buffed.

b) Float glass with the surface either polished or ground.

c) A specified stainless steel with the surface either polished or ground.

d) Cast iron with the surface ground to a specified finish.

e) Resin-bonded paper of specified grit size.

NOTE The measured coefficient of friction will depend not only on the material chosen but also on the surface finish of the test track (see Clause D.1).

6.3 Test pieces

Either moulded test pieces or test pieces cut from products may be used. Three test pieces shall be tested.

When planar test pieces are used, they shall be of smaller dimensions than the test track selected (see 6.2), so that it is possible to obtain linear motion between the two surfaces for at least 6 s, while maintaining contact (apparent contact) over the whole of the rubber surface throughout the test.

Test pieces shall normally be of a thickness between 1 mm and 8 mm. When the test surface is thinner than this, it shall be mounted on a support of adequate thickness using adhesive.

NOTE 1 In some circumstances, the contact area may be affected by the modulus of the underlying support, and it is then advisable to match as closely as possible the modulus of the test surface to that of the support.

The test piece shall not be stretched during mounting.

Any adhesive used shall not unduly swell or otherwise adversely affect the test piece.

Round off the leading edge of all planar test pieces to avoid buckling or digging in of this front edge.

NOTE 2 To reduce the possibility of stick-slip, it is advisable to keep the thickness of low-modulus test pieces below 4 mm.

When a test piece is made from a product, it may not be possible to cut a planar piece of adequate size. A suitable test piece may than be fabricated by mounting a number of small pieces cut from the product (for example, lengths of a windscreen-wiper blade may be mounted so that the wiping surfaces define a plane). Three small pieces, mounted at the corners of a triangle, will always define a plane. A greater number than this will need more careful mounting or perhaps additional preparation by buffing or abrasion. Alternatively, it may be better to use a different test geometry as discussed in Annex A.

7 Preparation

7.1 General

Materials may be tested as received, but where comparisons are to be made it is advisable to bring the surfaces to some standard condition. Texture is important since, in general, rough surfaces have a lower coefficient of friction than smooth surfaces when dry and a higher coefficient of friction than smooth surfaces when wet. Thus different coefficients of friction will be observed depending on the method of preparation used.

7.2 Surface texture

A test track made of float glass or mirror-finished metal shall be cleaned without other treatment (see 7.3). Other surfaces that need to be abraded shall be machine-ground, buffed or abraded by hand against resin-bonded paper of specified grit size.

Generally, test pieces prepared by splitting on a leather-splitting machine will need no further preparation other than cleaning.

7.3 Surface cleaning

Where contamination occurs in service and forms part of the agreed test conditions (see Clause 13), then it may be left, but where contamination is the result of the preparative procedure it shall, as far as possible, be removed.

It has to be recognized that complete removal of contaminants is not always possible, and sometimes the coefficient of friction is permanently altered by the residual contamination. For example, complete removal of silicone oil is rarely possible. For this reason, preparative techniques shall be chosen with great care. Where lubricants are needed for any abrasive, these should preferably be water-based rather than oil-based. Similarly, when mounting test pieces with adhesive great care shall be taken to keep the test surface free from adhesive. Care shall be taken not to contaminate the test surface with finger grease.

Where contamination has occurred, proceed as follows:

Blow all loose debris from the surface using a jet of clean, dry air or similar gas.

NOTE 1 A compressed-air line is not suitable as the air is usually wet and contaminated with oil.

Alternatively, brush debris away using a clean, dry, soft brush.

When the contaminants, such as grease, cling to the surface, select a suitable solvent from the following list:

a) distilled water plus a small amount of detergent;

b) distilled water only;

c) tap water;

d) ethyl alcohol;

e) isopropanol;

f) acetone;

g) butanone;

h) perchloroethylene;

i) toluene.

The chosen solvent shall not dissolve or unduly swell the surface being cleaned.

NOTE 2 Health and safety regulations apply to the use of some of these solvents.

In general, high-purity solvents are needed since it is only too easy to spread further contamination by using impure solvents. Similarly, any cloth or paper used for cleaning shall not be allowed to contact the neck of the storage vessel in order to avoid contaminating the solvent in the vessel.

Wet, with a little of the solvent, a piece of lintless cloth or tissue (which shall be unaffected by the solvent) and wipe the test surface in one direction only. Discard the cloth or tissue. Repeat this procedure twice more using a fresh tissue and fresh solvent.

When distilled water plus detergent has been used, remove the detergent by wiping the surface three times more with distilled water only.

In locations where the tap water is known to be very pure, rinsing under the tap may alternatively be used.

NOTE 3 Where contaminants are water-soluble, this is undoubtedly the most efficient cleaning procedure.

Drain off any excess solvent by holding the surface in a vertical plane, and allow the surface to dry in the air.

Handle the test pieces by the edges only, wearing gloves to avoid contamination with finger grease. Do not place the prepared surface in contact with any surface other than that against which it is to be tested.

Condition the test pieces in accordance with the procedure given in Clause 8.

8 Conditioning

8.1 Time lapse between vulcanization and testing

For all test purposes, the minimum time between vulcanization and testing shall be 16 h. For non-product tests, the maximum time between vulcanization and testing shall be 28 days and, for evaluations intended to be comparable, the tests shall, as far as possible, be carried out after the same time interval. For product tests, whenever possible, the time between vulcanization and testing shall not exceed 90 days. In other cases, tests shall be made within 60 days of the date of receipt of the product by the customer.

8.2 Protection of samples and test pieces

Samples and test pieces shall be protected as completely as possible from all external influences likely to cause damage or contamination during the interval between vulcanization and testing, e.g. light, heat, dust.

NOTE Additional guidance is given in ISO 2230 [1].

8.3 Conditioning of test pieces

Condition prepared test pieces for a minimum of 3 h at standard laboratory temperature.

If preparation includes buffing, the time interval between buffing and testing shall be not less than 16 h and not more than 72 h.

For tests at temperatures other than standard laboratory temperature, condition the test pieces at the temperature at which the test is to be conducted for a period sufficient to enable test pieces to attain substantial equilibrium in accordance with ISO 23529.

9 Test parameters

9.1 General

For guidance on the effect of test conditions on frictional behaviour, see Annex D.

9.2 Temperature of test

The test shall be carried out at standard laboratory temperature or at any other temperature(s), selected from those listed in ISO 23529, agreed between the interested parties.

NOTE At temperatures below the dew-point, moisture will condense on the test surfaces, and this may seriously affect the measured frictional force. To avoid this, it is necessary to conduct these tests in conditions of low humidity in an environmental chamber. Similarly, at 0 °C ice may form and to avoid this a very dry atmosphere is needed.

9.3 Velocity of test

Unless otherwise agreed or specified, the test shall be carried out at a velocity of 50 mm/min.

NOTE Doubling or halving the velocity gives little change in friction. Test velocities should therefore preferably be chosen a factor of 10 apart if a range is being studied. Frictional heating is greatest at higher velocities and, at values greater than 1 000 mm/min, cannot be ignored.

9.4 Normal load

The normal load shall be chosen to suit the application.

NOTE In the absence of an application, the preferred normal loads are 10 N, 50 N and 100 N.

10 Cleaning or renewal of the test track

The test track shall be cleaned or renewed each time a new test piece is used.

NOTE As testing proceeds, the surfaces change and friction may alter. It is not practicable to renew the test pieces after each test in a series involving changes in load, velocity and temperature. However, it is advisable to renew or clean the test track whenever the test piece is changed. This is the minimum procedure specified. The test track may be cleaned or renewed more frequently than this in cases where this seems appropriate.

11 Procedure A (initial friction measurements)

11.1 If the test temperature is other than standard laboratory temperature, set the environmental chamber to the specified temperature and allow the apparatus to reach this temperature.

11.2 Mount the test piece(s) in the apparatus, fixing them in place either mechanically or using adhesive. If tests are to be conducted over a range of temperatures, the same method of fixing shall be used throughout the temperature range.

11.3 Using packing pieces, or whatever means of adjustment is provided, adjust the test piece(s) so that the line of action of the load cell and the line of action of the drive mechanism both lie in the plane of contact of the test piece with the test track. If this is not possible, record the degree of offset to the nearest 0,5 mm.

11.4 Set the test piece(s) to the start position and select the velocity of test.

11.5 Select and apply the normal load.

NOTE With a horizontal apparatus, the normal load includes the weight of the test piece and its mounting.

11.6 Operate the mechanism which separates the surfaces.

11.7 Set the force-recording equipment to the required range (a force range approximately equal to the normal load applied) and check the zero.

11.8 After the conditioning period has passed (see 8.3), bring the two test surfaces together and within 5 s start the machine.

11.9 At the end of the test run, separate the surfaces again and return the machine to its starting position.

NOTE The return velocity need not be the same as the velocity of test.

11.10 Repeat steps 11.8 and 11.9 twice, making three measurements in all.

11.11 If the test track or test piece has a directional surface finish, then reverse the test track or test piece and repeat steps 11.1 to 11.10.

11.12 If further measurements are to be made, then select the appropriate velocity, temperature and normal load and repeat steps 11.1 to 11.10.

12 Procedure B (service behaviour)

12.1 As testing proceeds, the condition of the surface of the test piece and the test track change and the coefficient of friction alters. If this corresponds with service behaviour, the later values of the coefficient of friction may be more relevant than the early ones. Under these circumstances, proceed as given in 12.2 to 12.4.

12.2 Follow the procedure from 11.1 to 11.10.

12.3 Switch on the recording mechanism and repeat 11.8 to 11.9 50 times or as agreed between the interested parties.

12.4 Switch on the recording mechanism and repeat steps 11.8 to 11.10, recording three further traces (see Figure 2).

13 Procedure C (tests with added lubricants or contaminants)

13.1 Carry out steps 11.1 to 11.6.

13.2 By means of a spray, spatula or other suitable means, apply the specified lubricant or contaminant to one of the two test surfaces.

NOTE Typical lubricants or contaminants are water, water with added detergent, oil or grease.

13.3 Carry out steps 11.7 to 11.9.

NOTE On a vertical test track, it may be necessary to spray lubricant or contaminant onto the test track continuously.

13.4 Repeat steps 13.2 and 13.3 twice, making three measurements in all.

13.5 If further measurements are to be made, select the appropriate texture direction, velocity, temperature and normal load and repeat steps 13.1 to 13.4.

13.6 Dismantle the apparatus and thoroughly clean the test surfaces and the mounts in which they are fixed. As noted previously, with some contaminants, such as silicone oil, it is not possible to remove all traces of the contaminant. In this case, place the test track in a sealed polyethylene bag labelled with the type of contaminant and keep this particular track for future tests of this type. Do not use it for normal friction testing.

14 Stick-slip

14.1 It is not always possible to eliminate all stick-slip during testing but, if the oscillations extend over more than 30 % of the force range, try to reduce them following the procedure given in 14.2 to 14.7.

14.2 Check that the line of action of the mechanical drive and the line of action of the load cell both lie in the plane of contact of the test piece with the test track. Make adjustments to correct any misalignment.

14.3 Use a stiffer load cell, even if this has what seems to be too large a load capacity bearing in mind the minimum test force for that particular load cell.

14.4 Stiffen all couplings and eliminate loose joints.

14.5 Introduce cross-bracing into the frame of the machine if this seems too flexible.

14.6 Reduce the thickness of the test pieces and ensure that their leading edges are adequately rounded.

14.7 If these measures fail, carry out the test at a velocity two times to 10 times that of the original test velocity, noting this change in the test report.

15 Presentation of results

15.1 General

Record on each set of traces the normal load, velocity and temperature of test in addition to the sample numbers and other data relating to the two materials involved in the test.

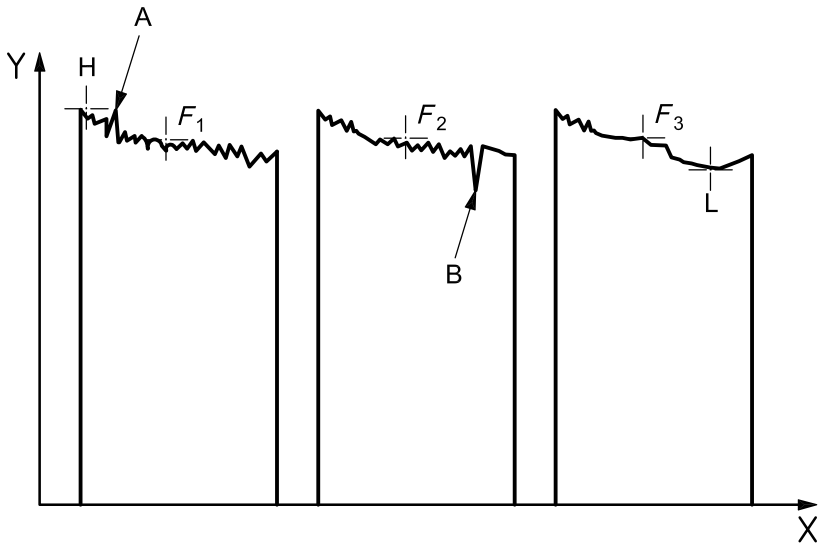
15.2 Calculation and expression of results (procedures A and C)

Typical repeat traces are shown in Figure 1. Surfaces are rarely completely uniform and some change in friction as testing proceeds is inevitable. Also, rubber is a visco-elastic material and takes time to respond to the forces applied to it. This means that the frictional force often depends on the length of time that the surfaces have been in contact or on the length of time since movement commenced. Frequently, therefore, precise values of the coefficient of friction cannot be quoted. This reflects reality, for as testing proceeds the minute areas of real contact change and with repeated testing both surface texture and surface condition are changed. Therefore, it is advisable to give a range of values within which the coefficient of friction between two materials tested under specified conditions would be expected to lie.

Examine each of the three traces recorded in 11.10 or 13.4. Mark and record the mid-point frictional-force value in each case (F_1, F_2 and F_3 in Figure 1). Divide the measured frictional force by the relevant normal load for each of the three traces and record the coefficients of friction so obtained to two decimal places. Repeat this for each of the three test pieces, giving nine values in all (in the case of test pieces with a directional surface texture there will be 18 values).

Calculate, to two decimal places, the mean of these nine values and record this as the mean coefficient of friction under the stated conditions. For surfaces with directional texture, quote the two separate means obtained.

Record also the maximum and minimum values on the nine (18) traces (see H and L in Figure 1). Calculate coefficients of friction from these values, as before. These values then represent the range in which the coefficient of friction of the two surfaces would be expected to lie.



Key

X time

Y frictional force

Figure 1 — Typical friction traces showing high and low points

Single brief excursions upwards, such as that shown at A in Figure 1, are usually due to a “step” in the track or to spot contamination with a high-friction material, for example an adhesive, while single brief excursions downwards, such as that shown at B, are usually due to a small area of lubricating contamination or a slight surface irregularity. Ignore these brief excursions because they are not really a property of the surface being tested, and calculate the results on the remaining trace. If there is any doubt, or if there are multiple excursions to high or low values, then repeat the test with fresh materials.

15.3 Calculation and expression of results (procedure B)

Typical traces obtained by procedure B are shown in Figure 2. In general, there is a trend upward or downward from the first test to the last, and the change between the first and third traces (A and C) is usually much larger than the change in friction level observed in the final three traces (D, E and F).

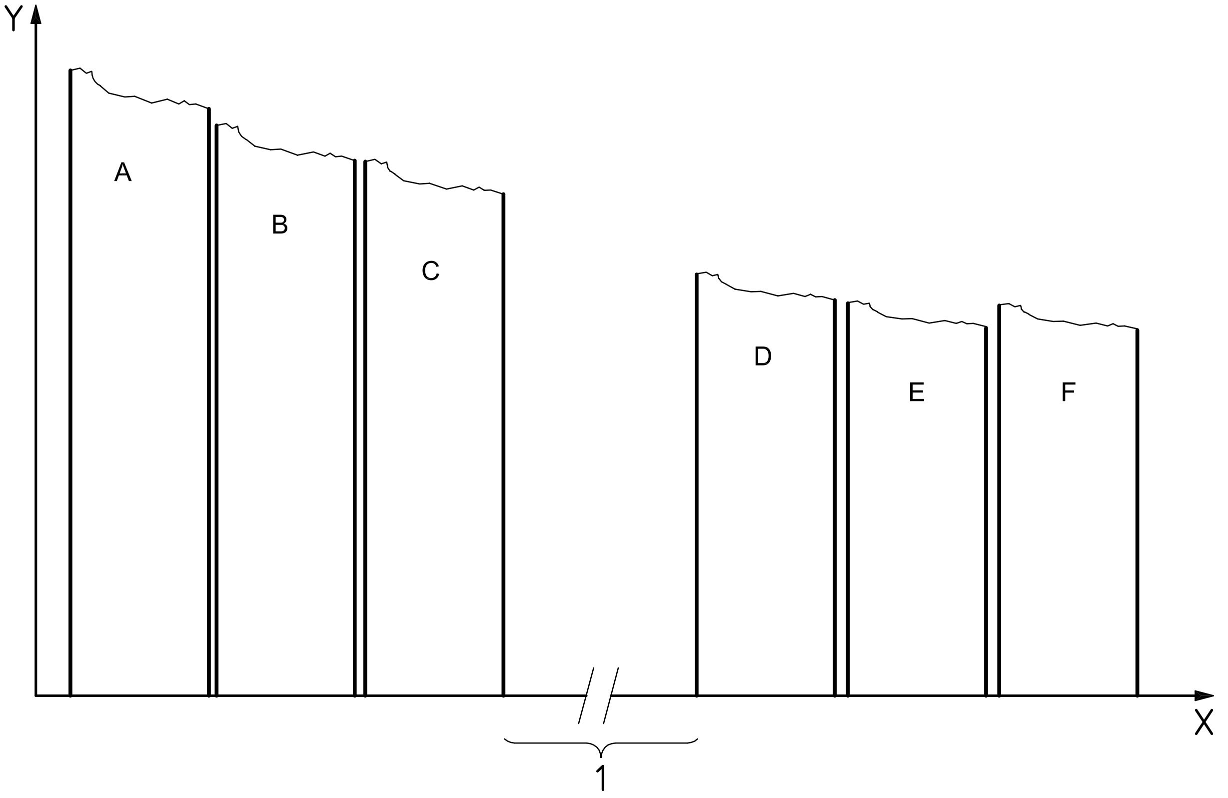
Since this test is intended to simulate service behaviour, where cross-contamination of the track and the test piece occur, it is the final three traces which are relevant. Ignore traces A, B and C and treat traces D, E and F in accordance with the procedure set out in 15.2.

15.4 Treatment of stick-slip

On each trace, draw in the locus of the mid-points of the stick-slip motion. Treat these loci in the same manner as the traces in Figure 1. Calculate the mean coefficient of friction for each trace in accordance with the procedure set out in 15.2 and calculate the mean value of the nine (18) values so obtained.

However, for the maximum and minimum values use the extreme range of the stick-slip motion, such as points H and L in Figure 3. Calculate the coefficients of friction corresponding to the force values at H and L and quote these as the extremes of the range in which the coefficient of friction would be expected to lie under these test conditions.

NOTE The amplitude of stick-slip motion is not solely a property of the surfaces under test, but is markedly dependent on the spring forces built into the apparatus. Excessive stick-slip can almost always be reduced by stiffening the apparatus and load cell. Consequently, the values calculated at H and L are as much a property of the apparatus as of the test materials.



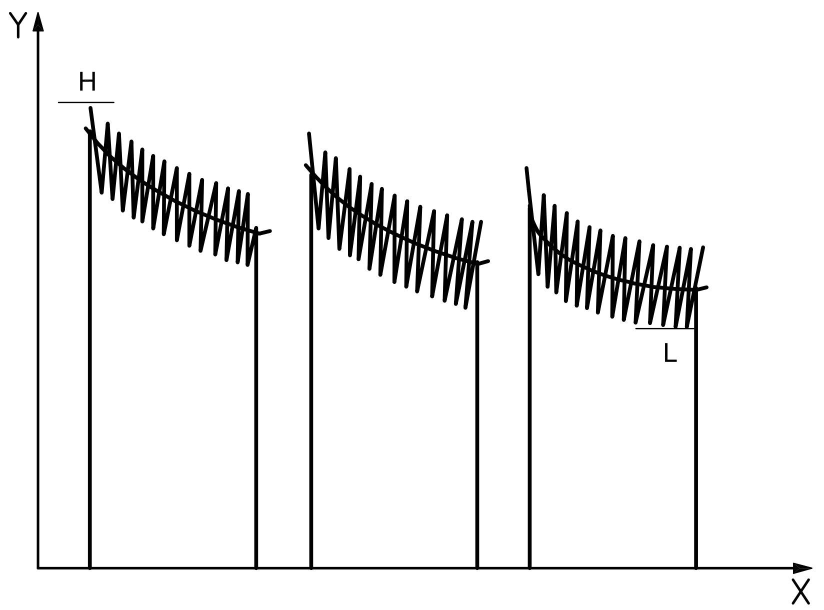
Key

X time

Y frictional force

1 50 runs

Figure 2 — Typical drift of results in extended tests



Key

X time

Y frictional force

Figure 3 — Typical stick-slip traces

16 Test report

The test report shall include the following information:

a) Sample details:

1) a full description of the rubber tested and the test track against which it was tested;

2) compound details and conditions of curing of the rubber, if known;

3) details of preparation of the test pieces, for example whether moulded or cut;

4) the surface preparation used and, where known, the surface roughness (or grit size if a test track of resin-bonded abrasive paper was used).

b) Test method and test details:

1) a reference to this International Standard;

2) the procedure used (A, B or C);

3) the type of apparatus used;

4) the conditions of test, including normal load, velocity, temperature and any lubricants or contaminants used;

5) the time and temperature of conditioning of the test pieces prior to testing;

6) details of any deviation from the procedure, e.g. the offset of the line of action of the load cell from the plane of contact of the two test surfaces.

c) Test results:

1) the mean value of the coefficient of friction, and the maximum and minimum values of the coefficient from the nine (18) friction traces;

2) the direction(s) of test for surfaces with a directional texture;

3) copies of complete friction traces, if required.

d) The date of the test.

Annex A
(informative)

Design principles

When one surface slides over another, a frictional force opposes the motion. The magnitude of this frictional force depends on the magnitude of the force acting normally to the surface (the normal force or normal load). The ratio of the frictional force to the normal force is termed the coefficient of friction.

In order to measure the magnitude of the frictional force, it is necessary to provide relative motion between the surfaces and to monitor the force with a load cell.

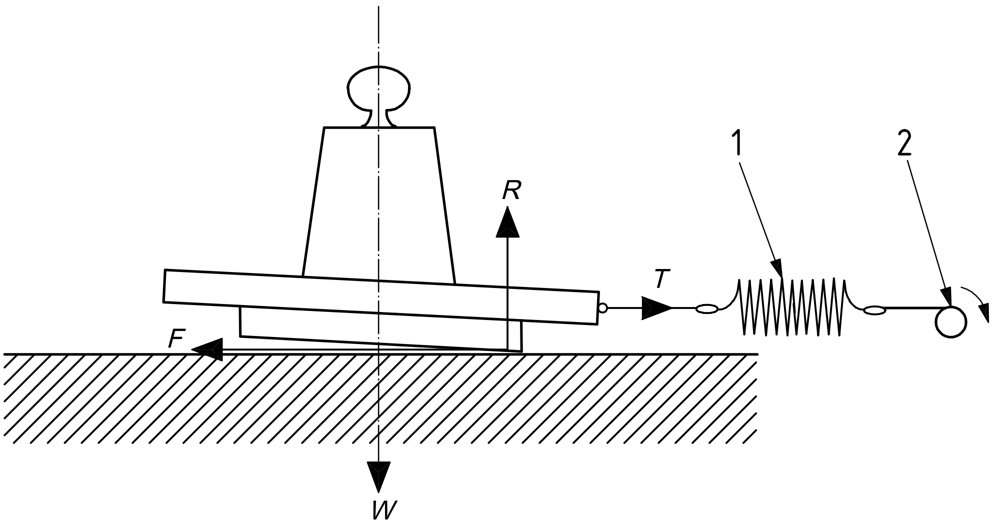
A typical simple arrangement is shown in Figure A.1, and at first sight this seems satisfactory enough.

However, the frictional force opposing motion lies in the friction plane, whereas the towing force T lies above it. This creates a clockwise torque which can only be balanced by the sled tilting on its forward edge, as shown (exaggerated) in Figure A.1. The anti-clockwise couple is provided by the weight W and the reaction R at the front edge of the sled (exaggerated for the sake of clarity).

Experimentally, this is an exceedingly poor arrangement since contact occurs over a reduced, uncertain and undefinable area. The arrangement is also unstable and liable to violent stick-slip motion.

When constructing an apparatus, therefore, it is important to ensure that the line of action of the load cell and the drive mechanism are both included in the plane of contact of the two surfaces. Diagrammatically, this is shown in Figure A.2 and it is clear that a more rigid arrangement than that illustrated in Figure A.1 is needed. This in turn has the advantage that stick-slip motion is considerably reduced. A fuller discussion will be found in the paper by James and Newell [3].

However, with this arrangement there are limits on the normal force and velocity of test that can be used, and for some products other test parameters may be more important. For example, bearing materials require a rotary test configuration capable of reaching high velocities. Similarly, V-belts, which generate relatively high normal loads, are better tested in an apparatus dedicated to this type of product.

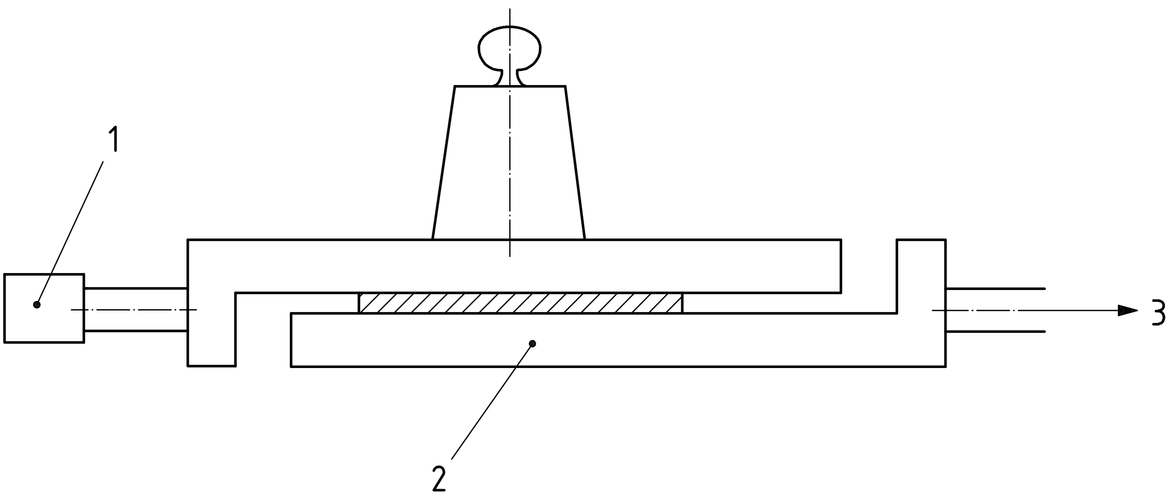


Key

1 load cell

2 drive

Figure A.1 — Effect of offset between the towing force and the frictional force



Key

1 load cell

2 track

3 to drive

Figure A.2 — An arrangement which keeps the towing force and the line of action of the load cell in the friction plane

Annex B
(informative)

Ball-on-flat geometry

An alternative approach to overcoming potential problems of contact area with planar surfaces is to use a rubber sphere on a plane track. If the stress-strain properties of the rubber are known, then the contact area can be calculated.

According to Hertz [4], when a smooth elastic sphere contacts a smooth plane, the radius of contact a is given by the equation

$$a^3 = \frac{9}{16} \times W \times \frac{R}{E}$$

where

R is the radius of the sphere;

W is the load;

E is Young's modulus (or rather an approximation to it in the case of rubber).

Friction theory states that the frictional force F is proportional to the contact area and to the shear strength S of the interface, as given by the equation

$$F = \pi a^2 S$$

Using the Hertz equation above, the relationship between the frictional force F and the normal force W becomes

$$F = \pi S \times \left(\frac{9}{16} \times \frac{R}{E} \right)^{\frac{2}{3}} \times W^{\frac{2}{3}}$$

and the coefficient of friction μ is then given by

$$\mu = \frac{F}{W} = \pi S \times \left(\frac{9}{16} \times \frac{R}{E} \right)^{\frac{2}{3}} \times W^{-\frac{1}{3}}$$

However, this rather idealized model is rarely encountered in service situations. When contact between a sphere and a plane, each with a degree of roughness, or contact over multiple contact points, is considered, Archard [5] established that

$$F \propto W^n$$

where $\frac{2}{3} < n < 1$

The value of n in the above equation varies with the complexity of the model. A fuller discussion is given in Bowden and Tabor's book on friction [6]. The contact between a cylinder and a plane may be analysed similarly.

Annex C
(informative)

Static friction and "stiction"

If, when the normal load is reduced to zero, there is still a force opposing motion, then there is adhesion between the surfaces (for example a licence holder on a car windscreen). This phenomenon is often referred to as "stiction" since no adhesive is involved and the force opposing motion appears to be friction. Electrostatic charge and capillary attraction may also generate adhesion between surfaces. In effect, this increases any external normal force applied.

Since the magnitude of this adhesive force is rarely known, the coefficient of friction is usually calculated on the basis of the applied normal load alone. This gives a higher figure for the coefficient of friction than would be obtained if the adhesion were absent, or could be allowed for numerically when estimating the normal load.

Often the stiction between surfaces depends on the time that they have been in contact, and in general the adhesion increases with time. This means that the frictional force opposing motion will also increase with the time of contact. Since the external normal force remains constant, the effect of this is to give an increasing coefficient of friction with longer contact times.

It is important, therefore, that in any test procedure the contact time is kept relatively constant between tests (preferably a short time unless the effect of stiction is being investigated). This may be achieved in one of two ways: either by starting the motion before the surfaces are brought together or by specifying a time limit between bringing the surfaces together and starting the motion. In general, the problems of stiction are greater with smooth surfaces than with rough surfaces, and when materials are being compared more reliable results can be obtained on surfaces with a slight degree of roughness (for example, 10 µm to 30 µm Rz roughness as defined in ISO 4287 [2]) rather than completely smooth surfaces. The force necessary to start motion is termed "static friction". The static friction of rubber is very difficult to measure since the numerical values obtained depend on the time the surfaces have been in contact and on the rate of rise of the applied shear force. Generally, the static friction of rubber is very low so that the test piece will move no matter how small the shear force that is applied. However, the rate of resulting movement is so small that it may take several weeks before any perceptible movement can be detected.

Additionally, it is almost impossible to distinguish static friction from stiction, which is static friction at zero normal load, and frequently the two are confused. The method of measuring friction described in this International Standard utilizes a number of selected velocities, and an indication of the trend at velocities close to zero (corresponding to the slow movements referred to above) can be obtained by carrying out measurements at the lowest velocity obtainable on the apparatus.

An apparatus for measuring static friction or stiction should be based on a slowly rising force ramp rather than on selected velocities. It also requires a very sensitive indicator of the initial motion. If these facilities are available, the general method described here can be adapted to the measurement of static or initial friction.

Annex D
(informative)

Other parameters

D.1 Roughness

On a very rough track, the coefficient of friction may be quite different from that obtained on a smooth track. This is particularly noticeable under lubricated conditions.

If the roughness is sufficient to cause cutting of the rubber surface (as with very rough garnet paper, for example), then the work done in cutting the rubber surface appears to the observer to be work done against friction. This in turn results in an observed coefficient of friction which is higher than that which would be obtained if the cutting action did not occur.

Similarly, if the roughness is of an undulating nature (as with wire gauze, for example), then the rubber surface suffers repeated deformations. Since rubber is a visco-elastic material, energy is lost in the process of deformation and recovery. This energy loss again appears as work done against friction and results in an increase in the observed coefficient of friction. This is particularly noticeable in wet conditions. The greater the hysteresis loss in the rubber, the more the friction is enhanced, but this carries with it the penalty that the heat generated by the hysteresis loss raises the temperature of the rubber. In turn, this temperature rise can also change the value of the coefficient of friction (see Clause D.3).

It is important, therefore, to specify (or to report if that is more appropriate) the surface finish of both the rubber and the test track. Attention is drawn to BS 1134, Parts 1 and 2 [7, 8], which give methods and guidance for the assessment of surface texture. It is even more important, when making comparisons of one rubber with another, to ensure that the conditions of test are identical.

D.2 Normal load

There is a relationship between frictional force and real area of contact. As the normal load is increased, the real area of contact increases and so does the frictional force. Over a wide range of normal loads, the coefficient of friction remains approximately constant (decreasing only slightly with load). However, at very high loads the real area of contact reaches a saturation value, and if the normal load is further increased the frictional force remains relatively constant. The implication of this is, of course, that the coefficient of friction falls at very high loads. Such high loads are generally beyond the range that can be investigated using the type of apparatus described here.

D.3 Velocity and temperature

It is not possible in this clause to give justice to the mathematical relationship between velocity and temperature. However, it may be sufficient to say that increasing velocity is equivalent to lowering temperature. The underlying relationship is that given by Williams, Landel and Ferry [9], and an excellent outline of the application of this equation to friction has been given by Grosch [10].

Theory shows that, if frictional force is plotted against the logarithm of velocity, a curve similar to that shown as curve (a) in Figure D.1 is obtained. Raising the temperature moves the curve to the right as indicated by curve (b) in the same figure. In practice, these curves cannot be established experimentally since at very high velocities frictional heating raises the temperature at the interface. As velocity increases, experimental results start on curve (a) and finish on curve (b), giving a broad peak as shown in curve (c) in Figure D.2.

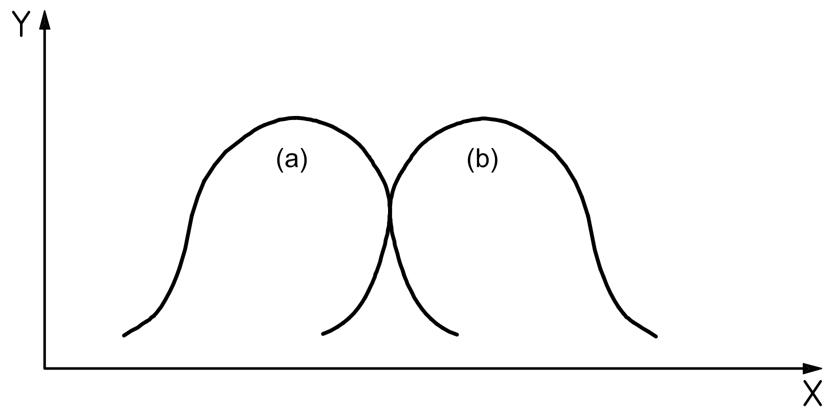
D.4 Fillers

Adding carbon black or other fillers to the rubber compound tends to flatten the curve of coefficient of friction against log velocity as shown in curve (d) in Figure D.2.

D.5 Glass-transition temperature T_g

The position of the curve of the coefficient of friction depends on the glass-transition temperature of the rubber. Materials with a low T_g occupy a place to the right and those with a higher T_g occupy a place further left as shown in Figure D.3.

At room temperature and in the range of velocities considered in this International Standard, most rubbers have a rising friction/velocity characteristic, and it is this property that makes them so useful in drive belts and similar applications. However, a rubber with a relatively high glass-transition temperature used at a relatively low temperature, for example 5 °C, may have a falling friction/velocity characteristic, and in this situation drive or grip may be uncertain and unstable. This is illustrated in Figure D.3. In this situation, the remedy is to choose a rubber with a lower glass-transition temperature, even though this will have an apparently lower coefficient of friction.

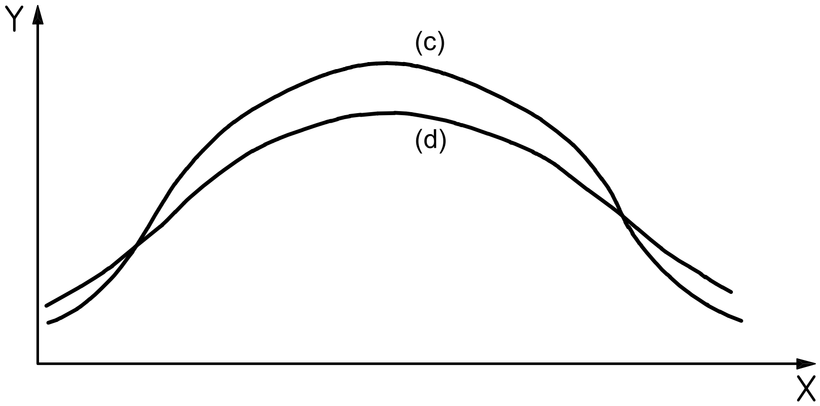


Key

X log velocity

Y coefficient of friction

Figure D.1 — Theoretical change in friction over a large velocity range, allowing for temperature increase at the interface

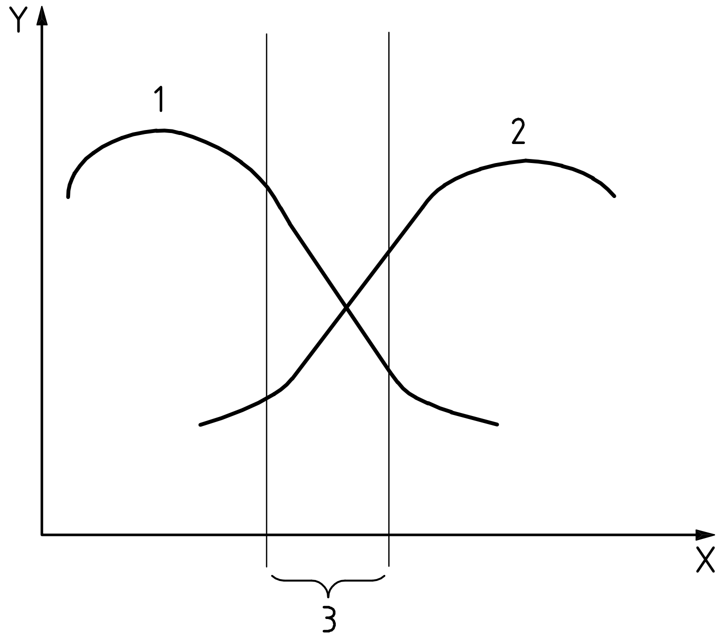


Key

X log velocity

Y coefficient of friction

Figure D.2 — Experimental change in friction over a large velocity range, allowing for temperature increase at the interface



Key

X log velocity

Y coefficient of friction

1 high T_g

2 low T_g

3 service-velocity range

Figure D.3 — Effect of glass-transition temperature on friction curves

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