INTERNATIONAL STANDARD

ISO 15117-1

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Coal flow properties —

Part 1:
Bin flow

Propriétés d'écoulement du charbon —

Partie 1: Écoulement d'une trémie

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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 15117-1 was prepared by Technical Committee ISO/TC 27, *Solid mineral fuels*, Subcommittee SC 1, *Coal preparation: Terminology and performance*.

ISO 15117 consists of the following parts, under the general title *Coal flow properties*:

— *Part 1: Bin flow*

— *Part 2: Rapid assessment*

Coal flow properties —

Part 1:
Bin flow

1 Scope

This part of ISO 15117 sets out methods for the measurement of the flow properties of coal, primarily for the design of bins and chutes. It also provides some guidance on the presentation of these data for analysis and design.

This part of ISO 15117 consists of a bulk density test and a yield locus test giving information on material flow properties. It also describes a further test, called the wall yield locus, which measures the friction between coal and bin wall material.

Although this part of ISO 15117 is nominally for coal, the principles and apparatus may be used for coke and other semi-cohesive particulate materials where a knowledge of flow properties is required.

NOTE Some discussion of the relevance of coal flow properties to bin design philosophy is provided in Annex A.

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 1213-2:1992, *Solid mineral fuels — Vocabulary — Part 2: Terms relating to sampling, testing and analysis*

ISO 1953:1994, *Hard coal — Size analysis by sieving*

ISO 589:1981, *Hard coal — Determination of total moisture*

ISO 13909-2: 2002, *Hard coal and coke — Mechanical sampling — Part 2: Coal — Sampling from moving streams*

ISO 13909-4: 2001, *Hard coal and coke — Mechanical sampling — Part 4: Coal — Preparation of test samples*

ASTM D 6128-00, *Standard Test Method for Shear Testing of Bulk Solids Using the Jenike Shear Cell*

3 Terms and definitions

For the purposes of this document, the terms and definitions in ISO 1213-2 and those below apply.

NOTE In this part of ISO 15117, the terms pressure and stress are used synonymously because this convention is used in research and literature on this subject. Some other terms have not yet been standardized in the literature. These are listed below, together with a reference to the preferred nomenclature.

3.1
axi-symmetric flow
SEE mass flow

3.2
bulk density
the mass of a sample of particulate solid including moisture, divided by its total volume

NOTE The level of consolidation stress is critical to any measurement of bulk density.

3.3
bulk material
semi-cohesive particulate material such as coal and other minerals

3.4
cohesion
the shear stress at yield under zero normal stress

NOTE This parameter is not normally quantified.

3.5
compaction
the process of permanent volume reduction of a bulk material by application of a consolidating stress

3.6
consolidation
SEE compaction

3.7
core flow
SEE funnel flow

3.8
critical consolidation, in a shear cell
the state existing in a bulk sample within a shear cell when the cell stem travel becomes independent of applied shear force

NOTE Under these conditions, the bulk material is deforming without change in voidage. The material is said to be in its critical state.

3.9
critical state
SEE critical consolidation

3.10
critical pipe or rathole diameter
the diameter of a rathole or pipe at which the rathole or pipe becomes unstable

NOTE The critical rathole diameter varies with consolidation pressures.

3.11
effective angle of internal friction
δ
the angle with the horizontal axis of a line through the origin and tangent to the Mohr circle through the end point of the yield locus

See Figure 4.

NOTE The line through the origin is called the effective yield locus.

3.12
expanded flow
flow from a bin which has two distinct cross-section regimes

NOTE Funnel flow exists in the lower cylindrical section of the bin whereas mass flow exists in the conical outlet hopper or hoppers.

3.13
flow function, instantaneous
FF
for a given bulk material, a plot of the unconfined yield strength σ_c versus the major consolidating pressure, values being obtained from the yield loci

NOTE This is a measure of the bulk strength or flowability of a bulk material, in a de-aerated state, when first loaded into a bin or consolidated in a shear cell.

3.14
flow function, time storage
for a given bulk material, a measure of the increase in unconfined yield strength of material subjected to standard consolidation conditions for a defined time, typically 24 h to 48 h

3.15
funnel flow
the flow that occurs during gravity storage when bulk material sloughs off the surface of the material and discharges through a vertical channel which forms within the material in the bin whenever material is drawn from the outlet

NOTE Material adjacent to the bin walls remains stationary.

3.16
hopper half-angle
α
the angle between one wall of the hopper and the vertical

3.17
major consolidating pressure
major consolidating stress
σ_1
the pressure given by the Mohr circle passing through the end point of the instantaneous yield locus and the tangent to the locus

See Figure 4.

3.18
mass flow
the flow that occurs when bulk material is in motion at every point in a bin whenever material is drawn from the outlet

NOTE Mass flow is normally symmetric and is usually axi-symmetric in three dimensions in a conical hopper, or plane in two dimensions in a wedge hopper.

3.19
natural fines
the fraction of the sample screened below 4 mm or 6 mm

3.20
particulate solid
an assembly of solid particles having properties independent of the number of particles present

SEE **bulk material** (3.3).

3.21
plane flow
SEE mass flow

3.22
shear apparatus
equipment for subjecting the material under test to shear deformation under conditions of controlled normal pressure

3.23
unconfined yield strength
σ_c
the major principal stress that must be applied tangentially to an unconfined surface to cause yielding

3.24
voidage or voids ratio
the volume of the voids within a quantity of bulk material, divided by total volume (voids plus solids)

3.25
yield locus, effective
see effective angle of internal friction

3.26
yield locus, instantaneous
the shear force versus normal force curve for plastic failure of an over-consolidated bulk material of given initial voidage; this defines conditions when material flow commences

3.27
yield locus, time
the shear force versus normal force curve for plastic failure of a bulk material after being held at rest under a standard pressure for a given time

3.28
yield locus, wall
ϕ
the locus of shear force versus applied normal force on a sample of bulk material moving in contact with a boundary surface or wall

NOTE This is the angle determined by the shear and normal force shown in Figure 10.

4 Notation

The following quantity symbols are used in this part of ISO 15117:

F Unconfined yield force under instantaneous conditions

h Compacted height, in bulk density test

S Steady-state shear force during the “shear consolidation” phase of the shear test

S_f Steady shear force obtained in the wall friction test

S_t An uncorrected value of S determined from the shear test

S_s The value of S selected for a particular level of consolidation, and used for prorating $(S_i)_t$ values

$\overline{S_i}$ Maximum value of shear force obtained during the “sample shear” phase of the shear test

$(\overline{S_i})_t$ An uncorrected value of S determined from the shear test

$(\overline{S_i})_p$ A corrected value of S obtained using Equation (1)

V Vertical force due to total vertical load applied at the shear plane during the “shear consolidation” phase of shear test X

$V = V_a + V_b$

V_a Vertical force due to the weight of the shear lid, shear ring and bulk solid above the shear plane, i.e. contained within the shear ring

V_b Vertical force due to the weight applied to the shear lid during the “shear consolidation” phase of the shear test

$\overline{V}_{bi}$ Vertical force due to the weight applied to the shear lid during the “sample shear” phase of the shear test

V_f Vertical force applied in the wall friction test

$\overline{V}_i$ Vertical force due to total vertical load applied at the shear plane during “sample shear” phase of the shear test

$\overline{V}_i = V_a + \overline{V}_{bi}$

V_t Vertical force due to the weight applied to the twisting lid during the “preconsolidation” phase of the shear test

V_1 Major consolidating force on sample

W_f Weights used in the wall friction test

W_h Mass of the weight hanger or carrier

σ_c Unconfined yield strength (or stress) of a bulk solid

σ_1 Major consolidation pressure (or stress) of a bulk solid

ϕ Wall friction angle

5 Sampling and sample preparation

5.1 Sampling

The sample for flow property analysis shall be taken in accordance with ISO 13909-2. Care should be taken at all stages of sampling, sample handling and testing to prevent undue breakage.

Where test results are to be used for design of bins and transfer points, the material sampled should be related to the “problem” i.e., in the state that creates the most difficult flow conditions. For example, where the material breaks down with time and moisture, a weathered sample should be used.

5.2 Sample preparation

5.2.1 General

Flow property measurements are carried out on the natural fines fraction of the sample. The top size of the fraction used shall be recorded.

The sample for testing shall be prepared by the methods given in ISO 13909-4. Sufficient sample shall be taken to yield at least 1 kg of the natural fines. If, however, time-delayed tests are to be carried out also, sufficient sample to yield 5 kg of minus 4 mm material is required.

5.2.2 Sample top size

After drying, the sample shall be sieved according to the method set out in ISO 1953 to separate the natural fines. All tests shall be carried out on the minus 4 mm material occurring naturally in the sample.

5.2.3 Sample division

Where necessary, the sample shall be divided by riffling or mechanical sample division to provide the required quantity for analysis. Dust loss and size degradation shall be minimized.

5.2.4 Moisture content

In consideration of specific problems, the sample may need to be dry or at a predetermined moisture content.

The screened sample shall be at the required moisture content. The moisture contents of the initial sample and screened sample shall be measured before and after flow property testing, in accordance with ISO 589, and should not differ by more than 0,5 % on a mass basis. Samples should be stored in sealed containers to maintain moisture content. The moisture content of the natural fines in relation to the bulk sample shall be determined.

6 Determination of yield locus

6.1 Apparatus

A Jenike-type, direct shear tester having provision for the continuous display of shear/deformation using a chart recorder is required. Standard shear cells (see Figure 1) have internal diameters of 95 mm or 63,5 mm.

The lower ring is fixed to the frame and the upper ring is free to move under the action of the applied force. Ring movement is resisted by the material under test in the shear cell. To carry out the test, a twisting lid, shear lid, mould ring, twisting wrench, weight carrier, weights, spoon, scraper and brush are required. The standard deformation rate is (2,5 ±0,2) mm/min.

Where preconsolidation pressures are above 50 kPa, a cell of 63 mm nominal inside diameter cell is preferred. The shear cell of smaller diameter permits the higher pressures to be generated with smaller, more manageable normal loads. The cell diameter used should be a part of any statement of results.

NOTE Strict comparison is possible only on results from cells of the same dimensions.

6.2 Instantaneous yield locus

6.2.1 General

The instantaneous yield locus is determined using the 95 mm low pressure cell (see 6.1). The shear cell shall be filled with a fresh sample for each test.

To ensure that the cell material is critically consolidated when measurements are made, the limited travel in the Jenike cell necessitates an iterative trial-and-error consolidation procedure. Critical consolidation is the point where cell stem travel is first independent of shear force as shown in Figure 3, curve B.

The trial-and-error procedure shall approach critical consolidation from below rather than above, as the latter can lead to erroneous results (see Figure 3, curve C, point X).

6.2.2 Preconsolidation of the sample

Place the cell base, shear ring and mould ring on the shear tester (see Figure 1). Adjust the offset of the shear ring to approximately 3 mm.

Place a sample of the material to be tested in the shear cell, layer by layer, each layer being spread lightly and uniformly with a spoon, taking care not to leave impressions which could lead to preferential shear planes. Scrape off excess material flush with the top of the mould ring. Cover the material with the twisting lid.

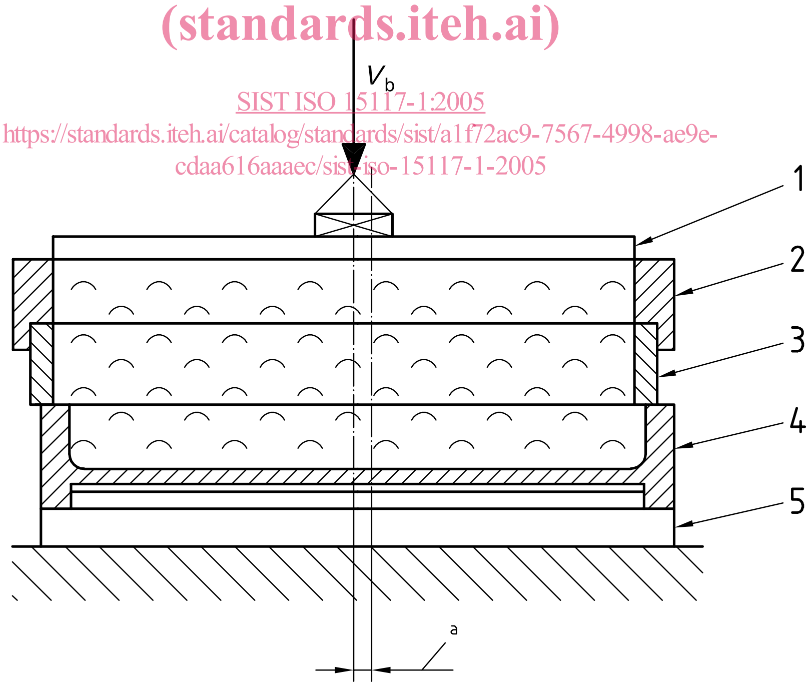
Apply a vertical force, V_t, to the twisting lid by means of a weight carrier, and, by using the special twisting wrench, apply a number of oscillating twists (amplitude approximately $\pm$ 20°) to the lid. During this procedure, care should be taken not to press down on the twisting lid and not to impede the motion of the shear ring, as it tends to follow the motion of the twisting lid.

Select the value of V_t and the number of twists to be applied by trial and error. For most dry samples, V_t is made equal to V, the normal force used in the consolidation-under-shear procedure described below. However, for high moisture samples, values of V_t equal to 2 to 4 times V may be required. The number of complete twists applied initially is about 20.

Remove the weight carrier from the twisting lid.

Lift off the mould ring while holding down the twisting lid and shear ring.

Slide the twisting lid off and scrape off the excess material flush with the top of the shear ring. In these operations, care should be taken to avoid any movement of the shear ring. Clean away excess material with the brush.



Key

1 twisting lid

2 mould ring

3 shear ring

4 base

5 frame

a Offset.

Figure 1 — Jenike shear cell — Set-up for preconsolidation

6.2.3 Shear consolidation

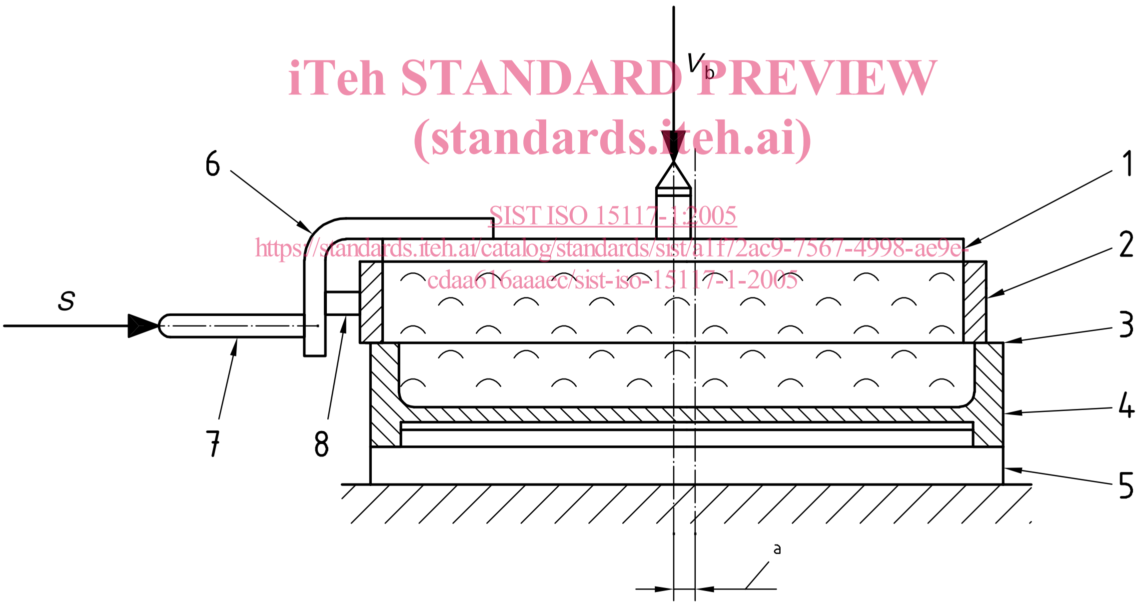
Consolidation of the sample is completed by a shearing operation, which causes the material to flow under the consolidating stresses until a steady-state shear value is reached, or closely approached.

Place the shear lid on the sample, taking care to centre it within the shear ring, and ensure that the drive bracket is aligned with the transducer stem. Apply the force, V_b, to the lid using an appropriate weight, and advance the stem of the direct shear tester against the bracket (see Figure 2).

Allow shearing to proceed until a condition is reached where a layer of the material across the whole sample is caused to flow plastically, and the recorded shear force reaches a steady value, S. Ideally, this steady value of shear force should be reached when the shear ring is concentric with the base of the cell.

Reverse the stem travel until the shear force drops to zero. Then remove the force, V_b.

It is important that the steady-state shear force, S, is reached as indicated by curve B, Figure 3; the sample is then critically consolidated. If the shear force continues to rise for the complete stem travel (curve A, Figure 3), the sample was under-consolidated during the preconsolidation phase. Generally, this means that an increase is needed in the preconsolidation force, V_t, or the number of twists used. If the shear force reaches a maximum then reduces (curve C, Figure 3), the sample was over-consolidated during the preconsolidation phase. Generally, this means that either the value of V_t or the number of twists was excessive. If either of these conditions occurs, the test should be repeated.



Key

1 shear lid
2 shear ring
3 shear plane
4 base
5 frame
6 bracket
7 loading stem
8 pin
a Offset.

Figure 2 — Jenike shear cell — Set-up for shear consolidation