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Hard coal — Determination of plastometric indices — Automated Sapozhnikov penetration plastometer method

Houille — Détermination des indices plastométriques — Méthode automatisée du plastomètre à pénétration Sapozhnikov

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Foreword

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 27, *Coal and coke*, Subcommittee SC 5, *Methods of analysis*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Historically the determination of plastic layer indices has been performed by manual operation. Firstly, the thickness of the plastic layer is detected with a probe by hand, then curves of the upper and lower layer are manually established and the results calculated. This process is labour intensive and required technicians with vast experience.

In recent years, the automated type of determinator was developed to measure the plastic layer indices. Displacement curves are auto-established by computer. The intelligent manipulator automatically measures the thickness of plastic layer and establishes curves of upper and lower plastic layer. The result is reported by the system automatically.

The objective of this document is to provide an alternative method for determining the plastic layer indices with automated Sapozhnikov penetration plastometer.

Hard coal — Determination of plastometric indices — Automated Sapozhnikov penetration plastometer method

1 Scope

This document specifies a method for the determination of plastometric indices with an automated Sapozhnikov penetration plastometer. These indices are the maximum thickness of the plastic layer, *Y*, in mm, and the final contraction, *X*, in mm.

This document is applicable to hard coals with a determined ash level of less than 15 % as dry basis as described in ISO 11722 and ISO 1171.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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, *Solid mineral fuels — Vocabulary — Part 2: Terms relating to sampling, testing and analysis*

ISO 3310-2, *Test sieves — Technical requirements and testing — Part 2: Test sieves of perforated metal plate*

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

ISO 13909-3, *Hard coal and coke — Mechanical sampling — Part 3: Coal — Sampling from stationary lots*

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

ISO 18283, *Coal and coke — Manual sampling*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
maximum thickness of plastic layer
Y
maximum perpendicular thickness between the upper and lower plastic layer

3.2
final contraction value
plastometric shrinkage
X
distance between the height of the coal sample at the temperature of 250 °C (the zero line) and at 730 °C

3.3
zero line
original height of the coal sample paralleling with abscissa axis drawn at the temperature of 250 °C

4 Principle

The coal sample is heated unidirectionally from the base at a standard rate under constant pressure whilst the plastic layer develops. The plastic layer thickness is automatically measured periodically throughout the test using a rounded end blunt probe. The manipulator arm lowers the probe through the paper tube created in the coal sample until a change in pressure is recorded. The volume changes are measured by displacement sensor and the displacement curve is auto-established by the computer. The curve representing changes of the upper and lower layer is generated by the least square method. The maximum thickness of the plastic layer is calculated by the maximum distance between both layers and final contraction is obtained by comparing volume at 250 °C and the end of a measurement automatically.

5 Materials

5.1 Cigarette rolling paper

Rolling papers (also known as blanks) small sheets, rolls, or leaves of paper, which are sold for rolling cigarettes either by hand or with a rolling machine.

5.2 Filter paper

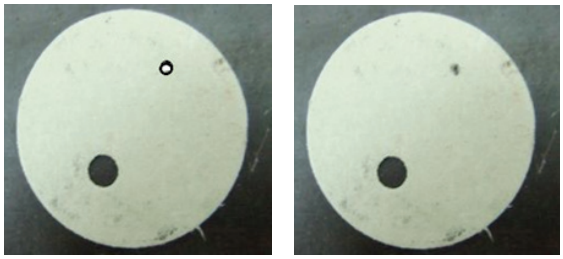
Qualitative filter paper, dimensions 60 mm wide and 190 mm to 200 mm long, used to line the inner wall of the steel retort.

5.3 Thin steel rod

The diameter of the thin steel rod is 3 mm. Cigarette rolling paper is wrapped around the rod to make a tube. The resultant paper tube is then placed into the steel retort and is surrounded by the coal after loading.

5.4 Refractory ceramic round pad

Heat resistant refractory ceramic pads with thickness of 1,0 mm and diameter of 59 mm for use on the top and bottom of the coal sample in the steel retort. The pads can be made by manual or mechanical means. Each base pad requires a hole to allow the thermocouple well to fit through and a mark corresponding the probe hole of the pressure plate. Each top pad requires two holes, one to allow the thermocouple well to fit through and one to allow the paper tube to fit through. Figure 1 shows an example of these pads.



Key

1 top pad

2 base pad

Figure 1 — Refractory ceramic round pad

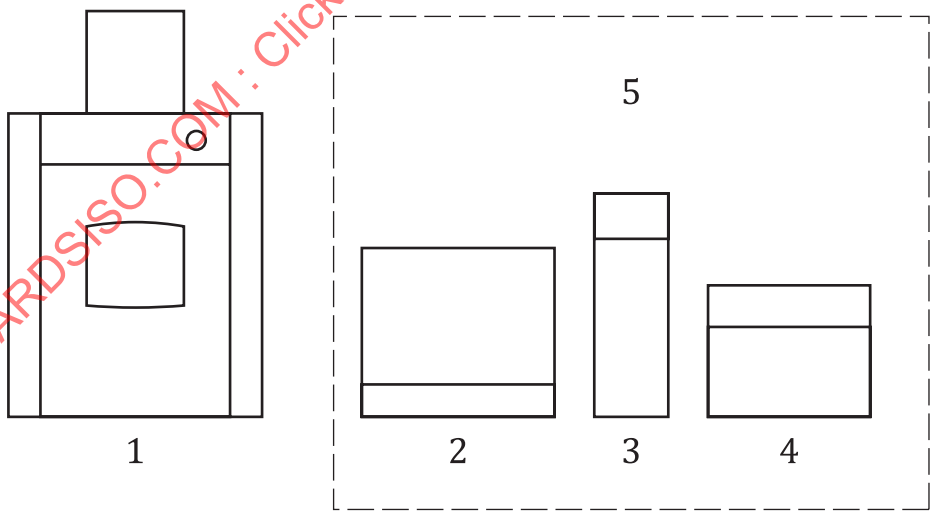
5.5 Abrasive cloth

Emery Cloth P80 grade is suitable for removing coke residue from steel retort and associated components.

6 Apparatus

6.1 Automated Sapozhnikov penetration plastometer

For determining plastometric indices with automated Sapozhnikov penetration plastometer, commercially available, consisting of determinator and the computer system. The computer system includes a computer, monitor, keyboard and printer (see Figure 2).



Key

1 determinator

2 monitor

3 computer

4 printer

5 computer system

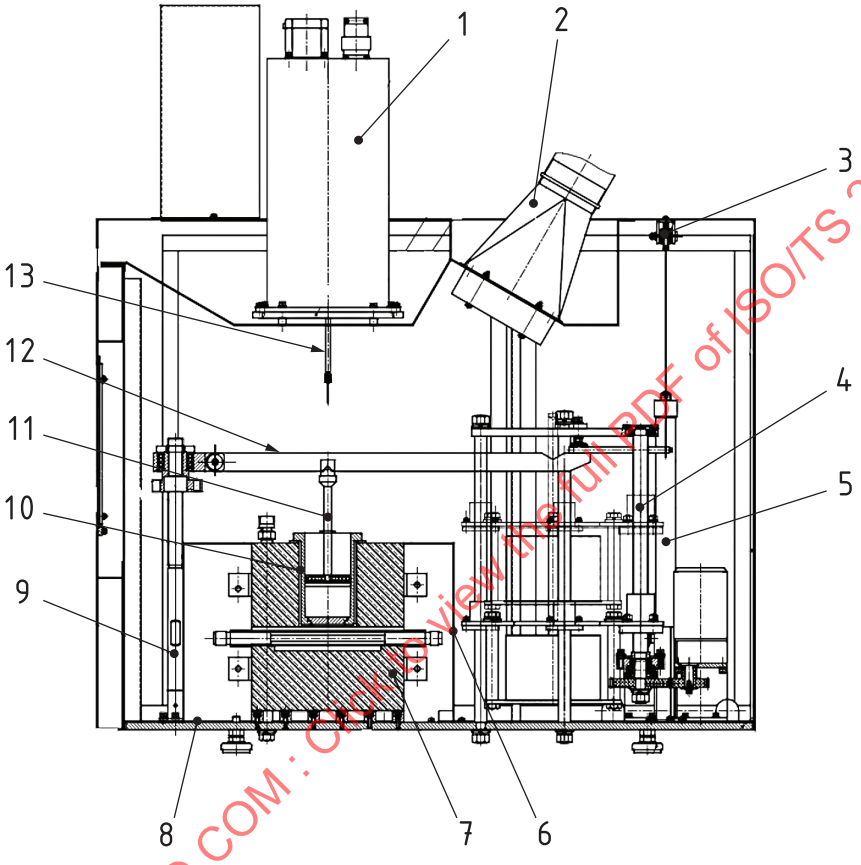
Figure 2 — Sketch of automated Sapozhnikov penetration plastometer

6.2 Determinator

The determinator shall consist of the following components as shown in Figure 3 and Figure 4.

The pressure applied by the Sapozhnikov plastometer apparatus to the cross section of loaded coal sample during the measurement of plastometric indices shall be $9{,}8 \times 10^4$ Pa (1 kg/cm^2).

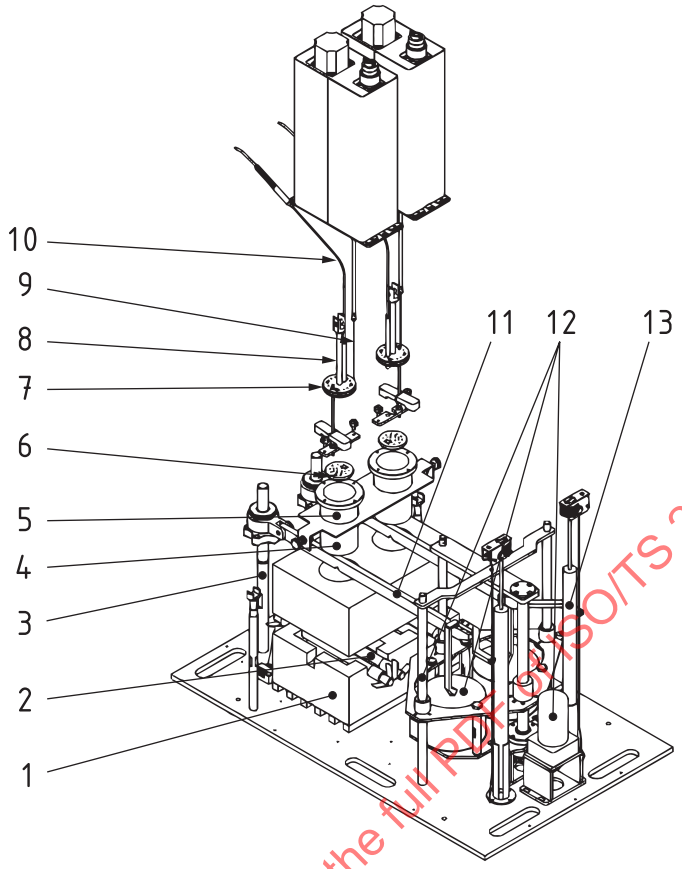
The pressure cross section on the loaded coal sample should be checked when the apparatus is newly purchased, moved to a new location or when major parts have been replaced. Annex B provides guidance on how to check the pressure on the cross section of the loaded coal sample.



Key

1	probe manipulator	8	base
2	exhaust	9	levelling assembly
3	pulley	10	steel retort
4	weight lifting device	11	pressure plate
5	displacement transducer	12	connecting arm
6	protective cover	13	probe and probe rod
7	brick stacks		

Figure 3 — Overview of a typical determinator



Key

1	electric furnace	7	pressure plate
2	heating elements	8	thermocouple well
3	levelling assembly	9	probe
4	steel retort	10	thermocouples
5	retort body	11	pressure lever assembly
6	retort base	12	weights elevating device
		13	displacement sensor

Figure 4 — Exploded view of a typical furnace assembly

6.2.1 Electric furnace

The furnace shall consist of two layers of rectangular furnace brick, each measuring 200 mm × 290 mm × 110 mm. The lower layer has a longitudinal groove to allow for visual inspection, and four latitudinal grooves that support the four heating elements. The upper brick layer sits over the lower brick layer and has two cylindrical holes that accommodate the steel retorts. The upper brick (see Figure 4) surface shall be flat and very carefully positioned according to manufacturer's specification, to ensure the alignment of the rolling paper tube, relative to the probe.

NOTE 1 Typically the furnace brick has the refractoriness of 1 670 °C~1 710 °C, in which the contents of Al_2O_3 are not less than 40 %, and appearance porosity is not more than 26 %. Other refractory bricks can be used provided the furnace can achieve these temperature specifications.

The furnace shall be heated electrically with automatic controls to ensure a heating rate of 3,0 °C/min ± 0,1 °C/min is maintained from 250 °C to 730 °C and a heating rate of about 8 °C/min is maintained before 250 °C.

NOTE 2 The difference between the displayed temperature and the target temperature is not more than 5 °C from 350 °C to 600 °C and 10 °C for other periods. The temperature is measured with the thermocouple positioned in the thermocouple well in the steel retort.

6.2.2 Heating elements

There are four silicon carbide elements each protected by a quartz glass tube 200 mm × 20 mm. The difference of resistance between the two series elements under each retort is not more than 0,5 Ω. The elements must have a resistance of 6 Ω to 8 Ω with an active length of 150 mm and diameter of 8 mm. The length of the cold end should be 60 mm long and diameter of 16 mm. The rated temperature of the heat zone should be 1 200 °C to 1 400 °C. The heating efficiency of the elements decreases at a distance of 15 mm from the cold end. The resistance of the heating elements must be checked at time intervals to ensure compliance with these temperature specifications.

Heating elements made from different materials may be used provided they can achieve these temperature specifications.

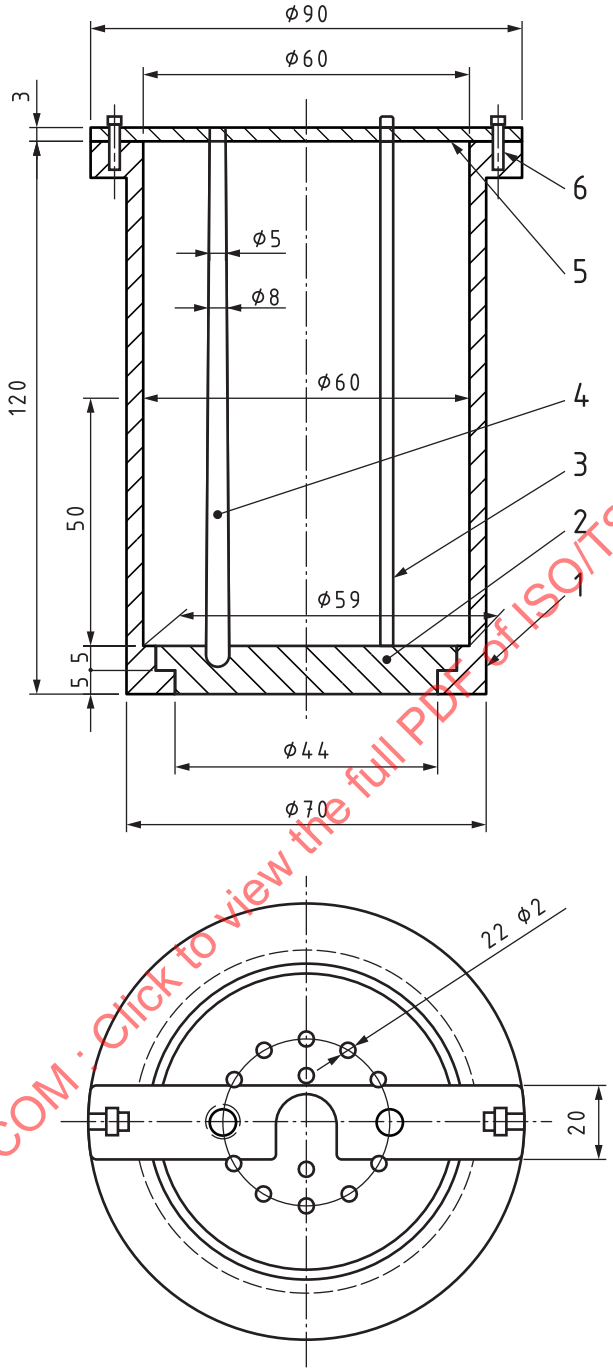
6.2.3 Steel retort

Component parts made with steel according to ISO C45E4[5] specifications shall consist of 6.2.3.1 to 6.2.3.3.

6.2.3.1 Retort body

The height from the inside base of the retort bottom to the top of the retort body shall be 110 mm. The retort body shall be tapered, the internal diameter at the bottom shall be 59 mm and the internal diameter, at a height 50 mm from the base, shall be 60 mm. The inner wall of the body should be smooth without scratches and/or dents. The internal diameter of the working range of the retort body shall be measured for conformance to specifications every 50 determinations. To check the diameter, measure six points (every 10 mm from bottom) on the retort body. The variations between the average results of 6 points and average diameter (59,5 mm) should be within 0,5 mm. The gap between the retort base and the retort body should also not be more than 0,5 mm. Specifications and layout of air holes are shown in Figure 5.

Dimensions in millimetres



Key

1	retort body	2	retort base
3	thin steel rod	4	thermocouple well
5	pressure plate	6	screws for pressure plate

Figure 5 — Steel retort body and other accessories

6.2.3.2 Retort base

Specifications and layout of gas ventilation holes are shown in Figure 6.

Dimensions in millimetres

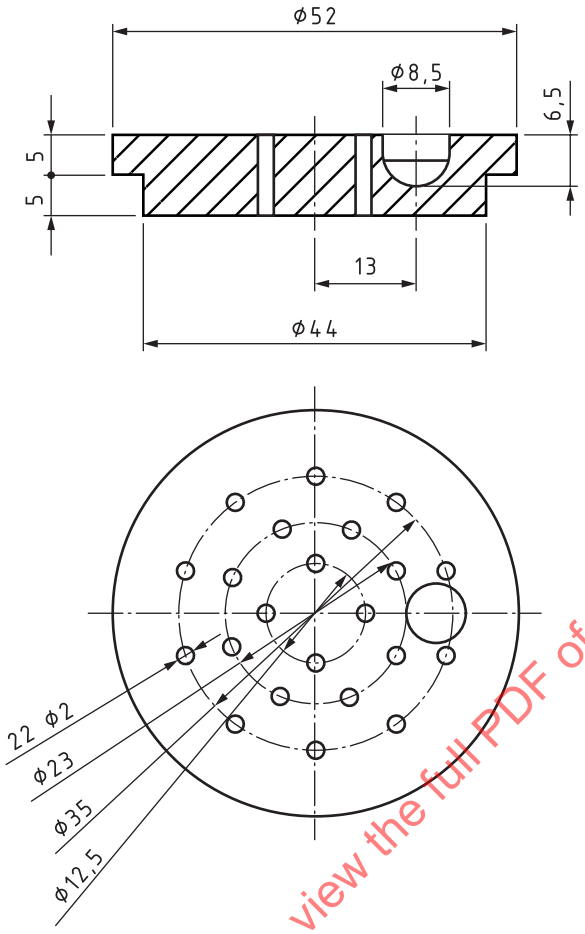


Figure 6 — Steel retort base

6.2.3.3 Pressure plate

There is a 5 mm thick ceramic insulating fibre disc between the upper and lower pressure discs of the pressure plate, dimensions and layout of 16 gas ventilation holes are shown in Figure 7.

Dimensions in millimetres

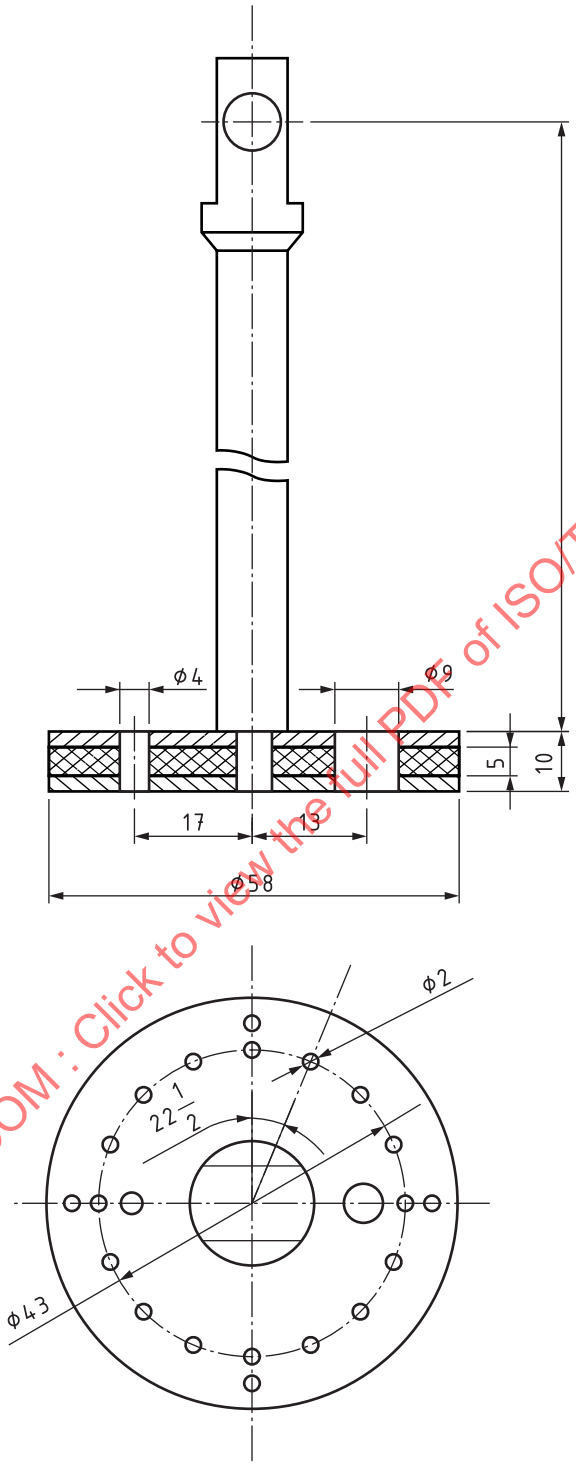


Figure 7 — Pressure plate

6.2.4 Thermocouples

Nickel-chromium and nickel-aluminium. The thermocouple and associated temperature measurement system shall be checked on a regular basis to ensure accuracy of measurement.

NOTE Thermocouples made from other materials can be used provided they can meet the temperature specifications.

6.2.5 Thermocouple well

A hollow, stainless steel well, closed at one end, that sits in the retort base, used to house the thermocouple, dimensions are shown in Figure 5. Inspect the condition of the well frequently and after 100 tests to check that it has not corroded.

6.2.6 Probe

The probe is a steel needle, 1 mm in diameter with a rounded blunt end. Before each determination, the probe shall be cleaned and checked to ensure it is straight. If it is not, it shall be replaced. The probe is connected to a probe rod and a manipulator equipped with a load cell that measures pressure differences between coal, plastic layer and semi coke. This measurement system shall be calibrated regularly to ensure measurement accuracy following manufacturer's specification.

A bottom height, as determined by the automated Sapozhnikov plastometer control software, of 45 mm ± 1 mm is required before commencing the determination.

6.2.7 Pressure lever assembly

The pressure applied by the pressure lever assembly of the Sapozhnikov plastometer apparatus as shown in Figure 2, to the cross section of loaded coal sample during the measurement of plastometric indices, shall be $9{,}8 \times 10^4$ Pa (1 kg/cm^2). Annex B provides a method for checking the pressure on the cross section of the loaded coal sample.

6.2.8 Displacement sensors

Measure changes in displacement of the retort charge, detected by movement of the pressure disc and connecting arm. The displacement sensor system shall be checked regularly to confirm accuracy of measurement.

6.2.9 Weights elevating device

Weights are automatically loaded and unloaded by the system.

6.2.10 Levelling assembly

Used to adjust the pressure lever to ensure it is balanced.

6.2.11 Exhaust device

Exhausting fumes generated during measurement.

6.3 Weighing device

A top loading balance with a resolution of at least 0,1 % relative of the test portion mass.

6.4 Spirit level gauge

An instrument designed to indicate whether the pressure lever is horizontal (level).

6.5 Callipers

To measure the internal height of the retort body, and the depth from the retort lip to the top of the pressure disc. These readings are required to confirm the height of the coal charge after loading the retort.

6.6 Double rolls crusher

Capable of crushing the sample to pass through a 1,5 mm round hole sieve.

6.7 1,5 mm round hole sieve

The round hole sieve shall be in accordance with requirements of ISO 3310-2.

6.8 Calibrated ruler

Ranging from 0 mm to 200 mm with a sensitivity of 0,1 mm.

7 Sample preparation

7.1 Collect a representative gross sample of coal in accordance with ISO 18283 or ISO 13909-1, ISO 13909-2, and ISO 13909-3. The laboratory sample shall be prepared in accordance with ISO 13909-4 or ISO 18283.

1,5 kg of coal crushed to pass a 4 mm sieve shall constitute the laboratory sample. This sample should be representative of the batch being tested.

7.2 Spread the laboratory sample on a tray and allow it to air dry to equilibrate with the laboratory atmosphere. Drying (other than air drying) should not be continued beyond this point to avoid the effect of oxidation on the plastometric indices of the coal sample. The drying temperature shall not exceed 40 °C. After the laboratory sample has been air dried to equilibration, stage crush the laboratory sample with a double rolls crusher to pass a 1,5 mm round hole sieve, ensuring that a minimum of fines is produced. The stage crushed sample constitutes the test sample.

If other methods are used to crush the sample to pass 1,5 mm, it is important that they do not generate excessive fines. The bulk density of the coal sample is affected by the particle size distribution when loaded into the steel retort and subsequently affects both the contraction, *X*, and plastic layer, *Y*, reported.

NOTE Deviation of the displacement curve from a starting position of 80 mm is caused by particle size distribution, bulk density and/or if the sample is not sufficiently dry. Confirmation of the starting position is described in 8.3.

7.3 Thoroughly mix the stage crushed sample, preferably by mechanical means and divide a portion of 500 g. Test the coal for plastometric indices on the same day, as soon as practical after preparing the sample passing 1,5 mm sieve. Avoid delays in so far as possible because the plastometric indices of coal may be significantly affected by deterioration and oxidation.

Refrigeration or inert gases should be used to minimize oxidation of prepared samples.

8 Calibration

8.1 Furnace-temperature calibration

Perform in accordance with manufacturer's instructions.

8.2 Displacement calibration

Perform in accordance with manufacturer's instructions.

8.3 Determination of zero-height

Fit the retort base into the retort body making sure that the marked grooves line up and the two surfaces are well connected and flat. Insert the pressure plate into the retort body, and place these steel retort units into the furnace. Align the pressure plates with the notched connecting arm. Attach the connecting arm with the bolts. Use the Sapozhnikov plastometer software to lower the weights. Adjust the lever-adjusting mechanism to make each lever horizontal, and confirm with a level gauge.

The automated Sapozhnikov plastometer control software displays in the status bar of the main screen, the factory-set zero-height is required to ensure that the zero line of the displacement curve of a dry 1,5 mm top size coal is drawn from a starting position of about 80 mm.

9 Preparation for testing

9.1 Cleaning retort

Remove coke residual from the steel retort and its base, thermocouple and pressure plate with abrasive cloth (5.5) to make it clean. Each hole on these components should be clear and not blocked.

9.2 Preparation of paper tube

Wind cigarette rolling paper (5.1) around a thin steel rod (5.3) to make a paper tube with diameter of 3 mm and about 60 mm long. Coat a thin layer of glue on the edge surface of the rolling cigarette paper to avoid unrolling of the paper tube. Fold up the bottom about 2 mm of the paper tube to seal the tube. The top end should be closely attached to the steel rod to keep coal from flowing into the paper tube.

9.3 Preparation of refractory ceramic pad

Prepare refractory ceramic pads according to the requirements of 5.4.

9.4 Loading retort

9.4.1 Fit the retort base into the retort body making sure that the marked grooves line up and the two surfaces are well connected and flat.

9.4.2 Using callipers, measure and record the internal distance of the retort base to the top of the retort body, *H*, see Figure 8. Rest the calliper on the top of the pressure plate and measure to the origin of the gas ventilation circles shown in Figure 7.

9.4.3 Insert the thermocouple well locating its base into the recess in the retort base. Fit the base refractory ceramic pad (5.4) into the retort body and gently push it to the base. Line the inside wall of the retort body close to the cup bottom with the filter paper (5.2).

9.4.4 Loosely attach the steel bars to the retort assembly with the two bolts. Position the paper tube (5.2) with thin steel rod (5.3) in the centre of the other hole of the steel bar. A brass guide is provided to align the paper tube/thin steel rod assembly in position on the base pad. The thermocouple well and the paper tube/thin steel rod are vertically fixed by the steel bar.

9.4.5 Thoroughly mix the stage crushed sample (7.3), preferably by mechanical means and divide to collect two sample portions of 100 g ± 0,5 g.

9.4.6 Load the coal sample into the retort assembly in four separate equal (25,0 g ± 0,1 g) sample portions. Take one of the portions and slide it through the funnel into the coal cup. Use the flattening rod to flatten coal samples loaded into the coal cup. Load another portion on the diagonal side and repeat the above operation of first portion. After each portion is added, level the coal surface to ensure

even distribution. The coal sample must not be tamped during this process. Ensure no coal enters the thermocouple well.

9.4.7 Carefully remove the steel bars and the brass guide while ensuring that the thermocouple well and thin steel rod, wrapped with cigarette rolling paper, are not disturbed. Place the top refractory ceramic pad (5.4) onto the coal surface aligning the two pre-cut holes with the thermocouple well and thin steel rod. Fold the excess filter paper over the top pad. The coal sample in the steel retort should now be sheathed in filter paper and refractory ceramic paper. Position the pressure plate by aligning the holes with the thermocouple well and the thin steel rod, and secure with the two bolts. Remount the steel bars and secure with the two bolts to fix the thermocouple well. The paper tube should be visible above the surface of the pressure plate.

9.4.8 Using callipers, measure and record the distance from the upper surface of the pressure plate to the top of the retort, *a*, in four different quadrants, see Figure 8.

9.5 Determination of the height of the coal sample in the steel retort

The height of the coal sample in the steel retort before heating shall be manually measured and calculated with Formula (1):

$$h = H \quad (a + b) \tag{1}$$

where

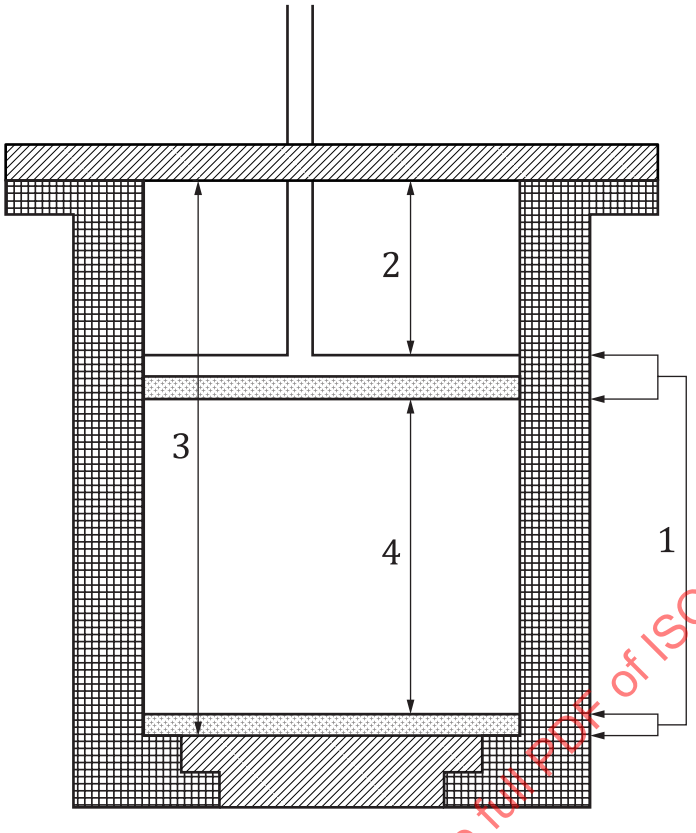
h is the height of the coal sample inside the steel retort, in mm;

H is the inner depth of the steel retort body, in mm (measured before coal sample is loaded);

a is the distance between the upper surface of the pressure plate and the top of the steel retort body, in mm (reported as the mean value from four different measurements around the steel retort body);

b is the total thickness of the pressure plate and the two round refractory ceramic pads (measured with callipers), in mm.

Using callipers, measure and record the thickness of a base pad, a top pad, and the pressure plate, *b*, for each retort, see Figure 8.



Key

1 total thickness of the pressure plate and the two round refractory ceramic pads (measured with callipers), in mm

2 distance between the upper surface of the pressure plate and the top of the steel retort body, in mm (reported as the mean value from four different measurements around the steel retort body)

3 inner depth of the steel retort body, in mm (measured before coal sample is loaded)

4 height of the coal sample inside the steel retort, in mm

Figure 8 — Loaded steel retort

The difference of the height of the coal sample inside the steel retort between duplicate tests shall not be more than 1 mm.

The automated Sapozhnikov plastometer control software measures the height of the coal sample immediately upon commencement of the analysis cycle, and this height should be more than 43 mm, with a tolerance of not more than 1 mm between the two retorts. The control software also determines the initial height of the coal sample. The bulk density of the coal sample in the steel retort affects both the contraction and plastic layer thickness measurements.

10 Test procedure

10.1 Place the loaded steel retorts into the furnace ensuring that the thermocouple well of each is positioned to the inside, with the steel rods and brass guides on the outside. Align the pressure plates and secure the pressure plate rod in its respective notched connecting arm. Attach the connecting arm with the bolts.

10.2 Use the Sapozhnikov plastometer software to lower the weights. Check each lever arm with a level gauge (6.4); adjust lever adjusting mechanism to ensure each lever is horizontal. The automated Sapozhnikov plastometer control software displays the “Initial Height” before heating. Record this value. This initial height is in the range of 80 mm to 90 mm, depending on sample size distribution and

bulk density. Gently rotate and remove each thin steel rod ensuring that the position of each cigarette rolling paper tube is unchanged and keeps vertical. Remove the brass guides.

10.3 Place the two parts of the probe positioning bases into the steel bars. Insert the probe into the hole between the positioning bases, and check that it has entered the cigarette rolling paper tube. Follow equipment manufacturer's directions to position the probe rod and firmly attach the probe. Check that the bottom height of the probe is 45 mm ± 1 mm with a tolerance of not more than 1 mm between the two retorts. Remove the probe positioning base. Insert the thermocouples into the thermocouple wells making sure they are seated correctly.

10.4 Record sample details and confirm the coal height in the steel retort before commencing the testing cycle. The automated Sapozhnikov plastometer control software starts heating the furnace at 8 °C/min until furnace temperature is 250 °C after which the heating rate shall be 3,0 °C/min ± 0,1 °C/min from 250 °C to 730 °C.

10.5 The automated Sapozhnikov plastometer control software starts to measure and record the contraction when the furnace temperature reaches 250 °C. The displacement sensor measures contraction continuously until the completion of the test at 730 °C.

10.6 The automated Sapozhnikov plastometer control software starts measuring the plastic layer thickness, *Y*, when the furnace temperature reaches 250 °C and stops when the furnace temperature reaches 650 °C. The frequency of measurement is dependent upon the shape of the displacement curve.

Displacement curve types include:

— Mountain, a smooth descending or a tiny wave (see Figure 9). The probe measures the top of the plastic layer every 5 min and the bottom of the plastic layer every 10 min.

— Zigzag or wave (see Figure 9). The probe measures the top of the plastic layer at the peak and the valley. The bottom of the plastic layer is only measured in the interval of 8 min to 10 min at the valley when forces are in equilibrium.

— Smooth downhill (*Y* value is under 7 mm) the probe measures the top of the plastic layer and the bottom of the plastic layer at the frequency of no more than once every 15 min.

10.7 The automated Sapozhnikov plastometer control software stops the test when the furnace temperature is at 730 °C.

10.8 The furnace shall be cooled to room temperature before the next determination can be performed.

NOTE If the plastic mass flows over the pressure plate or the layer of the plastic mass in the cigarette rolling paper tube rises abruptly then the test is deemed invalid.

11 Expression of results

11.1 All tests shall be made in duplicate and the mean values reported to the nearest 0,1 mm.

11.2 The automated Sapozhnikov plastometer control software prints out a report including at least the following information.

a) identification of the sample tested;

b) the method used by reference to this document, i.e. ISO/TS 20362:2022;

c) the date of the determination;

d) associated plastometric graphs for each determination with displacement curve type, the final contraction value, X, and plastic layer thickness, Y', the maximum thickness of plastic layer, Y, calculated, height of the coal sample, h, determined by automated determination, and initial height by automated determination etc. Annex A provides examples of various curves and associated X and Y measurement locations.

11.3 Displacement curve types include:

a) smooth descending type, see Figure 9 a);

b) smooth downhill type, see Figure 9 b);

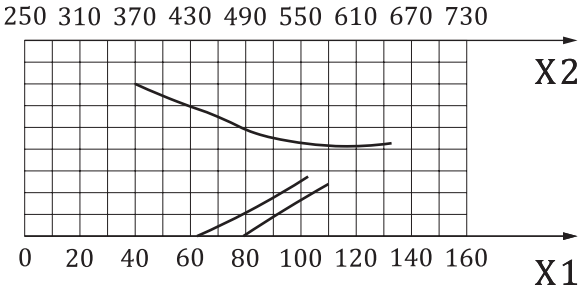
c) wave type, see Figure 9 c);

d) tiny wave type, see Figure 9 d);

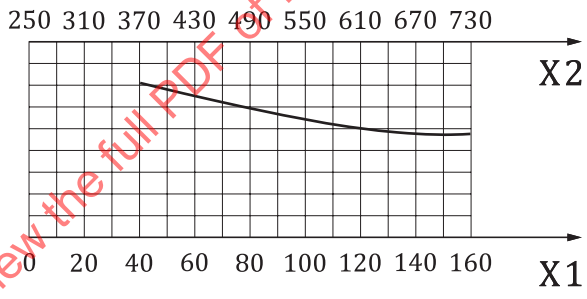
e) zigzag type, see Figure 9 e);

f) mountain type, see Figure 9 f);

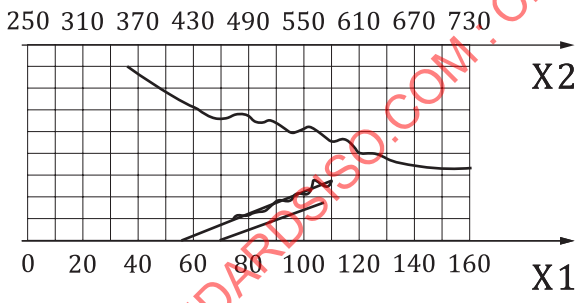
e) zigzag curve with hump type, see Figure 9 g) and Figure 9 h).



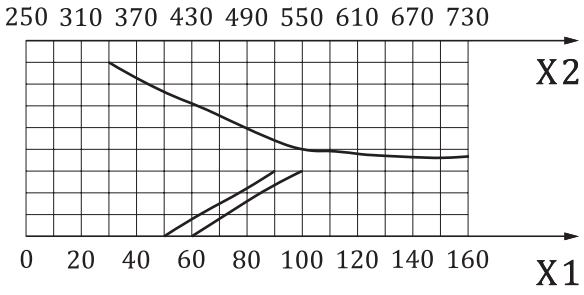
a) Displacement curve types — Smooth descending



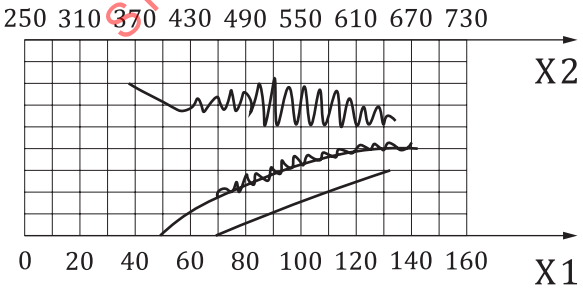
b) Displacement curve types — Smooth downhill



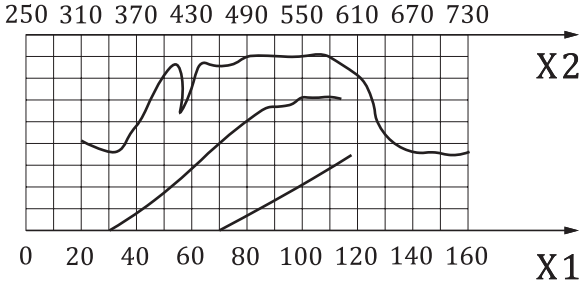
c) Displacement curve types — Wave



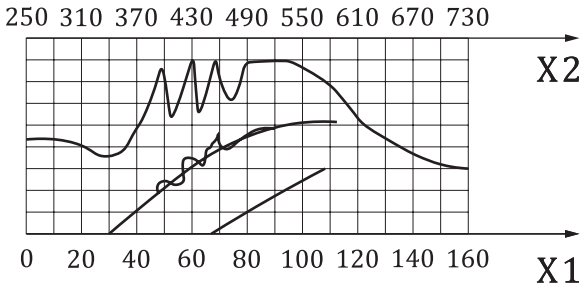
d) Displacement curve types— Tiny wave



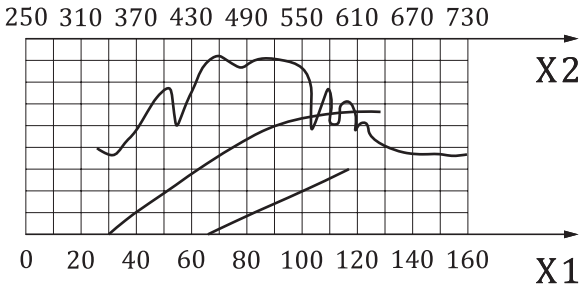
e) Displacement curve types — Zigzag



f) Displacement curve types— Mountain



g) Displacement curve types— Zigzag curve with hump



h) Displacement curve types— Zigzag curve with hump

Key

X1 time/min

X2 temperature/°C

Figure 9 — Displacement curve types

12 Precision

12.1 Repeatability limit

Repeatability values are not included in this document and will be added in a later version after completion of an interlaboratory study.

12.2 Reproducibility limit

Reproducibility values are not included in this document and will be added in a later version after completion of an interlaboratory study.

13 Test report

The test report shall include the following information:

a) identification of the sample tested;

b) the method used by reference to this document i.e. ISO/TS 20362:2022;

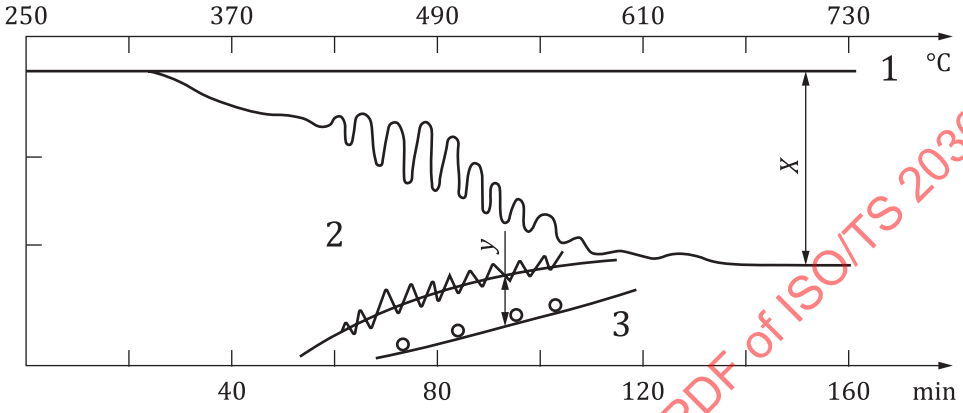
c) the date of the determination;

d) the results and the method of expression used.

Annex A
(informative)

Schematic diagram of processing on plastometric graph

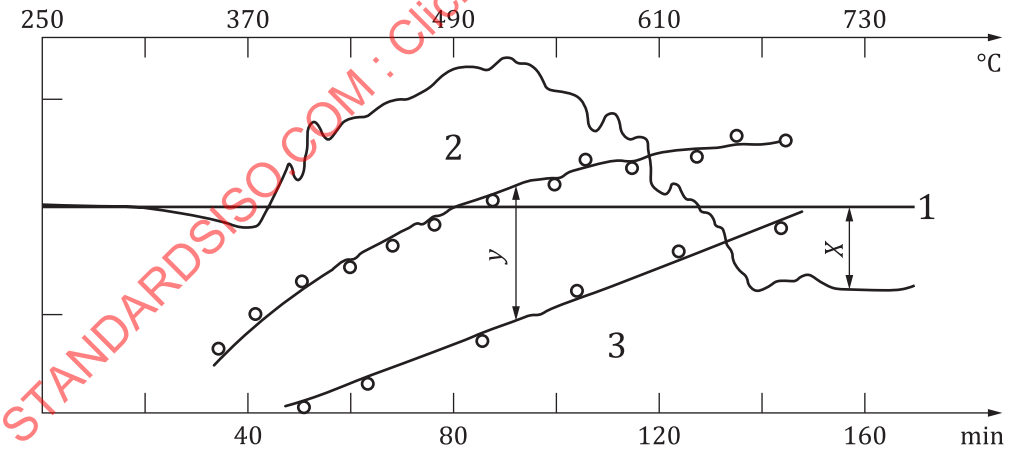
Figures A.1 to A.3 show examples of plastometric graphs with different types of curves.



Key

1 zero line
2 upper plastic level
3 bottom plastic level

Figure A.1 — Plastometric graph for zigzag curve



Key

1 zero line
2 upper plastic level
3 bottom plastic level

Figure A.2 — Plastometric graph for zigzag curve with hump