TECHNICAL REPORT

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# Paints and varnishes - Overview of test methods on hardness and wear resistance of coatings



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# Contents

Page

# Foreword

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This document was prepared by Technical Committee ISO/TC 35, *Paints and varnishes*, Subcommittee SC 9, *General test methods for paints and varnishes*.

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

The determination of the hardness and of the wear resistance is one of the most important preconditions for evaluating the resistance of coatings to mechanical stress.

The procedures and numerical data given in this document provide a rough overview; detailed information is found in the applicable standards.

For all of the methods for the evaluation of the hardness and of the wear resistance the visco-elastic properties have a wide influence on the test result. Consequently, the time between testing and evaluation are agreed and observed.

Mechanical properties of coatings depend on, among others, temperature and moisture content. Consequently, the tests should be carried out immediately after the conditioning phase.

The tests are preferably carried out in the climatic chamber.

Each method has its specific application. An unsuitable method may lead to false conclusions. All of the test methods require a certain expertise of the test person. For most of the test methods the test results depend on, among others, the film thickness of the coating to be tested.

# Paints and varnishes - Overview of test methods on hardness and wear resistance of coatings

## 1 Scope

This document provides an overview for selecting the most suitable test method regarding the evaluation of the hardness and the wear resistance of coatings.

Annex A gives a summarized list of test methods for the evaluation of the hardness and of the wear resistance of coatings for different stresses.

Methods for testing cross-linking (wear test in connection with solvents) and abrasion tests with multiple impacts are not covered by this document.

## 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 4618, *Paints and varnishes — Terms and definitions*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 4618 and the following apply.

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

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

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

**3.1**
**hardness**
ability of a dry film or coat to resist indentation or penetration by a solid object

[SOURCE: ISO 4618:2014, 2.136]

**3.2**
**wear**
irreversible change of a coating which is caused by the mechanical impact of moved objects

**3.3**
**stylus**
scratching tool with specified geometry

[SOURCE: ISO 22557:2019, 3.1]

**3.4**
**scratch**
line-shaped damage of a coating which is caused by the impact of a loaded object being moved over the coating

**3.5**
**mar**
blemish on the surface of a coating, extending over a particular area of the coating and visible due to the difference in the light-reflection properties of the area affected compared with the light-reflection properties of adjacent areas

[SOURCE: ISO 4618:2014, 1.152]

**3.6**
**abrasion**
*wear* (3.2) which is caused by removal of coating material on a surface

**3.7**
**repeatability conditions**
conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time

[SOURCE: ISO 5725-1:1994, 3.14]

**3.8**
**repeatability limit**
***r***
the value less than or equal to which the absolute difference between two test results obtained under *repeatability conditions* (3.7) may be expected to be with a probability of 95 %

[SOURCE: ISO 5725-1:1994, 3.16]

**3.9**
**reproducibility conditions**
conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment

[SOURCE: ISO 5725-1:1994, 3.18]

**3.10**
**reproducibility limit**
***R***
the value less than or equal to which the absolute difference between two test results obtained under *reproducibility conditions* (3.8) may be expected to be with a probability of 95 %

[SOURCE: ISO 5725-1:1994, 3.20]

# 4 Hardness tests

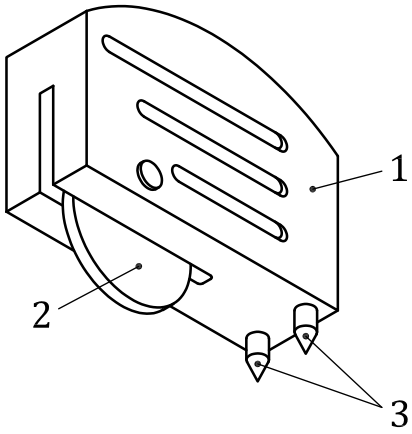
## 4.1 Indentation tests with resting indenter

### 4.1.1 Indentation test with Buchholz indenter

— **Description**

An indenter made of hardened steel, the shape and dimensions of which are specified in accordance with Buchholz, impacts the coating under a load (500 g, corresponding to 4,96 N) for 30 s and produces an indentation. After a resting time of 35 s the indentation length (mm) is determined under specified lighting conditions using a measuring microscope (×20 magnification).

Figure 1 shows the test device and Figure 2 shows the Buchholz indenter. Figure 3 illustrates the microscopic measurement of the indentation.

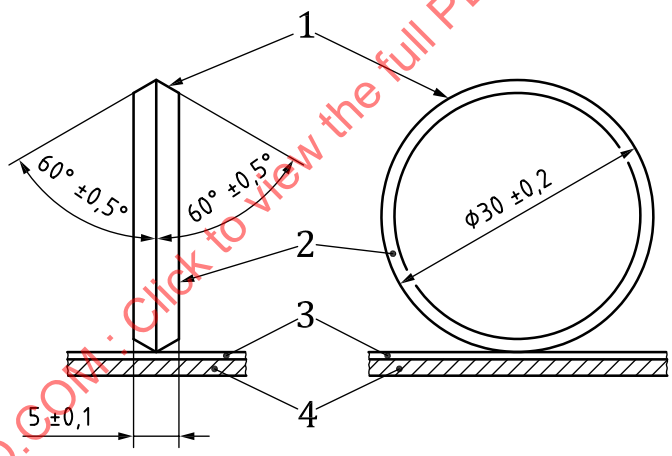



**Key**

1 steel block
2 indenter
3 tip

**Figure 1 — Indentation tester in accordance with Buchholz**

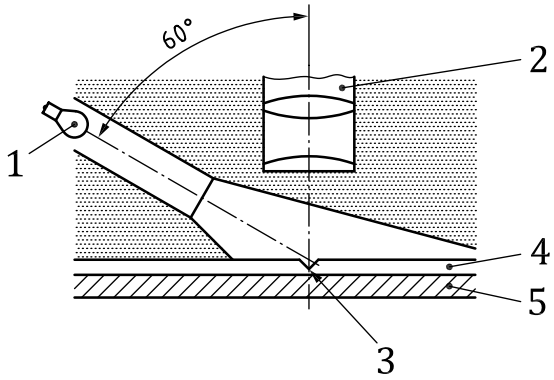
Dimensions in millimetres



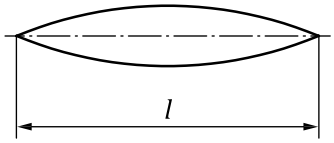

**Key**

1 indentation edge
2 indenter
3 coating
4 substrate

**Figure 2 — Buchholz indenter**




**a) Arrangement of the light source and of the microscope**




**b) Image of the Buchholz indentation**

**Key**

1 light source
2 microscope
3 indentation
4 coating
5 substrate
*l* indentation length

**Figure 3 — Measuring the Buchholz indentation**

— **Application**

The indentation test with Buchholz indenter is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h)

— First, lower the tips of the test device onto the coating, and then carefully lower the indenter.

— Leave the loaded indenter on the coating for 30 s and remove in reverse order.

— 35 s after removal of the load determine the indentation length (mm) using a measuring microscope (see Figure 3).

— **Evaluation**

Test result is the indentation length (mm), as mean value of five determinations.

— **Precision**

The repeatability limit *r* is 0,23 mm.

The reproducibility limit *R* is 0,45 mm.

— **Reference**

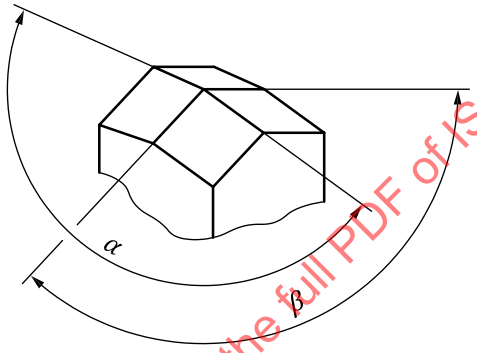
The indentation test with Buchholz indenter is specified in ISO 2815.

### 4.1.2 Indentation test with Knoop indenter

— **Description**

A diamond indenter, the shape and dimensions of which are specified in accordance with Knoop, impacts the coating under a load (25 g, corresponding to 0,245 N) for 18 s and produces an indentation. Immediately after removal of the load the length (mm) of the long diagonal of the indentation is determined using a measuring microscope. From this, the "Knoop Hardness Number" KHN (kg/mm$^2$) is calculated.

Figure 4 shows the dimensions of the Knoop indenter. Figure 5 shows the top view of the Knoop indentation.

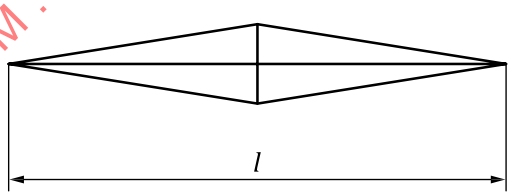



**Key**

$\alpha$ angle of the longitudinal edge (172,5°)

$\beta$ angle of the transverse edge (130°)

**Figure 4 — Dimensions of the Knoop indenter**




**Key**

$l$ indentation length

**Figure 5 — Top view of the Knoop indentation**

— **Application**

The indentation test with Knoop indenter is generally applicable.

— **Calibration**

On a reference block the KHN value is determined and compared to the nominal value.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

— Lower the test device onto the coating in a plane area.

— Lower the indenter and apply the specified test load.

— Leave the loaded indenter on the coating for 18 s.

— Immediately after the removal of the load, determine the indentation length $l$ (mm) using a measuring microscope (see Figure 5).

— **Evaluation**

Calculate the KHN value using the measured length $l$: KHN = 0,356 / $l^2$. (Factor 0,356 results from the test load and the shape factor of the indenter.)

Test result is the KHN value (kg/mm), as mean value of $n$ determinations. (The number $n$ is agreed.)

NOTE In accordance with ISO 4545-1, the Knoop hardness is expressed in HK, which is different from the KHN used here.

— **Precision**

The repeatability (in accordance with ASTM D1474/D1474M) is 9 %.

The reproducibility (in accordance with ASTM D1474/D1474M) is 24 %.

— **Reference**

The indentation test with Knoop indenter is specified in ASTM D1474/D1474M-13, Method A: Knoop Indentation Hardness.

A general method for the determination of the Knoop hardness HK is specified in ISO 4545-1.

For testing automobile coatings, the method is also described in References [47] and [56].

### 4.1.3 Indentation test with Pfund indenter

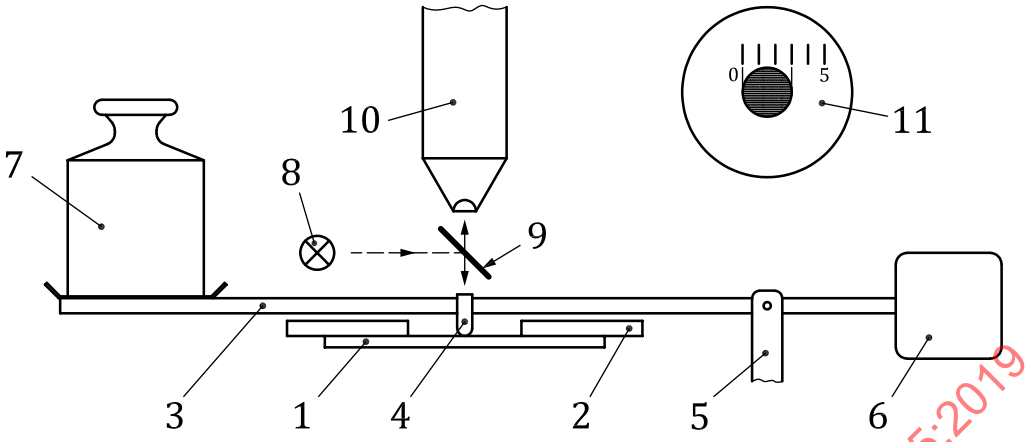
— **Description**

A transparent quartz or sapphire indenter (hemisphere Ø 0,318 mm), the shape and dimensions of which are specified in accordance with Pfund, impacts the coating under load (1 kg, corresponding to 9,8 N) for 60 s and produces an indentation. Immediately after that the diameter (mm) of the indentation under load by the transparent indenter is determined using a measuring microscope. From this, the "Pfund Hardness Number" PHN (kg/mm$^2$) is calculated.

Figure 6 shows the principle of the indentation test with Pfund indenter.






**Key**

1 test panel
2 stop
3 load arm
4 transparent indenter
5 pivot
6 tare weight
7 load weight
8 light source
9 semi-transparent mirror
10 measuring microscope
11 microscopic image (Pfund indentation and scale)

**Figure 6 — Principle of the indentation test**

— **Application**

The indentation test with Pfund indenter is generally applicable.

— **Calibration**

On a reference block the PHN value is determined and compared to the nominal value.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

— Lower the test device onto the coating in a plane area.

— Lower the indenter and apply the specified test load.

— Leave the loaded indenter on the coating for 60 s.

— After that, still loaded, determine diameter $d$ (mm) of the indentation through the transparent indenter using a measuring microscope.

— **Evaluation**

Calculate the PHN value using the measured diameter $d$: PHN = 1,27 / $d^2$. (Factor 1,27 results from the test load and the shape factor of the indenter.)

Test result is the PHN value (kg/mm$^2$), as mean value of at least 5 determinations.

— **Precision**

The repeatability (in accordance with ASTM D1474/D1474M) is 18 %.

The reproducibility (in accordance with ASTM D1474/D1474M) is 36 %.

— **Reference**

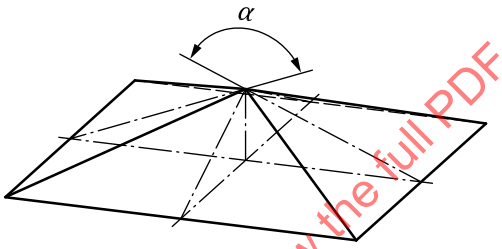
An indentation test with Pfund indenter is specified in ASTM D1474/D1474M-13, Method B: Pfund Indentation Hardness.

### 4.1.4 Indentation test with Vickers indenter

— **Description**

A diamond indenter, the shape and dimensions of which are specified in accordance with Vickers, is pressed into the coating under increasing, controlled load. The Martens hardness HM ($N/mm^2$) in dependence of the indentation depth (µm) and the respective test load (N).

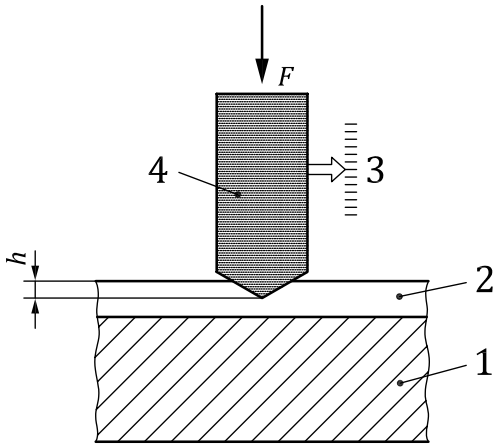
Figure 7 shows the dimensions of the indenter and Figure 8 shows the test principle.




**Key**

$\alpha$ pyramid angle (136°)

**Figure 7 — Schematic diagram of the Vickers indenter**




**Key**

1 substrate
2 coating
3 distance measuring device for the indentation depth
4 indenter with Vickers geometry
*h* indentation depth
*F* test load

**Figure 8 — Principle of the indentation test with Vickers indenter**

— **Application**

The indentation test with Vickers indenter is generally applicable.

— **Calibration**

On a certified calibration panel (e.g. glass of the BK 7 type) an indentation test with a specified load is carried out. From the load-indentation curve the HM value is determined and compared to the certified value.

— **Procedure**

— Agree the test parameters:

— The number and the values of the test load levels (N) [the test load levels are normally selected proportionally (test load)$^{1/2}$].

— Position the test panel in the test device and set the agreed test parameters.

— Start the test procedure and record the indentation depth *h* (µm) in dependence of test load *F* (N).

— **Evaluation**

Calculate the values for the Martens hardness HM = $F/26{,}43\ h^2$ (N/mm$^2$) from the *h*-values and the corresponding *F*-values. (Factor 26,43 results from the shape factor of the indenter.)

Test result is the Martens hardness HM (N/mm$^2$) for an agreed indentation depth *h* (µm) and/or the hardness profile (HM as a function of *h*).

— **Precision**

No precision data are currently available.

— **Reference**

An indentation test with Vickers indenter is specified in ISO 14577-1 and ISO 14577-4.

For testing automobile coatings slightly deviating procedures are described in References [42] and [45].

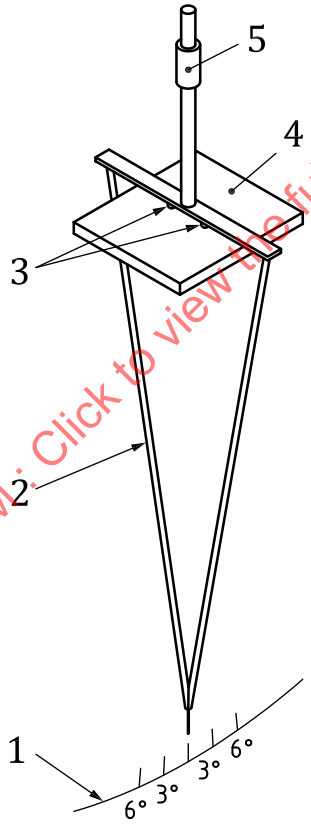
## 4.2 Indentation tests with oscillating indenter

### 4.2.1 Oscillation damping test with König pendulum

— **Description**

A pendulum, the shape, mass and dimensions of which are specified in accordance with König, together with its two integrated tungsten-carbide balls (Ø 5 mm) is lowered on the coating, displaced by 6°, and released. The damping duration (s) of the pendulum swing until reaching the specified final displacement (3°) is determined.

Figure 9 shows the test principle.






**Key**

1 angle scale
2 König pendulum
3 tungsten-carbide ball
4 test panel
5 adjusting weight

**Figure 9 — Principle of the test with König pendulum**

— **Application**

The oscillation damping test with König pendulum is generally applicable.

— **Calibration**

On a polished, plane glass panel the duration of a pendulum swing and the damping duration are determined and compared to the corresponding nominal values.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Position the test panel in the test device.

— Lower the pendulum with the integrated hard-metal balls onto the coating so that the tip of the pendulum is aligned with the zero point of the scale.

— Displace pendulum by 6° and release.

— Determine the damping duration (s) until reaching the final displacement (3°) by using a stop watch.

— **Evaluation**

Test result is the damping duration (s), as mean value of three determinations.

— **Precision**

The repeatability limit *r* is 7 s, corresponding to 5 swings.

The reproducibility limit *R* is 14 s, corresponding to 10 swings.

— **Reference**

The oscillation damping test with König pendulum is specified in ISO 1522 and ASTM D4366.

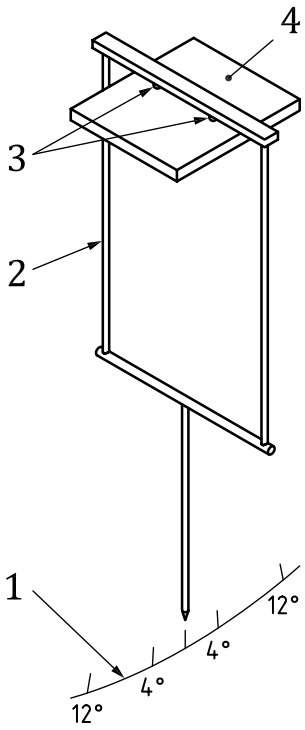
For testing automobile coatings a slightly deviating method is described in Reference [61].

### 4.2.2 Oscillation damping test with Persoz pendulum

— **Description**

A pendulum, the shape, mass and dimensions of which are specified in accordance with Persoz, together with its two integrated tungsten-carbide balls (Ø 8 mm) is lowered on the coating, displaced by 12°, and released. The damping duration (s) of the pendulum swing until reaching the specified final displacement (4°) is determined.

Figure 10 shows the principle.




**Key**

1 angle scale
2 Persoz pendulum
3 tungsten-carbide ball
4 test panel

**Figure 10 — Principle of the test with Persoz pendulum**

— **Application**

The oscillation damping test with Persoz pendulum is generally applicable.

— **Calibration**

On a polished, plane glass panel the duration of a pendulum swing and the damping duration are determined and compared to the corresponding nominal values.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Position the test panel in the test device.

— Lower the pendulum with the integrated hard-metal balls onto the coating so that the tip of the pendulum is aligned with the zero point of the scale.

— Displace pendulum by 12° and release.

— Determine the damping duration (s) until reaching the final displacement (4°) by using a stop watch.

— **Evaluation**

Test result is the damping duration (s), as mean value of three determinations.

— **Precision**

The repeatability limit *r* is 3 %.

The reproducibility limit *R* is 8 %.

— **Reference**

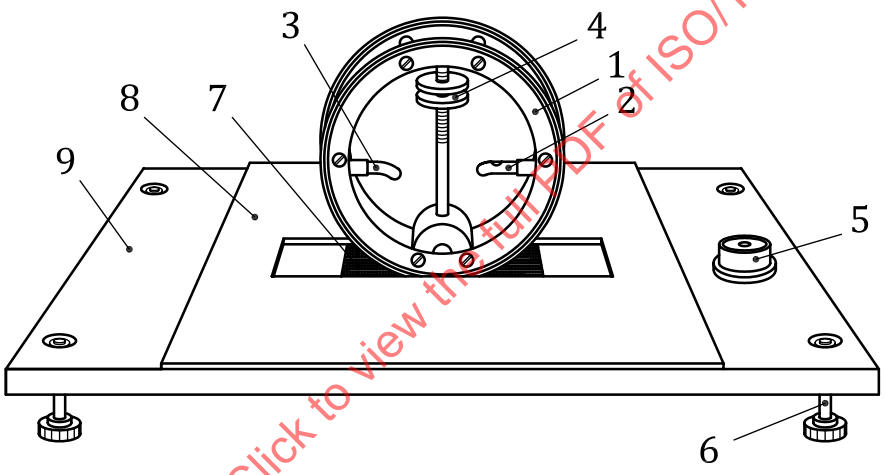
The oscillation damping test with Persoz pendulum is specified in ISO 1522 and ASTM D4366.

### 4.2.3 Oscillation damping test with rocker

— **Description**

A rocker, the shape, mass and dimensions of which are specified in accordance with Sward, together with its two races is lowered on the coating, displaced by 22° and released. The number of swings until reaching the specified final displacement (16°) is determined.

Figure 11 shows the test arrangement.




**Key**

1 race
2 level for final displacement
3 level for initial displacement
4 adjustment apparatus
5 levelling level
6 adjustable foot
7 test panel
8 clamp mask
9 glass panel

**Figure 11 — Arrangement of the oscillation damping test with rocker**

— **Application**

The oscillation damping test with rocker is generally applicable.

— **Calibration**

On a glass panel the number of swings within a time period of 60 s is determined and compared to the nominal value.

— **Procedure**

  — Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

  — Secure the test panel with the clamp mask on the levelled glass plate (see Figure 11).

  — Lower the rocker with the two races onto the coating, displace by 22° and release.

  — Determine the number of swings until reaching the final displacement (16°).

— **Evaluation**

  Test result is the number of swings, multiplied by two, within the specified angle range, as mean value of four determinations.

— **Precision**

  No precision data are currently available.

— **Reference**

  The oscillation damping test with rocker is specified in ASTM D2134.

# 5 Wear resistance tests

## 5.1 Single-scratch tests

### 5.1.1 Scratch test with pencils

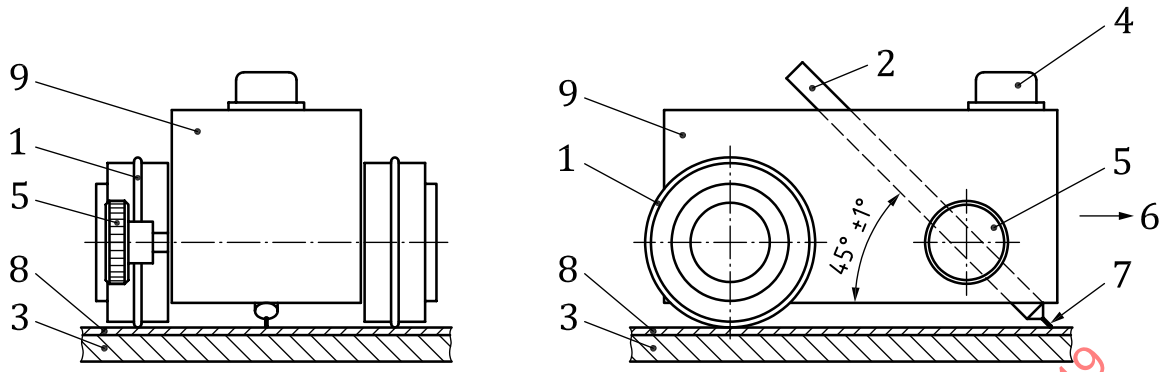
— **Description**

  A pencil lead with specified geometry is pushed over the coating at an angle of 45° and a test load of 7,5 N. The hardness degree is gradually increased in the range of 9B to 9H until a damage of the coating is visible. The highest hardness degree is determined for which no damage is detected.

  Figure 12 shows the set-up of the device. Figure 13 shows the shape of the pencil lead after using a special sharpener.



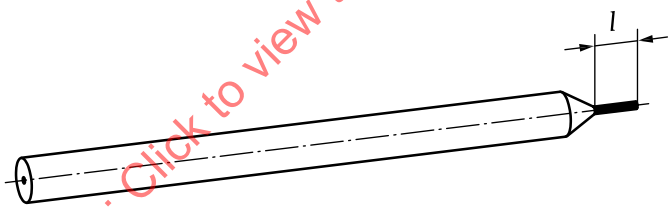
 




**Key**

1 rubber O-ring
2 pencil
3 substrate
4 levelling device
5 clamping device
6 test direction (“pushing”)
7 pencil lead
8 coating
9 metal block

**Figure 12 — Device for scratch test with pencils**




**Key**

*l* lead length (5 mm to 6 mm)

**Figure 13 — Pencil after sharpening**

— **Application**

The scratch test with pencils is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Prepare the pencils in accordance with Figure 13 and sand the tips of the leads plane.

— Secure a pencil of a “medium” hardness degree in the horizontally aligned device in accordance with Figure 12 and lower the device onto the coating.

— Push the loaded pencil lead over the coating with constant speed in the direction of arrow 6 in Figure 12.

— After 30 s visually inspect the coating (if agreed, using a magnifier, magnification ×6 to ×10) for damages and, if applicable, determine the type of damage.

— Carry out further scratch tests with varied pencil hardness degrees until a damage of at least 3 mm length is detectable on the coating.

— Based on this, carry out scratch tests with decreasing pencil hardness degrees until the coating is not damaged any more.

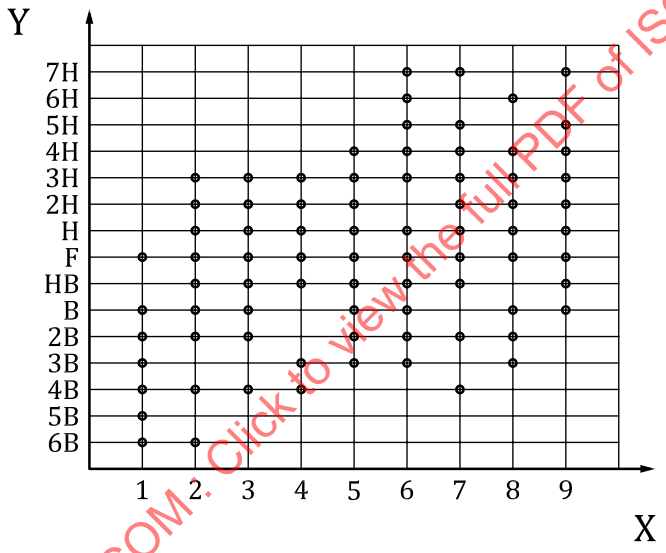
— **Evaluation**

Test result is the highest pencil hardness degree for which no damage, i.e. any visual deviation from the undamaged area, is detected on the coating.

— **Precision**

No precision data are currently available.

Figure 14 graphically shows the results of scratch tests with pencils which have been carried out by different persons, on different coatings, and with different types of pencils.




**Key**

X identifications of coatings

Y hardness degrees of the leads

**Figure 14 — Results of scratch tests with pencils**

The results of the measurements in accordance with Figure 14 suggest that the scratch test with pencils is not meaningful for the comparison of different coatings. It is more meaningful to carry out relative assessments within a range of test panels which show significant differences during the scratch test with pencils.

— **Reference**

A scratch test with pencils is specified in ISO 15184.

For testing coil coatings a slightly deviating method is described in EN 13523-4.

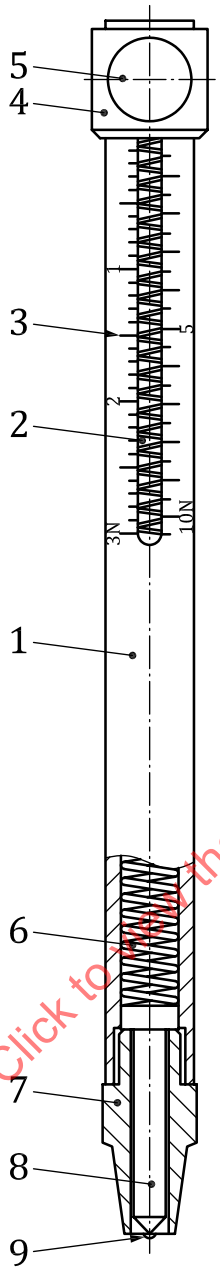
Further methods with higher test load are described in References [53] and [57].

### 5.1.2 Scratch test with ball stylus 1

— **Description**

A tungsten-carbide ball stylus (diameter 0,50 mm, 0,75 mm, or 1,00 mm) loaded with a test load in the range of 0,5 N to 20 N is manually moved over the surface of a coating. A produced damage is visually inspected and assessed. The lowest test load for mars (classification test) is determined, or if the coating is marred using the agreed test load ("pass/fail" test).

Figure 15 shows the set-up and the function of the device.






**Key**

1 metal sleeve
2 slot
3 scale (test load)
4 slider
5 locking screw
6 pressure spring
7 head piece
8 ball stylus with (9)
9 spherical hard-metal tip

**Figure 15 — Hardness pen for the scratch test with ball stylus 1**

— **Application**

The scratch test with ball stylus 1 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree test variation:

— Classification test (varied test load);

— “Pass/fail” test (fixed, specified test load).

— Agree test tool:

— Ball stylus A1 (tip diameter 0,50 mm);

— Ball stylus A2 (tip diameter 0,75 mm);

— Ball stylus A3 (tip diameter 1,00 mm).

— Condition the test paneltest panel (23 °C / 50 % relative humidity / ≥ 16 h), if not agreed otherwise.

— Insert the agreed ball stylus into the hardness pen and adjust the intended or agreed test load.

— Secure the test panel onto a support, vertically press down the hardness pen onto the surface and move over the coating uniformly (speed about 10 mm/s / test distance ≥ 10 mm).

— Visually inspect the test distance and determine whether the coating has been marred.

— When carrying out the test as classification test determine the minimum test load (N) for marring by carrying out further scratch tests.

— Carry out all scratch tests in duplicate on the same test panel.

— **Evaluation**

Test result is

— for carrying out the test as classification test: minimum test load (N) for marring, and

— for carrying out the test as “pass/fail” test: the information if the coating is marred under the agreed test conditions (“fail”) or not (“pass”).

Additionally, the type of damage is indicated.

— **Precision**

No precision data are currently available.

— **Reference**

The scratch test with ball stylus 1 is specified in ISO 22557, Method A: Test with ball stylus.

For testing automobile coatings slightly deviating methods are described in References [50], [55] and [58].

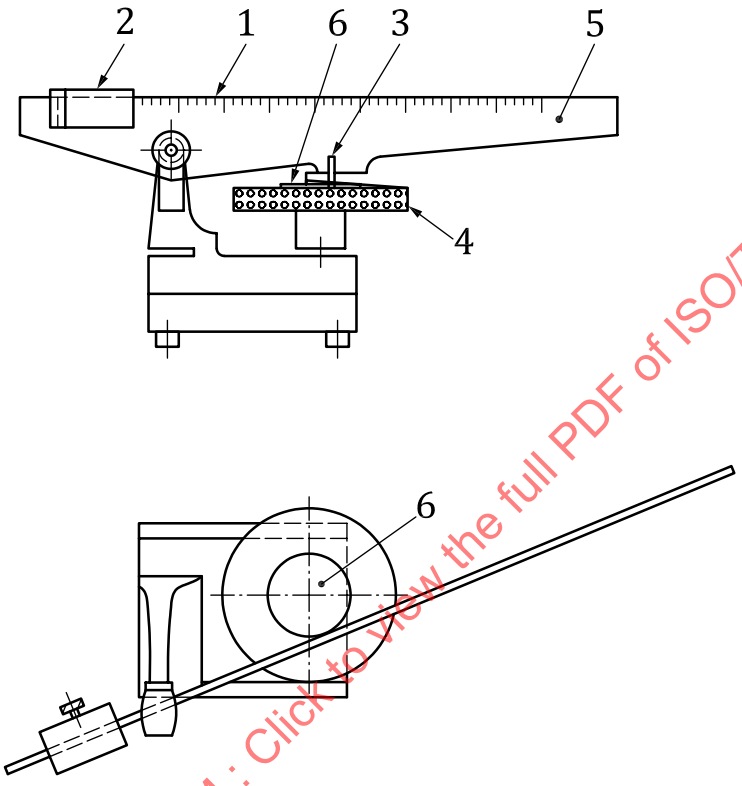
For testing furniture surfaces slightly deviating methods are described in References [51] and [52].

### 5.1.3 Scratch test with ball stylus 2

— **Description**

By means of a diamond stylus (tip radius 0,09 mm) radially displaced scratch tests with test loads in accordance with a specified loading scheme are carried out on the rotating (5 $min^{-1}$) test panel. The scratch resistance (N) is determined as lowest test load for a continuous scratch mark as well as the characteristic value "stress group" (6-step classification) which is derived from it.

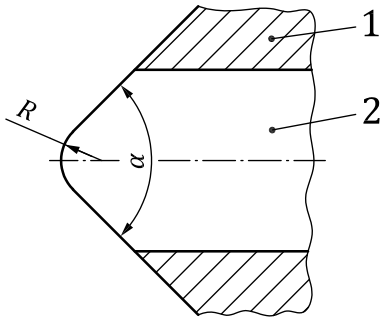
Figure 16 shows the set-up of the test device. Figure 17 shows the dimensions of the test stylus.




**Key**

1 scale for adjusting the test load
2 moveable load weight
3 stylus with inserted diamond
4 motor-driven turntable
5 load arm
6 clamping device

**Figure 16 — Set-up of the device for the scratch test with conical stylus 2**




**Key**

1 stylus shaft

2 diamond insert with spherical tip

$R$ radius of the spherical tip: $R$ = (0,090 ± 0,003) mm

$\alpha$ cone angle: $\alpha$ = (90 ± 1)°

**Figure 17 — Dimensions of the tip of the conical stylus 2**

— **Application**

The stress test with conical stylus 2 is preferably carried out on coated furniture surfaces.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / 7 d).

— For the pre-test position the test panel on the turntable of the test device.

— Load the conical stylus with 5 N and carry out a scratch test over the entire circumference (1 rotation).

— By means of further scratch tests with roughly varied test load approximately determine the lowest test load for which a continuous scratch mark is visible.

— Position the test panel for the main test on the turntable of the test device.

— Increase the final test load determined in the pre-test by 1 N, load the conical stylus with it, and carry out a scratch test.

— By means of further scratch tests with finely decreased test loads determine the highest test load for which no continuous scratch mark is visible.

— **Evaluation**

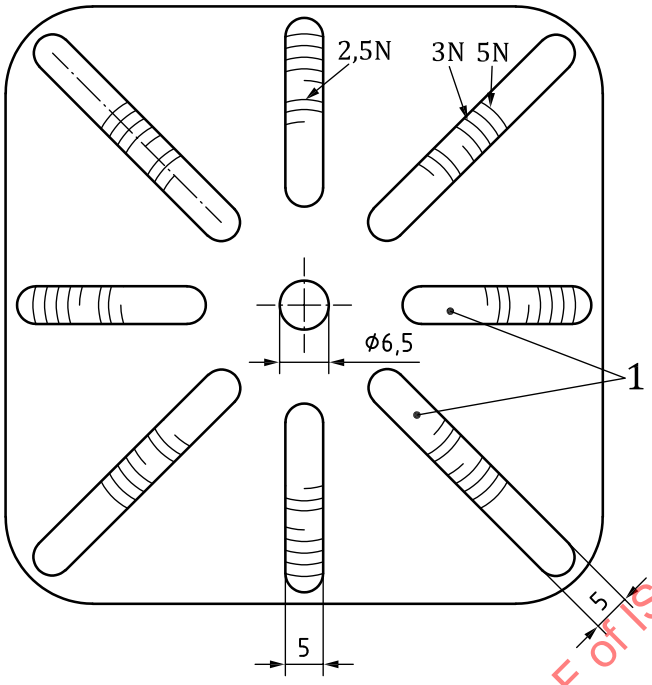
Visually evaluate the damage pattern of the main test in a specified light cabin and by means of an inspection template in accordance with Figure 18. Determine the lowest test load (N) which results in a continuous scratch mark, which is then considered scratch resistance.

Test result is

— the scratch resistance (N), as mean value of three determinations, with indication of the single values, and

— the characteristic value “stress group” (6-step classification: 4 A to 4 F) derived from the scratch resistance by means of numerical criteria.

Dimensions in millimetres




**Key**

1 inspection slot with visible scratch marks

**Figure 18 — Test panel with attached inspection template**

— **Precision**

No precision data are currently available.

— **Reference**

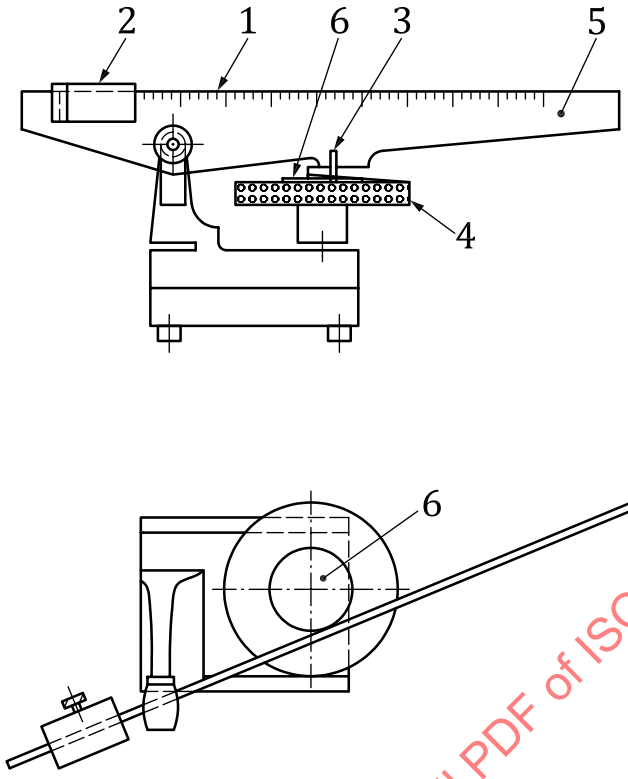
The scratch test with ball stylus 2 is specified in DIN 68861-4.

### 5.1.4 Scratch test with conical stylus 3

— **Description**

By means of a diamond stylus (tip radius 0,09 mm) radially displaced scratch tests with four specified test loads in the range of 1 N to 6 N are carried out on the rotating (5 $min^{-1}$) test panel. A characteristic value (degree 1 to degree 5) is determined by comparison of the damage pattern to reference images.

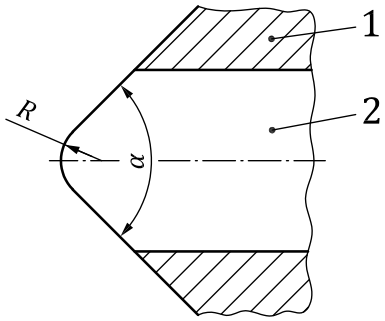
Figure 19 shows the set-up of the test device. Figure 20 shows the dimensions of the test stylus.




**Key**

1 scale for adjusting the test load
2 moveable load weight
3 stylus with inserted diamond
4 motor-driven turntable
5 load arm
6 clamping device

**Figure 19 — Set-up of the device for the scratch test with conical stylus 3**




**Key**

1 stylus shaft
2 diamond insert with spherical tip
$R$ radius of the spherical tip: $R$ = (0,090 ± 0,003) mm
$\alpha$ cone angle: $\alpha$ = (90 ± 1)°

**Figure 20 — Dimensions of the tip of the conical stylus 3**

— **Application**

The scratch test with conical stylus 3 is preferably carried out on HP(D)L [High-pressure (decorative) laminate] films.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / 72 h).

— Secure the test panel on the turntable of the test device.

— Load the conical stylus with 1 N and carry out two scratch tests, with only a slight distance in between, over the entire circumference (1 rotation).

— Repeat this process with the test loads 2 N, 4 N, and 6 N in sufficient distance in each case.

— Treat the stressed surface using a contrast agent (graphite, talcum, or ethanolic colouring solution, depending on the lightness / colour of the test panel).

— **Evaluation**

Visually evaluate the damage pattern in a specified light cabin and classify in 5 steps (degree 1 to degree 5) by means of reference images (see Figure 21).

Test result is the determined characteristic value (degree).

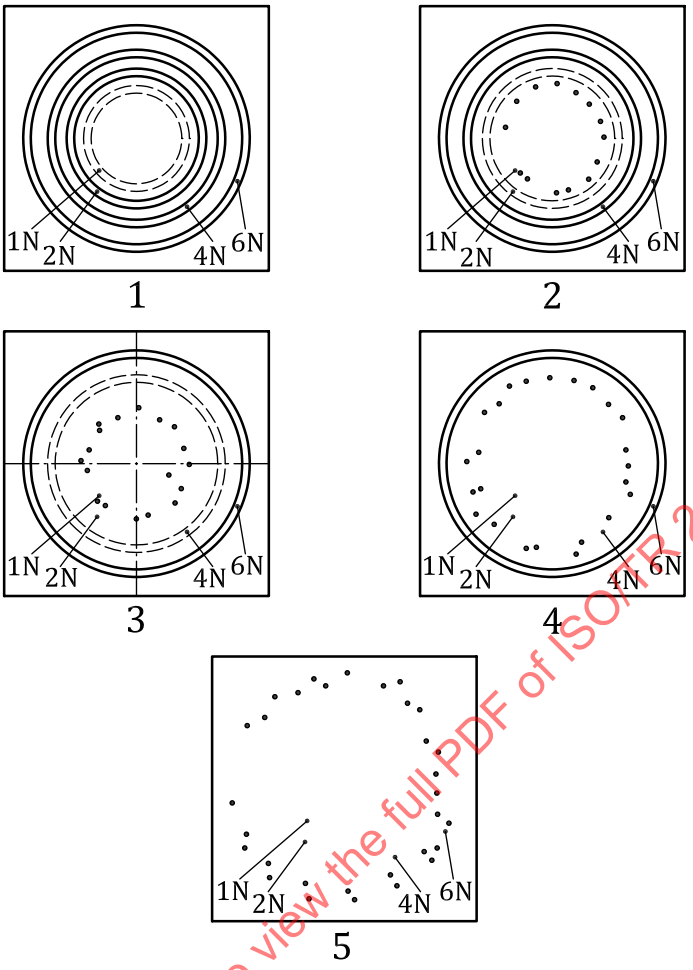



**Figure 21 — Reference images for degree 1 to degree 5**

— **Precision**

No precision data are currently available.

— **Reference**

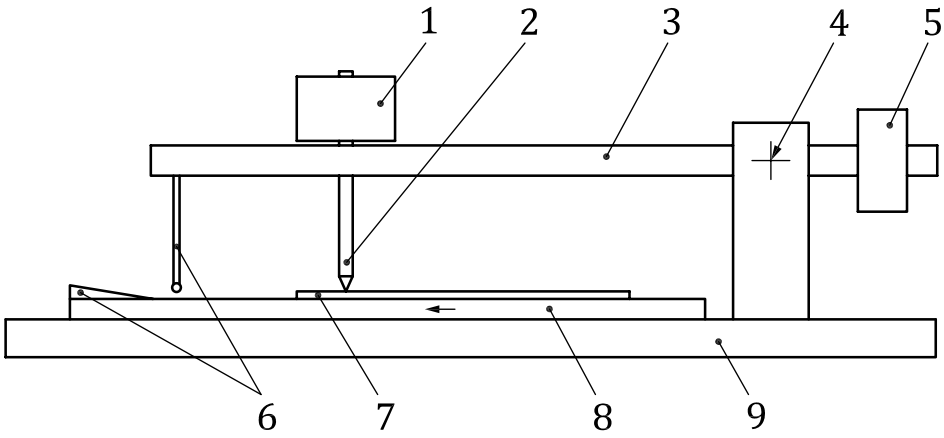
The scratch test with conical stylus 3 is specified in EN 438-2:2016, Clause 25, and in ISO 4586-2:2018, Clause 14.

### 5.1.5 Scratch test with conical stylus 4

— **Description**

A conical stylus (Ø 0,5 mm / 1,0 mm) loaded with a test load in the range of 1 N to 20 N is pulled over the surface (test distance ≥40 mm) with constant speed (35 mm/s). The lowest test load for the penetration of the conical stylus down to a specified film (classification test) is determined or whether the penetration down to the specified film occurs for an agreed test load ("pass/fail" test).

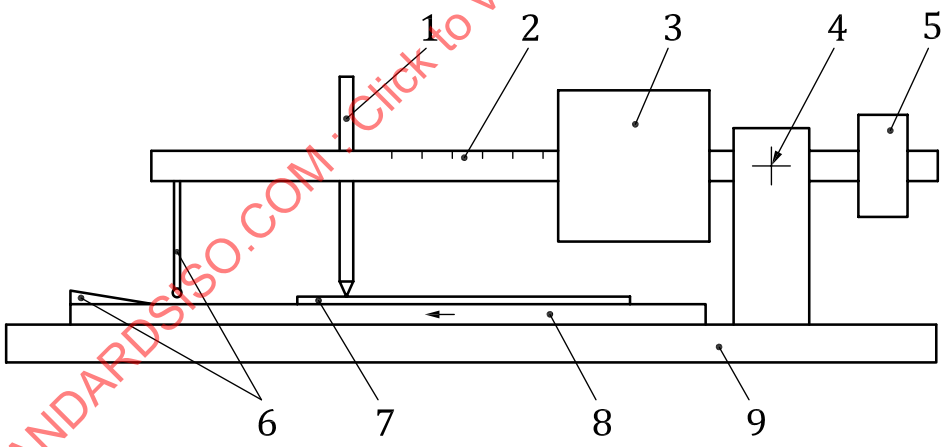
Figures 22 and 23 show two variations of the test device.




**Key**

1 attached weight
2 stylus
3 load arm
4 pivot for load arm
5 tare weight
6 lowering apparatus (ramp and guide bolt)
7 test panel
8 specimen holder (is motorically moved in the direction of the arrow)
9 base plate

**Figure 22 — Device for the scratch test with conical stylus 4 (variation with attached weight)**




**Key**

1 stylus
2 load arm with scale
3 slide weight
4 pivot for load arm
5 tare weight
6 lowering apparatus (ramp and guide bolt)
7 test panel
8 specimen holder (is motorically moved in the direction of the arrow)
9 base plate

**Figure 23 — Device for the scratch test with conical stylus 4 (variation with slide weight)**

— **Application**

The scratch test with conical stylus 4 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree test specification:

— Scratch down to the substrate;

— Scratch down to an agreed film.

— Agree test variation:

— Classification test (varied test load);

— "Pass/fail" test (fixed, specified test load).

— Agree test tool:

— Stylus A (tip radius 0,50 mm / tungsten carbide);

— Stylus B (tip radius 0,25 mm / tungsten carbide);

— Stylus C (tip radius 0,50 mm / ruby);

— Stylus D (tip radius 0,25 mm / ruby).

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Secure the test panel on the specimen holder of the test device.

— Mount the agreed stylus into the horizontal load arm and tare the load arm.

— Load the stylus, carry out a scratch test, and evaluate the result using a magnifier (≥×4).

— When carrying out the test as classification test carry out further scratch tests with varied test load (0,5-N steps) until the coating is penetrated in the specified way.

— When carrying out the test as "pass/fail" test determine whether the coating is penetrated or not in the specified way when carrying out the scratch test with the agreed test load.

— **Evaluation**

Test result is

— for carrying out the test as classification test the lowest test load (N) from three determinations for which the coating was penetrated in the specified way, and

— for carrying out the test as "pass/fail" test the conclusion, whether the coating was penetrated ("fail") or not ("pass") in the agreed way in at least one of six scratch tests with the agreed test load.

— **Precision**

For the repeatability limit *r* no data are currently available.

The reproducibility limit *R* is 30 %.

— **Reference**

The scratch test with conical stylus 4 is specified in ISO 1518-1.

For testing coil coatings a slightly deviating method is described in EN 13523-12.

For testing automobile coatings a slightly deviating method is described in Reference [54].

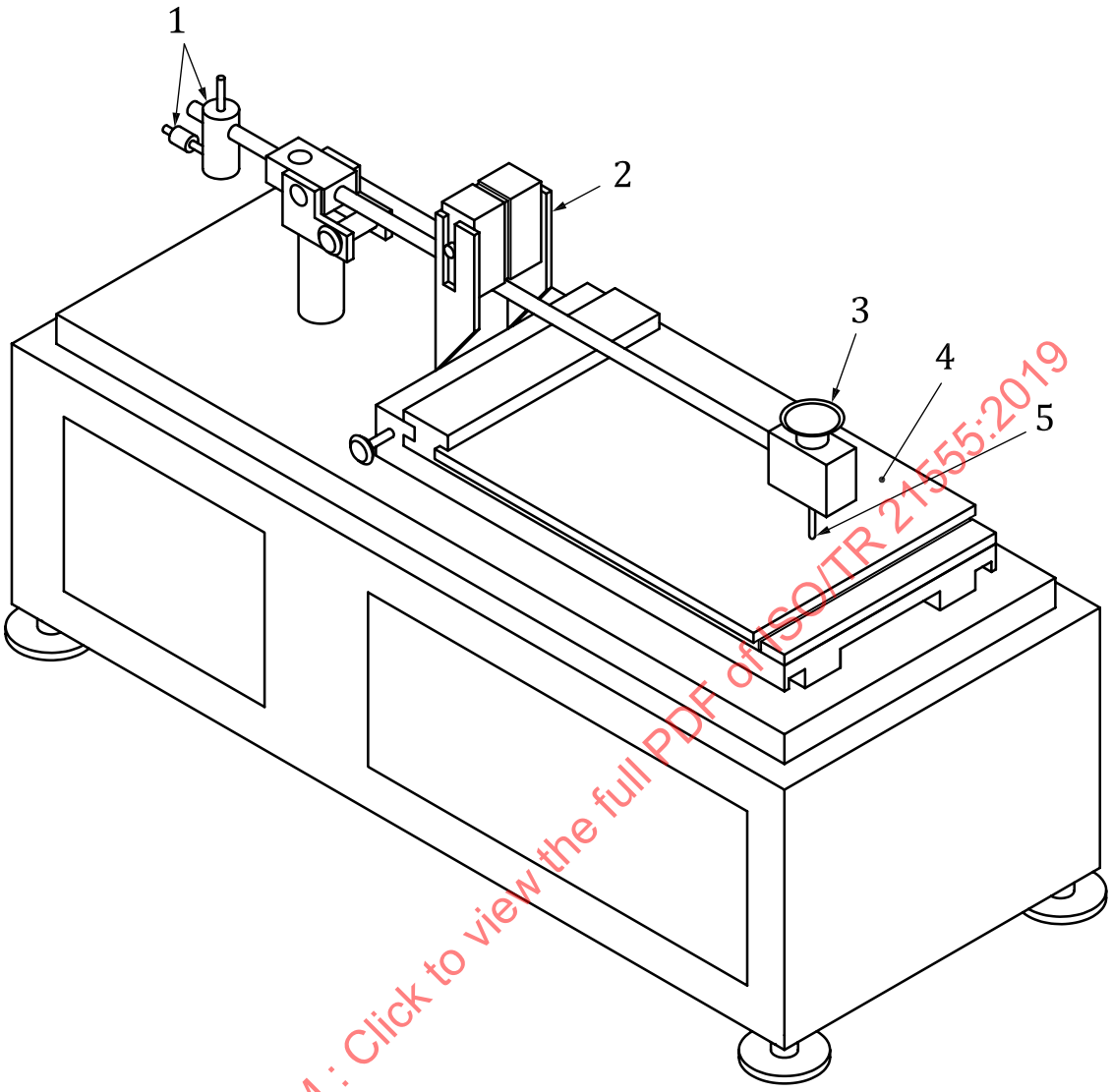
For testing automobile coatings similar methods are described in References [43], [49] and [50].

### 5.1.6 Scratch test with conical stylus 5

— **Description**

A loaded conical stylus (Ø 0,06 mm) is pulled over the coating (test distance 100 mm) with constant speed (10 mm/s). During this, the test load is increased automatically and linearly dependent on the test distance. The test load range of the conical stylus can be varied by means of the mass of the load weight and possibly of the additional weight. The lowest test load (g) is determined for which a damage is visually detectable on the coating.

Figure 24 shows the set-up of the test device. Figure 25 shows the dimensions of the test stylus.

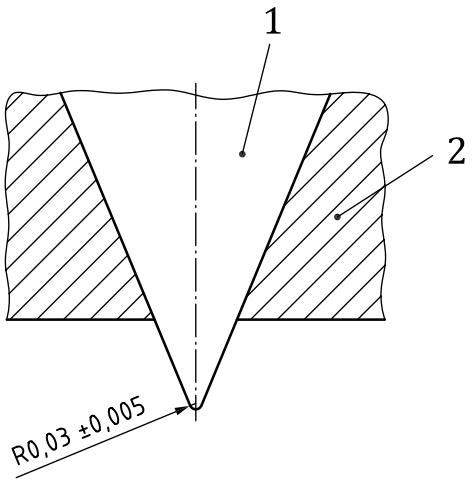



**Key**

1 tare weight
2 weight for continuously increasing test load
3 bowl for additional weight
4 test panel on slide table
5 test stylus

**Figure 24 — Device for the scratch test with conical stylus 5**

Dimensions in millimetres




**Key**

1 diamond or sapphire insert

2 stylus shaft

**Figure 25 — Dimensions of the tip of the conical stylus 5**

— **Application**

The scratch test with conical stylus 5 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Secure the test panel on the specimen holder of the test device.

— Mount the stylus into the load arm and tare the load arm.

— Select test load range, e.g.:

— Load weight 50 g / 100 g / 200 g gives without additional weight the test load range 0 g to 50 g (corresponding to 0 N to 0,49 N) / 0 g to 100 g (corresponding to 0 N to 0,98 N) / 0 g to 200 g (corresponding to 0 N to 1,96 N);

— Load weight 100 g gives with additional weight of 200 g the test load range 200 g (corresponding to 1,96 N) to 300 g (corresponding to 2,94 N).

— Start the automatic scratch test and possibly repeat with different test load ranges until a damage is visually detectable (optionally by means of a magnifier).

— **Evaluation**

From the total length of the damage and the masses of load weight and additional weight the lowest test load (“critical load”) is calculated, for which a damage is visible on the coating.

Test result is

— the critical load (g), as mean value of three determinations, and

— the type of damage (plastic deformation, scratches on the surface, cohesion failure, etc.).

— **Precision**

No precision data are currently available.

— **Reference**

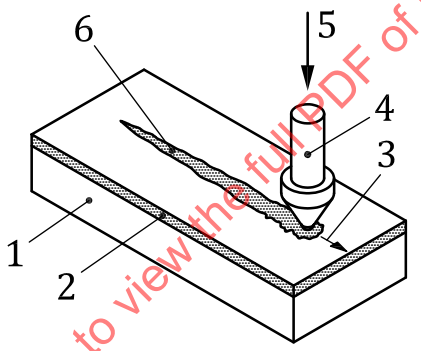
The scratch test with conical stylus 5 is specified in ISO 1518-2.

### 5.1.7 Scratch test with conical stylus 6

— **Description**

By means of a diamond conical stylus (Ø 1 µm to 100 µm) a scratch test with constantly increasing test load $F$ to a maximum of 50 mN is carried out and the remaining scratch depth $h$ (µm) is determined. The feed rate is 0,5 mm/min to 10 mm/min; the speed of the load increase is 5 mN/min to 200 mN/min. The "Plastic Resistance" value PR (mN/µm) and the "Fracture Resistance" value FR (mN) are determined.

Figure 26 shows the test principle.




**Key**

1 substrate
2 coating
3 scratch direction
4 diamond conical stylus
5 test load
6 scratch mark

**Figure 26 — Principle of the scratch test with conical stylus 6**

— **Application**

The scratch test with conical stylus 6 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree the diameter of the conical stylus in the range of 1 µm to 100 µm.

— Agree the feed rate of the conical stylus in the range of 0,5 mm/min to 10 mm/min.

— Agree the increase speed of the test load for the "Scratch-Scan" in the range of 5 mN/min to 200 mN/min.

— Agree the final test load for the “Scratch-Scan” until about 50 mN.

— Agree the same scanning load for the “Pre-Scan” and the “Post-Scan” in the range of 0,1 mN to 1 mN.

— Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

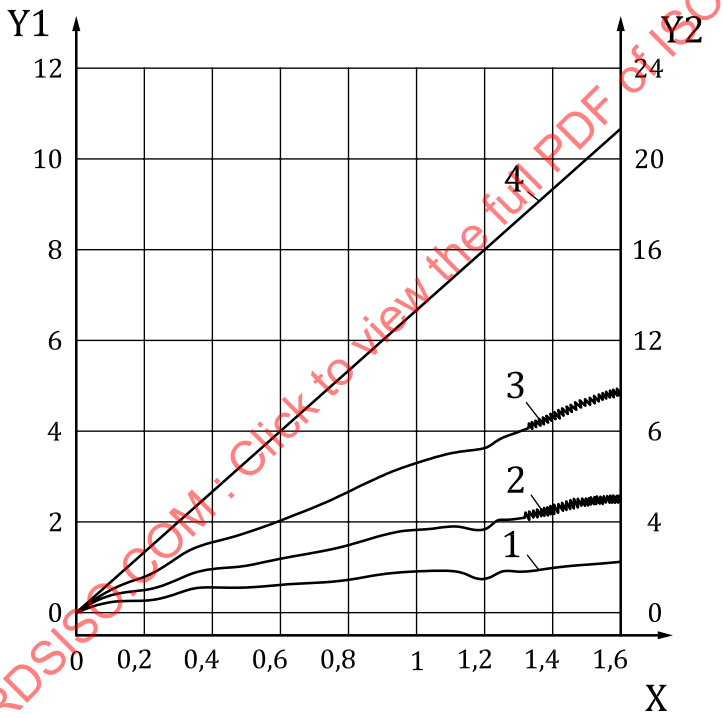
— Secure the test panel in the test device and pre-select the agreed scanning load.

— Carry out the “Pre-Scan”. The surface profile of the coating is scanned and these data are saved.

— For the “Scratch-Scan” pre-select the agreed parameters on the device and direct it in the same line as the “Pre-Scan”. During this, the conical stylus penetrates the coating with controlled, increasing test load.

— Again, set the agreed scanning load on the device and direct the “Post-Scan” in the same line as the “Pre-Scan” and the “Scratch-Scan”. The profile generated by the plastic deformation in the scratch mark is scanned and these data are saved.

— Figure 27 graphically shows typical results of the scans.




**Key**

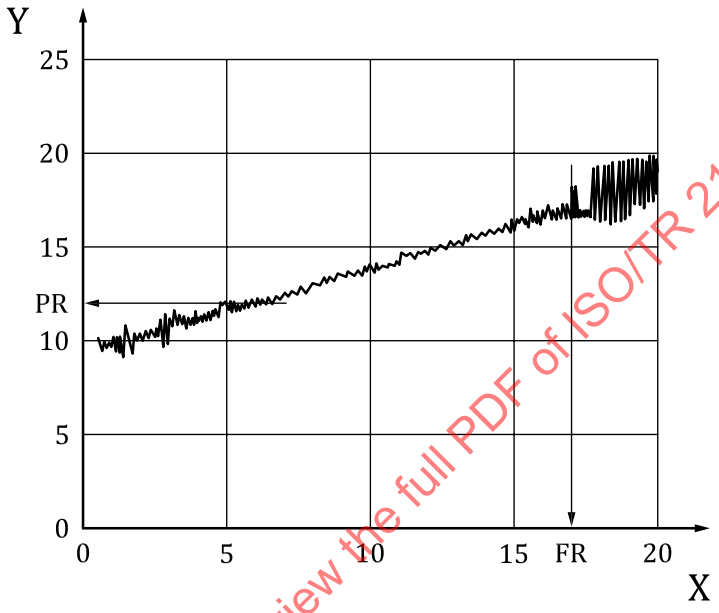
1 “pre-scan”
2 “post-scan”
3 “scratch-scan”
4 test load curve
X horizontal test distance (mm)
Y1 vertical stylus displacement (µm)
Y2 test load (mN)

**Figure 27 — Measuring curves (example)**

— **Evaluation**

By calculating the difference from the data of the "Pre-Scan" and the "Post-Scan" the remaining depth of the scratch mark *h* (µm) depending on the test load *F* (mN) is calculated. From this, the "Plastic Resistance" values PR (mN/µm) in accordance with PR = *F* / *h*. Figure 28 shows a typical curve of PR as function *F*.

The PR fluctuations in the right section of the curve in accordance with Figure 28 are caused by the breaking of the coating. The lowest test load of this fluctuation range is called "Fracture Resistance" FR (mN) (see Figure 28).




**Key**

X test load (mN)
Y "plastic resistance" (mN/µm)
FR "fracture resistance" value (17 mN)
PR "plastic resistance" value (12 mN/µm) for an agreed test load of 5 mN

**Figure 28 — "Plastic Resistance" depending on the test load (example)**

Test results are the "Plastic Resistance" value (mN/µm) for an agreed test load (mN) and the "Fracture Resistance" value (mN), in each case as mean value of three determinations, with indication of the range.

— **Precision**

No generally applicable precision data are currently available.

— **Reference**

The scratch test with conical stylus 6 is specified in ASTM D7187.

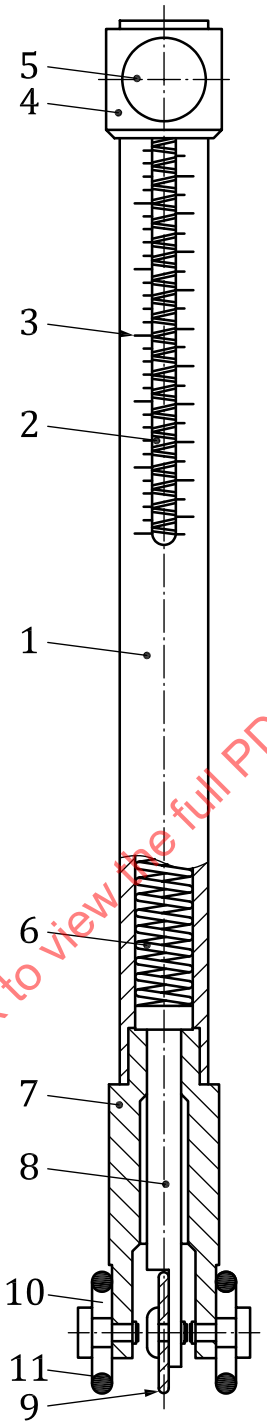
### 5.1.8 Scratch test with disc-shaped stylus

— **Description**

A test disc made of stainless steel, copper, thermoset, or polymethylmethacrylate (PMMA) loaded with a test load in the range of 0,5 N to 20 N is manually moved over the surface of the coating. A produced damage is visually inspected and evaluated. The lowest test load for marring of the

coating (classification test) is determined or whether the coating is marred for the agreed test load ("pass/fail" test).

Figure 29 shows the set-up and the function of the device and Figure 30 shows the dimensions of the test disc.






**Key**

| | | | |
|---|---|---|---|
| 1 | metal sleeve | 7 | head piece |
| 2 | slot | 8 | disc-shaped stylus, consisting of test disc holder and (9) |
| 3 | scale (test load) | | |
| 4 | slider | 9 | test disc |
| 5 | locking screw | 10 | supporting wheel |
| 6 | pressure spring | 11 | rubber O-ring |

**Figure 29 — Hardness pen for the scratch test with disc-shaped stylus**

Dimensions in millimetres

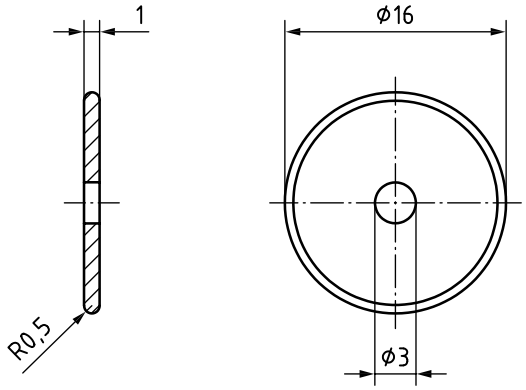



**Figure 30 — Dimensions of the test disc**

— **Application**

The scratch test with disc-shaped stylus is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree test variation:

— Classification test (varied test load);

— "Pass/fail" test (fixed, specified test load).

— Agree test tool:

— Test disc B1 (stainless steel),

— Test disc B2 (copper),

— Test disc B3 (thermoset),

— Test disc B4 (PMMA).

— Condition the test panel (23 °C / 50 % relative humidity / ≥ 16 h), if not otherwise agreed.

— Insert the agreed test disc into the hardness pen and adjust the intended and agreed test load.

— Secure the test panel onto a support, vertically press down the hardness pen onto the surface and uniformly move over the coating (speed about 100 mm/s / test distance ≥ 100 mm).

— Visually inspect the test distance and determine if the coating has been damaged.

— When carrying out the test as classification test determine the minimum test load (N) for damaging the coating by carrying out further scratch tests.

— Carry out all scratch tests in duplicate on the same test panel.

— **Evaluation**

Test result is

— for carrying out the test as classification test: the minimum test load (N) for damaging the coating, and

— for carrying out the test as “pass/fail” test: the information whether the coating has been damaged (“fail”) or not (“pass”) under the agreed test conditions.

In addition, the type of the damage is indicated.

— **Precision**

No precision data are currently available.

— **Reference**

The scratch test with disc-shaped stylus is specified in ISO 22557, Method B: Test with disc stylus.

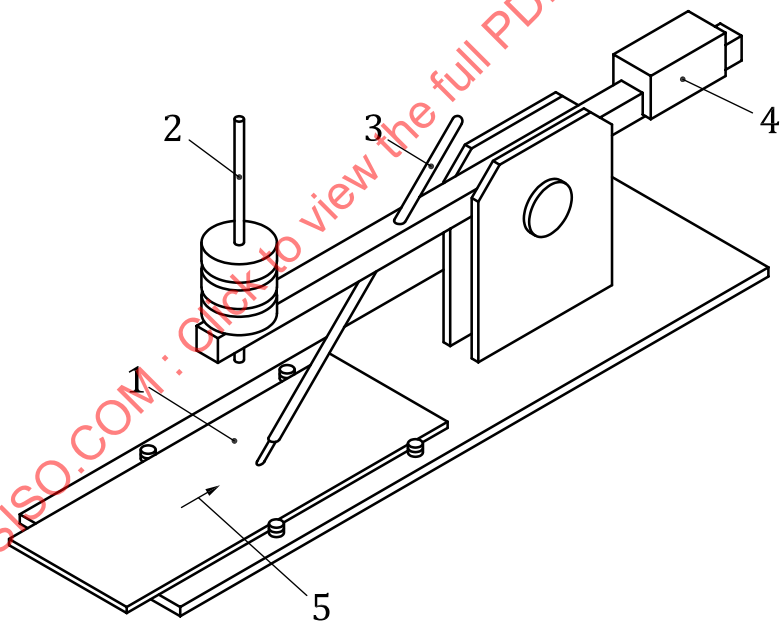
For testing automobile coatings a similar method is described in Reference [44].

### 5.1.9 Scratch test with U-shaped stylus

— **Description**

A U-shaped stylus loaded with a test load of up to 5 kg (corresponding to 49 N) is pulled over the coating (test distance ≥ 75 mm) with constant speed (3 mm/s to 6 mm/s). The lowest test load is determined for which the coating is marred. In addition, the type of the damage is indicated.

Figure 31 shows the test device. Figure 32 shows the shape and dimensions of the stylus.




**Key**

1 test panel
2 holder for load weights
3 holder for test tools
4 tare weight
5 moving direction of the test panel

**Figure 31 — Device for the scratch test with U-shaped stylus**

Dimensions in millimetres

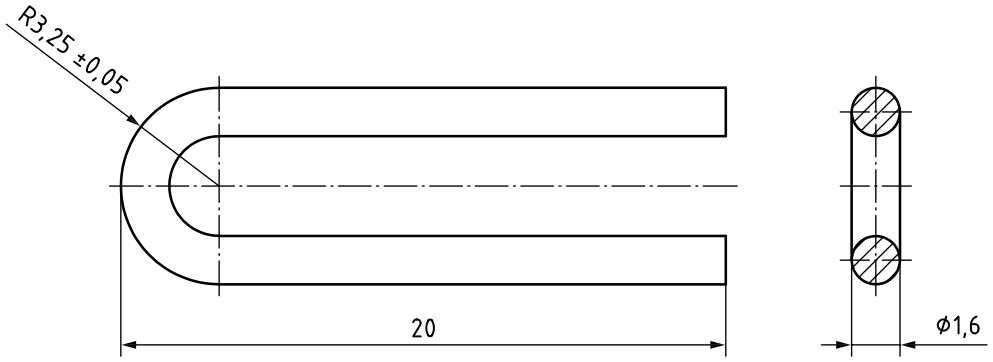



**Figure 32 — U-shaped stylus**

— **Application**

The scratch test with U-shaped stylus is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).

— Position the test panel on the specimen holder of the test device.

— Mount the stylus into the horizontal load arm and tare the load arm.

— Load the stylus, carry out a scratch test, and visually evaluate the result (optionally by means of a magnifier).

— Carry out further scratch tests with varied test load (increment ≥ 0,1 N) until a scratch is visible on the coating.

— **Evaluation**

Test result is

— the lowest test load (g) for which the coating is marred during at least two of five determinations, and

— the type of the damage (plastic deformation, scratches on the surface, cohesion failure, etc.).

— **Precision**

No precision data are currently available.

— **Reference**

The scratch test with U-shaped stylus is specified in ISO 12137.

A slightly deviating method is described in ASTM D5178.

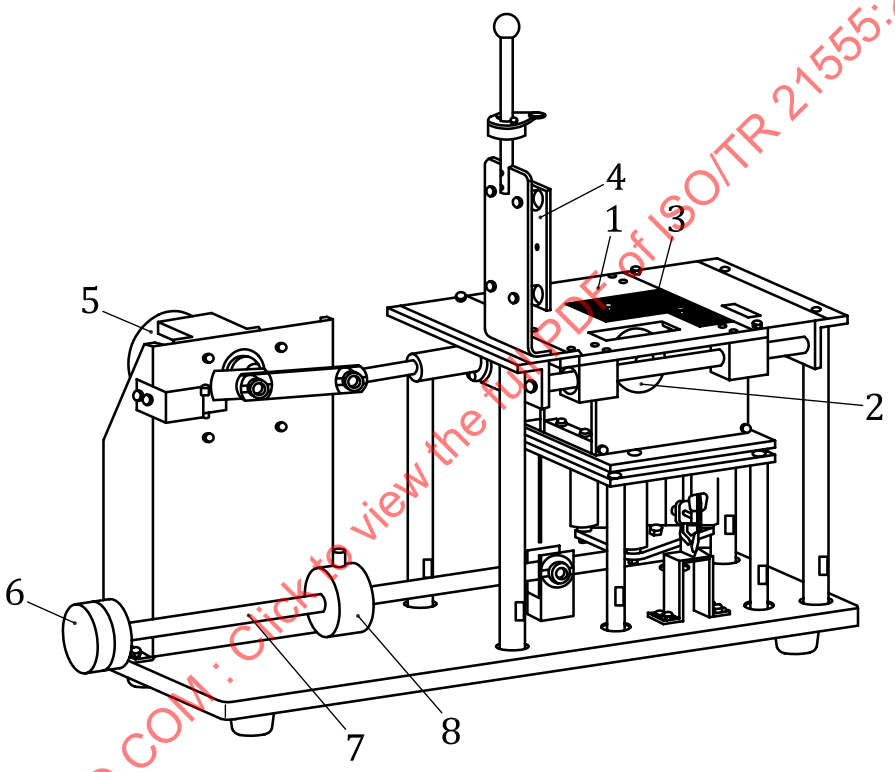
## 5.2 Multiple scratch tests

### 5.2.1 Multiple scratch test with locked abrasive wheel

— **Description**

A locked abrasive wheel (Ø 50 mm), covered with a 12 mm wide $Al_2O_3$ polishing paper with grain size 3 µm is pressed onto the coating (test load 500 g, corresponding to 4,9 N). The test panel is reciprocated (stroke length 30 mm / 40 double strokes/min). A mechanism rotates the abrasive wheel by a small angle, so that always a new area of the abrasive paper is effective. The relative decrease of gloss (%) after 10 double strokes is determined.

Figure 33 shows the test principle.




**Key**

1 specimen stage
2 abrasive wheel
3 specimen guide
4 specimen press
5 specimen reciprocating motor
6 load
7 load scale
8 load adjust

**Figure 33 — Principle of the multiple scratch test with locked abrasive wheel**

— **Application**

The multiple scratch test with locked abrasive wheel is preferably carried out on high-gloss coatings.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

— Determine the gloss of the coating (in gloss units) in two points of the intended test area in accordance with ISO 2813 with geometry 20° and calculate the mean value ($g_i$ in gloss units).

— Position the test panel in the test device, apply the agreed test load, and start double-stroke motion.

— After 10 double strokes, determine the gloss of the coating (in gloss units) in two points of the test area in accordance with ISO 2813 with geometry 20° and calculate the mean value ($g_f$ in gloss units GU).

— **Evaluation**

Test result is the relative decrease of gloss ("per cent gloss retention") $100 \times (g_f / g_i)$ (%), calculated from the averaged gloss values $g_i$ and $g_f$.

— **Precision**

The precision of the method depends on the characteristics of the product tested. For the transparent poly(methyl methacrylate) (PMMA) sheet specified in ISO 7823-1, the following values are valid.

The repeatability limit is 10 %. Detailed information is given in ISO 7784-3:2016, Table 2.

The reproducibility limit is 22 %. Detailed information is given in ISO 7784-3:2016, Table 2.

— **Reference**

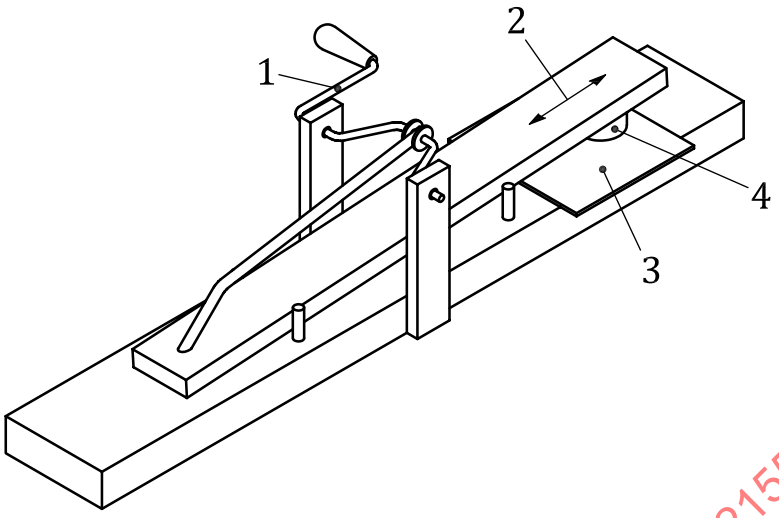
The multiple scratch test with locked abrasive wheel is specified in ISO 7784-3 and ASTM D6037-18, Test Method B.

### 5.2.2 Multiple scratch test with abrasive cylinder

— **Description**

An agreed abrasive cylinder (three specified types), which is lined with an agreed abrasive material, is pressed onto the coating (test load 9 N or 22 N, depending on the type of abrasive cylinder) and is reciprocated under the influence of an abrasive medium (1 double stroke/s). The stroke length and the number of double strokes are agreed. Prior to and after the stress application the gloss is measured in the area of the scratch mark (in gloss units for an agreed geometry). In agreement, the scratch mark can also be assessed by measuring the haze or the brightness.

The test device is given in Figure 34.




**Key**

1 crank mechanism (crank handle)
2 direction of motion
3 test panel
4 abrasive cylinder

**Figure 34 — Device for the multiple scratch test with abrasive cylinder (“crockmeter”)**

— **Application**

The multiple scratch test with abrasive cylinder is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

NOTE The procedure is described as an example for the test criterion “gloss”.

— Agree abrasive cylinder (selection from three specified variations).
— Agree abrasive material (cotton tissue, abrasive paper, felt etc.).
— Agree abrasive medium (abrasive paste, abrasive powder, water etc.).
— Agree stroke length.
— Agree number of double strokes.
— Agree geometry for gloss measurement in accordance with ISO 2813.
— Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).
— Mark three measuring points on the test panel by using a jig and with the agreed geometry measure the gloss (gloss units GU) in these locations crosswise to the intended stroke direction.
— Clamp the abrasive material onto the abrasive cylinder.
— Position the test panel in the test device with the help of the marks and apply, if applicable, the agreed abrasive medium.
— Lower the abrasive cylinder onto the coating with the corresponding test load and start the double-stroke motion.

— After the agreed number of double strokes measure the gloss (GU) with the agreed geometry crosswise to the stroke direction in the marked measuring points.

— **Evaluation**

Test result is the gloss mean value (GU) prior to and after the stress application with indication of the geometry.

In addition, the absolute gloss difference (GU) and/or the relative gloss difference (%) in relation to the gloss value prior to the stress application can be indicated.

— **Precision**

No precision data are currently available.

— **Reference**

The multiple scratch test with abrasive cylinder is specified in ISO 21546.

For testing high-gloss coatings a similar method is also described in ASTM D6279.

For testing automobile coatings similar methods are described in References [48], [60] and [46].

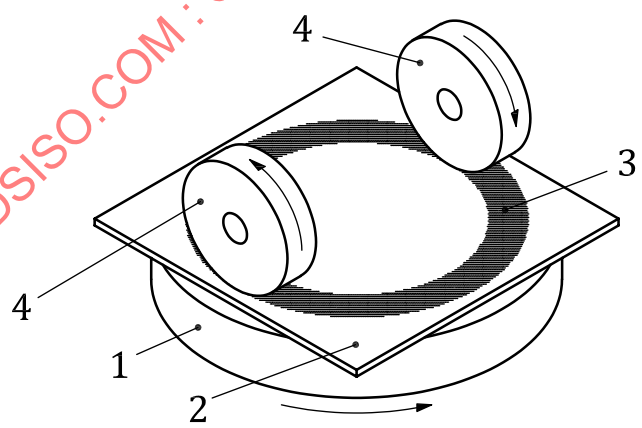
For testing textiles, a similar test method is described in ISO 105-X12.

### 5.2.3 Multiple scratch test with rotating abrasive wheels

— **Description**

Two agreed, pivot-mounted abrasive rubber wheels are pressed onto the coating of the rotating (60 $min^{-1}$) test panel using a test load of 500 g (corresponding to 4,9 N). The eccentric arrangement of the axes of the abrasive wheels relative to the axis of rotation causes a cross-wise abrasive wear. The relative decrease of gloss (%) is calculated from the gloss values (GU), measured with the 20° geometry prior to and after the stress application (10 rotations of the test panel).

Figure 35 shows the test principle.




**Key**

1 turntable
2 test panel
3 multiple scratch zone
4 abrasive wheel

**Figure 35 — Principle of the multiple scratch test rotating abrasive wheels**

— **Application**

The multiple scratch test with rotating abrasive wheels is preferably carried out on high-gloss coatings.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Condition test panel (23 °C / 50 % relative humidity / ≥ 24 h).

— Determine the gloss of the coating in four points of the intended test area in accordance with ISO 2813 with geometry 20° and calculate the mean value ($g_i$ in gloss units GU).

— Secure the test panel on the turntable of the test device, lower the refreshed abrasive wheels onto the coating with the specified test load and start turntable rotation.

— After 10 rotations, determine the gloss of the coating in four points of the test area in accordance with ISO 2813 with geometry 20° and calculate the mean value ($g_f$ in gloss units GU). During gloss measurement the exact positioning of the measuring device on the multiple scratch mark is observed.

— **Evaluation**

Test result is the relative decrease of gloss ("per cent gloss retention") $100 \times (g_f / g_i)$ (%), calculated from the averaged gloss values $g_i$ und $g_f$.

— **Precision**

No precision data are currently available.

— **Reference**

The multiple scratch test with rotating abrasive wheels is specified in ASTM D6037-18, Test Method A.

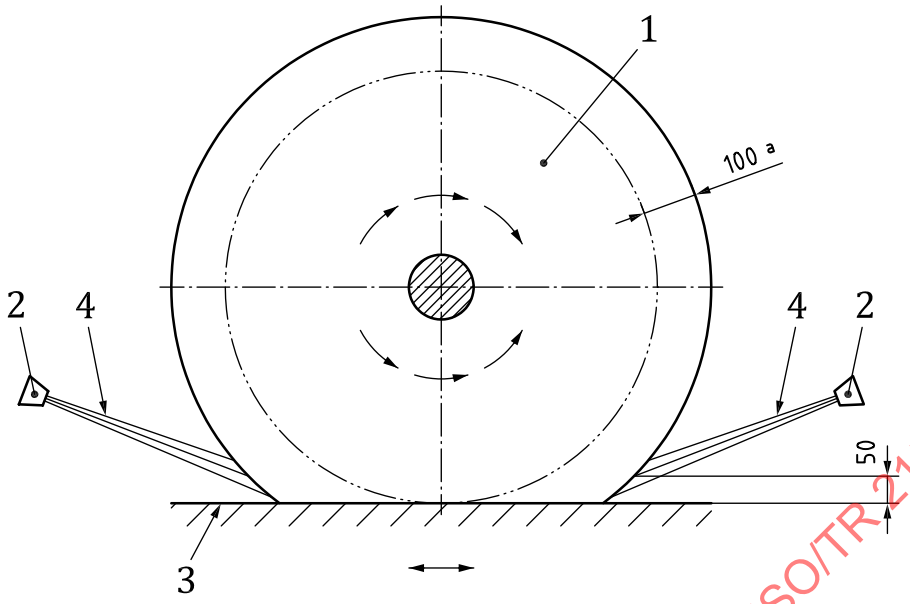
### 5.2.4 Multiple scratch test with rotating brush

— **Description**

The surface of the coating is marred by means of a rotating scrubbing brush with poly ethylene (PE) bristles (X profile) and the impact of a scrubbing suspension containing quartz powder. The following is specified: dimensions, number of rotations and type of brush, stroke and speed of the motion of the test panel, as well as composition and jet parameters (pressure, volumetric flow rate, jet width) of the scrubbing suspension. The change of appearance of the coating is determined by visual assessment by means of gloss, haze, or tristimulus values.

Figure 36 shows the test principle.

Dimensions in millimetres




**Key**

1 brush (Ø 1000 × 400) mm with
- bristle length 440 mm
- number of rotations 127 $min^{-1}$

2 spray nozzle (nozzle pressure 300 kPa, corresponding to 3 bar)

3 specimen holder with test panel (moved at 5 m/min in the direction of arrow)

4 jet of the scrubbing suspension (impacts on the brush 50 mm above 3) with
- spray angle 65°
- spray rate 2,2 l/min

a Depth of immersion.

**Figure 36 — Principle of the multiple scratch test with rotating brush**

— **Application**

The multiple scratch test with rotating brush is preferably carried out on automobile coatings.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree the method for the assessment of the appearance of the coating prior to and after the stress application:

— Visual assessment in accordance with ISO 13076;

— Determination of the gloss value in accordance with ISO 2813 (for this, also the geometry as agreed);

— Determination of the haze in accordance with ISO 13803;

  - Determination of the tristimulus values in accordance with ISO 11664 (for this, also the measuring conditions is agreed).
- Assess the appearance of the coating in three points in the agreed way and calculate the mean value from the results.
- Position the test panel in the test device and start the test procedure (scrubbing suspension jet, brush rotation, double-stroke motion).
- Clean the test panel after 10 double strokes. Again, assess the appearance of the coating in three points in the agreed way and calculate the mean value from the results.

— **Evaluation**

Test result is the absolute and relative (%) change of the averaged assessments.

— **Precision**

For the assessment by means of gloss measurement (geometry 20°) the following applies:

The repeatability limit *r* is 14 GU.

The reproducibility limit *R* is 20 GU.

— **Reference**

The multiple scratch test with rotating brush is specified in ISO 20566.

For testing transparent varnishes a slightly deviating method is described in Reference [59].

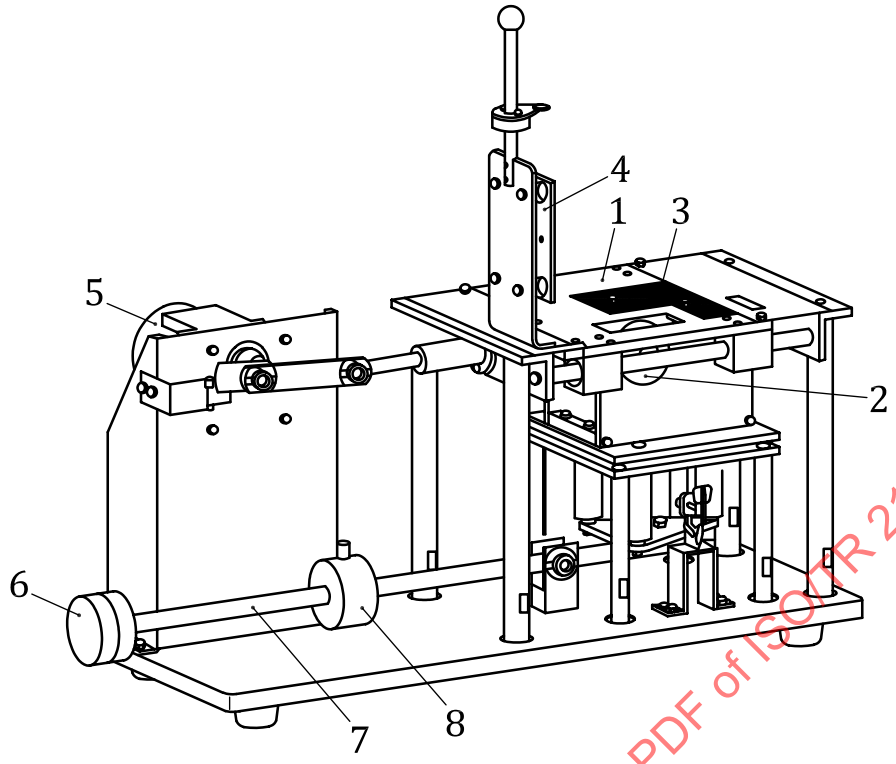
## 5.3 Dry abrasion tests

### 5.3.1 Abrasion test with locked abrasive wheel

— **Description**

A locked abrasive wheel (Ø 50 mm), covered with a 12 mm wide abrasive paper with agreed grain size is pressed onto the coating (test load 6,9 N). The test panel is reciprocated (stroke length 30 mm / 40 double strokes/min). A mechanism rotates the abrasive wheel by a small angle, so that always a new area of the abrasive paper is effective. The mass (mg) of the abraded material after 100 double strokes is determined.

Figure 37 shows the test principle.




**Key**

1 specimen stage
2 abrasive wheel
3 specimen guide
4 specimen press
5 specimen reciprocating motor
6 load
7 load scale
8 load adjust

**Figure 37 — Principle of the abrasion test with locked abrasive wheel**



— **Application**

The abrasion test with locked abrasive wheel is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree grain size of the abrasive paper.

— Condition test panel and abrasive paper (23 °C / 50 % relative humidity / ≥ 16 h).

— Weigh test panel and position in the test device.

— Adjust the specified test load and start double-stroke motion.

— After 100 double strokes, weigh the test panel again and determine the loss in mass (mg) caused by the abrasion.

— In sum, apply the stress on three test panels and determine the loss in mass (mg).

— **Evaluation**

Test result is the mean value of the losses in mass and the three single values (mg).

— **Precision**

No precision data are currently available.

— **Reference**

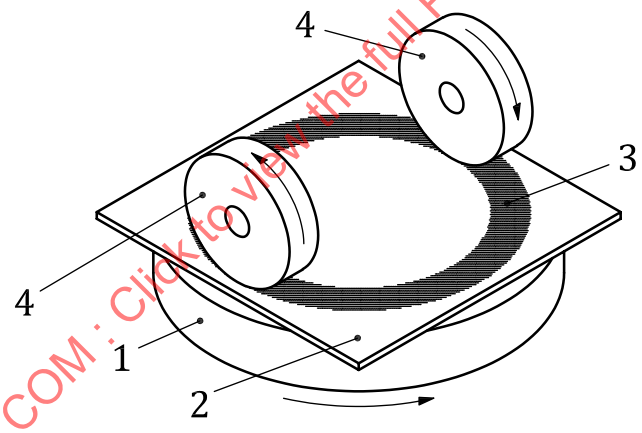
The abrasion test with locked abrasive wheel is specified in ISO 7784-3.

### 5.3.2 Abrasion test with rotating abrasive wheels 1

— **Description**

Two pivot-mounted abrasive wheels (rubber wheels covered with abrasive paper with grain size 180) are pressed onto the coating of the rotating (60 $min^{-1}$) test panel (test load 250 g, corresponding to 2,45 N for each wheel). The eccentric arrangement of the axes of the abrasive wheels relative to the axis of rotation causes a crosswise abrasive wear. The number of rotations is determined until the first damage is visible and until complete abrasion occurs.

Figure 38 shows the test principle.




**Key**

1 turntable
2 test panel
3 wear zone
4 abrasive wheel

**Figure 38 — Principle of the abrasion test with rotating abrasive wheels 1**

— **Application**

The abrasion test with rotating abrasive wheels 1 is preferably carried out on HP(D)L [High-pressure (decorative) laminate] coatings.

— **Calibration of abrasive paper**

An abrasion test with 500 rotations is carried out on a zinc reference panel with specified preparation method, thickness, and hardness. The loss in mass caused by the abrasion is compared to a specified nominal value.

— **Procedure**

  — Condition test panel and abrasive paper (23 °C / 50 % relative humidity / ≥ 72 h).

  — Secure test panel on the turntable of the test device.

  — Lower abrasive wheels with specified abrasive paper on the coating.

  — Turn on suction device and start turntable rotation.

  — Determine the number of rotations $n_i$ for the "initial abrasion point IP" (first clearly visible abrasion effect).

  — Determine the number of rotations $n_f$ for the "final abrasion point FP" (complete abrasion in three separate points).

— **Evaluation**

  Calculate the "resistance to surface abrasion" = $(n_i + n_f) / 2$ from the $n_i$ and $n_f$ values.

  Test result is the

  — $n_i$ value, as mean value of three determinations, and

  — "resistance to surface abrasion", as mean value of three determinations.

— **Precision**

  No precision data are currently available.

— **Reference**

  The Abrasion test with rotating abrasive wheels 1 is specified in EN 438-2:2016, Clause 11.

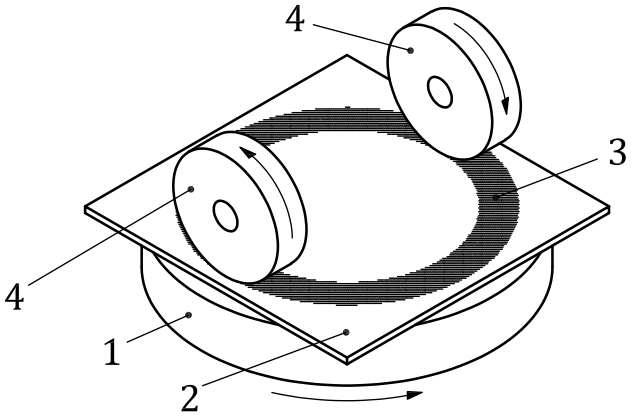
  A slightly deviating method is described in EN 438-2:2016, Clause 12.

### 5.3.3 Abrasion test with abrasive wheels 2

— **Description**

  Two pivot-mounted abrasive wheels (rubber wheels covered with abrasive paper with grain size 180) are pressed onto the coating of the rotating (60 $min^{-1}$) test panel (test load 5,4 N for each wheel). The eccentric arrangement of the axes of the abrasive wheels relative to the axis of rotation causes a cross-wise abrasive wear. The number of rotations is determined until the first clearly visible abrasion effect.

  Figure 39 shows the test principle.




**Key**

1 turntable
2 test panel
3 wear zone
4 abrasive wheel

**Figure 39 — Principle of the abrasion test with rotating abrasive wheels 2**

— **Application**

The abrasion test with rotating abrasive wheels 2 is preferably applied on coated furniture surfaces.

— **Calibration of abrasive paper**

An abrasion test with 500 rotations is carried out on a zinc reference panel with specified preparation method, thickness, and hardness. The loss in mass caused by the abrasion is compared to a specified nominal value.

— **Procedure**

— Condition test panel and abrasive paper (23 °C / 50 % relative humidity / ≥ 7 d).

— Diagonally divide the surface of the coating into four quadrants (see Figure 40) using a pen; subsequently, secure the test panel on the turntable of the test device.

— Lower the abrasive wheels with additional weights and the specified abrasive paper on the coating.

— Turn on suction device and start turntable rotation.

— Replace the sandpaper after every 200 revolutions. Continue the test this way until the "initial point of wear IP" is reached. Determine number of rotations for the "initial point of wear IP" (first clearly visible abrasion effect in all of the four quadrants).

— For transparent coatings use a colouring material (e.g. methylene blue) for the assessment of the wear condition.

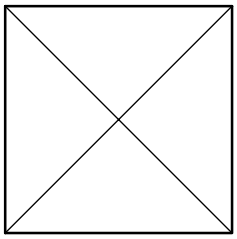


**Figure 40 — Surface of the test panel with quadrant division**

— **Evaluation**

Test result is the number of rotations for the “initial point of wear IP”, as mean value of three determinations.

— **Precision**

No precision data are currently available.

— **Reference**

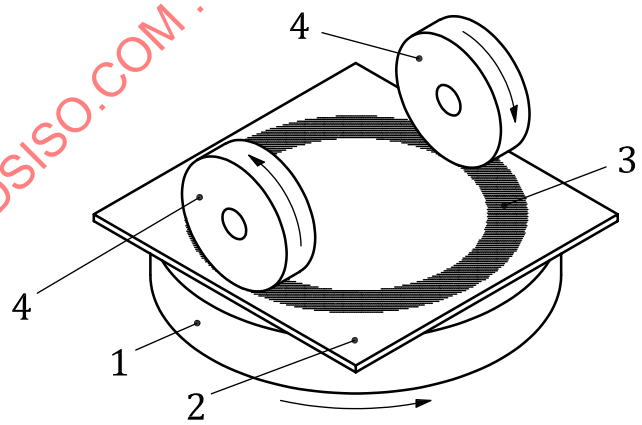
The abrasion test with rotating abrasive wheels 2 is specified in EN 15185.

### 5.3.4 Abrasion test with rotating abrasive wheels 3

— **Description**

Two pivot-mounted abrasive wheels (rubber wheels covered with abrasive paper with agreed grain size) are pressed onto the coating of the rotating (60 $min^{-1}$) test panel with agreed load. The eccentric arrangement of the axes of the abrasive wheels relative to the axis of rotation causes a cross-wise abrasive wear. The mass (mg) of the abraded matter after an agreed number of rotations is determined.

Figure 41 shows the test principle.




**Key**

1 turntable
2 test panel
3 wear zone
4 abrasive wheel

**Figure 41 — Principle of the abrasion test with rotating abrasive wheels 3**

— **Application**

The abrasion test with rotating abrasive wheels 3 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree grain size of the abrasive paper.

— Agree test load up to approx. 10 N.

— Agree the number of rotations.

— Condition test panel and abrasive paper (23 °C / 50 % relative humidity / ≥ 16 h).

— Weigh test panel and secure on the turntable of the test device.

— Lower the abrasive wheels on the coating and, if necessary, attach additional weights for the agreed test load.

— Turn on suction device and start turntable rotation.

— After the agreed number of rotations weigh the test panel again and determine the loss in mass (mg) caused by the abrasion.

— In sum, apply the stress on three test panels and determine the loss in mass (mg).

— **Evaluation**

Test result is the mean value of the losses in mass and the three single values (mg).

— **Precision**

No precision data are currently available.

— **Reference**

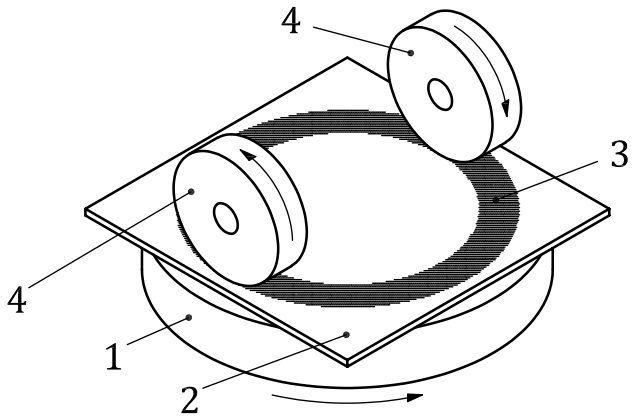
The abrasion test with rotating abrasive wheels 3 is specified in ISO 7784-1.

### 5.3.5 Abrasion test with rotating abrasive wheels 4

— **Description**

Two agreed pivot-mounted abrasive rubber wheels are pressed onto the coating of the rotating (60 $min^{-1}$) test panel with agreed load. The eccentric arrangement of the axes of the abrasive wheels relative to the axis of rotation causes a cross-wise abrasive wear. The mass (mg) of the abraded matter after an agreed number of rotations is determined.

Figure 42 shows the test principle.




**Key**

1 turntable
2 test panel
3 wear zone
4 abrasive wheel

**Figure 42 — Principle of the abrasion test with rotating abrasive wheels 4**

— **Application**

The abrasion test with rotating abrasive wheels 4 is generally applicable.

— **Calibration**

A calibration method is not specified.

— **Procedure**

  — Agree type of abrading wheel.
  — Agree test load up to approx. 10 N.
  — Agree the number of rotations.
  — Condition test panel (23 °C / 50 % relative humidity / ≥ 16 h).
  — Refresh abrasive wheels by running them against resurfacing disc.
  — Weigh test panel and secure on the turntable of the test device.
  — Lower the abrasive wheels on the coating and, if necessary, attach additional weights for the agreed test load.
  — Turn on suction device and start turntable rotation. Resurface the wheels after every 500 cycles.
  — After the agreed number of rotations weigh the test panel again and determine the loss in mass (mg) caused by the abrasion.
  — In sum, apply the stress on three test panels and determine the loss in mass (mg).

— **Evaluation**

Test result is the mean value of the losses in mass and the three single values (mg).

— **Precision**

No precision data are currently available.

— **Reference**

The abrasion test with rotating abrasive wheels 4 is specified in ISO 7784-2.

A slightly deviating method is described in ASTM D4060.

For testing coil coatings a slightly deviating method is described in EN 13523-16.

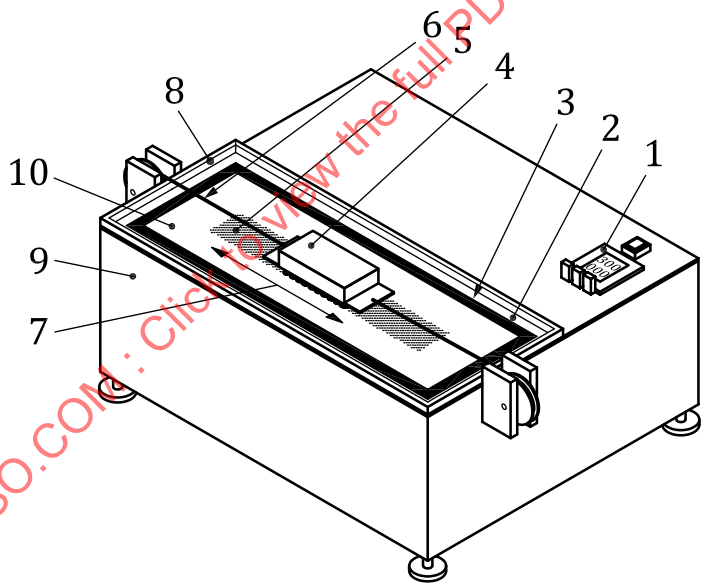
## 5.4 Wet abrasion tests

### 5.4.1 Scrub test with brush

— **Description**

A polyamide bristle brush, loaded with a weight, is reciprocated on the coating under the influence of a scrubbing liquid. The following is specified: Composition and amount of the scrubbing liquid, type and dimensions of the scrub brush, the test load of 454 g (4,45 N), as well as stroke length (400 mm) and stroke frequency (37 double strokes per minute) of the scrubbing motion. The number of double strokes for the abrasion of the coating is determined, absolute or relative (%) in comparison to a reference specimen.

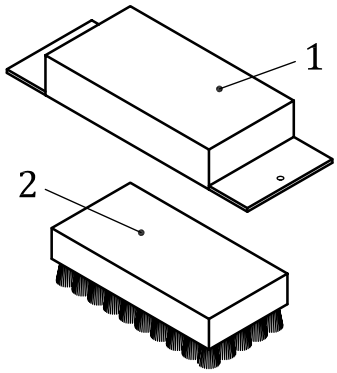
Figure 43 shows the set-up of the test device and Figure 44 shows the components of the abrading unit.




**Key**

1 counter
2 glass panel
3 substrate (matt black PVC film)
4 abrading unit
5 scrub mark
6 traction rope
7 direction of stroke motion
8 stainless steel tank
9 housing
10 coating

**Figure 43 — Set-up of the device for the scrub test with brush**




**Key**

1 brush box
2 polyamide bristle brush

**Figure 44 — Components of the abrading unit**

— **Application**

The scrub test with brush is preferably carried out on dispersion coatings.

— **Calibration**

A calibration method is not specified.

— **Procedure**

— Agree test method:

— Absolute determination (test method A);

— Relative determination (test method B).

— Prepare test panel: Apply the coating material to be tested to a matt black polyvinylchloride (PVC) film using a 180 µm split doctor blade and dry (23 °C / 50 % relative humidity / 7 d).

— If necessary (test method B), prepare the reference specimen in the same way.

— Position the test panel with a supporting sheet-metal strip underneath the middle section in the test device and uniformly wet the surface (5 ml water).

— Saturate the bristles of the scrubbing brush with 10 g of the specified scrubbing liquid.

— Put the scrubbing brush on the coating, load with the brush holder, and start the double-stroke motion.

— Repeat the wetting of the coating and the saturating of the scrubbing brush in cycles (after 400 double strokes each).

— Monitor the area of the supported sheet metal and determine the number of double strokes $n_T$, as soon as the coating is scrubbed down in this area.

— If necessary (test method B), determine the respective number of double strokes $n_R$ for the reference specimen.

— **Evaluation**

Test result is the

— number of double strokes $n_T$, as mean value of two determinations (test method A), and

— relation ($n_T$ / $n_R$) × 100 (%), as mean value of two determinations (test method B).

— **Precision**

Test method A:

— The repeatability limit (in accordance with ASTM D2486-17) is 30 %.

— The reproducibility limit (in accordance with ASTM D2486-17) is 58 %.

Test method B:

— The repeatability limit (in accordance with ASTM D2486-17) is 25 %.

— The reproducibility limit (in accordance with ASTM D2486-17) is 58 %

— **Reference**

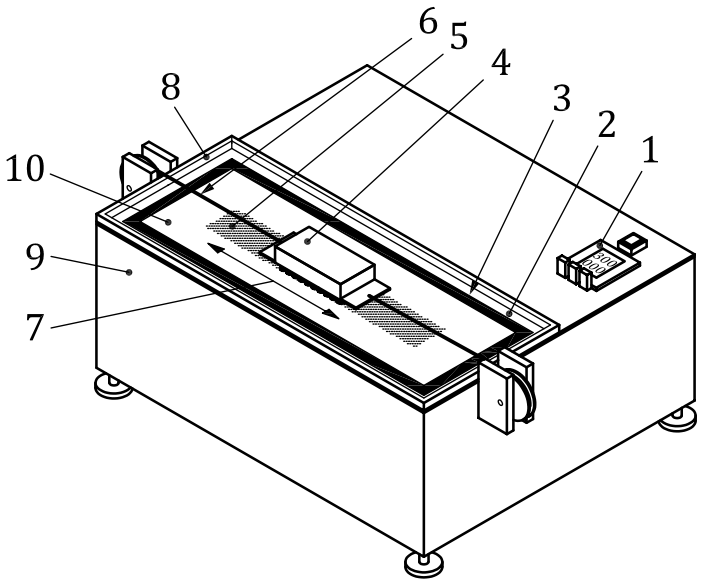
The scrub test with brush is specified in ASTM D2486.

### 5.4.2 Scrub test with non-woven web 1

— **Description**

A non-woven web, soaked with a scrubbing liquid and loaded with a load panel, is reciprocated on the coating. The following is specified: Composition and amount of the scrubbing liquid, type and dimensions of the non-woven web, type and dimensions of the load panel, as well as stroke length (300 mm) and stroke frequency (37 double strokes/min) of the scrubbing motion. After 200 double strokes the surface-specific loss in mass (g) and the mean loss of film thickness (µm), caused by the wet abrasion, is determined.

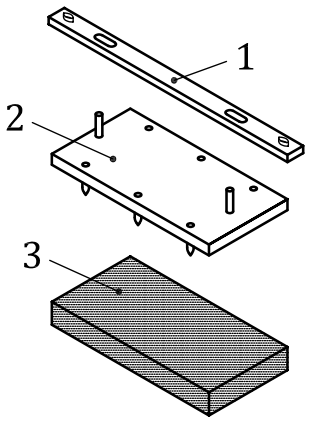
Figure 45 shows the set-up of the test device and Figure 46 shows the components of the abrading unit.




**Key**

1 counter
2 glass panel
3 substrate (matt black PVC film)
4 abrading unit
5 scrub mark
6 traction rope
7 direction of stroke motion
8 stainless steel tank
9 housing
10 coating

**Figure 45 — Set-up of the device for the scrub test with non-woven web 1**




**Key**

1 driving pins
2 load panel
3 non-woven web

**Figure 46 — Components of the abrading unit**