
Paints and varnishes — Adhesion of coatings

Peintures et vernis — Adhérence des revêtements

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Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on 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 the following URL: www.iso.org/iso/foreword.html.

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

Introduction

The determination of the adhesive strength is one of the most important preconditions for evaluating the protective function of coatings.

This document offers a helpful overview for the selection of the test method most suitable for each individual case in regard to the evaluation of the adhesive strength.

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Paints and varnishes — Adhesion of coatings

1 Scope

This document summarises the common methods for evaluating the adhesive strength of coatings on a substrate, which can be another coating beneath or the substrate itself. The test methods and evaluation methods are described in [Clauses 4, 5, and 6](#). In the case of standardized test methods the respective standard is referenced in regard to procedure and evaluation. [Annex A](#) compares the methods in the synoptic [Tables A.1, A.2, and A.3](#).

Often the adhesive strength cannot be sufficiently evaluated by means of a single method.

The purely physical methods for measuring the adhesive strength are such in which mechanical quantities (e.g. force or torsion moment) are measured directly.

All other methods are based on the evaluation of behaviour under mechanic stress according to practical conditions. For these methods the viscoelastic properties have a wide influence on the evaluation of the adhesive strength, so that it can only be tested comparatively within one method.

Each method has its specific application. An unsuitable method can lead to false information. All of the test methods for the evaluation of the adhesive strength require a certain routine of the test person, especially in regard to identifying the separation line. For most of the test methods the test results, among other things, depend on the film thickness of the coating to be tested. In addition, for several methods differences between tests on a test sheet and in practice can occur, due to different roughness of the substrate.

Effects of delamination caused by weathering or corrosion influences are not subject of this document.

In case cohesion failures predominantly occur during an adhesive strength test, this is no measure for the adhesive strength. However, information can be given on the protective effect of the coating against corrosion.

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

adhesion

phenomenon of attachment at the interface between a solid surface and another material caused by molecular forces

Note 1 to entry: Adhesion should not be confused with cohesion.

[SOURCE: ISO 4618:2014, 2.7]

3.2

cohesion

forces that bind a film or coat into an integral entity

Note 1 to entry: Cohesion should not be confused with adhesion.

[SOURCE: ISO 4618:2014, 2.55]

3.3

adhesion failure

detachment of a coating from the substrate caused by external forces

Note 1 to entry: The substrate can be another coating beneath or the working material.

3.4

cohesion failure

loss of coherence within a coating caused by external forces

3.5

adhesive strength

force required to detach a coating from a substrate or another coating

[SOURCE: ISO 4618:2014, 2.8]

3.6

wet adhesive strength

adhesive strength (3.5) immediately after previous exposure to moisture

3.7

separation line

interface in which *adhesion failure* (3.3) occurs

3.8

failure pattern

entirety of the visual coating defects, which are caused by an *adhesive strength* (3.5) test

3.9

failure pattern assessment

classification of a *failure pattern* (3.8) by means of criteria or reference patterns

3.10

failure pattern analysis

quantitative evaluation of a *failure pattern* (3.8) with specification of the relative percentages of area for *adhesion failure* (3.3) and *cohesion failure* (3.4) as well as the separation line(s)

3.11

main separation line

separation line with the largest area

3.12

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]

3.13 repeatability limit

r

the value less than or equal to which the absolute difference between two test results obtained under *repeatability conditions* (3.12) may be expected to be with a probability of 95 %

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

3.14 reproducibility conditions

conditions where independent 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]

3.15 reproducibility limit

R

the value less than or equal to which the absolute difference between two test results obtained under *reproducibility conditions* (3.14) may be expected to be with a probability of 95 %

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

4 Adhesive strength tests without scratch/cut

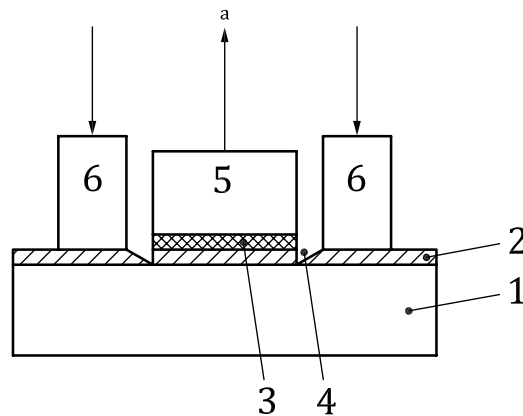
4.1 Tests with mechanical stress application on the coating

4.1.1 Pull-off test

— Principle

A uniformly increasing tensile force is applied to a test cylinder (metal cylinder of diameter 20 mm), which is adhered to the coating, until the test cylinder is pulled off. The pull-off strength is determined by calculating the tensile force to pull off the test cylinder and the area of the test cylinder.

The principle of the pull-off test is illustrated schematically in [Figure 1](#).



Key

- 1 substrate
- 2 coating
- 3 adhesive film
- 4 free punch
- 5 test cylinder
- 6 outer ring to support the test panel
- a The pull-off direction.

Figure 1 — Principle of the pull-off test

— Application

The pull-off test is generally applicable.

— Procedure

- Attach the test cylinder to the coating by means of a previously tested adhesive.
- Cut the coating around the circumference of the test cylinder using a suitable tool through to the substrate (see [Figure 1](#)).
- Attach the test specimen to the test apparatus so that it is supported and the test cylinder is connected to the pulling unit, centred and without being wedged.
- Carry out the pull-off process with a uniformly increasing tensile force and measure when the test cylinder is pulled off.

— Evaluation

The test result is the pull-off strength (MPa) = the tensile force when pulling off the test cylinder divided by the area of the test cylinder.

Specify the result of the failure pattern analysis (see the procedure specified in [6.2.1](#)).

— Precision

Precision data are not available at present.

— Reference

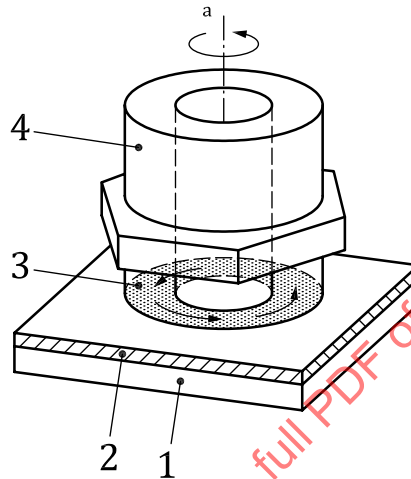
The pull-off test is specified in ISO 4624 and ISO 16276-1.

4.1.2 Twist-off test

— Principle

By means of a motor-driven test apparatus a uniformly increasing torsion moment is introduced to a test cylinder (a metal cylinder of a 12 mm or 15 mm diameter and a 6 mm drill), which is adhered to the coating, until it is twisted off. The adhesive strength (“shear strength”) can be read directly from the test apparatus as shear stress ($\text{N/mm}^2 = \text{MPa}$).

[Figure 2](#) illustrates the principle of the twist-off test in a schematic diagram. [Figure 3](#) shows the minimum distance between the test cylinders for repeated tests.



Key

- 1 substrate
- 2 coating
- 3 adhesive
- 4 test cylinder
- a The axis of rotation.

Figure 2 — Principle of the twist-off test

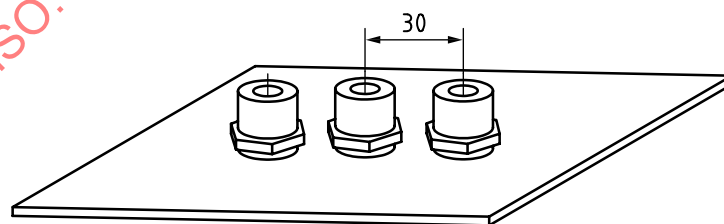


Figure 3 — Minimum distance between the test cylinders

— Application

The twist-off test is generally applicable.

— Procedure

- Use a sufficiently thick substrate (minimum 0,7 mm) or a substrate with reinforcement adhered to the backside in order to avoid deformation during testing.
- Adhere the test cylinder to the coating using a previously tested adhesive. For repeated tests observe a minimum distance between the test cylinders (see [Figure 3](#)).

- Attach the test apparatus at the hexagon bolt of the test cylinder (see [Figure 2](#)) and secure the test panel against twisting.
- Start torsional stress and read the shear stress from the apparatus when the test cylinder is twisted off.
- Evaluation

The test result is the shear stress ($\text{N/mm}^2 = \text{MPa}$), which is read from the apparatus and interpreted as the twist-off strength.

Specify the result of the failure pattern analysis (see the procedure specified in [6.2.1](#)).
- Precision

Precision data are not available at present.
- Reference

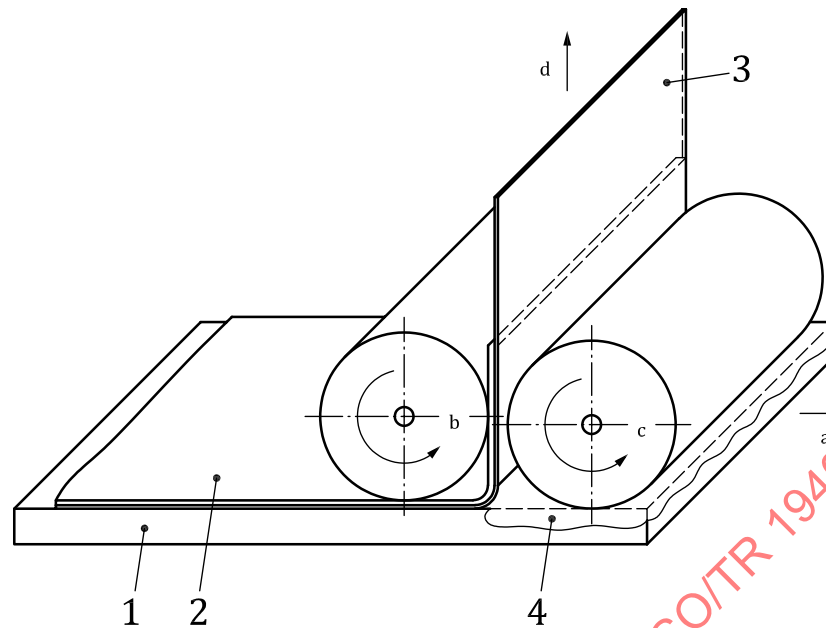
The twist-off test is specified in Reference [\[50\]](#).

4.1.3 Peel-off test 1

- Principle

A fabric specified by material, thread size, and mesh size is bedded into a newly applied coating material. After curing of the coating a tensile tester grabs the overlapping fabric, and due to continuous tensile force at 90° the coating is peeled off from the substrate. The peel strength is determined as the force required for peeling off and referring to the width of the test specimen.

[Figure 4](#) schematically shows the peel-off process and the function of a 90° -peel-off apparatus.

**Key**

- 1 substrate
- 2 coating
- 3 fabric
- 4 tape (uncoated end of the test panel)
- a The direction of movement of the test panel.
- b The direction of rotation of the pressing roller on the coating.
- c The direction of rotation of the pressing roller on the uncoated test panel.
- d The direction of peel-off (tensile tester).

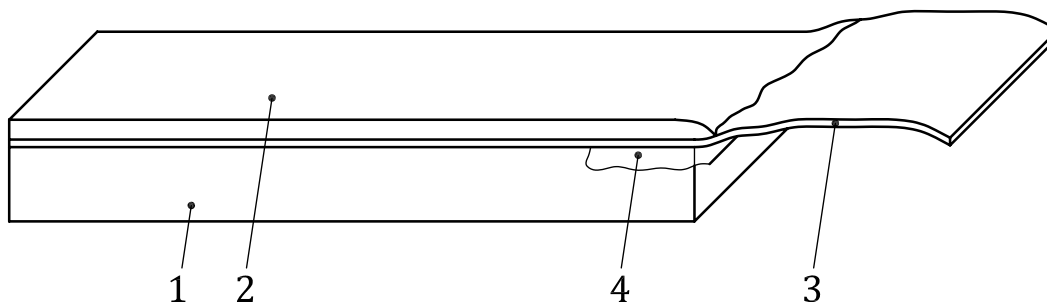
Figure 4 — Principle of the peel-off test 1

— Application

The peel-off test 1 is preferably carried out on automotive coatings.

— Procedure

- Coat the test panel (dimensions 15 mm × 100 mm) sparing a 10 mm wide strip at the edge of the narrow side. Subsequently bed the fabric so that it remains for about 50 mm uncoated and overlaps at the uncoated end of the test panel (see [Figure 5](#)).



Key

- 1 substrate
- 2 coating
- 3 fabric
- 4 tape (uncoated end of the test panel)

Figure 5 — Test panel with coating and fabric

- After drying/hardening of the coating mount the test panel into a tensile tester equipped with a 90°-peel-off apparatus (see [Figure 4](#)) and clamp the free end of the fabric.
- Start the peel-off process and record the tensile force (peel strength) required for peeling off.
- Evaluation

Determine the mean peel strength over a peel-off distance of at least 50 mm for five test specimens, disregard the beginning and the end of the test.

The test result is the mean value (with standard deviation) from the five individual determinations, which is designated as the peel strength (N/15 mm width of test specimen).

Specify the result of the failure pattern analysis (see the procedure specified in [6.2.1](#)).
- Precision

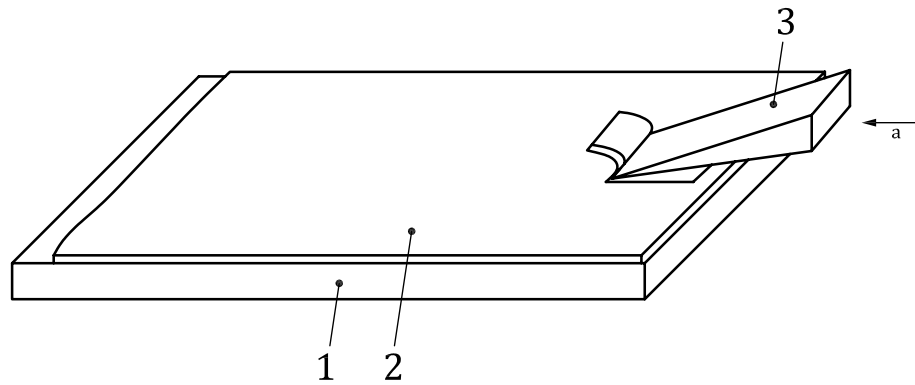
Precision data are not available at present.
- Reference

The peel-off test 1 is specified in Reference [\[47\]](#).

4.1.4 Peel-off test 2

- Principle

The coating is peeled off from the substrate under specified conditions by means of an electrically driven test apparatus. The force is determined which is required for peeling off and which refers to the width of peeling off. [Figure 6](#) illustrates the peel-off process in a schematic diagram.

**Key**

- 1 substrate
- 2 coating
- 3 peel-off tool
- a The peel strength.

Figure 6 — Principle of the peel-off test 2

— Application

The peel-off test 2 is generally applicable.

— Procedure

- Specify the peel-off tool (cutting angle/width), setting angle, peel-off speed and peel-off distance.
- Mount the test panel into the peel-off apparatus and start the peel-off process.
- During testing record the force (peel strength) required for peeling off.

— Evaluation

Determine the mean peel strength over the peel-off distance, disregard the beginning and the end of the peel-off process.

The test result is the mean peel strength divided by the width of the peel-off tool (N/mm).

— Precision

Precision data are not available at present.

— Reference

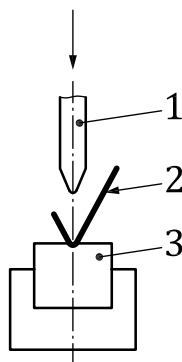
The peel-off test 2 is specified in Reference [35].

4.2 Tests with continuous deformation of test specimens**4.2.1 Bend test with a wedge-shaped conical mandrel**

— Principle

The test panel is deformed from the direction of the substrate side by pressing in a wedge-shaped conical mandrel of specified geometry. The smallest radius of the mandrel is determined for which no defect of delamination in the deformed area is detectable.

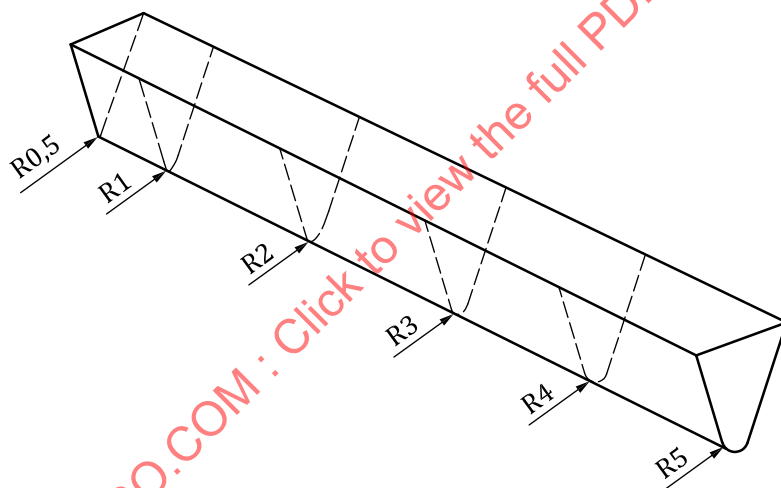
Figure 7 shows the test principle in a schematic diagram. Figure 8 illustrates the dimensions of the wedge-shaped conical mandrel.



Key

- 1 wedge-shaped conical mandrel
- 2 test panel (after deformation)
- 3 elastic pad

Figure 7 — Principle of the bend test with a wedge-shaped conical mandrel



Key

- R radius – the number specifies the bending radius in mm

Figure 8 — Measures of the wedge-shaped conical mandrel

— Application

The bend test with a wedge-shaped conical mandrel is preferably carried out on coil coatings.

— Procedure

- Put the test panel with the coated side onto an elastomer panel.
- From the direction of the substrate side press the mandrel by hand (with lever transmission) or by means of a pneumatic apparatus into the panel until the deformation results in a V-shape.

Doing so, the longitudinal axis of the mandrel shall be parallel to the direction of rolling of the substrate.

— Evaluation

Examine the coating in the deformed area for delamination using a magnifier and determine the smallest bending radius for which no defect can be detected.

The test result is this bend radius (mm) divided by the thickness of the substrate (mm).

— Precision

Precision data are not available at present.

— Reference

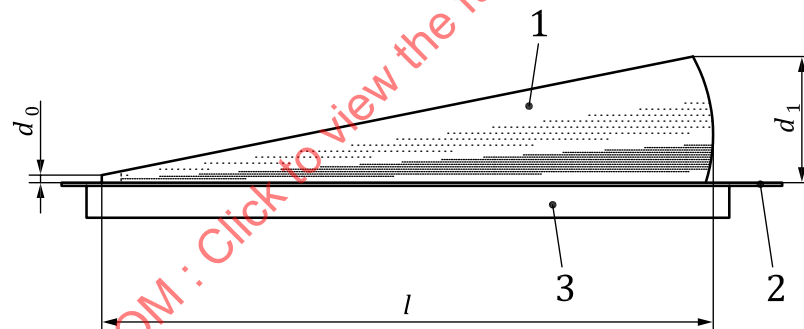
The bend test with a wedge-shaped conical mandrel is specified in EN 13523-7.

4.2.2 Bend test with a conical mandrel

— Principle

The test panel is bent around a conical mandrel of specified dimensions and is deformed accordingly. The length (mm) of the produced defect is determined.

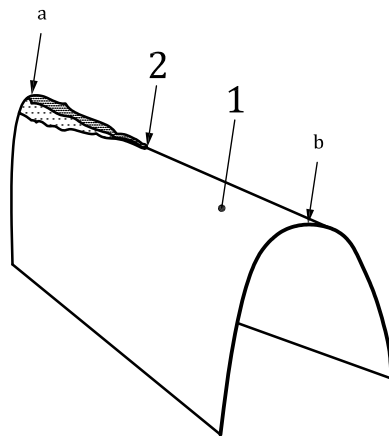
[Figure 9](#) shows the principle of the bend test with a conical mandrel. [Figure 10](#) shows the bent test panel.



Key

- 1 conical mandrel
- 2 test panel
- 3 clamping element
- l length of the mandrel (203 mm)
- d_0 smallest diameter of the mandrel (3,1 mm)
- d_1 largest diameter of the mandrel (38 mm)

Figure 9 — Test arrangement of the bend test with a conical mandrel



Key

- 1 test panel
- 2 end of the crack in the coating
- a The small radius of the bent test panel.
- b The large radius of the bent test panel.

Figure 10 — Bent test panel with delamination

— Application

The bend test with a conical mandrel is generally applicable for coatings on deformable substrates.

— Procedure

- Mount the test panel into the test apparatus, coating facing outwards, and bend uniformly around the mandrel.

— Evaluation

Visually examine the delaminated area of the coating (10× magnifier).

The test result is the length (mm) of the delamination (the mean value rounded to whole numbers of the three single values).

— Precision

The repeatability limit r is 23 mm.

The reproducibility limit R is 46 mm.

— Reference

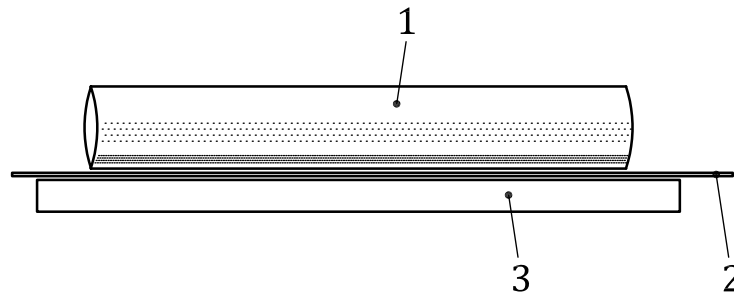
The bend test with a conical mandrel is specified in ISO 6860.

4.2.3 Bend test with a cylindrical mandrel 1

— Principle

The test panel is bent around a cylindrical mandrel and is deformed accordingly. The exchangeable mandrels in the bending apparatus have diameters of 2 mm, 3 mm, 4 mm, 5 mm, 6 mm, 8 mm, 10 mm, 12 mm, 16 mm, 20 mm, 25 mm, and 32 mm. The largest diameter of the mandrel (mm) is determined for which a defect of the coating is visible after bending around that mandrel. The method can also be carried out as a “pass/fail” test.

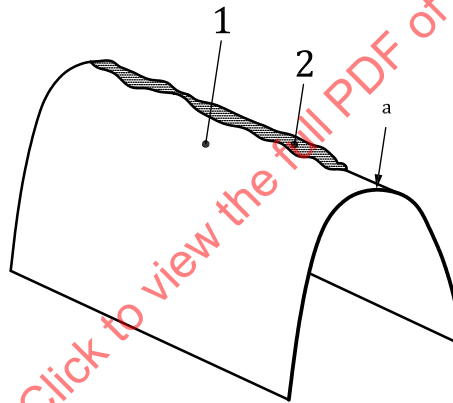
Figure 11 shows the principle of bending around a cylindrical mandrel. Figure 12 shows the bent test panel.



Key

- 1 cylindrical mandrel
- 2 test panel
- 3 clamping element

Figure 11 — Test arrangement of the bend test with a cylindrical mandrel 1



Key

- 1 test panel
- 2 crack in the coating
- a The radius of the bent test panel.

Figure 12 — Bent test panel with delamination

— Application

The bend test with a cylindrical mandrel 1 is generally applicable for coatings on deformable substrates.

— Procedure

- Insert a mandrel of medium diameter into the bending apparatus.
- Mount the test panel into the test apparatus, coating facing outwards, and bend uniformly around the mandrel.
- Visually examine the coating on the deformed test panel for defects and specify the diameter of the mandrel for the next bend test:
 - a) when the coating has been damaged select the next larger mandrel;
 - b) when the coating has not been damaged select the next smaller mandrel.

- Continue bend tests until the final result has been determined.
- When carrying out the test as a “pass/fail” test bend the test specimen around the mandrel of the agreed diameter and visually examine the coating for defects.

— Evaluation

The test result is the largest diameter of the mandrel (mm) for which a defect of the coating is visible after bending around that mandrel or the information that for all mandrels no defect can be detected after bending.

When carried out as a “pass/fail” test specify if the coating has been damaged (“fail”) or not (“pass”) for the agreed diameter of the mandrel.

— Precision

The method should only be considered as an approximation test and not as one giving precise results. The reproducibility limit R , determined in a round-robin test with six participants and two coating systems, has been set at 50 %, and is only specified here in order to convey a rough impression of the precision.

— Reference

The bend test with a cylindrical mandrel 1 is specified in ISO 1519.

4.2.4 Bend test with a cylindrical mandrel 2

— Principle

The test panel is bent around a cylindrical mandrel and deformed accordingly. The exchangeable mandrels in the bending apparatus have diameters in the range of 0,5 mm to 5,0 mm, in steps of 0,5 mm. The smallest diameter of the mandrel (mm) is determined for which no defect of the coating is visible after bending around that mandrel.

[Figure 13](#) shows a typical mandrel bending apparatus for exchangeable cylindrical mandrels.

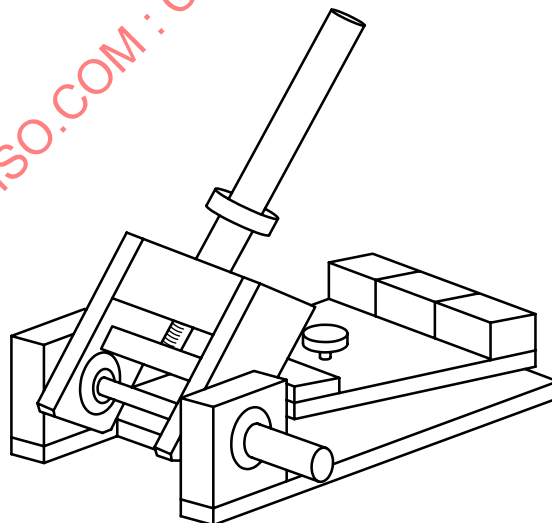


Figure 13 — Mandrel bending apparatus for exchangeable cylindrical mandrels

— Application

The bend test with a cylindrical mandrel 2 is preferably carried out on coil coatings.

— Procedure

- Insert a mandrel of medium diameter into the bending apparatus.
- Mount the test panel into the test apparatus so that the uncoated side faces the mandrel.
- Bend the test panel uniformly around the mandrel.
- Examine the coating on the deformed test panel for defects and specify the diameter of the mandrel for the next bend test:
 - a) when the coating has been damaged select the next larger mandrel;
 - b) when the coating has not been damaged select the next smaller mandrel.
- Continue bend tests until the final result has been determined.

— Evaluation

Visually examine the delaminated area of the coating using a magnifier and determine the smallest bending radius for which delamination is not yet detectable.

The test result is the bending radius (mm) divided by the thickness of the substrate (mm).

— Precision

Precision data are not available at present.

— Reference

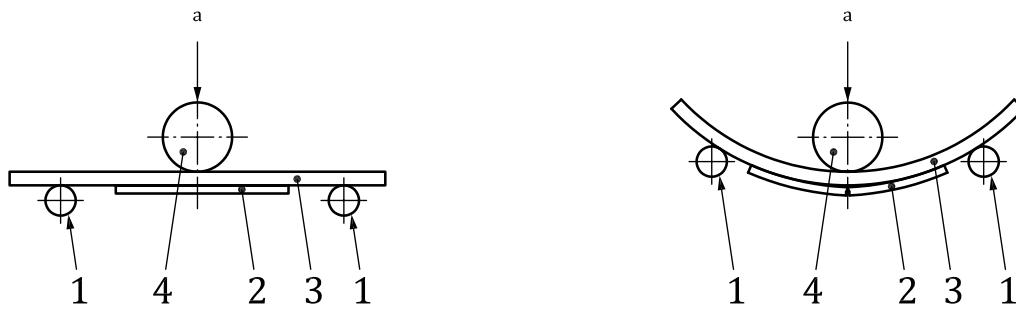
The bend test with a cylindrical mandrel 2 is specified in EN 13523-7.

4.2.5 Three point bending method

— Principle

The coating is applied as specified to a substrate of specified dimensions. The test specimen is continuously bent by means of a bending apparatus at a speed of 0,5 mm/s. From the recorded force-distance graph information in regard to the adhesion of the coating is taken.

[Figure 14](#) illustrates the test principle.



a) Test specimen prior to stress application

b) Test specimen after stress application

Key

- 1 struts (diameter 6 mm, length >15 mm, centre distance 33 mm)
- 2 coating (25 mm × 5 mm)
- 3 substrate (30 mm × 10 mm)
- 4 compression bar (diameter 12 mm, length >15 mm)
- a The direction of stress application.

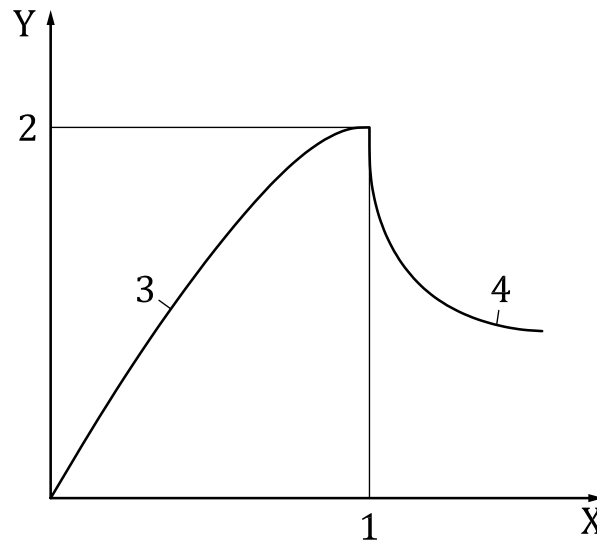
Figure 14 — Principle of the three point bending test

— Application

The three point bending method is applicable for coatings on flexible substrates.

— Procedure

- Coat the substrate panels by means of a template.
- Dry/harden the coating and determine the dry film thickness.
- Mount the specimen in accordance with [Figure 14](#) into the test apparatus and start the bending process.
- During the bending process record the force-distance graph (see [Figure 15](#)).

**Key**

- X bending distance
- Y bending force
- 1 maximum bending distance
- 2 maximum bending force
- 3 linear range
- 4 failure extent

Figure 15 — Force-distance graph

— Evaluation

Read from the force-distance graph (see [Figure 15](#)):

- the gradient of the curve (N/mm) in the linear range,
- the maximum bending force (N) and the maximum bending distance (mm), and
- a qualitative description of the failure extent.

— Precision

Precision data are not available at present.

— Reference

The three point bending method is specified in NF T 30-010.

A similar method is specified in EN 1966.

4.2.6 T-bend test 1

— Principle

The test panel is successively bent around itself. Doing so the coating shall be facing outwards. The smallest radius is determined around which the test panel can be bent without any loss of adhesion.

[Figure 16](#) shows a common bending apparatus and explains the bending process. [Figure 17](#) illustrates the individual stages of the bending process.

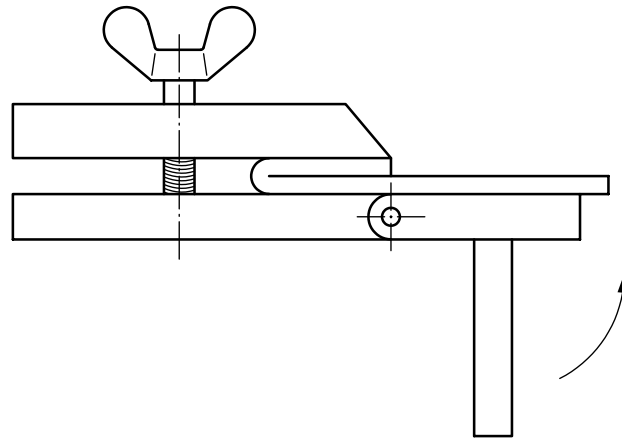


Figure 16 — Common bending apparatus

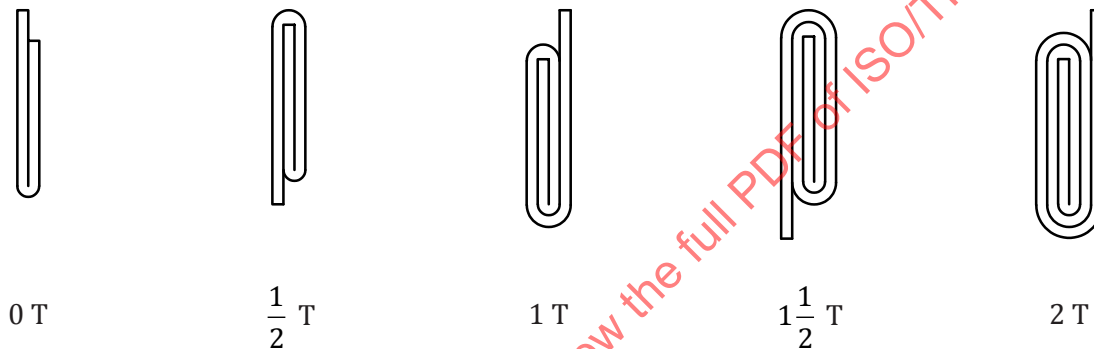


Figure 17 — Stages of the bending process from 0 T to 2 T

— Application

The T-bend test 1 is preferably carried out on coil coatings.

— Procedure

- Mount the test panel into the bending test apparatus with the coated side facing down and swivel the bending plate as far as it goes.
- Take out the bent test panel and then complete the 180° bending by means of the bending apparatus, resulting in the bent condition illustrated in [Figure 16](#).
- Continue bending the bent test panel in the same way.
- After each bending examine the bent area for delamination using a magnifier.
- The test is completed when no delamination is detectable for the first time.

— Evaluation

The smallest radius is determined around which the test panel can be bent without delamination, expressed in “T units” (see [Figure 17](#)).

— Precision

Precision data are not available at present.

— Reference

The T-bend test 1 is specified in EN 13523-7.

4.2.7 T-bend test 2

— Principle

The test panel is bent around a distance piece with the coating facing outwards. The distance piece can be a solid bending piece or consist of a pile of substrate panels. Alternatively, the test panel can also be bent around itself. The smallest bending distance is determined for which no loss of adhesion is detectable. The method can also be carried out as a “pass/fail” test.

[Figure 18](#) shows the process of the T-bend test around a solid bending piece using a bench vice. [Figure 19](#) illustrates representative examples for both of the other types of the process.

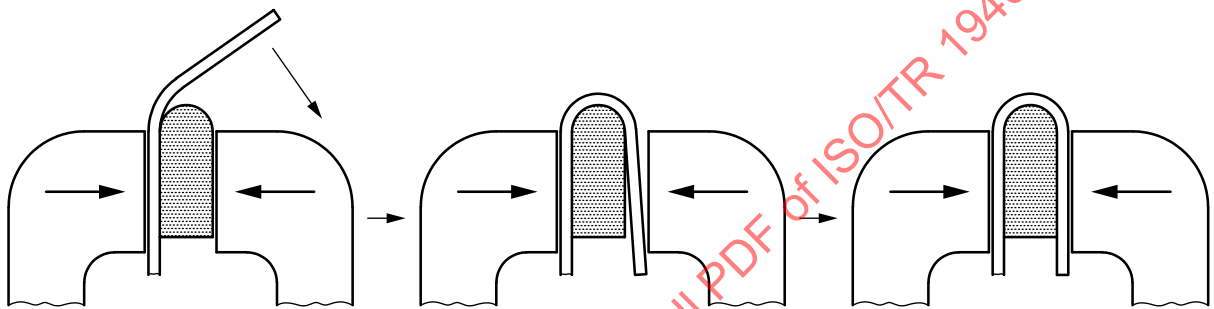


Figure 18 — Bending around a bending piece



a) Bending with panels as distance pieces (example 2T) **b) Bending method with a bench vice (example 2T)**

Figure 19 — Further types of the process

— Application

The T-bend test 2 is generally applicable for coatings on deformable metal substrates.

— Procedure

— Specify the type of the process:

- a) bending around solid bending pieces,
- b) bending around bending pieces consisting of substrate panels,
- c) bending procedure.

— Carry out the bend test in accordance with [Figure 18](#) or [Figure 19](#) and examine the bent area for delamination using a magnifier.

- Carry out further bend tests with increasing bending distance until no loss of adhesion is detected.
- When carrying out the test as a “pass/fail” test carry out the T-bend test with the agreed bending distance and examine for delamination.
- Evaluation

The test result is the smallest bending distance for which no loss of adhesion is detectable, expressed by the equivalent number of substrate panels in T units.

When carried out as a “pass/fail” test specify if the coating has been damaged (“fail”) or not (“pass”) after bending with the agreed bending distance.
- Precision

The repeatability limit r is 0,7 T.

The reproducibility limit R is 1,2 T.
- Reference

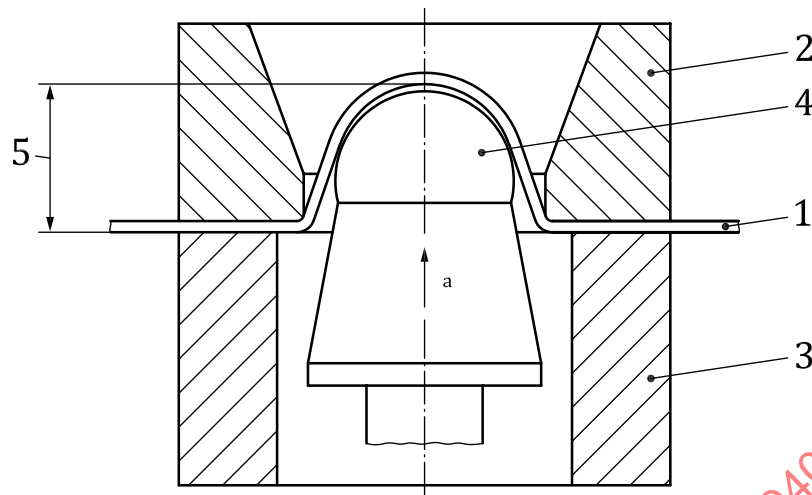
The T-bend test 2 is specified in ISO 17132.

4.2.8 Cupping test 1

- Principle

The test panel is clamped between a die (inner diameter 27 mm) and a retaining ring. From the direction of the uncoated side a ball indenter (diameter 20 mm) deforms the test panel at a constant speed. The distance of the indenter (cupping) is determined until defects are visually detectable. The method can also be carried out as a “pass/fail” test.

[Figure 20](#) illustrates the test arrangement of a cupping apparatus in a schematic diagram.

**Key**

- 1 test panel
- 2 die
- 3 retaining ring
- 4 ball indenter
- 5 cupping
- a The direction of movement of the indenter.

Figure 20 — Principle of the cupping test 1

— Application

The cupping test 1 is generally applicable for coatings on deformable substrates.

— Procedure

- Mount the test panel into the cupping apparatus with the coated side facing outwards.
- Press the indenter at a constant speed (0,1 mm/s to 0,3 mm/s) from the backside into the test panel. Observe the coating in the indented area using optical tools.
- When the first defects of the coating are visible stop the indenter movement and read the distance (cupping) from the apparatus.
- When carrying out the test as a “pass/fail” test indent the test specimen until the agreed distance (cupping) is reached and examine for defects of the coating.

— Evaluation

The test result is the mean value (mm) of a double determination, which is then referred to as the cupping value.

When carried out as a “pass/fail” test specify if the coating has been damaged (“fail”) or not (“pass”) until the agreed cupping value had been reached.

— Precision

The repeatability limit r is 2 mm.

The reproducibility limit R is 4 mm.

— Reference

The cupping test 1 is specified in ISO 1520.

4.3 Test with impact stress application

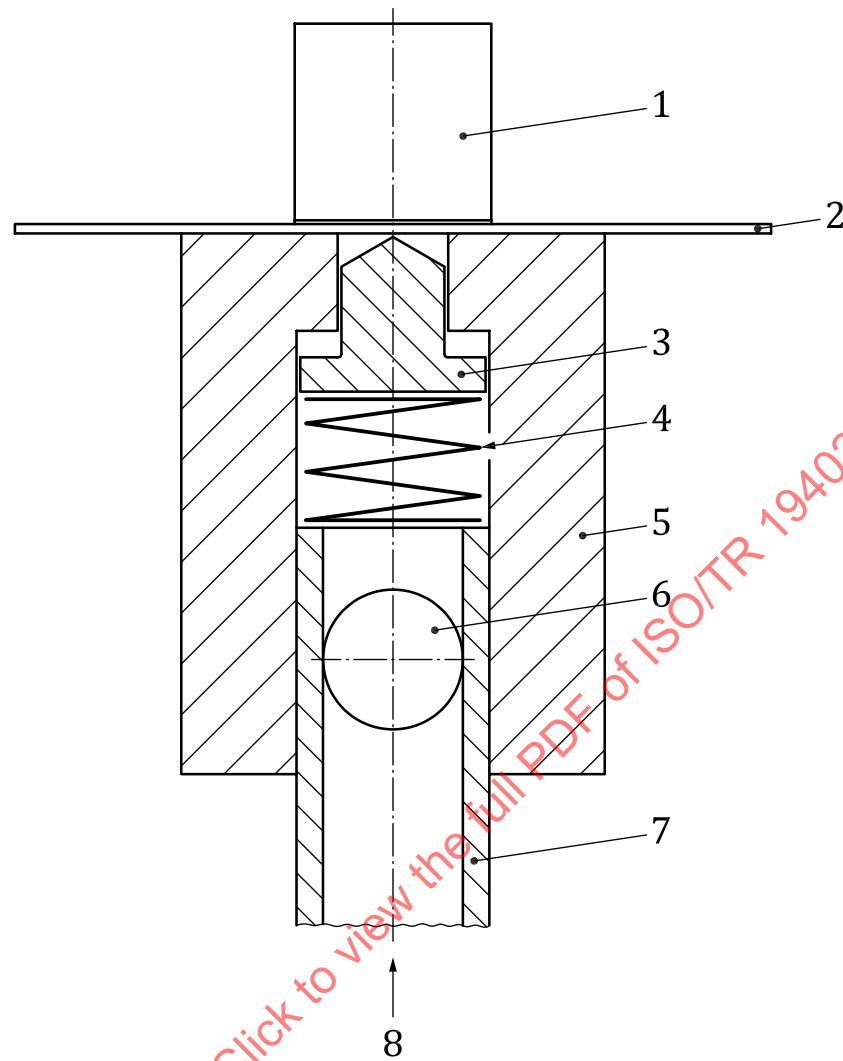
4.3.1 Single-impact test 1

— Principle

A single guided impact body (a wedge-shaped steel plunger), which receives its impact impulse from a steel ball, which is also guided and accelerated by pressurised air, impacts the coating. The impact energy is specified by a calibration method. The width (mm) of the damaged area is determined.

[Figure 21](#) illustrates the test principle. [Figure 22](#) shows details and the measures of the impact body.

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**Key**

- 1 counter weight
- 2 test panel
- 3 impact body
- 4 spring
- 5 casing
- 6 steel ball
- 7 tube
- 8 pressurised air

Figure 21 — Principle of the single-impact test 1

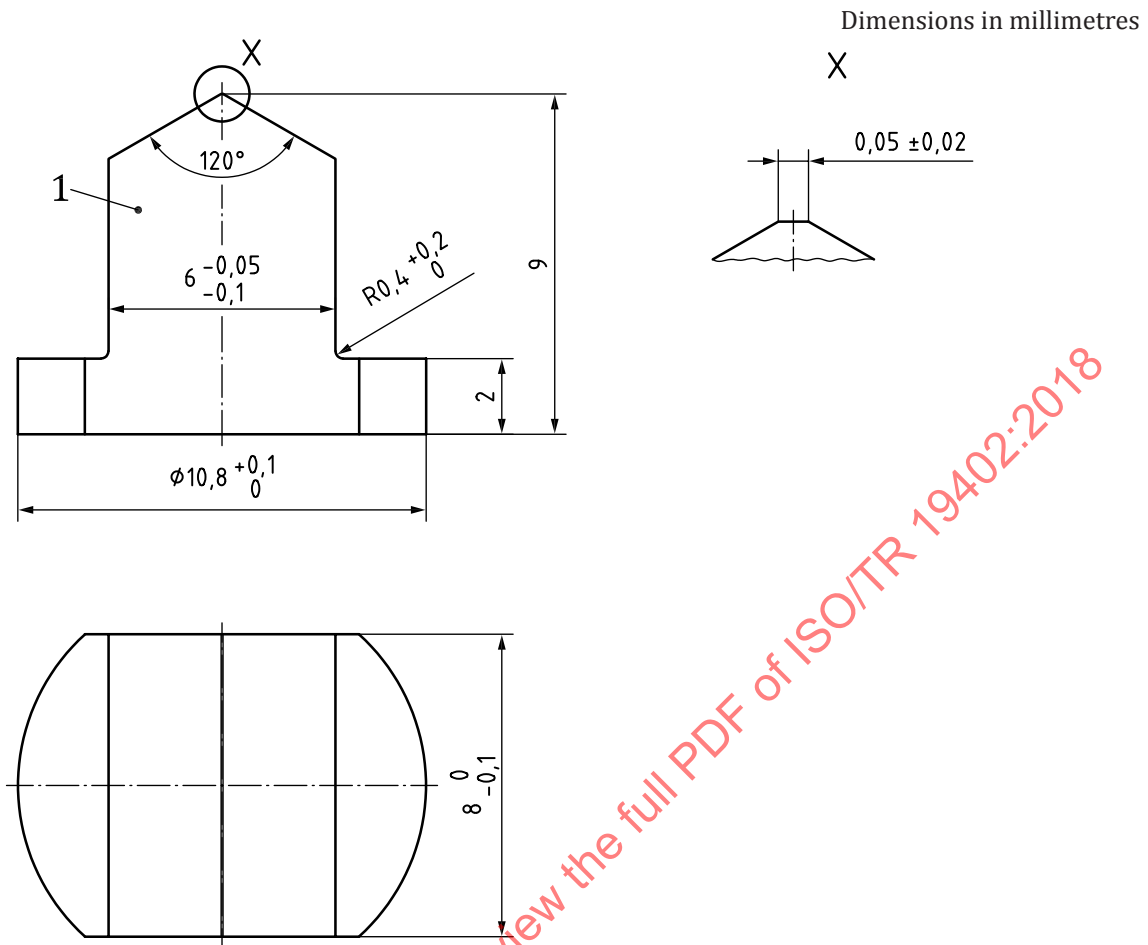


Figure 22 — Impact body

— Application

The single-impact test 1 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Put the test panel on the test apparatus with the coating facing down and load with the counter weight (see [Figure 21](#)).
- Introduce the single impact.
- Remove parts of the coating, which have not been detached completely, e.g. by using a tape.

— Evaluation

The defect can be visually captured or by means of the digital image evaluation (see the procedure specified in [6.3.1](#)).

The test result is the mean value of the total width (mm) of the damaged coating of the three single determinations.

Specify the separation line(s).

— Precision

The repeatability limit r is 1,0 mm.

The reproducibility limit R is 1,5 mm.

— Reference

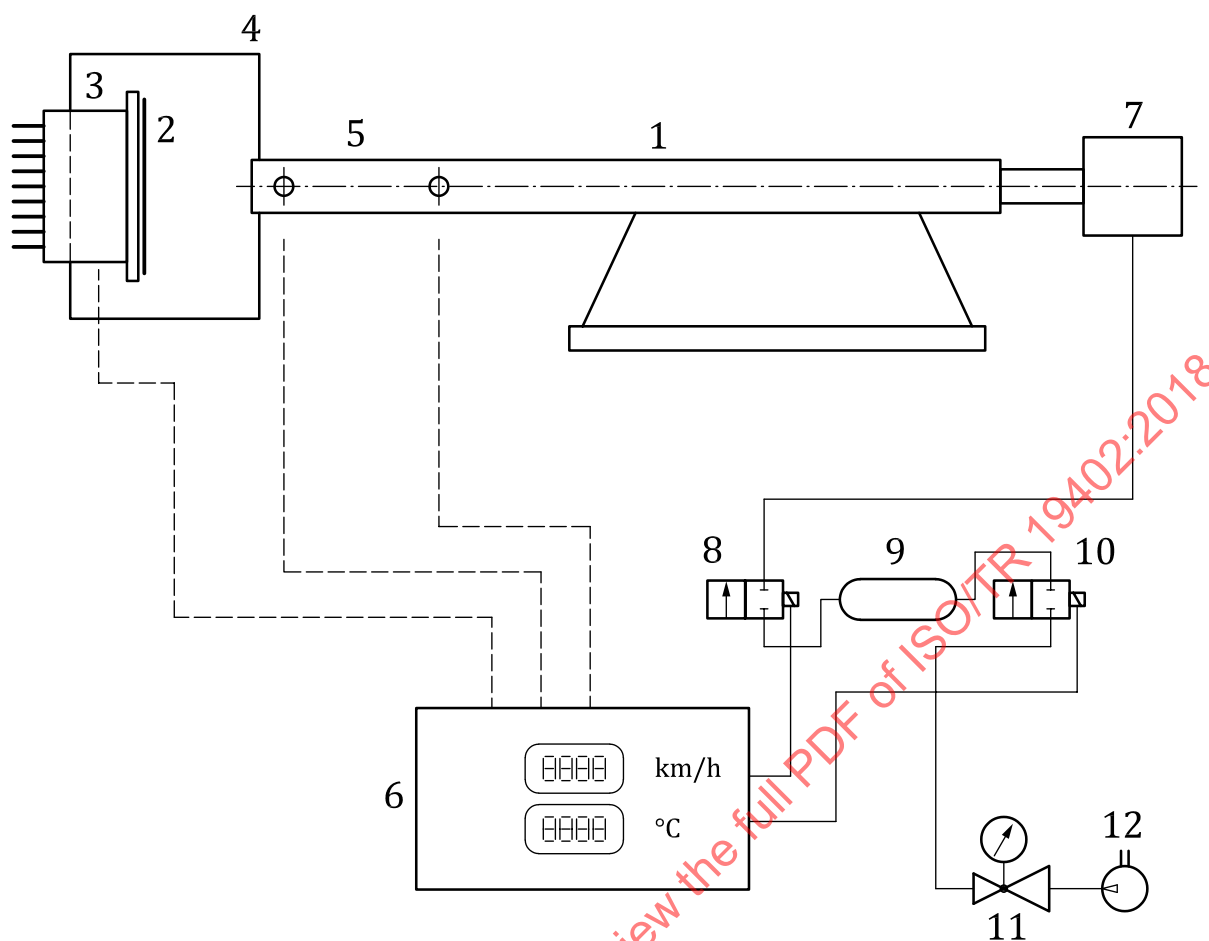
The single-impact test 1 is specified in ISO 20567-2.

4.3.2 Single-impact test 2

— Principle

A single free flying impact body (ball bearing ball of diameter 2 mm) impacts the temperature-controlled test panel at a speed of 250 km/h at an angle of 88°. The area of defect (mm²) is determined which is measured by means of a measuring template for areas.

The functional schematic diagram of the single-impact apparatus is illustrated in [Figure 23](#).



Key

- 1 acceleration tube for the impact body
- 2 test panel
- 3 sample table, temperature-controlled and movable
- 4 protective casing
- 5 light barrier for speed measurement
- 6 control device with display for speed and temperature
- 7 closing (feed of the impact body)
- 8 starting valve
- 9 pressurised air storage
- 10 charging valve
- 11 pressure control
- 12 pressurised air supply

Figure 23 — Functional schematic diagram of the single-impact test apparatus 2

— Application

The single-impact test 2 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Mount the test panel into the test apparatus.

- Set an agreed test temperature (-20 °C, 0 °C, or 23 °C) and wait until the test specimen reaches this temperature.
- Introduce the single impact (speed 250 km/h).
- Remove parts of the coating, which have not been detached completely, e.g. by using a tape.
- Evaluation

Measure the area of defect using the measuring template for areas in accordance with 6.2.2.

The test result is the mean value of the damaged areas (mm²) of the three single determinations.

Specify the separation line(s).
- Precision

The repeatability limit r is 5 %.

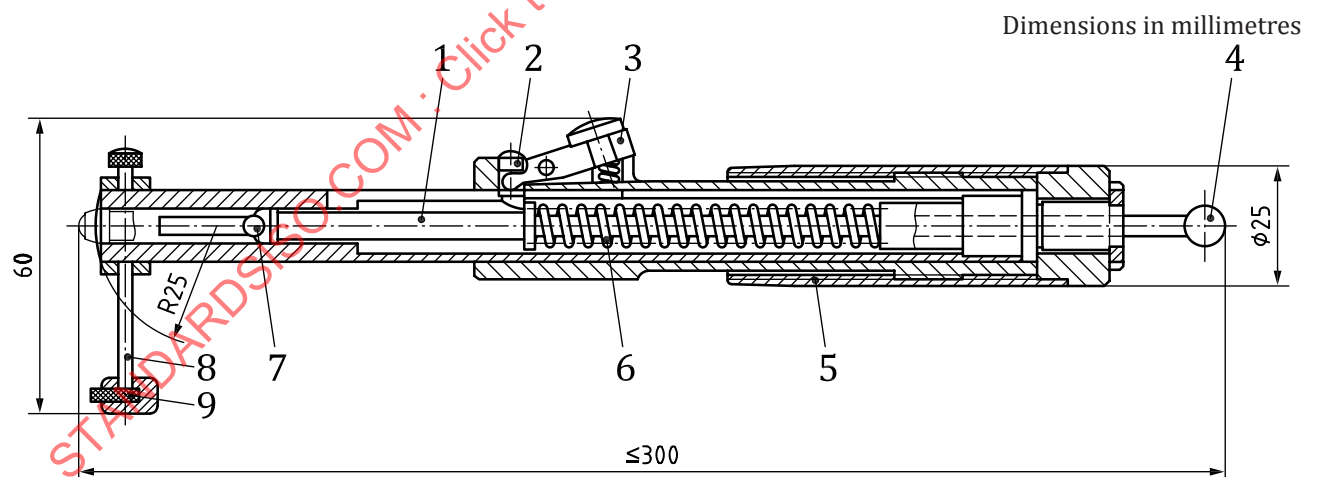
The reproducibility limit R is 10 %.
- Reference

The single-impact test 2 is specified in ISO 20567-3.

4.3.3 Single-impact test 3

- Principle

A single guided impact body with a hemispherical end (diameter 5 mm) impacts the coating of the test specimen which has been cooled down to -40 °C. The impact energy is defined by the specified prestress of a pressure spring. The defect pattern is classified in two stages (a “pass/fail” test). [Figure 24](#) shows the arrangement of the single-impact test apparatus.



Key

- | | | | |
|---|------------------------|---|---------------------|
| 1 | impact pin | 6 | pressure spring |
| 2 | holder | 7 | steel ball |
| 3 | trigger | 8 | stand |
| 4 | handle | 9 | soft-rubber padding |
| 5 | force-adjusting sleeve | | |

Figure 24 — Arrangement of a single-impact test apparatus 3

— Application

The single-impact test 3 is preferably carried out on automotive coatings on plastic substrates.

— Procedure

- Condition the test specimen for 24 h at $(-40 \pm 3) ^\circ\text{C}$.
- Set an impact force of 90 N on the test apparatus.
- Put the test specimen on a rigid base, put the test apparatus on top, and trigger the single impact.
- Visually examine the coating in the impact area for cracks and chippings.

— Evaluation

The test result is a “pass/fail” decision depending on whether film delamination occurs (“fail”) or not (“pass”).

— Precision

Precision data are not available at present.

— Reference

The single-impact test 3 is specified in Reference [49].

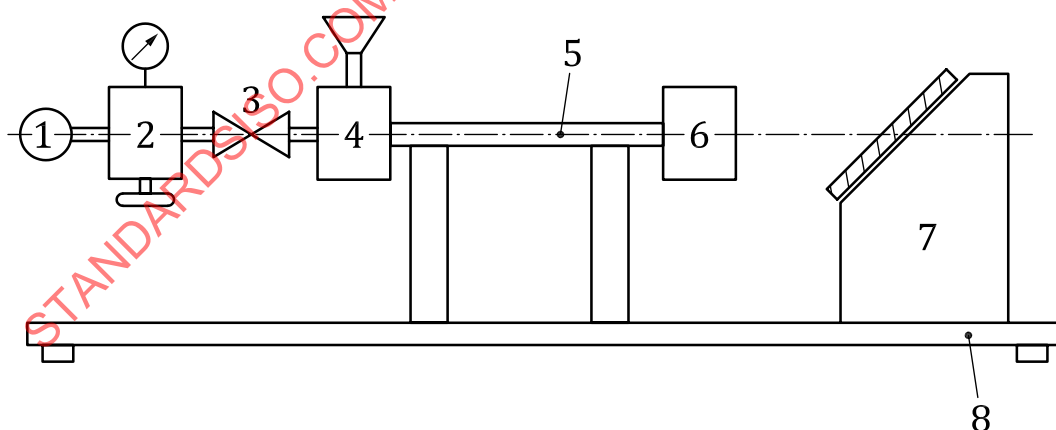
The test apparatus is specified in ISO 4532.

4.3.4 Single-impact test 4

— Principle

A single free flying impact body (ball bearing ball of diameter 2,5 mm, coated with SiC granulate with specified particle size fraction) impacts the coating at an adjustable speed in the range of 100 km/h to 250 km/h at a variable angle at room temperature.

Figure 25 shows the arrangement of the test apparatus in a schematic diagram.



Key

- | | | | |
|---|-------------------------------|---|------------------------------|
| 1 | pressurised air outlet | 5 | acceleration tube |
| 2 | pressure control (adjustable) | 6 | double light barrier |
| 3 | valve | 7 | sample table with test panel |
| 4 | projectile magazine | 8 | base panel |

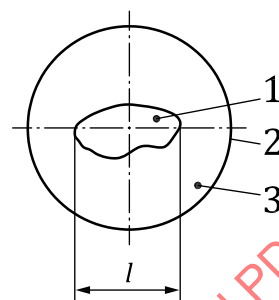
Figure 25 — Arrangement of a single-impact test apparatus 4

— Application

The single-impact test 4 is preferably carried out on automotive coatings on plastic substrates.

— Procedure

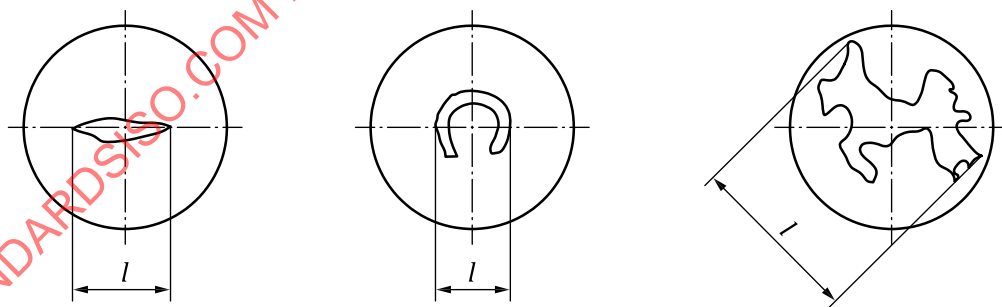
- Secure the test panel at the apparatus.
- Set the agreed test parameters (ball speed and impact angle).
- Shoot 10 balls with specified minimum distance onto the coating.
- Remove the loosely adhering coating material by pulling off using a tape.
- Measure the length (mm) in accordance with [Figures 26, 27, and 28](#) using a magnifier with graduated scale.



Key

- 1 delamination defect
- 2 impact
- 3 coating surface (dented)
- l* maximum extent of the delamination defect

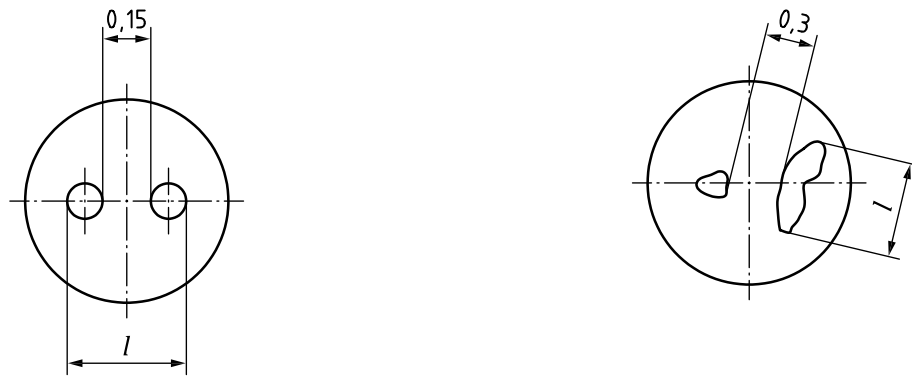
Figure 26 — Evaluation of the impact pattern



Key

- l* maximum extent of the delamination defect

Figure 27 — Examples for single defects



a) Distance between the single defects $\leq 0,2$ mm

b) Distance between the single defects $> 0,2$ mm

Key

l a) maximum extent of the combined single defects; b) maximum extent of the largest single defect

Figure 28 — Examples for multiple defects

— Evaluation

The test result is the mean value of the measured lengths (mm) for the 10-fold determination.

— Precision

Precision data are not available at present.

— Reference

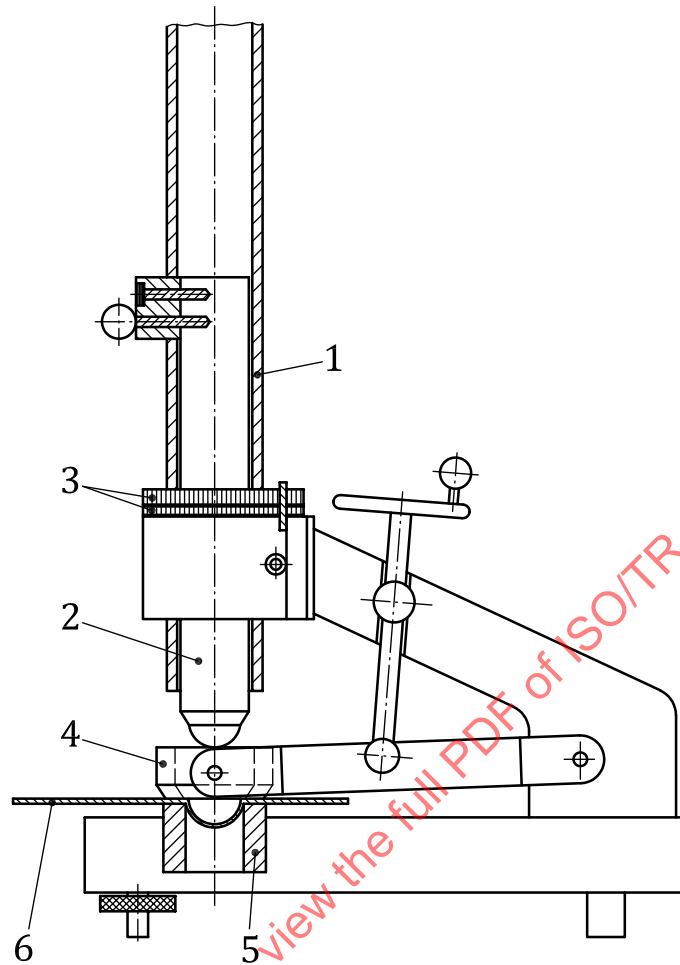
The single-impact test 4 is specified in Reference [39].

4.3.5 Falling-weight test 1

— Principle

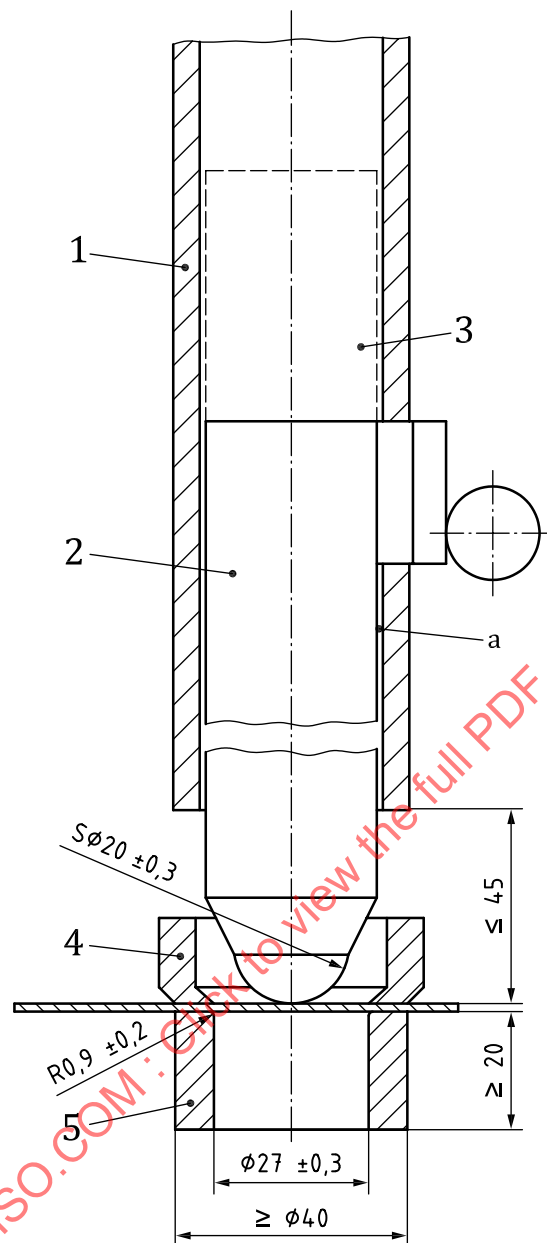
An impact body (mass 1 kg or 2 kg) with a hemispherical end (diameter 20 mm) falls from an adjustable height (up to 1 000 mm) onto the test panel, which is clamped onto a die (inner diameter 27 mm). The impact depth can be definably limited. The impact can be introduced to the coated (dent) or the uncoated (bulge) side of the test panel. The lowest impact energy is determined, expressed as the impact body mass and falling height, for which a defect of the coating is visually detectable (classification test). The test can also be carried out as a “pass/fail” test.

Figure 29 shows the general arrangement of a falling-weight test apparatus. Figure 30 specifies details on carrying out the test and the dimensions.

**Key**

- 1 guide tube
- 2 impact body
- 3 stops for impact depth
- 4 clamping sleeve
- 5 die
- 6 test panel

Figure 29 — Falling weight test apparatus 1

**Key**

- 1 guide tube
- 2 impact body (1 kg)
- 3 optional additional weight (1 kg)
- 4 clamping sleeve
- 5 die
- a The difference between the inner diameter of the guide tube and the outer diameter of the impact body is $(0,7 \pm 0,2)$ mm.

Figure 30 — Measures of the guide tube and impact body**— Application**

The falling-weight test 1 is generally applicable.

— Procedure

- Secure the test panel as agreed (dent/bulge) on the test apparatus.
- Adjust the stops to the agreed value.
- Select an impact body (1 kg or 2 kg) and specify a falling height for the beginning.
- Carry out the falling-weight test.
- Visually examine the coating in the deformed area for defects (10× magnifier).
- Vary the impact energy (the mass of the impact body/the falling height in steps of 25 mm) until the final result has been determined. Use higher masses of impact bodies if necessary.
- When carrying out the test as a “pass/fail” test it is tested under specified conditions of the falling weight (agreed mass of the impact body and falling height) and then examined for defects of the coating.
- For both types of carrying out (classification test and “pass/fail” test) confirm the result by repetition.

— Evaluation

When carried out as a classification test the lowest impact energy is specified, expressed as the mass of the impact body (kg) and the falling height (mm), for which a defect of the coating is visually detectable.

When carried out as a “pass/fail” test specify if the coating has been damaged (“fail”) or not (“pass”) under the agreed conditions of the falling weight.

— Precision

Precision data are not available at present.

— Reference

The falling-weight test 1 is specified in ISO 6272-1 and ASTM D2794.

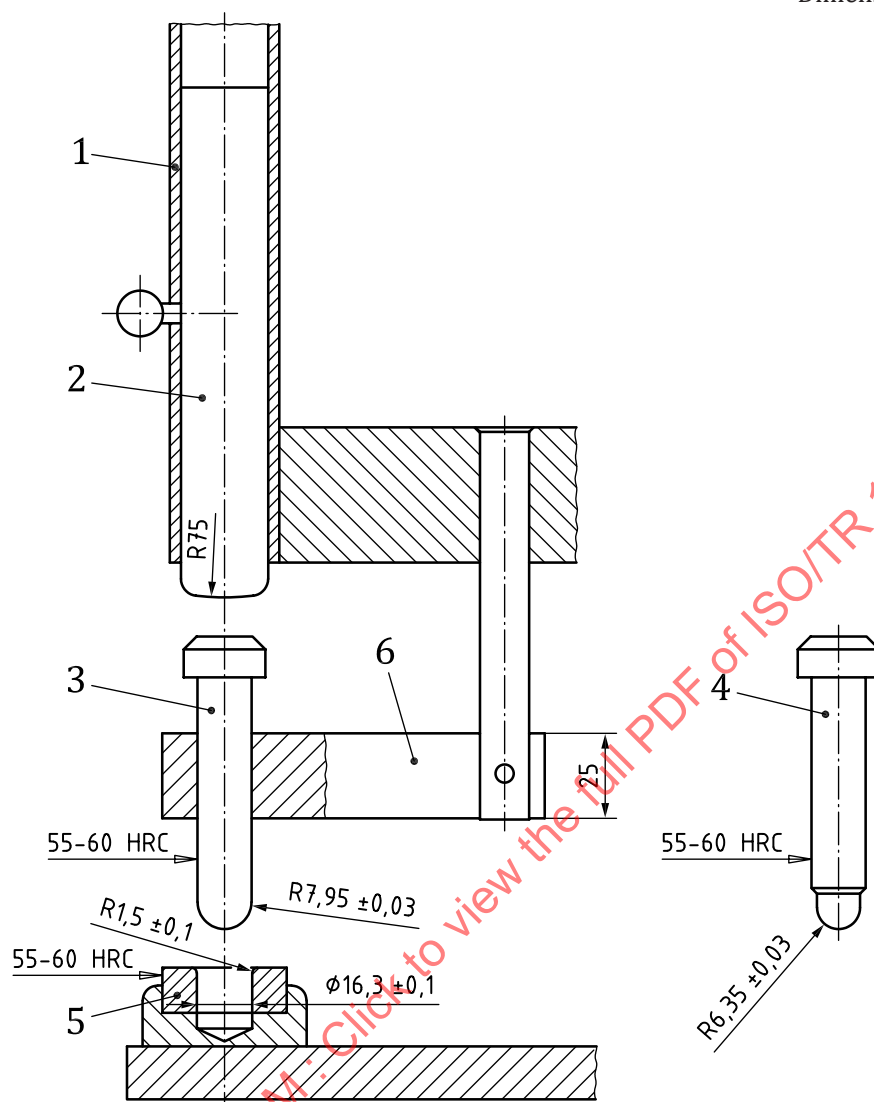
4.3.6 Falling-weight test 2

— Principle

A weight (mass 1 kg or 2 kg) falls from an adjustable height (up to 1 000 mm) onto an impact body (male die) with a hemispherical end (diameter 12,7 mm or 15,9 mm), which then deforms the test panel. The impact can be introduced to the coated (dent) or the uncoated (bulge) side of the test panel, which lies on a die (inner diameter 16,3 mm). The lowest impact energy (kg · m) is determined for which a defect of the coating is visually detectable.

[Figure 31](#) shows the arrangement of the test apparatus and the dimensions.

Dimensions in millimetres



Key

- 1 guide tube
- 2 weight
- 3 impact body diameter 15,9 mm
- 4 impact body diameter 12,7 mm
- 5 die
- 6 guide ring

Figure 31 — Falling weight test apparatus 2

— Application

The falling-weight test 2 is generally applicable.

— Procedure

- Mount the test panel as agreed (dent/bulge) into the test apparatus.
- Select an impact body (1 kg or 2 kg) and specify a falling height for the beginning.
- Carry out the falling-weight test.

- Visually examine the coating in the deformed area for defects (10× magnifier/chemical contrasting, see the procedure specified in [6.1.1](#)).
- Vary the impact energy (the mass of the impact body/the falling height in steps of 25 mm) until the final result has been determined. Confirm the result by repetition.
- Evaluation

The test result is the lowest impact energy (product from the mass of the weight and the falling height, in kg · m) for which a defect of the coating is visually detectable.
- Precision

Precision data are not available at present.
- Reference

The falling-weight test 2 is specified in ISO 6272-2 and ASTM D2794.

4.3.7 Falling-weight test 3

- Principle

An impact body (mass 1 kg or 2 kg) with a hemispherical end (diameter 20 mm) falls from an adjustable height (up to 1 000 mm) onto the test panel, which is clamped onto a die (inner diameter 27 mm). The impact can be introduced to the coated (dent) or the uncoated (bulge) side of the test panel. The maximum impact energy (J) is determined for which no defect of the coating is detectable

The falling-weight test 3 is similar to the falling-weight test 1 (see the procedure specified in [4.3.5](#)) and the same test apparatus is used.
- Application

The falling-weight test 3 is preferably carried out on coil coatings.
- Procedure
 - Secure the test panel as agreed (dent/bulge) on the test apparatus.
 - Select an impact body (1 kg or 2 kg) and specify a falling height for the beginning.
 - Carry out the falling-weight test and subsequently carry out a 60° pull-off in the deformed area using a specified tape.
 - Visually examine the coating in the deformed area for defects (10× magnifier).
 - Vary the impact energy (the mass of the impact body/the falling height) until the final result has been determined.
- Evaluation

The test result is the maximum impact energy (J), for which no defect of the coating can be detected. The impact energy is calculated from the mass of the impact body and the falling height.
- Precision

Precision data are not available at present.
- Reference

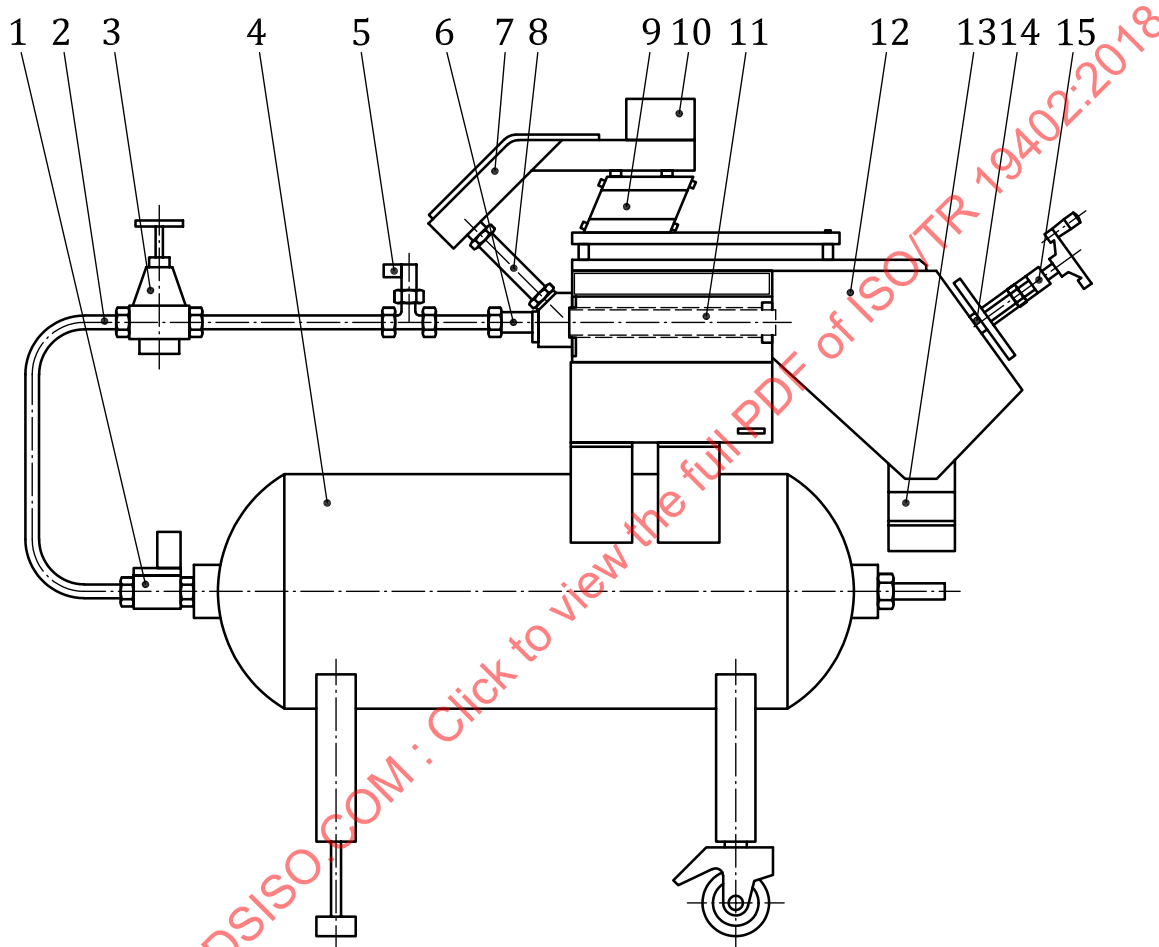
The falling-weight test 3 is specified in EN 13523-5 and ASTM D2794.

4.3.8 Multi-impact test 1

— Principle

Sharp-edged, with pressurised air accelerated impact bodies (chilled casting granulate, grain size 4 mm to 5 mm) impact the coating (impact area 80 mm × 80 mm) at room temperature and an angle of 54°. The method can also be combined with other stresses (e.g. corrosion test). A characteristic value is attributed to the defect pattern by means of 10 reference images.

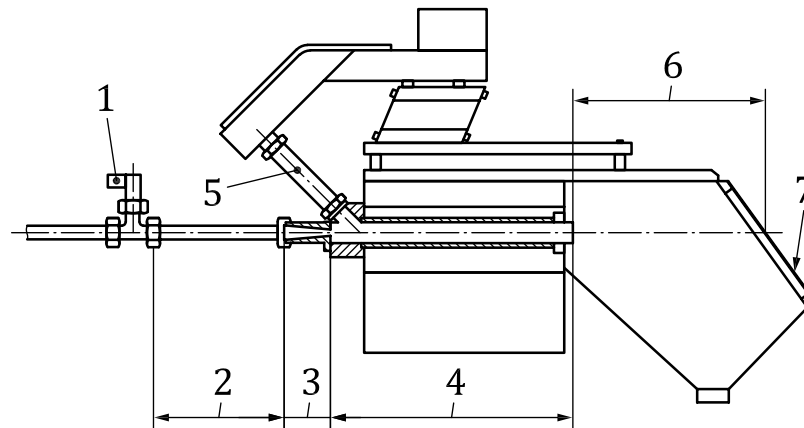
[Figure 32](#) shows an example for the general view of a multi-impact test apparatus. [Figure 33](#) illustrates details for carrying out the test.



Key

- | | | | |
|---|--|----|---|
| 1 | magnetic valve | 9 | vibration conveyor |
| 2 | pressurised air tube | 10 | feed hopper for granulate |
| 3 | pressure reducer (operating pressure) | 11 | acceleration tube (accessible from the back for exchange) |
| 4 | pressure store (90 l) | 12 | protective casing |
| 5 | pressure measuring device (operating pressure) | 13 | collection container for granulate |
| 6 | acceleration nozzle | 14 | test panel |
| 7 | granulate slide | 15 | test specimen clamping device |
| 8 | feed tube | | |

Figure 32 — Multi-impact test apparatus 1 — General view

**Key**

- | | | | |
|---|--|---|------------|
| 1 | pressure measuring device for the operating pressure | 5 | feed tube |
| 2 | intermediate tube | 6 | free steel |
| 3 | acceleration nozzle | 7 | opening |
| 4 | flange and acceleration tube | | |

Figure 33 — Multi-impact test apparatus 1 — Details for carrying out the test

— Application

The multi-impact test 1 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Mount the test panel into the test apparatus and set the operating pressure to 100 kPa (=1 bar) for method A or 200 kPa (=2 bar) for methods B or C.
- Shoot 500 g of granulate onto the test specimen in 10 s.
- For methods A or B repeat the granulate impact.
- For method C carry out an agreed exposure (corrosion test, weathering test, etc.) before the second granulate impact.
- Remove parts of the coating, which have not been detached completely, e.g. by using a tape.

— Evaluation

The test result is the characteristic value, which is obtained by means of visual comparison of the damaged area with reference images. The classification of the characteristic value has 10 steps. The reference image for the characteristic value 2,5 is given in [Figure 34](#).

Specify the separation line(s).

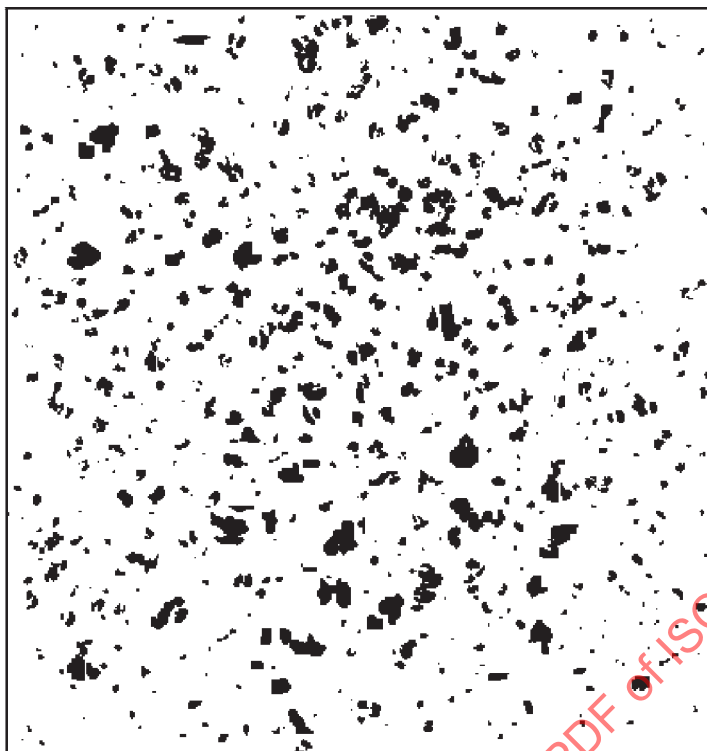


Figure 34 — Reference image for the characteristic value 2,5

Instead of the visual comparison the characteristic value can also be determined with the help of the digital image evaluation (see the procedure specified in [6.3.2](#)).

— Precision

The repeatability limit r is 0,5 classification units.

The reproducibility limit R is 1,0 classification units.

— Reference

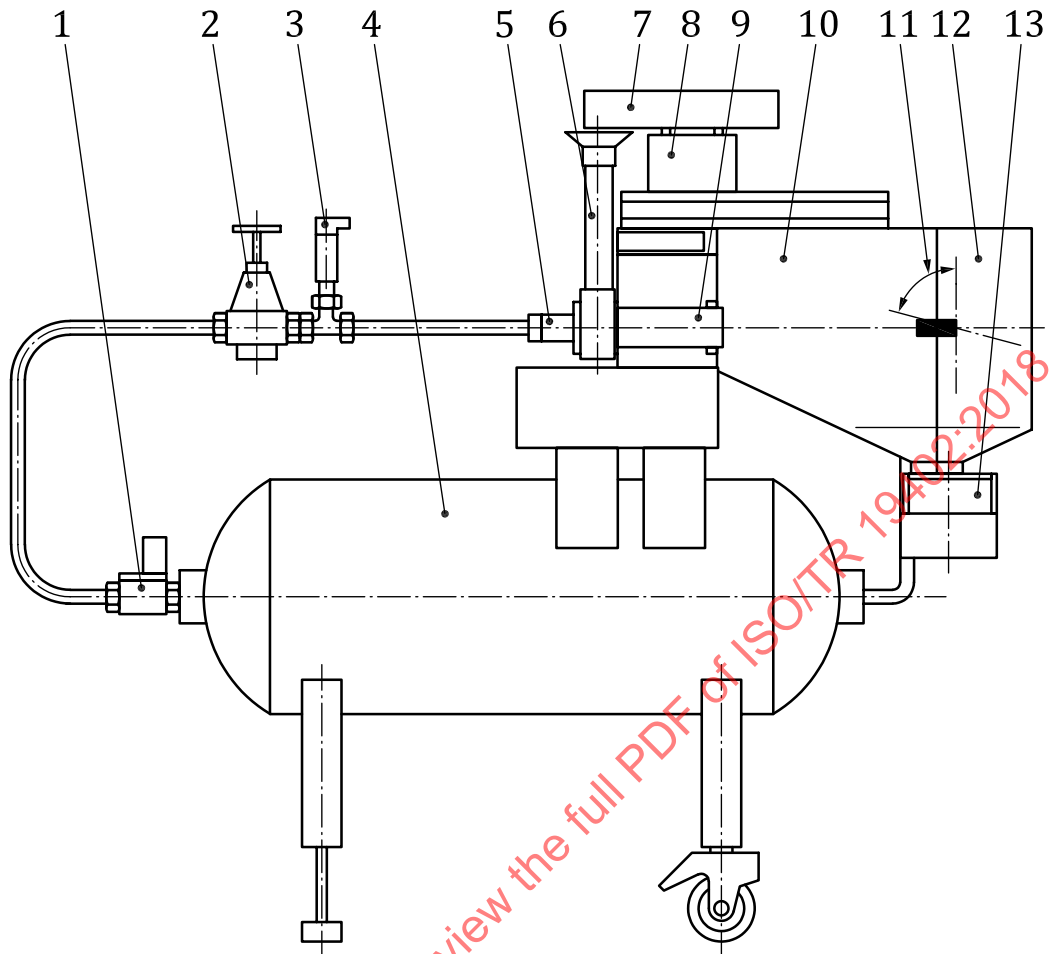
The multi-impact test 1 is specified in ISO 20567-1.

4.3.9 Multi-impact test 2

— Principle

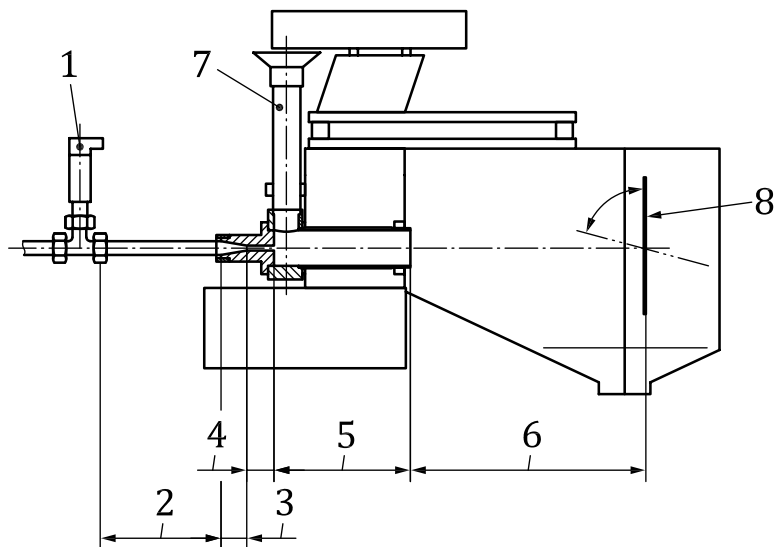
With pressurised air accelerated impact bodies (natural gravel, sieve fraction 9,5 mm to 16 mm) impact the coating at an angle of 45° or 90°. A characteristic value is attributed to the defect pattern by means of reference images or assessment criteria.

[Figure 35](#) shows an example for the general view of a multi-impact test apparatus. [Figure 36](#) illustrates details for carrying out the test.

**Key**

- | | |
|--|---|
| 1 magnetic valve | 8 vibration conveyor |
| 2 pressure reducer (operating pressure) | 9 acceleration tube (accessible from the back for exchange) |
| 3 pressure measuring device (operating pressure) | 10 protective casing |
| 4 pressure store (90 l) | 11 test specimen clamping device (angle adjustable) |
| 5 acceleration nozzle | 12 swing door for changing test specimens |
| 6 feed tube with hopper | 13 collection container for the impact material |
| 7 feed slide | |

Figure 35 — Multi-impact test apparatus 2 — General view



Key

1	pressure measuring device	5	acceleration tube
2	intermediate tube	6	free steel
3	acceleration nozzle (conical area)	7	feed tube for impact material
4	acceleration nozzle (cylindrical area)	8	test specimen clamping device (angle adjustable)

Figure 36 — Multi-impact test apparatus 2 — Details for carrying out the test

— Application

The multi-impact test 2 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Mount the conditioned test panel at the agreed angle into the test apparatus and set the operating pressure to (480 kPa = 4,8 bar).
- Shoot 550 ml of gravel onto the test specimen in 10 s.
- Remove parts of the coating, which have not been detached completely, e.g. by using a tape.

— Evaluation

Attribute a characteristic value to the defect pattern by means of reference images or assessment criteria.

— Precision

The repeatability (in accordance with ASTM D 3170) is at least 1 classification unit.

The reproducibility (in accordance with ASTM D 3170) is at least 2 classification units.

— Reference

The multi-impact test 2 is specified in ASTM D 3170 and SAE J 400.

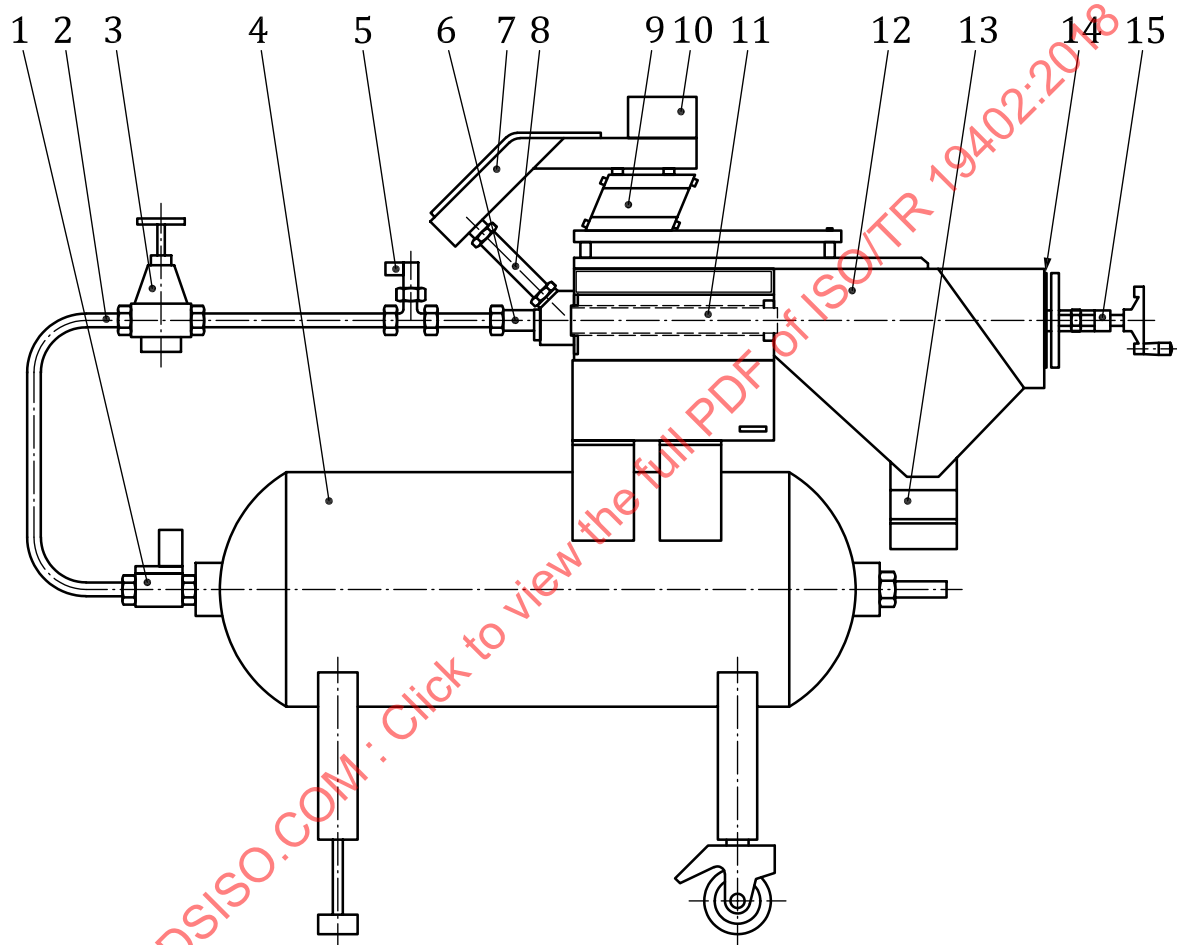
Further methods with different test parameters and evaluations are specified in References [32], [34], [37], [43] and [44].

4.3.10 Multi-impact test 3

— Principle

Sharp-edged, with pressurised air accelerated impact bodies (chilled casting granulate, grain size 4 mm to 5 mm) impact the coating at room temperature and at an angle of 90°. After an immersion test the granulate impact is repeated. The size/number of defects of delamination is determined (6-step/5-step classification).

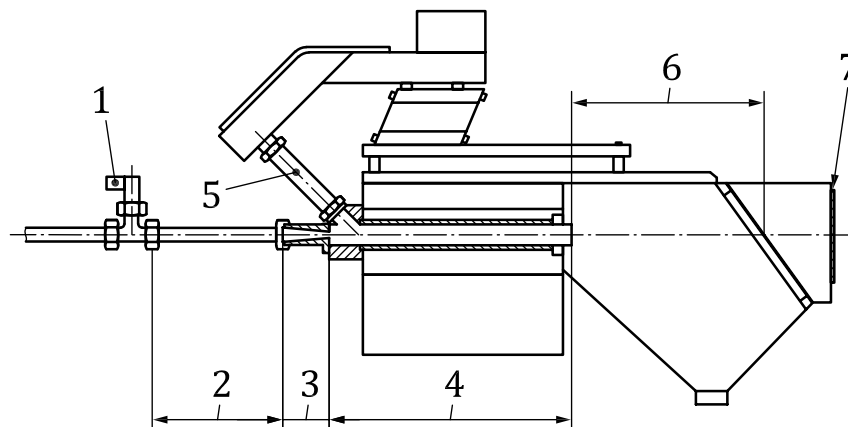
Figure 37 shows an example for the general view of a multi-impact test apparatus. Figure 38 illustrates details for carrying out the test and the dimensions.



Key

- | | |
|--|--|
| 1 magnetic valve | 9 vibration conveyor |
| 2 pressurised air tube | 10 feed hopper for granulate |
| 3 pressure reducer (operating pressure) | 11 acceleration tube (accessible from the back for exchange) |
| 4 pressure store (90 l) | 12 protective casting |
| 5 pressure measuring device (operating pressure) | 13 collection container for granulate |
| 6 acceleration nozzle | 14 test panel |
| 7 granulate slide | 15 test specimen clamping device |
| 8 feed tube | |

Figure 37 — Multi-impact test apparatus 3 — General view



Key

- | | | | |
|---|--|---|------------|
| 1 | pressure measuring device for the operating pressure | 5 | feed tube |
| 2 | intermediate tube | 6 | free steel |
| 3 | acceleration nozzle | 7 | opening |
| 4 | flange and acceleration tube | | |

Figure 38 — Multi-impact test apparatus 3 — Details for carrying out the test

— Application

The multi-impact test 3 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Mount the test panel into the test apparatus and set the operating pressure to 100 kPa (=1 bar).
- Shoot 500 g of granulate onto the test specimen in 10 s.
- Carry out the immersion test (DI water/40 °C/24 h) with the test specimen.
- Again shoot 500 g of granulate onto the test specimen in 10 s.
- Remove the loosely adhering coating material in the damaged area by pulling off using a tape.

— Evaluation

After visual inspection of the impacted area specify as the test result:

- a) the size of the delamination defects (6-step classification by comparing with reference images);
- b) the number of delamination defects referring to the standard impact area (5-step classification);
- c) the number of impacts down to the substrate.

— Precision

Precision data are not available at present.

— Reference

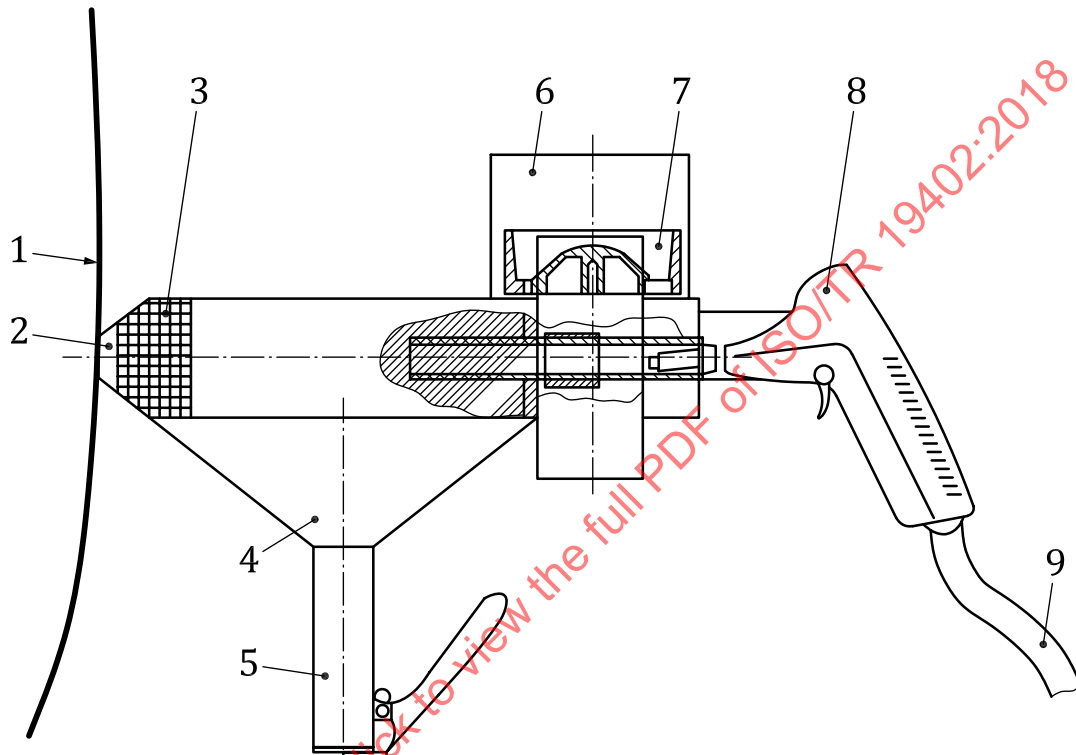
The multi-impact test 3 is specified in Reference [38].

4.3.11 Multi-impact test 4

— Principle

Sharp-edged, with pressurised air accelerated impact bodies (chilled casting granulate, grain size 2,4 mm to 3,2 mm) impact the coating at room temperature and at an angle of 90°. A characteristic value is attributed to the defect pattern by means of 4 reference images.

Figure 39 shows the mobile multi-impact test apparatus.



Key

- | | | | |
|---|--------------------------------|---|------------------------|
| 1 | test specimen | 6 | dosing unit |
| 2 | impact window | 7 | barrel magazine |
| 3 | air outlet opening | 8 | air-blowing device |
| 4 | granulate collection container | 9 | pressurised air supply |
| 5 | emptying valve | | |

Figure 39 — Measurement arrangement of the multi-impact test apparatus 4

— Application

The multi-impact test 4 is preferably carried out on automotive coatings in order to determine the stone-chip resistance.

— Procedure

- Set airflow at the test apparatus so that the produced dynamic pressure is in accordance with the specified value.
- Press the impact opening to the test specimen and shoot 100 g of granulate onto the coating.

— Remove the loosely adhering coating material by pulling off using a tape.

— Evaluation

The test result is the characteristic value, which is obtained by visual (10× magnifier) comparison of the damaged area with reference images (4-step classification).

— Precision

Precision data are not available at present.

— Reference

The multi-impact test 4 is specified in Reference [48].

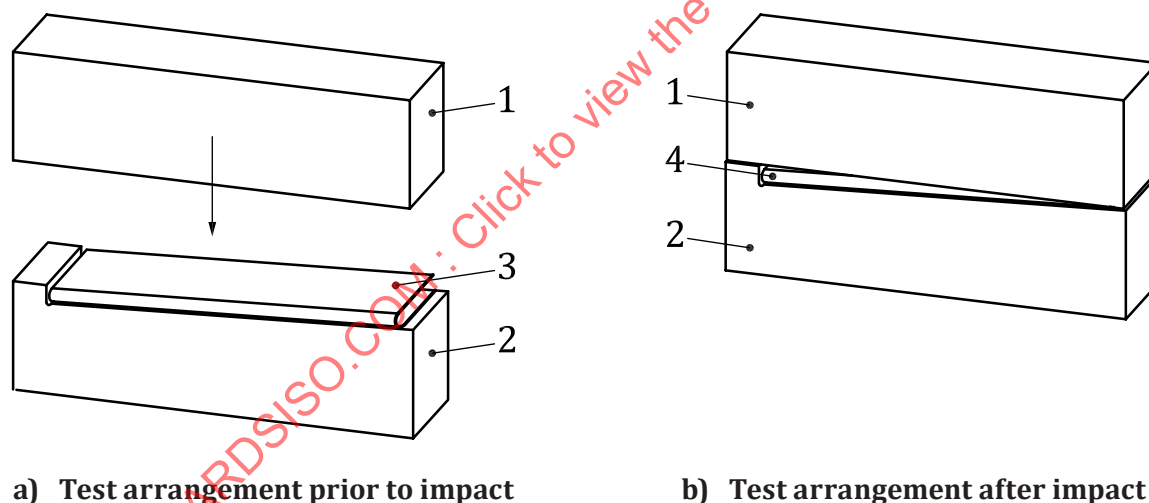
The test apparatus is described in patent specification DE 102 31 802.

4.3.12 Impact-bend test

— Principle

The test panel, which has been pre-bent around a cylindrical mandrel of diameter 5 mm into a U-shape, is wedge-like deformed in a die on which a drop hammer (2,3 kg) impacts from a height of 650 mm. Damages of the coating down to the metallic substrate are visualized by means of a chemical contrasting and visually assessed. The length (mm) of the damaged area is determined.

Figure 40 shows the test arrangement.



Key

- 1 drop hammer
- 2 die
- 3 U-shaped pre-bent test panel
- 4 wedge-like formed test panel

Figure 40 — Test arrangement of the impact-bend test

— Application

The impact-bend test is preferably carried out on coatings for packaging on steel substrate. The test method simulates by approximation the fabrication processes for the production of e.g. cans (punching, folding, flanging, etc.).

- Procedure
 - Apply the test panel at the 5 mm mandrel with the uncoated side facing outwards and bend into a U-shape.
 - Insert the pre-bent test panel into the wedge-shaped indentation of the die in accordance with [Figure 40 a](#)).
 - Let the drop hammer impact the pre-bent test panel.
 - Put the deformed test panel in a beaker into the contrasting agent (see the procedure specified in [6.1.1](#)); afterwards rinse with water and dry.
- Evaluation

Visually inspect the damaged area of the coating.

The test result is the length (mm) of the defect (rounded to whole numbers).
- Precision

Precision data are not available at present.
- Reference

The impact-bend test is specified in Reference [\[36\]](#).

5 Adhesive strength tests with scratch/cut

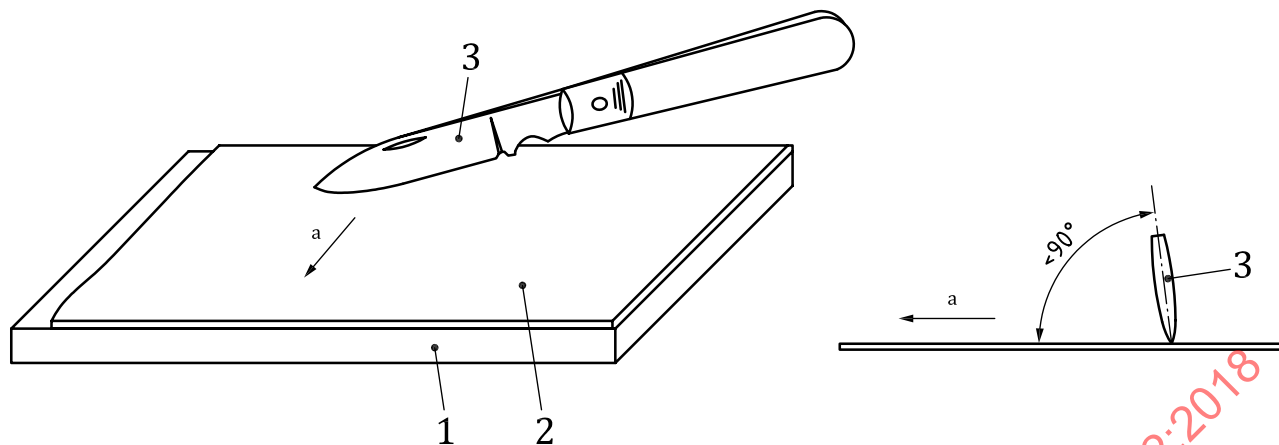
5.1 Tests with single scratch

5.1.1 Scratch test 1

- Principle

The coating is scratched down to the substrate using a defined knife and the defect pattern of the test distance is classified in 6 steps by means of assessment criteria and reference images.

[Figure 41](#) shows the principle of scratch test 1.



Key

- 1 substrate
- 2 coating
- 3 cable stripping knife
- a The pulling direction of the blade.

Figure 41 — Principle of the scratch test 1

— **Application**

The scratch test 1 is preferably carried out on automotive coatings.

— **Procedure**

- Secure the test specimen to a base.
- Scratch the coating down to the substrate over a length of 50 mm by pulling the blade of the knife. In order to test the composite between several coats vary the pressure accordingly.
- Carry out at least three individual determinations.

— **Evaluation**

The test result is the characteristic value, which is obtained by visual comparison of the damaged area with reference images taking into account assessment criteria (6-step classification).

— **Precision**

Precision data are not available at present.

— **Reference**

The scratch test 1 is specified in Reference [31].

5.1.2 Scratch test 2

— **Principle**

The coating is scratched down to the substrate (similar to scratch test 1) in a limited area using a knife, and the defect pattern is classified in 6 steps by means of assessment criteria.

— **Application**

The scratch test 2 is preferably carried out on automotive coatings.

— Procedure

Put down the blade of the knife perpendicular to the coating at an angle of 30° towards the test specimen, and in a limited area scratch the coating down to the substrate.

— Evaluation

The test result is the characteristic value, which is obtained after visual inspection of the damaged area and classification in accordance with specified assessment criteria (6-step classification).

— Precision

Precision data are not available at present.

— Reference

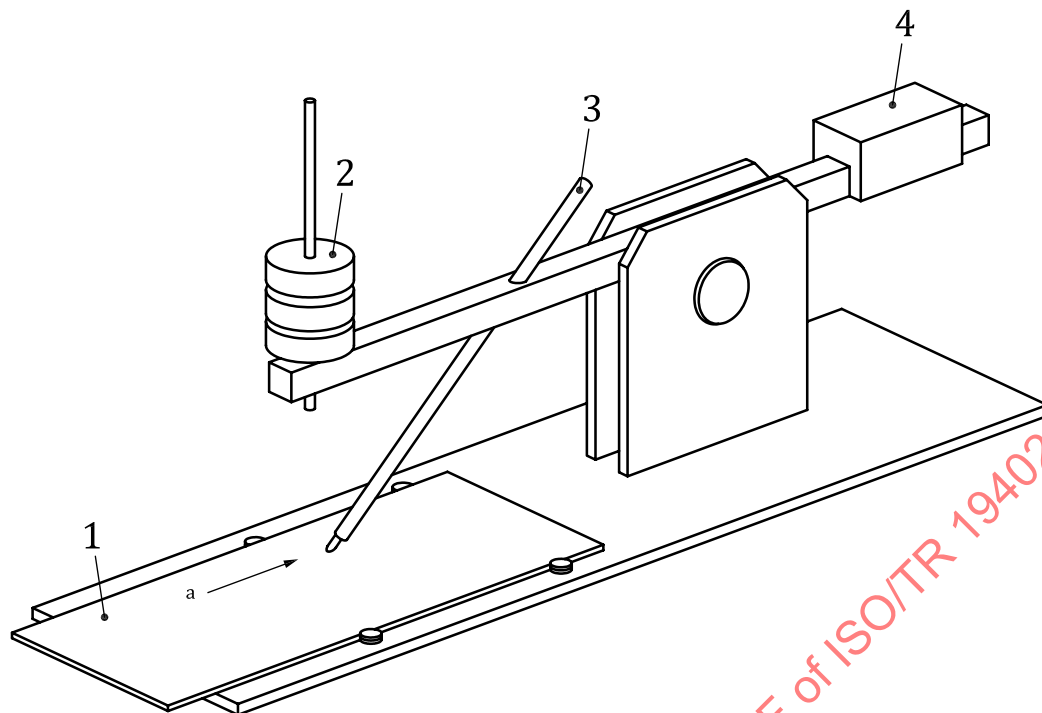
The scratch test 2 is specified in Reference [45].

5.1.3 Scratch test 3 (Scrape-adhesion test)

— Principle

A loaded test tool is pulled over the surface of the test specimen at a speed of about 20 mm/s. The load is varied in steps of 0,5 kg (max. 10 kg) until the coating peels off. The lowest load (kg) is determined for which delamination occurs.

[Figure 42](#) illustrates the test apparatus in a schematic diagram. [Figure 43](#) shows the shape and dimensions of the test tool.



Key

- 1 test panel
- 2 holder for weights
- 3 holder for test tool
- 4 counterweight
- a The direction of movement of the test panel.

Figure 42 — Arrangement of the scratch test apparatus 3

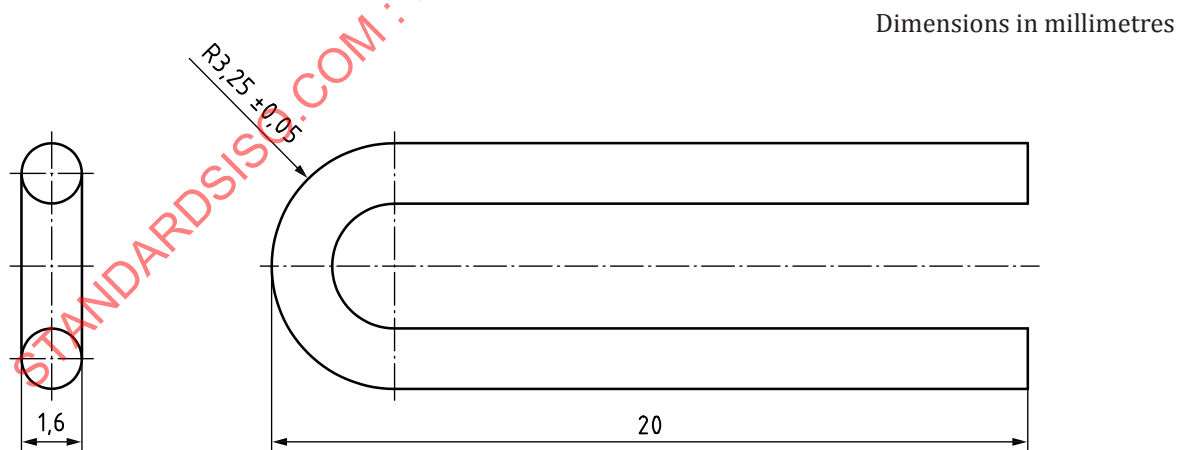


Figure 43 — Test tool (curved stylus)

— Application

The scratch test 3 is generally applicable.

— Procedure

- Secure the test panel to the apparatus and set in advance a medium test load.

- Carry out the scratch test and visually examine the test scratch for delamination.
- Repeat this process with varied test load until the final result has been determined.
- Evaluation

The test result is the lowest test load (kg) which leads to delamination and which has been confirmed by 5-fold repetition.

- Precision

Precision data are not available at present.

- Reference

The scratch test 3 is specified in ASTM D 2197.

A similar method is described in ISO 12137.

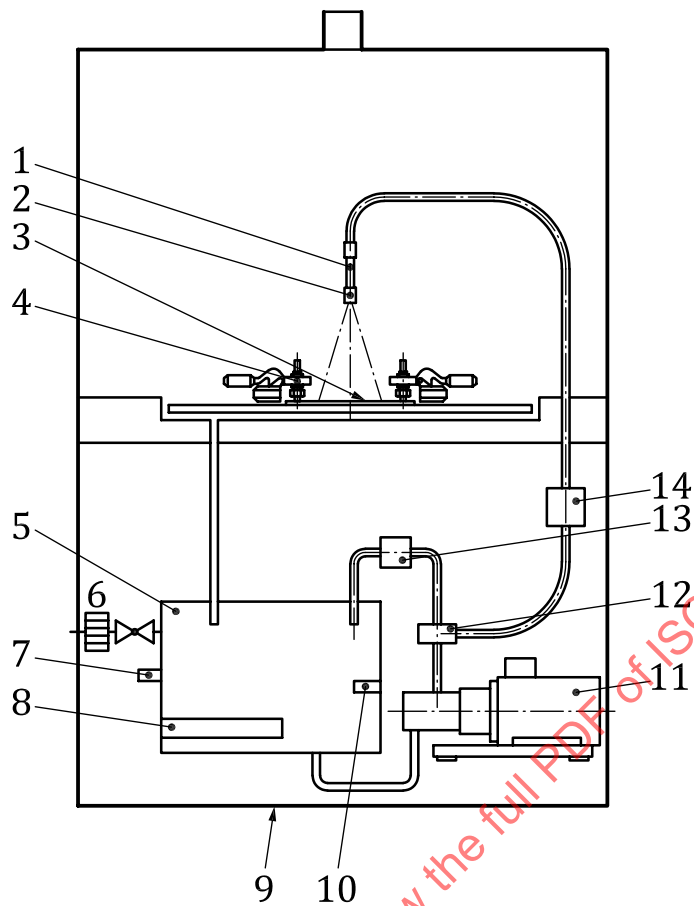
5.2 Test with multiple scratch (without deformation of test specimens)

5.2.1 Pressure-water jetting test

- Principle

The coating, pre-damaged by an X-cut/scratch down to the substrate, is exposed to a pressure-water stress with hot water. The water temperature (60 °C), the impact angle (90°), the jetting distance (100 mm or 130 mm), the volumetric flow rate (11,3 l/min), and the jetting time (30 s or 60 s) are specified. The intensity of the pressure-water jetting is specified by a calibration method. The delamination resulting from the exposure to the pressure-water jet is classified in 6 steps by means of reference images. In addition, the total area of defect (mm²) can be specified.

[Figure 44](#) illustrates the arrangement of a pressure-water jet test apparatus in a schematic diagram. [Figure 45](#) shows the dimensions of the X-cut/scratch.



Key

- | | | | |
|---|--|----|--------------------------------|
| 1 | flow calming section | 8 | heating |
| 2 | high-pressure valve, height adjustable | 9 | base frame, moveable |
| 3 | test specimen | 10 | temperature sensor |
| 4 | clamping element | 11 | high-pressure pump |
| 5 | feed tank | 12 | bypass security valve |
| 6 | floating valve with filter | 13 | pressure relief security valve |
| 7 | water shortage safeguard | 14 | pressure transmitter |

Figure 44 — Schematic arrangement of a pressure-water jet test apparatus

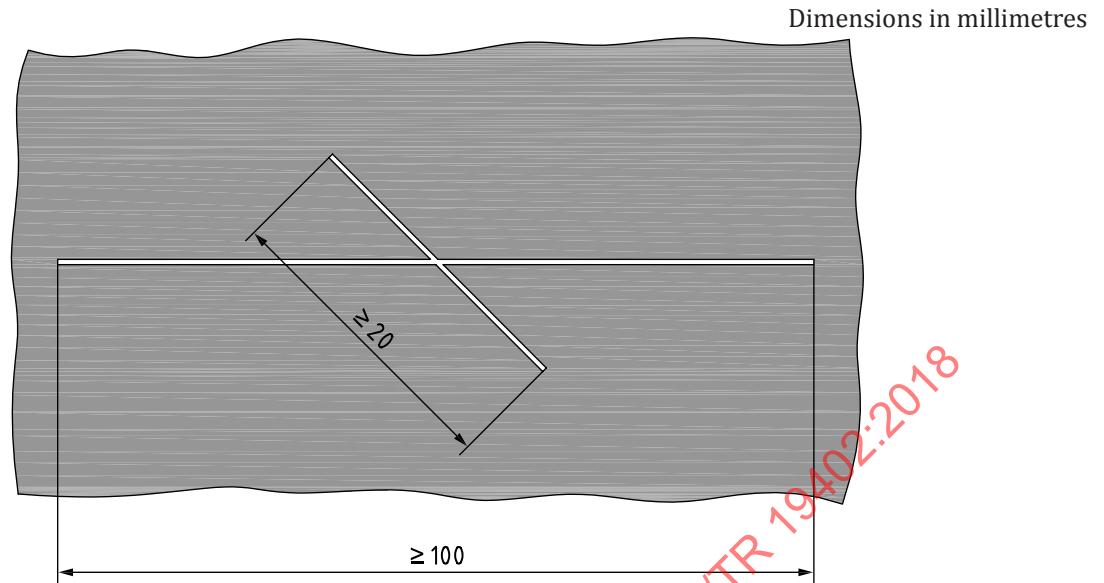


Figure 45 — Introduction of the cuts or scratches (St Andrew's cross)

— Application

The pressure-water jetting test is preferably carried out on automotive coatings.

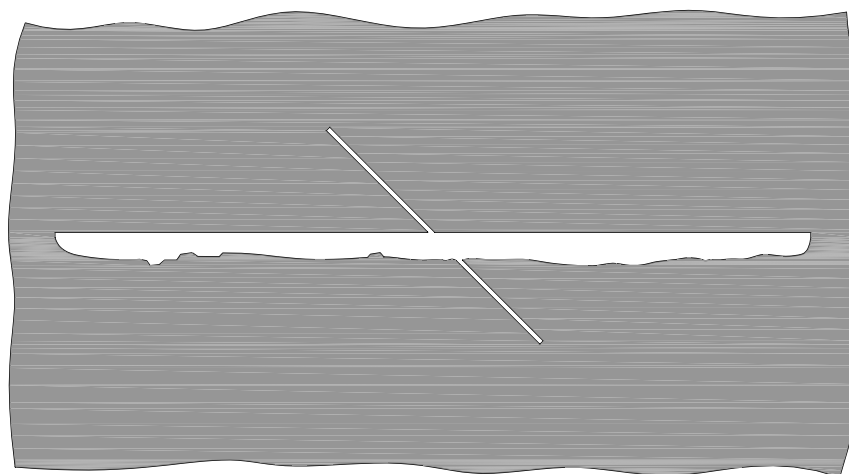
— Procedure

- Introduce the X-cut or cross-scratch (see [Figure 45](#)) to the test specimen using a knife (utility knife) or a scratching tool in accordance with Sikkens and remove the remaining coating from the cut or scratch.
- Attach the test specimen to the test apparatus and set the agreed test parameters:
 - a) jetting distance 100 mm (test method A and B) or 130 mm (test method C);
 - b) jetting time 30 s (test method A) or 60 s (test method B and C).
- Guide the pressure-water jet during the testing time uniformly along the longer cut or scratch (see [Figure 45](#)).

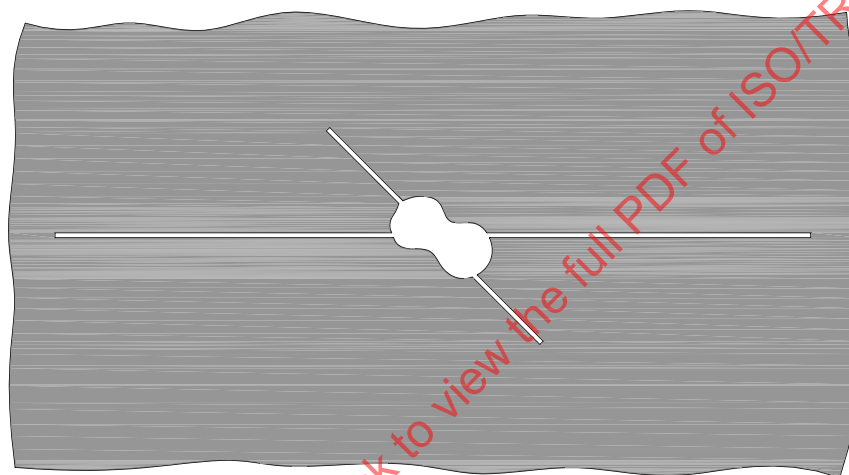
— Evaluation

The test result is the characteristic value, which is obtained by visual comparison of the damaged area with reference images (6-step classification). [Figure 46](#) illustrates typical examples for the reference images.

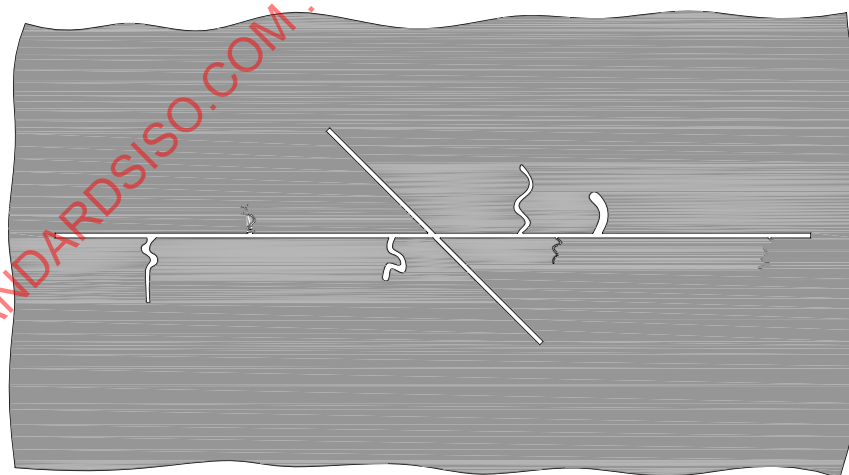
In addition, the total area of defect (mm²) can be indicated.



Characteristic value 7a



Characteristic value 7b



Characteristic value 7c

Figure 46 — Reference images for characteristic value 7

— Precision

The repeatability limit r is 1 classification unit.

The reproducibility limit R is 2 classification units.

— Reference

The pressure-water jetting test is specified in ISO 16925.

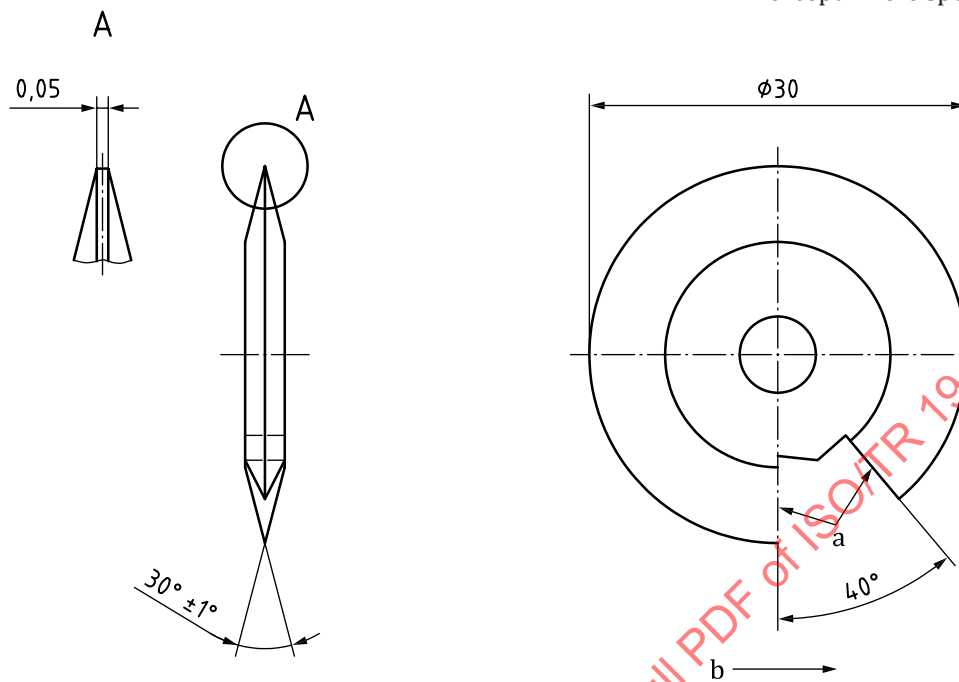
5.2.2 Cross-cut test 1

— Principle

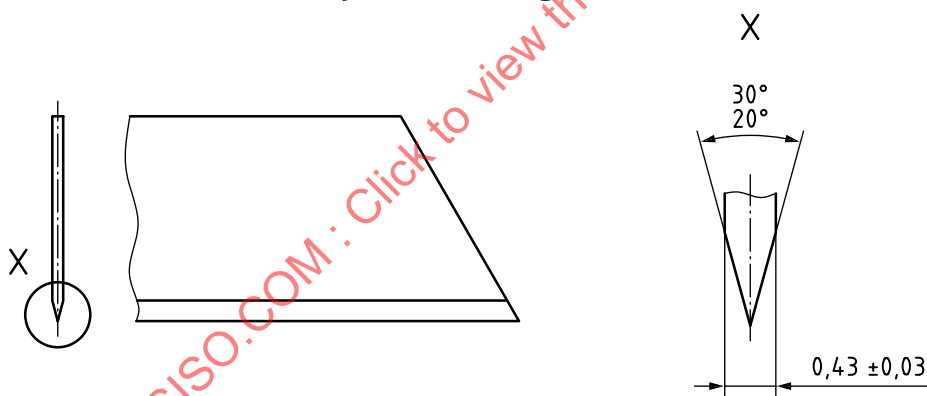
6 parallel cuts are introduced down to the substrate. This process is intersectingly repeated at an angle of 90° so that a lattice pattern is formed, consisting of 25 single square sections. The spacing of cuts is specified in dependence on the substrate and the film thickness. As cross-cutting tools single-blade and multi-blade cutting tools with specified blade geometry are required, which are handheld or motor-driven. The cross-cut value is determined by a 6-step classification of the produced defect by means of reference images.

[Figures 47](#) and [48](#) show valid cutting tools of single- and multi-blade cutting tools (shape and dimensions).

Dimensions in millimetres,
except where specified otherwise



a) Round cutting tool

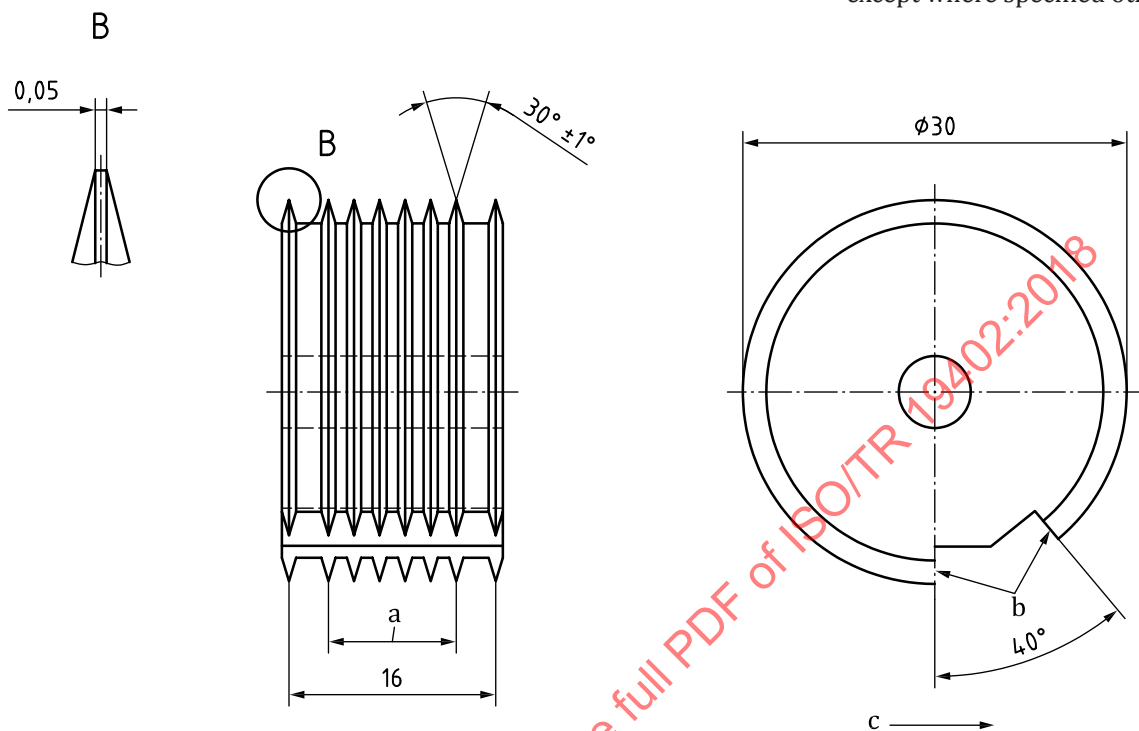


b) Knife blade

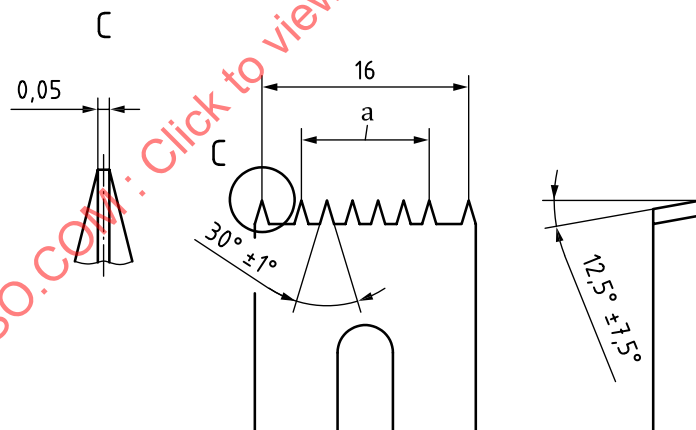
- a The cutting edge.
- b The direction of the cut.

Figure 47 — Examples for cutting tools of single-blade cutting tools

Dimensions in millimetres,
except where specified otherwise



a) Round cutting tool



b) Flat cutting tool

- a The width across all six cutting edges.
- b The cutting edges.
- c The direction of the cut.

Figure 48 — Example for cutting tools of multi-blade cutting tools

— Application

The cross-cut test 1 is generally applicable for coatings with film thicknesses up to 250 μm .

— Procedure

— Specify the spacing of cuts:

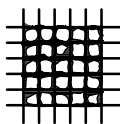
- a) 1 mm for hard substrates (e.g. metal, hard plastics) and film thicknesses up to 60 μm ;
- b) 2 mm for soft substrates (e.g. wood, plaster) and film thicknesses up to 60 μm or for any substrates and film thicknesses in the range of 61 μm to 120 μm ;
- c) 3 mm for any substrates and film thicknesses in the range of 121 μm to 250 μm .

— Put down the cutting edge(s) of the cross-cut tool on the coating, perpendicular to it, and carry out the cross-cut at a uniform cutting speed.

— Remove parts of the coating, which have not been detached completely, e.g. by using a tape.

— Evaluation

The test result is the cross-cut value, which is obtained by visual comparison of the damaged area with reference images. The characteristic values are classified in 6 steps. The reference image for characteristic value 2 is given in [Figure 49](#).



NOTE The coating has flaked along the cutting edges and/or on the intersections of the cuts. A cross-cut area greater than 5 %, but not greater than 15 %, is affected.

Figure 49 — Reference image for cross-cut value 2

— Precision

The repeatability limit r is 1 cross-cut value.

The reproducibility limit R is 2 cross-cut values.

— Reference

The cross-cut test 1 is specified in ISO 2409.

5.2.3 Cross-cut test 2

— Principle

6 or 11 parallel cuts spaced 1 mm or 2 mm are introduced to the coating down to the substrate by means of a knife. This process is intersectingly repeated at an angle of 90° so that a lattice pattern is formed, consisting of 25 or 100 single square sections. The number of cuts and spacing of cuts are specified in dependence on the film thickness. After a tape test the produced defect is classified in 6 steps by means of reference images.

— Application

The cross-cut test 2 is generally applicable for coatings with film thicknesses up to 125 μm .

— Procedure

— Specify cross-cut geometry:

- a) 11 cuts spaced 1 mm apart for film thicknesses up to 50 μm ;
- b) 6 cuts spaced 2 mm apart for film thicknesses in the range of 51 μm to 125 μm .

- Carry out the cross-cut at a uniform cutting speed.
- Brush the cross-cut area and pull off a tape at 180°.
- Evaluation

The test result is the characteristic value, which is obtained by visual comparison of the damaged area with reference images (6-step classification).
- Precision

The repeatability limit (in accordance with ASTM D 3359) is 1 classification unit.

The reproducibility limit (in accordance with ASTM D 3359) is 2 classification units.
- Reference

The cross-cut test 2 is specified in ASTM D 3359.

5.2.4 Cross-cut test 3

- Principle

11 parallel cuts are introduced to the coating down to the substrate. This process is intersectingly repeated at an angle of 90° so that a lattice pattern is formed, consisting of 100 single square sections. The spacing of cuts is specified in dependence on the coating system. A knife with specified blade geometry, which is preferably equipped with a breakable blade, is used as the cutting tool. After a tape test the number of single sections in which delamination predominantly occurred is determined.
- Application

The cross-cut test 3 is preferably carried out on automotive coatings.
- Procedure
 - Specify the distance of the cuts:
 - a) 1 mm for single-coat coatings;
 - b) 2 mm for multi-coat coatings.
 - Put down the blade of the cutting tool on the coating at an angle between 35° and 45° and carry out the cross-cut at a uniform cutting speed.
 - Carry out a 45° pull-off in the deformed area using a specified tape.
- Evaluation

The test result is the number of single sections, in which at least 50 % of the coating has peeled off.

Specify the separation line(s).
- Precision

Precision data are not available at present.
- Reference

The cross-cut test 3 is specified in Reference [42].

5.2.5 X-cut test 1

— Principle

Two cuts, intersecting at an angle between 30° and 45° and with a length of 40 mm, are introduced to the coating down to the substrate by means of a single-blade cutting tool in accordance with cross-cut test 1 (see 5.2.2). The produced defect is classified in 6 steps by means of reference images.

— Application

The X-cut test 1 is preferably carried out on corrosion protection coatings of steel constructions.

— Procedure

- Put down the blade of the cutting tool on the coating, perpendicular to it, and carry out the X-cut at a uniform cutting speed.
- Remove parts of the coating, which have not been detached completely, e.g. by using a tape.

— Evaluation

The test result is the characteristic value, which has been obtained by visual comparison of the damaged area with reference images. The characteristic values are classified in 6 steps. The reference image for the characteristic value 3 is given in Figure 50.



NOTE Irregular chippings on the cuts up to 3,0 mm on each side over the largest part of the lengths of the cuts.

Figure 50 — Reference image for the characteristic value 3

— Precision

Precision data are not available at present.

— Reference

The X-cut test 1 is specified in ISO 16276-2.

5.2.6 X-cut test 2

— Principle

Two cuts, intersecting at an angle between 30° and 45° and with a length of 40 mm, are introduced to the coating down to the substrate by means of a knife. After a tape test the produced defect is classified by means of six assessment criteria.

— Application

The X-cut test 2 is generally applicable.

- Procedure

- Carry out the X-cut at a uniform cutting speed.
 - Carry out a 180° pull-off in the deformed area using a tape.

- Evaluation

The test result is the characteristic value, which is obtained after visual inspection of the damaged area and classification in accordance with specified assessment criteria (6-step classification).

- Precision

Precision data are not available at present.

- Reference

The X-cut test 2 is specified in ASTM D 3359.

5.2.7 X-cut test 3

- Principle

Two cuts, intersecting at an angle of 30° and with a length of 40 mm, are introduced to the coating down to the substrate by means of a knife. After a tape test the produced defect is classified by means of 6 reference images.

- Application

The X-cut test 3 is preferably carried out on automotive coatings.

- Procedure

- Put down the blade of the cutting tool on the coating at an angle between 35° and 45° and carry out the X-cut at a uniform cutting speed.
 - Carry out a 45° pull-off in the deformed area using a specified tape.

- Evaluation

The test result is the characteristic value, which is obtained by visual comparison of the damaged area with 6 reference images.

- Precision

Precision data are not available at present.

- Reference

The X-cut test 3 is specified in Reference [41].

5.2.8 X-cut test 4

- Principle

Two cuts, intersecting at an angle between 20° and 30° and with a length of about 80 mm, are introduced to the coating down to the substrate by means of a scratching tool or a knife. After a tape test the produced defect is classified in 4 steps by means of assessment criteria.

- Application

The X-cut test 4 is preferably carried out on automotive coatings.

— Procedure

- Carry out the X-cut at a uniform cutting speed.
- Carry out a pull-off in the deformed area using a specified tape.

— Evaluation

The test result is the characteristic value, which is obtained after visual inspection of the damaged area and classification in accordance with specified assessment criteria (4-step classification).

— Precision

Precision data are not available at present.

— Reference

The X-cut test 4 is specified in Reference [46].

5.2.9 Scribe test with a square-diagonal grid

— Principle

9 parallel scratches with a spacing of 3 mm are introduced to the coating down to the substrate by means of a hard-metal needle. This process is intersectingly repeated at an angle of 90°. In addition, diagonal scratches are introduced in one direction, so that a lattice pattern is formed, consisting of 128 triangular sections. After a tape test the defect pattern is classified in 11 steps by comparison with reference images.

[Figure 51](#) illustrates the square-diagonal grid.

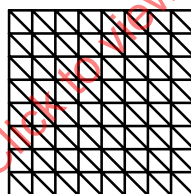


Figure 51 — Square-diagonal grid

— Application

The scribe test with a square-diagonal grid is preferably carried out on automotive coatings.

— Procedure

- Put down the scribe tool on the coating, perpendicular to it, and produce the scribe pattern at a uniform scribing speed.
- Brush the remains of the coating out of the scribes.
- Carry out a 180° pull-off in the scribed area using a specified tape.

— Evaluation

The test result is the characteristic value, which is obtained by visual comparison of the damaged area with 11 reference images.

— Precision

Precision data are not available at present.

— Reference

The scribe test with a square-diagonal grid is specified in Reference [33].

5.2.10 Scribe test with a rhombus grid

— Principle

6 parallel scratches are introduced to the coating down to the substrate by means of a hard-metal needle. This process is intersectingly repeated at an angle of 60° , so that a lattice pattern is formed, consisting of 25 single rhombic sections. The spacing between the scratches shall be selected so that the length of the rhombus edges is 5 mm. After a tape test the number of the rhombic sections in which delamination occurred is determined and a 2-step classification is carried out.

Figure 52 illustrates the rhombus grid.

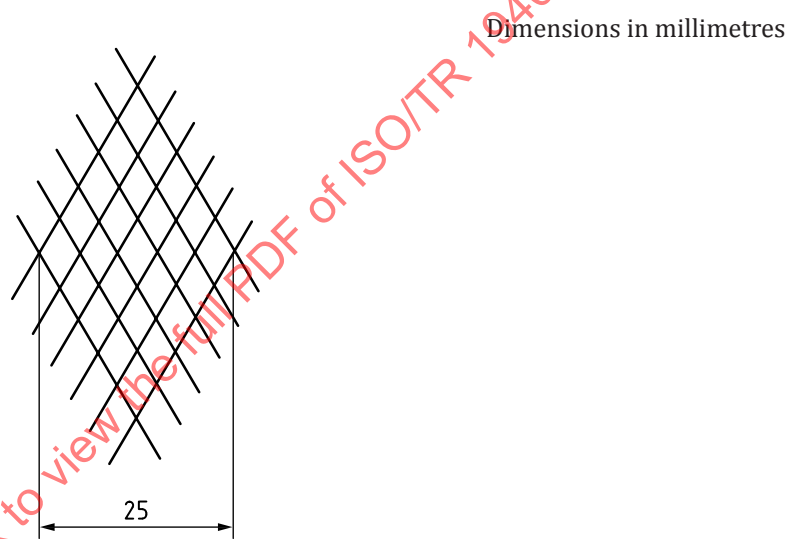


Figure 52 — Rhombus grid

— Application

The scribe test with a rhombus grid is preferably carried out on automotive coatings of two-component polyurethane basis.

— Procedure

- Put down the scribe tool on the coating, perpendicular to it, and produce the scribe pattern at a uniform scribing speed.
- Brush the remaining coating out of the scribes.
- Carry out a 180° pull-off in the scribed area using a specified tape.

— Evaluation

Determine the number n of the rhombic sections of the coating that has peeled off.

The test result is a “pass/fail” decision depending on whether n is < 2 (“pass”) or n is ≥ 2 (“fail”).

— Precision

Precision data are not available at present.

— Reference

The scribe test with a rhombus grid is specified in Reference [33].

5.3 Test with multiple scratch (with deformation of test specimens)

5.3.1 Cupping test 2

— Principle

2 or 6 parallel cuts spaced 5 mm or 1 mm are introduced to the coating down to the substrate by means of a knife. This process is intersectingly repeated at an angle of 90° so that a lattice pattern is formed, consisting of 1 or 25 single square section(s). Number of cuts and spacing of cuts are specified in dependence on the film thickness. Subsequently, a cupping (cupping test 1, see 4.2.8) with an agreed maximum distance of the indenter is carried out in the cross-cut area. The relative extent of the delaminated area (%) is determined.

Figure 53 illustrates both of the cross-cut types in a schematic diagram (cross-cut geometry and positioning on the test panel).

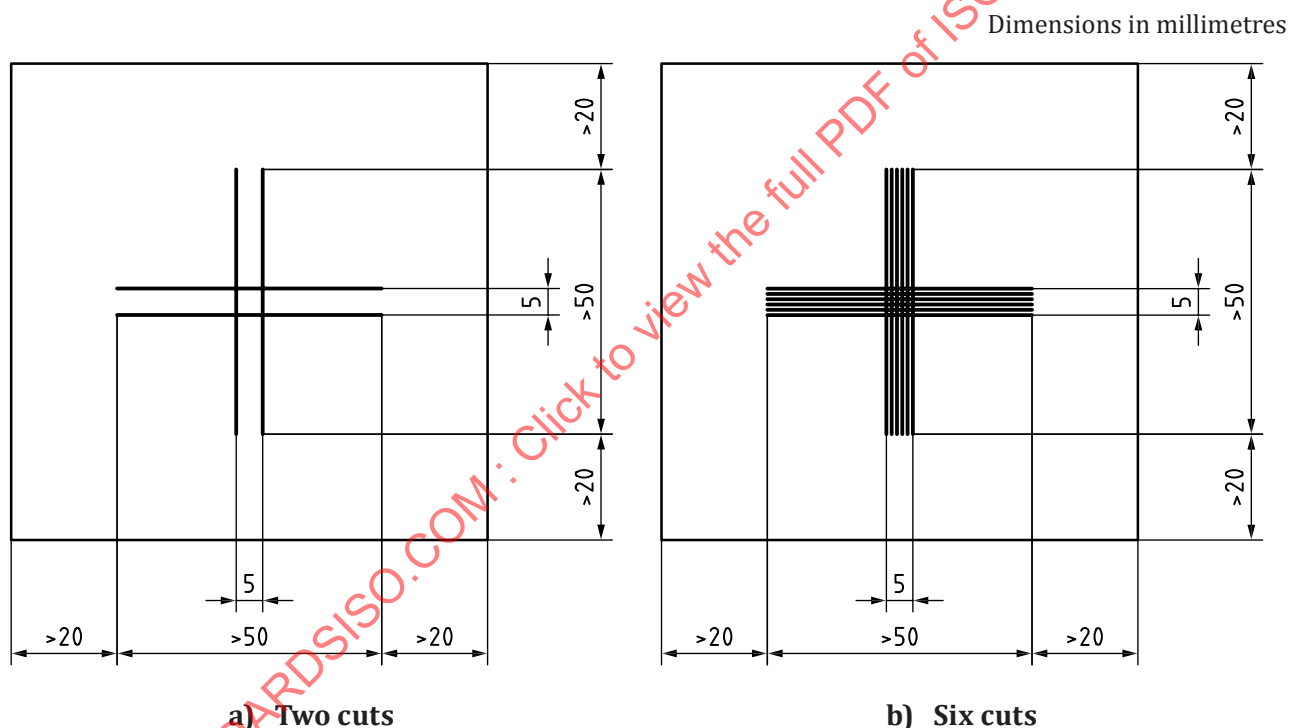


Figure 53 — Cross-cut geometries

— Application

The cupping test 2 is preferably carried out on coil coatings.

— Procedure

— Agree on a maximum distance of the indenter (cupping) and make sure by pre-testing that the coating does not crack before reaching this size of a bulge.

— Specify cross-cut geometry:

- a) 6 cuts with 1 mm spacing for film thicknesses below $60\ \mu\text{m}$;
- b) 2 cuts with 5 mm spacing for film thicknesses greater than or equal to $60\ \mu\text{m}$.