SRI LANKA STANDARD 1256: PART 43: 2019
(ISO/TR 19402: 2018)
UDC 667.661

METHODS OF TEST FOR PAINTS AND VARNISHES
PART 43: ADHESION OF COATINGS

SRI LANKA STANDARDS INSTITUTION

Sri Lanka Standard
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PART 43: ADHESION OF COATINGS

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(ISO/TR 19402: 2018)

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Sri Lanka.

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This Standard does not purport to include all the necessary provisions of a contract

Sri Lanka Standard
METHODS OF TEST FOR PAINTS AND VARNISHES
PART 43: ADHESION OF COATINGS

NATIONAL FOREWORD

This Standard was approved by the Sectoral Committee on Chemical and Polymer Technology and authorized for adoption and publication as a Sri Lanka Standard by the Council of the Sri Lanka Standards Institution on 2019-09-11.

The text of the International Standard ISO/TR 19402: 2018 Paints and varnishes – Adhesion of coatings has been accepted for adoption as a Sri Lanka Standard which summarises the common methods for evaluating the adhesive strength of coatings on a substrate, which can be another coating beneath or the substrate itself.

This Standard is identical with ISO/TR 19402: 2018 Paints and varnishes – Adhesion of coatings, published by the International Organization for Standardization (ISO).

TERMINOLOGY AND CONVENTIONS

The text of the International Standard has been accepted as suitable for publication, without deviation, as a Sri Lanka Standard. However, certain terminology and conventions are not identical with those used in Sri Lanka Standards. Attention is therefore drawn to the following:

a) Wherever the words "International Standard" appear referring to a particular Standard they should be interpreted as "Sri Lanka Standard".

b) The comma has been used throughout as a decimal marker. In Sri Lanka Standards it is the current practice to use the full point at the base as the decimal marker.

c) Wherever page numbers are quoted, they are ISO page numbers.

Cross References

International Standard	Corresponding Sri Lanka Standard
ISO 4618, Paints and varnishes – Terms and definitions	SLS 1541, Terms and definitions for paints and varnishes

SLS 1256 Part 43: 2019

TECHNICAL REPORT

ISO/TR 19402

First edition
2018-08

Paints and varnishes — Adhesion of coatings

Peintures et vernis — Adhérence des revêtements

Reference number
ISO/TR 19402:2018(E)

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Published in Switzerland

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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).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

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.

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

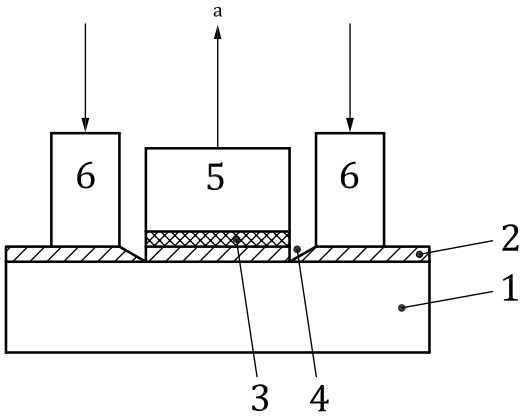
4.1 Tests with mechanical stress application on the coating

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

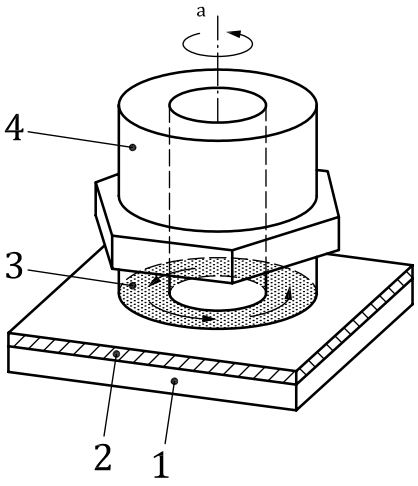
The pull-off test is specified in ISO 4624 and ISO 16276-1.

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 (N/mm^2 = 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

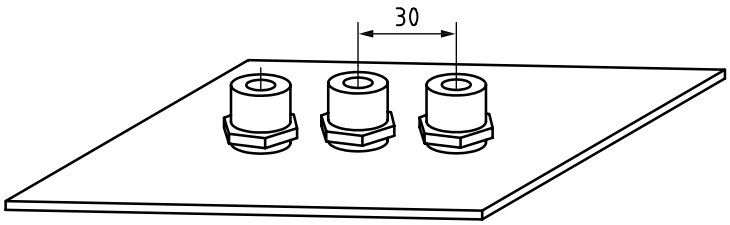


Figure 3 — Minimum distance between the test cylinders

— 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 (N/mm^2 = 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

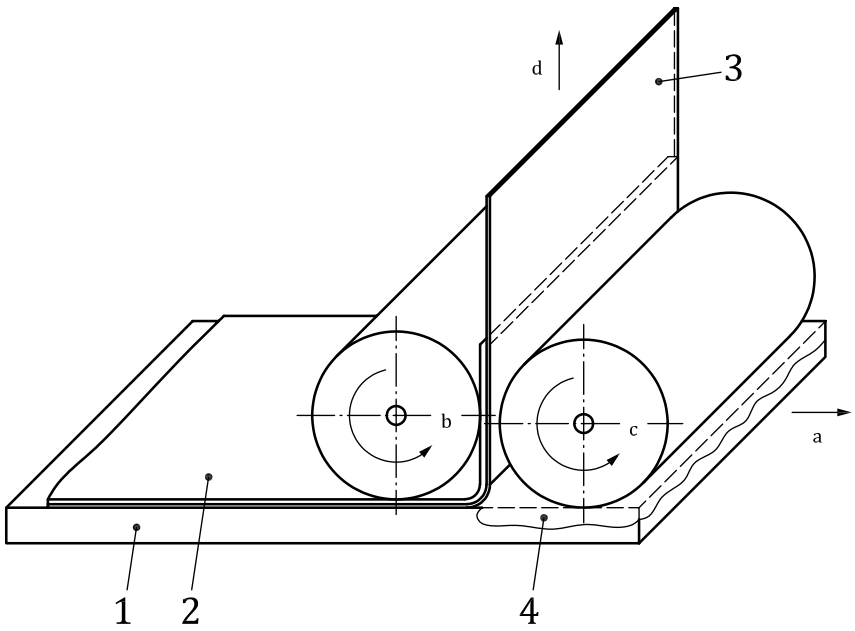
The twist-off test is specified in Reference [50].

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).

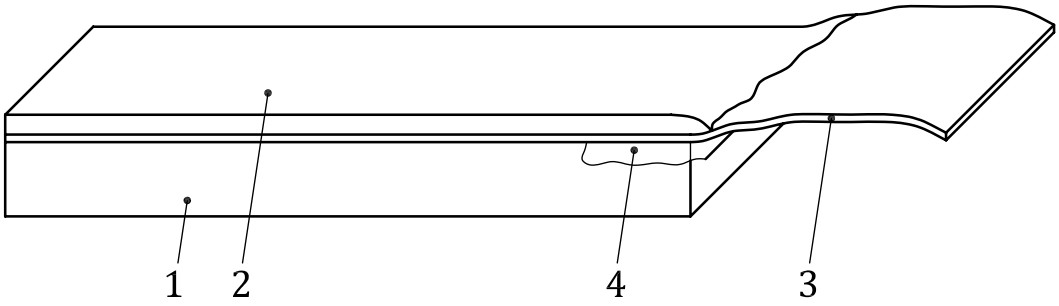
Figure 4 — Principle of the peel-off test 1

— 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.

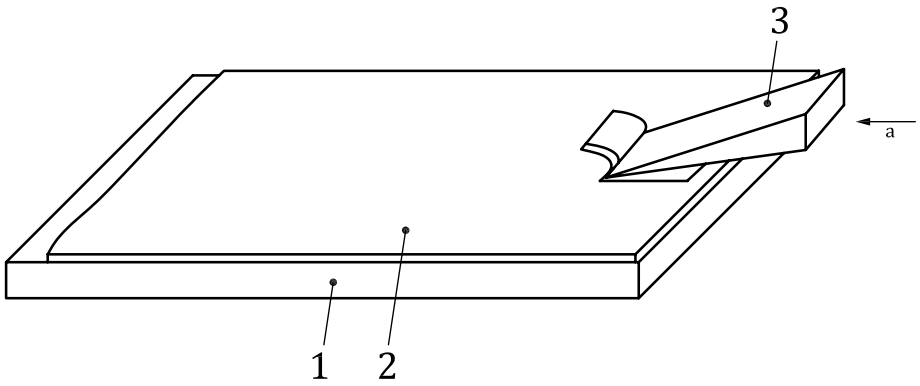
— Reference

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].

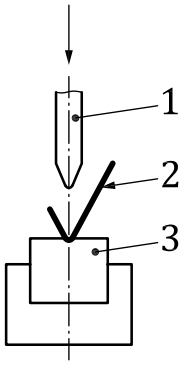
4.2 Tests with continuous deformation of test specimens

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.

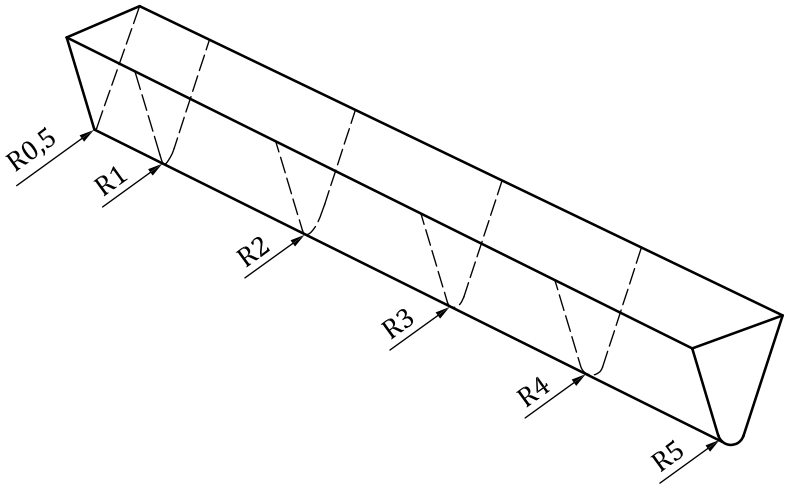
Figure 7 shows the test principle in a schematic diagram. Figure 8 illustrates the dimensions of the wedge-shaped conical mandrel.



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

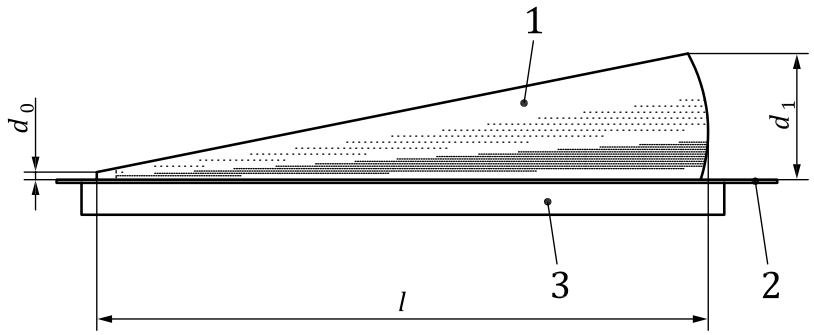
The bend test with a wedge-shaped conical mandrel is specified in EN 13523-7.

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.

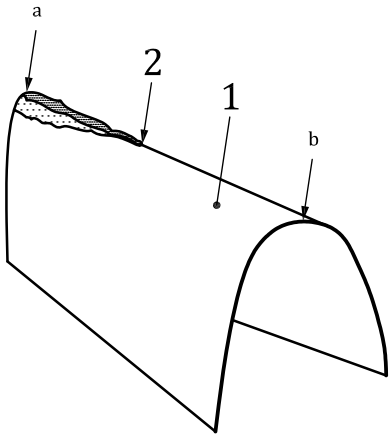
Figure 9 shows the principle of the bend test with a conical mandrel. Figure 10 shows the bent test panel.



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

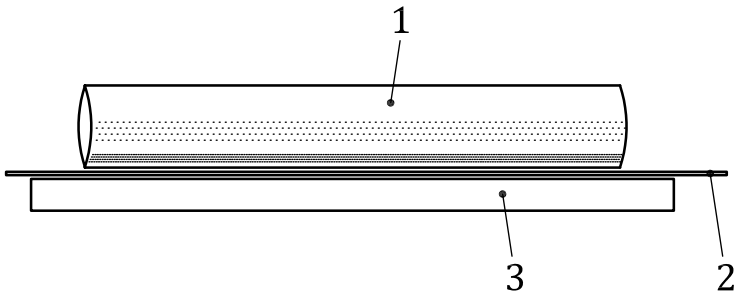
The bend test with a conical mandrel is specified in ISO 6860.

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.

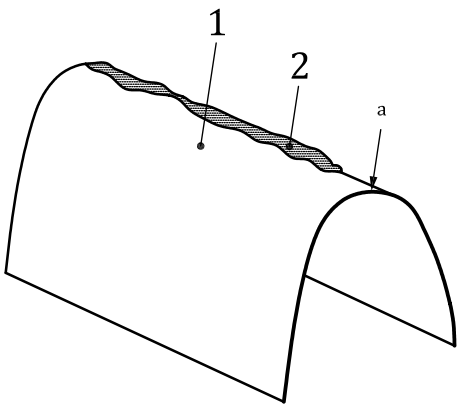
Figure 11 shows the principle of bending around a cylindrical mandrel. Figure 12 shows the bent test panel.



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.

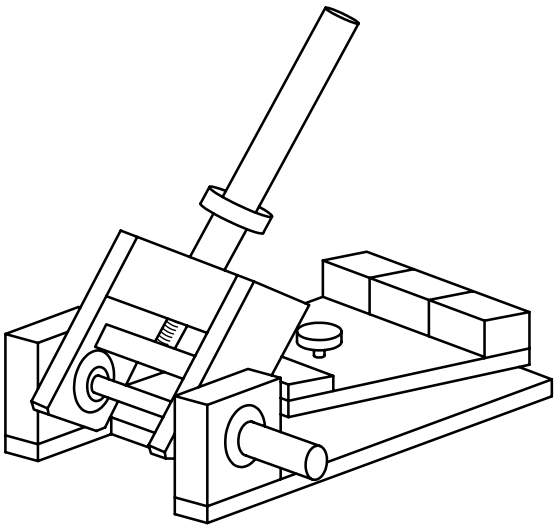


Figure 13 — Mandrel bending apparatus for exchangeable cylindrical mandrels

— 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

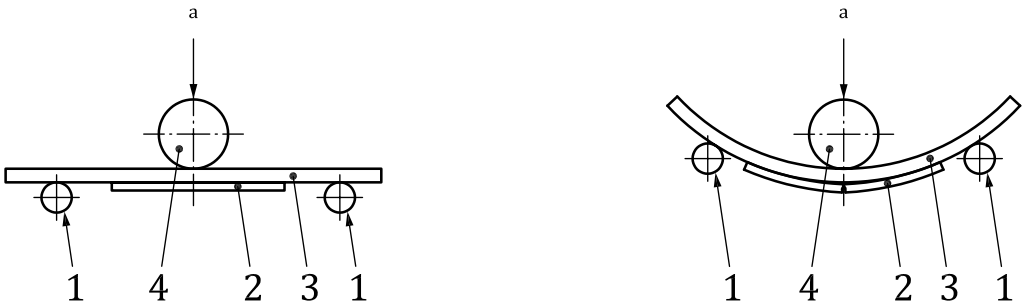
  The bend test with a cylindrical mandrel 2 is specified in EN 13523-7.

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.

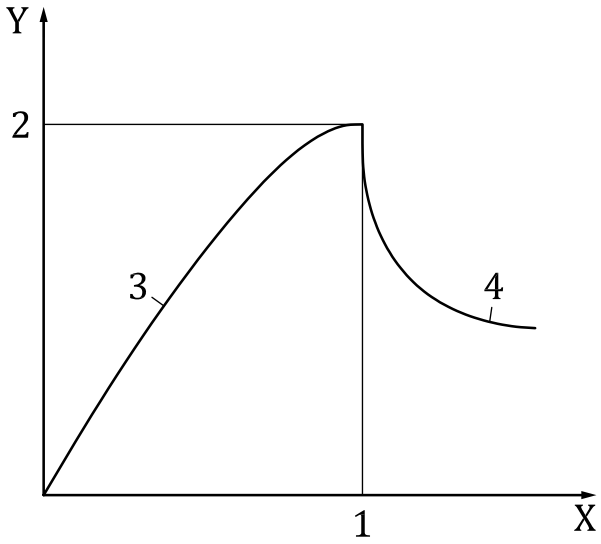
— Procedure

— 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.

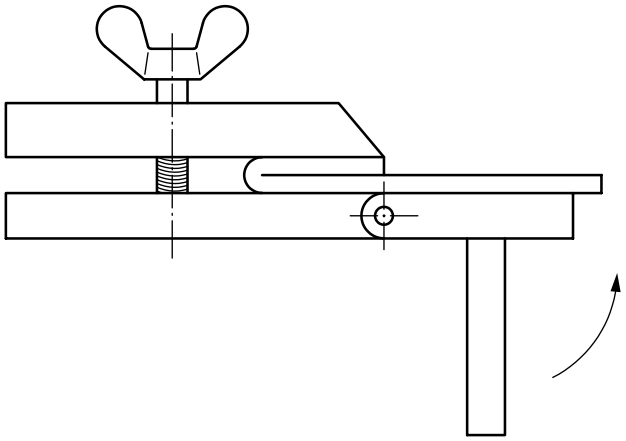


Figure 16 — Common bending apparatus

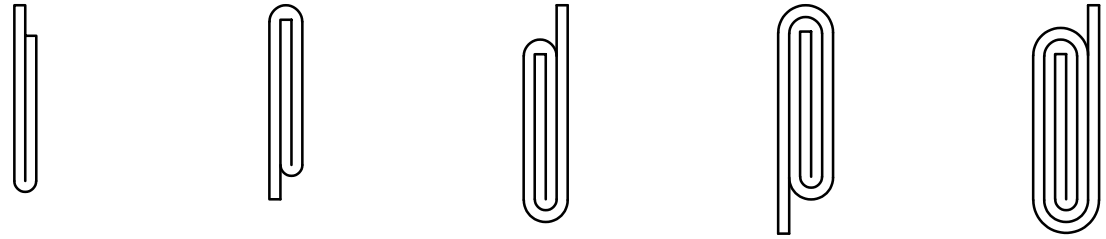


Figure 17 — Stages of the bending process from 0 T to 2 T

— 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.

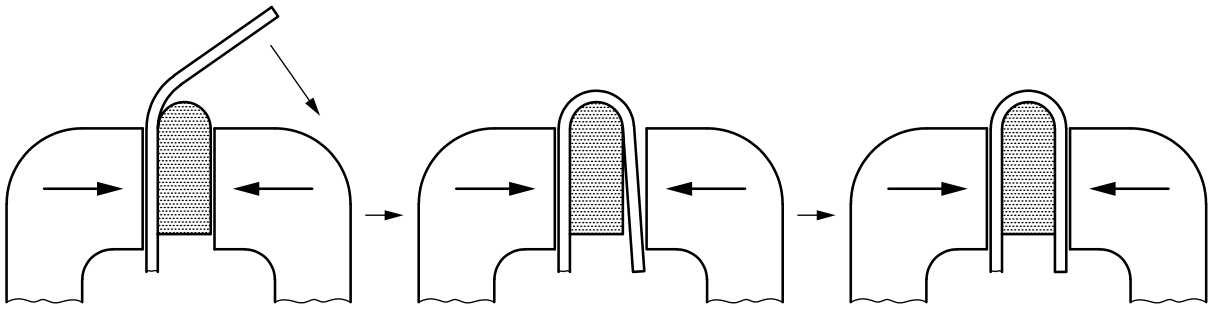


Figure 18 — Bending around a bending piece

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

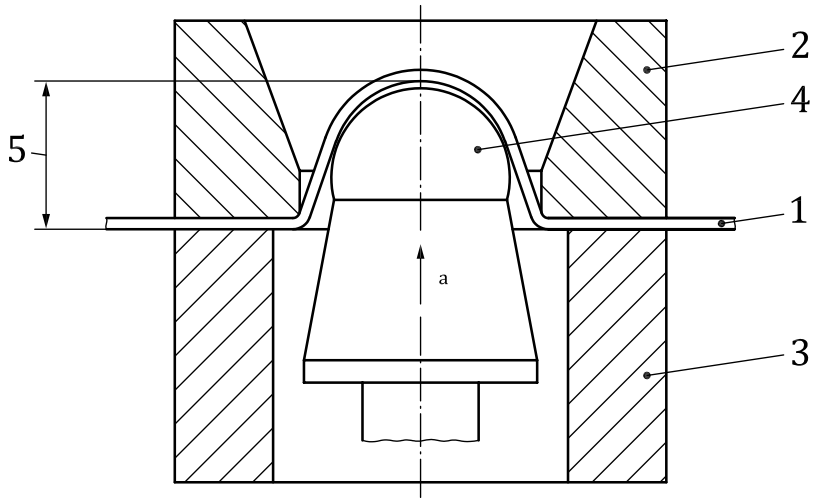
The T-bend test 2 is specified in ISO 17132.

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.

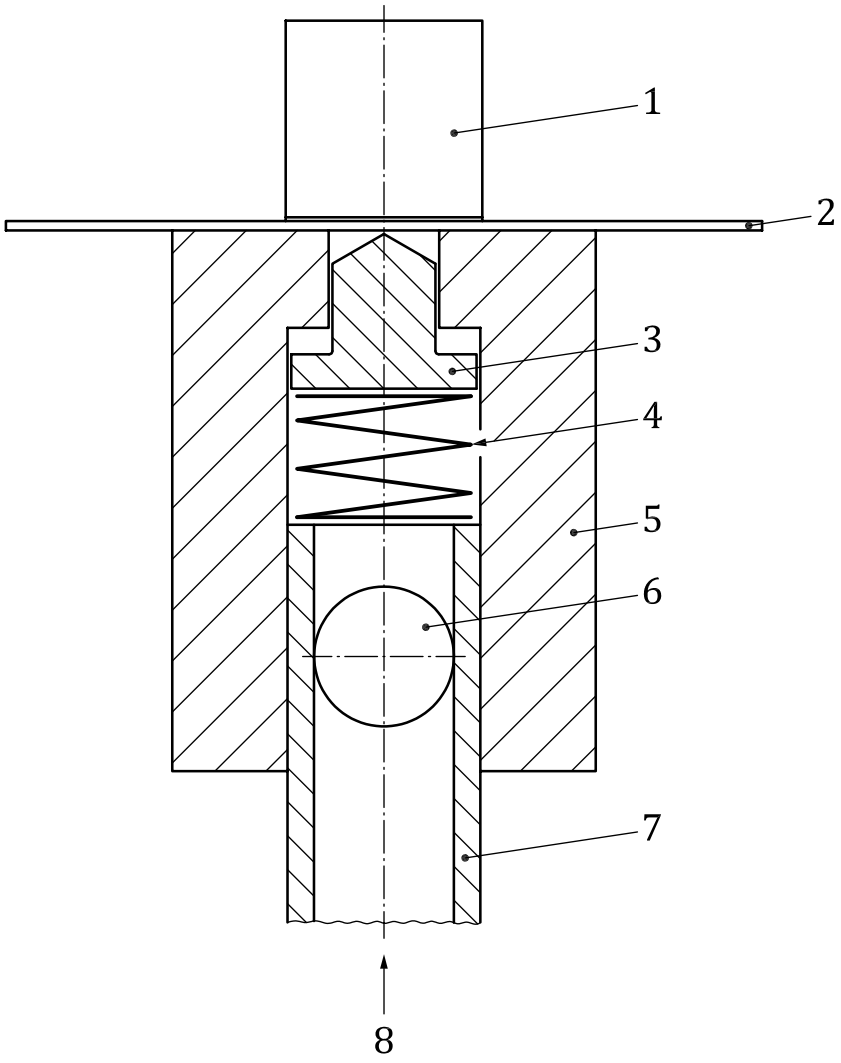
4.3 Test with impact stress application

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.



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

Dimensions in millimetres

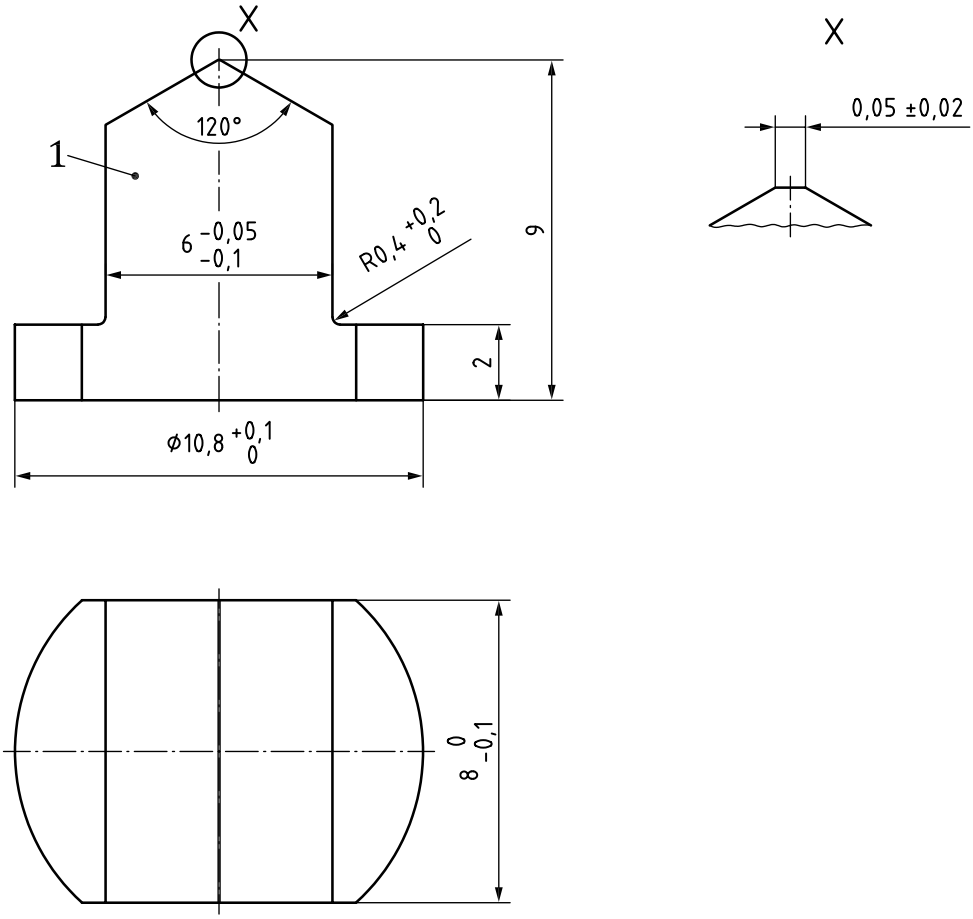


Figure 22 — Impact body

— 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

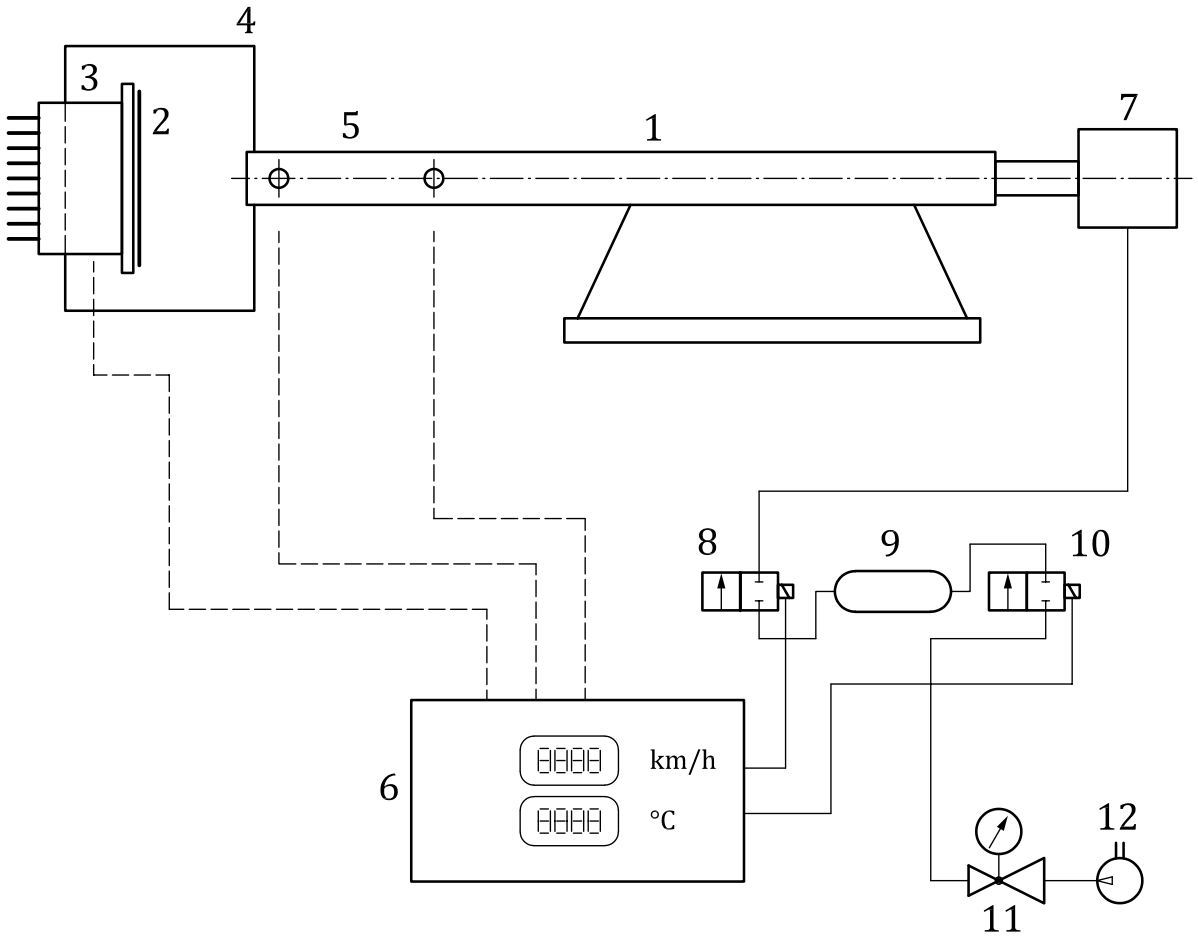
The single-impact test 1 is specified in ISO 20567-2.

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 (mm^2) 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 (mm^2) of the three single determinations.

Specify the separation line(s).

— Precision

The repeatability limit *r* is 5 %.

The reproducibility limit *R* is 10 %.

— Reference

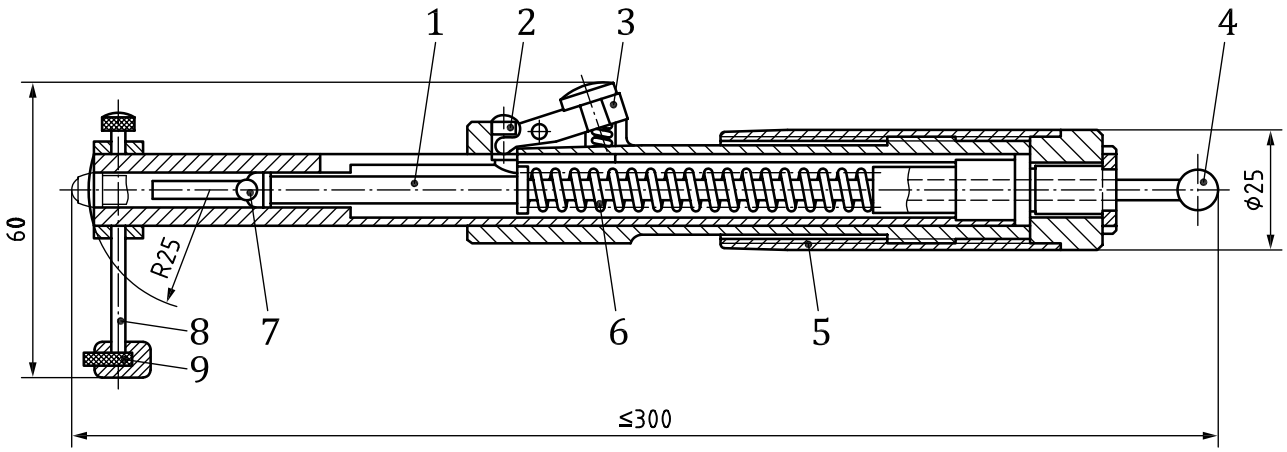
The single-impact test 2 is specified in ISO 20567-3.

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.

Dimensions in millimetres



Key

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

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 ± 3) °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].

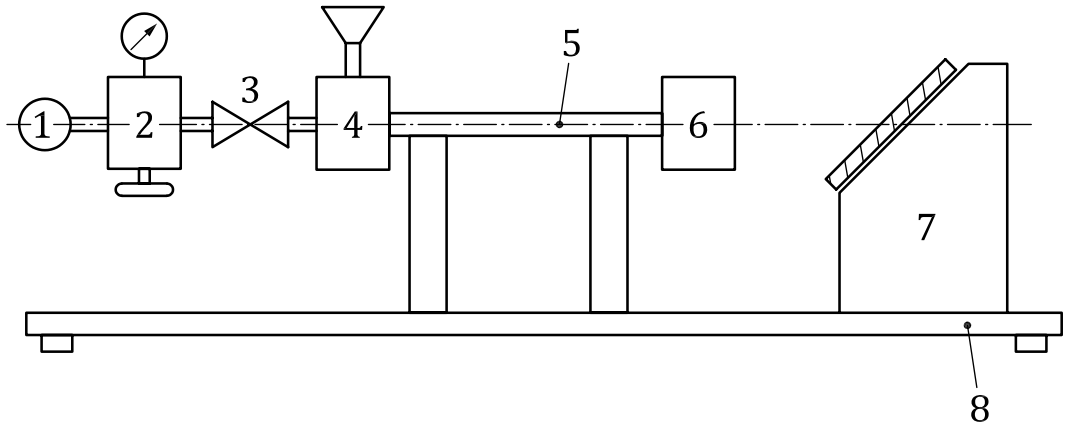
The test apparatus is specified in ISO 4532.

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

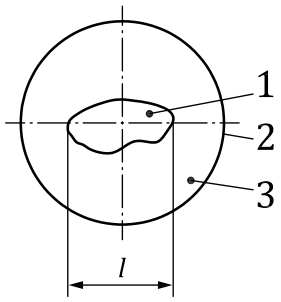
— Secure the test panel at the apparatus.

— 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.

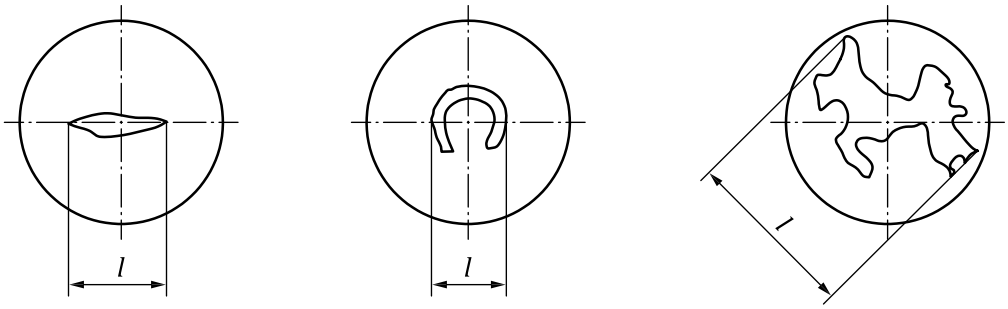
— Measure the length (mm) in accordance with Figures 26, 27, and 28 using a magnifier with graduated scale.



Key

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

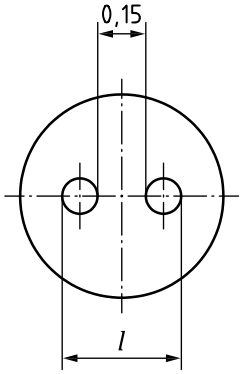
Figure 26 — Evaluation of the impact pattern



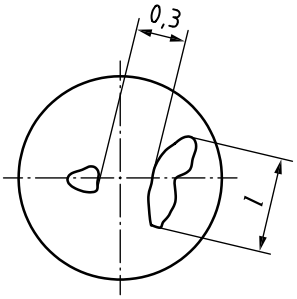
Key

l maximum extent of the delamination defect

Figure 27 — Examples for single defects



a) Distance between the single defects ≤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

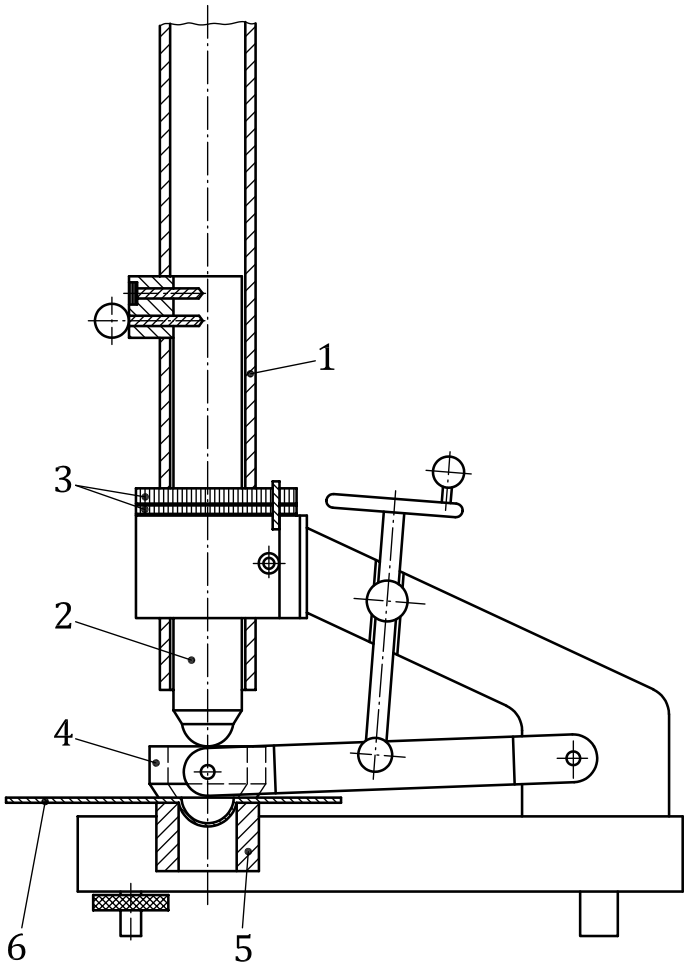
The single-impact test 4 is specified in Reference [39].

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.

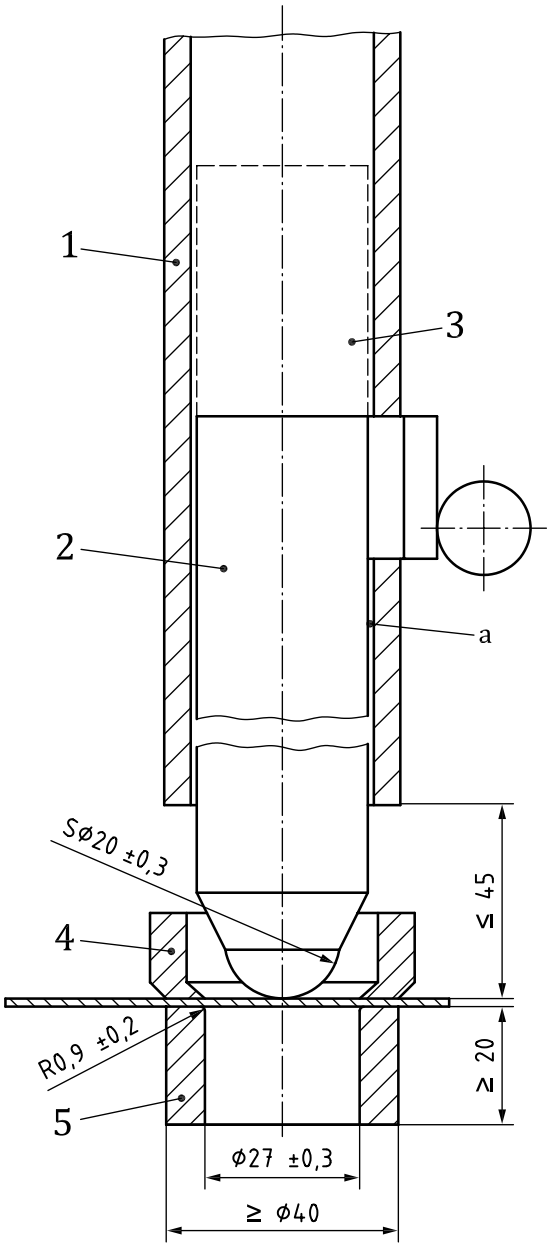


Key

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

Dimensions in millimetres



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 ± 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.

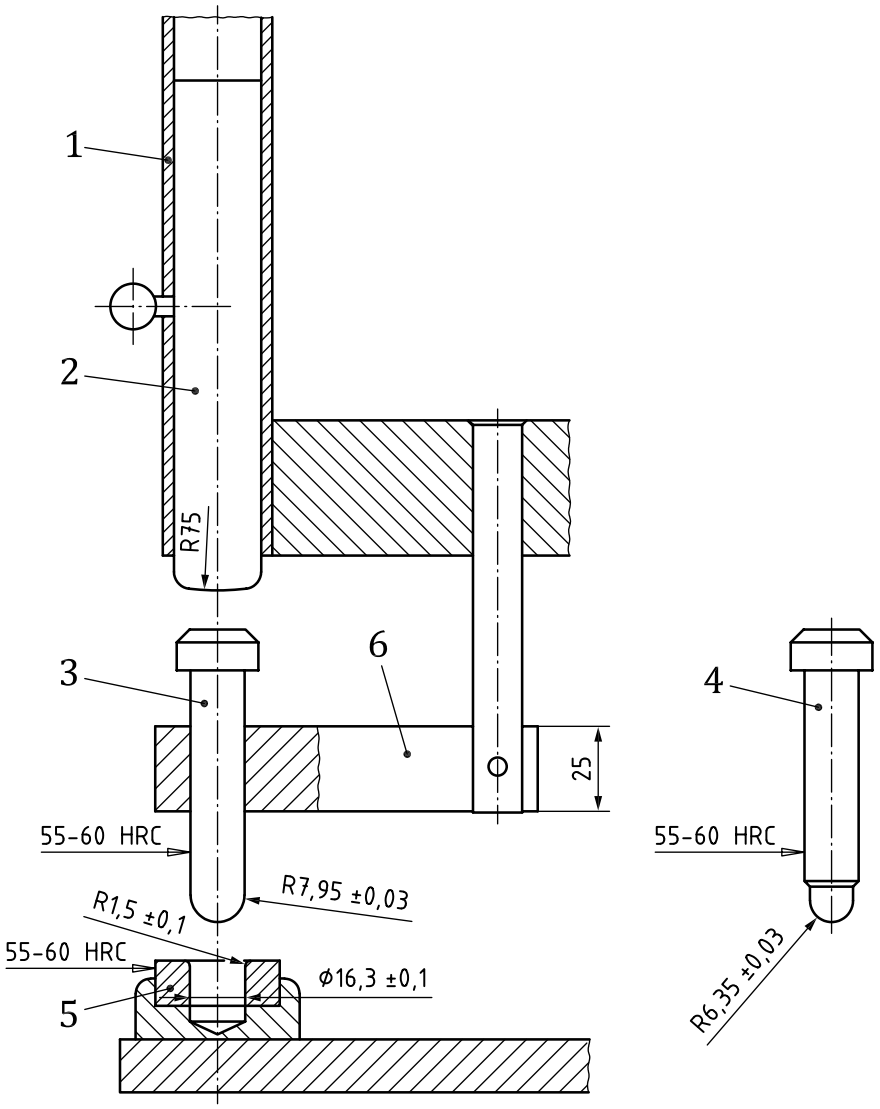
4.3.6 Falling-weight test 2

— 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

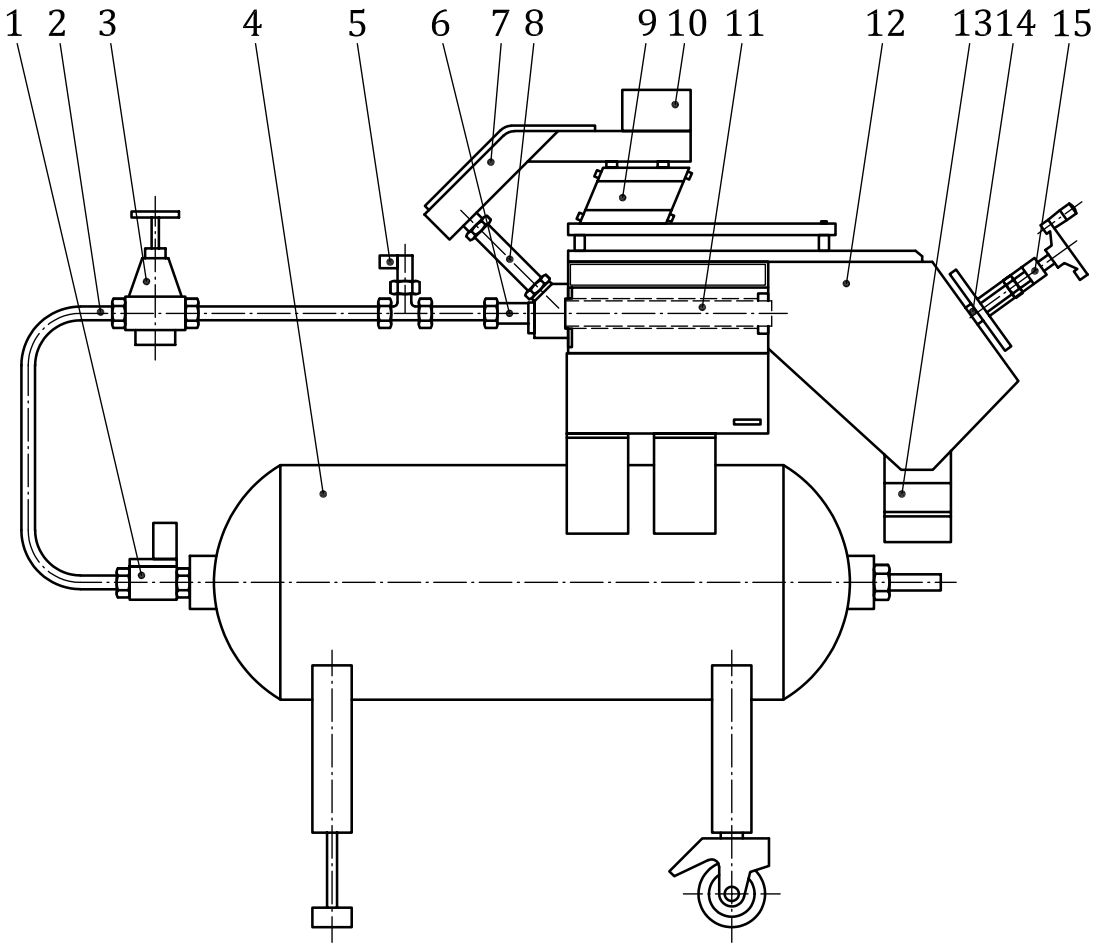
  The falling-weight test 3 is specified in EN 13523-5 and ASTM D2794.

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.

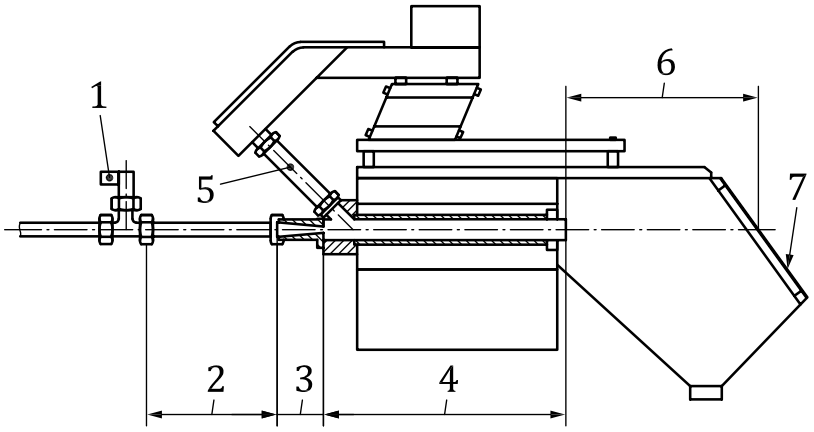
Figure 32 shows an example for the general view of a multi-impact test apparatus. Figure 33 illustrates details for carrying out the test.



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).

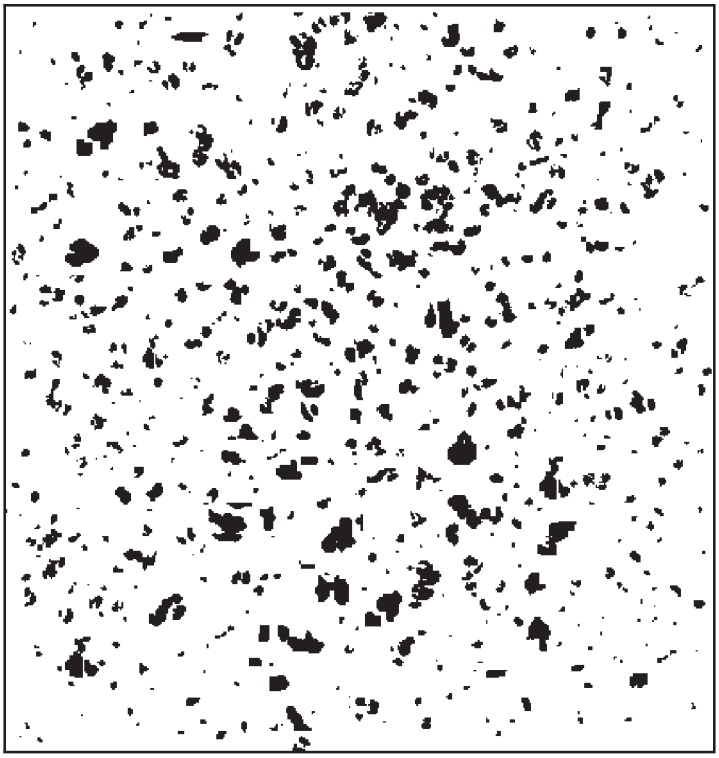


Figure 34 — Reference image for the characteristic value 2,5

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

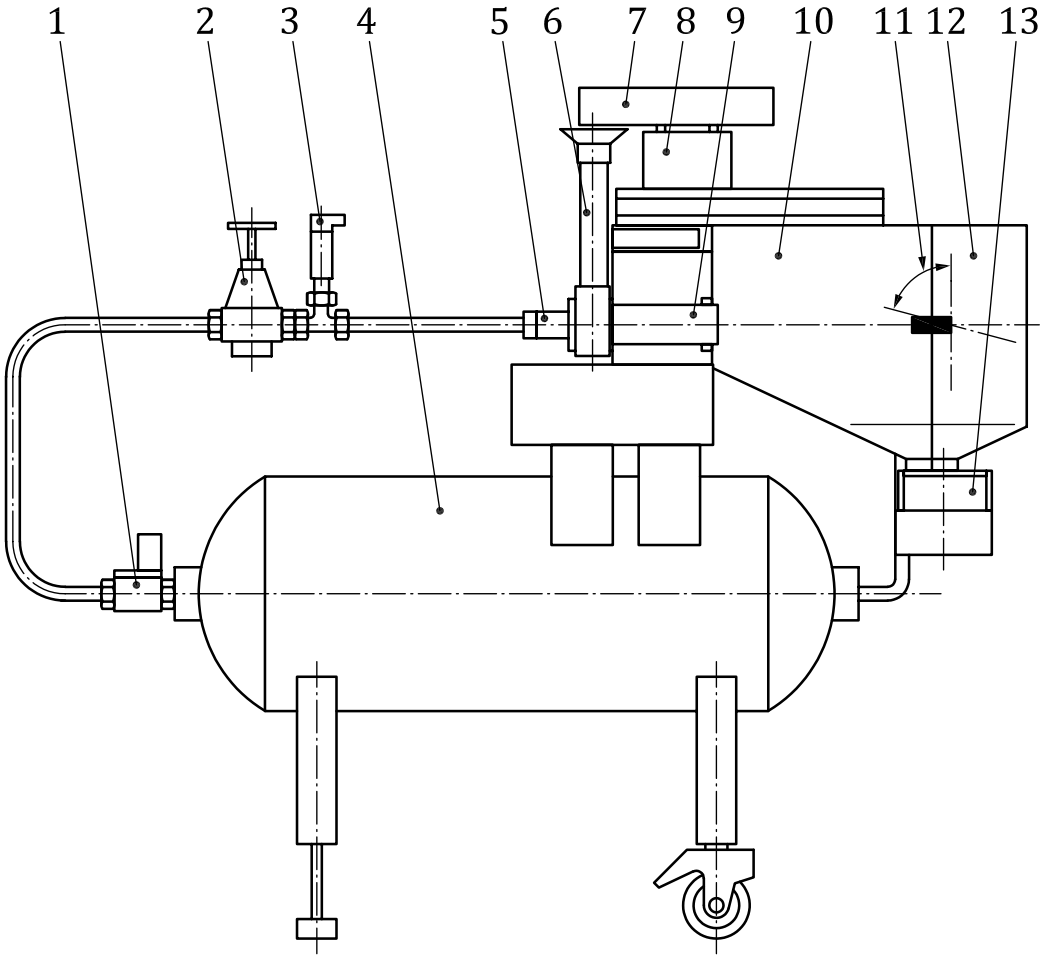
The multi-impact test 1 is specified in ISO 20567-1.

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.

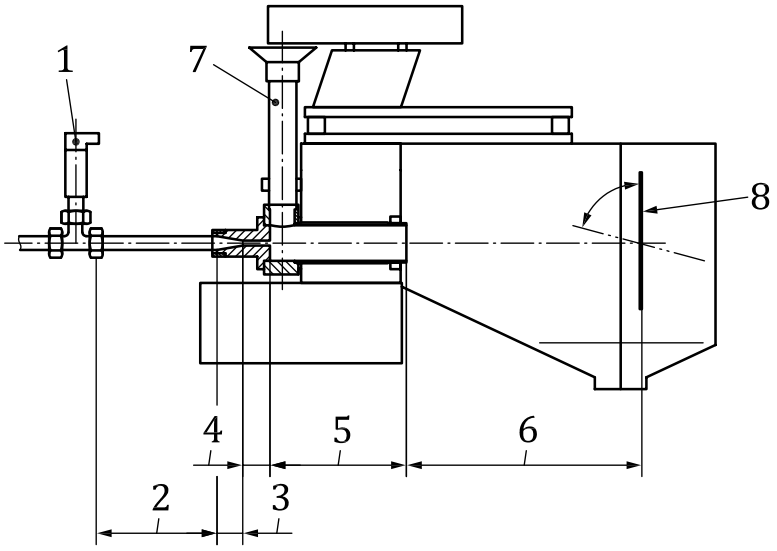
Figure 35 shows an example for the general view of a multi-impact test apparatus. Figure 36 illustrates details for carrying out the test.



Key

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

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.

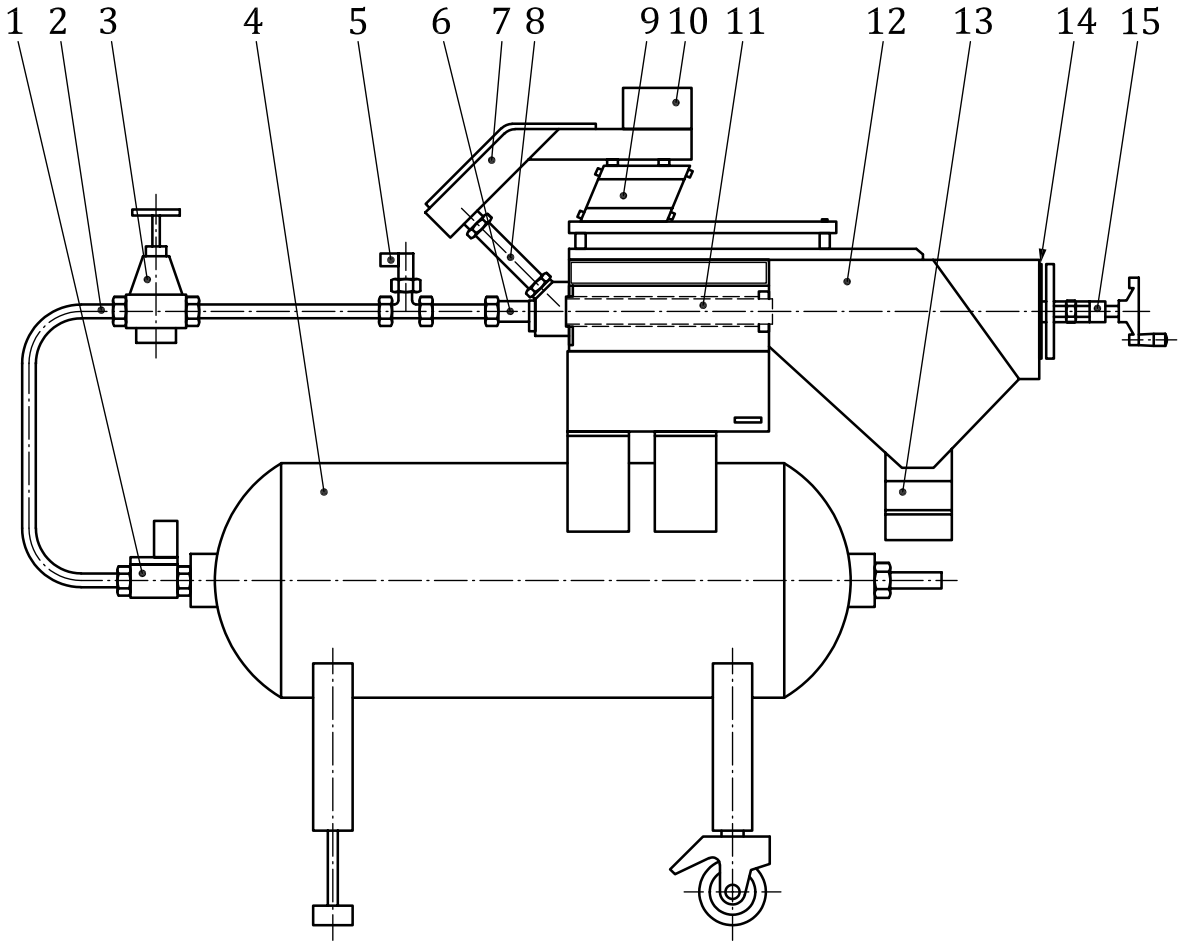
Further methods with different test parameters and evaluations are specified in References [32], [34], [37], [43] and [44].

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).

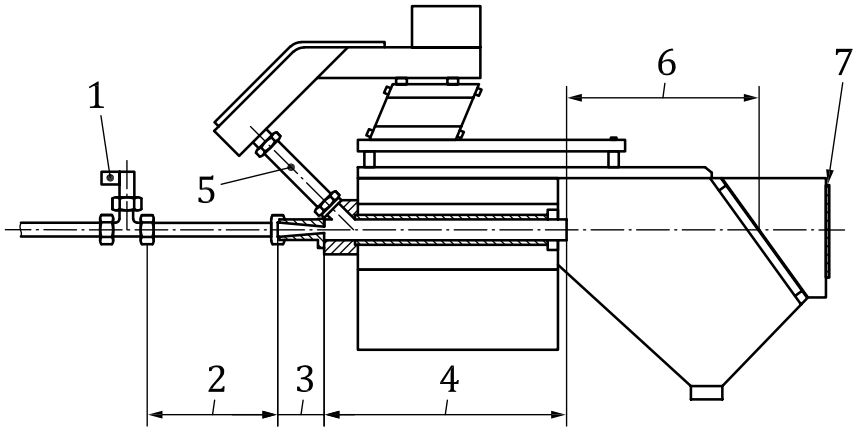
Figure 37 shows an example for the general view of a multi-impact test apparatus. Figure 38 illustrates details for carrying out the test and the dimensions.



Key

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

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

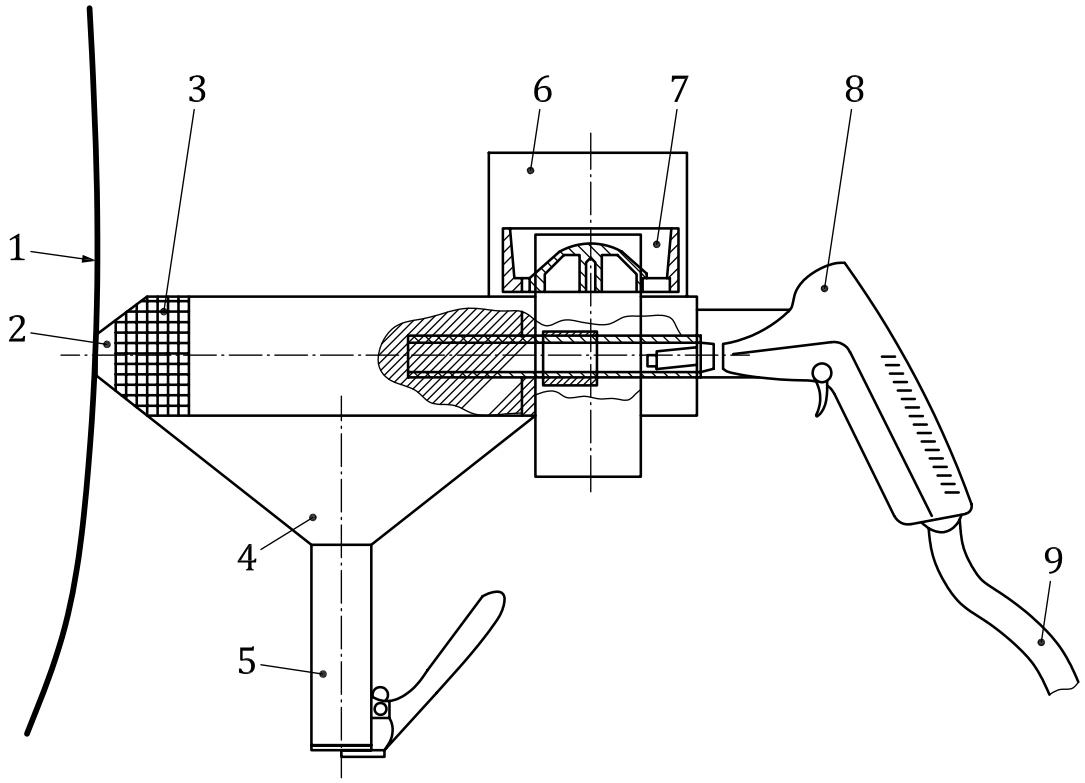
The multi-impact test 3 is specified in Reference [38].

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].

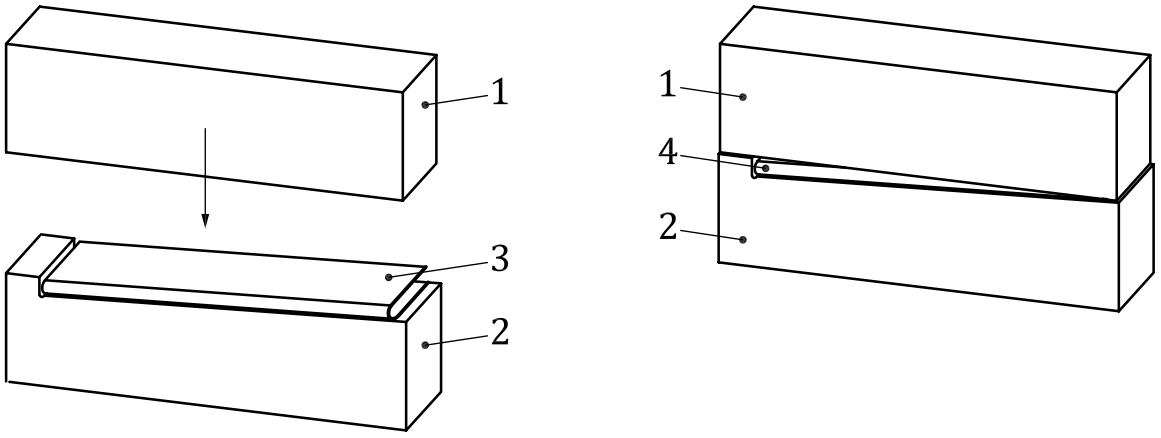
The test apparatus is described in patent specification DE 102 31 802.

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.



a) Test arrangement prior to impact **b) Test arrangement after impact**

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

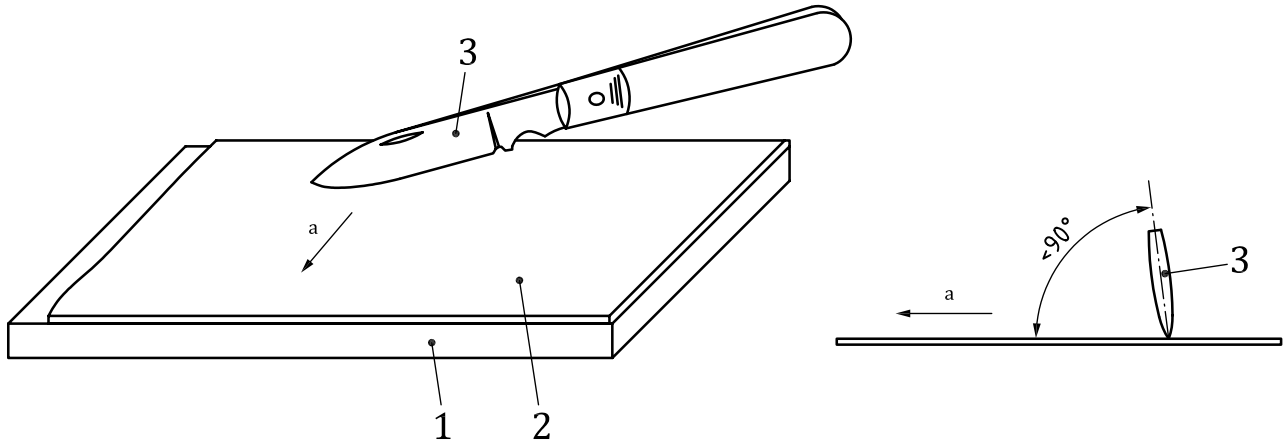
5.1 Tests with single scratch

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

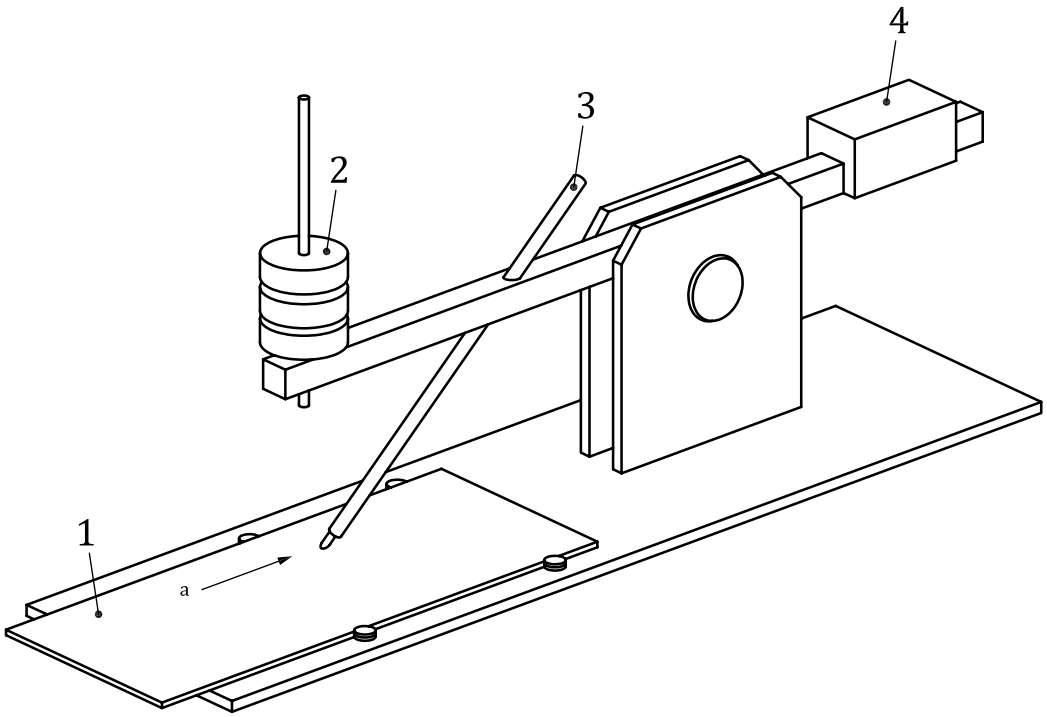
The scratch test 2 is specified in Reference [45].

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

Dimensions in millimetres

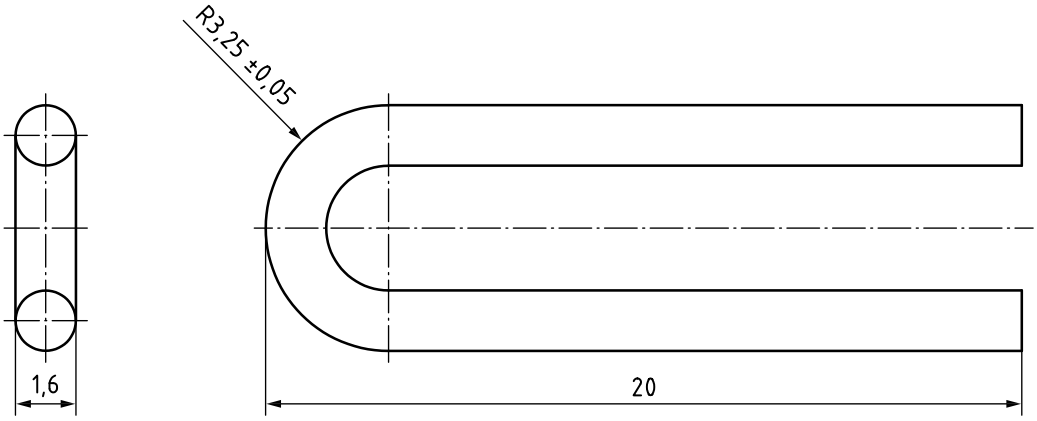


Figure 43 — Test tool (curved stylus)

— 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.

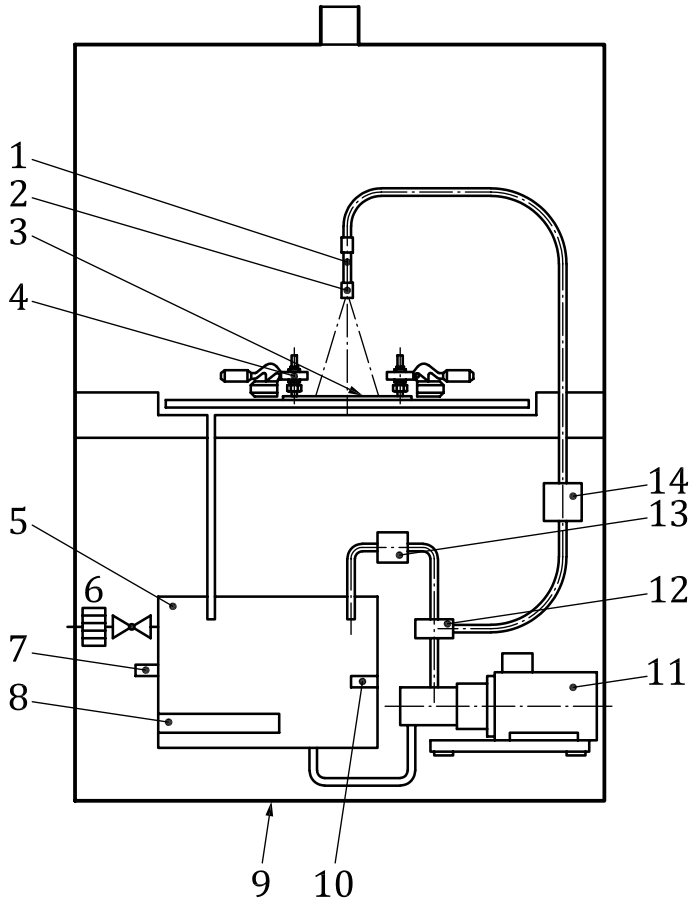
5.2 Test with multiple scratch (without deformation of test specimens)

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 (mm^2) 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

Dimensions in millimetres

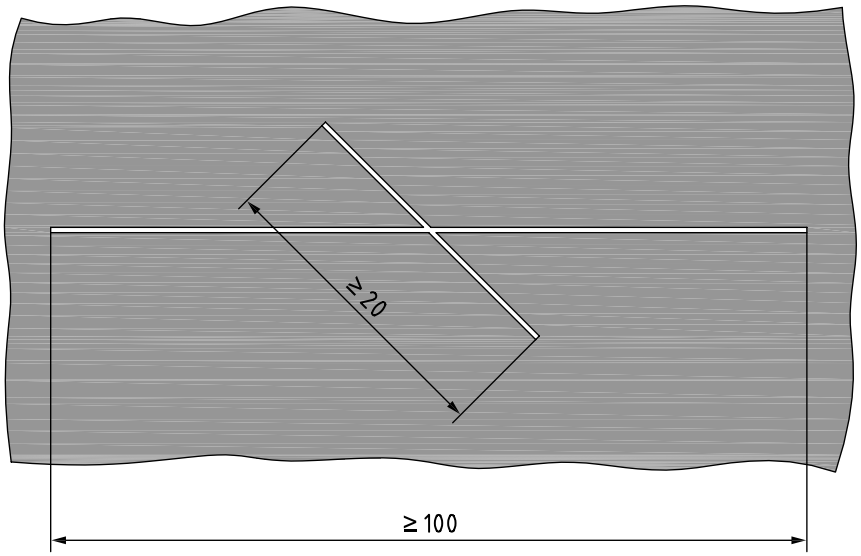


Figure 45 — Introduction of the cuts or scratches (St Andrew's cross)

— 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);

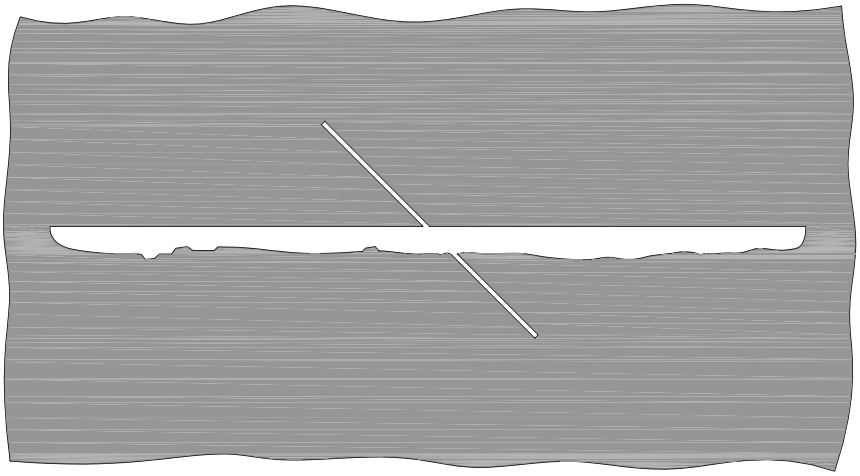
b) jetting time 30 s (test method A) or 60 s (test method B and C).

— Guide the pressure-water jet during the testing time uniformly along the longer cut or scratch (see Figure 45).

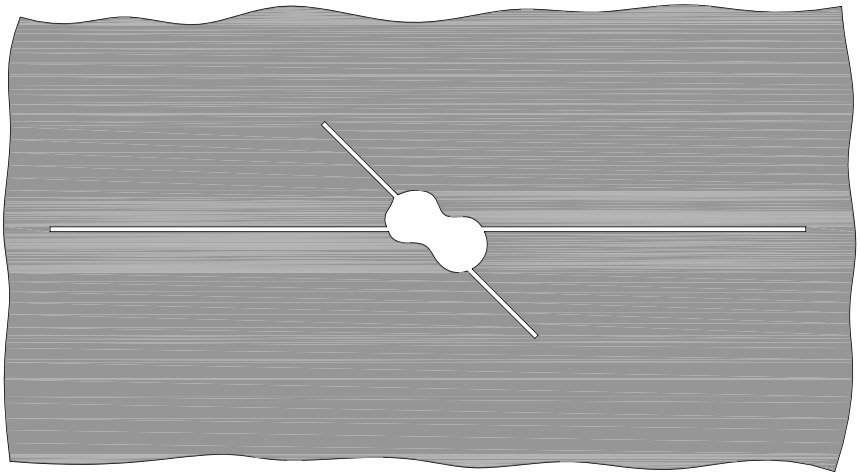
— Evaluation

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.

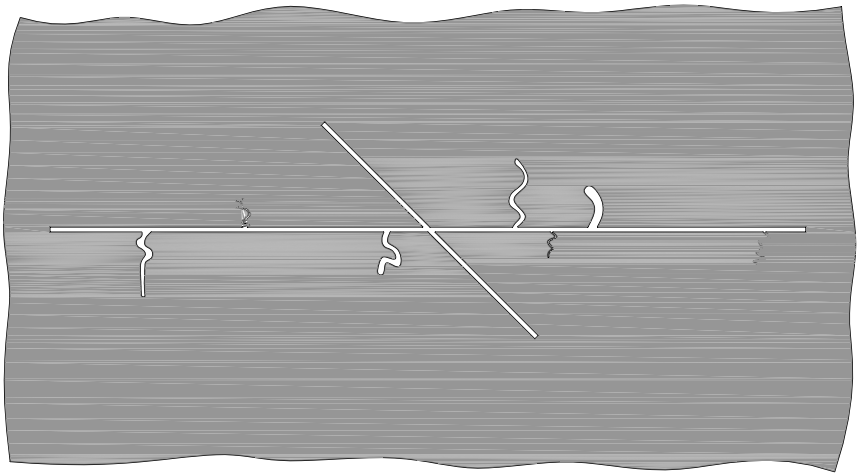
In addition, the total area of defect (mm^2) can be indicated.



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.

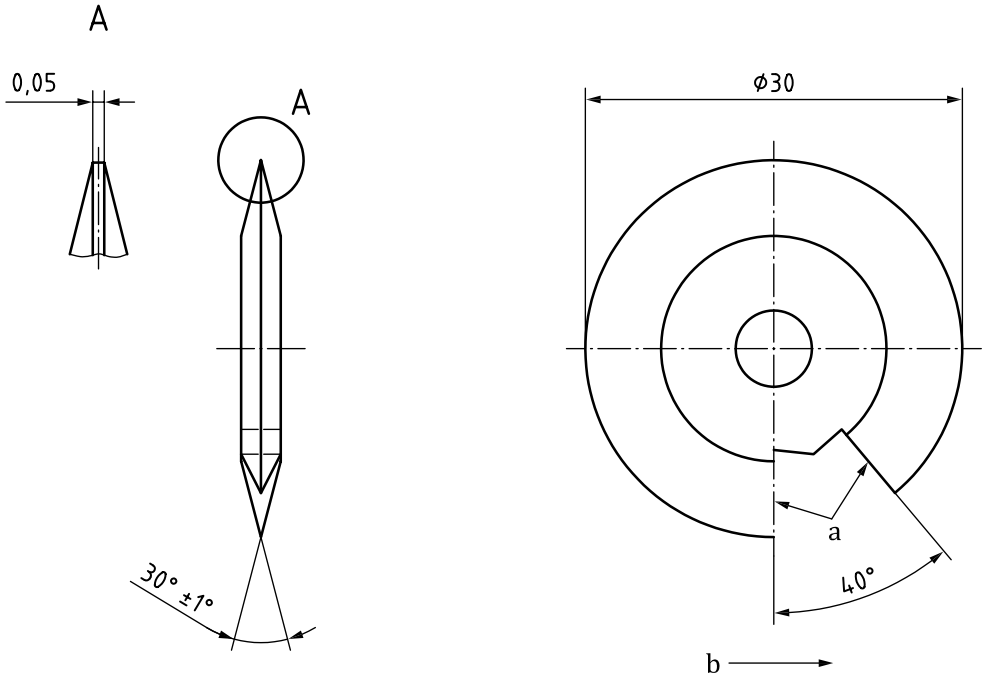
5.2.2 Cross-cut test 1

— Principle

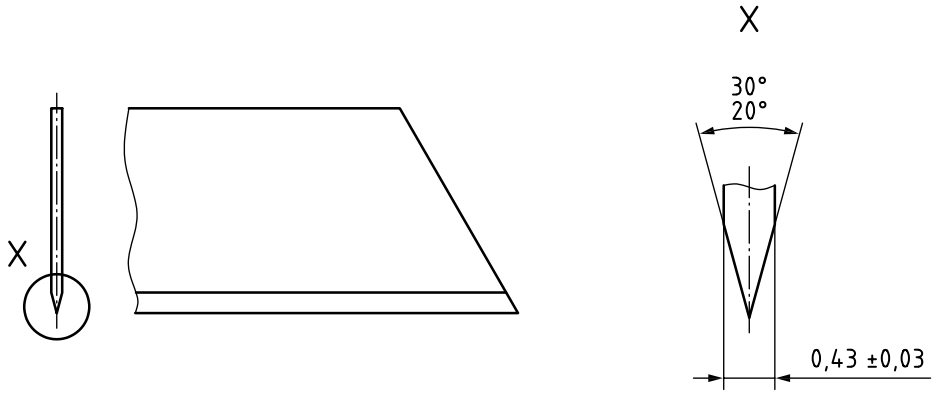
6 parallel cuts are introduced down to the substrate. This process is intersectingly repeated at an angle of 90° so that a lattice pattern is formed, consisting of 25 single square sections. The spacing of cuts is specified in dependence on the substrate and the film thickness. As cross-cutting tools 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



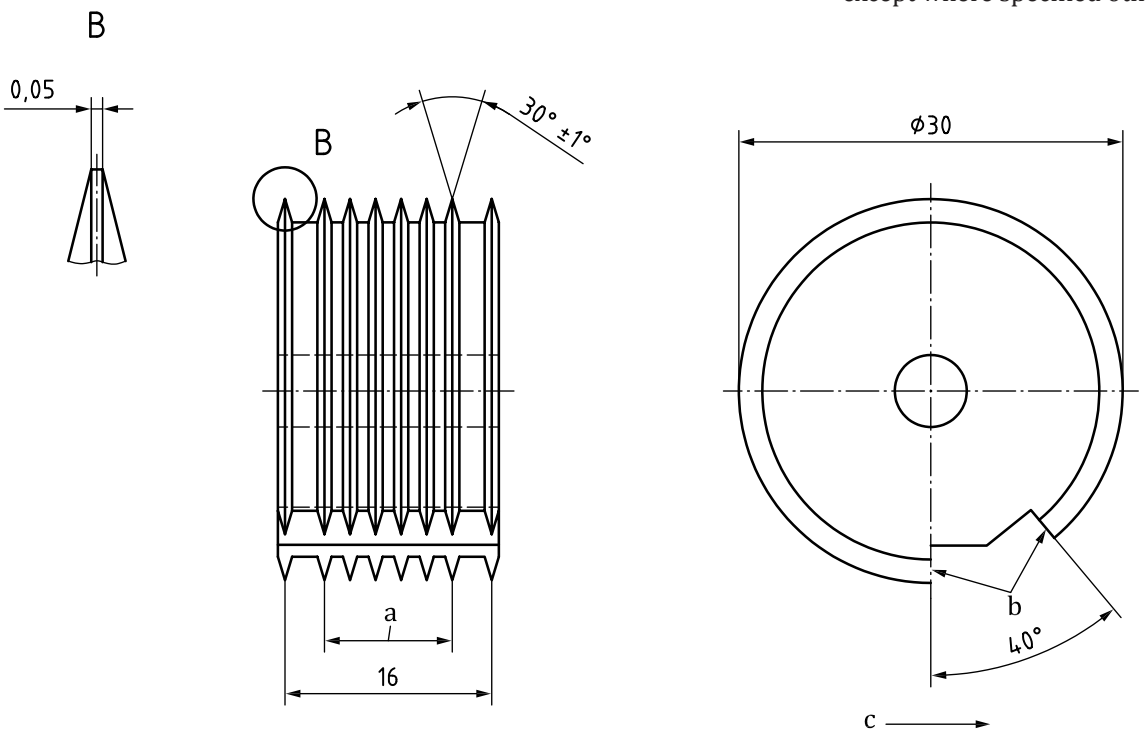
b) Knife blade

a The cutting edge.

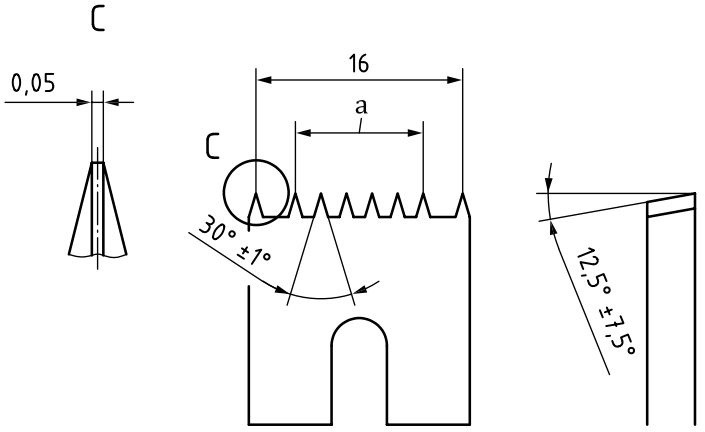
b The direction of the cut.

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;

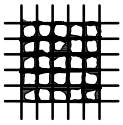
    c) 3 mm for any substrates and film thicknesses in the range of 121 µm to 250 µm.

  — 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.

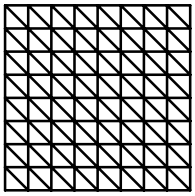


Figure 51 — Square-diagonal grid

— 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.

Dimensions in millimetres

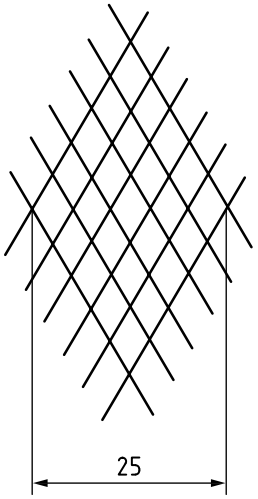


Figure 52 — Rhombus grid

— 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)

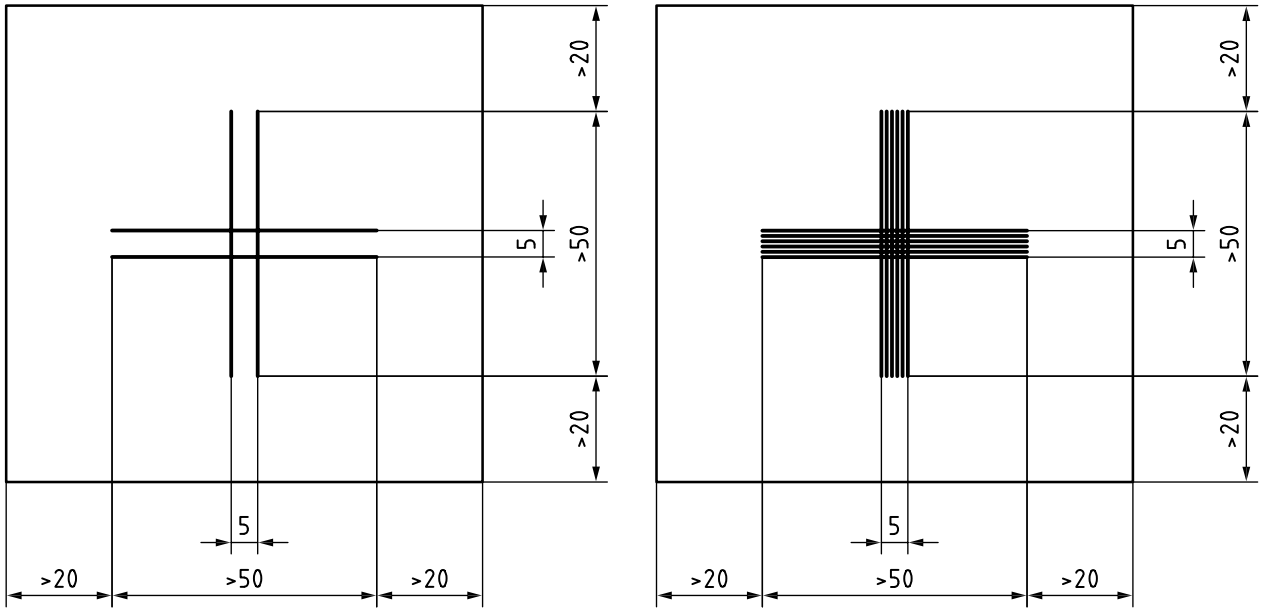
5.3.1 Cupping test 2

— 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).

Dimensions in millimetres



a) Two cuts **b) Six cuts**

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 µm;

b) 2 cuts with 5 mm spacing for film thicknesses greater than or equal to 60 µm.

- Carry out the cross-cut in accordance with Figure 53 at a uniform cutting speed.
- Carry out the cupping to the agreed dimension.
- Remove loose parts of the coating:
  a) for film thicknesses below 60 µm use a knife and tweezers;
  b) for film thicknesses greater than or equal to 60 µm by means of a 60° pull-off with a specified tape.

— Evaluation

The test result is

- for film thicknesses below 60 µm the relative percentage (%) of the coating sections pulled off with the tape.
- for film thicknesses greater than or equal to 60 µm the peeling off as percentage of the distance between the highest position of the bulge and its base line.

— Precision

Precision data are not available at present.

— Reference

The cupping test 2 is specified in EN 13523-6.

6 Evaluation methods for adhesive strength

6.1 Auxiliary methods

6.1.1 Contrasting 1

— Principle

The damaged surface of the coating is exposed to a copper sulfate solution. Defects going down to the steel substrate become clearly visible by chemical precipitation of metallic copper: on steel substrate a copper coloured, well-adhering film precipitates, on a galvanized surface a black coat which can be easily wiped away.

— Application

Contrasting 1 is generally applicable for delaminations, which go down to the (galvanized) steel substrate.

— Procedure

- Prepare the hydrochloric (in accordance with ASTM) or the citric-acid/sulfuric (in accordance with IVLV) copper sulfate (CAS-No 7758-98-7) solution.
- Apply the solution to the coating by means of a soaked cloth (ASTM) or by immersion (IVLV), let react for 15 min (in accordance with ASTM) or 5 min (in accordance with IVLV) and rinse with water.

— For galvanized steel substrate the zinc coat can be dissolved by reaction of the acidic contrasting agent for a longer period. Then, the copper coloured film is formed instead of the black coat which can be easily wiped away.

— Evaluation

The evaluation depends on the selected adhesive strength test method.

— Reference

Contrasting 1 is specified in ASTM D 2794 and Reference [36].

6.1.2 Contrasting 2

— Principle

The test specimen with the damaged coating is immersed in a copper sulfate solution and cathodically polarised (electro-conductively connected) on the substrate side. Defects going down to the substrate become clearly visible by electrochemical deposition of metallic copper.

— Application

Contrasting 2 is generally applicable for delaminations, which go down to the conductive substrate.

— Procedure

— Prepare the sulfuric copper sulfate (CAS-No 7758-98-7) solution.

— Immerse the test specimen together with the counter-electrode and apply a direct voltage (12 V) for 30 s, so that the substrate of the test specimen is cathodically connected. Subsequently rinse with water.

— Evaluation

The evaluation depends on the selected adhesive strength test method.

— Reference

Contrasting 2 is specified in Reference [40].

6.2 Visual methods

6.2.1 Failure pattern analysis

— Principle

The failure pattern is visually characterized based on the types of failure and their areas.

— Application

The failure pattern analysis can be carried out for extended delaminations (e.g. pull-off test).

— Procedure

Visually (with a magnifier, if necessary) assess the delamination area for occurring types of failure and estimate their areas.

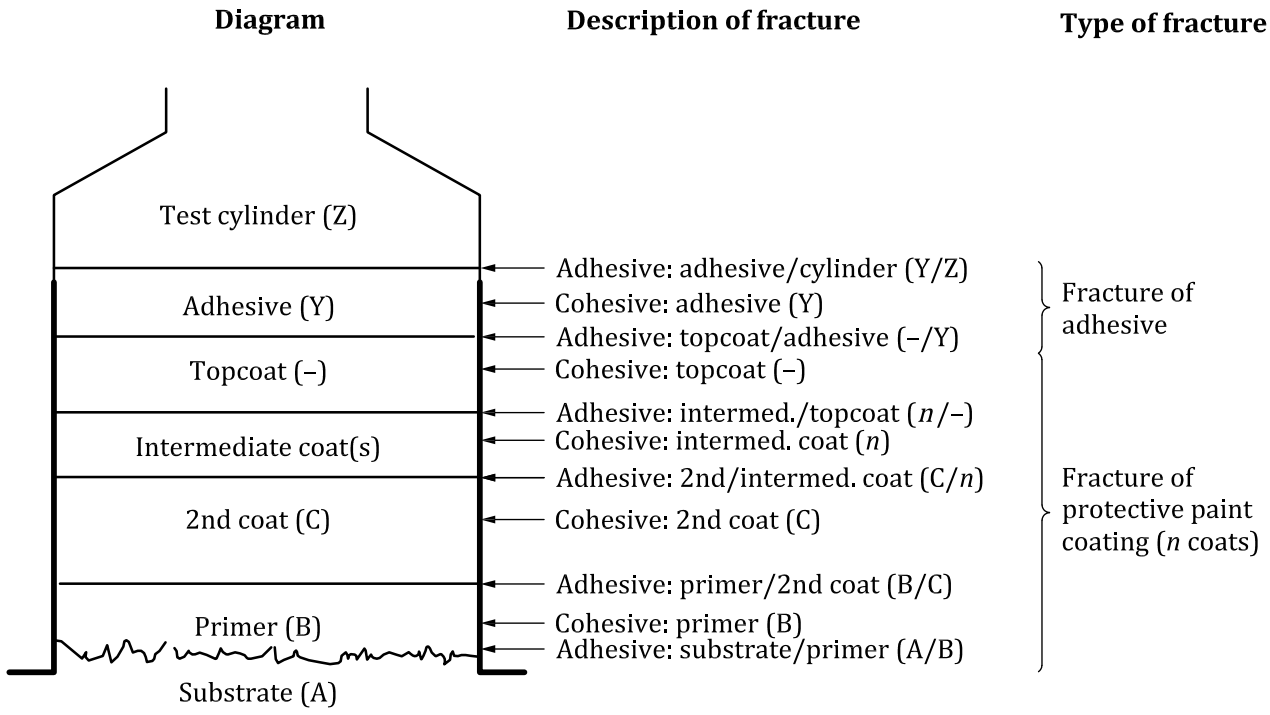
— Evaluation

As a result the obtained types of failure are specified as a symbolic abbreviatory notation (see Table 1 and Figure 54), together with the attributed area percentages (%, in relation to the total area of defect). Estimate the area of failure for each type of failure to 10 % (absolute).

Additionally, the main separation line can be specified.

Table 1 — Visual evaluation of failure patterns

Abbreviatory notation	Type of failure
Y/Z	Adhesion failure between the adhesive and the test cylinder
Y	Cohesion failure in the adhesive
–/Y	Adhesion failure between the top coat and the adhesive
n/*m*	Adhesion failure between the *n*-th and *m*-th coat of a multi-coat system
n	Cohesion failure in the *n*-th coat of a multi-coat system
B/C	Adhesion failure between the first and the second coating
B	Cohesion failure in the first coating
A/B	Adhesion failure between the substrate and the first coating
A	Cohesion failure in the substrate



NOTE The terms "test cylinder" and "adhesive" in Clause 3 refer to the pull-off test and twist-off test.

Figure 54 — Types of failure

— Reference

The failure pattern analysis is specified in ISO 4624 and ISO 16276-1.

6.2.2 Comparison of areas

— Principle

The extent of the delamination is determined by means of a measuring template for areas.

— Application

The comparison of areas can be carried out for all nearly circular delaminations.

— Procedure

— Put the measuring template for areas (see Figure 55) on the delaminated areas of the coating.

— Attribute a circular opening in the template to the delaminated area by visual comparison and read the respective area value (mm^2).

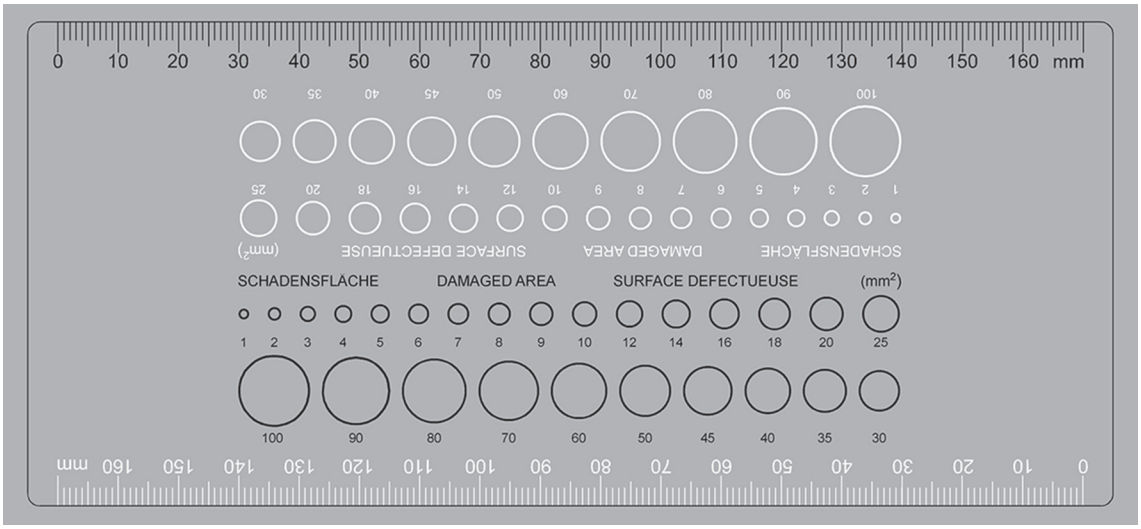


Figure 55 — Measuring template for areas

— Evaluation

As a result indicate the area (mm^2) of the delaminated section.

— Reference

The comparison of areas is specified in ISO 20567-3.

6.2.3 General assessment

— Principle

The defects produced by an adhesive strength test are visually examined in regard to the quantity and/or size and classified in 6 steps by means of criteria.

— Application

The relative assessment is generally applicable.

— Procedure

Visually inspect (as agreed with magnifier) the damaged area of the coating and attribute a characteristic value for the quantity/size of defects to the image by means of specified criteria (see tables 2 and 3).

Table 2 — Characteristic values for the assessment of the quantity of defects

Characteristic value	Quantity of defects
0	None, i.e. no detectable defects
1	Very few, i.e. some just significant defects
2	Few, i.e. small but significant amount of defects

Table 2 *(continued)*

Characteristic value	Quantity of defects
3	Moderate, i.e. medium amount of defects
4	Considerable, i.e. serious amount of defects
5	Dense, i.e. dense pattern of defects

Table 3 — Characteristic values for the assessment of the size of defects

Characteristic value	Size of defects
0	Not visible under 10× magnification
1	Only visible under magnification up to 10×
2	Just visible with normal corrected vision
3	Clearly visible with normal corrected vision (up to 0,5 mm)
4	Range 0,5 mm to 5 mm
5	Larger than 5 mm

— Evaluation

As a result the obtained characteristic value(s) for the quantity or (and) the size of the defects is (are) indicated.

— Reference

The relative assessment is specified in ISO 4628-1.

6.3 Instrumental methods

6.3.1 Digital image evaluation 1

— Principle

The general requirements for an electronic system for image capturing, image editing, image evaluation, and image assessment of coating defects are specified.

— Application

The digital image evaluation 1 is generally applicable.

— Procedure

The procedure depends on the selected test method.

— Evaluation

The evaluation depends on the selected test method.

— Reference

The digital image evaluation 1 is specified in ISO 21227-1.

6.3.2 Digital image evaluation 2

— Principle

Primary images of the test specimen to be assessed as well as of reference test specimens are captured by means of digital image capture under specified conditions. The multi-impact characteristic value is automatically determined by electronic comparison of the digitally edited primary images.

— Application

The digital image evaluation 2 is coordinated with the evaluation of stone-chippings in accordance with multiple-impact test 1 (see 4.3.8).

— Procedure

— Set optimal conditions for image capturing (lighting, image section, resolution).

— Capture primary images of the test panel and reference panels.

— Set a suitable threshold value and have the multi-impact characteristic value determined by the evaluation system by comparing the image data.

— Evaluation

The test result is the obtained multiple-image characteristic value.

Additionally, the main separation line detected by the evaluation system can be indicated.

— Reference

The digital image evaluation 2 is specified in ISO 21227-2.

Annex A

Synoptical tables for the methods

Table A.1 — Adhesive strength tests without scratch/cut

Principle	Method	Reference	Description [evaluation auxiliaries] — Test result	Application	Subclause
Mechanical stress application on the coating	Pull-off test	ISO 4624 ISO 16276-1	Adhered test cylinder, loaded with increasing tensile force → tensile stress (N/mm²) at failure + failure pattern analysis	Generally applicable	4.1.1
	Twist-off test	See 4.1.2	Adhered test cylinder, stressed with increasing torsion moment → shear stress (N/mm²) at failure + failure pattern analysis	Generally applicable	4.1.2
	Peel-off test 1	VOLVO STD 1029,5476[47]	Fabric partially bedded into liquid coating; after curing 90° peel-off with tensile tester → Peel strength (N/width of the fabric) + failure pattern analysis	Automotive coatings	4.1.3
	Peel-off test 2	See 4.1.4	Remove coating from the substrate as defined using a peeling tool → mean peel strength referring to the width of the peel-off (N/mm)	Generally applicable	4.1.4
Continuous deformation of test specimens	Bend test with a conical mandrel	EN 13523-7	Bending around a wedge-shaped conical mandrel of radius (0,5 to 5) mm [magnifier] → (smallest bending radius without delamination) divided by thickness of the substrate	Coil coatings	4.2.1
	Bend test with a conical mandrel	ISO 6860	Bending around a conical mandrel of diameter (3,1 to 38) mm [magnifier] → length of the crack in the coating (mm)	Coatings on deformable substrates	4.2.2
	Bend test with a cylindrical mandrel 1	ISO 1519	Bending around a cylindrical mandrels of diameters (2 to 32) mm → largest diameter of mandrels (mm) for cracking of the coating/ delamination	Coatings on deformable substrates	4.2.3
	Bend test with a cylindrical mandrel 2	EN 13523-7	Bending around a cylindrical mandrels of diameters (1 to 10) mm [magnifier] → (smallest bending radius without delamination) divided by thickness of the substrate	Coil coatings	4.2.4

Table A.1 *(continued)*

Principle	Method	Reference	Description [evaluation auxiliaries] — Test result	Application	Subclause
Continuous deformation of test specimens	Three point bending test	NF T 30-010 EN 1966	Deform test specimen under defined mechanical conditions until the coating cracks → information on adhesion from the force-distance graph	Coatings on deformable substrates	4.2.5
	T-bend test 1	EN 13523-7	Coiling by means of repeated 180° bend [magnifier] → (smallest bending radius without delamination) divided by thickness of the substrate	Coil coatings	4.2.6
	T-bend test 2	ISO 17132	180° bend around distance piece(s) + tape test [magnifier] → smallest distance without cracking of the coating/delamination	Coatings on deformable metal substrates	4.2.7
	Cupping test 1	ISO 1520	Slow cupping with ball tool [microscope] → distance of indenter (mm) until cracking of the coating	Coatings on deformable substrates	4.2.8
Impact stress application	Single-impact test 1	ISO 20567-2	90° impact with guided plunger → total width (mm) of the peeled of coating	Automotive coatings	4.3.1
	Single-impact test 2	ISO 20567-3	88° impact with free flying ball [measuring microscope or magnifier + template for circular areas] → area of the defect (mm^2) + separation line(s)	Automotive coatings	4.3.2
	Single-impact test 3	ISO 4532 VW TL 211[49]	90° impact with guided ball → 2-step classification (“pass/fail”)	Automotive coatings on plastic substrates	4.3.3
	Single-impact test 4	RENAULT D24 1699[39]	45° impact with free flying SiC-coated ball + tape test [measuring magnifier] → mean value of the maximum extents of the defects (mm)	Automotive coatings on plastic substrates	4.3.4
	Falling-weight test 1	ISO 6272-1 ASTM D2794	Dent/bulge with ball and variable falling energy [magnifier] → mass (kg) + minimum falling height (mm) for cracking of the coating	Generally applicable	4.3.5
	Falling-weight test 2	ISO 6272-2 ASTM D2794	Dent/bulge with ball and variable falling energy [chemical contrast treatment + magnifier/testing of pores] → minimum impact energy (kg m) for cracking of the coating	Generally applicable	4.3.6
	Falling-weight test 3	EN 13523-5 ASTM D2794	Bulge with ball and variable falling energy + test tape [magnifier] → maximum falling energy (Joule) without cracking/peeling off of the coating	Coil coatings	4.3.7

Table A.1 *(continued)*

Principle	Method	Reference	Description [evaluation auxiliaries] — Test result	Application	Subclause
Impact stress application	Multi-impact test 1	ISO 20567-1	54° impact with chilled casting granulate + tape test [reference images] → 10-step classification + separation line(s)	Automotive coatings	4.3.8
	Multi-impact test 2	SAE J 400	45°/90° impact with natural gravel + tape test [4 series of reference images / assessment criteria] → 8-step classification	Automotive coatings	4.3.9
	Multi-impact test 3	PSA D24 1312[38]	90° impact with chilled casting granulate + tape test [reference images] → Classification of the delamination defects according to size (in 6 steps) / number (in 5 steps)	Automotive coatings	4.3.10
	Multi-impact test 4	VW PV 3.14.4[48]	90° impact with chilled casting granulate + tape test (reference images) → 4-step classification	Automotive coatings	4.3.11
	Impact-bend test	IVLV Merkblatt 11 Part 5[36]	Test panel bent in a U-shape, impact with wedge-shaped tool [chemical contrast treatment] → length of the crack of the coating (mm)	Paints and varnishes for packagings	4.3.12

Table A.2 — Adhesive strength tests with scratch/cut

Principle	Method	Reference	Description [evaluation auxiliaries] — Test result	Application	Sub-clause
Single scratch	Scratch test 1	DAIMLER PBODC361[31]	Scratching off with blade of a pocket knife [assessment criteria] → 6-step classification	Automotive coatings	5.1.1
	Scratch test 2	VOLVO STD 1029,5473[47]	Scratching off with blade of a pocket knife + manually peeling of the coating [assessment criteria] → 4-step classification	Automotive coatings	5.1.2
	Scratch test 3	ISO 12137-1 ASTM D 2197	Single scratch with variable test load → minimal test force (kg) for peeling off of the coat	Generally applicable	5.1.3
Multiple scratch without deformation of the test specimen	Testing of resistance to pressure-water jetting	ISO 16925	30° X-cut/scratch + defined pressure-water jetting with hot water [reference images] → 6-step classification + optional: area of defect (mm^2)	Coatings on vehicles	5.2.1
	Cross-cut test 1	ISO 2409	90° cross-cut 6 × 1 mm / 6 × 2 mm / 6 × 3 mm [reference images] → 6-step classification	Generally applicable; film thickness up to 250 µm	5.2.2
	Cross-cut test 2	ASTM D 3359 Method B	90° cross-cut 11 × 1 mm / 6 × 2 mm + tape test [magnifier/reference images] → 6-step classification	Generally applicable; film thickness up to 250 µm	5.2.3
	Cross-cut test 3	TOYOTA TSH 1506G[42]	90° cross-cut 11 × 1 mm / 11 × 2 mm + tape test → Number of squares with > 50 % delamination	Automotive coatings	5.2.4
	X-cut test 1	ISO 16276-2	X-cut (30° to 45°) + tape test [reference images] → 6-step classification	Corrosion protection coatings	5.2.5
	X-cut test 2	ASTM D 3359 Method A	X-cut (30° to 45°) + tape test [assessment criteria] → 6-step classification	Generally applicable	5.2.6

Table A.2 *(continued)*

Principle	Method	Reference	Description [evaluation auxiliaries] — Test result	Application	S-ub-clause
Multiple scratch without deformation of the test specimen	X-cut test 3	TOYOTA TSH 1503G[41]	X-cut (30°) + tape test [reference images] V 6-step classification	Automotive coatings	5.2.7
	X-cut test 4	VOLVO STD 1029,5475[46]	X-cut/scratch (20° to 30°) + tape test [assessment criteria] V 4-step classification	Automotive coatings	5.2.8
	Scribe test with square-diagonal grid	FORD FLTM BI 106-01 Method B[33]	90° cross-scratch 9 × 3 mm + diagonal scratches in one direction + tape test [reference images] V 11-step classification	Automotive coatings	5.2.9
	Scribe test with rhombus grid	FORD FLTM BI 106-01 Method D[33]	60° cross-scratch + tape test V 2-step classification (“pass/fail”)	Automotive coatings	5.2.10
Multiple scratch with deformation of the test specimen	Cupping test 2	EN 13523-6	90° cross cut 6 × 1 mm / 2 × 5 mm + slow, limited cupping with ball tool + tape test/manual peeling off the coat [magnifier] V relative percentage of delamination (%)	Coil coatings	5.3.1

Table A.3 — Evaluation methods for adhesive strength

Principle	Method	Reference	Description	Application	Sub-clause
Contrasting	Contrasting 1	ASTM D 2794 IVLV Merkblatt 11 Part 5[36]	Marking of coating defects down to the substrate by means of chemical precipitation of copper from a solution containing $CuSO_4$	(Galvanized) steel substrates	6.1.1
	Contrasting 2	RENAULT D24 1702[39]	Marking of coating defects down to the substrate by means of electrochemical precipitation of copper from a solution containing $CuSO_4$	Electrically conductive substrates	6.1.2
Visual assessment	Failure pattern analysis	ISO 4624 ISO 16276-1	Assessing the pulled-off area by compiling a failure pattern classification based on types of failures and their area percentages	Defects caused by pull-off test	6.2.1
	Comparison of area	ISO 20567-3	Classification of (nearly) circular areas of defect by means of a template for circular areas	Single-impact defects	6.2.2
	General assessment	ISO 4628-1	Assessment system for 6-step classification of coating defects according to number/size	Generally applicable	6.2.3
Instrumental assessment	Digital image evaluation 1	ISO 21227-1	General guidelines for digital image capturing and image editing for the evaluation of coating defects	Generally applicable	6.3.1
	Digital image evaluation 2	ISO 21227-2	Application of digital image capturing and image editing on the evaluation of multi-impact defects	Stone-chipping defects after multi-impact stone-chipping test 1	6.3.2

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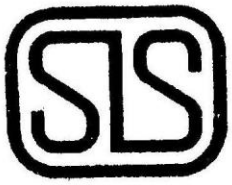

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The Sri Lanka Standards Institution (SLSI) is the National Standards Organization of Sri Lanka established under the Sri Lanka Standards Institution Act No. 6 of 1984 which repealed and replaced the Bureau of Ceylon Standards Act No. 38 of 1964. The Institution functions under the Ministry of Science & Technology.

The principal objects of the Institution as set out in the Act are to prepare standards and promote their adoption, to provide facilities for examination and testing of products, to operate a Certification Marks Scheme, to certify the quality of products meant for local consumption or exports and to promote standardization and quality control by educational, consultancy and research activity.

The Institution is financed by Government grants, and by the income from the sale of its publications and other services offered for Industry and Business Sector. Financial and administrative control is vested in a Council appointed in accordance with the provisions of the Act.

The development and formulation of National Standards is carried out by Technical Experts and representatives of other interest groups, assisted by the permanent officers of the Institution. These Technical Committees are appointed under the purview of the Sectoral Committees which in turn are appointed by the Council. The Sectoral Committees give the final Technical approval for the Draft National Standards prior to the approval by the Council of the SLSI.

All members of the Technical and Sectoral Committees render their services in an honorary capacity. In this process the Institution endeavours to ensure adequate representation of all view points.

In the International field the Institution represents Sri Lanka in the International Organization for Standardization (ISO), and participates in such fields of standardization as are of special interest to Sri Lanka.

Printed at the Sri Lanka Standards Institution, 17, Victoria Place, Elvitigala Mawatha, Colombo 08.