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Thermal spraying — Tubular coating tensile test

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European foreword

This document (EN 17393:2020) has been prepared by Technical Committee CEN/TC 240 “Thermal spraying and thermally sprayed coatings”, the secretariat of which is held by DIN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2021, and conflicting national standards shall be withdrawn at the latest by January 2021.

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Introduction

The determination of tensile strength of a thermally sprayed coating can be of substantial importance regarding product-supporting quality control as well as coating development and, moreover, can have an effect on important factors such as transfer efficiency, microstructure, surface quality, etc. Only a little effort is required to carry out the tubular coating tensile test (TCT). However, it provides reproducible values for the mechanical strength of sprayed coatings and gives information on influences resulting from spraying conditions.

Microscopic examinations of the fractured surface can provide further information on failure modes and support the quality assessment of the coating microstructure as well as the assessment of influences resulting from loads during the TCT test.

1 Scope

This document specifies the procedure for the determination of coating strength, and hence of cohesive strength in a tubular coating tensile test.

The test is intended to determine the tensile coating strength parallel to the spray layers (normal to the spray direction) and to identify differences in particle cohesion quality, as caused by defects as internal delamination at cracks or oxides between the spray particles or splats.

The tubular coating tensile test is suitable for sprayed coatings deposited using metallic materials (not carbides and ceramics).

The tubular coating tensile test is not suitable for fused sprayed coatings deposited using self-fluxing alloys.

The test supports quality assurance and is intended to be applied for the purpose of coating optimization by identifying the influences of coating parameters and spray materials on the coatings' quality. Furthermore, the coating in particular for cold sprayed coatings can be compared with the characteristics of similar solid materials and the coating's quality can be assessed.

This test is not recommended for thin coatings (coating thickness < 500 µm), since massive scattering of results is to be expected here. Due to the size of the specimen, it is particularly suitable to apply the tubular coating tensile test for coating processes that use a concentrated spray jet and a highly focused spray spot, as in the case of cold spraying, high velocity flame spraying (HVOF) or plasma spraying. Applying the tubular coating tensile test for coating processes that use a broad spray jet, such as flame spraying and arc spraying, may require special spraying measures, e.g. the use of a template to ensure a nearly vertical impingement angle.

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.

EN ISO 14916, *Thermal spraying — Determination of tensile adhesive strength (ISO 14916)*

EN ISO 14917, *Thermal spraying — Terminology, classification (ISO 14917)*

EN ISO 7500-1:2018, *Metallic materials — Calibration and verification of static uniaxial testing machines — Part 1: Tension/compression testing machines — Calibration and verification of the force-measuring system (ISO 7500-1:2018)*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN ISO 14917 and the following apply.

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <https://www.iso.org/obp>

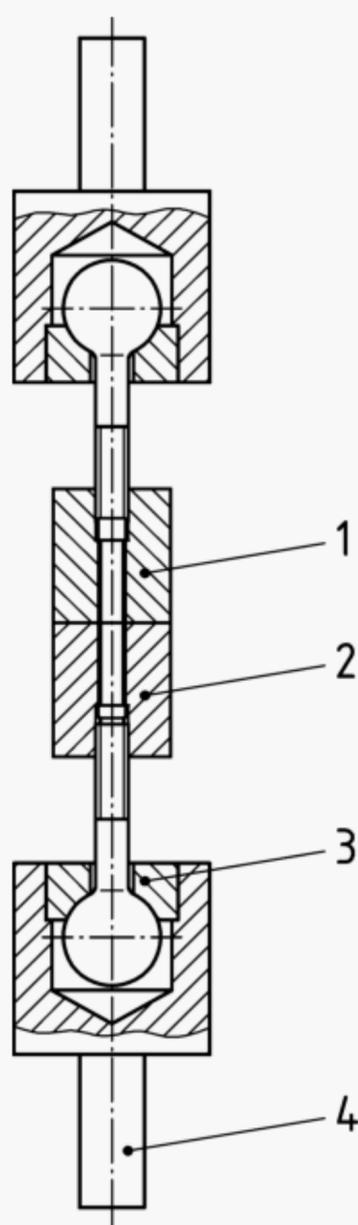
3.1 tensile coating strength

$R_{m,TCT}$

tensile strength of the coating determined in a tension test, parallel to the coating layers (normal to the spray direction), which is calculated from the quotient of the maximum load F_m and the coating's cross-section

4 Testing equipment

A tensile testing machine in accordance with EN ISO 7500-1:2018, class 1, shall be used having a suitable clamping system to ensure concentric clamping and loading of the specimens, see Figure 1.



Key

- 1 substrate 1
- 2 substrate 2
- 3 ball joint
- 4 clamping part

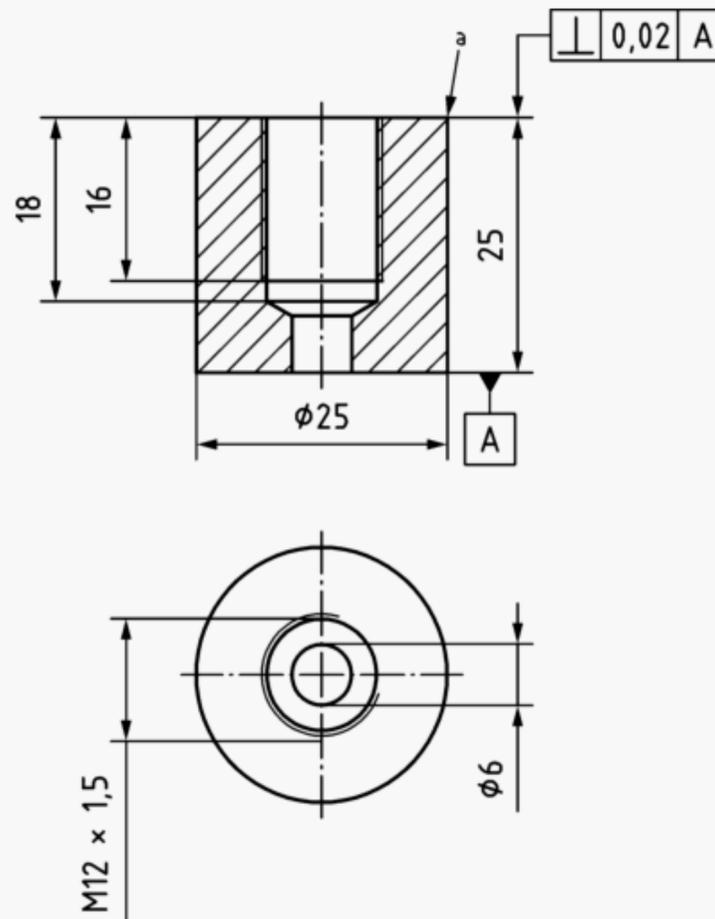
Figure 1 — Tubular coating tensile test arrangement

5 Specimens

5.1 Shape of base samples

The base samples are made of aluminium or non alloy steel. Their outer dimensions shall be equal to those of the specimens used in the determination of tensile adhesive strength according to EN ISO 14916 (diameter: 25 mm or 40 mm), and they have a central bore (6 mm through bore) for fixation, see Figure 2. Rounding or chamfering the front face is not permitted.

Dimensions in millimetres



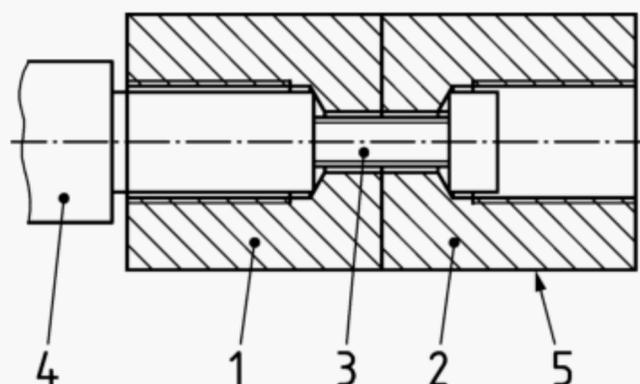
Key

a sharp edge

Figure 2 — Base sample

5.2 Preparation of the specimen to be sprayed

Install the base samples in the fixture, see Figure 3, and adjust them to the maximum common diameter (tolerance $\pm 0,02$ mm) using a lathe. A uniform surface quality Rz of about $40 \mu\text{m}$ shall be achieved. This type of levelling is important, because otherwise a discrepancy between the two cylinders would significantly weaken the coating that is to be applied. The diameter that is reached, D_i , which is represented in the drawing as the outer diameter of the specimen (underneath the coating), shall be recorded.



Key

- 1 substrate 1
- 2 substrate 2
- 3 fixing screw
- 4 fixture
- 5 coating

Figure 3 — Specimen to be sprayed (consisting of 2 base samples)

5.3 Specimen to be sprayed, preparation and coating

The preparation of the specimen to be sprayed as well as the spraying parameters, such as the spraying procedure, spray material, coating thickness, energy data, movement pattern, etc., shall be in accordance with the specifications for the spraying procedure of the corresponding workpiece, if any.

The rotating specimen to be sprayed shall be coated over the entire length of its outer surface.

The temperature of the specimen to be sprayed shall under no circumstances exceed those values reached when spraying the corresponding workpiece, if any, which can occur particularly when applying coatings of larger thicknesses. The sprayed specimen shall be removed from the fixture and the central fixing screw shall be taken out. Then the specimen can be directly tested in a tensile testing machine using the same clamping devices as in the tensile adhesive strength test according to EN ISO 14916. See Figure 1 in Clause 4.

5.4 Determination of outer diameter

After spraying, and before the test, the outer diameter shall be measured in at least 3 points along the surface of the cylinder length of the spray specimen, where one section shall be on the junction between the base samples. For each measurement section, the diameter shall be measured rotated by 90°, and the mean value shall be calculated.

The maximum diameter tolerance is $\pm 0,01$ mm.

Only suitable instruments, which need to be calibrated and traceable to national standards, shall be used during measurement. They shall be capable of measuring the diameter with an accuracy of at least 0,01 mm.

5.5 Number of specimens to be tested

Three specimens, which have been coated in one spray cycle using identical process parameters, shall be tested.

6 Test procedure

The specimen, with attached clamping arrangement, is inserted torque-free and bending-free into the tensile testing machine and loaded in tension at a constant rate and shock-free until fracture occurs.

The yoke moves at a speed of $(1 \pm 0,24)$ mm/min or $(0,017 \pm 0,004)$ mm/s until breakage occurs. The maximum load F_m , in kN shall be recorded.

Testing is performed at room temperature. For a series of tests, equal test conditions shall be ensured.

7 Possible sources of fault during procedure

Possible sources can be:

- a) irregular coating thickness;
- b) coating thickness is too small;
- c) coating thickness is too large;
- d) testing speed is too high;
- e) clamping inside the tensile testing machine not torque-free or bending-free.

8 Evaluation

When loaded in tension, the geometrical arrangement of base samples and the coating causes stress concentrations at the front faces of the base sample as a result of the notch effect. This shall be taken into account for comparison with conventional tensile tests. The notch factor K has been determined by simulations based on FEM and verified by experiments.

For the calculation of tensile coating strength according to this TCT test, the following values shall be assumed:

- for aluminium base sample: $K = 1,5$;
- for non alloy steel base sample: $K = 1,7$.

The tensile coating strength determined by TCT test is obtained with Formula (1) as follows:

$$R_m = K \times R_{m,TCT} \quad (1)$$

where

R_m is the tensile coating strength in MPa;

K is the notch factor;

$R_{m,TCT}$ is the coating strength in MPa measured during the TCT test.

EXAMPLE Determination of tensile coating strength (base samples made of aluminium)

$D_a = 26,1$ mm (diameter of the specimen after thermal spraying)

$D_i = 24,05$ mm (diameter of the specimen before thermal spraying)

$F_m = 25,13$ kN (maximum reached tensile load)

$$R_{m,TCT} = \frac{4 \times F_m}{(D_a^2 - D_i^2) \times \pi}$$

$$R_{m,TCT} = 311 \text{ MPa}$$

$$R_m = 1,5 \times R_{m,TCT} = 466 \text{ MPa}$$

9 Test report

The following shall be documented in the test report for each specimen:

- a) reference to this standard, i.e. EN 17393:2020;
- b) inspection body, examiner, date;
- c) material of the base samples;
- d) specification of the spray material;
- e) preparation of the base sample surface to be coated;
- f) spraying procedure;
- g) thickness of coating (tolerance: $\pm 0,01$ mm);
- h) designation of specimen and diameter (D_a and D_i ; tolerance: $\pm 0,01$ mm);
- i) tensile strength in MPa for each single specimen as well as the averaged value of the three specimens of a series;
- j) standard deviation;
- k) results of the metallographic inspection or reference to its report number.

An example of a test report is given in Annex A (informative).

Annex A (informative)

Test report for the tubular coating tensile (TCT) test according to EN 17393

The user of this form is permitted to reproduce this form without prejudice to the rights of CEN regarding the entirety of the document.

A.1 General

Manufacturer: Inspection body:
Component designation: Substrate material:
Function of the coating: Chemical analysis:
Procedure qualification:

A.2 TCT specimen

Material of the specimen: Nominal diameter:

A.3 Surface preparation for spraying

Programme no.:
Specimen degreased: passed/failed
Blasting procedure (manually/mechanised):
Blasting medium, type: Grain size:
Blasting pressure: bar Blasting distance/angle:
Visual inspection: Cleanliness, uniformity, acc. to EN ISO 8501-1: passed/failed
Roughness, e.g. acc. to EN ISO 8503-1: passed/failed
Date/time of blasting:

A.4 Spraying procedure for TCT specimens — Component

Spraying procedure acc. to EN ISO 14917: Date/time of spraying:
Spraying instruction (TSPS) for component: /TSPS for TCT specimen:
Spraying manually:yes/no
Spraying mechanised: Spraying programme no.: Rev. Index:
Spray material:
Designation according to standard:
Grain size/wire diameter:

Chemical composition (main elements):

Pre-heating: yes/no Pre-heating temperature: °C Cooling: yes/no Cooling medium:

Spraying distance: mm

Surface velocity:m/min (relative velocity between spray torch and component)

Coating thickness: as sprayed: Roughness as sprayed: *Rz*

Number of TCT specimens sprayed:

Thermal sprayer/operator:

A.5 Preparation of specimens for the tubular coating tensile (TCT) test

Number of TCT specimens tested:

Nominal outer diameter of the coated specimen: mm

A.6 Testing of TCT specimens

Inspection body:

Transport of specimens necessary: yes/no

Testing machine: Designation no.: Type: EN ISO 7500-1, class 1

Testing apparatus: Type: ball joint/universal joint:

Increase of load: N/s /mm/s

Conditions: Ambient temperature: °C;

Date/time of test:

A.7 Test results

Tubular coating tensile (TCT) test	Unit	Required value	Measured values				
			1	2	3	4	5
Specimen no.		-					
Specimen designation		-					
Outer diameter of specimen	mm	-					
Tested area	mm ²	-					
Coating thickness	µm						
Coating strength $R_{m,TCT}$	MPa						
Coating strength R_m	MPa						
		Results	Test result: P/F^a				
			Passed	Failed			
Target value	MPa						
Arithmetic mean	MPa						
Standard deviation	MPa						
Relative standard deviation	%						
^a P = passed; F = failed							

Date of issue:

Verifying:

For inspection body:

Name: Signature:

For manufacturer:

Name: Signature:

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