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ISO 21452

Specification and requirements of thermal spray coatings for power plant boiler tubes

Spécification et exigences des revêtements de projection thermiques pour les tubes de chaudière des centrales électriques

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Foreword

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This document was prepared by Technical Committee TC 107, *Metallic and other inorganic coatings*.

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

Introduction

Thermal power generation is the main form of power generation in the world. As an important part of the thermal power plant, the safe and stable operation of the boiler is very important for the thermal power plant. However, the four tubes of the boiler (water wall, superheater, reheater and economizer) are in contact with the flame or high-temperature flue gas for a long time, and the working environment is harsh. During operation, the tubes are affected by wear, high-temperature oxidative corrosion, high-temperature operation and other factors, which lead to leakage and directly threaten the safe operation of the thermal power plant. Thermally sprayed technology is an effective technology to improve the surface quality and prolong the service life of boiler tubes. So far, thermal spraying technology and metal and metal ceramic coatings have been widely used in the protection of various boilers (such as circulating fluidized bed boilers and biomass boilers) in the global energy industry. In the process of power plant operation, the type of coating is determined by the specific working conditions of various boiler tubes.

This document provides guidance for the application of thermal sprayed coatings on four boiler tubes and promotes technical progress in the energy industry.

Specification and requirements of thermal spray coatings for power plant boiler tubes

1 Scope

This document specifies the procedure and requirements of thermal sprayed coatings for water walls and superheaters of coal-fired and biomass boilers involving the selection of coating materials, pre-treatment, 12/15CrMoV steel substrate preparation and post-treatment as well as the quality and performance evaluation of the coatings.

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 3233-1, *Paints and varnishes — Determination of percentage volume of non-volatile matter — Part 1: Method using a coated test panel to determine non-volatile matter and to determine dry-film density by the Archimedes' principle*

ISO 11357-4, *Plastics — Differential scanning calorimetry (DSC) — Part 4: Determination of specific heat capacity*

ISO 13826, *Metallic and other inorganic coatings — Determination of thermal diffusivity of thermally sprayed ceramic coatings by laser flash method*

ISO 14918, *Thermal spraying — Qualification testing of thermal sprayers*

3 Terms and definitions

For the purpose of this document, the following terms and definitions shall apply.

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

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

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

3.1
coal-fired boiler
equipment that produces steam or hot water through heat exchange between the heat energy released by the combustion of coal

3.2
biomass boiler
equipment that produces steam or hot water through heat exchange between the heat energy released by the combustion of biomass

3.3
water wall
wall mainly used to absorb the radiant heat emitted by the flame and high-temperature flue gas in the furnace

Note 1 to entry: Usually laid on the inner wall of the furnace, the water wall has the role of cooling and protecting the furnace wall.

3.4
superheater
component of a boiler system that heats the steam above its saturation temperature, also known as a steam superheater

4 Recommended thermal spray coating materials for boiler tubes

This document recommends the appropriate coatings for the following boiler tubes:

a) water wall of a coal-fired boiler;

b) superheater of a coal-fired boiler;

c) water wall of a biomass boiler;

d) superheater of a biomass boiler.

Generally, damage to tubes includes corrosion, wear, coking and so on. Therefore, on the basis of the failure type, the coating materials outlined in Table 1 are recommended.

Table 1 — Failures and recommended coating materials for variable boiler tubes

Rollers	Failures				Tube materials	Recommended coating materials
	Corrosion	Wear	Fatigue	Coking		
Water wall of a coal-fired boiler	/	√	√	√	12/15 Cr1MoV steel	NiCrTi NiCr-B_4C NiCr-Cr_3C_2
Superheater of a coal-fired boiler	/	√	/	√	12Cr1MoV steel	FeCrBMoC NiCr-Cr_3C_2
Water wall of a biomass boiler	√	√	√	√	15 Cr1MoV steel	NiCrBSi NiCrMoNb
Superheater of a biomass boiler	√	√	/	√	12/15 Cr1MoV steel	NiCrMoNb
NOTE In this table, "√" means "possessing this failure form" and "/" means "there is no such failure form".						

5 Preparation of thermal spray coatings for variable boiler tubes

5.1 Pre-treatment of variable boiler tubes

The surface of the tubes shall be inspected and reviewed to ensure their suitability before spraying. The following surface preparation procedure is recommended:

a) Surface cleaning: Remove all kinds of impurities on the surface of the object, such as grease, dirt, oxide scale and rust, especially the welding part at the root of the pipe. No oxide scale and other impurities that hinder the coating or coating adhesion are allowed. The suggested steps are as follows:

1) Alkali washing: The boiler tube is cleaned with alkaline solution and the temperature is heated to 70 °C to 80 °C for 48 h. Among them, the mass concentration of Na_2CO_3 is 0,5 % to 1 % and the mass concentration of NaOH is 0,3 % to 0,5 %.

2) After alkali washing, clean the boiler tube with water until the pH value is 7 to 8.

3) Acid pickling: The boiler tube is cleaned with acid solution and the temperature is heated to 70 °C to 80 °C for 48 h. Among them, the mass concentration of hydrochloric acid is 6 % and the mass concentration of corrosion inhibitor is 0,3 %.

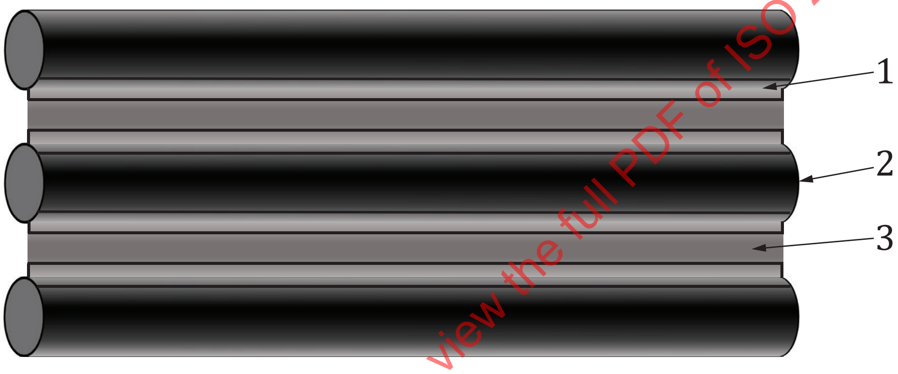
4) After pickling, rinse boiler tube surface with water to neutral.

b) Surface roughening: Dry sandblasting is recommended. Quartz sand with nominal grain size 1,00 mm to 1,40 mm or corundum sand shall be used as an abrasive for sandblasting, and 0,83 to 1,00 mm quartz sand, nominal grain size 0,85 mm to 1,18 mm, is preferred for sandblasting in the furnace. The compressed air pressure used while sandblasting should be greater than 0,4 MPa and 0,1 MPa for a suction blast system and a pressure blast system, respectively. Compressed air shall be free of oil and water. The sandblasting distance is 100 mm to200 mm and the included angle is 45° to 70°. The final surface roughness, Ra, shall be 5,4 µm to 6,0 µm after sandblasting. After sandblasting, the surface of the pipe that passes the inspection shall be protected from secondary oil contamination. The workpiece storage time shall not exceed 4 h before thermal spraying. When the humidity is greater than 85 %, the storage time shall be reduced to 2 h.

5.2 Thermal spraying

Thermal spraying should be operated according to ISO 14918 and ISO 14921. For the spraying of boiler tubes, the following points shall be taken into consideration:

a) Spray the edge chamfer or arc part (see Figure 1) first, then spray the middle part.



Key

1 edge chamfer

2 arc part

3 middle part

Figure 1 — Schematic diagram of boiler tubes

b) When spraying, the spray gun should swing back and forth to ensure uniform spraying. The number of each swing is determined by the temperature of the matrix.

c) The temperature of the substrate in the spraying process should not exceed 200 °C. If the temperature is likely to exceed this figure, the substrate should be cooled to a maximum of 80 °C before spraying.

d) In the cooling process, dust or other debris on the surface is brushed clean with an air gun or wire brush to ensure a good combination between layers.

5.3 Post-process of thermal sprayed coatings

The post-process of thermal sprayed coatings in boiler tubes includes sealing of pores and heat treatment.

a) Coating inspection: After thermal spraying, the coating inspection should be performed by measuring coating thickness, roughness, microhardness and bonding strength.

b) Sealing: Thermal sprayed coatings for all boiler tube types should undergo a sealing process. Once the spraying is finished, sealing the pores as soon as possible is recommended. For sealing, a range of different sealants and procedures are available, which should follow the supplier's instructions. The sealing agent shall withstand the high temperature of 400 °C to 600 °C.

6 Coating quality and performance evaluation

The performance of a coating determines its service life; therefore, it is required to evaluate the coating quality and performance.

6.1 Coating quality

Coating quality shall be inspected in accordance with ISO 14918. However, thermal spray coating on different boiler tubes shall possess the qualities outlined in Table 2.

Table 2 — Recommended performance indicators for variable boiler tubes

	Performance indicators				
	Microhardness $HV_{0.3}$	Thermal conductivity W/(m·K)	Porosity	Hot corrosion kinetic constant $mg^2/(cm^4·h)$	Erosive wear rate $mg/(cm^2·h)$
Water wall of a coal-fired boiler	600-800	≥25	≤5 % for as-sprayed; ≤1 % after sealing	≤1,5	20-35
Superheater of a coal-fired boiler	400-700	≥15	<1 %	≤1,5	15-30
Water wall of a biomass boiler	300-500	≥20	<1 %	≤1	20-30
Superheater of a biomass boiler	>300	≥15	<1 %	≤1	10-20

6.2 Performance evaluation of coatings

6.2.1 Microhardness

The hardness of the coating is related not only to the hardness of the material itself but also to the coating structure, pore distribution and oxide content. The difference in spraying methods or conditions often leads to the difference in the above factors, resulting in the difference in the coating hardness of the same material. Vickers indentation is deeper than the Knoop's under the same load; therefore, the Vickers microhardness test is more suitable for the thermal sprayed coatings, which can be tested according to ISO 6507-1.

The following should be considered for the hardness measurement for thermal sprayed coatings on boiler tubes:

a) The load selection for the test depends on the thickness and hardness range of the test piece. The highest load shall be used within the allowable range of the thickness of the test piece to obtain the largest size indentation, thus reducing the relative error of measurement. It is therefore recommended to select the load for which the diagonal of the obtained indentation shall not be less than 10 micrometres.

b) The dwell holding time shall be between 10 s and 30 s.

c) At least ten points shall be measured on the same test piece, and the average value of the ten points shall be taken as the hardness value of the tested piece. The distance between the indentation centre and the edge of the test piece and between the two adjacent indentation centres shall not be less than 2,5 times the diagonal indentation length. For metallic coatings, the distance shall not be less than five times the diagonal length of the indentation.

6.2.2 Bonding strength

The bonding strength of the coating should be measured according to ISO 14916.

6.2.3 Porosity

The evaluation of the porosity of coatings is covered by should follow the steps given in ISO/TR 26946.

6.2.4 Thermal conductivity

The laser flash method uses a pulsed laser to irradiate one surface of the sample and then monitors the temperature change of the other surface through an infrared thermometer. The thermal conductivity of the material can be calculated by measuring the thermal diffusivity of the coating by laser flash method and then combining the specific heat capacity and bulk density of the material. The specific calculation is given in Formula (1):

$$\lambda = \alpha \cdot \rho \cdot C_p \quad (1)$$

where

λ is the thermal conductivity, expressed in W/(m·K);

α is the thermal diffusivity, expressed in m^2/s;

ρ is the bulk density of the coating, expressed in Kg/m^3;

C_p is the specific heat capacity, expressed in J/(Kg·K).

For the measurement of the thermal conductivity of thermal sprayed coatings on boiler tubes, the following recommendations should be considered:

a) The thermal conductivity of the coating shall be tested in accordance with ISO 13826 and the dimension of the sample shall be Φ 10 mm × 1,5 mm.

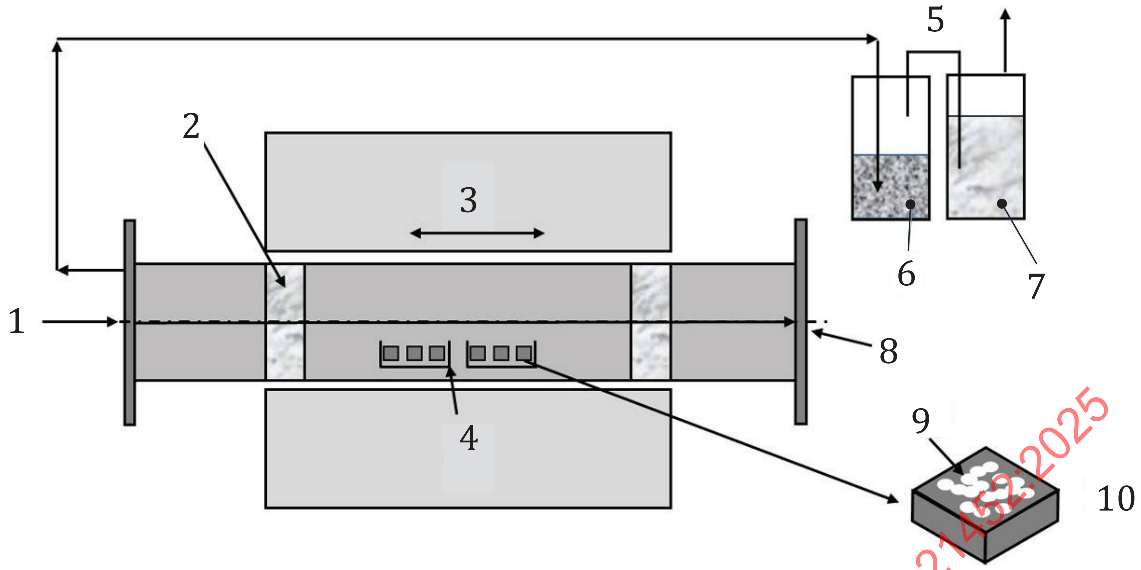
b) The density of the coating shall be obtained by Archimedes drainage method in accordance with ISO 3233-1.

c) The specific heat capacity shall be measured by the specific heat tester in accordance with ISO 11357-4. The sample diameter shall be (5,5 ± 0,1) mm, and the coating thickness shall be 0,4 mm to 0,7 mm.

6.2.5 High-temperature corrosion test

— Specimen preparation: Substrate materials were prepared with square matrix samples having dimensions of (15 to 20) mm × (15 to 20) mm × (5 to 10) mm by electric discharge wire cutting method. The samples shall be chamfered. Specimens shall be subjected to oil removal treatment, cleaning with alcohol and then drying. All six surfaces of the specimen shall be roughened by sandblasting with a suction blast system. The sandblasting pressure shall be 0,6 MPa to 0,7 MPa, the sandblasting angle 50° to 60°, and the sandblasting distance 100 mm to 120 mm. The final surface roughness, Ra, shall be 5,4 µm to 6,0 µm after the sandblasting.

— High-temperature corrosion: Grind the mixed or single salt (salt: NaCl, KCl or Na_2SO_4, analytically pure, white crystalline powder) and configure it into a fine salt powder according to the working conditions. The salt shall be evenly coated on the upper surface of the specimen with a brush. The total amount of salt coated shall be controlled within 5 mg/cm² to 6 mg/cm² and the salt coating error shall be controlled within ±0,3 mg/cm². Measure the mass of the coated specimen and crucible separately before the experiment. Place the salt-coated specimen in an alumina crucible. The hot corrosion test shall be carried out in a tubular furnace at 500 °C to 700 °C with an accuracy of ±5 °C (see Figure 2). Put the salt-coated specimen into the tubular furnace together with the alumina crucible. Take the crucible and specimen out from the furnace every 10 h, measure the mass and then put it back into the furnace to continue the hot corrosion test. Repeat the cumulative hot corrosion cycle (10 to 20) times.



Key

1	air
2	cotton insulation brick
3	hot area of a tubular furnace
4	alumina crucibles
5	vent
6	condensate
7	scrubbers
8	quartz tube
9	ground salt powder upon the surface
10	fully coated specimen

Figure 2 — Diagram of a high-temperature corrosion test device

For the hot corrosion test, the following points should be considered:

a) Specimen requirement: The size of the specimen shall be (15 to 20) mm × (15 to 20) mm × (5 to 10) mm, and the specimens shall be chamfered.

b) In the process of spraying, six surfaces of square samples shall be treated with full coating spraying.

c) The hot corrosive medium: A mixture of NaCl, KCl, and Na_2SO_4, and the molar ratio is 1:1:1.

d) Temperature: 600 °C to 800 °C.

e) Corrosion kinetics: Since the corrosion is not uniform on the surface, the corrosion kinetics is analysed by the following two methods:

1) Microscopic inspection: The corrosion degree of the coating is evaluated by observing the cross section of the sample. In order to test the thickness of corrosion layer and inner oxidation layer of the coating accurately, the specimens should be cut, cleaned, mounted and polished. A scanning electron microscope is used to measure the corrosion depth.

2) Mass method: The corrosion dynamics are understood by plotting thermogravimetric measurements of mass change per unit surface area as a function of the number of cycles. In addition, plot the mass change per unit surface area squared with the number of cycles to obtain the thermal corrosion mass gain kinetic constant (see Annex A). The fitting formula is given in Formula (2):

$$\left(\frac{\Delta w}{A}\right)^2 = k_p \cdot t \quad (2)$$

where

Δw is the mass increment, expressed in mg;

A is the coating area, expressed in cm^2;

k_p is the kinetic constant of mass gain in hot corrosion, expressed in $mg^2/(cm^4 \cdot h)$;

t is the corrosion time, expressed in h.

6.2.6 High-temperature erosion wear test

High-temperature erosion wear properties of thermal-sprayed coatings determine their performances on boiler tubes. Referring to the ASTM G211, it is possible to test the erosion experiment of the coating hit by solid particles at high temperatures. However, for the thermal sprayed coating on boiler tubes, the following special requirements shall be followed:

a) Specimen preparation (see 6.2.5).

b) High-temperature erosion system: As shown in Figure 3, the sample is heated directly by the power supply and the rotary plate is driven by a high-speed motor for high-speed rotation movement to provide the power required for erosion. Sand particles fall from the drop bucket above the rotary plate to the sand separator. The sand particles are thrown out at high speed and hit the sample surface around the rotary plate under the action of centrifugal force.

c) In the process of spraying, six surfaces of square samples shall be treated with full coating spraying. The final surface roughness, *Ra*, shall be 1 μm to 2 μm after polishing.

d) Sand particles: The sand particles should be sharp-edged brown corundum sand with a 0,5 mm to 1 mm diameter.

e) Test temperature: The test temperature should be selected in accordance with the specific working conditions of the tubes. The recommended test temperatures are 400 °C to 700 °C for tubes of biomass boiler and 600 °C to 800 °C for tubes of a coal-fired boiler.

f) Impact angle: $0 < \theta \leq 90^\circ$

g) Impact speed: $10 \leq \upsilon \leq 100$ m/s

h) Erosion distance: $40 \leq L \leq 60$ mm

i) Wear rate measurement, is given in Formula (3):

$$W = (m_1 - m_0) / (S \cdot h) \tag{3}$$

where

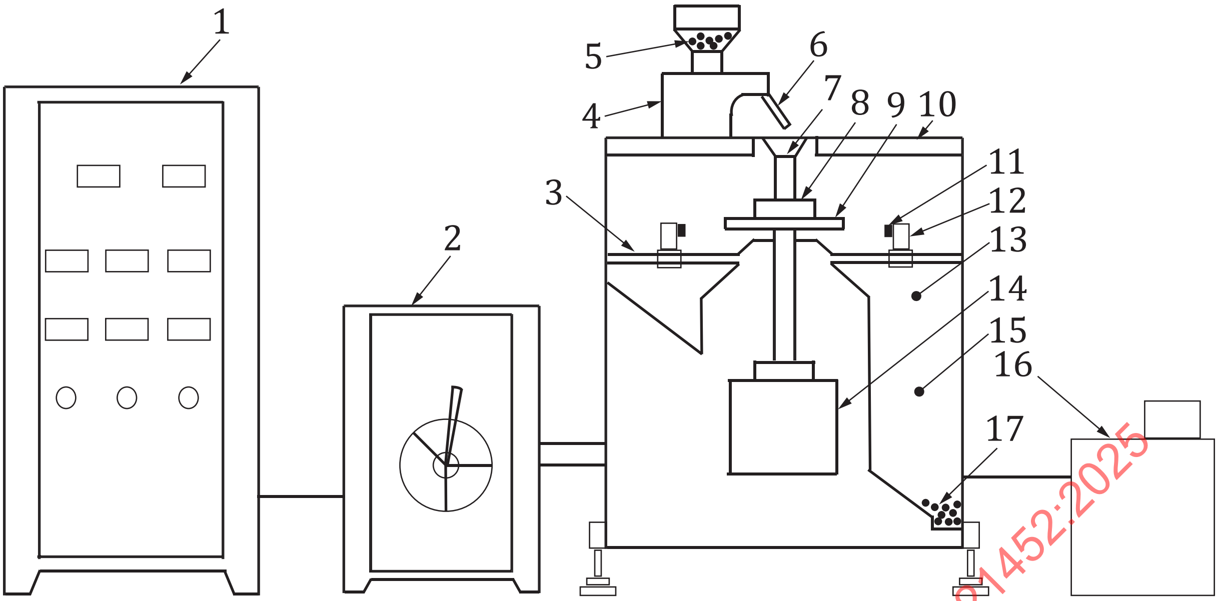
W is the wear rate, expressed in mg/cm^2;

m_1 is the mass after wear, expressed in mg;

m_0 is the mass before wear, expressed in mg;

S is the surface area, expressed in cm^2;

h is the erosion time, expressed in h.



Key

1	control cabinet	7	funnel	13	erosion box
2	heating electric power	8	sand separator	14	motor
3	bracket	9	turnplate	15	slip board
4	sand feeder	10	enclosure cover	16	water cooling system
5	sand grains	11	specimen	17	sand outlet
6	shakeout tank	12	electrode		

Figure 3 — Schematic diagram of a high-temperature erosion wear test device