INTERNATIONAL STANDARD

ISO 28721-5

First edition
2016-02-15

Vitreous and porcelain enamels — Glass-lined apparatus for process plants —

Part 5: Presentation and characterization of defects

Emaux vitrifiés — Appareils émaillés pour les installations industrielles —

Partie 5: Présentation et caractérisation des défauts

Reference number
ISO 28721-5:2016(E)

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Foreword

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

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

The committee responsible for this document is ISO/TC 107, *Metallic and other inorganic coatings*, and in collaboration with Technical Committee CEN/TC 262, *Metallic and other inorganic coatings*.

ISO 28721 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 262, *Metallic and other inorganic coatings*, in collaboration with ISO Technical Committee ISO/TC 107, *Metallic and other inorganic coatings*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 28721 consists of the following parts, under the general title *Vitreous and porcelain enamels — Glass-lined apparatus for process plants*:

— *Part 1: Quality requirements for apparatus, components, appliances and accessories*

— *Part 2: Designation and specification of resistance to chemical attack and thermal shock*

— *Part 3: Thermal shock resistance*

— *Part 4: Quality requirements for glass-lined flanged steel pipes and flanged steel fittings*

— *Part 5: Presentation and characterization of defects*

Vitreous and porcelain enamels — Glass-lined apparatus for process plants —

Part 5: Presentation and characterization of defects

1 Scope

This part of ISO 28721 establishes a system for the cataloguing of defects in enamellings for chemical service and vessels. In addition, it describes some types of areas in which defects have been treated and which can easily be confounded with enamelling defects. It serves for a consistent language use concerning the designation and characterization of enamelling defects.

This part of ISO 28721 is limited to detectable defects and does not purport to fully take into consideration all occurring types of defects. It does **not** evaluate enamelling defects; the classification carried out is based on experience and corresponds, as far as possible, to ISO 28721-1.

NOTE Regarding the acceptance of glass lined equipment for use in process engineering, ISO 28721-1 applies.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 28721-1, *Vitreous and porcelain enamels — Glass-lined apparatus for process plants — Part 1: Quality requirements for apparatus, components, appliances and accessories*

3 Terms and definitions

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

3.1
enamelling defect
defect arising during the enamelling of equipment and pipelines to be used in process engineering

3.2
reparable enamelling defect
enamelling defect that can be remedied without thermal post-treatment

EXAMPLE Defect that can be remedied by polishing.

3.3
non-reparable enamelling defect
defect in the enamel coating that renders a component unfit for its respective intended use

3.4
refiring
further enamel firing (also local), with or without another application

3.5
re-enamelling
complete new creation of the enamel coating

4 Enamelling defects

4.1 Colour lines

4.1.1 General

The enamelling defects strain lines (4.1.2), tearings (4.1.3) and pearl lines (4.1.4) are closely related to one another. The causes of their development and their appearances are similar.

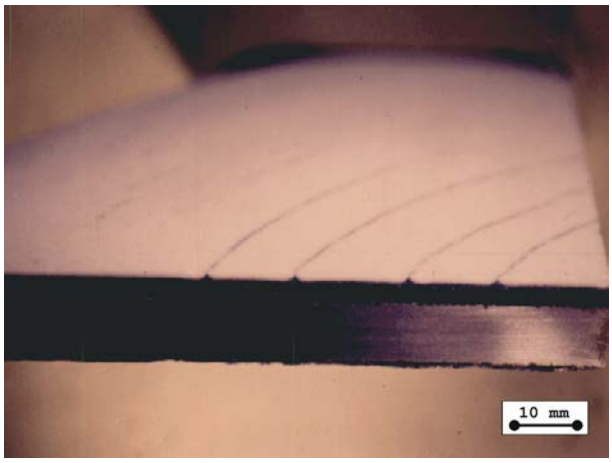
4.1.2 Strain lines

4.1.2.1 Further designations

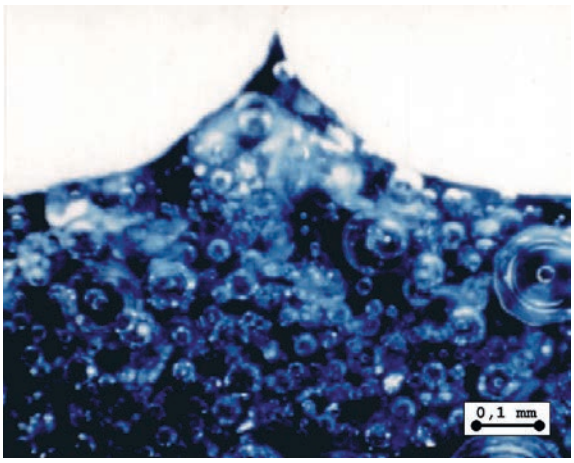
Merged strain lines, linearly upward fused ground coat and hairlines.

4.1.2.2 Description

Strain lines are lines that are always dark and running parallel, or concentrically in the usually blue or white glass cover coat (see Figure 1). In a severe case of strain lines, a number of bubbles or blisters in a single line can appear, forming a pearl line (4.1.4).



a) White cover coat with macroscopically detectable strain lines



b) Lateral view, white cover coat exploring leapt up dark ground coat

Figure 1 — Strain lines

4.1.2.3 Origin and causes

Strain lines arise during enamelling due to thermally or mechanically induced stress in the component. When heating up, the ground coat and the covering bisque cracks open. During firing, parts of the ground coat penetrate into the cover coat.

Possible causes are the following:

— a wrong combination of steel/ground coat/cover coat;

— weld seam made from non-suitable filler material;

— mixing zones in the weld metal;

— non-adapted temperature control during enamelling of constructively unfavourable components, e.g. components showing mass accumulation;

— plastic deformation of the component during enamelling.

4.1.2.4 Classification

Non-reparable enamelling defect.

4.1.2.5 Suggestions for defect treatment

Re-enamelling, taking into consideration the causes mentioned in 4.1.2.3.

4.1.3 Tearings

4.1.3.1 Further designations

Hairlines.

4.1.3.2 Description

Tearings are mostly dark lines, running parallel or concentrically in the cover coat, i.e. lines that are always dark in blue enamel and either dark or light and transparent in white enamel. In contradiction to pearl lines (see 4.1.4), the lines do not show large blisters and are closely related to strain lines (see 4.1.2). Unlike strain lines, however, these lines are recessed (see Figure 2).

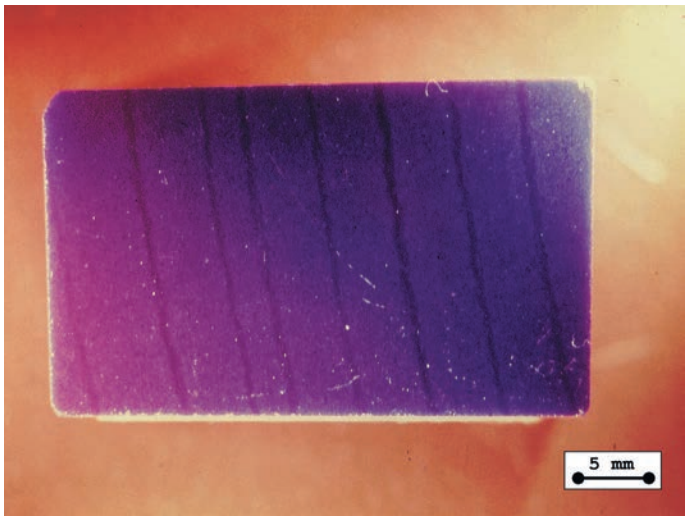


Figure 2 — Tearings

4.1.3.3 Origin and causes

Tearings arise during enamelling due to thermally or mechanically induced stress in the component. When heating up, the enamel bisque and/or the enamel coating crack(s) open. These cracks merge again during firing. If only the cover coat is affected, dark lines appear. If the crack runs through to the metal surface, blisters in the form of pearl lines also (see 4.1.4) arise along the crack (for causes, see 4.1.2.3).

4.1.3.4 Classification

Non-reparable enamelling defect. As, without carrying out destructive testing, it cannot be determined whether parts of the ground coat leap up, toleration is generally not possible for safety reasons.

4.1.3.5 Suggestions for defect treatment

Re-enamelling, taking into consideration the causes mentioned in 4.1.3.3.

4.1.4 Pearl lines

4.1.4.1 Further designations

Bubble lines and blister lines.

4.1.4.2 Description

Pearl lines are blisters lying behind each other in a line, often combined with strain lines (see 4.1.1) or tearings (see 4.1.2 and Figure 3).

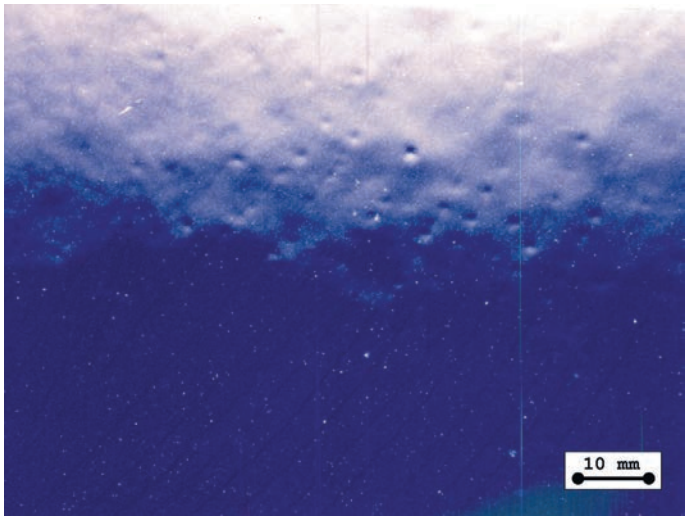


Figure 3 — Pearl lines, i.e. series of blisters in line, in zones showing strain lines (see 4.1.2)

4.1.4.3 Origin and causes

Pearl lines arise during enamelling due to thermally or mechanically induced restraints in the component. When heating up, the enamel bisque and the enamel coating crack open through to the steel. During firing, the metal oxidizes, a process accompanied by gas-forming reactions in the boundary layer. The lines run to form strain lines (see 4.1.2), along which blisters and pores are positioned as if on a string of beads (for causes, see 4.1.2.3).

4.1.4.4 Classification

Non-reparable defect.

4.1.4.5 Suggestions for defect treatment

Re-enamelling, taking into consideration the causes mentioned in 4.1.4.3.

4.1.5 Shore lines

4.1.5.1 Further designations

None.

4.1.5.2 Description

Shore lines are a group of parallel or nearly parallel lines appearing as a deviation in colour (darker in blue enamel and more transparent in white enamel). These lines, that are usually a few millimetres wide and at least one centimetre long, can be positioned anywhere on the enamel surface (see Figure 4).

Shore lines are usually wider than strain lines (see 4.1.2), due to a greater width and irregular edges in the longitudinal direction.

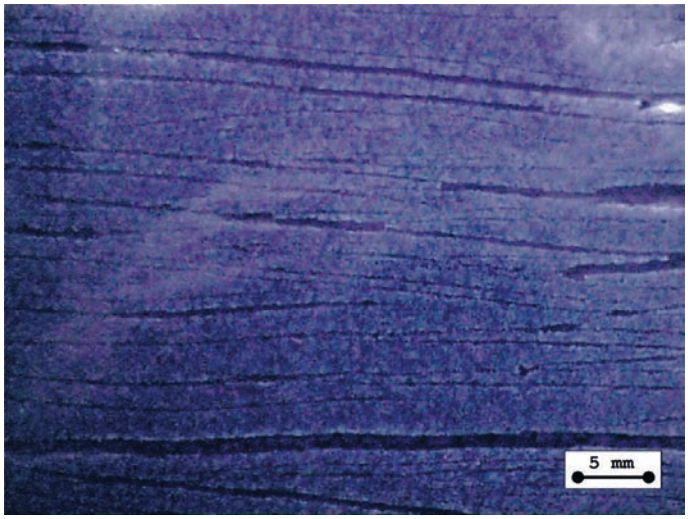


Figure 4 — Dark blue shore lines on a blue enamel surface

4.1.5.3 Origin and causes

Following the drying of the bisque, the smaller enamel particles concentrate on the surface and form a thin and lighter-coloured upper layer following enamelling. Therefore, the defects of this layer appear darker. In order to remove dust before firing, the enamel bisque is cleaned by means of a hand broom. If, in doing so, the surface of the bisque is slightly damaged, these scratch marks appear as dark lines following firing.

4.1.5.4 Classification

Shore lines are a colour defect and affect neither the resistance nor the mechanical strength negatively.

4.1.5.5 Suggestions for defect treatment

Not necessary.

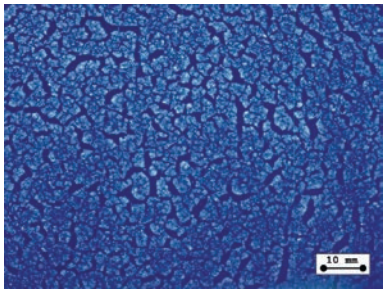
4.1.6 Drying cracks

4.1.6.1 Further designations

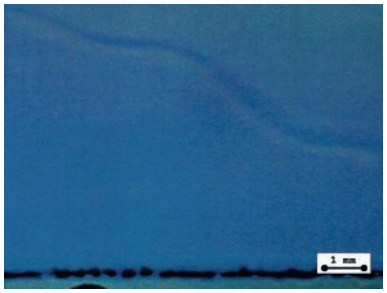
Crocodiling.

4.1.6.2 Description

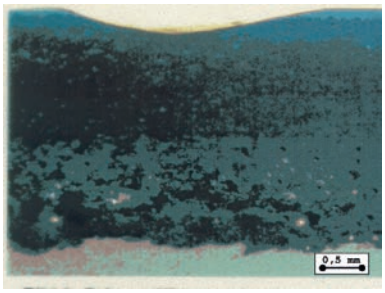
Drying cracks are wide and often netlike lines in the enamel, that are in most cases slightly recessed. Typical of these defects is the irregular, wound course of the lines. In the line itself, usually no blisters appear in the enamel. In the areas of mass accumulations of the steel, the lines can also be arranged orderly, similar to strain lines (see 4.1.2). The overall irregular course, however, stays unchanged. The enamel coating under drying cracks is usually free of defects (see Figure 5).



a) Drying crack



b) Drying crack



c) Defect-free enamel coating under drying crack

Figure 5 — Drying cracks of different distinctness, as well as with underlying defect-free enamel coating

4.1.6.3 Origin and causes

As a result of cracks in the enamel bisque, in the respective areas the enamel cannot merge to form a homogeneous coating during firing. The underlying enamel layer, that is mostly darker, becomes visible. Due to the contraction of the liquid enamel, the edges are in most cases slightly raised and have a higher proportion of fine blisters, visible in the form of a lighter colour. Unlike strain lines (see 4.1.2), drying cracks are not caused by construction. There are four major causes for the origin of these lines:

— knocking of the coated component before firing;

— firing of an incompletely dried bisque;

— unfavourable bisque structure of the applied enamel slip layer, due to application mistakes;

— intensive mechanical damage to the bisque.

4.1.6.4 Classification

Drying cracks are classified by their degree of distinctness. If they are only slightly distinct, they are surface features which affect neither the chemical resistance nor the mechanical strength: at the deepest points of the line, the agreed minimum coating thickness is maintained, and there are no large blisters to be seen at the edges of the lines. The defect may be kept unremedied. In the case of more distinct defects, those which extend over large areas, blisters in the edges or an intensive brightening of the enamel, the defect is a non-reparable enamelling defect.

4.1.6.5 Suggestions for defect treatment

In the case of distinct defects, repair by grinding and subsequent refiring.

4.2 Boiling defect

4.2.1 Further designations

Full penetration of the ground coat.

4.2.2 Description

A boiling defect is a dark, greenish spot on the surface of the enamel, possibly combined with a small depression (see Figure 6).

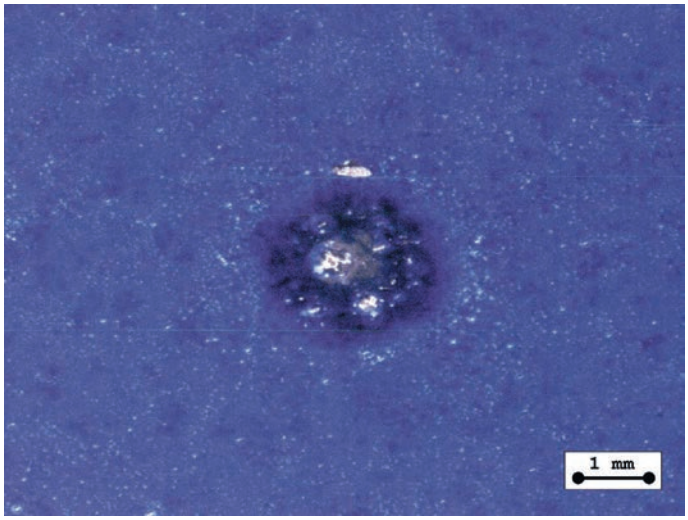


Figure 6 — Boiling defect

4.2.3 Origin and causes

A large blister in the ground coat rises to the surface of the enamel and draws the ground coat up behind it. The blister opens and partly or completely merges again. The ground coat lays punctiformly exposed in the otherwise intact enamel coating. In most cases, the reason for the gas-forming reaction is a contamination of the steel surface or an insufficient adaptation between the surface tension of the ground coating and that of the cover coat.

4.2.4 Classification

Reparable defect.

4.2.5 Suggestions for defect treatment

Insertion of a tantalum plug, if admissible, or refiring.

4.3 Rough enamel surface

4.3.1 Underfired areas

4.3.1.1 Further designations

None; the designation orange peel is not correct for this defect.

4.3.1.2 Description

Underfired surfaces are rough, not smoothly fused areas in the cover coat affecting parts of the component (e.g. at mass accumulations, at the contact surfaces, at the collar) or the whole component (see Figure 7). Macroscopically rough, inadequately fused areas can easily be confounded with devitrified microscopically rough areas (see 4.3.2 and Figure 8).

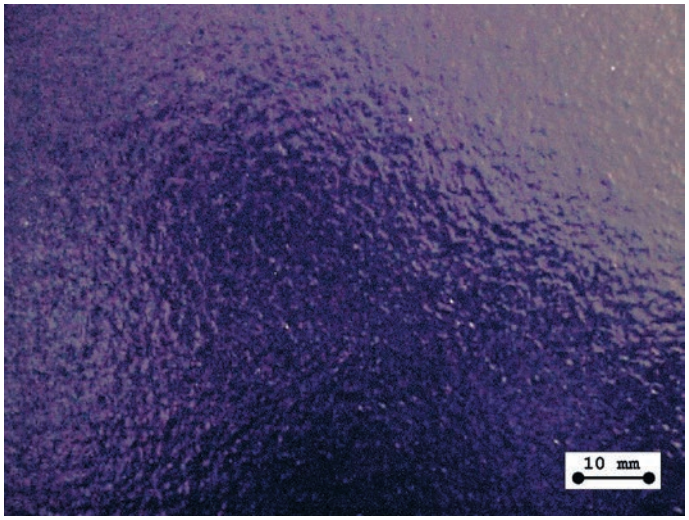


Figure 7 — Rough enamel surface, caused by inadequately fused enamel with a glossy surface

4.3.1.3 Origin and causes

As a result of too low a firing temperature and/or too short a soaking time, the enamel is not fused completely.

4.3.1.4 Classification

Non-reparable enamelling defect.

4.3.1.5 Suggestions for defect treatment

Refiring.

4.3.2 Eggshell

4.3.2.1 Further designations

Crystallized enamel.

4.3.2.2 Description

Eggshell enamel are areas in the cover coat affecting parts of or the whole component and appearing not to be smoothly fused. In these areas, the enamel is only slightly glossy. Possibly, the surface can be felt to be clearly rough. In these areas, the enamel can be of a lighter colour. This defect occurs only in glass enamel (see Figure 8).

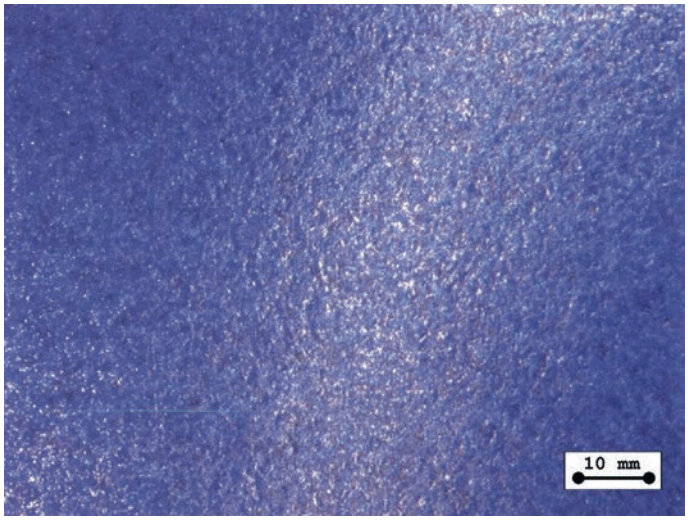


Figure 8 — Eggshell or crystallized enamel with a matt and rough surface

4.3.2.3 Origin and causes

The defect is caused by semi-crystallization. Causes promoting crystallization can be the following:

— too high a number of cycles;

— too long a holding time in the kiln at crystallization temperature, thus too long a period of nucleation and/or crystal growth;

— the composition of the enamel;

— contaminations in the enamel;

— surface crystallization by dust;

— poorly fused frit;

— an application mistake.

4.3.2.4 Classification

Non-reparable enamelling defect.

4.3.2.5 Suggestions for defect treatment

Refiring or re-enamelling.

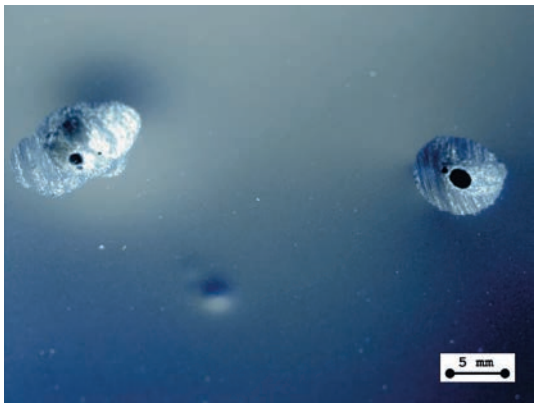
4.4 Dimple

4.4.1 Further designations

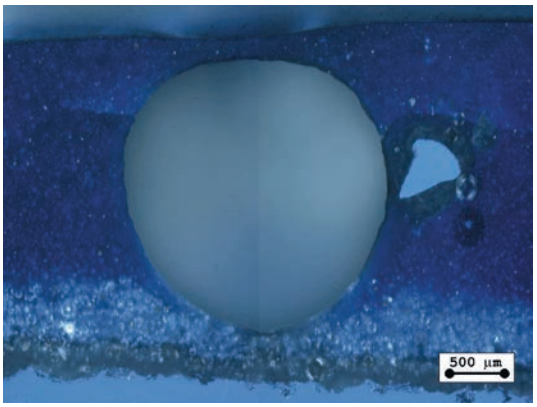
Glass eye.

4.4.2 Description

A dimple is a more or less recessed dent with underlying closed blister, or funnel-shaped indentation with underlying open blister. At these points, no discharge can be detected in the high-voltage test (see Figure 9).



a) Three closed dimples, two of which are ground



b) Cross-grinding, showing the cause of the dimple (metal particles, here glossy white)

Figure 9 — Closed dimples

4.4.3 Origin and causes

This defect can be ascribed to a local, strongly gas-forming reaction. The reasons for these reactions are various; it is possible that parts of the ground coat have been drawn up with a blister (see also 4.2).

4.4.4 Classification

Reparable enamelling defect, if admissible.

4.4.5 Suggestions for defect treatment

Grinding or polishing, insertion of a tantalum plug, if admissible, or refiring with local application.

4.5 Pinholes

4.5.1 Further designations

None.

4.5.2 Description

Pinholes are fine, pinhole-like indentations in the mostly smooth enamel surface. Pinholes can occur individually or in groups (see Figure 10).

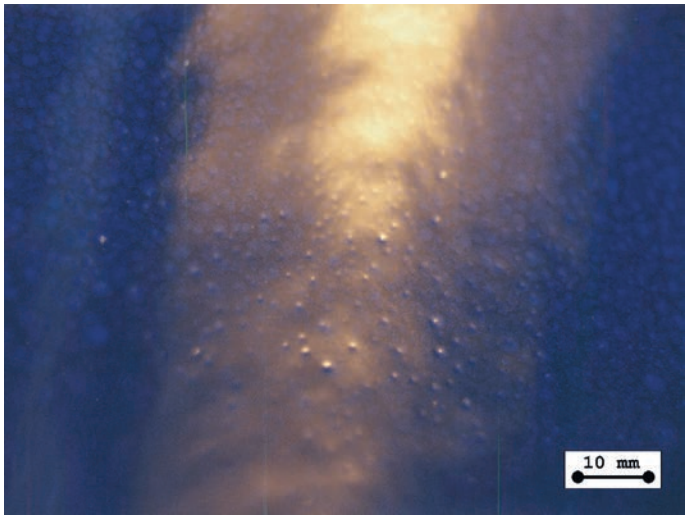


Figure 10 — Pinholes, small crater-shaped indentations in the cover coat

4.5.3 Origin and causes

Pinholes are the results of gas emissions occurring during the final firing of the cover coat. When cooling down, the blisters contract, resulting in pinhole-like indentations.

There can be different reasons for the origin of pinholes; in most cases, it is difficult to assign them to one particular cause. Possible reasons are the following:

— a closed firing atmosphere;

— a thick enamel application;

— enamel slip that had been stored for too long (excessive addition of electrolytic salts due to loss of set of aged enamel slurry);

— applied slip that had been insufficiently dried;

— surface contaminations.

4.5.4 Classification

Surface defect opposed to the generally required smooth surface. The chemical resistance and the mechanical properties are not affected negatively, as long as the minimum coating thickness is maintained.

4.5.5 Suggestions for defect treatment

Not required.

4.6 Contamination

4.6.1 Chamotte/refractory clay

4.6.1.1 Further designations

None.

4.6.1.2 Description

Chamotte, or refractory clay particles, are small white or yellow particles, about 1 mm long or less, that have superficially merged into the enamel surface (see Figure 11).

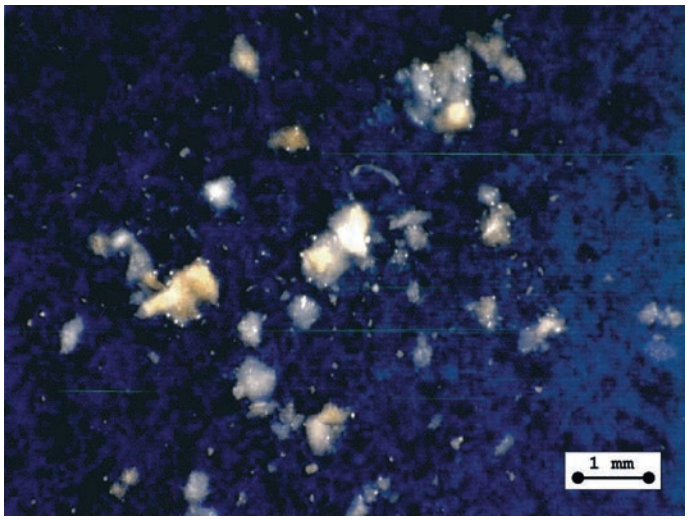


Figure 11 — Refractory clay particles in an enamel surface

4.6.1.3 Origin and causes

Refractory clay particles originate from the refractory material of the fusing or enamelling kilns. During the firing of the enamel, they merge into the surface.

4.6.1.4 Classification

Reparable enamelling defect.

4.6.1.5 Suggestions for defect treatment

Grinding and polishing in order to remove larger particles. Dust-fine contaminations on the surface may be accepted in accordance with ISO 28721-1.

4.6.2 Scale

4.6.2.1 Further designations

None.

4.6.2.2 Description

Scale particles are small black, sharp-edged discs of ferrous oxides merged into the enamel surface. The discs can be oriented parallel or not parallel to the enamel surface (see Figure 12).

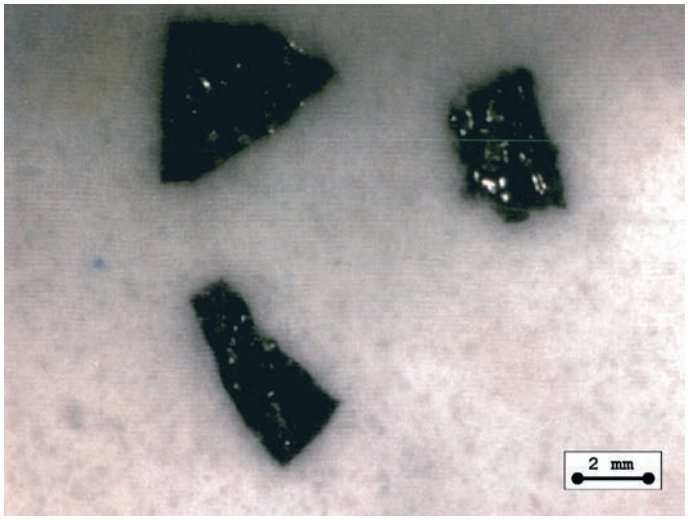


Figure 12 — Scale particles in an enamel surface

4.6.2.3 Origin and causes

Scale particles are contaminations in the firing chamber. When the kiln is opened, these particles are swirled due to convection, fall down onto the component and get stuck on the enamel. Primarily, this enamelling defect occurs in the vicinity of the large container openings.

4.6.2.4 Classification

Reparable enamelling defect.

4.6.2.5 Suggestions for defect treatment

In accordance with ISO 28721-1, or refiring with local application.

4.6.3 Ceramic fibres

4.6.3.1 Further designations

None.

4.6.3.2 Description

Ceramic fibres are thin white fibres, merged into the surface of the enamel (see Figure 13).

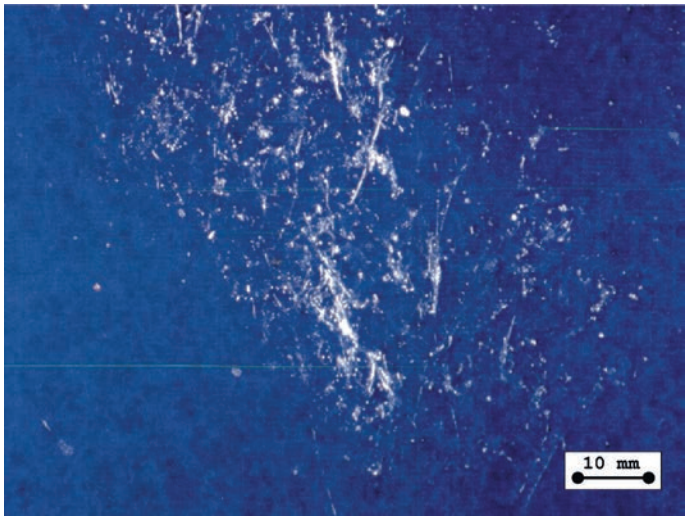


Figure 13 — Ceramic fibres in an enamel surface

4.6.3.3 Origin and causes

Ceramic fibres are part of the insulating material of the enamelling kilns and occur loosely scattered in the firing chamber in the form of contaminations. During enamel firing, they can merge into the surface.

4.6.3.4 Classification

Reparable enamelling defect.

4.6.3.5 Suggestions for defect treatment

In accordance with ISO 28721-1, or refiring with local application.

4.7 Colour deviations

4.7.1 Water marks

4.7.1.1 Further designations

Water stains.

4.7.1.2 Description

Water marks are individual or several stains in the enamel surface with light-coloured borders (see Figure 14).

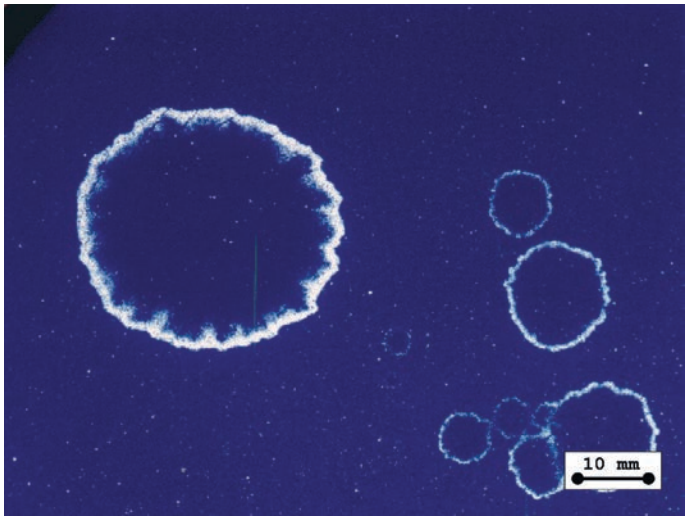


Figure 14 — Water stains on an enamel surface

4.7.1.3 Origin and causes

Water marks are caused by drops of water or sweat on the enamel bisque. Here, due to migration processes, salts are mobilized and transported to the edges of the drops. There, they crystallize and are subsequently fired in.

4.7.1.4 Classification

Optical enamelling defect; the chemical resistance and the mechanical properties of the enamel are not affected negatively.

4.7.1.5 Suggestions for defect treatment

Not required.

4.7.2 Colour stains

4.7.2.1 Further designations

None.

4.7.2.2 Description

Colour stains are punctiform colour deviation in the cover coat. These spots or stains are smooth and glossy. Their shape is more or less circular, unlike the merged-in contaminations such as chamotte (4.6.1), ceramic fibres (4.6.3) from the kiln, flakes of the mill brick cover coat or the milling balls. Often, the stains are milky and transparent (white spots on blue enamel; see Figure 15).

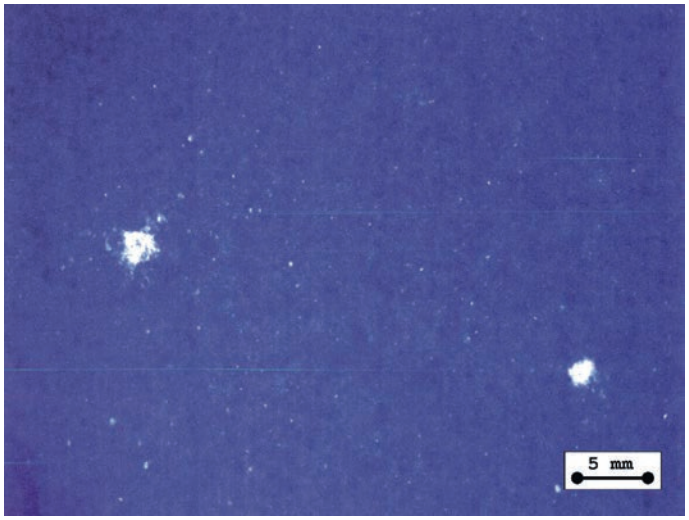


Figure 15 — White stains on an enamel surface

4.7.2.3 Origin and causes

Punctiform deposits of enamel particles of another colour on the component result in local colour stains in the cover coat.

4.7.2.4 Classification

The chemical resistance and the mechanical properties of the enamel are not affected negatively.

4.7.2.5 Suggestions for defect treatment

Not required.

5 Repaired areas

5.1 Polished area

5.1.1 Further designations

None.

5.1.2 Description

A polished area is a dull, mostly circular indentation in the enamel surface showing polishing traces. In most cases, the fine blister structure of the cover coat is visible in the polished enamel surface (see Figure 16).

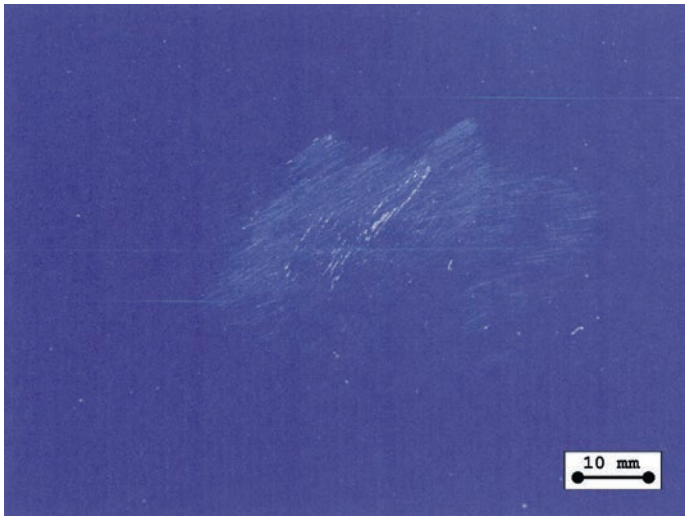


Figure 16 — Polished area

5.1.3 Origin and causes

Grinding and subsequent polishing of the enamel.

5.1.4 Classification

Consequence of admissible repair.

5.1.5 Suggestions for defect treatment

Not required.

5.2 Enamel-covered area after grinding

5.2.1 Further designations

None.

5.2.2 Description

This is an area showing an optical change in colour, a slight brightening in the case of blue enamel or a slight greying in the case of white enamel (see Figure 17).

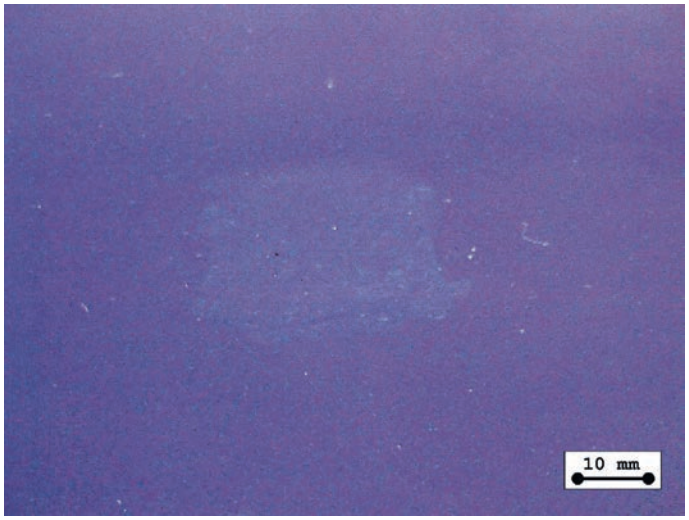


Figure 17 — Enamel-covered area after grinding, visible as a light stain in the blue cover coat

5.2.3 Origin and causes

Covering of an area after grinding with a thin enamel coating. The colour deviation is a result of a change in the proportion of fine blisters.

5.2.4 Classification

Consequence of admissible repair

5.2.5 Suggestions for defect treatment

Not required.

ICS 25.220.50

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