CASE STUDY OF DEFECTS ON VITREOUS ENAMEL COATING

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Abstract

Vitreous enamel coatings play a very important role in the coating production process of steel in accordance with the technical and aesthetic properties. Surface quality of the enamel coating can be affected by various defects. In this study, some examples of case of defects, mainly the loss of adhesion are presented on different type of products. The reasons of the adhesion lost are different according to usage of products.

Keywords: Vitreous enamel, enamel surface defects, poor adherence, usage of product

1. INTRODUCTION

The vitreous enamel coatings are created from material, which is obtained by the melting or fritting of a mixture of inorganic materials, applied to a metal substrate in either the form of a suspension in water or a dry powder, in one or more layers, which will, when heated to a temperature sufficient for fusion to take place, be bonded chemically and physically to the metal substrate. Enamel is composed of oxide forms, applied on a metal substrate with a firing temperature range of 800 - 870°C. Vitreous enamel coatings play a very important role in the coating production process of steel in accordance with the technical and aesthetic properties. Enamel coatings combine aesthetically pleasing colours and glossy finishing with excellent technical properties, such as corrosion protection and durability: this was the main reason for vitreous enamel success in many fields, such as household and industry. Enamel coatings are mainly used to protect steel components for high-duty technological applications, such as flue pipes, chemical reaction vessels, and gas turbines. This vitreous coating still represents an extremely modern coating, with high-performance characteristics, mainly attributable to the glassy nature of the matrix.

2. VITREOUS ENAMEL COATING PROPERTIES

2.1 Quality requirements of enamel coatings

The basis metal should be suitable for enamelling, e.g. according to EN 10209, EN 10025, EN 10111. The dimensions and the thickness of the material should be appropriate to the specific requirements of the enamelling process to ensure satisfactory mechanical stability of the final enamelled product. The pre-treatment of steel surface has a great effect on quality of enamel coatings (degreasing, blasting, pickling).

There exist a lot of standards that are dealing with the required properties of the enamel coating. The following quality requirements for the vitreous enamel coating are specified: the resistance to chemical corrosion by different acid and alkaline solutions, the thermal shock resistance, the impact resistance, the abrasion resistance, the scratch hardness, the adherence, the enamel layer thickness, the defects in the enamel layer and the colour. The selection of test methods for vitreous and porcelain enamelled areas of articles, mentions the properties (and corresponding standards) is given in ISO 4528. For products which are already enamelled, results of measurements and tests that have been carried out, (as part, of the quality control process) shall be available.

The thickness of the porcelain and vitreous enamel coating should meet the maximum and the minimum values as defined for the specified area(s) of application and should be as consistent as possible. Measuring should be done by magnetic method according to EN ISO 2178. The total layer thickness varies correspondingly with the number of coating layers. The coating should show good adherence to the basic metal.

The usual service life of an enamel coating depends on a number of factors, from its chemical composition, thickness to service conditions. The porcelain and vitreous enamel coating should have sufficient chemical and corrosion resistance for the specific area(s) of application according to EN ISO 28706 and EN ISO 9227.

Low voltage test for detecting and locating defects according to ISO 8289 is a non-destructive method and therefore, is completely different from the high voltage test specified in ISO 2746.

2.2 Classification of defects

Vitreous enamelling is only one of several surface protective processes, but one which holds a leading position from the aspect of quality. Surface quality of the enamel coating can be affected by various defects. Although the formation of defects can often be attributed to a combination of several unfavourable parameters, which leads to a practically infinite number of individual faults, quite often one factor dominates a typical defect type. The defects are classified in groups according to the underlying base materials and application processes in ISO 19496-2 [1]: fish scales, chipping, dimples, blisters, bubbles, pores, black emission, beads, burn-off, crack, impurities, etc.

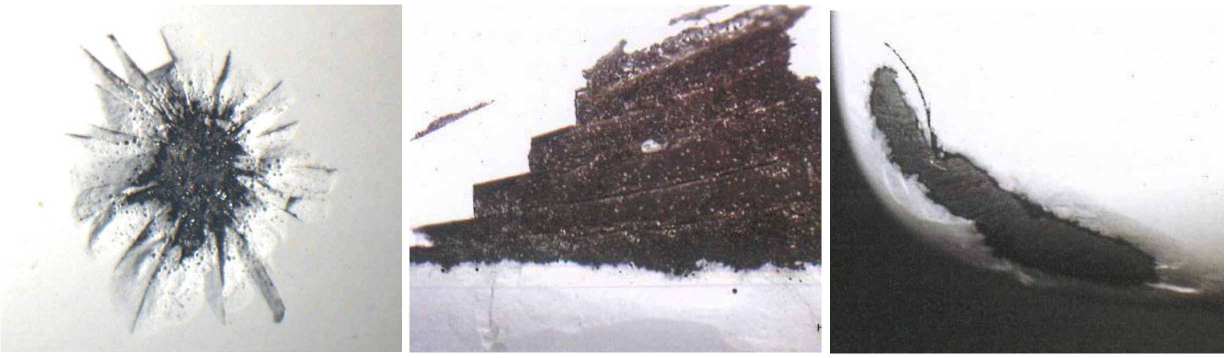

Figure 1 The example of chipping of enamel coating according to ISO 19496-2

Thermal stress occurs as the results of different thermal conductivity between metallic substrate and enamel coating (**Table 1**). Thermal shock resistance is stated for enamels from 100 to 240 °C depending on the type of enamel and especially the thickness of the coating - coatings with a lower thickness resist higher thermal shocks.

Table 1 The relation between thermal conductivity and enamel coating density

coating type	density ($kg.dm^{-3}$)	thermal conductivity coefficient ($W.m^{-1}K^{-1}$)
standard	2.48	1.17
with bubbles	2.45	1.09
with small bubbles	2.36	1.05
slightly foamed	2.28	0.80
foamed	2.16	0.46

Poor adherence of the enamel is a very severe quality spoiling appearance which can lead to rapid destruction of the steel/enamel composite. Classification of adherence is standardised in EN 10209.

3. CASE STUDY OF ENAMEL COATING DEFECTS

All evaluation had been done on the real products with the enamel coatings - some of them in-situ on products without possibility of destructive evaluation (storage tank, chemical reactor, sign tables, etc).

3.1 Chemical reactor

Chemical reactor was used for 5 years for preparation of dilute sulphuric acid solution. The enamel coating was applied on inner surface with the thickness from 1370 to 1690 µm.

On the inner surface there are local defects in the enamel coating (ISO 19496-2) - chippingg of part of the enamel layer around the holes in the coating, under which intense corrosion attack has occurred (**Figure 2**). The size of the defects is very different from holes with a diameter of about 5 mm to a large hole with a diameter of about 100 mm. In the place of defects, the enamel coating is sufficiently adherent to the underlying steel - it does not spontaneously peel off from the underlying steel. The enamel coating is under-corroded at the point of the defects - corrosion damage to the steel extends below the enamel layer in depth and width.

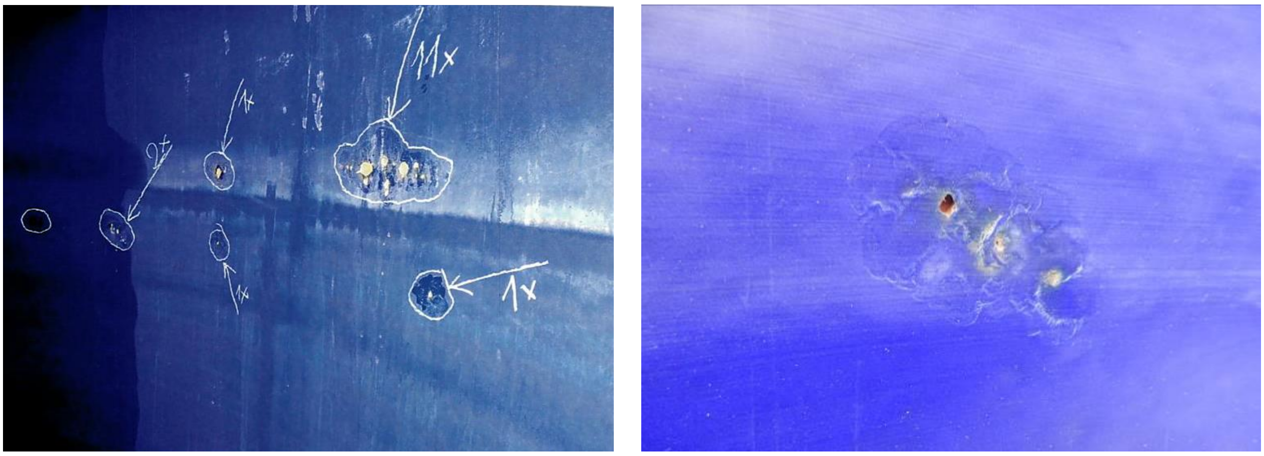

Figure 2 The example of defects on inner surface of chemical reactor

In the chipped layer there were found cracks. The coating was disturbed to a depth of ca 100 to 300 µm by gradual dissolution of the layer. The rate of gradual dissolution of the enamel can be estimated at about 0.05 mm/y, but it was slower than the values specified for enamel resistance in common acids. According to EN ISO 28721-2 have enamel coatings on fittings, pipes, pumps, mixers and other equipment in the chemical industry meet the quality requirements: thickness of coating 1.0 to 2.2 mm, temperature to crack forming ≥ 190°C, corrosion rate 0.08 mm/y at hydrochloric acid and corrosion rate 0.40 mm/y at sodium hydroxide.

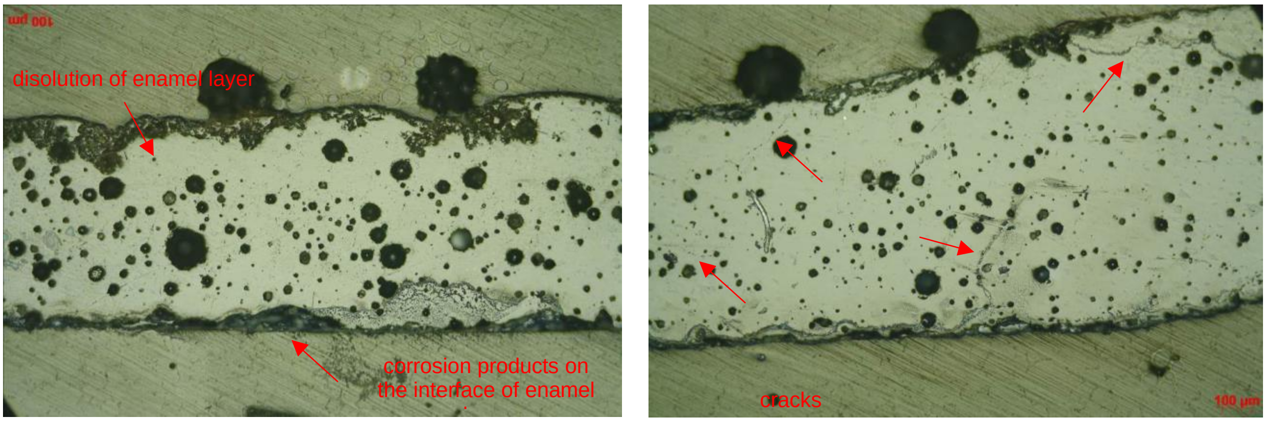

Figure 3 The bubbles and cracks in the chipped enamel layer

The porosity was tested by high-voltage test - at 12 kV the pores occurred on defects´ areas and at 15 kV the pores occurred on whole area. The cross section of chipped enamel layer shows cracks in it (**Figure 3**). The chemical analysis of this layer shows the changes of its composition due to dissolution by chemical attack.

3.2 Steel sheet as storage tanks, roof and various sign tables

These products have simple shape and they are exposed in the atmosphere or water conditions for long-term periods. The observed defects result from the production technology (application and burning of enamel coatings), the mechanical reason (vibration of tables around the screws´ holes), low and incontiguous enamel layers.

For part of roof of swimming pool Sutka, Prague, the sheet with enamel coating were used (originally the silo and similar tanks are produced from these sheets). The construction was suspended for 20 years. The condition of these sheet was control before the completion of the construction. The enamel coating was damaged on the cutting edges and around the screws´ holes where the layer was cracked and chipped, substrate steel corroded (**Figure 4**). Remaining surface was without any defects. The local defects were repair and sheets are still served as roof, now for 12 years.

Figure 4 The typical defects on roof sheets after 20 years

Figure 5 The evaluated storage tanks

The enamel sheets for cylindric storage tanks for chemical fertilizers was other evaluated objects. The damage of coating - chipping - was found after 1 year of exposure on the inner and outer surfaces around the screws´ holes - **Figure 5**. On these areas the steel corrosion occurred. Thickness of coating was ca 465 μm on the both side on surfaces without damage. On the damaged areas the coating thickness was ca 250 µm. The porosity of coating was measured by high-voltage test according by EN ISO 2476 at 2 900 V - the test does not prove any defects.

Both these objects were made from large sheets produced by large technology, but there are many small objects with enamel coating used commonly as various sign tables - houses numbering, names of street, indication of electric poles, etc.

One of example is the sign table from electric pole after 20 years exposure at atmospheric conditions (**Figure 6**). The defects occurred on the edges and on the back side of table. There are many large open pores from which the corrosion of substrate steel spreading. The enamel coating thickness is 250 to 320 μm on the front side depending on the color of layer and only 133 μm on the back side.

Figure 6 The evaluated sign table

The same defects were found on the special tables used for water level measuring in river Elbe. After 1 year of service intensive steel corrosion occurred on the edges of tables (**Figure 7**). The enamel coating thickness was nonuniform and varies from 280 to 395 μm of white coating on the front side and from 50 to 195 μm of black coating on the back side of tables. The thickness of the enamel coating for the water environment should vary from 100 to 500 µm, depending on the water corrosivity.

The low-voltage test was performed with a porosimeter Elcometer 270. A voltage of 67.5 V was used for measuring coatings with a thickness greater than 300 µm. On the front side, pores and defects in the continuity of the coating were indicated only rarely - ca 3 - 5 pores on the edge of each sample. The number of pores even on the back side of all battens exceeds the recommended value of 5 pores/1 m^2 of surface area (EN 14431).

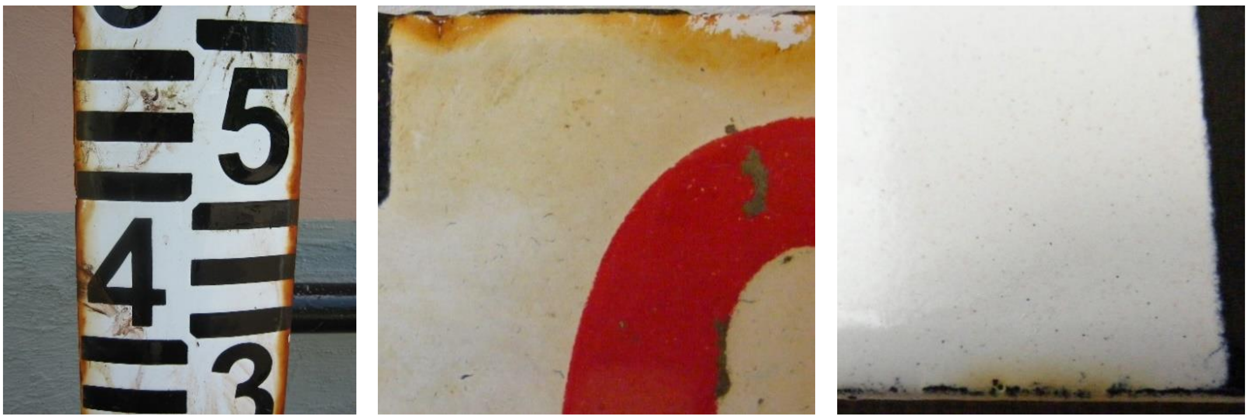

Figure 7 The typical defects on tables

4. CONCLUSION

Failures and defects can manifest themselves at various times in the life of a coating. To determine the cause and mechanism of coating failure, all possible contributory factors must be evaluated together with a detailed history from the time of application to the time the failure was first noted.

The estimated defects had the local character but in the areas of defects the corrosion of substrate steel was very intensive. The main reasons of enamel coating failures were the nonuniform thickness of layers and pores in the layer. Mechanical stress by vibration and/or assembly caused many identified defects. The mechanical or other stress may cause immediately the damage of enamel coatings and nonprotected steel surface starts to corrode.

One advantages of enamel coating is than if the corrosion of substrate steel started due to any defects (chipping, open pores, etc.) the corrosion does not continue under the coating layers opposite to paint layers. But on the other hand, the repair of such defect cannot be done the original technology. Usually, the paint coatings are used for this purpose which do not have the same durability and protective efficiency.

When enamel coatings are damaged, repair is quite difficult to proceed although the technology for restoring the utility of enamelled equipment, which makes it possible to cover localized defects with a coating almost as good as the original coating, has been developed [2]. This technology is based on the method of partial reenamelling and formation of a vitreous enamel coating on the defective zones after firing at 760-780 °C. Some local defects as pinholes may be repair by laser technique [3]. But still the main point should be prevention of failure and achieve product liability [4].

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