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Evidence of gas permeation in electrostatically painted steel cylinders

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ABSTRACT

The process of gas generation, entrapment and subsequent permeation through coatings applied on the surface of metals for corrosion protection purposes is the cause for the development of a defect known as "fish-scaling". Particularly, in operations like enamelling or painting of metals, this phenomenon affects strongly the surface quality of the items and the development of further processing operations. In this work, the reasons that promote the development of defects in electrostatically painted steel during the manufacture route of fire extinguishers are analysed. The surface and cross section analyses of the samples conducted by optical and scanning electron microscopy suggest that the degradation of the coating is caused by gas migration from the metal-coating interface to the surface of the cylinders. Water used during cleaning and descaling operations acted as a potential gas source being hydrogen the element responsible for the formation of both, structural defects in the coating and cracks in the steel substrate. The degradation mechanisms of the steel and the coatings are found and explained in terms of manufacturing process of the cylinders.

1. Introduction

During the application of enamels and organic coatings on metallic products for corrosion protection purposes, a variety of surface or internal defects can be formed; the most common of these is known as "fish scaling" [1–12]. This defect has been defined as the development of a considerable amount of hollow semicircles on the surface of coated items, which together resemble fish scales that exert a detrimental surface aspect [1].

Apart from a bad aspect, this defect promotes the development of additional degradation mechanisms that contribute to the catastrophic failure of components used in engineering applications [2,6–11,19,20]. The root cause of this defect has been associated with the generation and entrapment of gases, typically hydrogen, during or after the coating process. However, additional mechanisms like the presence of contamination particles in the coating have also a considerable impact on the overall degradation of the coated metallic products [2,4–6,7,11,17]. It is worth mentioning that this particular defect is often found after the application of vitreous coatings on metals nevertheless, its presence has also been detected during the fabrication of organic coatings. Deflorian et al. [11] mentioned that the protective behaviour of organic coatings deposited

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on the surface of metallic systems is strongly related to the defects formed during fabrication but, establishing the exact causes that promote their formation, represents a difficult process. Though, defect detection as well as damage classification and quantification for paints and resins deposited on metallic products can be successfully determined by means of electrochemical techniques [8–11].

Based on the reason that fish scaling defects can lead to catastrophic failure of equipment used for safety applications [5,6,8–11,19], in this work, the evidence of defect formation and the causes that promote this phenomenon on the surface of electrostatically painted steel during the fabrication of fire extinguishers is presented.

2. Experimental procedures

A local manufacturer of fire extinguishers reported the development of surface defects i.e. bumps and pinholes all of them located at exactly the same region on the body of electrostatically painted steel cylinders. An important part of the manufacture route of these items includes welding a round end-cap to the bottom of the cylinder as it is indicated in Fig. 1 then; the items are painted by electrostatic means [21]. After this process, the defects appeared on the surface of the specimens exactly at the opposite region of the heat-affected zone formed during the welding process (Fig. 1). Development of defects in these items is unacceptable given that they could promote water entrapment at the interface coating-steel, causing pitting of the metal.

It is worth mentioning that before the painting process, the cylinders are descaled in a solution of 15% HCl in distilled water. Once cleaned and dried, they are placed in the induction furnace of an electrostatic painting line where they are heated to 260 °C, which is the temperature that favours a prompt melting of the epoxy compound that is sprayed onto their surfaces by a series of nozzles. Once coated, the epoxy compound is let to cure at 240 °C for 4 min and after this time; cooling of the cylinders occurs by means of blowing dry air inside the chamber under a laminar flow regime.

To obtain information on the nature and the causes of the degradation, cylinders that showed a considerable amount of defects were removed from the manufacturing line and were then carefully sectioned using a precision diamond saw. Once cut, cross sections were prepared using standard metallographic procedures that included grinding with silicon carbide emery papers and polishing with diamond solutions of 6 and 1 µm respectively.

After preparation, the surface and cross sections of the specimens were analysed using optical (OM) and scanning electron microscopy (SEM). When the samples were observed in the optical microscope polarized light, dark and bright field imaging modes were used. Alternatively, prior to the SEM analysis, the specimens were coated with a thin layer of gold applied by sputtering means. The analyses were conducted using a field emission gun scanning electron microscope that was operated at a maximum acceleration voltage of 10 kV. Images were taken at different working distances using both, backscattered and secondary electron detectors and when required, qualitative chemical analyses were conducted by means of energy dispersive X-ray spectroscopy (EDX).

3. Results

Fig. 2 gives a scanning electron micrograph taken from the surface of faulty specimens. The defects appeared as circles and semi-circles with diameters that ranged from few microns up to 1 mm.

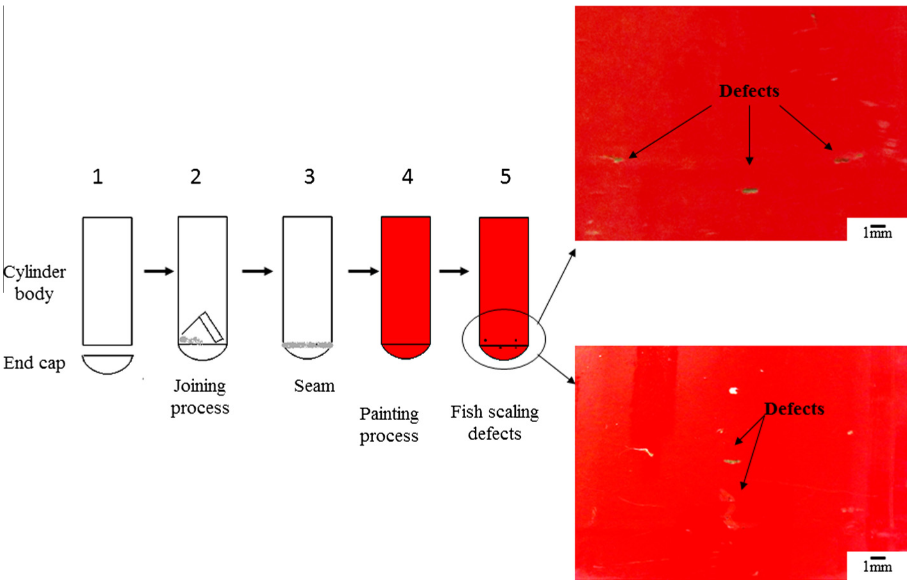

Fig. 1. Schematic representation of the process route and photographs of the defects found on the surface of the cylinders.