Electrodeposition of Coatings, Part V: Surface Defects

This article continues a series on electrodeposition coatings published in previous issues of CoatingsTech.

Although electrodeposition (ED) coatings suffer far less from surface defects than do most other coatings, problems can still occur. In this article, I will cover craters, including conventional contamination-type, pinhole cratering or gassing (rupture), and two other gassing defects, all of which mar appearance and may hurt corrosion resistance. Most of this information comes from my papers in Proceedings, Electrocoat 92 Conference, March 1992, pp.10-1 to 10-19, and J. Coat. Technol. 62 (789), 115 (1990). These defects have been studied for many years and effective strategies for avoidance have been developed, but the defects still appear occasionally, and their causes are rarely understood.

Contamination such as mineral oil or silicone falling in, on, or under ED coatings can cause cratering, but the amount of the contaminant that it takes to cause the defects is many times that which would cause severe cratering with just about any other coating. A standard resistance test involves spattering a wet e-coated panel with a mist of mineral oil using a test tube brush. That rarely produces craters. I have added oil to lab e-coat baths, which, happily, emulsified it and gave no craters when deposited. The conclusion is that, if an ED coating is cratering, there must be heavy contamination or a really sensitive coating. I worked on one case where silicone gaskets had been used in new pumps for a large e-coat tank, resulting in craters all over the units. Changing the pumps and filtration with oil-absorbing filter materials had little effect, so the silicone had to be removed by coating out a large number of units in normal production. Eventually, all of it was gone and subsequent units were crater-free.

However, various gassing mechanisms can produce craters as well as pinholes—volcano-like pops or bubbles in the e-coat layer and sometimes in topcoats over it. Historically, the most common type of gassing is pinhole cratering (rupture), which occurs at high voltage with both anodic and cathodic electrodeposition, but is due to different mechanisms. With anodic coatings, the cause is Joule heating, that is, water in the deposited coating is heated by the deposition process itself. The temperature at the coating-substrate interface rises considerably and the water in that area becomes so hot that it boils. The resultant water vapor blows bubbles and holes through the coating. Joule heating depends primarily on voltage and can be avoided by applying the coating below the rupture voltage.

Although Joule heating does occur in cathodic ED coatings, the main effect of rupture is electrical discharge, electric sparks that occur during deposition and blow holes in the coating. However, even more defects are caused by the voluminous evolution of hydrogen and water vapor that accompanies sparking. This results in large numbers of bubbles on the wet surface, as shown in the upper part of Figure 1. On baking, most of the bubbles collapse, leaving a few volcano–like structures and many pinholes, like those in the lower part of the figure. For those of you using anodic ED, electrical discharge is not something you need to worry about, as it does not occur with an anodic process.

Rupture/pinhole cratering in cathodic coatings occurs at high voltages and/or with zinc-coated steels, particularly zinc-iron and zinc-nickel alloys. The exact mechanism and the reasons why some zinc-coated steels have lower pinhole cratering voltage thresholds than others are not known, but a lot has been learned about preventing the defects. Lower voltages, higher bath temperatures, and thicker coatings prevent or reduce the defects. In addition, fewer craters are produced at a given voltage by ramping or stepping so that the entrance voltage is lower than the exit voltage by 50V or greater. This can raise the cratering threshold for that substrate above the operating voltage.

There is another defect, galvanized gassing, that looks like pinhole gassing, but is caused by small defects (e.g., flaps, blisters, bubbles) in or under the zinc layer in electrogalvanized steel (and very occasionally in hot-dipped galvanized or zinc alloys). Cross sections show small bubbles in the e-coat and larger ones in the layers above it. There is some evidence that the bubbles are caused by hydrogen and, possibly, methane that has been trapped in or under the zinc layer and is released by baking. The key, tell-tale difference between galvanized gassing and pinhole gassing is the fact that the former can be reproduced without an ED coating. Topcoats alone over “bad” steel will produce defects. The defect is not an e-coat problem at all!

Yet another gassing defect is due to over-rolling or stamping damage of zinc-coated steel. The defect appears as pinholes, craters, small bubbles, or roughness in the ED coating. These stems from small cracks in the zinc layer caused by rolling (skin passing) in the steel mill or that occur during stamping or other forming. The exact cause of the defects is not known, but it may be due to higher conductivity or electrical activity, which leads to a greater tendency to spark during the deposition process and/or causes an increase in hydrogen formation. Similar defects have been seen in hem flange areas where they are difficult to distinguish from craters due to oil coming out of the hem flange. Solvent stripping of such defects followed by examination with optical microscopy or SEM revealed the cracks.