C23 *In Situ* Hardening of a Steel Tank: Carbon Diffusion Over 35 Years at Ambient Temperatures

Anastasia Micheals, MS, Forensic Materials Consulting, 1784 Sanchez Street, San Francisco, CA 94131-2741*

After attending this presentation, attendees will understand the importance of diffusion in materials, particularly in surface hardening of steel.

This presentation will impact the forensic science community by presenting a case study where low temperature diffusion has a large impact on the properties of steel.

During recoating of the interior of a 35-year-old, 1.2MG municipal water tank, the interior coal tar pitch epoxy coating was being removed by sandblasting where the goal was a white metal finish. Initial sandblasting with silica resulted in unexpectedly low removal rates. Time was of the essence, so the abrasive was switched to steel abrasive, a more expensive material. The blasting still took much longer than scheduled and anticipated.

A disk taken from the roof of the tank was cut in half; Piece A, not cleaned in any way, and Piece B, sweep blasted with steel abrasive. Optical microscopy, Scanning Electron Microscopy (SEM), and Energy Dispersive X-ray Spectroscopy (EDS) were performed on both A and B.

Uncleaned A, under the optical microscope (Figure 1), showed a cracked coal tar pitch epoxy coating. In some areas, the coating had spalled away and red iron oxide scale formed. Under SEM, a region containing both coating and corrosion was examined (Figure 2). The corrosion had a typical iron oxide appearance (Figure 3). The coal tar coating (Figure 4) showed some surface deposits and surface cracks.

Elemental analysis of Piece A by EDS was unremarkable, with carbon, iron, and oxygen from the coal tar coating and steel tank material. Silicon, aluminum, potassium, magnesium, calcium, sulfur, and chlorine were also present, likely deposits from the well water held in the tank.

Optical microscopy of B showed that the sweep blasting, while incomplete, had removed most of the coal tar coating (Figure 4). Residual red iron oxide and black regions consistent with the coal tar coating seen on the uncleaned piece were found. Piece B was examined in the SEM. The surface was somewhat rough, indicating incomplete sweep blasting. EDS of the area again revealed no unexpected elements.

Spot elemental analysis was performed on an area of sweep-blasted B, where a cross-section from the pitch coating to the bare steel was visible (Figure 6) at three locations; pitch coating, mid coating, and bare steel (Table 1.). The additional elements detected, likely deposits from groundwater, were silicon, calcium, aluminum, magnesium, potassium, sulfur, and chlorine.

Element	Atomic %		
	Spot 1	Spot 2	Spot 3
Carbon	50.1	33.2	1.7
Oxygen	34.9	31.8	22.6
Iron	0.4	30.1	65.3
Additional elements	14.6	4.9	10.4

Table 1. Concentration of elements found at three different spots on a cross-section of Piece B.

At Spot 1, the top of the coating, carbon from the coal tar pitch epoxy was detected. Hydrogen was also likely present, although EDS cannot detect it. At Spot 2, a significant amount of iron was detected. The ratio of iron to oxygen was approximately 1:1, which suggests iron oxide of the form FeO, a black oxide. The presence of carbon suggests carbon diffusion into the iron oxide. At Spot 3, the primary element present was iron.

Piece A is representative of the present condition of this 35-year-old tank and coal tar coating. Over time, volatile organic compounds evaporated from the pitch, causing it to lose elasticity. Cracks in the coating then initiated and grew. Water penetrated through the cracks to the steel and formed ferrous oxide (FeO), the iron corrosion that forms in limited-oxygen environments. The corrosion propagated underneath the coating (Figure 7), allowing spallation. The iron, then exposed to oxygen, converted from black FeO to red Fe_2O_3.

Piece B reveals a second process, carbon diffusion. Carbon will readily diffuse into iron, at a rate dependent on temperature. The carbon gradient discovered in Piece B indicates that the carbon diffusion process has been taking place over the 35-year lifetime of the tank. Although the maximum ambient temperature was relatively low (~100º F), the long time allowed significant carbon diffusion to occur, causing surface hardening of the low carbon steel. This diffusion rate was verified by Fick's Second Law.

The goal of sand blasting was to remove the pitch layer and the top surface of the steel, leaving a clean steel surface for recoating. The increase in hardness from that of the expected low carbon steel material, to a high carbon steel of around 2.5%, resulted in exceptionally low material removal rates by sand blasting.

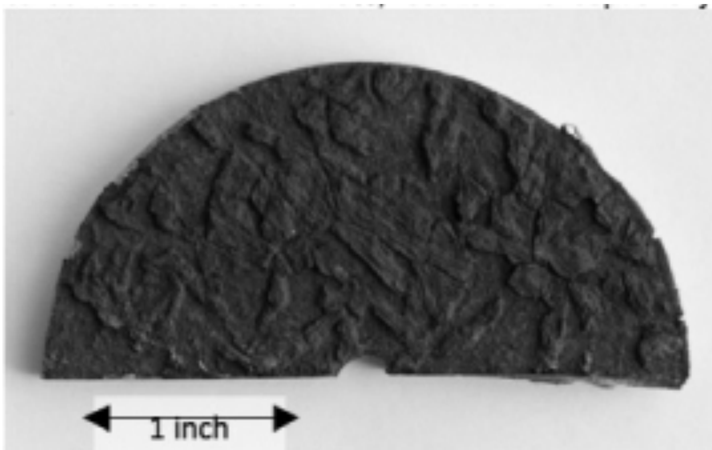

Figure 1. Water tank specimen, Piece A, no cleaning.

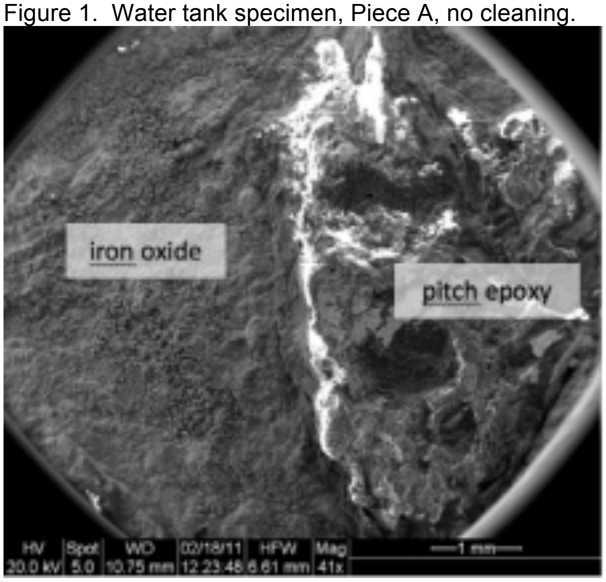

Figure 2. Electron micrograph of A, in a region with both red iron oxide corrosion and pitch epoxy coating.

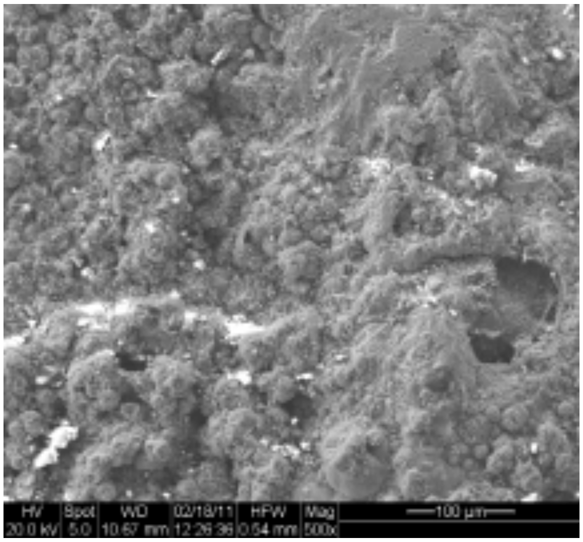

Figure 3. Electron micrograph of corrosion from A. The bubbles are typical of rust; EDS analysis confirmed the composition of the rust to be Fe_2O_3.

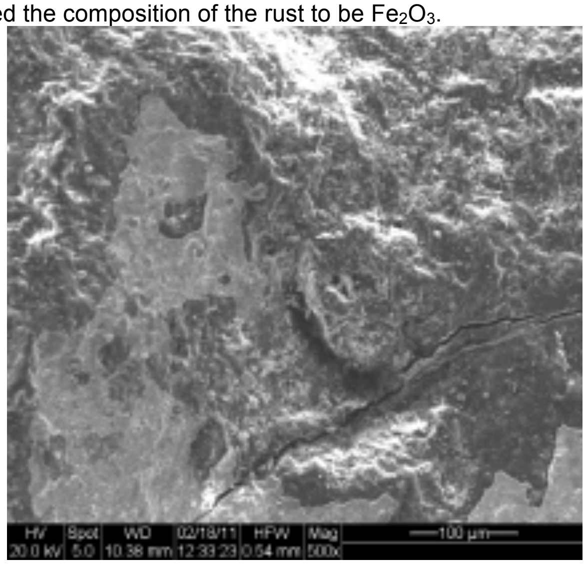

Figure 4. Electron micrograph of the pitch epoxy coating from A. The light areas are surface deposits. The crack is typical of those found in the coating.

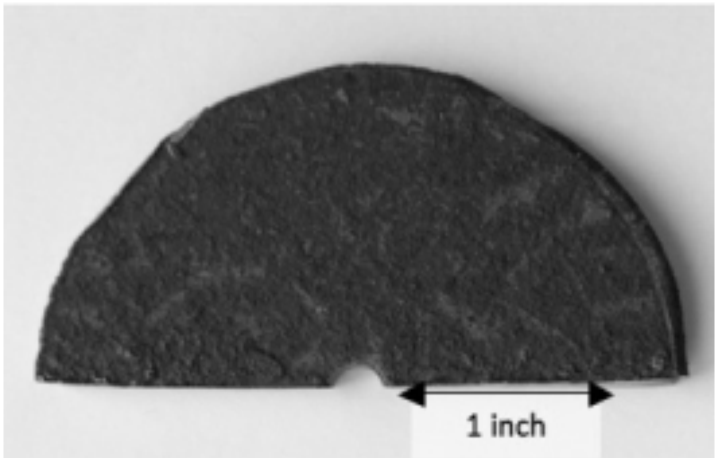

Figure 4. Water tank specimen, Piece B, sweep blasted.

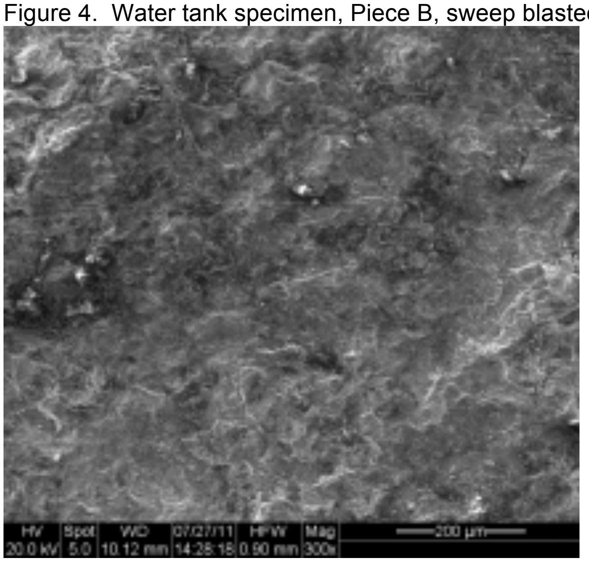

Figure 5. Electron micrograph of B. The rough surface is a result of sweep blasting with steel abrasive, which did not penetrate to the steel substrate.

 ** Presenting Author*

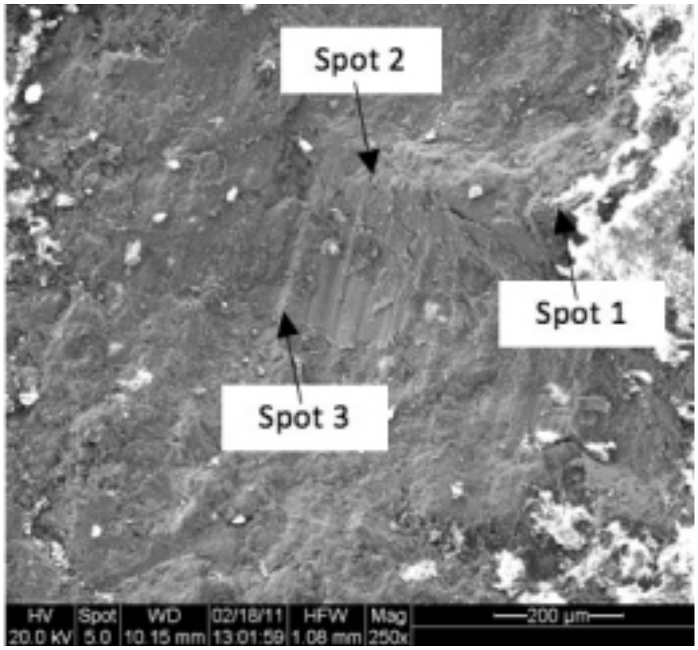

Figure 6. Area of EDS analysis.

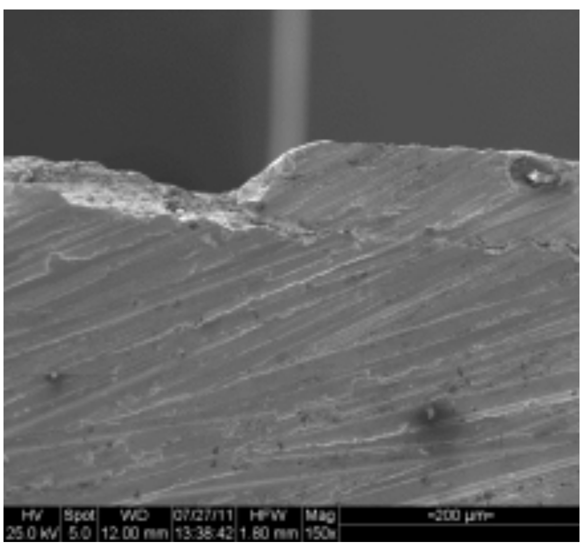
Figure 7. This cross section shows the propagation of corrosion beneath the coating.

Diffusion of Carbon in Steel, Corrosion, Oxidation