When after only a few years, coating failures (Figs. 1 and 2) and deterioration of the interior concrete surface had occurred in many portions of a Midwestern city sewer line, the city officials wanted to recoup damages. A proposed remedial plan developed by the city's consultants with a price tag of approximately $24 million served as the catalyst for the city to take legal action against the project designers, contractors, and coating and pipe suppliers. In turn, several area law firms representing the contractors engaged an investigative team. The team's mandate: evaluate the current condition of the sewer line, determine the cause(s) of the reported distress, and recommend remedial measures so that the line would perform its intended function for the remainder of its 50-year design life. This article describes the findings of the investigative team.

The Investigative Process
Getting the Background
• Documentation: The initial steps in this investigation involved extensive review of all project documentation. This included everything from contracts and correspondence with design and construction engineers to inspectors' field notes and records of enforcement of environmental regulations of industrial effluent. Published information on the varied elements related to the construction and function and on maintenance of concrete sanitary sewers was also reviewed. Videotapes (of deterioration in the sewer line) taken by the city's consultant were also examined.
• Design: Of most significance was the fact that the pipeline was grossly oversized for the then-current needs. The resultant large headspace in the pipe set up an ideal environment for the growth of sulfur-oxidizing bacteria. In addition, the minimal gradient of the line contributed to slow flow, resulting in longer retention times, developing hydrogen sulfide (H₂S). The sulfur-oxidizing bacteria convert the H₂S gas to sulfuric acid, an aggressive chemical that disintegrates concrete. The stage had been set for a disastrous scenario.

Petrographic Examination Used To Analyze a Distressed Sewer Line Coating

By Steven H. Gebler, P.E., Laura Powers, Terry Willems, Rachel Detwiler, P.E., Construction Technology Laboratories, Inc.
• Construction: The technical specifications were below the standards typically used in the construction industry. They were lacking in detail and direction and did not clearly state the responsibilities for specific tasks. Of particular concern to the team was the selection of the coating for the interior of the concrete pipe as well as the application process itself.

In anticipation of the generation of H₂S and corrosion from sulfuric acid, a coal tar epoxy (CTE) coating was specified to protect the interior of the reinforced concrete pipes. It was specified that the coating of the pipe be performed at the manufacturer’s plant, noting the lining was to be “a high-build, polyamide-cured two-component coal tar epoxy coating, Military Specification MIL-P-23236.” However, the military specification is intended for use on shipboard tanks subjected to fuel and salt water, not for concrete sewer pipe interiors subject to chemical and microbial attack.

Moreover, although inspection of the sewer line revealed evidence of substantial external hydrostatic pressure from the groundwater acting on the pipe, the specifications did not specify a waterproof barrier system on the exterior. Published literature revealed that hydrostatic pressure alone can cause premature debonding of a coating.

Methods for measuring coating thickness and holidays were not specified, nor was the frequency of testing.

• Environment within the Pipeline: The field investigations of the sewer line found very low pH values, indicating highly acidic conditions on the pipe walls above the flow line as well as significant concentrations of H₂S gas. Continuous exposure to a pH below 3 is considered a severe environment for concrete corrosion and is extremely conducive to the growth of the bacteria thiobacillus thiooxidans. It was well known that a dramatic increase in conversion of sulfide in the liquid to H₂S gas above the effluent level occurs when the pH drops from 7 (neutral) to 6 (acidic) and below. Significantly, all of the conditions that contribute to the generation of H₂S and acid in sewers were present in the pipeline.

At least 19 industrial plants were discharging their waste into this sewer line. It was noted that acidic effluent from two of the plants added greatly to the corrosive conditions in the sewerline. Further, the effluent from one of those plants also produced carbon disulfide (CS₂). This is a very strong solvent that attacks CTE—
the protective coating used in this pipe.

- Site Inspections: Once the background information had been obtained, the field investigators entered the pipeline (still in service) for inspection (Fig. 3).

The team conducted visual inspection and physical examination, and they recorded their observations. The team worked upstream and downstream from each entry point, hammer sound testing and probing the concrete for its integrity, examining the coating to determine its present thickness, measuring the pH in areas of altered concrete and the temperature of the effluent, observing the depth of flow and the condition of exposed rebar, and selecting areas for collecting samples.

The CTE coating was failing throughout most of the areas examined. There were fluid-filled blisters under pressure in abundance at most locations. The concrete between the blisters remained intact (Fig. 4).

- Gathering the Evidence: Careful consideration was given as samples were collected for examination and testing. The procedure for removing a coating sample proved somewhat tedious: a good representative and properly obtained sample was deemed one in which the coating surface was not punctured in the process. Thirty-three representative samples of coating, altered concrete, and groundwater were examined. Additionally, 31 concrete cores were removed for testing.

![Fig. 5: A view of the back of coal tar epoxy coating revealed varying amounts of whitish crystalline deposits identified as gypsum; 10X magnification](image)

![Fig. 6: Photomicrograph of backside of coal tar epoxy showing gypsum crystals; 35X magnification.](image)

**Putting Petrography to Work**

- Under the Microscope: Samples of the deteriorated CTE coating were examined. Photomicrographs documented varying amounts of whitish crystalline deposits (identified mainly as gypsum) near the interior surface of the pipe (Figs. 5 and 6). Crystalline gypsum deposits are underlain by soft altered paste. Many of the coating samples had splits, tears, and cracks. Some occurred at thin spots in the highly variable overall coating thickness. These conditions were readily apparent when viewing the concrete surface profile peaks shown in the photomicrographs.

While a few pinholes in the CTE were observed, it was evident that they had little to no effect on the blistering or peeling of the coating. The conclusion was that typically there was a single coat of epoxy. The brittleness of the coating (whether wet or dry) along with its color and microporosity indicated that the coal tar portion of the coating system was partially leached out (Fig. 7). All cores were examined microscopically using the procedures for petrography outlined in ASTM C 856. The petrographic process involves examination of a cut and lapped specimen, first by the naked eye, then by stereomicroscope at magnifications up to 40X, and then by polarized-light microscope at magnifications up to 400X using thin sections prepared from areas of interest. The analyst could then determine the composition of the concrete and study the CTE/concrete interface.

The findings from these examinations showed that crystalline gypsum deposits on the back of the coating...
were present in virtually all of the samples taken above the flow line. The team concluded that the moisture that had infiltrated the concrete pipe because of external hydrostatic pressure allowed the crystals to form. It was evident that the crystallization pressures exerted by the formation of gypsum literally forced off the coating, causing failure (Fig. 8). The microscopical examinations were able to differentiate between pinholes in CTE, which are due to application of CTE, and other causes. Figure 9 illustrates a tear in the CTE, not a pinhole. The tear in the CTE developed due to expansion of the altered paste (gypsum behind the coating). The pressures exerted by the gypsum are significantly greater than the adhesion of the CTE/concrete bond. Since CTE is permeable, gases such as H₂S can move easily through it. The severe chemical environment within the pipeline served to leach out the binder, increasing its permeability and making it brittle.

Conclusion
The photomicrographs clearly documented the gypsum crystals forcing off the coating as the mechanism of failure. The field observations coupled with the test results and measurements pointed to definitive resolutions. Petrographic examination was the key to obtaining clear evidence in this investigation. No other method could have been applied to accomplish similar definitive documentation. Proper selection of samples and precise removal of the specimens were essential, as were the microscope and the expertise of the petrographer.

Notes
1. American Concrete Institute, “A Guide to the Use of Waterproofing, Dampproofing, Protective and Decorative Barrier Systems for Concrete,” ACI 515.1R-79, ACI Committee 515, Manual of Concrete Practice (Detroit, MI: American Concrete Institute, 1980, revised 1985).