445
doi:10.1017/S1431927615003025 Paper No. 0223
Microsc. Microanal. 21 (Suppl 3), 2015

The Role of Computed X-ray Tomography in a Metallurgical Analysis

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Metallographic examination has been an integral part of a failure analysis for nearly the past century. As metallurgists we are always interested in the structure-property relationship for a material that is the subject of a failure investigation. In many instances, indicators of why a component failed can be hidden and very subtle such as a manufacturing defect, a crack, the microstructure, or some other metallographic feature. When a failure analysis is being conducted we often rely on cross-sectional analysis of an identified feature or in suspect areas when features are not visible.

The use of computed X-ray tomography (CT) in conjunction with metallographic analysis can greatly benefit a failure investigation resulting in a more comprehensive picture than what metallographic analysis can provide alone. Computed X-ray tomography is a radiographic technique where a series of X-ray images are reconstructed into a three-dimensional model of a component that has information regarding its internal features. Differences in material density show up as grey scale contrast in an X-ray image and can be utilized to visualize the internal structure or features. For example, materials with higher density absorb more X-rays than lighter materials resulting in less transmitted X-rays being detected by a detector.

During a failure investigation, the use of CT as one of the initial steps, allows a non-destructive overview of the entire structure of the component and can be used to identify internal features of interest that can later be investigated by metallurgical analysis. For example, the depth of graphitic corrosion penetration of a grey cast iron water pipe may only be superficial in certain locations, but may reach full penetration in other locations. CT can be employed to identify locations of near through wall penetration, which can subsequently be sectioned and prepared for metallographic analysis showing the internal microstructure and confirming that the mode of failure is graphitic corrosion (Figure 1).

A second example is a carbon steel heat exchanger tube/tube sheet weld area where leaks occurred (Figure 2). On the exterior surface, a large feature was observed where steam likely escaped resulting in erosion and enlargement of the larger initial penetration. CT analysis as a first step in the failure analysis indicated that a crack-like feature could be observed at the root of the weld only in a few isolated locations adjacent to the large eroded area. Cross sectioning through this location showed that the crack was branched and further microscopic and elemental analysis indicated that the crack was filled with corrosion product with evidence of sodium. The investigation concluded that the likely cause of failure was caustic cracking initiating at the root of the weld induced by built up caustic ions from the feed water (Figure 2). Without the use of CT prior to sectioning and metallographic analysis the isolated locations of cracking may never have been identified and the failure analysis may not have been able to identify the failure mode.

Similar failure analyses could indicate the directionality of cracking indicating whether cracking initiated from the internal surface or the outside surface of a pipe allowing the identification of the environmental cracking agent (e.g., a heating solution versus product).

This work illustrates the complimentary benefits of CT and metallographic analysis in a failure analysis through a series of failure analysis examples.

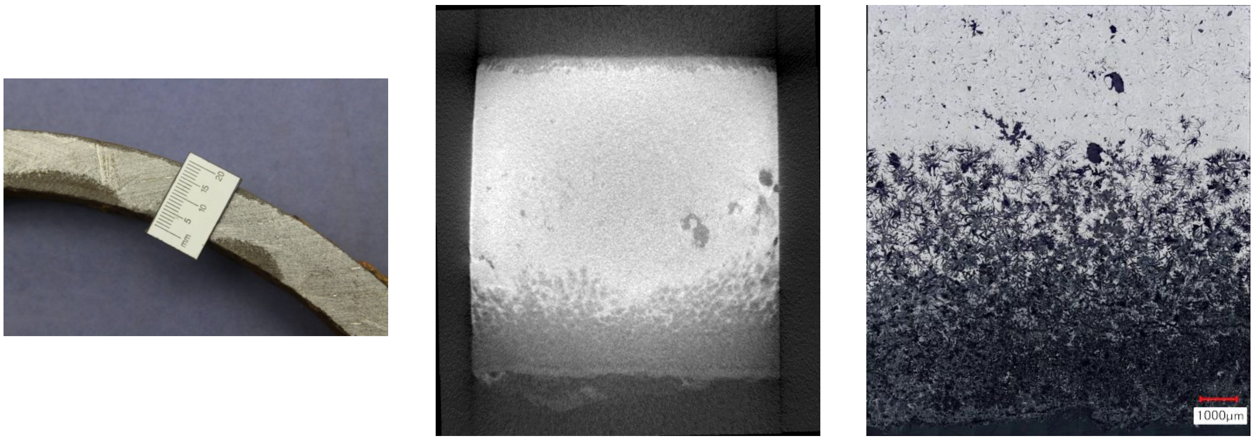

Figure 1. Overall photograph, CT cross section, and optical microscope image of graphitic corrosion in grey cast iron water pipe. Dark areas indicate the location of graphitic corrosion.

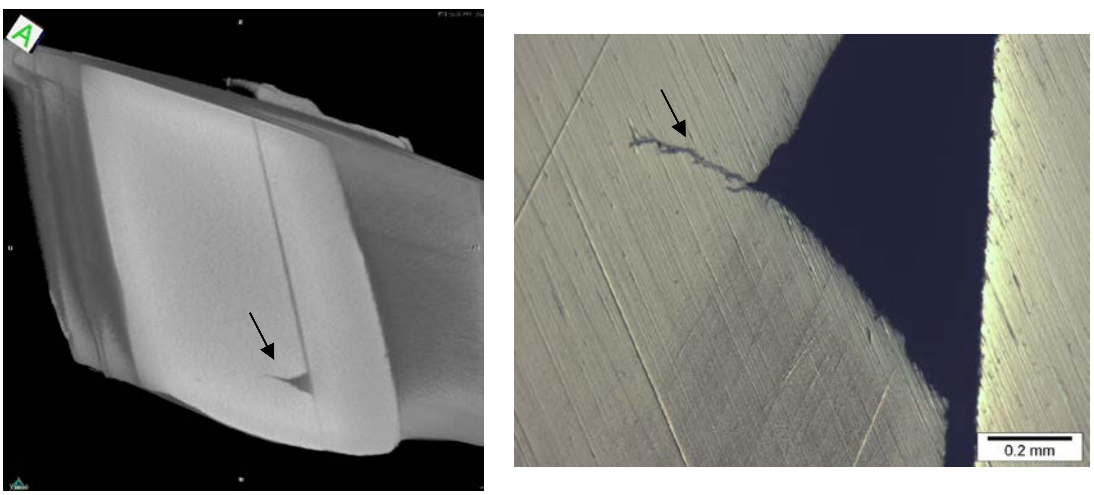

Figure 2. CT cross section through a three dimension projection and optical microscope image of a roughly polished cross section of a welded carbon steel heat exchanger tube/tube sheet. Arrows indicate the location of observed cracking.

https://doi.org/10.1017/S1431927615003025 Published online by Cambridge University Press