09/2011

INDUSTRY NOTICE

Structural Integrity Associates, Inc.®

GRAPHITIZATION

Historically, graphitization in carbon and lower alloy steels used in fossil power plants has been managed based on what was thought to be a complete understanding of how the different "types" or morphologies of graphitization could act to influence material performance. However, recent events have revealed a new, and previously undocumented, form of graphitization that, like its chain-type "cousin", can significantly degrade the strength and toughness of a material such that catastrophic failure can (and has) occurred.

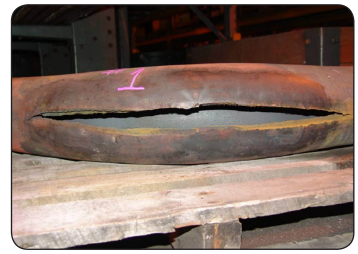
Figure 1 PSH Piping Failure

Earlier this year, Structural Integrity performed a comprehensive root cause analysis of catastrophic failures in boiler external primary superheater (PSH) piping (Figure 1). Ultimately, it was positively determined that a previously undocumented form of graphitization was responsible for the failures. Further investigation to establish the extent of the problem found similar degradation in more than one operating unit.

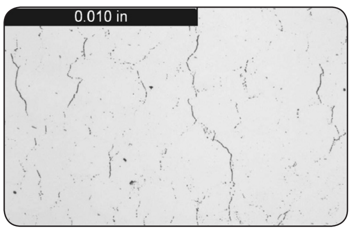

Figure 2 Volumetric Grain Boundary Graphitization

Immediately prior to the latest failure in 2011, conditions at the plant were normal, with pressure and temperature at the primary superheater inlet holding steady. Stress analysis confirmed that the piping had been properly dimensioned for the design and operating conditions, including an operating temperature of approximately 830°F. The failed pipe had been in service for approximately 275,000 hours at the time of the most recent rupture. A review of available information leading up to the rupture event indicated that there was no apparent operational "triggering" incident that could explain the sudden failure of the piping. In addition, based on the best available information regarding the impact of potential damage mechanisms/morphologies on the integrity of the primary superheater inlet piping, it was believed that the piping was being effectively monitored to detect any damage that could adversely affect component serviceability as part of the utility's High Energy Piping Program.

The failed pipe was fabricated from carbon-½molybdenum steel in accordance with the requirements of the SA-335 specification for P1 piping. Surprisingly, the metallurgical examination of the failed piping revealed a unique form of graphitization in which patches of graphite initiated within certain grain boundaries of a preferred orientation and these small regions of graphite then linked up to form zones of weakness along the line aligned grained boundaries. This resulted in a significant loss of material ductility and toughness, as compared to the expected properties for P1 material.

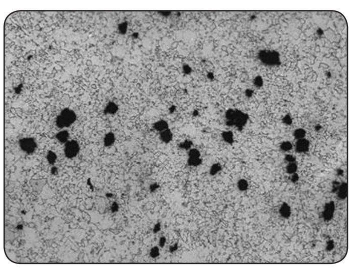
Figure 3 Typical Graphitization in Low Alloy Steel

Even though P1 material is known to graphitize after prolonged exposures to elevated temperatures, the morphology of the graphitization in the piping bends was unique and to this point undocumented. Specifically, the damage was generally planar, was located entirely within the grain boundaries, and was widely distributed volumetrically throughout the base metal, as shown in Figure 2. This planar form is significantly different from the previously documented forms of graphitization that occur in either the base metal or weld heat affected zones, specifically the nodular or chain-type morphologies, as shown in Figure 3. The examination of the primary superheater piping also showed that the grain boundary graphitization can form subsurface at stress-raising notches such as common fabrication defects like surface laps, as shown in Figure 4.

In light of this most recent failure it is clear that a re-thinking of approach is in order for the detection of volumetric degradation associated with this newly identified form of graphitization in P1 material. Structural Integrity recommends that owner/operators re-evaluate their condition assessment and asset management programs to ensure that the potential for this damage is addressed. Plant records should be reviewed to determine the presence of P1 steel piping and the operating conditions under which such material has been in service.

The range of observations indicates that this is an industry-wide concern. Structural Integrity and EPRI are continuing to work on this issue with plans to develop a program that will:

- Identify and quantify the factors that influence the development and progression of damage
- Assess the reliability of applied assessment inspection techniques
- Identify possible nondestructive means of damage detection
- Evaluate the effectiveness of predictive lifing models

If you have any questions or additional experience regarding this important issue contact:

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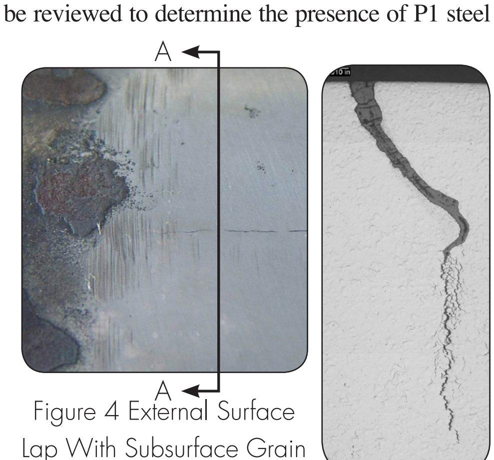

Figure 4 External Surface Lap With Subsurface Grain Boundary Graphitization

Section: A-A