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# Best practice guidelines for detecting and mitigating waterside cracking (stress-assisted corrosion) in power and recovery boilers

## Summary

This Technical Information Paper (TIP) provides guidelines for detecting and mitigating stress-assisted corrosion (SAC) in boiler components. SAC, also called corrosion fatigue or waterside cracking (WSC), is a corrosion mechanism that produces crack-like damage, often in a multi-crack network, on water-contacted surfaces in tubes, headers and piping in all types of boilers. SAC usually occurs adjacent to the footprint of an external attachment, near a weld and wherever the internal surface of a carbon steel tube or pipe experiences cyclic stress high enough to cyclically rupture the magnetite scale. A potential consequence of this corrosion damage mechanism is a leak, which may cause jet-eroding consequential damage on adjacent components. In some instances the cracking damage weakens the tube or pipe so it splits open or produces a “window” leak/hole.

## Scope

This TIP describes the SAC damage mechanism and its controlling parameters, based on comprehensive research studies by the power utility industry in Europe and N. America; boiler components likely to experience SAC; inspection and testing methods; fitness-for-service assessment, and general guidelines for mitigating SAC.

SAC is most effectively found and managed with an owner-accountable testing and inspection program with formal analytical and testing practices and procedures, done by mill personnel and non-destructive testing technicians qualified to find SAC and monitor its progress over time.

## Safety precautions

Non-destructive testing methods and other tasks and procedures described in this TIP have safety risks associated with entering boilers and pressurized equipment for inspection and repair. All jurisdictional and mill safety requirements for these activities apply.

## Background

Carbon steel in contact with deaerated boiler feedwater relies on a protective, iron oxide (magnetite) scale to control corrosion. SAC, a corrosion fatigue mechanism, cyclically fractures magnetite scale in boiler tubes and pipes in a network pattern related to stress acting on the internal surface. Steel exposed at the fractured scale corrodes a bit to reestablish the protective scale layer, producing a surface locally more susceptible to continual fracture of the scale layer in the established pattern. The resulting damage typically is a cluster of parallel, elongated pits, grooves and fissures. Since SAC depends on the local stress, more than one affected place can occur in one tube header or pipe. In cross-section the damage is characterized by blunt-tipped, trans-granular cracks. From the multiple cracks one or two cracks ultimately predominate and penetrate far into and ultimately through the component wall.

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SAC can affect all types of pressurized carbon steel boiler components – tubes, pipes, headers and drums. Because corrosion rates are slow, SAC rarely affects boilers <10 years old, but affects about 50% of boilers >20 years old. SAC growth rates are accelerated by higher levels of dissolved oxygen in the feedwater and more frequent scale-fracturing stress cycles. Boilers that see more trips and service cycles are more likely to have SAC.

SAC has been comprehensively studied by organizations in the power utility industry, including the Electric Power Research Institute (EPRI), whose published research and service findings include:

1. SAC occurs where the local strain exceeds 0.2%, i.e., exceeds the steel yield strength.
2. Components operating at higher temperature (pressure) are more susceptible to SAC because magnetite scales fracture more easily and reform more slowly in higher feedwater temperature.
3. SAC is more likely and grows more rapidly in boiler feedwater with higher dissolved oxygen content, typically resulting from inadequate feedwater deaeration or periodic emptying of the waterside. Boilers restarted with nondeaerated water are more susceptible to SAC damage.
4. Acid cleaning to remove scale inside boiler tubes and headers does not, per se, exacerbate SAC but often is followed by leaks because chemical cleaning unblocks scale-filled fissures and grooves.
5. SAC damage associated with external attachments on tube and pipe does not automatically reduce the component's pressure rating because of the attachment's reinforcing effect. [This also is discussed in detail in Sharp's paper in Reference Articles below.]

Practical guidelines issued by EPRI relating to corrosion fatigue are paraphrased as follows:

- Corrosion fatigue failures occur near support attachments, usually in water-wall tubing but also in economizer tubing, particularly where there is high heat flux and where stress from high restraint can develop. Typical locations include attachments for wind-box casings, buckstays and scallop-bars; also where tubes connect to headers and to other tubes.
- Corrosion fatigue is discontinuous. It is characterized by multiple, trans-granular cracks, with small cracks adjacent to at least one main crack, initiating on the inside of the tube in-line to the highest applied stresses and propagating during transient periods. Tube sampling and metallurgical analysis is the most reliable way to validate corrosion fatigue.
- Eddy current testing (ferritic materials only), digital radiography, magnetic particle testing and/or phased array ultrasonic shear-wave testing may be used to detect and quantify damage. Determining the extent of damage is difficult due to access limitations, but vulnerable locations should be determined. Enlist qualified professional support when resolving the problem for the long-term as it may require redesigning and/or modifying existing attachments.

Severe SAC damage is visible inside a tube or pipe, especially after acid-cleaning removes magnetite scale. Indeed, as discussed later, methodically examining the ID tube samples removed for other purposes is a recommended practice for determining if a boiler has SAC. However, remote or video visual inspection in tubes in place is not a reliable method for detecting SAC. Figure 1 shows the cleaned internal surface of a boiler tube with typical SAC caused by local strain from an external attachment.

Figure 2 shows a cross-section through and the waterside surface a boiler tube with SAC almost halfway through a 6.4 mm (0.26 in.) tube wall. The SAC damage has typical wide, oxide-filled, trans-granular fissures with rounded shapes and narrow parts along the crack believed to be where the crack grows faster, probably because greater crack depth increases the pressure-induced stress at the crack tip.



**Fig. 1.** Stress-assisted corrosion (SAC) damage in the internal surface of a 75 mm (3-in.) OD steel boiler tube with the scale removed to expose the crack-like damage.

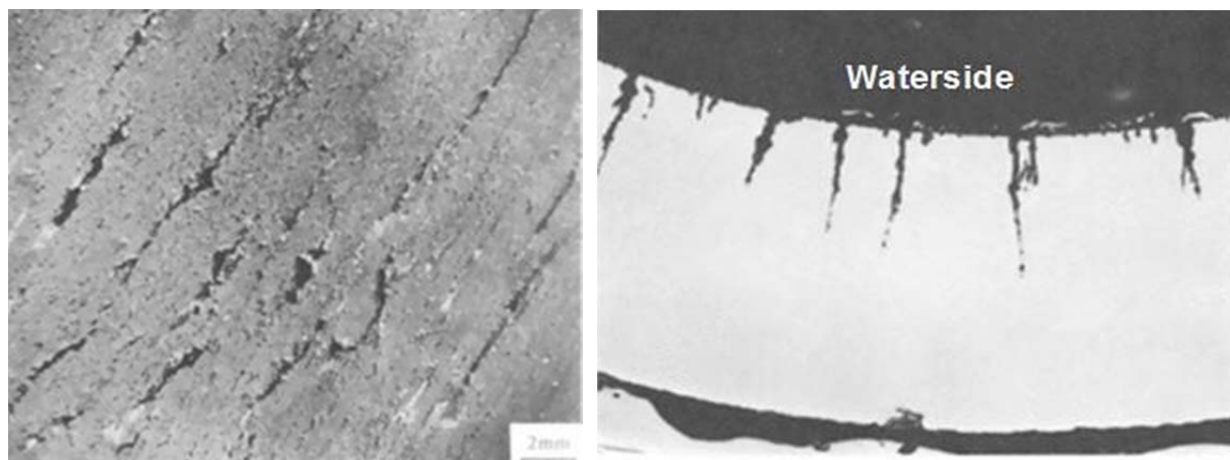


**Fig. 2.** Internal surface (left) and cross-section (right) of hot wall from 65 mm (2.60 in.) tube in a power boiler (1).

Figure 3 shows SAC in the blast-cleaned internal surface of superheater tube bend with no attachment. Internal pitting initially detected by ultrasonic thickness testing was not severe enough to matter and the SAC damage was detected by random “shadow” RT of the superheater loops for internal pits. [Bennett and Meiley provide a similar case history (2).]