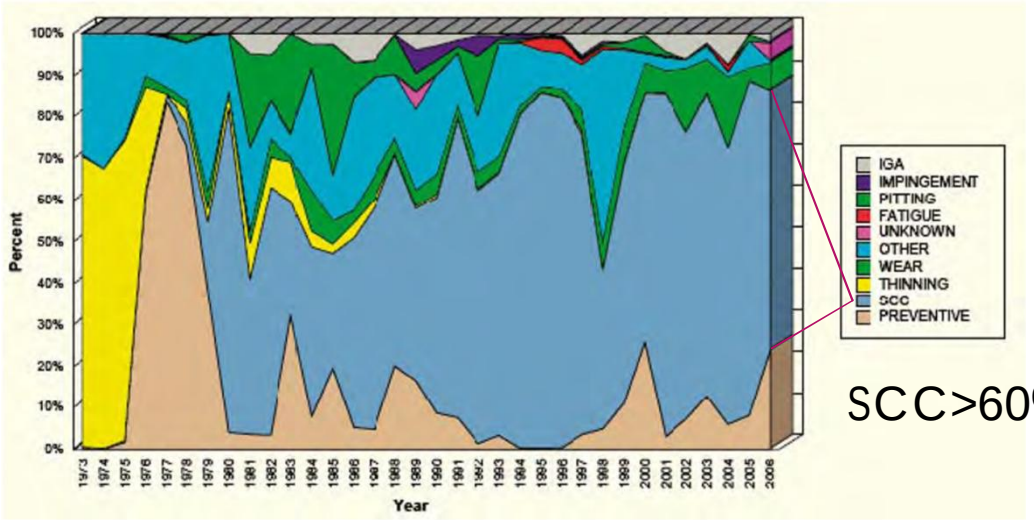
Effect of lead on SCC susceptibility of steam generator body material under PWR secondary side crevice conditions



Worldwide causes of PWR steam generator (SG) tube degradation [EPRI, 2006].
Over 60% of SG tube failures are caused by SCC.

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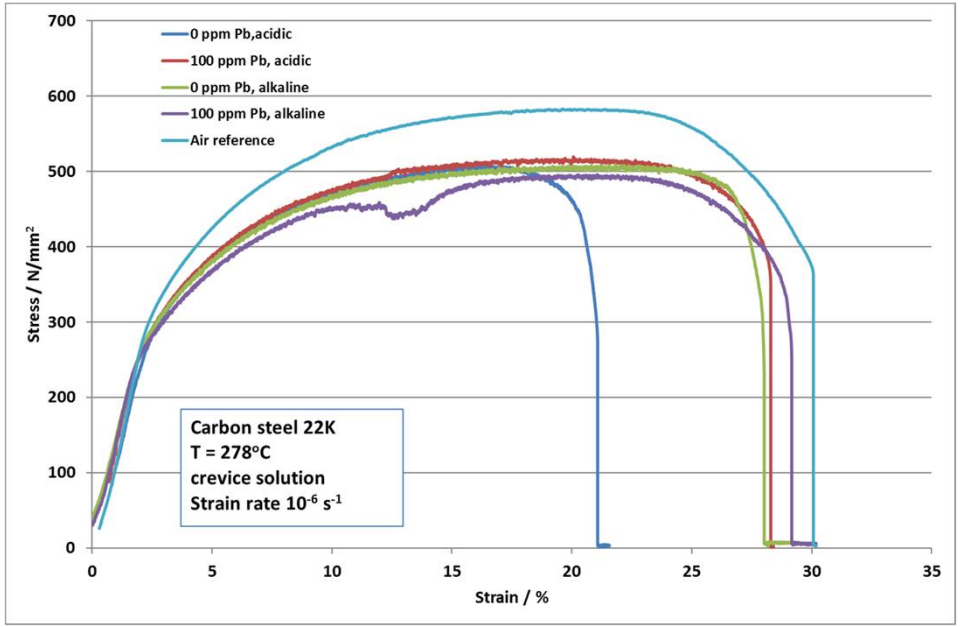
Steam generator crevice environment

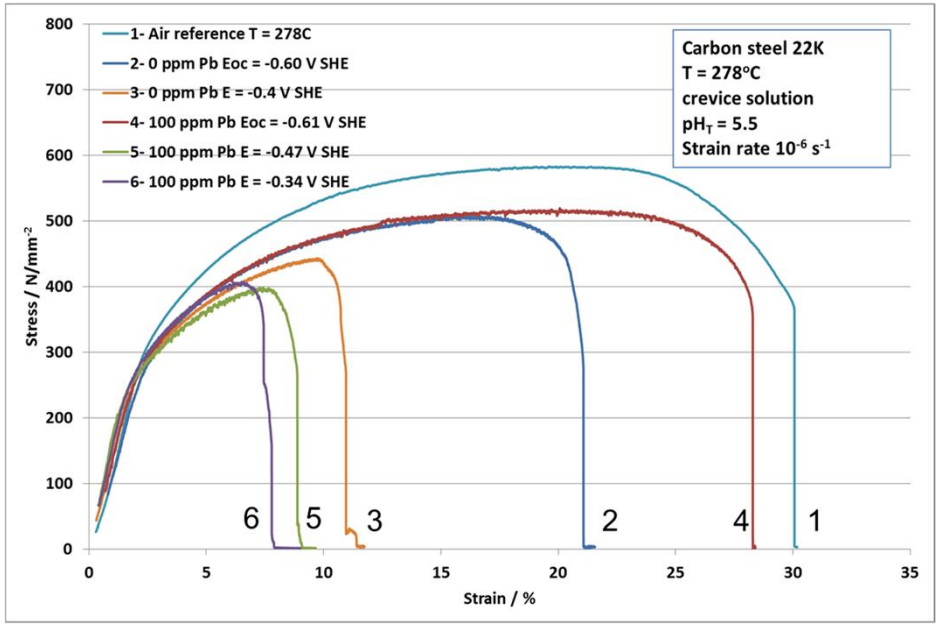
- Magnetite (Fe_3O_4) oxide particles form due to corrosion of feed water line, enter the SG and deposit there.
- Water filling the deposits evaporates as almost pure steam due to boiling, leaving impurities behind à after some time of operation, an agressive crevice chemistry is formed (either acidic or alkaline).
- Lead (from 100 up to 10000 ppm) has been found in almost all steam generator deposit samples extracted from operating plants.
- In some VVER –plants (Russia and Czech Republic) wall-through SCC cracks have been found near the bi-metallic welds of carbon steel to stainless steel à concern of the possible detrimental effect of Pb.

SG body material (carbon steel 22K) Slow strain rate testing - 1



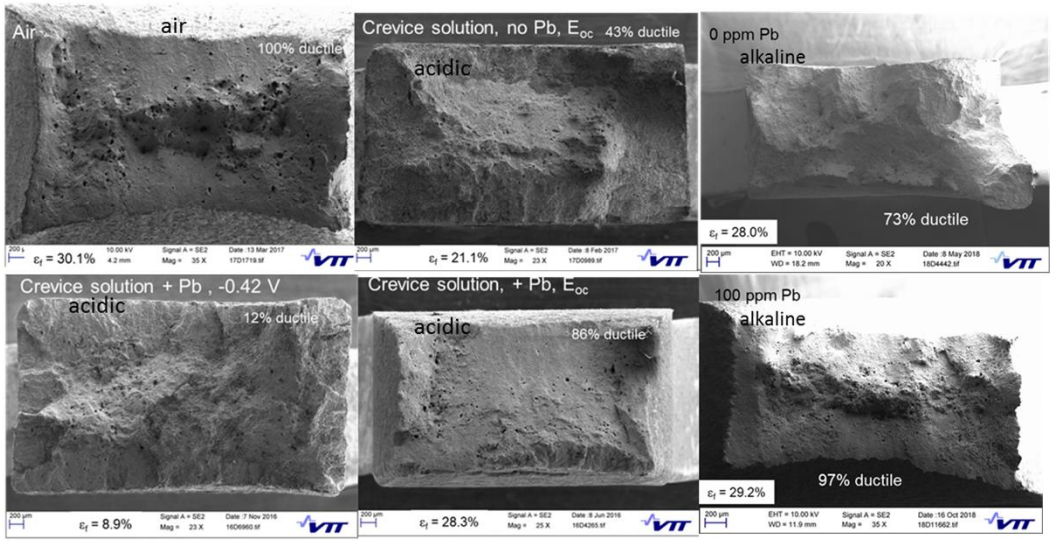
- Carbon steel 22K is susceptible to SCC in both acidic and alkaline crevice conditions
- SCC susceptibility is strongest in acidic conditions without lead (Pb)
- à to minimize SCC in carbon steel, plants should run the secondary side chemistry so that the crevice chemistry will be neutral or slightly alkaline
- à Pb is beneficial

SG body material (carbon steel 22K) Slow strain rate testing - 2



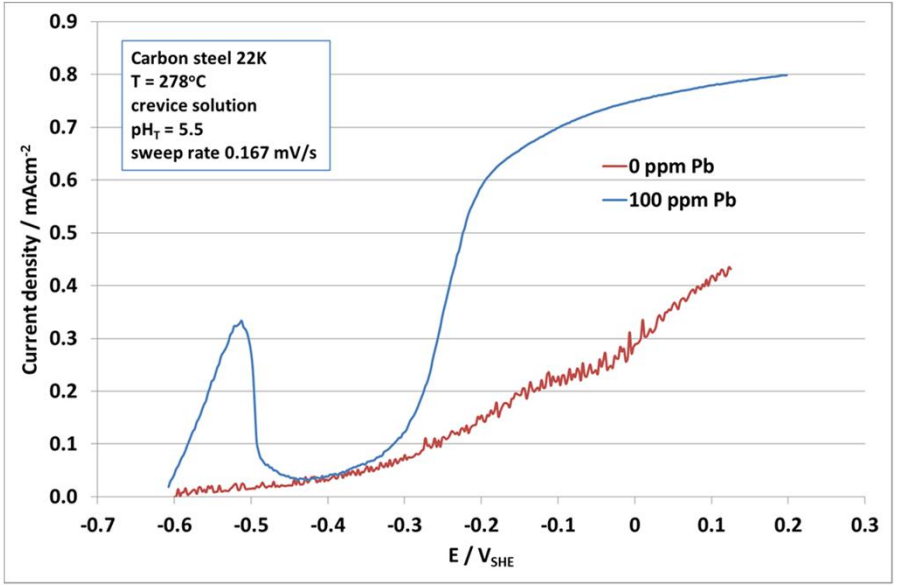
- Oxygen in-leakage into the SG was simulated by increasing the potential by about 0.1 to 0.2 V
- The fracture strain decreased radically to about 10% or less, indicating a very strong susceptibility to SCC, irrespective of Pb
- à oxygen in-leakage is detrimental and should be avoided

SG body material (carbon steel 22K) Fracture surface appearance



- In air, the fracture surface is 100% ductile.
- In alkaline crevice conditions, the fracture surface is 73% ductile without Pb and 97% ductile with Pb.
- In acidic crevice conditions, the fracture surface is 43% ductile without Pb and 86% ductile with Pb.
- In acidic crevice conditions at elevated potential (simulating oxygen in-leakage), the fracture surface is only 12% ductile, indicating very high susceptibility to SCC

SG body material (carbon steel 22K) The effect of lead (Pb)



- Without Pb, the current density increases as a function of potential.
- Above -0.35 V_{SHE} the rate of increase becomes higher, because of magnetite starts to transform to heamatite.
- In presence of Pb, an active peak appears at about -0.55 V_{SHE}, indicating dissolution of Pb as $PbCl^-$, followed by passivation (decrease of current density), and further rapid increase above -0.35 V_{SHE}.
- The effect of Pb is to partially weaken the passive magnetite layer so that corrosion localisation necessary for SCC becomes more difficult.

SG body material (carbon steel 22K) The effect of lead (Pb)

Coclusions

- Body material of steam generator (carbon steel 22K) is susceptible to SCC in typical crevice conditions, much more so under acidic than alkaline conditions à to minimize SCC in carbon steel, *plants should run the secondary side chemistry so that the crevice chemistry will be neutral or slightly alkaline*.
- Addition of lead (Pb) *improves* the resistance of carbon steel 22K to SCC in both acidic and alkaline conditions à *no concern with Pb in case of carbon steel*.
- The effect of Pb is to partially weaken the passive magnetite layer so that corrosion localisation necessary for SCC becomes more difficult.
- Increase of potential dramatically increases the susceptibility to SCC *à plants need to prevent oxygen in-leakage into the steam generator*.