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

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INTRODUCTION

Lead (Pb) is known to cause lead induced stress corrosion cracking (PbSCC) of nickel based materials normally used in steam generator (SG) tubing, i.e. alloy 600 and alloy 690. Lead is found in almost all deposit samples taken from SGs, the source being impurities in the structural materials, chemicals used or, in extreme cases, lead blankets used for radioactive protection during outage periods. In some PWRs, wall through cracks have been found in SG body at locations of dissimilar (low alloy steel to stainless steel) welds. During boiling operation, impurities in the SG water accumulate in crevices formed under deposits, since the impurities are mainly non-volatile. Depending on the nature of the impurities, the crevice chemistry thus formed may become strongly acidic or alkaline. Very little is known about the susceptibility of low alloy steels to PbSCC, and thus a study was made to the role of Pb in this respect.

MATERIAL & METHOD

Carbon steel 22K, the body material of VVER SGs was studied under secondary side crevice conditions. A combination of mechanical tests (slow strain rate, SSRT), electrochemical tests (voltammetry and electrochemical impedance spectroscopy, EIS) and post-test examination of exposed surfaces with scanning electron microscopy (SEM) and glow discharge optical emission spectroscopy (GDOES) techniques was used in this work. Carbon steel 22K was studied in a SG crevice environment (both acidic and alkaline) with chloride and sulphate, with and without 100 ppm Pb, at the temperature of T = 278°C.

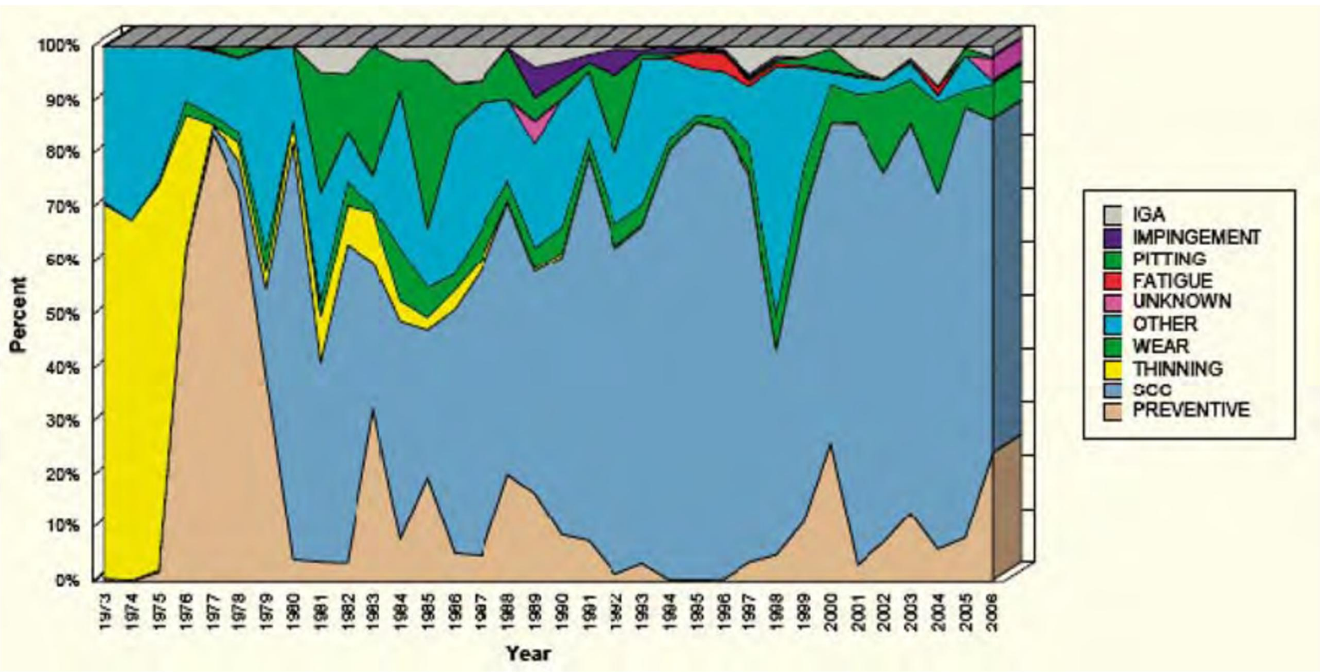

Figure 1. Worldwide causes of PWR steam generator (SG) tube degradation [EPRI, 2006]. Over 60% of SG tube failures are caused by SCC.

During SG operation, deposits (mainly magnetite from feed water line) form within the SG, and since impurities in the water are not volatile, they concentrate within and under the deposits. Depending on the impurities in the bulk water, the crevice chemistry can end up acidic or alkaline. The crevice conditions studied in this work are shown in Table 1.

Table 1. The crevice environments studied in this work.

Crevice condition	NaCl (wppm)	Na_2SO_4 (wppm)	Pb (wppm)	H_2SO_4 (wppm)	pH at T= 278°C
Acidic	330	740	0 and 100	98	5.5
Alkaline	330	740	0 and 100	0	7.0

Slow strain rate testing (SSRT)

In slow strain rate testing, a tensile specimen is slowly pulled into fracture (strain rate of 10^{-6} s^{-1} or less, resulting in testing times of days or weeks), allowing enough time for corrosion processes to take place. The susceptibility to SCC is judged from reduction in the strain to fracture (in comparison to that in air at the same temperature), and from fracture surface appearance. Figure 2 shows the results from SSRT for air and both the acidic and alkaline crevice conditions.

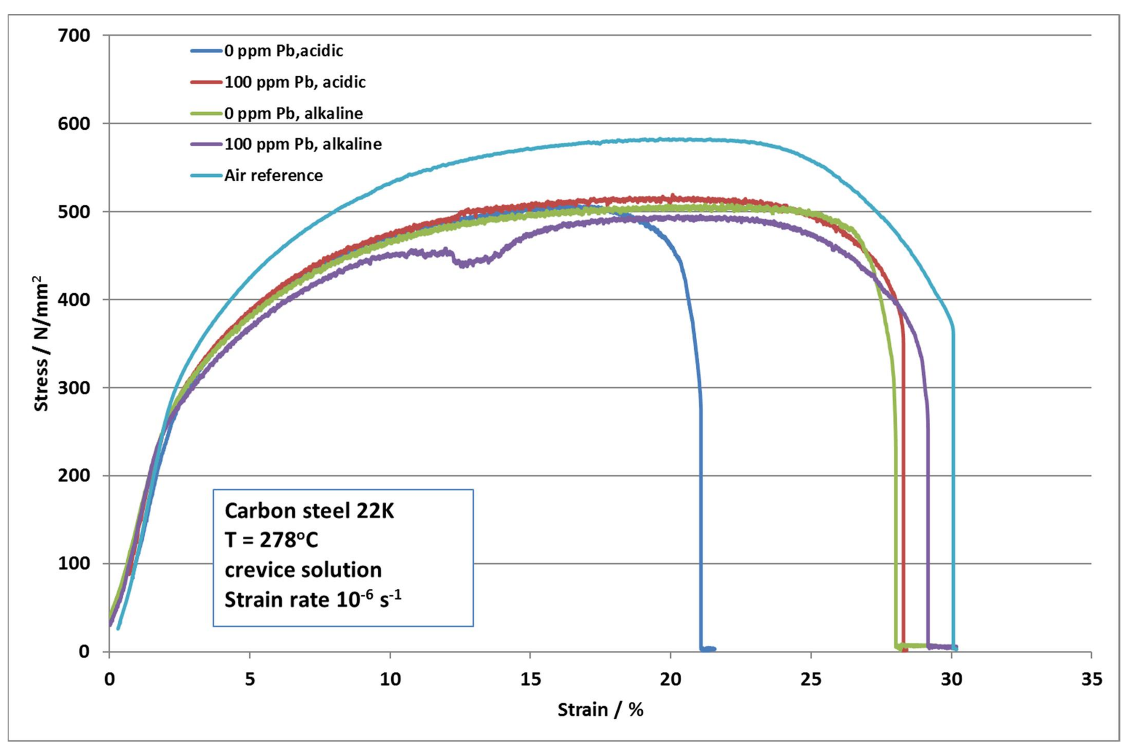

Figure 2. Slow strain rate curves for air (reference), as well as acidic and alkaline crevice conditions. The fracture strain is clearly lowest in acidic crevice conditions without Pb, indicating relatively strong susceptibility to SCC. Addition of 100 ppm Pb is seen to increase the fracture strain in acidic conditions, i.e. a positive effect.

An oxygen in-leakage into SG affects strongly the corrosion behaviour of SG materials, typically accelerating the corrosion processes. The effect of oxygen can be simulated experimentally by increasing the electrochemical potential (ECP). In Figure 3, increasing the ECP by a mere 0.1 to 0.2 V (to -0.47V < E < -0.34V) is seen to result in a drastic decrease of the fracture strain down to 10% or even less, indicating a severe susceptibility to SCC.

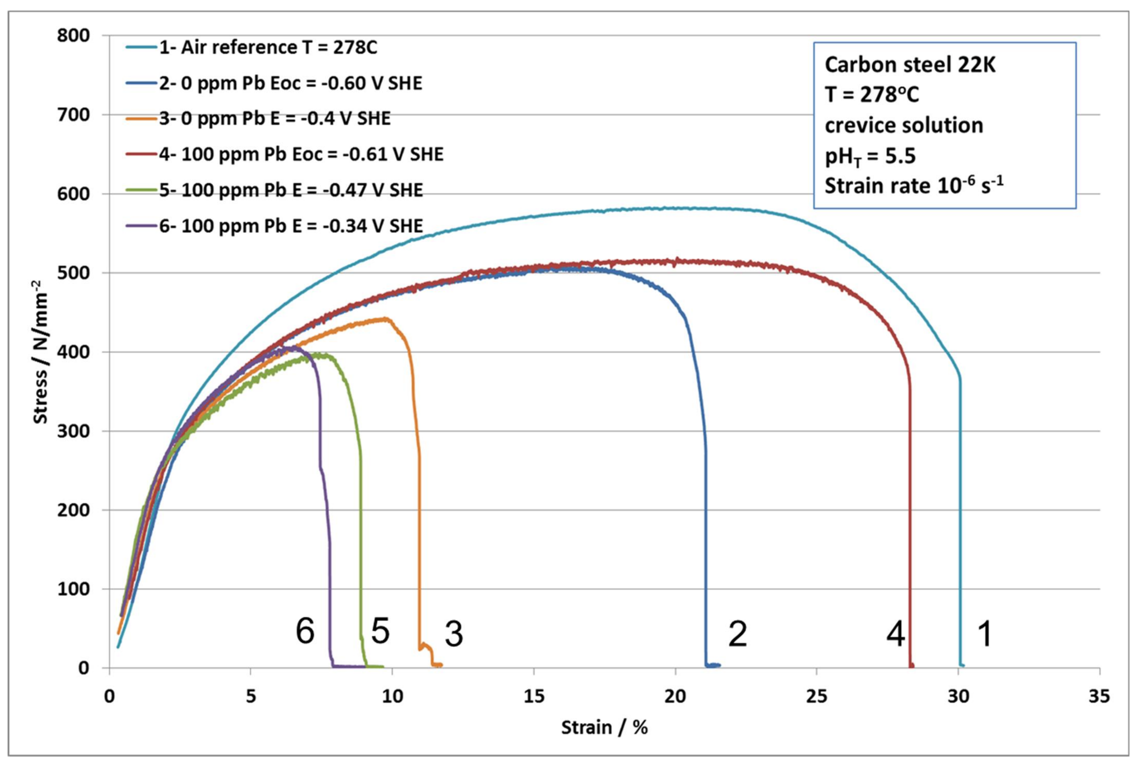

Figure 3. Slow strain rate curves in acidic crevice environment. At elevated potentials (simulating the effect of oxygen in-leakage), curves 3,5 and 6, the fracture strain is very low, indicating severe susceptibility to SCC.

The polarisation curve (electrochemical testing) shown in Figure 4 reveals that addition of 100 ppm Pb results in partial activation (increase of current density) of the surface both in the area of corrosion potential (close to E = -0.6V) and at potentials higher than about E = -0.3V. Apparently this partial activation prevents the localization of corrosion necessary for SCC, thus reducing the susceptibility of carbon steel 22K to SCC, as also evidenced by the slow strain rate curves in Figures 2 and 3.

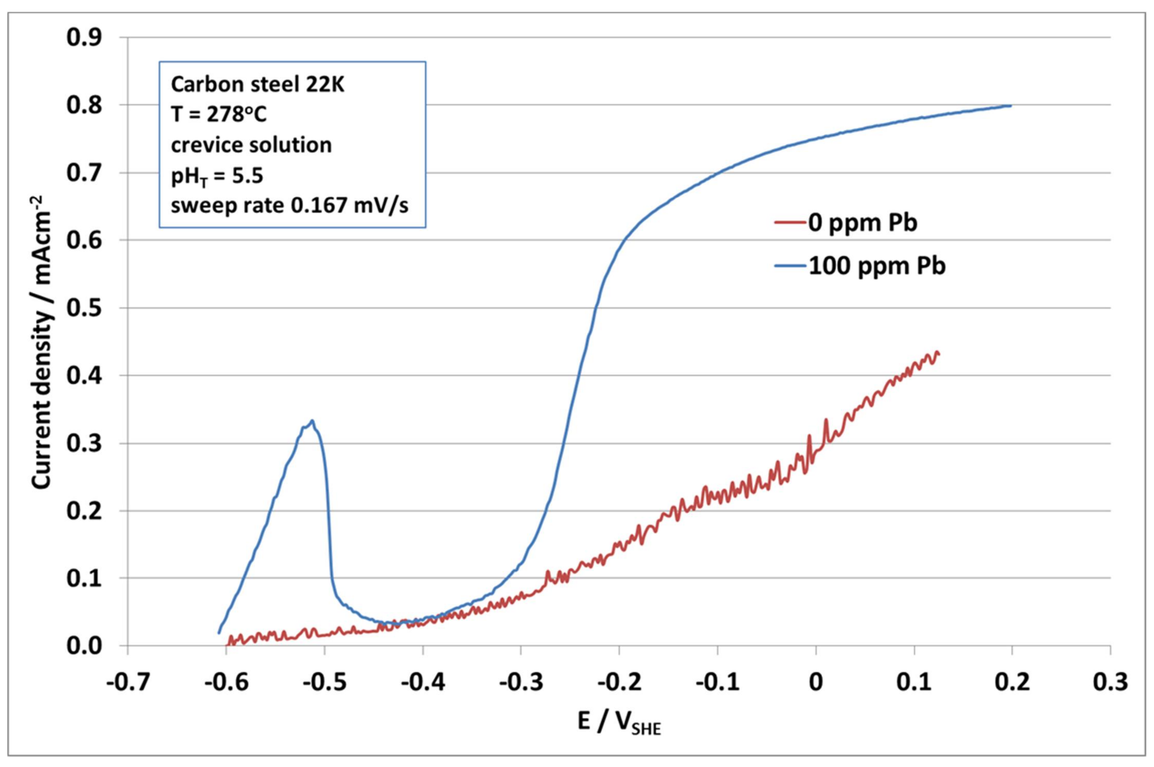

Figure 4. Polarisation curve (i.e. current density vs. potential) of steel 22K in acidic crevice conditions with and without Pb. In precence of Pb, an active peak can be seen in the current density at -0.6V<E< -0.5V, and at potentials higher than E = -0.3V, the current densities are much higher than without Pb.

Conclusions

Steam generator body material (low alloy steel 22K) is susceptible to stress corrosion cracking (SCC) in both acidic and alkaline crevice conditions at T = 278°C. Under alkaline crevice conditions the susceptibility is, however, less evident. Addition of 100 ppm Pb reduces the susceptibility to SCC under both types of crevice conditions. Increasing the potential, as in a simulated oxygen inleakage to the steam generator, dramatically increases the susceptibility to SCC.

Based on the results, in relation to PWR secondary side chemistry control, avoiding impurities in the bulk chemistry leading to acidic crevice conditions is recommended. With regard to SCC of SG body material (carbon steel), Pb is not a problem.

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