Performance of binary Ni-Cr and ternary Ni-Cr-Al alloys in stagnant liquid lead at 650 and 750 °C

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Motivation

Lead-cooled fast reactors (LFR) with improved efficiency resp. higher operating temperature of 750 °C are technology options for an appropriate future energy supply and for the minimization of high-level nuclear waste. At > 600 °C, high- Ni steels or Ni-based alloys have to be used for reasons of strength and creep resistance. The corrosion of potential structural materials in liquid lead (alloys) is mainly due to the dissolution of the various constituents of the metallic materials by the liquid metal. In order to minimize dissolution of metallic structure materials, oxygen is added to liquid lead, to promote formation of self-healing protective oxide films on the material surfaces.

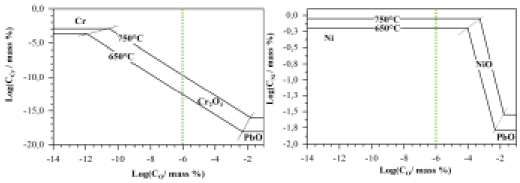
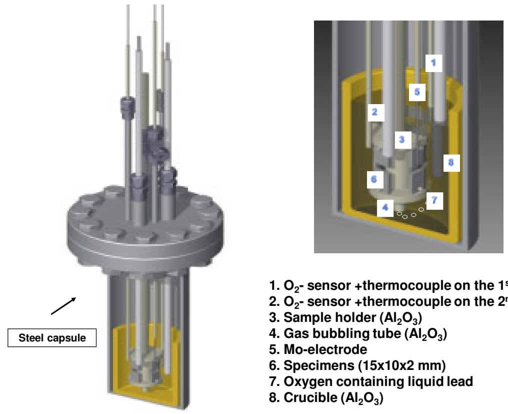


Fig.1 Concentration of Ni and Cr dissolved in Pb at 650 °C/ 750 °C, green line shows the experimental oxygen concentration in the liquid lead

Corrosion test apparatus



1. O_2- sensor +thermocouple on the 1st level
2. O_2- sensor +thermocouple on the 2nd level
3. Sample holder (Al_2O_3)
4. Gas bubbling tube (Al_2O_3)
5. Mo-electrode
6. Specimens (15x10x2 mm)
7. Oxygen containing liquid lead
8. Crucible (Al_2O_3)

Fig.2 Experimental steel capsule with sample holder and specimen arrangement

The study of the oxidation and dissolution behavior of binary Ni-Cr-alloys (with 0, 25, 30, 35 and 48 mass % Cr) in stagnant liquid lead at 650 and 750 °C and c_o=10^{-6} mass % dissolved oxygen was carried out. Additionally, the influence of up 1 to 5 mass% Al in ternary alloys with 35 mass% Cr was investigated, too.

Corrosion scale of binary Ni-Cr alloys

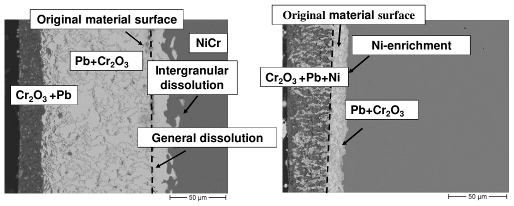


Fig.3 SEM/EDX Analysis of the cross-section of Ni30Cr alloy

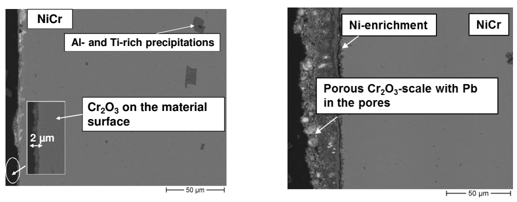


Fig.4 SEM/EDX Analysis of the cross-section of Ni48Cr alloy

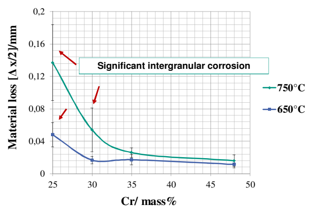


Fig.5 Material loss depending on Cr-content at 650 and 750 °C

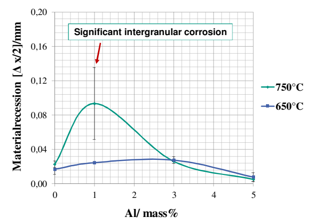


Fig.6 Material loss depending on Al-content by Ni35Cr at 650 and 750 °C

Corrosion scale of ternary Ni-Cr-Al alloys

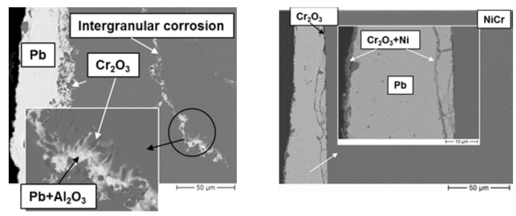


Fig.7 SEM/EDX Analysis of the cross-section of Ni35-1Al alloy

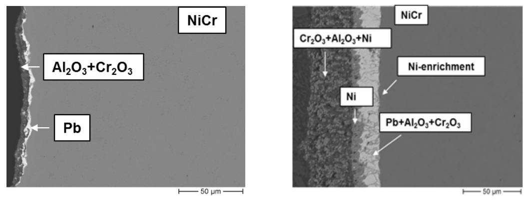


Fig.8 SEM/EDX Analysis of the cross-section of Ni35-5Al alloy

Analysis of oxidation and dissolution behavior of binary NiCr-alloys

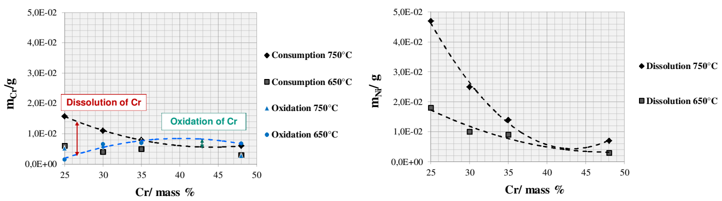


Fig.9 Quantitative estimation of the oxidation/dissolution behavior based on the calculation of the mass of consumption/oxidizing Cr and dissolved Ni

Binary Ni-Cr-alloys at 650 and 750 °C

- **Alloys with lower Cr-content form Cr_2O_3 away from the material surface and show the significant material loss, (Fig. 5) . Also tendency for intergranular penetration of lead, (Fig.3) was observed**
- **Reduction of temperature to 650 °C exhibit significant difference by solubility of Ni and Cr, corresponding to (Fig.1).**
- **High Cr-content and lower temperature favores the oxidation of Cr at the cost of Cr consumption, (Fig.9 (left)). That results in formation of oxide direct on the material surface, (Fig.4)**

Ternary Ni-Cr-alloys at 650 and 750 °C

- **Lower Al-content has delayed the formation of chromia and makes favorable selective leaching of nickel, themselves, however, no protective oxide layer forms, especially in the case of lower Al-content at 750 °C, (Fig.7).**
- **The corrosion attack in the form of intergranular penetration at lower Al-content (1 mass %) was observed, (Fig.7 (right)).**
- **5 mass % Al in Ni35Cr-alloy didn´t form oxide directly on the metal surface. Oxide is often porous and by reducing of the exposure temperature has disolved nickel, (Fig.8 (right)).**

Conclusions

- **Only at 650 °C through the preferred oxidation of Cr, a barrier against the high Ni-dissolution was achieved .**
- **But formation of oxide scale away from the material surface didn't lead to protection against corrosion of binary resp. ternary alloys.**

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