Thermal ageing and EAC research for plant life management

Ulla Ehrnstén[1], Matias Ahonen[2], Mykola Ivanchenko[1], Caitlin Huotilainen[1], Jari Lydman[1], Aki Toivonen[1], Unto Tapper[1], Roman Mouginot[3], Yuri Yagodzinskyy[4], Hannu Hänninen[4]
[1]VTT Technical Research Centre of Finland Ltd, [2] Neste Ltd, [3]Femto Tools AG, [4]Aalto University

Abstract

The THELMA, Thermal ageing and EAC research for plant life management, project addresses the behaviour of nuclear materials in light water reactor environments. Two doctoral theses and numerous publications have been published. THELMA also acts as the platform for reporting on international research. This knowledge is key for failure analyses and the assessment of long-term behaviour of materials in light water reactors (LWR).

Thermal ageing of Alloy 690

Thermally treated Ni-based Alloy 690, with high Cr-content, has been successfully used in steam generators (SG) for nearly 30 years. It is also used in forged and rolled conditions as replacement for Alloy 600, and in new-builds. The thermal ageing behaviour of Alloy 690 was investigated in the thesis work by R. Mouginot, using versatile methods, e.g. nano-hardness, microscopy (light, scanning, transmission and atomic force) and X-ray diffraction. The observed metallurgical changes due to thermal ageing were intergranular (IG) carbide growth and lattice contraction, Figure 1. Lattice contraction is indicative of short range ordering (SRO). SRO also increases lattice micro-stresses, while carbides may act as hydrogen trap sites, Figure 1. Both phenomena can affect the primary water stress corrosion cracking (PWSCC) susceptibility of the material. The work has increased the understanding of the long-term behaviour of Alloy 690, which is important, e.g., for OL3, with a design life of 60 years.

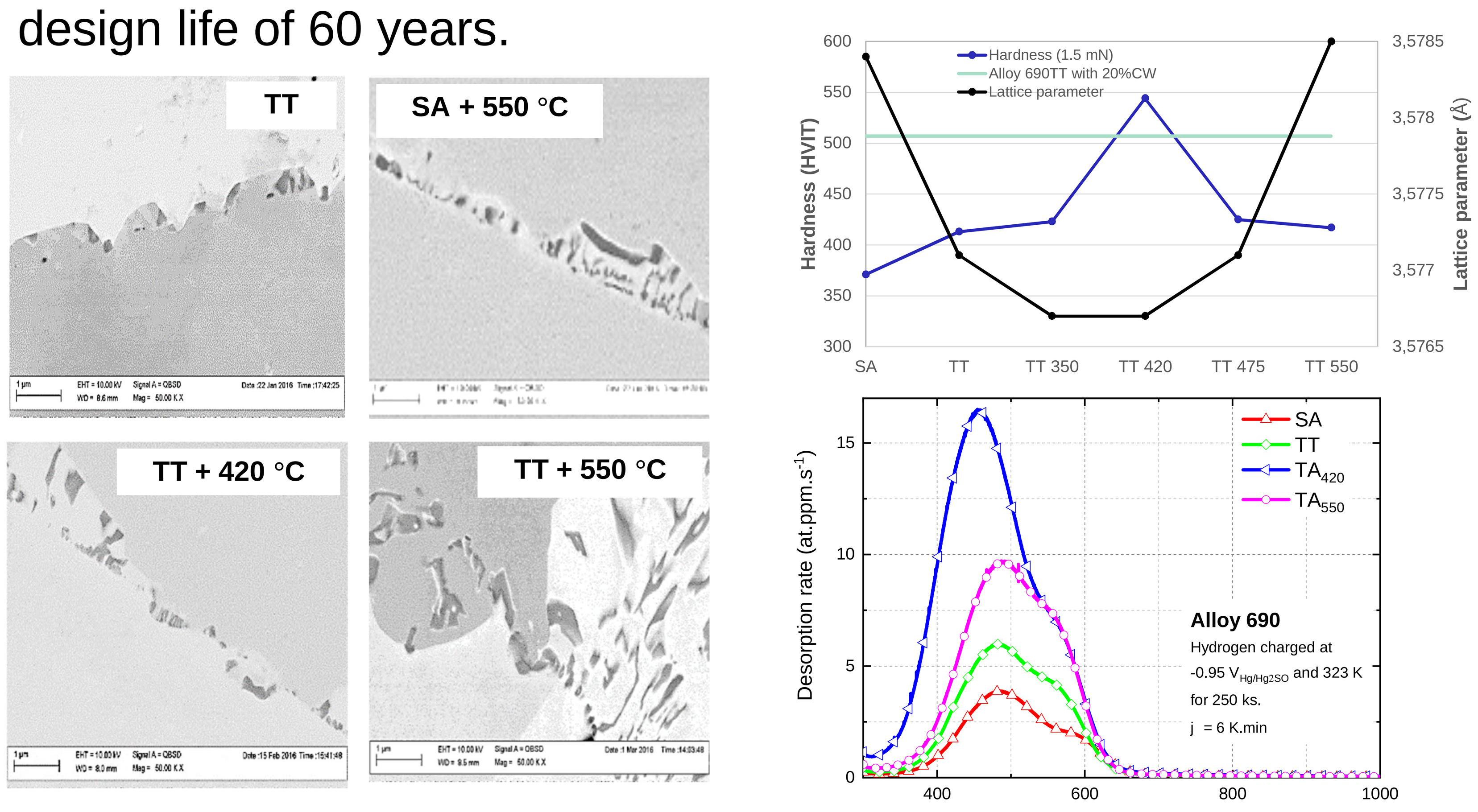

Figure 1. Thermal ageing of Alloy 690 causes IG carbide growth (left) and lattice contraction (upper right), which indicates SRO. Thermal aging of Alloy 690 increases hydrogen uptake during charging (lower left).

Thermal ageing of cast stainless steel

Plant aged Type 316 cast stainless steel from the hot and cold legs of a steam generator after 70 kh at 325 °C and 274 °C, respectively show increased hardness, Figure 2, and decreased mechanical properties.

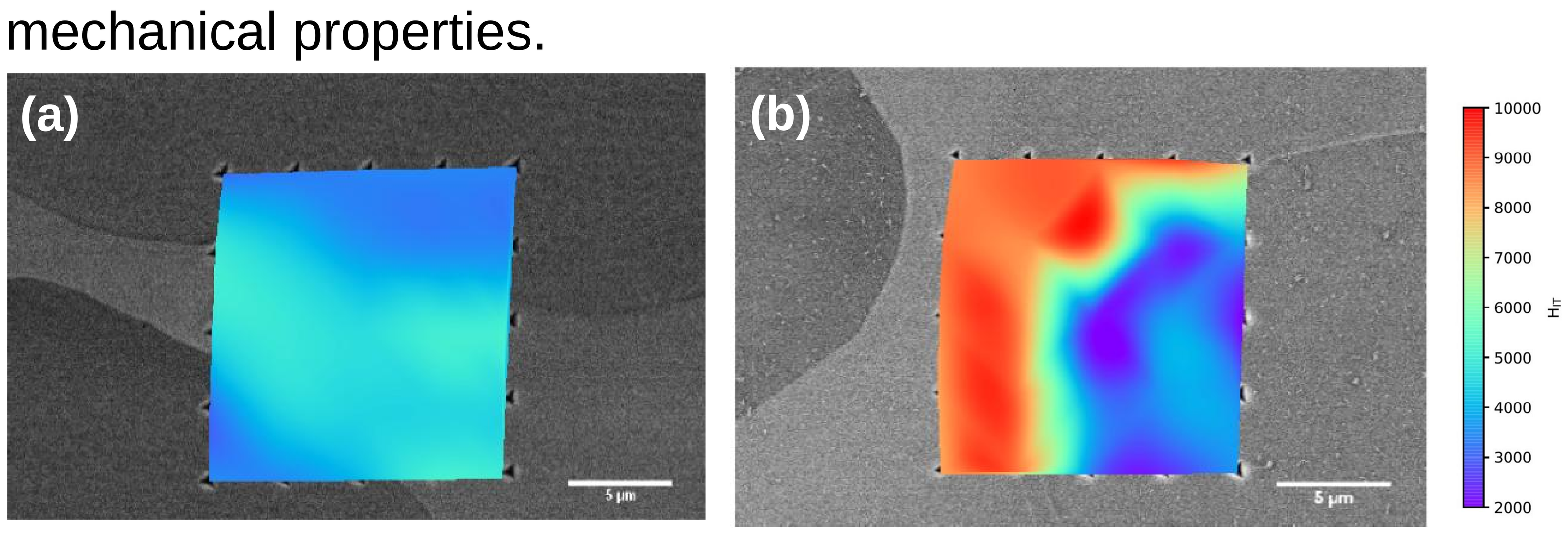

Figure 2. Thermal ageing increase the nano-hardness of the ferrite phase in the dual phased cast stainless steel. In (a) the solution annealed condition and (b) thermally aged condition of the hot leg material are shown.

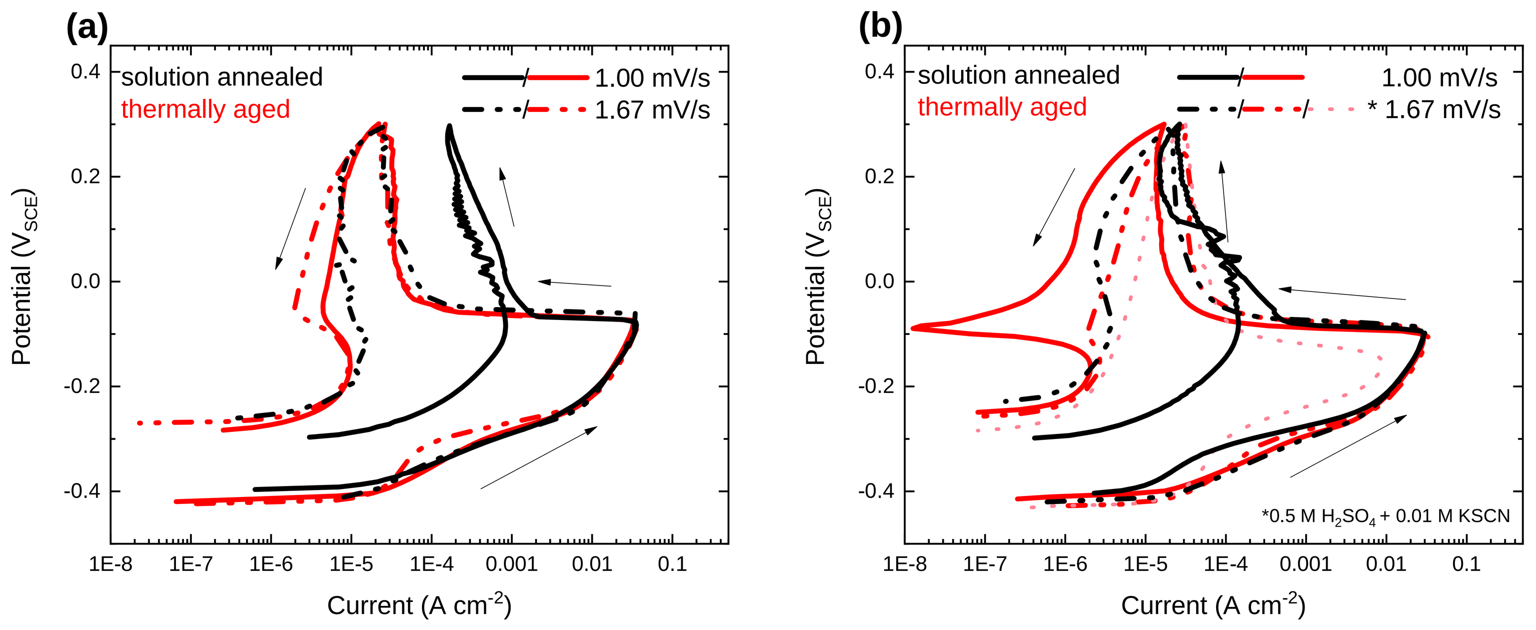

Figure 3. The electrochemical response is stronger with slower scan rate in both the (a) hot leg and (b) cold leg materials. The response vs thermal ageing is not straight forward, as it is for laboratory aged materials.

Electrochemical methods are successfully used for laboratory aged materials at higher temperatures. Plant aged materials show a different response, which must be understood and acknowledged in the methods used. The ageing process is complex with several temperature and time-dependant mechanisms. These results highlight the value of getting access to real, plant-aged material, for which Ringhals is greatly acknowledged.

Factors affecting brittle fracture initiation in pressure vessel weld metal

The reactor pressure vessel (RPV) is the most important component in a nuclear power plant (NPP). Combining mechanical testing, used for life time assessment, with microstructural investigations improve the knowledge about factors affecting brittle fracture, and thereby the understanding of what is due to intrinsic material properties, and what is due to test scatter. The knowledge is used for mechanistic understanding and test performance assurance. The results show lower fracture toughness when initiation is in the reheated zone compared to the as-welded microstructure, Figure 4.

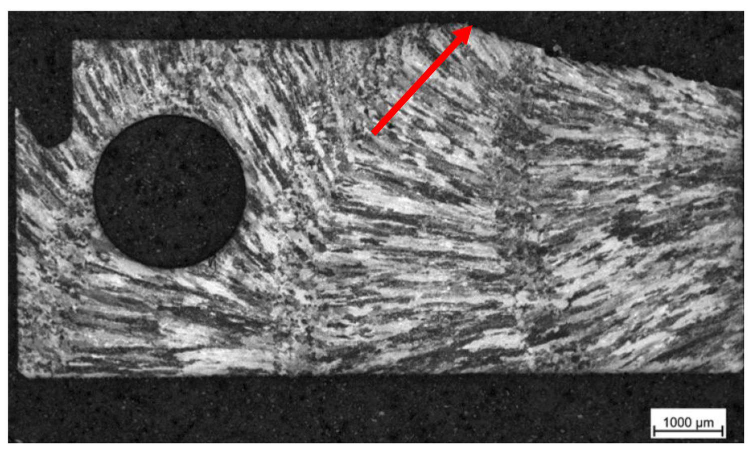

Figure 4. Typical microstructure of RPV weld metal. The arrow shows the location of brittle fracture initiation.

Conclusions

- **Thermal ageing of Alloy 690 causes short range ordering and carbide growth, which may increase the susceptibility to stress corrosion cracking in a hydrogenated PWR environment.**
- **Thermal ageing of cast stainless steel at plant operating temperatures shows similarities, but also differences compared to materials aged at higher temperatures, and research methods used must acknowledge the differences.**
- **An increased understanding of brittle fracture in pressure vessel materials is achieved when mechanical testing and microstructural investigations are combined.**
- **Knowledge built in THELMA is used in stakeholder assignments.**

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Contact
Principal Scientist Ulla Ehrnstén
Tel. +358 405354057
Ulla.Ehrnsten@vtt.fi