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Long-term integrity of copper overpack

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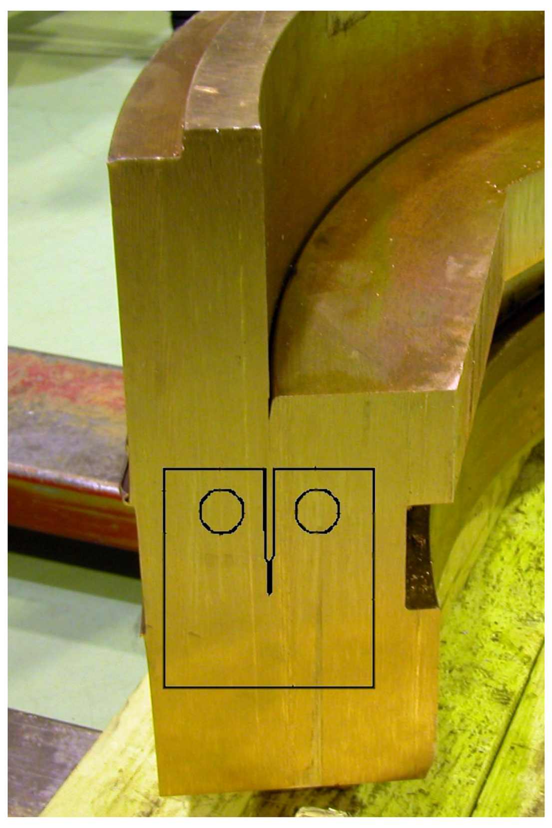

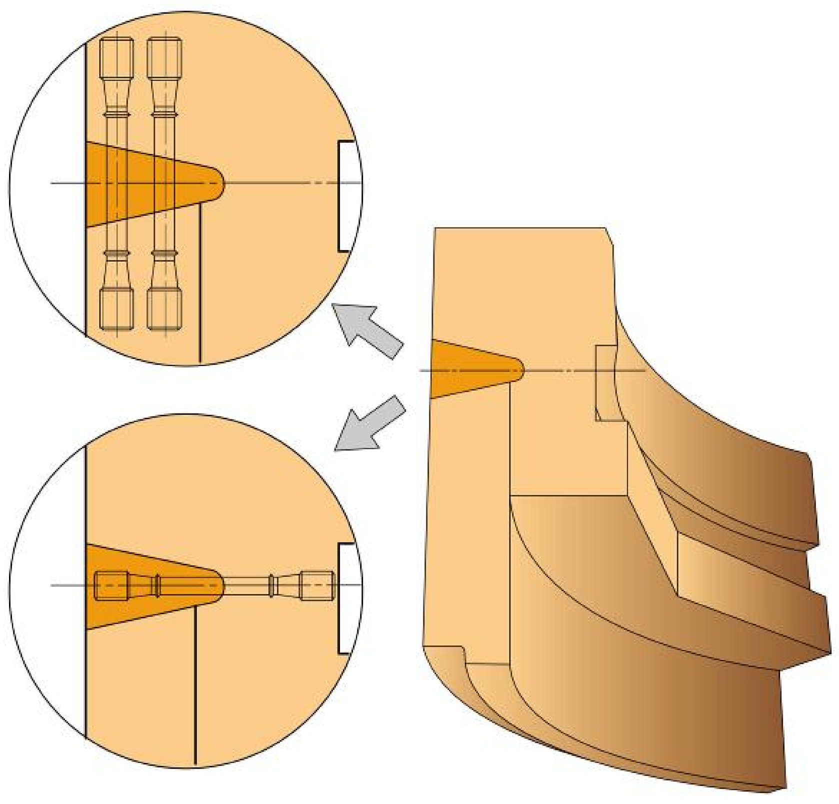

The aim

The project aimed to provide long term experimental evidence and model-based predictions for the authorities to support the decision-making on acceptable and safe final disposal in the repository. The results have provided an extensive body of data, supporting information and added resources such as experimental facilities and human expertise in the area of damage mechanisms, modelling, long term life management and evidence-based understanding of the materials of interest.

Mechanical testing

Changes in base material and FSW welds of OFP copper have been investigated after low temperature (150-175°C), low stress (35-120 MPa) creep experiments. The observed changes in the multiaxial (CT) specimens tested up to 30 000 h (3.4 years) at 175°C appear to be largely restricted to widening recovery zones at stressed grain boundaries and to increasing grain boundary cavitation (Figs. 1-2) that had first emerged after 15 000 h of testing at the natural (joint) notch tip. The cavitation damage appears to be related to the combined local strain and stress state in front of the notch/crack tip. The results from CT tests and earlier tests with nominally uniaxial but defective specimens suggest that multiaxiality is important in controlling and limiting creep life. In comparison, fast evolving intergranular creep damage, crack branching and low ductility was confirmed in pure (OFHC) copper in CT specimens tested up to 10 400 h (1.2 years), while much higher creep ductility has been retained in OFP copper so far.

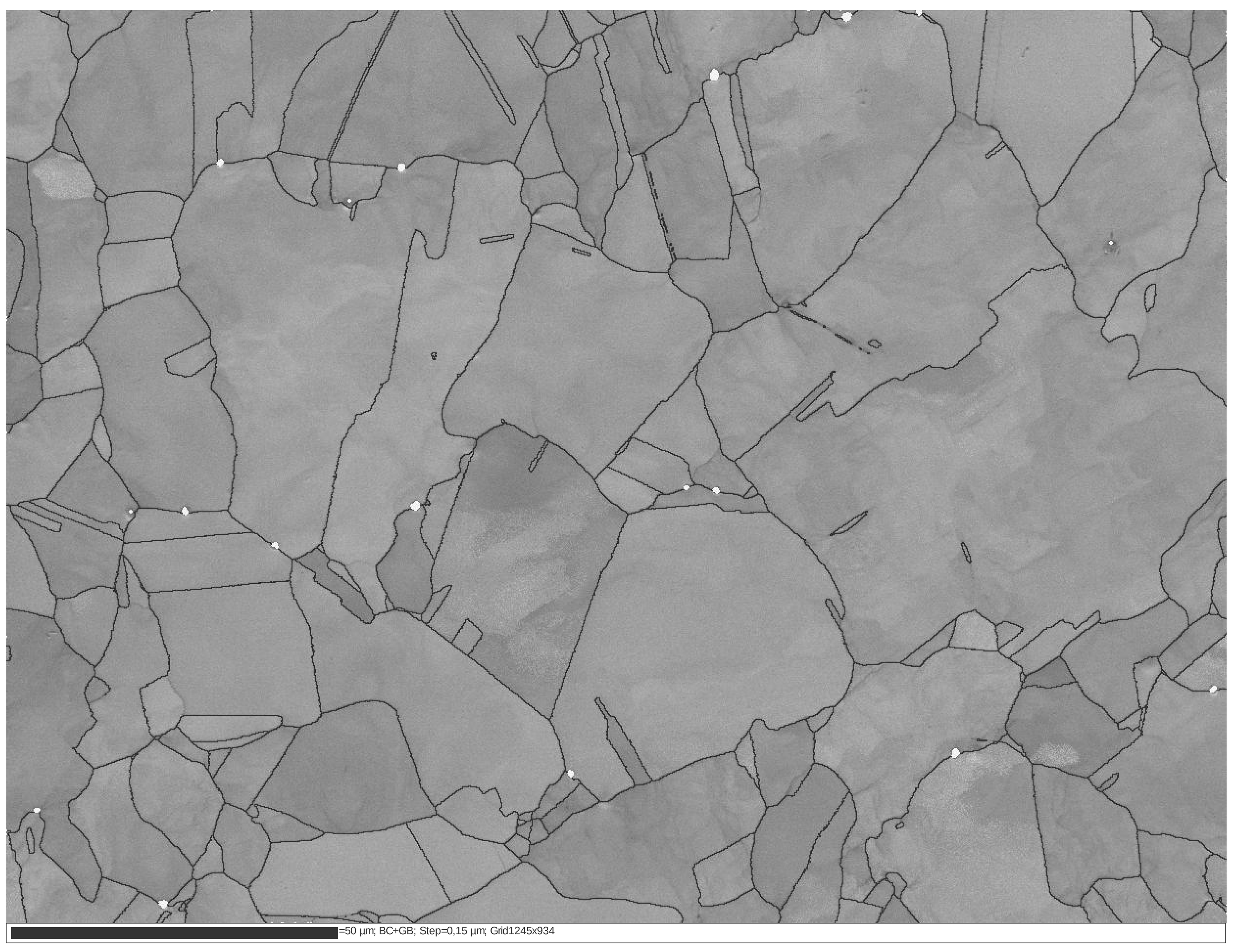

Fig. 1. Grain boundary cavities near the crack tip of the CT specimen after 25000 h of testing (stir region).

Life prediction

The longest continuing uniaxial creep test (150°C/120 MPa) for OFP copper has exceeded 75 000 h (8.5 years). For damage modelling it is of interest that interrupted testing of the longest uniaxial specimen has also shown distributed microcracking. The observed effect of small scale natural weld (FSW) defects suggests increasing notch weakening with increasing time to rupture (decreasing stress). The test results continue to support creep modelling and have been used for life assessment with the latest expected temperature history of the canister at different assumed stress levels, using a combined Wilshire and LCSP creep model for OFP copper (Fig. 3). The resulting predicted allowable (constant) stress level for a lifetime of 100 000 years would be about 140 MPa for the copper overpack.

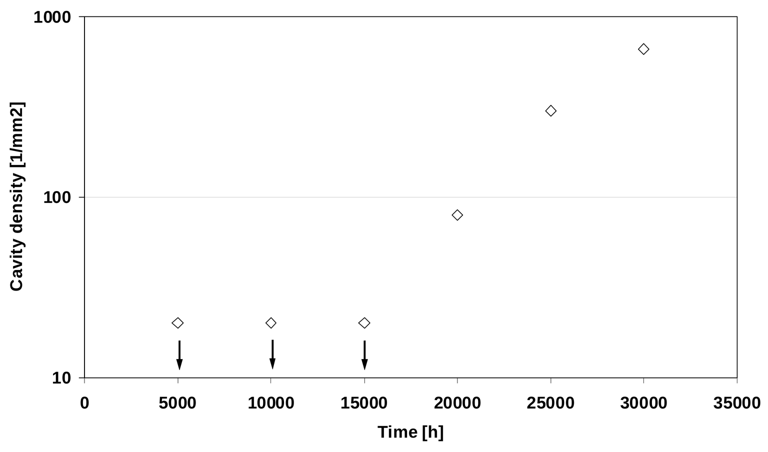

Fig. 2. Grain boundary cavity density in the OFP copper CT-specimen with friction stir weld at 175°C/35 MPa reference stress

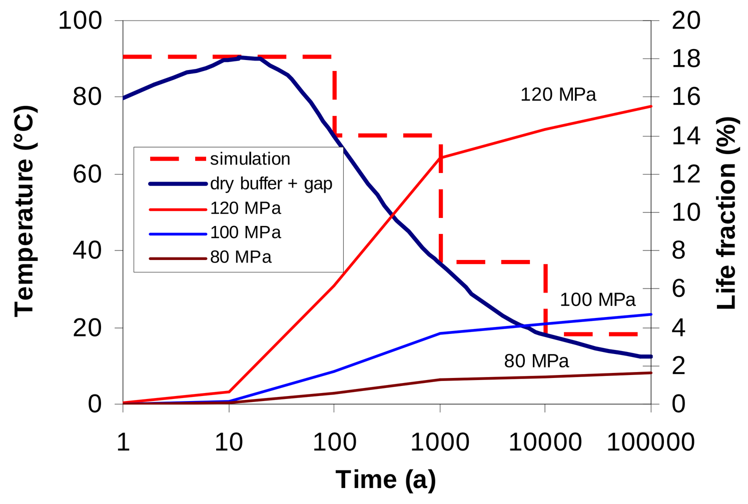

Fig. 3. The temperature history of the copper canister and the corresponding predicted life fraction at three stress levels in final disposal conditions using the dry buffer assumption; dashed line is a conservative estimate for temperature history used in life prediction.

Corrosion testing

In the combined corrosion and creep testing with welded CT specimens immersed in aerated simulated Olkiluoto groundwater at 90°C, heavy general corrosion up to a depth of about 2 mm was observed already after 4400 h of testing (Fig. 4). In comparison to this, no significant indications of localised corrosion have been observed. Further work is suggested to clarify the temperature dependence of reported stress corrosion under reducing groundwater conditions.

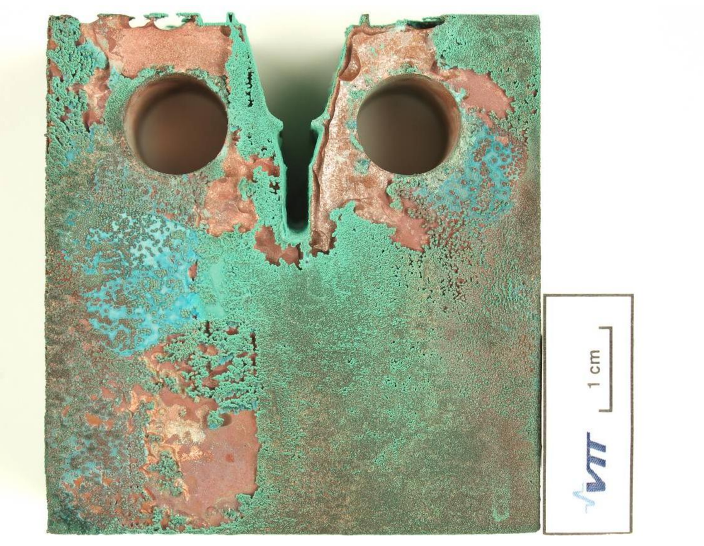

Fig. 4. Extensive general corrosion in the CT specimen after 4400 h (90°C) in aerated simulated Olkiluoto groundwater

Recommendations

The results appear to carry important implications relevant for the final disposal conditions. The earlier assumption of low stress level in repository conditions may not hold as very high stresses are also foreseen by the SKB design report for the copper overpack even after long times. It is suggested that the vessel stress analysis is repeated using the VTT creep model for an independent verification of the stresses especially in the weld region, and the effect of multiaxiality is clarified in terms of claimed notch strengthening versus observed life shortening.