Low-Cycle Fatigue and Crystal Plasticity of 316H Stainless Steel

Research area: Nuclear Materials and Modelling

PI: Miss Megan Taylor, University of Bristol

Funders: EDF

Contact details: mt16628@bristol.ac.uk

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The Challenge

All fourteen of the UK's advanced gas cooled reactors (AGR's) are due to be shutdown within the next 12 years and with no immediate plans to replace the lost energy, life extension of the existing reactors is the most favourable option.

To be able to safely extend the lifetimes of the UK's nuclear reactors, understanding the material is likely to fail will be crucial. To be able to do this a deep understanding of how cyclic thermal stresses affect the material will be very important.

Figure 1

AGR at Torness.

Type 316H is an austenitic stainless steel that contains a higher carbon content than its parent, 316. The elevated carbon content of 316H allows it to reach a greater yield strength and tensile strength that other similar alloys. 316H is used throughout the nuclear industry in structural components including pipes and headers due to its favourable corrosion properties and high strength at elevated temperatures which are crucial due to these components being in contact with high temperature and pressure steam.

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A nuclear power station will experience several hundred start-ups and shutdowns during its lifetime for reasons including, but not limited to; refuelling, power trips and repairs. During the start-up/shutdown process, a reactor is subjected to cyclic thermal stresses and subsequent plasticity is induced within the material. This low-cycle fatigue (LCF) alters the creep ductility of the material, and is part of what will be investigated.

The Solution

A component is subjected to low-cycle fatigue if it is under relatively high stress and fails within 10^5 cycles. Macroscopic plastic deformation will take place within the material since low-cycle fatigue takes place in the plastic region, near or above the proportional limit. The creep response a material exhibits is affected by the cyclic pre-straining conditions that the material was subjected to, of which, whether the materials' prior cycle was completed in tension or compression will be explored.

A model that could effectively predict the level of damage within 316H plant components would prove extremely valuable in assessing whether a plant life extension can take place. If a reliable model were produced, power outage times could be drastically reduced as structural integrity assessments for 316H will become redundant. As well as this, components can be replaced exactly when they need to be, as opposed to conservatively replacing them based on the current condition.

I am working on two aspects of this problem; creating a single crystal Matlab model and conducting LCF experiments. The Matlab model will be complementary to a polycrystal model also being developed by providing an insight into the material response on a single crystal scale and how this can be compared to a larger scale where more crystals are added to simulate bulk materials.

As briefly outlined above, the LCF experiments consist of introducing different levels of prior plasticity into a specimen and observing how this changes the creep response of the material.

The Impact

These experiments will not only provide an understanding of the relationship between the amount of creep strain accumulated and the levels of hardening taking place due to the prior loading but can also be fed into the model so a more accurate and representative result can be achieved.