Corrosion of Spent AGR Fuel Cladding

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OBJECTIVE

The fuel cladding is the component that encapsulates the fuel pellets to keep fission products from contact with the environment. The fuel cladding of the UK's advanced gas reactors (AGR), illustrated in Figure A, is made of austenitic stainless steel alloy 20Cr/25Ni/Nb. Spent AGR fuel clad during interim storage in the cooling ponds may suffer corrosion. The extent of corrosion are correlated to the radiation-induced damage to the fuel clad. The objective of this project is to quantify the electrochemical (corrosion) behaviour of the as-manufactured, annealed, and irradiated AGR fuel cladding in chloride (Cl^-), thiosulphate ($S_2O_3^{2-}$) and nitrate (NO_3^-) aqueous environments at the order of parts per million (ppm) concentration levels. The anodic polarization method was employed to quantify the metal's electrochemical behaviour with respect to an electrolyte-containing test solution by the pitting potential parameter, $\mathbf{E_{pit}}$. As-manufactured and thermally annealed (650°C) AGR fuel clad was sourced from Sellafield Ltd. Additionally, transmission and scanning electron microscope was employed to study the correlation between the microstructure evolution and the corrosion behaviour.

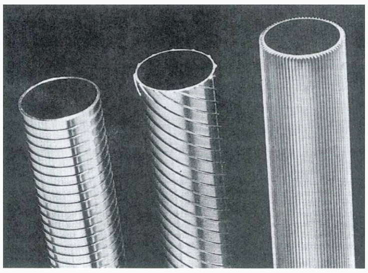

Figure A – AGR Fuel Cladding

1. INTRODUCTION

Alteration to the AGR fuel clad's austenite structure due to nuclear irradiation principally results in chromium depletion from the grain boundaries (Figure B). Metal dissolution reactions ($M \rightarrow M^{n+} + ne$) could potentially occur along the chromium depleted grain boundaries; the electrons are consumed for cathodic reactions ($O_2 + 2H_2O + 4e \rightarrow 4OH^-$) at the metal's surface while the metal ions (M^{n+}) accumulated around the pits attract Cl^- to maintain charge neutrality. Pits may grow through hydrolysis reactions ($M^+ + H_2O \rightarrow MOH + H^+$) leading to generation of cracks and possibly breach the fuel clad.

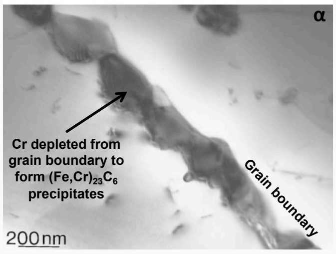

Figure B – Potential for corrosion at grain boundaries

2. ELECTROCHEMICAL EXPERIMENTS

Pitting corrosion in metals is commonly studied using the *anodic polarisation method*. Principally, a metal's susceptibility to pitting with respect to an electrolyte-containing test solution in the cell (Figure C) is quantified by the pitting potential parameter, $\mathbf{E_{pit}}$. Noble metals and less corrosive test solutions, for example, exhibit higher $\mathbf{E_{pit}}$ values. Figure D shows the measured $\mathbf{E_{pit}}$ values of stainless steel 316L with respect to test solutions prepared from analytical grade sodium chloride (NaCl) in the following molarity: 0.5, 0.1, 0.05, 0.025, and 0.01. The average $\mathbf{E_{pit}}$ at 0.5M NaCl is +0.30V versus Ag|AgCl and is increasingly noble as the NaCl concentration decreases. Future work will involve measuring $\mathbf{E_{pit}}$ of the clad sourced from Sellafield with respect to chloride (Cl^-), thiosulphate ($S_2O_3^{2-}$) and nitrate (NO_3^-) containing test solutions at the concentration levels reported in the cooling ponds.

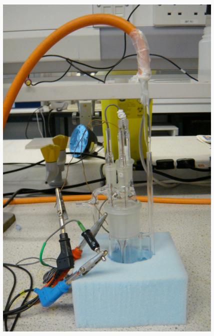

Figure C – Anodic Polarisation Cell

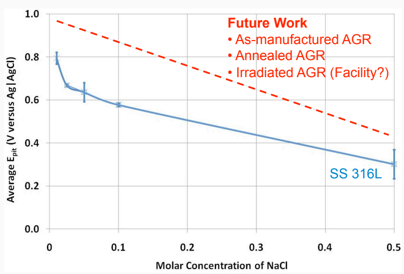

Figure D – $\mathbf{E_{pit}}$ of SS 316L corresponding to various NaCl concentrations

3. MICROSTRUCTURE CHARACTERISATION

This project also focuses on determination of the microstructure evolution of the as-manufactured, annealed, and irradiated fuel clad on the metal's electrochemical (corrosion) behaviour. Figure E shows the microstructure of the as-manufactured and annealed AGR fuel clad in the scanning electron and optical microscope; the annealed clad, as expected, have larger grains due to relief of dislocations in its crystal lattice. Figure Fa shows a TEM specimen of the as-manufactured clad prepared using the Focused Ion Beam (FIB) instrument. The microstructure comprises of elongated grains (Figure Fb), evident of hot extrusion and cold work during manufacturing of the clad, that measured approximately 6x1x1μm with a polycrystalline diffraction pattern (Figure Fc).

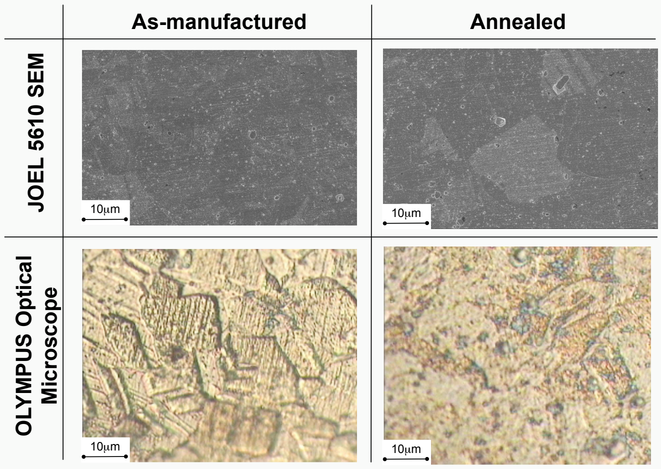

Figure E – Microstructure of as-manufactured and annealed AGR fuel clad in optical and scanning electron microscope

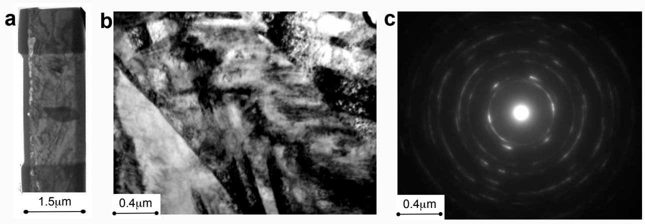

Figure F – TEM of as-manufactured AGR fuel clad

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