Oxidation Growth Stresses in an Alumina-Forming Ferritic Steel Measured by Creep Deflection*

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Deflection tests have been used to estimate the stresses developed in the alumina layer formed during short-term oxidation of a Fe–22Cr–5Al–0.3Y Feralloy steel at 1000°C. Elastic analysis of the deflecting specimen is inappropriate under these test conditions because of the low creep strength of the alloy. Accordingly, a recent creep analysis has been used in this work using currently determined creep properties of the alloy substrate. The results of the analysis show that for the thin oxides produced (<1 μm), the planar stress within the oxide layer is everywhere compressive. Average values are approximately 850 MPa after 0.5 hr oxidation but reduce to <200 MPa after 6.5 hr. These values are very much less than would be expected under conditions of elastic deformation.

KEY WORDS: oxide growth stresses; deflection test; creep analysis; alumina; Feralloy.

INTRODUCTION

High temperature alloys rely on the formation of a dense, adherent surface oxide layer to provide protection from chemically aggressive environments but such layers are vulnerable to mechanical damage. Stresses developed during oxide growth can contribute to the loss of integrity of the protective layer and much work has been undertaken both to understand and to

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measure such stresses.\textsuperscript{1,2} In situ techniques are obviously desirable since stresses may be measured in the absence of thermal stresses induced during cooling. Although there has been increasing use of high temperature X-ray diffraction (XRD) to try and meet this requirement, the resolution of the technique seems insufficient to monitor rapidly-changing levels of stress (e.g., in the early stages of oxidation) or low stresses in later stages of oxidation. An alternative in situ technique is the deflection test in which growth stresses are manifested by the bending of a thin metal sample oxidized only on one surface. Strain magnification resulting from the bending geometry permits low stress levels to be determined, at least in principle. The approach has been widely used\textsuperscript{3-5} but has suffered from the absence of a credible method of stress analysis since, until recently, all available methods have assumed either elastic\textsuperscript{3-6} or athermal plastic\textsuperscript{6,7} deformation. Under high temperature conditions, it is much more likely that deformation will occur by thermally-activated creep processes. A stress analysis of the deflection test under creep conditions has recently become available\textsuperscript{8} and it is the intention in this paper to make a first application of the method to analyze new deflection data from an alumina-forming ferritic steel.

**EXPERIMENTAL TECHNIQUES**

The deflection and oxidation tests were undertaken on an alumina-forming Fecralloy of composition (wt.%): Fe-22Cr-5Al-0.3Y. Foil specimens for deflection testing, measuring $50 \times 10 \times 0.22$ mm, were prepared by hot-rolling and precision grinding (600 grit SiC). A hole of diameter 1 mm was drilled into the end of each specimen. The specimens were then washed in water, rinsed in ethanol and air-dried. Protective silica coatings of thicknesses 0.8 μm and 4 μm were applied to a single face of each specimen using an RF sputter coater. The coated samples were then annealed in a vacuum furnace for 5 min at 1100°C.

The deflection tests were carried out by fixing the upper edge of the specimen in a pair of Fecralloy clamps which were supported on an alumina rod. A quartz fiber with a hook at one end was hung from the hole in the lower end of the specimen. The specimen was lowered into the vertical furnace which was at the test temperature. The quartz fiber was long enough to project out of the furnace and was protected by a glass enclosure. Lateral displacements of the quartz fiber as a function of time were measured using a travelling microscope. The experimental arrangement is shown schematically in Fig. 1.

Creep tests were carried out under direct loading in air at 1050°C and 1100°C. Specimens were of rectangular cross-section with a gauge length of 50 mm, width 5 mm and thickness 2 mm. Temperature and extension were