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Developing Mechanistic Understanding of the Effect of Temperature and Environment on the Hold Time Fatigue Behavior of Haynes 282 Alloy

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Advanced ultra-supercritical coal-powered steam plants achieve significant efficiency gains via higher operating temperatures and pressures than existing plants. A significant challenge is developing materials for these more aggressive operating conditions and environment. This study was undertaken to develop an understanding of the hold time fatigue mechanism of the Ni-based superalloy Haynes 282 and to separate out the environmental and creep effects of the fatigue behavior. Crack growth rate experiments on samples of Haynes 282 were conducted at temperatures of 1200, 1400, and 1600F in air, steam, and vacuum environments (compact tension sample, 25 ksi in1/2, R = 0.1). Foils from tested samples were then prepared from the bulk free surface oxide and from the fracture surface adjacent to and far from the crack tip using focused ion beam scanning electron microscopy (FIB-SEM). Transmission electron microscopy (TEM) was used to identify various phases present in the resulting oxides, with an attempt to correlate structure to crack growth rate.

Figure 1 shows crack growth rate data from samples tested at 1200, 1400, and 1600F in air, steam, and vacuum conditions. At 1200°F and 1400°F, crack growth rates are accelerated in steam, and delayed in vacuum, with respect to the air tests. However at 1600F, crack growth rates among the three environments tend to converge. The data suggest a pure environmental fatigue interaction at 1200F, a predominantly environmental-fatigue interaction at 1400F, and a pure creep-fatigue interaction at 1600F.

The oxide structure at the free surfaces of all the samples was similar showing internal Al_2O_3 oxidation, gamma prime phase depletion, and hexagonal $Cr_2O_3$and Ti-rich oxides at the surface of the oxide. Figure 2 shows oxide structure at the crack tip for samples tested at 1400F in air and steam. A key observation is the delayed formation of Al_2O_3 and Cr_2O_3 at the crack tip of specimens tested in air versus those tested in steam. Despite having a higher free energy of formation, mixed Ni oxides form first at the crack tip in air, leaving in their wake a large degree of local porosity. In contrast, specimens tested in steam, under a lower oxygen partial pressure, formed thick continuous layers of Cr_2O_3 directly at the crack tip, with limited porosity. The degree of porosity formed at the crack tip in air is believed to promote a more compliant crack tip, relative to the thick Cr_2O_3 layer, and is thought to retard crack propagation through crack path deflection and strain accommodation.

In summary, environmental-fatigue interactions dominated at temperatures of 1400F and below. At 1600F, some environmental interaction was detected even as creep effects were becoming dominant. Near-field crack tip oxidation characteristics, and not bulk oxidation resistance, drive the variation in the hold time fatigue behavior over the range of temperatures and waveforms evaluated. The transition from crack tip porous NiO and Ni-rich spinel to dense Al_2O_3/Cr_2O_3 may accelerate hold time fatigue in steam environments.

References:

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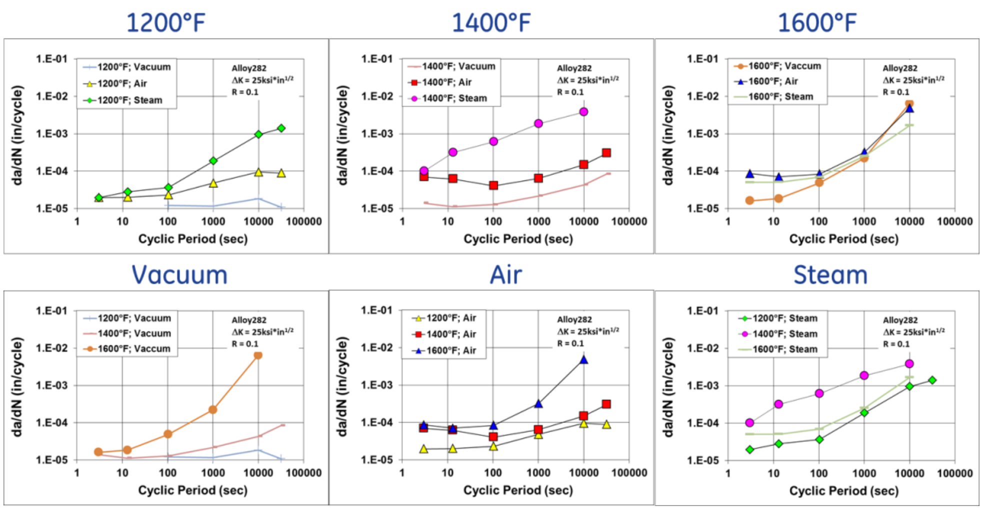

Figure 1. Crack growth rate for Haynes 282 at 1200, 1400, 1600F in air, steam, and vacuum.

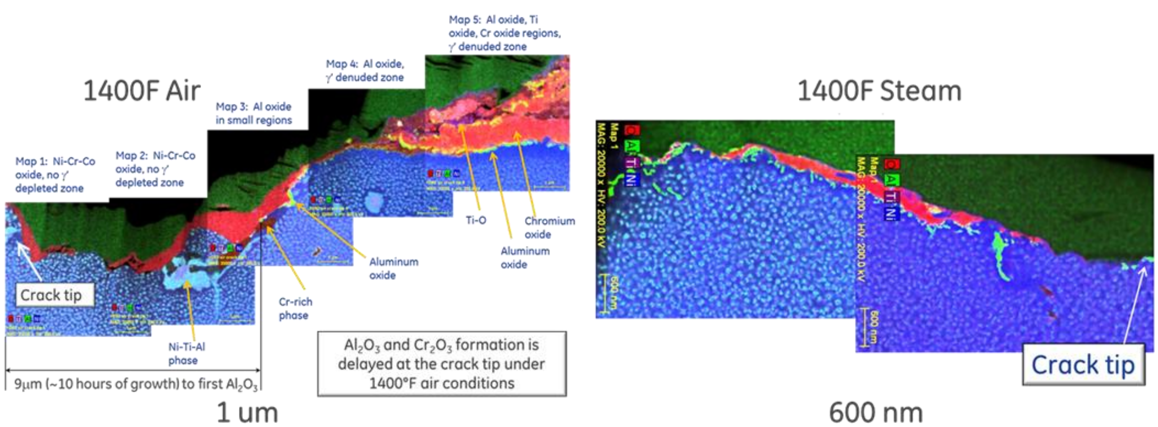

Figure 2. O, Al, Ti, Ni (red, green, purple, blue respectively) TEM EDS maps at crack tip of samples tested at 1400F in air and steam.

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