OXIDATION OF HIGH-TEMPERATURE ALLOY WIRES IN DRY OXYGEN AND WATER VAPOR

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High-temperature alloy wires are proposed for use in seal applications in future space vehicles. The alloys offer the potential for improved wear resistance of the seals. However, the wires must withstand high-temperature environments which contain both oxygen and water vapor. In this study, alloy wires are evaluated for oxidation resistance in dry oxygen and oxygen/water vapor environments.

Five compositions of alloy wires were studied as shown in Table 1. All wires were nominally 250 micrometers in diameter, except the PM2000 which had a nominal diameter of 150 micrometers. Coils of wire were formed to achieve a total surface area of about 3 to 5 cm^2. The coiled wires were oxidized in flowing oxygen at 1204°C for 70h. Several compositions were also tested in 50% water vapor/50% oxygen. Oxidation kinetics were continuously monitored by thermogravimetry (TGA). Post-test analysis included X-Ray Diffraction (XRD), Scanning Electron Microscopy (SEM) and Energy Dispersive Spectroscopy (EDS) for phase identification and morphology.

The weight change results for dry oxygen tests are shown in Figure 1. As expected, the alumina forming alloys, Kanthal A1 and PM2000 performed the best. Weight change results for water vapor tests for these two compositions plus the baseline material Haynes 188 are shown in Figure 2. Again, the alumina-forming compositions outperformed the Haynes 188.

The oxidation resistance of these alloys is predictable since alumina-forming alloys are expected to outperform chromia-forming alloys at this temperature. However, the water vapor results as well as features of the oxidation kinetics due to the small diameter of the wires provide interesting insights into oxidation behavior of these materials. Several of these results will be highlighted.

First, the Haynes 188 wires were found to completely oxidize under test in both dry oxygen and water vapor after 20 to 30 hours exposure. In dry oxygen the weight gain reached a plateau at 19 mg/cm^2 as complete oxidation occurred. Microstructural analysis shows compositional layering effects in the oxide as a result of sequential depletion of the chromium and tungsten components. In water vapor, however, a regime of linear weight loss began after about 20 hours as volatile hydroxide formation, e.g. $WO_2(OH)_2(g)$ and $Ni(OH)_2(g)$, continued even after the wire was completely oxidized. Microstructural and compositional analysis of the wire after water vapor exposure shows the presence of porous layers as well as the complete loss of tungsten from the remaining oxide.

The Kanthal A1 wires showed excellent oxidation behavior in both dry oxygen and water vapor as determined by weight change kinetics. However, microstructural evaluation showed complete loss of adherence of the oxide scale for both test conditions, leaving detached sheaths of oxide. Bare metal wires with no trace of oxide were observed for some cross-sections of the Kanthal A1 exposed in water vapor.

The PM2000 wires showed excellent oxidation behavior in dry oxygen as determined by weight change kinetics. The discontinuity in weight change at 40 to 50h is tentatively attributed to a change in oxide growth from alumina to chromia. EDS analysis indicated the aluminum content of the wires was completely depleted after the 70h exposure in dry oxygen. Microstructural analysis revealed adherent scales, an inner chromia-rich oxide layer, and outer alumina layers. Void formation within the metal wire interior was also observed. In the water vapor exposure, breakaway oxidation occurred just as the 70h test ended. EDS analysis indicated the aluminum content of the wires was also completely depleted after the water vapor exposures. Microstructural analysis revealed some cross-sections of the wire showed protective oxides, while others showed initial stages of breakaway oxidation with chromia and iron rich surface oxide formation. Still other areas of the same wire showed complete oxidation of the entire cross-section.

In conclusion, the alumina-forming wires outperform the baseline Haynes 188 composition for oxidation resistance at proposed seal conditions. Additionally, TGA of small diameter wires offers unique opportunities for studying oxide volatility, oxide adherence, and breakaway oxidation.

Table 1. Composition of alloy wires used in this study.

Alloy	Composition, wt%
Haynes 188	Co base, 22 Cr, 22 Ni, 14 W, Fe< 3, Mn <1.25, 0.5 Si, 0.12 La, trace: C, B
Haynes 230	Ni base, 22 Cr, 14 W, Co<5, Fe<3, 2 Mo, 0.5 Mn, 0.4 Si, 0.3 Al, trace: C, La, B
Haynes 214	Ni base, 16 Cr, 4.5 Al, 3 Fe, 0.2 Si, trace: Mn, Zr, C, B, Y
Kanthal A1	Fe base, 22 Cr, 5.8 Al
PM 2000	Fe base, 20 Cr, 5.5 Al, 0.5 Ti, 0.5 Y_2O_3

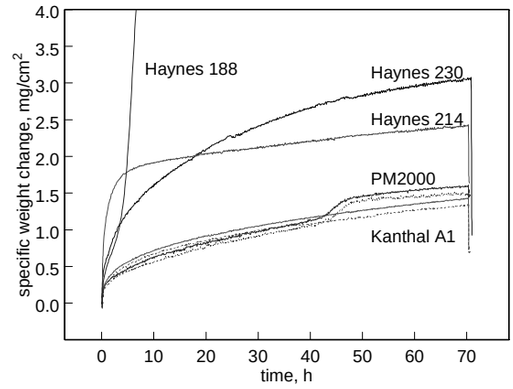

Figure 1. Specific weight change for coiled wires exposed at 1204°C, in dry O_2 flowing at 0.4 cm/s.

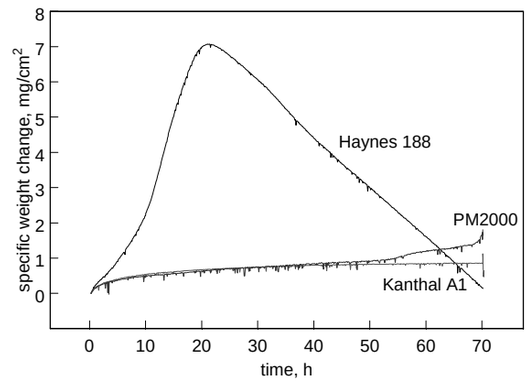

Figure 2. Specific weight change for coiled wires exposed at 1204°C, in 50% H_2O/50% O_2 flowing at 4.4 cm/s.

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