

Effects of Water Vapor on Cyclic Oxidation of Ni-Al Binary Alloys

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Because water vapor is a major product of hydrocarbon fuel combustion, its affect on the high temperature oxidation of engine components is of interest. Earlier work has revealed adverse effects of water vapor during cyclic oxidation of iron-based alumina forming alloys^[1-3] and commercial nickel-based alloys^[4-6]. For this reason, the present study of model Ni-Al alloy behaviour was undertaken.

Alloys of Ni-50Al, Ni-23Al, and Ni-14Al (atom percent) were prepared by argon electric arc melting using non-consumable electrodes. Chemical analysis confirmed that the alloys contained <10ppm sulfur. These alloys were subjected to cyclic oxidation in dry air, and also air containing $p_{H_2O}=0.12$ atm at a total pressure of 1 atm and $T=1200^{\circ}C$. Each cycle consisted of 1 hr reaction at $1200^{\circ}C$ and 10 min cooling in an environment at $60^{\circ}C$.

Scale spallation was observed for all alloys in both atmospheres. Results for β -Ni-50Al are shown in Figure 1. Oxygen uptake took place for the first 40 cycles, followed by continuous weight decrease, in agreement with earlier findings^[7,8]. Similar kinetics were observed in the wet air atmosphere reaction.

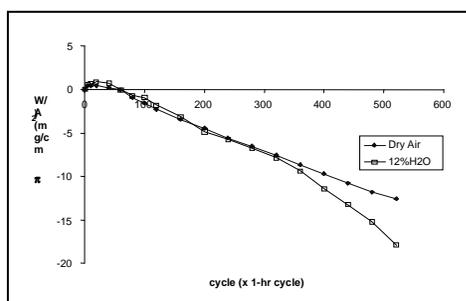


Figure 1 Kinetics of Ni-50 Al

The 2-phase ($\gamma+\gamma'$) Ni-23Al alloy lost weight rapidly from the beginning of the reaction in both gases, as shown in Figure 2. The presence of steam accelerated the weight loss process.

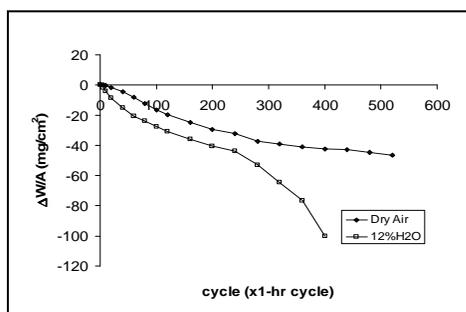


Figure 2 Kinetics of Ni-23Al

The γ -phase Ni-14Al alloy showed very little net weight change for more than 200 cycles in dry air, and then rapidly lost weight. In wet air, the onset of rapid weight loss occurred much earlier.

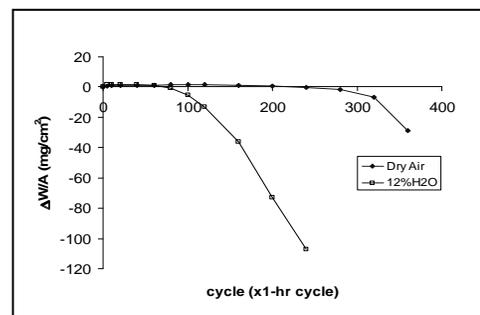


Figure 3 Kinetics of Ni-14Al

A parameter $\phi_{\Delta m} = t_{dry}/t_{wet}$ ^[4] was used as a measure of the steam effect. Here Δm was a specified weight loss (in $mg\ cm^{-2}$) and $\phi_{\Delta m}$ was the ratio of the number of cycles in dry and wet air required to produce this weight loss. Values for the different alloys are shown in Table 1.

Table 1 Values of t_{dry}/t_{wet}

Alloy	ϕ_{10}	ϕ_{15} *	ϕ_{20}
Ni-50Al	1.10	1.2*	-
Ni-22.88Al	2.63	2.32	2.13
Ni-14Al	2.85	2.70	2.61

*Based on extrapolation

Analysis by X-Ray diffraction showed that α - Al_2O_3 was the only oxide present on Ni-50Al reacted in dry air. However, this alloy reacted with wet air produced both α - Al_2O_3 and Boehmite ($Al_2O_3 \cdot H_2O$). The γ and $\gamma+\gamma'$ alloys reacted in both wet and dry air produced mixtures of α - Al_2O_3 , $NiAl_2O_4$ and NiO. No hydrated oxide was found on the γ and $\gamma+\gamma'$ alloys.

Examination by SEM revealed that Ni-50Al developed similar topographic features during reaction in both wet and dry air. A network of oxide ridges with a thin, flat oxide scale in between was developed on the external surface. Cavities developed in the metal at the alloy-scale interface. These were hexagonal in shape and grew larger with time. In addition, oxide whiskers formed on the scale exterior. The two lower aluminum content alloys developed similar scales in both atmospheres. An outer layer of NiO was formed on top of a layer of $NiAl_2O_4$. In some areas where spallation occurred, α - Al_2O_3 and spinel had reformed. These alloys also underwent internal oxidation after long reaction times, the Ni-14Al being attacked internally more quickly than Ni-23Al alloy.

Alloy oxidation kinetics are discussed in terms of the different reaction product morphologies.

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