Oxidation of $\gamma'$-Ni$_3$Al and $\gamma'$-Ni$_3$Al(Si) Intermetallic Compounds at Low-Oxygen Pressures

H. C. Yi,* W. W. Smeltzer,† and A. Petric‡

Received February 8, 1995; revised May 29, 1995

The oxidation behavior of $\gamma'$-Ni$_3$Al and $\gamma'$-Ni$_3$Al(Si) ($\text{Ni}_{75}\text{Al}_{25}$)$_{20}$Si$_5$ intermetallic compounds was studied at 1073 K and oxygen partial pressures of $5 \sim 9 \times 10^{-6}$ atm, $1.2 \times 10^{-14}$ atm, and $1.2 \times 10^{-19}$ atm by means of a manometric apparatus, and Rhines packs of NiO/Ni and FeO/Fe, respectively. Oxidation kinetics were determined either by recording weight gains or by measuring the internal-oxidation-zone depths. The structures and morphologies of oxides were also studied. Relatively low oxidation rates occurred for both compounds when oxidized in the manometric apparatus, while fast internal oxidation was observed for both compounds in the NiO/Ni pack. The fastest oxidation occurred in the $\gamma'$-Ni$_3$Al compound in the FeO/Fe pack. A healing Al$_2$O$_3$ layer was formed on the surface of $\gamma'$-Ni$_3$Al(Si) compound in the FeO/Fe pack, indicating a synergistic effect between the solute elements in the compound at the oxygen pressures corresponding to the dissociation of FeO. The oxidation rate was found to depend on the volume expansion associated with solute-atom oxidation.

KEY WORDS: Ni$_3$Al, Rhines pack, internal oxidation.

INTRODUCTION

The nickel–aluminide intermetallic compounds ($\gamma'$-Ni$_3$Al and $\beta$-NiAl) have superior high-temperature oxidation resistance. There have been a number of studies on the kinetics and structure of oxides during oxidation of both

† Institute for Materials Research, McMaster University, Hamilton, Ontario, Canada L8S 4M1.
‡ Department of Materials Science and Engineering, McMaster University, Hamilton, Ontario, Canada L8S 4L7.
γ'-Ni₃Al⁴⁴ and β-NiAl compounds.⁵⁻⁹ Generally, the oxidation behavior is complex and depends on grain size and crystallographic orientation of surface grains, as well as temperature and oxygen partial pressure.

When γ'-Ni₃Al is exposed to oxygen, the oxidation rate is large initially and NiO, Ni₅Al₂O₄, and Al₂O₃ all form during a fast-growth, transient stage. Eventually a stable structure develops with an NiO external scale, an Ni₅Al₂O₄ intermediate layer and a continuous, healing, pure α-Al₂O₃ film at the internal-oxidation front at which time the oxidation rate drops drastically.¹ The oxidation mechanism of the β-NiAl compound is quite different. Metastable Al₂O₃ phases form during the transient stage of oxidation and eventually transform into α-Al₂O₃ with the time required for this transformation being highly dependent on the temperature.⁸

Previous studies on the oxidation behavior of the compounds have been mainly focused on the effect of third element,¹ crystallographic orientation,⁸ varied temperatures,¹²,⁵⁻⁹ and oxidation kinetics and mechanisms. Recently, Schumann et al. studied the oxidation behavior of single-crystal γ'-Ni₃Al at an oxygen pressure lower than the dissociation pressure of NiO.³ It was found that after a short time of oxidation, a continuous γ-Al₂O₃ layer formed which eventually transformed into α-Al₂O₃. It was also found that the base metal (Ni) was transported out to the surface along the oxide–metal interface in order to release the compressive stresses generated during oxide growth.⁴ This base-metal, outward-transport phenomenon had already been reported to occur in other systems such as Ag–Al,¹⁰ Pd–Ag–In–Sn,¹¹ Ag–In,¹² and Ni–Al–Si.¹³ Both lattice diffusion and dislocation-pipe diffusion were proposed as the stress-relief mechanisms.

The authors have recently reported results on the oxidation of γ-Ni–Al–Si alloys at varied oxygen pressures.¹³,¹⁴ This paper deals with the oxidation behavior of the γ'-Ni₃Al and γ'-Ni₃Al(Si) compounds at various oxygen pressures.

**EXPERIMENTAL PROCEDURE**

Alloys were obtained by arc melting pure Ni (99.999%), Al (99.999%), and Si lump (99.999%) constituents and casting into an approximately 10-mm-diameter cylindrical copper mold. Two compositions were prepared: one with Ni₅Al (Ni₇₅Al₂₅) and another with Ni₃(Al, Si), nominally Ni₇₅Al₂₀Si₅. The ingots were annealed at 1173 K for 96 hr, and optical metallographic examination showed that the microstructures were homogeneous and had a grain size of about 0.5 mm. Sample disks of less than 1-mm thickness and 10-mm diameter were cut from the ingots for oxidation study. They were polished to a 1-μm diamond finish.