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Oxidation of the single-crystal Ni-base superalloy DD32 containing rhenium in air at 900 and 1000 °C

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Abstract

The oxidation behavior of a single-crystal Ni-base superalloy DD32 was studied in air at 900 and 1000 °C. The oxide morphology and microstructure were analyzed by X-ray diffraction (XRD), SEM/EDS. The scales formed at 900 and 1000 °C were complicated, with an outer layer of columnar NiO, an intermediate layer mainly composed of complex oxides and a small amount of spinels, and an inner continuous layer of α-Al_2O_3. At 900 and 1000 °C, two oxidation steps appear in the oxidation kinetics. The first one is controlled by NiO growth and the second by Al_2O_3 growth once a continuous Al_2O_3 layer formed under the previously grown NiO layer after a critical time.

Keywords: Single-crystal (SC) superalloy; Oxidation; NiO; α-Al_2O_3

1. Introduction

Nickel-base superalloys are extensively used in turbine blades of industrial gas turbines and jet engines, which require both mechanical strength and oxidation resistance. Alloying elements are usually added to improve mechanical properties, including Mo, W, Ta, Re and Nb through the solid solution hardening and Al and Ta via formation of a γ' precipitate in a γ-nickel matrix. Carbon is used to improve grain boundary properties while Al and Cr are added to develop oxidation resistance.

Thermodynamic considerations have shown that Al_2O_3 or Cr_2O_3 are the stable oxide phase formed on Ni-base superalloys, which commonly contain Al or Cr at concentrations sufficient to allow their selective oxidation to form a protective scale. In order to improve the high temperature properties, it is increasingly necessary to develop and use single-crystal nickel-base superalloy. These alloys possess not only improved mechanical properties, such as stress rupture [1,2] and fatigue resistance [3,4], but also better oxidation and hot corrosion resistance [5–7]. Investigations of the oxidation of Ni–Cr–Al [8], Co–Cr–Al [9] and Fe–Cr–Al alloys [10] clearly indicated the oxidation processes include the initial stage and subsequent steady-state period. Furthermore, Giggins and Pettit [8] suggested that Ni–Cr–Al alloys between 1000 and 1200 °C oxidized under steady-state conditions were controlled by one of three oxidation different mechanisms, depending on the contents of Cr and Al in the Ni–Cr–Al alloys. For alloys with low Cr and Al concentrations, the subscale cannot become continuous and NiO in the external scale predominates. When the NiO layer becomes virtually continuous, the oxidation reaction proceeds under steady-state conditions and is controlled by transport through the NiO layer (Mechanism I). For alloys with smaller Cr and Al concentrations, the aluminum continues to be oxidized internally and the continuous duplex layer is enriched in chromium. When the Cr_2O_3 scale becomes continuous, steady-state conditions have been achieved and the oxidation reaction is controlled by transport of chromium through the layer of Cr_2O_3 (Mechanism II). For alloys with larger aluminum concentrations, the Al_2O_3 subscale zone becomes continuous beneath the duplex oxide

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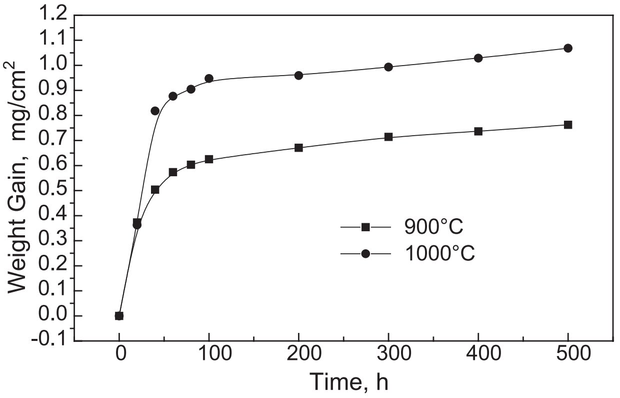

Fig. 1. Oxidation kinetics of the SC superalloy DD32 at 900 and 1000 °C.

layer. Steady-state conditions are reached when the Al_2O_3 layer becomes continuous and the oxidation reaction is controlled by transport through the Al_2O_3 scale (Mechanism III).

In this paper, the oxidation behavior of a single-crystal Ni-base superalloy DD32 was studied at 900 and 1000 °C, with the aim of observation of surface morphology and microstructure, analysis of growth model and oxidation mechanism of the single crystal superalloy at high temperature.

2. Experimental procedures

Superalloy substrate disks (4 mm×ϕ15 mm) used in this study were machined from Ni-base single-crystal (SC)

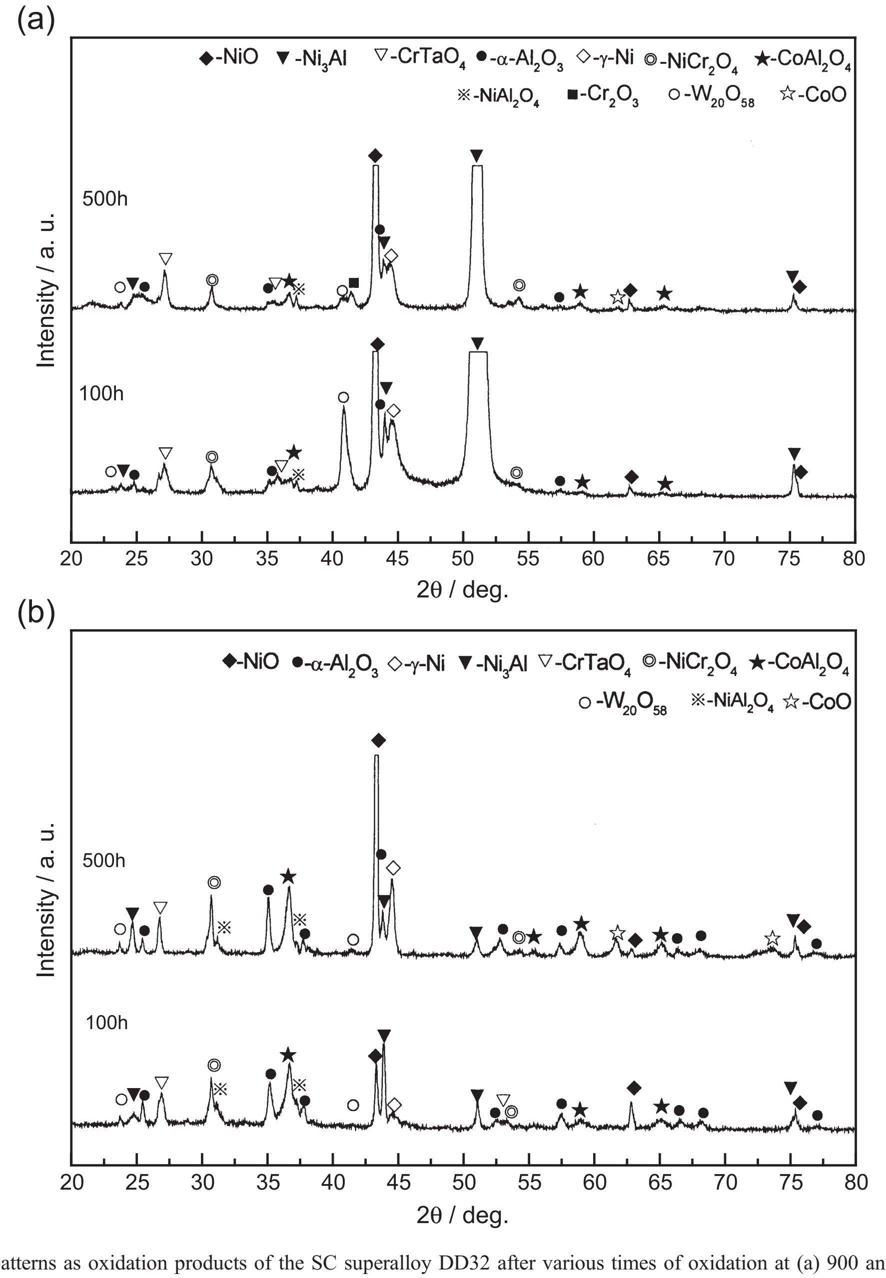

Fig. 2. XRD patterns as oxidation products of the SC superalloy DD32 after various times of oxidation at (a) 900 and (b) 1000 °C.