Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Creep-rupture Behaviors of a Diffusionally Aluminized Alloy 617

Injin Sah [a], Sung Hwan Kim [b], Changheui Jang [b*]
[a]*Nuclear Hydrogen Reactor Technology Development Division, KAERI, Yuseong-gu, Daejeon 305-353, Republic of Korea*
[b]*Department of Nuclear and Quantum Engineering, KAIST, Yuseong-gu, Daejeon 305-701, Republic of Korea*
[*]Corresponding author: chjang@kaist.ac.kr

1. Introduction

A solid-solution strengthened polycrystalline Ni-base superalloy, Alloy 617 (Ni-22Cr-11Co-9Mo-1Al in wt.%), is considered as a key component for the application of an intermediate heat exchanger (IHX) in a very high temperature gas-cooled reactor (VHTR) [1]. In light of the surface reaction, a sufficient Cr content in the matrix leads to an external chromia (Cr_2O_3) layer on the surface with the occurrence of internal oxides (Al_2O_3) into the matrix. It is well known that the internal oxides will reduce the effective cross-sectional area and/or be a notch under the loading condition. Thus, there have been extensive efforts to improve the oxidation resistance by imposing an aluminized layer (β-NiAl or γ′-Ni_3Al) for Ni-Cr alloys [2]. Of course, the improvement of the oxidation resistance by developing an external alumina layer on the surface was already described by the authors [3]. However, only limited studies were carried out to correlate the aluminide structures with the high temperature mechanical properties (creep or creep-fatigue) [4]. Therefore, in this study, the influence of the aluminizing on the creep-rupture behaviors is presented.

2. Methods and Results

2.1 Experimental Procedure

A commercial grade Ni-base superalloy, Alloy 617 (heat # 8617 9 8805), was used in this study. For the aluminizing process, a diffusional heat treatment was employed for the pre-deposited Al layer (thickness of 7 μm). After aluminizing heat treatment (AHT; 600 ^oC/0.5 h), an inter-diffusion heat treatment (IDHT; 1150 ^oC/0.5 h) was followed to form the aluminide structures near the surface under high vacuum conditions ($\leq 1.33\times10^{-4}$ Pa).

A scanning electron microscope (SEM; FEI Sirion) was applied to observe the microstructure of the aluminized layer and below. In addition, a glow discharge spectrometer (GDS; LECO GDS850A) analysis was employed down to about 220 μm below the surface. To evaluate the mechanical properties, constant loading creep-rupture testing was carried out at 900 ^oC in air for both the as-received and aluminized specimens (plate-type thickness of 2 mm).

2.2 Characteristics of the Aluminized Layers

Fig. 1 shows the cross sectional micrographs of the diffusionally aluminized Alloy 617 near the surface. While the grain boundaries are partially covered with Cr-rich $M_{23}C_6$ carbides for the as-received, three distinctive regions, such as an aluminized layer (γ′-Ni_3Al), an inter-diffusion zone (IDZ; $M_{23}C_6$ and σ), and an affected substrate (Ni-depleted and Al-enriched), are apparent for the aluminized specimens. In particular, in the IDZ, discontinuous carbides ((Cr,Mo)-rich $M_{23}C_6$) are developed owing to the substantial supply of carbon from the grain boundaries. In addition, discontinuous intermetallics (Co-rich σ) are formed underneath the carbides owing to the depletion of carbon [3].

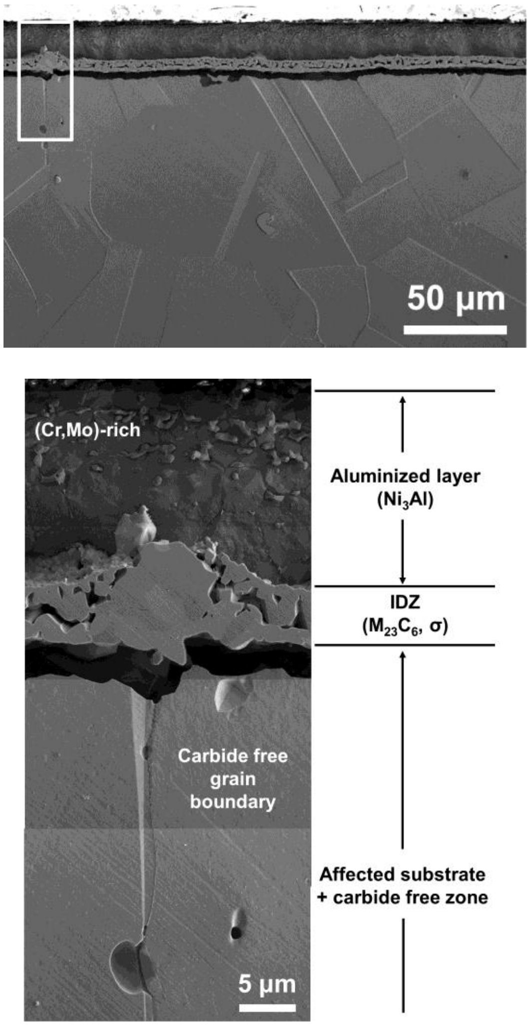

Fig. 1. Cross sectional SEM micrographs of the aluminized Alloy 617.

2.3 Creep-rupture Behaviors

As shown in Fig. 2, creep-rupture tests were carried out to identify the rupture lives of the aluminized Alloy 617. It is clear that the rupture lives of the aluminized specimen are shorter than those of the as-received specimen. Assuming that the creep-rupture behaviors of the polycrystalline Alloy 617 follow a simplified equation at relatively high stress levels, the reduction of the creep strengths is evaluated.

$\sigma = a\, t^{b}$ (243 ≤ t ≤ 2059 h for the as-received)

where σ is the applied stress (MPa), t is the creep-rupture time (h), and a and b are constants. The ratio of creep strengths for the aluminized specimen over the as-received is 87.8, 78.8, 81.2 and 81.2 % under the applied stress of 47.3, 39.6, 35.6, and 30.9 MPa, respectively.

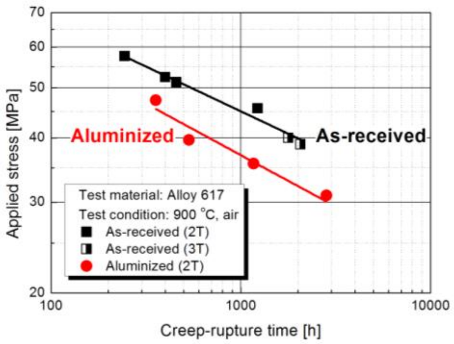

Fig. 2. Creep-rupture lives of the as-received and aluminized.

Even if three regions are observable in SEM micrographs (Fig. 1), a GDS analysis indicates that the carbon depleted zone is present up to 200 μm below the affected substrate (Fig. 3). The sharpest decrease of carbon content is detected just below IDZ where the carbon content reaches its minimum in the affected substrate compared with the average values in the substrate. A gradual increase of carbon, which might result mainly from the solute atoms in the matrix, is exhibited in the carbide free zone.

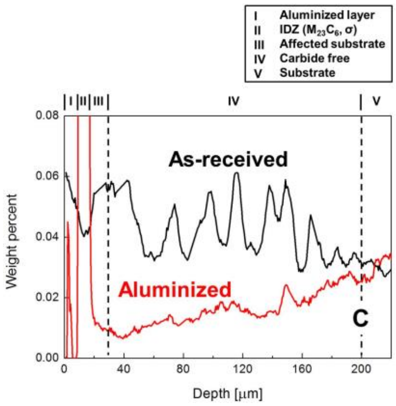

Fig. 3. GDS depth profile of the carbon in the aluminized specimen compared to the as-received Alloy 617.

It is well known that the inter-granular carbides will effectively hinder the grain boundary sliding under high-temperature tensile loading conditions [5]. In this case, the reduced creep strengths (82.5±3.8 %) accord well with the extent of a carbide free zone (200 μm in each surface), which covers about 20 % of the entire cross sectional area of the creep specimens (2 mm). Thus, the extensive formation of a carbide free zone proposed in this investigation is believed to lead to the shorter creep-rupture lives of the aluminized specimen than those of the as-received specimen.

3. Conclusions

For a diffusionally aluminized polycrystalline Alloy 617, creep-rupture testing was conducted to correlate the high-temperature creep-rupture properties with the aluminized microstructures occurred near the surface. Through the depth profiling analysis of the constituent elements by a GDS analysis, the aluminized specimens could have four distinct regions, such as an aluminized layer (γ′-Ni_3Al), an inter-diffusion zone (IDZ; $M_{23}C_6$ and σ), an affected substrate (Ni-depleted and Al-enriched), and a carbide free zone. In particular, the extensively formed carbide free zone below the affected substrate will reduce the creep-rupture strengths because the inter-granular carbides present along the grain boundaries effectively impede the grain boundary sliding under high-temperature tensile loading conditions.

ACKNOWLEDGEMENT

This study was supported by the Nuclear Research and Development Program of the National Research Foundation of Korea grant funded by the Korean government (MSIP). (Grant Code: NRF-2013M2A8A6035683 and NRF-2012M2A8A2025682) of Korea.

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