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Long-Term Aging Effects on Microstructure and Tensile Properties of Ni-base Superalloys

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1. Introduction

A very high temperature gas-cooled reactor (VHTR) is the one of the near-term generation-IV (Gen-IV) reactors. The operating condition would be up to 900 °C with 8-9 MPa for 60 years, to which intermediate heat exchanger (IHX) and hot gas duct is exposed [1]. For such harsh operating conditions of VHTR, solid solution hardening Ni-base superalloys are considered as candidate materials. Various alloying elements such as Mo, Co, W, Cr, Al, Mn and others are added in Ni-base superalloys to improve strength, creep, and oxidation resistance at high temperature [2-4]. Some elements would form carbides such as $M_{23}C_6$, M_6C and Ti(C,N) at grain boundaries and within grain [5-6]. Strength and creep resistance are increased when intergranular carbides are present as discrete particles by pinning grain boundaries and thereby inhibit grain boundary sliding. Meanwhile, after long term exposure at high temperature, additional carbides are developed and diffused then coarsened at grain boundary. It could deteriorate mechanical properties. In this study, the effects of long-term ageing on the microstructure and mechanical properties of Ni-base superalloys were investigated.

2. Experimental and Results

Two Ni-base superalloys, Alloy 617 and Haynes 230 were used in this study. The chemical compositions and microstructures of the Ni-base superalloys are shown in Table I and Fig.1.

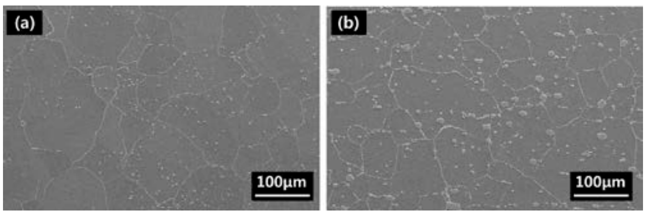

Fig. 1. Microstructures of as-received (a) Alloy 617 and (b) Haynes 230.

2.1 Specimen Preparation

Each block of Alloy 617 and Haynes 230 were aged in air at 800 °C and 900 °C for 10000 h. After aging, blocks were air-cooled and then miniature tensile specimens were machined at 2 mm from the surface of blocks to avoid carbide free zone and internal oxidation region.

2.2 Tensile test

The tensile tests of Alloy 617 and Haynes 230 were conducted at room temperature with the strain rate of 3.33 x 10^{-4} s^{-1} following ASTM E08. The results of the tests were summarized in Fig. 2 and table II. As figures indicate, elongation of aged specimens at both temperatures was reduced compared to as-received one. Furthermore, tensile strength of 800 °C aged Alloy 617 and Haynes 230 was increased while it was decreased for 900 °C aged ones.

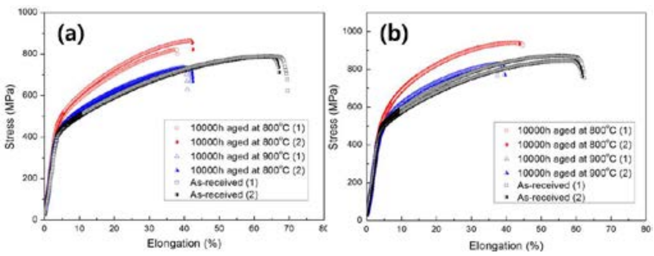

Fig. 2. Results of tensile tests of as received and aged at 800 °C and 900 °C on (a) Alloy 617 and (b) Haynes 230 for 10000 h.

Table II. Quantification of average values from tensile tests.

		YS (MPa)	UTS (MPa)	Elongation (%)
Alloy617	As-received	392	789	66
	Aged at 800°C	412	843	39
	Aged at 900°C	375	733	42
Haynes230	As-received	475	857	62
	Aged at 800°C	480	940	44
	Aged at 900°C	435	824	38

Table I: Chemical compositions of the Alloy 617 and Haynes 230 (wt.%).

	Ni	Cr	Fe	C	Si	Mn	Ti	Al	Co	Mo	W	La
Alloy 617	Bal.	21.6	1.14	0.10	0.50	0.05	0.35	1.50	11.8	8.92	-	-
Haynes 230	Bal.	21.5	2.94	0.10	0.38	0.46	-	0.29	0.36	1.09	13.8	0.02

2.3 Microstructure Evaluation

Cross-sectional microstructures of failure area of tensile tested were observed by SEM to characterize the fracture mode. For Alloy 617, as shown in Fig. 3, intergranular fracture was occurred at both aging temperatures because of the carbides formed and coarsened at high temperature. As shown in Fig. 3, discrete carbides were observed at 800 ^oC, but linked carbides were formed at grain boundary at 900 ^oC Carbides affected mechanical properties by decreasing elongation of aged Alloy 617 compared to as-received specimens. The higher tensile strength was observed for aging at 800 ^oC than that at 900 ^oC, as carbides are more likely to be formed at 800 ^oC than that at 900 ^oC in Ni-base superalloys [2],

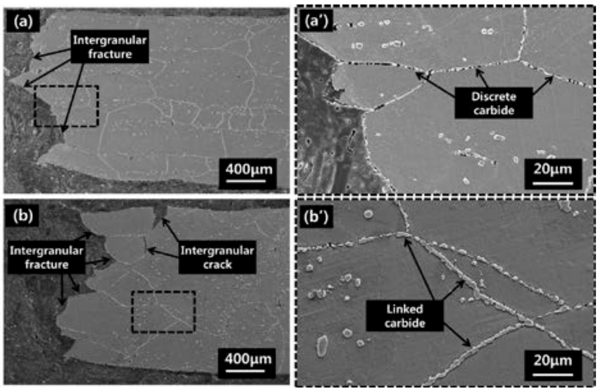

Fig. 3. Cross-sectional microstructure of Alloy 617 aged at 800 ^oC, (a) low magnitude with (a') high magnitude and aged at 900 ^oC, (b) low magnitude with (b') high magnitude.

In case of Haynes 230, as shown in Fig. 4, intergranular fracture was also observed at both aging temperatures with increasing amount of carbides at grain boundary and inside grain.

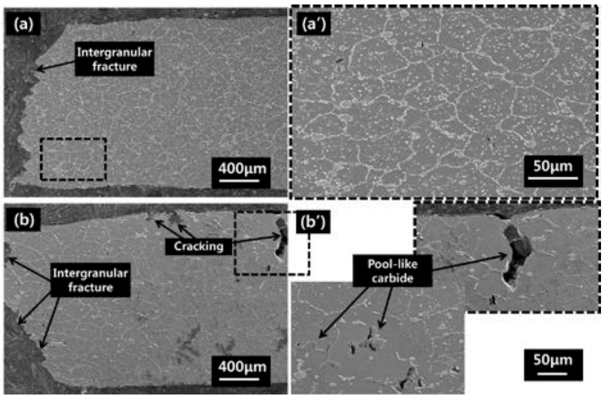

Fig. 4. Cross-sectional microstructure of Haynes 230 aged at 800 ^oC, (a) low magnitude with (a') high magnitude and aged at 900 ^oC, (b) low magnitude with (b') high magnitude.

For Haynes 230, pool-like carbides were formed after aging at 900 ^oC. To form pool-like carbides, other carbides were transferred then, locally carbide depleted area was developed. Those largely coarsened carbides have very weak resistance to applied stress. Therefore, cracks were developed by breaking brittle carbides when stress was applied during the tensile test. As a result, tensile properties of Haynes 230 aged at 900 ^oC were inferior to as-received and aged at 800 ^oC**.**

3. Conclusions

From the microstructure observation and tensile tests of Ni-base superalloy, Alloy 617 and Haynes 230, aged at 800 ^oC and 900 ^oC for 10000 h, the following conclusions were drawn;

- During high temperature aging process for long time, additional carbides were developed and coarsened at grain boundary and inside grain.
- Depending on the aging temperature, behaviors of carbides were different. In Alloy 617, linked carbides were formed at 900 ^oC while discrete one was developed at 800 ^oC at grain boundary. In case of Haynes 230, coarsened pool-like carbides surrounded by carbide depleted area were formed at 900 ^oC, but it was not observed at 800^oC.
- Tensile strength of Alloy 617 and Haynes 230 were increased after aging at 800 ^oC though it was decreased aging temperature at 900 ^oC due to more carbide formation at 800 ^oC.
- Elongations of aged Ni-base superalloys were decreased by the effect of coarsened brittle carbide at grain boundary.

REFERENCES

[1] J. K. Wright, Next Generation Nuclear Plant Intermediate Heat Exchanger Materials Research and Development Plan, INL/EXT-08-14107, PLN-2804F, 2008.
[2] Q. Wu, H. Song, R. Swindeman, J. P. Shingledecker, V. K. Vasudevan, Microstructure of Long-Term Aged IN617 Ni-Base Superalloy, Metallurgical and Materials Transactions A, Vol. 39A, p. 2569, 2008.
[3] T. S. Jo, J. H. Lim, Y. D. Kim, Dissociation of Cr-rich $M_{23}C_6$ carbide in Alloy 617 by severe plastic deformation, Journal of Nuclear Materials, Vol. 406, p. 360, 2010.
[4] J. Veverkova, A. Strang, G. R. Marchant, H. V. Atkinson, High Temperature Microstructural Degradation of Haynes Alloy 230, 11th International Symposium Superalloys 2008, Pennsylvania, USA, 2008.
[5] S. Petronic, A, Milosavljevic, Heat Treatment Effect on Multicomponent Nickel Alloys Structure, Faculty of Mechanical Engineering Transactions, Vol.35, p.189, 2007.
[6] R. Yong-Hua, G. Yong-Xiang, H. G. Xiang, Characterization of $M_{23}C_6$ Carbide Precipitated at Grain Boundaries in a Superalloy, Metallography, Vol. 22, p. 47, 1989.