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Carbide Transformation in Haynes 230 during Long-term Exposure at High Temperature

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1. Introduction

A solid solution hardened Ni-base superalloy, Haynes 230, is one of the candidate materials in very high temperature gas-cooled reactor (VHTR) benefitting its high temperature strength, creep and oxidation resistance [1]. However, during prolonged exposure at elevated temperature, the formation and ripening of primary and secondary carbides could result in a subsequent deterioration of the mechanical properties [2,3]. Nevertheless, long-term aging behaviors of Haynes 230 at high temperature have not been fully investigated yet. In this study, long-term aging tests of Haynes 230 was carried out to evaluate microstructure changes especially in carbide evolution. In addition, its consequential effects on tensile property such as tensile strength and elongation were discussed.

2. Methods and Results

2.1 Materials and Experimental

A wrought Ni-base superalloy, Haynes 230, was used in this study. The chemical compositions are listed in Table 1. For the high temperature aging test, blocks of Haynes 230 was aged in a furnace at 800 ^{o}C and 900 ^{o}C up to 20000 h. After the high temperature exposure, mini-sized tensile specimens were machined for the tensile tests of aged Haynes 230 at room temperature.

Table 1: Chemical Composition of Haynes 230 (in wt.%)

Ni	Cr	W	Fe	C	Mn
Bal.	21.5	13.8	2.94	0.10	0.46
Si	Al	Co	Mo	La	
0.38	0.29	0.36	1.09	0.001	

2.2 Carbide evolution during aging at 800 ^{o}C

Fig. 1 and Table 2 show the microstructure evolution and chemical compositions of W-rich carbides during aging at 800 ^{o}C. In as-received condition, primary W-rich M_6C carbides (around 30 at.% W) were randomly distributed while Cr-rich $M_{23}C_6$ carbides were observed along the grain boundary as reported previousy [2-4]. As aging progressed, a large amount of secondary carbides within the grains were generated. Thick and continuous grain boundary Cr-rich $M_{23}C_6$ carbides were formed. Moreover, the primary M_6C carbides were broken down and showed a high W content (60-70 at.%) compared to un-aged M_6C carbides

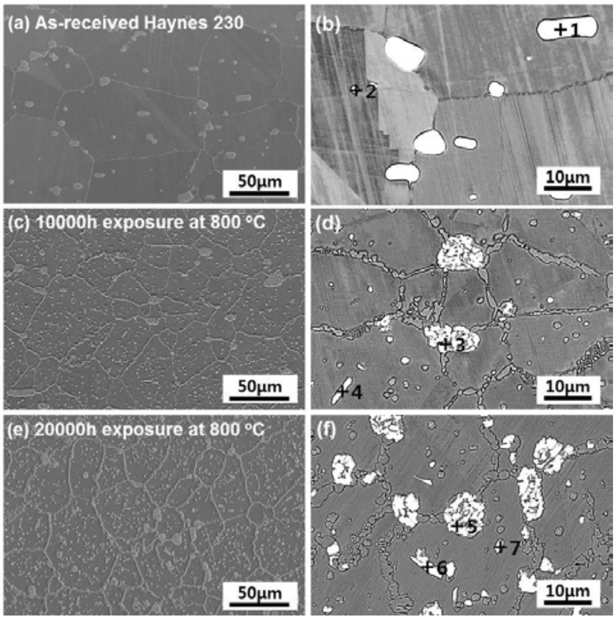

Fig. 1. Microstructure evolution as increasing aging period at 800 ^{o}C (a), (b): as-received, (c), (d): 10000 h, (e),(f): 20000 h

Table 2 : Chemical compositions of carbide in Fig. 2 (in at.%)

	+1	+2	+3	+4	+5	+6	+7
C	11.5	10.1	11.0	8.8	11.2	9.5	10.7
W	**31.3**	**30.3**	**62.5**	**61.1**	**66.0**	**63.8**	**71.3**
Cr	**23.7**	**23.9**	**7.2**	**8.9**	**6.8**	**8.0**	**4.6**
Ni	**29.1**	**31.4**	**12.2**	**14.3**	**10.0**	**12.8**	**8.9**
Mo	4.4	4.3	7.1	6.9	6.0	5.9	4.5

2.3 Carbide evolution during aging at 900 ^{o}C

Fig. 2 shows the changes in microstructure of Haynes 230 after aging at 900 ^{o}C for 1000 and 3000 h. Very fine secondary carbides were found within the grains. Moreover, film-like continuous grain boundary Cr-rich $M_{23}C_6$ carbides were formed [5].

However, as increase in exposure time over 10000 h, the fine carbides formed within the grains at relatively short-term exposure was coarsened but less degree than 800 ^{o}C. The thick and coarsened grain boundary carbides were formed compared to that in 3000 h exposure. In addition, the coarsened Cr- and Ni-rich phases (49 % Cr, 33 % Ni, 8 % W, 2% Mo, and 8 % C in at.%) surrounded by the carbide depleted region were developed along the grain boundary. Near the phase, thin and high W-rich M_6C (60-70 at.% W) carbides were also observed along the grain boundary locally.

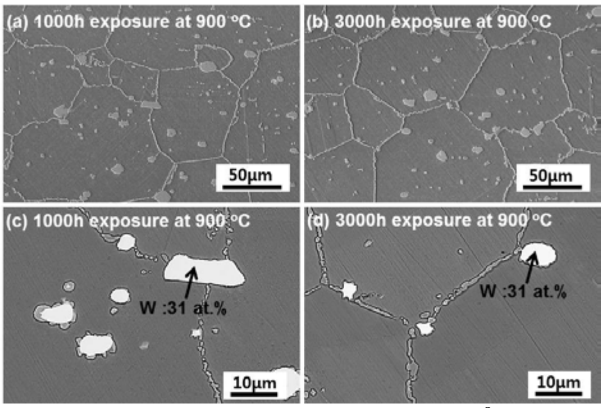

Fig. 2. Microstructure evolution after aging at 900 °C (a), (c): 1000 h, (b), (d): 3000 h

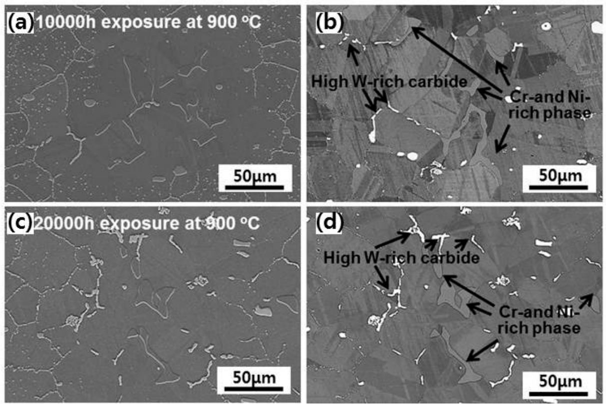

Fig. 3. Microstructure evolution as increasing aging period at 900 °C (a), (c): 10000 h, (b), (d): 20000 h

2.4 Degradation of Tensile property during the long-term aging process

The effects of microstructure evolution especially carbide transformation on degradation of mechanical property were assessed by tensile test at room temperature as a function of aging temperature and exposure time, and the results are shown in Fig. 4. The ultimate tensile strength (UTS) after aging at 800 °C for 10000 and 20000 h are higher than those of as-received and 900 °C aging specimens. However, at 900 °C, the values of UTS underwent transition from increase (until 3000 h) to decrease (over 10000 h) compared to as-received materials. The loss of ductility would be associated with coarsened and continuous grain boundary carbides as well as coarsened Cr- and Ni-rich phase along the grain boundary [2].

3. Conclusions

1. In Haynes 230, a nucleation of the secondary carbides was dominant at 800 °C ageing while growth at 900 °C ageing. In addition, after aging at 800 °C, transition of primary W-rich M_6C carbides (break down) were observed and it showed high W content (up to 70 at.% W) compared to un-aged W-rich M_6C carbides (around 30 at.% W).
2. Coarsened Cr- and Ni-rich phase surrounded by carbide depleted region and high W-rich M_6C carbide along the grain boundary were formed only at 900 °C after long-term exposure above 10000 h.
3. Tensile strength of aged Haynes 230 increased at 800 °C while decreased at 900 °C due to the formation of secondary carbide within the grains at 800 °C. Decrease in elongation would be resulted from the coarsened and continuous carbides at the grain boundary as well as Cr- and Ni-rich phase along the grain boundary.

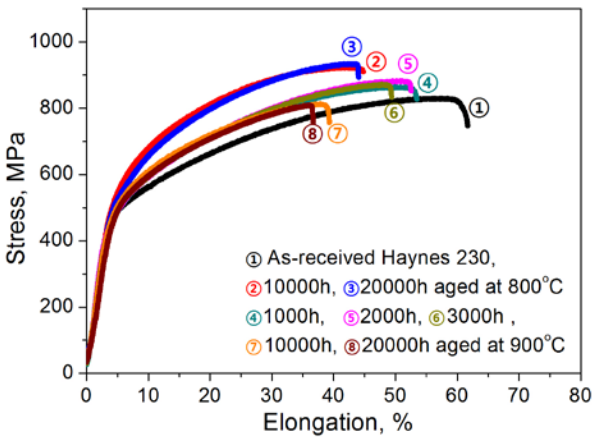

Fig. 4. The result of room temperature tensile test of aged Haynes 230

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REFERENCES

[1] J. Chang, Y.W. Kim, K.Y. Lee, Y.W. Lee, W.J. Lee, J.M. Noh, M.H. Kim, H.S. Lim, Y.J. Shin, K.K. Bae, K.D Jung, A Study of a Nuclear Hydrogen Production Demonstration Plant, Nuclear Engineering and Technology, vol. 39, p. 111, 2007.
[2] D. Kim, I. Sah, C. Jang, Effects of High Temperature Aging in an Impure Helium Environment on Low Temperature Embrittlement of Alloy 617 and Haynes 230, Journal of Nuclear Materials, Vol. 405, p. 9, 2010.
[3] K. Mo, G. Lovicu, H. Tung, X. Chen, J.F. Stubbins, High Temperature Aging and Corrosion Study on Alloy 617 and Alloy 230, Journal of Engineering for Gas Turbines and Power, Vol. 133, p. 052908-1, 2011.
[4] G. Bai, J. Li, R. Hu, T. Zhang, H. Kou, H. Fu, Effect of Thermal Exposure on the Stability of Carbides in Ni-Cr-W Based Superalloy, Materials Science and Engineering A, Vol. 528, p. 2339, 2011
[5] T.J. Garosshen, G.P. McCarthy, Low Temperature Carbide Precipitation in a Nick Base Superalloy, Metallurgical Transactions A, Vol. 16, p. 1213, 1985