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Microstructural Damages of Alloy 617 under Creep Stress at Elevated Temperature

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1. Introduction

Creep of high-temperature materials often limit the lives of components and structures designed to operate for long periods under stress at elevated temperatures. Nickel-base superalloy, Alloy 617 in particular which is considered as a prospective material for hot gas duct and intermediate heat exchanger in very high temperature gas cooled reactor, was studied for creep properties. Effect of dynamic recrysallization (DRX) and intergranular oxidation on creep properties which are one of the major degradation mechanisms during creep were investigated.

2. Experimental

The material tested was a commercial nickel-base superalloy Alloy 617 which is a solid solution hardening alloy by adding Mo and Co. Chemical composition of Alloy 617 (in wt%) is listed in Table 1.

Round-bar specimens were used for creep and tensile tests, with gauge length of l_0 = 19.05 mm and 6.35 mm in diameter. The strain was measured by extensometer. A strain rate of 2 x 10^{-4} sec^{-1} was applied during tensile test. Tensile properties of Alloy 617 are listed in Table 2. Creep test was carried out in air and helium environments using the helium gas of containing small amount of 1.8 ppm H_2O, 1.4 ppm O_2, at 800°C, 900°C and 1000°C.

Table I. Chemical Composition of Alloy 617

	Ni	Cr	Mo	Co	Al	C	Ti	Si	Mn	Fe
Alloy 617	Bal.	21.8	9.42	12.0	1.1	.08	.38	0.1	.04	1.2

Table II. Tensile Properties of Alloy 617

Temperature [°C]	Ys [MPa]	UTS [ksi]	%El	%RA
800	244.9	269.4	109.4	74.6
900	132.0	153.6	115.2	75.4
1000	53.3	70.7	89.6	60.3

3. Results and Discussion

3.1 Creep Behaviors of Alloy 617

Fig. 1 shows the relationship between creep stress and time to rupture of Alloy 617 tested in air and pure helium environments. Creep life in helium environment was longer several times than that in air due to less corrosive environment.

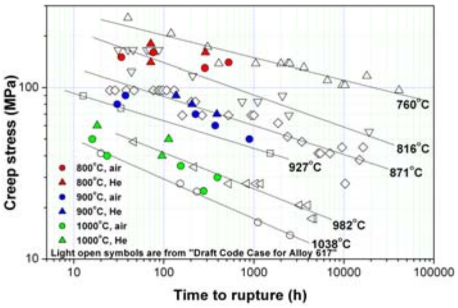
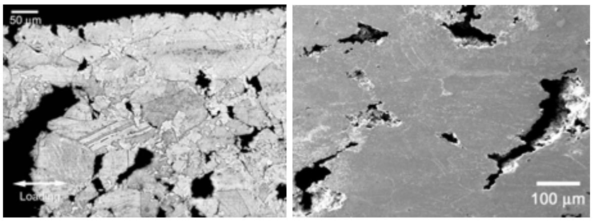


Fig. 1. Creep stress vs. time to rupture of Alloy 617

3.2 Hardening by DRX

High temperature DRX accompanied the formation of sub-grains and the serration of grain boundary as shown in Fig. 1(a). The considerable large sizes of the serrated voids were formed along the serrated grain boundary, as shown in Fig. 1(b).



(a) (b)

Fig. 1. DRX of Alloy 617 crept under creep stress of 50 MPa at 900°C

DRX disturbs the movement of dislocations and constrains the grain boundary sliding, which causes the hardening as shown in Fig. 2.

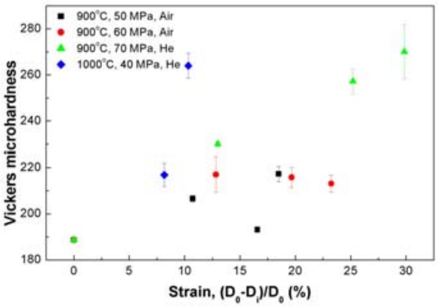


Fig. 2. Micro-hardness test results of Alloy 617 crept at elevated temperature

At 800°C, DRX did not occur and RA after creep rupture was not much different with RA after tensile test as shown in Fig. 3. Above 900°C, however, the occurrence of DRX led to the significant decrease in RA below 30 % at 1000°C. Although DRX is generally developed under high strain [1], it is significant even below 10 % strain at 1000°C. It indicates that the development of DRX becomes more severe with increasing temperature.

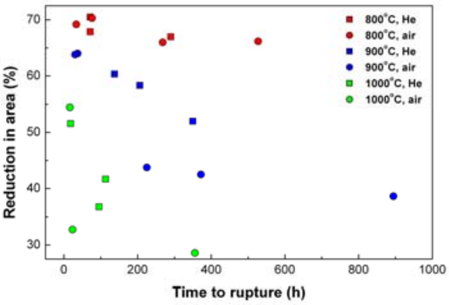
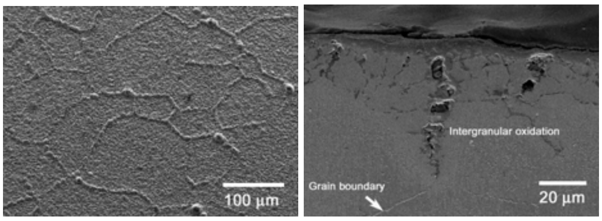


Fig. 3. %RA of Alloy 617 crept at elevated temperature

3.3 Crack Initiation by Intergranular Oxidation

The consumption of Cr below the scale by the development of Cr-rich scale such as Cr_2O_3 and $NiCr_2O_4$ enhances the internal oxidation of Al_2O_3 [2]. Since grain boundary diffusion of metal ions is generally faster than lattice diffusion at relatively low temperature below 2/3 of melting point [3], the fast outward diffusion of Cr^{3+} ions along grain boundary leads to the preferential formation of Cr-rich oxides along grain boundary as shown in Fig 4(a). A decrease in Cr concentration in grain boundary and the fast inward diffusion of O^{2-} ions along grain boundary might cause the severe intergranular oxidation along grain boundary. Large elongated intergranular oxides provided the crack initiation site under creep stress as shown in Fig. 4(b).



(a) (b)

Fig. 4. (a) Cr-rich oxides developed along grain boundary by intergranular oxidation and (b) crack initiation in grain boundary at 900°C

3.4 Creep Test under VHTR environment

Fig. 5 shows the schematic diagram of helium gas loop to simulate the VHTR environment. Experimental investigations are in preparation in order to check the effect of flow rate, partial pressure of impurities such as O_2, H_2O, CO, CO_2, CH_4 and H_2. Other Ni-base superalloys, such as alumina-forming Haynes 214 and another candidate superalloy for VHTR, Haynes 230, Hastelloy X, is being tested.

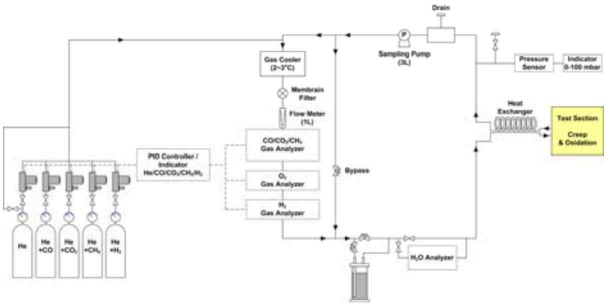


Fig. 5. Schematic diagram of helium gas loop

4. Conclusions

Dynamic recrystallization accompanied hardening at high temperature by the formation of sub-grains and the serration of grain boundary. Hardening was more significant at higher temperature. The serration grain boundary also induced the formation of large size of voids even at low strain which would make the easy crack propagation.

Intergranular oxidation was induced by the decrease in Cr concentration in grain boundary and the fast inward diffusion of O^{2-} ions along grain boundary. Intergranular oxides provided the crack initiation sites during creep.

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