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Influence of Thermal Ageing on Mechanical Properties of Alloy 617

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1. Introduction

A Very High Temperature Reactor (VHTR) system is a gas-cooled reactor with operation goal of producing hydrogen at temperature up to 900-1000°C, pressure up to 7 MPa, and design life up to 60 years. Alloy 617 is identified as one of the candidate materials in the Gen-IV reactor systems for component because of its excellent mechanical properties and corrosion resistance at the temperature range of 760 to 1000°C [1-5].

During long-term service at the high temperatures, metallic materials inevitably undergo aging processes which result in microstructure evolution and changes in mechanical properties. To develop design guidelines for Alloy 617, a mechanistic understanding on the aging effects, which would arise during long-term and high-temperature exposure, becomes very important [1]. However, the design guideline of mechanical properties on long-term aging such as tensile and creep properties was not given from some elevated temperature design (ETD) codes: ASME code, RCC-MRx, or elsewhere. Therefore, to establish a design guideline on thermal aging effects of Alloy 617, experimental aging data should be sufficiently prepared, and its mechanical behavior for thermal aging should be understood well.

In this study, the changes of mechanical properties such as hardness, tension, and creep behaviors of thermally-aged Alloy 617 for 2-years (2y) at 900°C were investigated in comparison with the unaged (or virgin) material. A series of creep tests was conducted with different applied stress levels at 900°C. Oxidation layer and micro-hardness for the aged samples were measured. Crept microstructures were observed and discussed.

2. Methods and Results

2.1 Experimental procedures

Commercial grade nickel-based superalloy, Alloy 617 (brand name: Haynes 617) of a hot-rolled plate with a thickness of 25.9mm (1.020 inch) was used for this study. Chemical compositions are given as (wt,%), Al: 1.06, B: <0.002, C: 0.08, Co: 12.3, Cr: 22.2, Cu: 0.0268, Fe: 0.9496, Mn: 0.0295, Mo: 9.5, Ni: 53.11, P: 0.003, S: <0.002, Si: 0.0841, Ti: 0.41. The thermal aging specimens were prepared with the rectangular blocks of 26 mm in height, 42 mm in width, and 90 mm in length. The blocks were constantly maintained for 2 years (17,520 h) in the box furnace. After thermal aging, the blocks were taken out from the box furnace, and the tension and creep test specimens were cut by electric discharge machine (EDM) from the blocks. The dimension of the tensile specimens was a plate type of 2.0 mm in thickness and 6.25 mm in width of gage length. The tensile tests were performed at the temperatures of R.T., 400, 600, 700, 800, 850, 900, and 950°C with the strain rate of 5.85E-04 (1/s). The dimension of the creep specimens was a cylindrical form of 30 mm in gauge length and 6 mm in diameter. The creep tests were performed under different applied stress levels at 900°C. The creep strain data with elapsed times was taken automatically by a personal computer through an extensometer attached to the creep specimens. The creep curves with variations were obtained, and the minimum creep rate was obtained by calculating the secondary creep stage from the strain–time creep curves.

2.2 Tensile and creep rupture properties

After 2y-thermal aging at 900°C, the high-temperature tensile properties and creep rupture properties were investigated. The creep test results of the aged material were compared with those of the unaged (virgin) results using various creep plots.

Fig. 1 shows a comparison of the 0.2% yield strength (YS) and ultimate tensile strength (UTS) for the 2y-aged and unaged materials with the temperature variations. The aged material reveals clearly a reduction in the tensile strengths compared with the unaged specimens. However, in the tensile elongation, it was identified that the aged material was reversely increased compared with the unaged one.

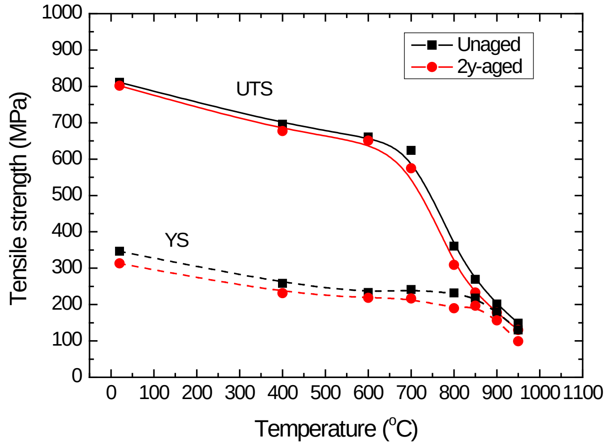

Fig. 1. Comparison of the tensile strengths with the high temperatures for the 2y-aged and unaged materials

Fig. 2 shows a comparison of the log stress vs. log time to rupture for the 2y-aged and unaged materials at 900°C. The creep stress of the aged material is reduced compared with that of the virgin one. The reason for this is that the micro-hardness value (Hv) was decreased for about 28.4%: Hv=206 in the aged material and Hv=288 in the unaged material, as shown in Fig. 3. In addition, the 2y-aged material was more decreased in the micro hardness value than the 1y-aged material. It was thus attributed to the softening of material during thermal aging period.

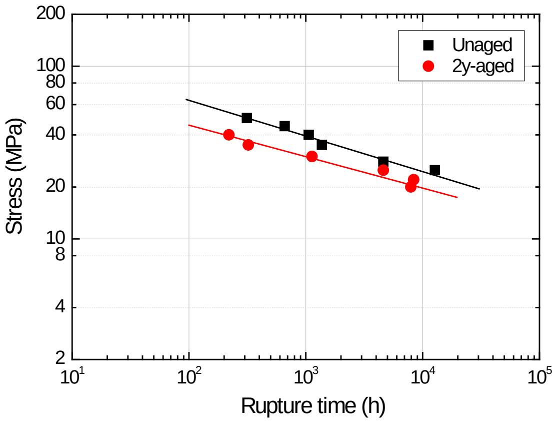

Fig. 2. Comparison of the log stress vs. log time to rupture in the virgin and aged material at 900°C

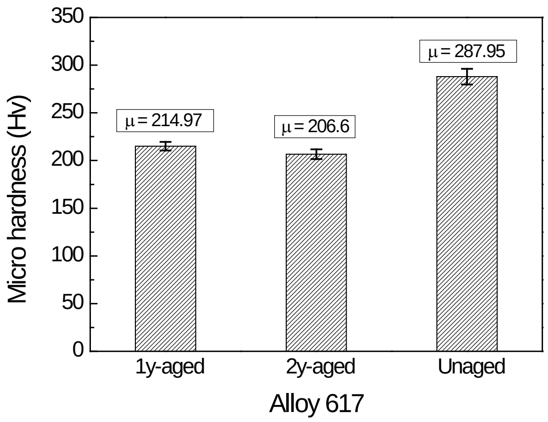

Fig. 3. Comparison of micro-hardness value for the 2y-aged and unaged material at 900°C

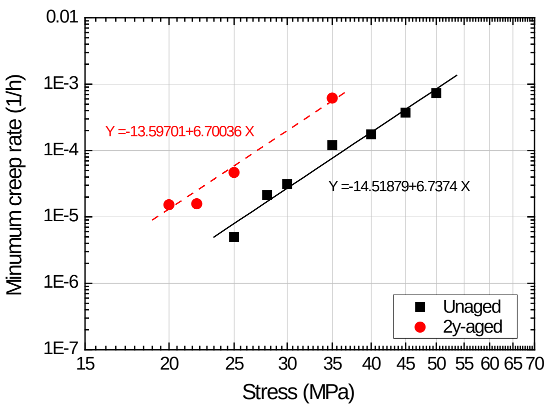

Fig. 4. Comparison of creep rate vs. stress in the 2y-aged and unaged materials at 900°C

Fig. 4 shows a comparison of log (creep rate) vs. log (stress) for the 2y-aged and unaged materials. The creep rate of the 2y-aged material is significantly faster than that of the unaged one. The relationships between the creep rate and stress follow a good linearity. In the comparison of the Monkman-Grant (M-G) relationships between creep rupture time and creep rate, it was investigated that a marginal difference in slope was for the two materials. Thus, at this creep condition of Alloy 617, it is assumed that creep deformation corresponds to power-law creep region, and its mechanism is governed by a climb of dislocation. The *A* and *n* values of Norton's power-law constants for the unaged and aged materials can be obtained using Fig. 4.

Fig. 5 shows the variations of creep rupture ductility with the creep rupture times for the 2y-aged and unaged materials tested at 900°C. The 2y-aged material is higher in creep rupture elongation and reduction of area than unaged material. But, the rupture ductility is almost constant with an increase in the rupture time for two materials. The reason for this is that in the lower stress of longer time, the creep rupture of Alloy 617 mainly occurs due to cavity formation rather than failure by necking.

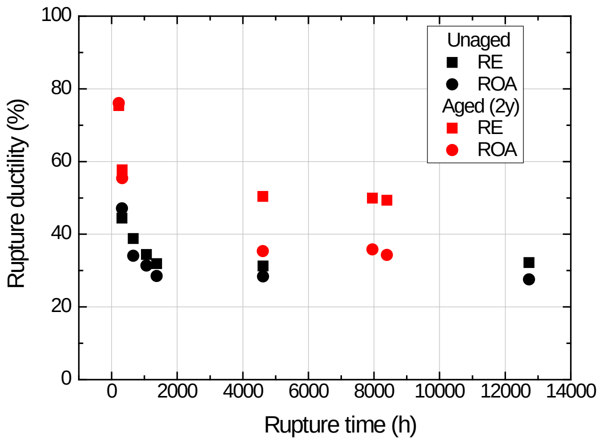

Fig. 5. Comparison of creep rupture elongation vs. rupture time in the 2y-aged and unaged materials at 900°C

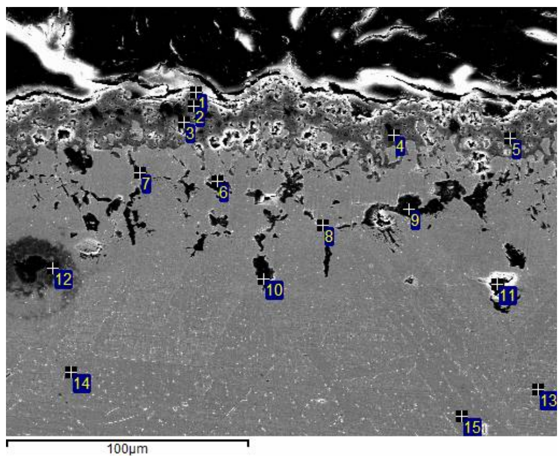

Fig. 6. SEM photos showing oxidation layer formed in the sample after 2-years aging at 900°C

Fig. 6 shows a SEM photo of oxidation layer formed in the materials after 2 years aging at 900^oC. The precipitates formed during 2y-thermal aging were investigated by energy dispersive spectroscopy (EDS) analysis. Oxidation layer in the outer surface was formed for about 20 mm thickness. The outer oxides were mainly analyzed as Cr_2O_3, and just below, some minor voids are developed with along the grain boundary. Inside the specimen, large voids remain due to coarsening precipitates. It is assumed that coarsening precipitates in the aged material deteriorated the rupture time or strength.

3. Conclusions

In the tensile strength, the 2y-aged material revealed clearly a decrease compared with the unaged material. However, in the tensile elongation, the aged material was identified to be reversely increased when compared with the unaged one. The micro-hardness value of the 2y-aged material was reduced for about 28.4% compared with that of the virgin material. The creep strength of the 2y-aged material was lower than that of the virgin one, and it was also faster in the creep rate than the virgin material. However, the rupture ductility of the aged material was higher than that of virgin material. It was found that outer oxidation layer was formed for Cr_2O_3 of about 20 mm thickness. Further investigation is planned to be continued for the 3-years aging specimens under an identical-temperature condition.

Acknowledgements

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