*Transactions of the Korean Nuclear Society Autumn Meeting*
*Gyeongju, Korea, October 26-27, 2017*

# Creep Rupture Behavior of Thermally-Aged Alloy 617 at 900°C

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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 prepare a design guideline on thermal aging effects of Alloy 617, experimental data should be sufficiently provided, and its mechanical behavior owing to aging should be understood.

In this study, the creep rupture behavior for Alloy 617 which was thermally aged for 1 year at 900°C was comparatively investigated with the virgin material. After thermal aging, 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 1 year (8,760 h) in the box furnace. After 1-year aging, the blocks were taken out from the box furnace, and creep specimens from the blocks were machined with a cylindrical form of 30 mm in gauge length and 6 mm in diameter. Creep tests were conducted under different applied stress levels at 900°C. Creep strain data with elapsed times was taken automatically by a personal computer through an extensometer attached to the creep specimens. 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 Creep rupture properties*

For the specimens after 1-year aging at 900°C, the creep rupture data such as the rupture time, minimum creep rate, rupture elongation and reduction of area were investigated, and creep rupture properties for the aged specimens were compared with those of the unaged (virgin) specimens using various creep plots.

Fig. 1 shows a comparison of the log stress vs. log time to rupture for the unaged and aged specimens at 900°C. It can be seen well that there are some differences in the creep rupture time between the virgin and aged specimens. Creep stress of the aged material is significantly reduced compared with that of the virgin one. The reason for this is that the micro-hardness value (Hv) was reduced for about 26%: Hv=214 in the aged material and Hv=288 in the virgin material, as shown in Fig. 2. It means that the virgin material occurred softening due to thermal aging, and the reduction of creep strength followed by aging damage. As shown in Fig. 1, although the fitted lines for two materials revealed a parallel relation, a reduction factor (R.F = ratio of creep strength in aged material to unaged material) is larger with an increase in the rupture time. It is important because the R.F value in longer rupture time is higher than the R.F in short rupture time.

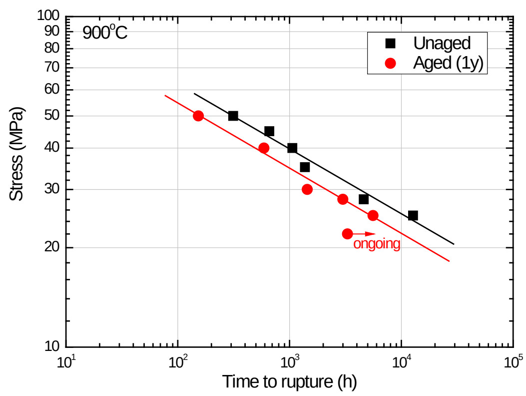


Fig. 1. Comparison of the log stress vs. log time to rupture in the virgin and aged material at 900°C

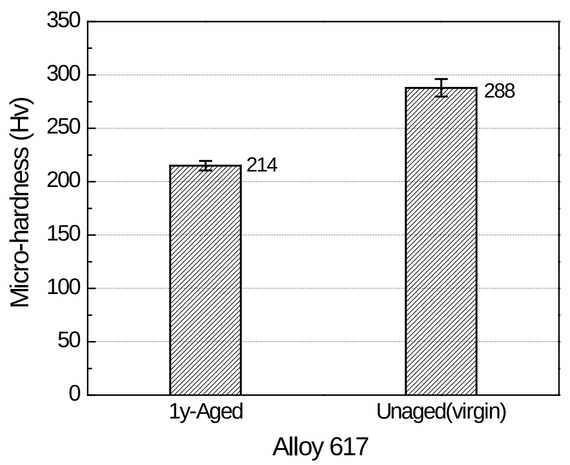


Fig. 2. Comparison of micro-hardness value for the aged and unaged material at 900$^{o}$C

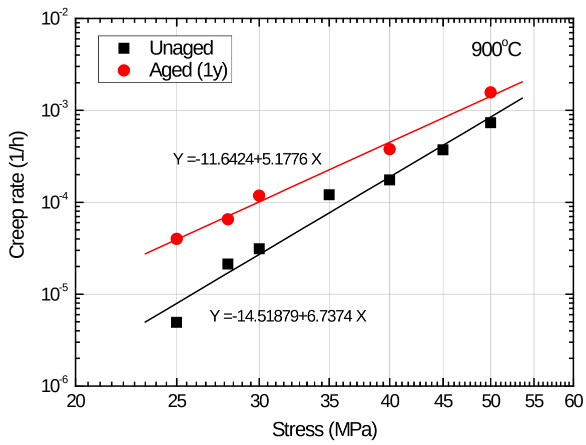


Fig. 3. Comparison of creep rate vs. stress in the aged and unaged materials at 900$^{o}$C

Fig. 3 shows a comparison of creep rate vs. stress in the unaged and aged materials. The creep rate of the aged material is 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. 3.

Fig. 4 shows a comparison of creep rupture elongation vs. rupture time in the unaged and aged materials at 900$^{o}$C. Aged material is higher in rupture elongation than unaged material, and the rupture elongation of two materials reveals increased with an increase in stress. However, in the low stress region of 25 MPa, the rupture elongation is small difference between the 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.

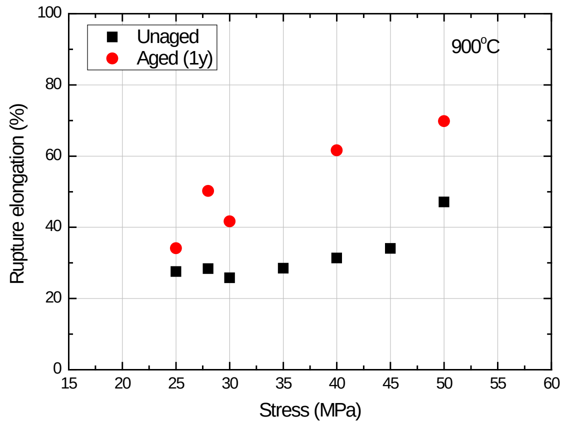


Fig. 4. Comparison of creep rupture elongation vs. rupture time in the aged and unaged materials at 900$^{o}$C

Fig. 5 shows a SEM photo of oxidation layer formed in the materials after 1-year aging at 900$^{o}$C. Oxidation layer in the outer surface is 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.

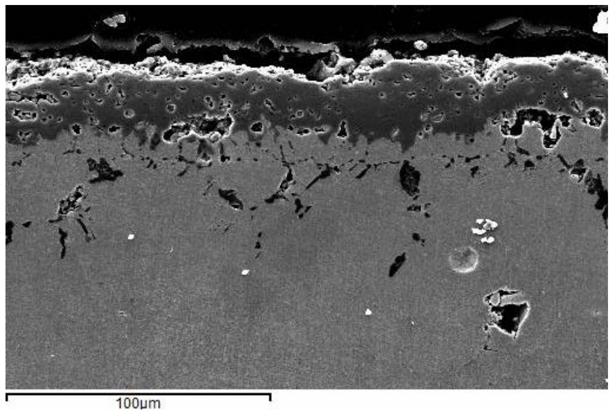


Fig. 5. SEM photos showing oxidation layer formed in the sample after 1-year aging at 900$^{o}$C

## 3. Conclusions

Creep rupture behavior for thermally-aged Alloy 617 for 1 year at 900$^{o}$C was comparatively investigated with the virgin material. Creep strength of the aged material was reduced compared with that of the virgin one. Micro-hardness value of the aged material was reduced for about 26% compared with that of the aged material. Creep rate of the aged material was faster than that of the unaged one. However, the aged material was higher in rupture elongation than unaged material, and the rupture elongation of two materials revealed increased with an increase in stress. Outer oxidation layer was formed for $Cr_2O_3$ of about 20 mm thickness. Further investigation is planned to be continued for 2-years aging specimens under an identical-temperature condition.

**Acknowledgements**

This study was supported by the Korean Ministry of Education, Science & Technology through its National Nuclear Technology Program.

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