Changes of Mechanical Properties after 3-Years Thermal Ageing at 900°C of Alloy 617

Woo-Gon Kim[a*], I.N.C. Kusuma[b], Sah Injin[a], Seon-Jin Kim[b], Eung-Seon Kim[a], Min-Hwan Kim[a]
[a] *Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353,*
[b]*Pukyong National University, 100 Yongdang-dong, Nam-gu, Busan, 608-739*
[*]*Corresponding author: wgkim@kaeri.re.kr*

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 [1,6]. 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, changes of mechanical properties such as hardness, tension, and creep behaviors after 3-years (y) thermal ageing at 900°C of Alloy 617 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 3y (26,280 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 Changes of tensile and creep rupture properties

After 3y-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 3y-aged and unaged materials with the temperature variations. The aged material reveals clearly a reduction in the tensile strengths compared with the unaged materials. However, the tensile strengths among the aged materials appeared to be similar as asymptotic behavior. In the tensile elongation, it was found to be identified that the aged materials were reversely increased compared with the unaged one.

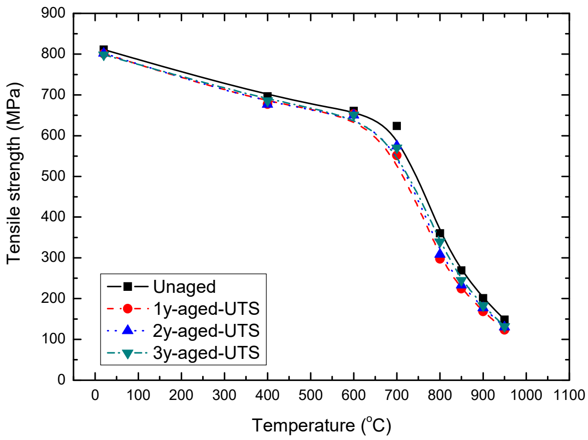

Fig. 1. Comparison of the tensile strengths with temperature variations for the aged and unaged materials

Fig. 2 shows a comparison of the log stress vs. log time to rupture for the aged and unaged materials at 900°C. Creep stress of aged materials is reduced when compared with that of the virgin one. The reason for this is that micro-hardness value (Hv) was decreased in the aged materials, as shown in Fig. 3. In addition, the 3y-aged material was slightly decreased in the micro hardness value compared with the 1y-aged material. It is supposed due to the softening of material resulted from thermal aging effects.

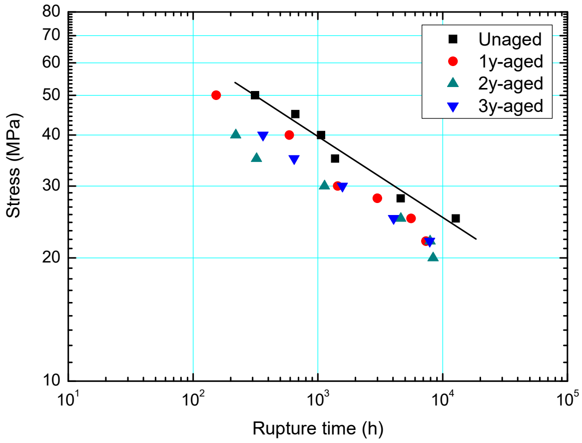

Fig. 2. Comparison of the log stress vs. log time to rupture in the aged and unaged materials at 900°C

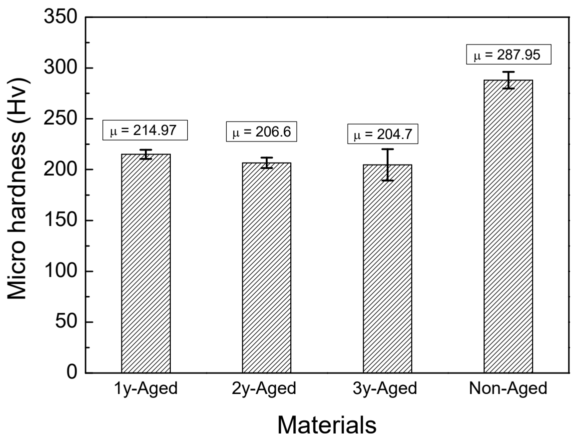

Fig. 3. Comparison of micro-hardness value for the aged and unaged materials at 900°C

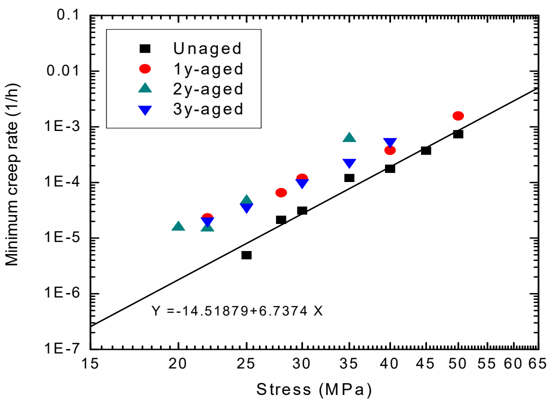

Fig. 4. Comparison of creep rate vs. stress in the aged and unaged materials at 900°C

Fig. 4 shows a comparison of log (creep rate) vs. log (stress) for the aged and unaged materials. The creep rate of the 3y-aged material is significantly faster than that of the unaged materials. However, there is no difference in the creep rates among the aged materials. The plots between the creep rate and stress reveals 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 by Fig. 4.

Fig. 5 shows the variations of creep rupture ductility with the creep rupture times for the aged and unaged materials tested at 900°C. The 3y-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. 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.

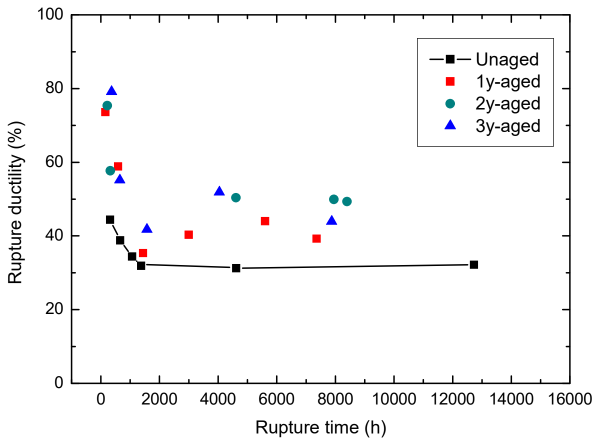

Fig. 5. Comparison of creep rupture elongation vs. rupture time in the aged and unaged materials at 900°C

3. Conclusions

In the tensile strength, the 3y-aged material revealed a decrease compared with the unaged material. However, there was no difference in the tensile strengths among the aged materials. In the tensile elongation, the aged materials were identified to be reversely increased when compared with the unaged one. The micro-hardness value of the 3y-aged material was reduced for about 28.8% compared with that of the virgin material. The creep strength of the 3y-aged material was lower than that of the virgin one, and it was also faster in the creep rate than the virgin material. On the other hand, the rupture ductility of the aged material was higher than that of virgin material. It was identified that the creep strengths and creep rates among the aged materials showed asymptotic behavior.

In the further investigation, we are planned to be continued for the 4-years aging specimens under an identical-temperature condition.

Acknowledgements

This research was supported by Nuclear Research & Development Program of the National Research Foundation of Korea (NRF) funded by the Ministry of Science, ICT & Future Planning (2012M2A8A2025682 and 2016M2A8A1952772).

REFERENCES

[1] W. Ren and R. Swimdeman, A review of aging effects in Alloy 617 for Gen-IV nuclear reactor applications, Proceedings of ASME PVP 2006-ICPVT-11-93128, Vancoucer, 2006.

[2] W.G. Kim, S.N. Yin, W.S. Ryu and J.H. Chang, Analysis of the creep rupture data of Alloy 617 for a high temperature gas cooled reactor. Proceedings of CREEP8, ASME PVP 2007-26834, Texas, 2007.

[3] C. Jang, D. Lee and D. Kim, Oxidation behavior of an Alloy 617 in very high temperature air and helium environments. Int Jnl of Press Vessels and Piping, Vol.85, pp. 368-377, 2008.

[4] S. Dewson and X. Li. Selection Criteria for the High Temperature Reactor Intermediate Heat Exchanger. Proceedings of ICAPP 05, Paper No.5333, Seoul, 2005.

[5] W.G. Kim, S.N. Yin, G.G. Lee, J.Y. Park, S.D. Hong and Y.W. Kim, Creep properties of Alloy 617 in air and Helium environments at 900^{o}C, Transactions of the KNS Spring Meeting, Taeback, Korea, May 26-27, 2011.

[6] W. G. Kim, I.N.C. Kusuma, I. Sah, S.J. Kim, E.S. Kim and M.H. Kim, Influence of Thermal Ageing on Mechanical Properties of Alloy 617, Transactions of the KNS Spring Meeting, Jeju, Korea, May 23-24, 2019.