Effect of post-weld heat treatment on creep behavior of heat-affected zone in 2.25Cr-1Mo steel

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It is important to predict the creep strength to develop heat-resistant steels. The Cr heat-resistant steels are strengthened by several factors such as precipitation, dislocation, and so on. Therefore, the prediction of creep strength by these contributions based on the microstructures is essential. Especially, the heat-affected zone (HAZ) in weld joints of the steels shows lower creep strength compared with base materials. To predict the creep strength of HAZ in weld joints, we have to evaluate and predict the microstructure evolution during welding, post-weld heat treatment (PWHT), and creep deformation, then establish the creep constitutive equation based on the microstructure evolution. In this study, using HAZ simulated samples of 2.25Cr-1Mo heat-resistant steel with various PWHTs, the microstructures were evaluated and simulated, and the effect of the microstructure on the creep behavior was investigated.

2.25Cr-1Mo heat-resistant steel was prepared, and the HAZ thermal cycle was also applied (called HAZ simulated samples). Various PWHTs between 600 and 720ºC were also conducted to vary the microstructure of HAZ simulated samples. Creep test was performed at 550ºC with 140MPa. The precipitations were evaluated by SEM observation and simulated by MatCalc software. The crystallographic analysis was conducted by SEM/EBSD, and the dislocation density was evaluated by XRD measurement.

The microstructures of the HAZ simulated samples with various PWHTs were investigated. Regarding the contribution to the strengthening mechanism, the precipitation and the dislocation were changed by the temperature of PWHT, and the creep resistant stress was estimated by these strengthening factors. The creep constitutive equation including the microstructure evolution was proposed based on the microstructure analysis and the creep tests. By using the creep constitutive equation, the creep curves of the HAZ simulated samples with different PWHT were well predicted and it was demonstrated that the PWHT condition affects the creep lives.

Keywords: *Heat-resistant steel, Creep, Heat affected zone,*

1. Introduction

In order to develop heat-resistant steels for next generation thermal power plant, it is important to evaluate the creep strength of the heat-resistant steels. The Cr heat-resistant steels are strengthened by several factors such as precipitation, dislocation, and so on. Therefore, the prediction of creep strength by these contributions based on the microstructures is essential. Especially, the heat-affected zone (HAZ) in weld joints of the steels shows lower creep strength compared with base materials[1)]. Also, post-weld heat treatment (PWHT) is usually conducted to reduce the residual stress due to welding process. To predict the creep strength of HAZ in weld joints, we have to evaluate and predict the microstructure evolution during welding, PWHT, and creep deformation, then establish the creep constitutive equation based on the microstructure evolution. In this study, using HAZ simulated samples of 2.25Cr-1Mo heat-resistant steel with various PWHTs, the microstructures were evaluated and simulated, and the effect of the microstructure on the creep behavior was investigated.

2. Procedures

2.25Cr-1Mo heat-resistant steel was prepared, and its chemical composition is shown in Table 1. The sample was heat treated as normalizing at 930ºC for 1800 s and tempering at 720ºC for 1800 s. In addition, the HAZ thermal cycle at 925ºC for 15 s was also applied (called HAZ simulated samples). Various PWHTs between 600 and 720ºC for 2 hours were also conducted to vary the microstructure of HAZ simulated samples. Creep test was performed at 550ºC with 140MPa.

The precipitations were evaluated by SEM and TEM observations with EDS analysis. The crystallographic analysis was conducted by SEM/EBSD to obtain the grain boundary density, and the dislocation density was evaluated by XRD measurement.

The precipitation in the samples with several PWHT conditions and during creep deformation was estimated by MatCalc software which can simulate the precipitation behavior. In this simulation, the precipitates such as $M_{23}C_6$, M_7C_3, M_2C and Fe_3C were considered, and their nucleation sites were input based on the experimental observation.

Table 1 Chemical composition of steel.

C	Si	Mn	Cu	Ni	Cr	Mo	Fe
0.14	0.25	0.54	0.16	0.16	2.39	1.02	Bal.

3. Results and discussion

The microstructures of HAZ simulated samples with various PWHT were investigated. The precipitations formed in the samples are mainly $M_{23}C_6$ and Fe_3C. As the PWHT temperature increases, the amount of $M_{23}C_6$ becomes large, but that of Fe_3C becomes small. These precipitations can be simulated by MatCalc and the fraction of precipitations were well predicted. The grain boundary density was evaluated by EBSD, and the result shows that the grain boundary density becomes low that is the grain grows as the PWHT temperature increases. The dislocation density was also evaluated by XRD, and it decreases as the PWHT temperature increases.

The strengthening factors were estimated by the microstructure observation. In this study, we estimated each strengthening factors, such as precipitation strengthening, dislocation strengthening, grain size strengthening etc., and the sum of their contributions was considered as a creep resistance stress. The change in the each strengthening value and the creep resistance stress with PWHT temperature is shown in Fig. 1. The contribution of dislocation and precipitation is relatively large compared with others. The creep resistance stress based on PWHTed samples decreases as the PWHT temperature increases.

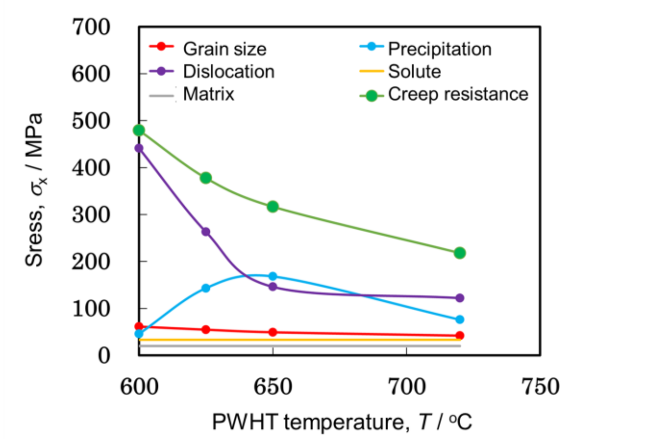
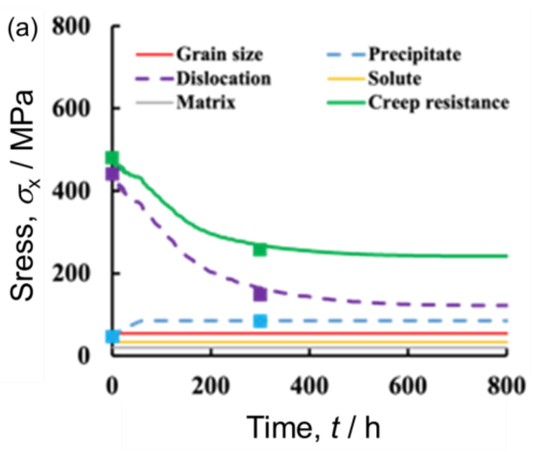


Fig. 1 Change in each strengthening with PWHT temperature.

The evolution of microstructure during creep deformation is also considered to predict the creep behavior. Therefore, some samples of interrupted creep test were prepared, and the microstructures were evaluated. In the case of lower PWHT temperatures such as 600ºC and 625ºC, the number of $M_{23}C_6$ increases and the dislocation density decreases during creep deformation. On the other hand, in the case of higher PWHT temperature, 720ºC, the microstructure including precipitation and dislocation density changed little. By applying MatCalc for precipitation and Kocks-Mecking model for dislocation density, the evolution of precipitation and dislocation density during creep deformation can be predicted well, and the change in the creep resistance stress and each strengthening was also estimated, as shown in Fig. 2.

The creep constitutive equation considering the initial microstructure and the evolution of microstructure during creep deformation was proposed based on our previous study2). By considering the change in the creep resistance stress, the creep curves of the HAZ simulated sample with different PWHT were well predicted, as shown in Fig. 3.



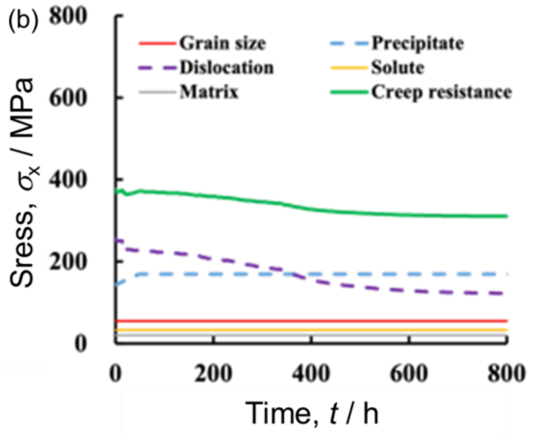


Fig. 2 Change in each strengthening during creep test for the samples of (a) PWHT at 600ºC and (b) PWHT at 625ºC.

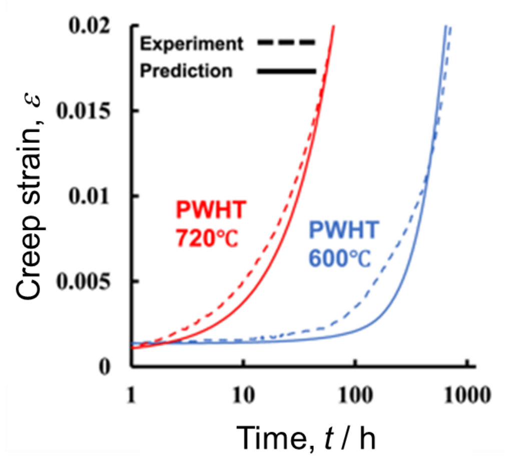


Fig. 3 Creep curves of experiments and predictions based on the creep constitutive equation.

4. Conclusions

(1) As PWHT temperature increases, the creep resistance stress becomes low due to the coarsening of precipitates and decrease of dislocation density.

(2) The creep deformation behavior can be predicted well by estimating the creep resistance stress of initial microstructures and predicting the evolution of dislocation density and precipitate during creep deformation.

Acknowledgments

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References

1) K. Laha, K.B.S Rao and S.L. Mannan: Mater. Sci. Eng. A 129 (1990) 183-195.
2) S. Nambu: Netsu Shori (J. Jpn. Soc. Heat Treat.) 60 (2020) 55-58.