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A Study on Creep Characteristics Evaluation and Creep Life Prediction of Alloy 690 Steam Generator Tube

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1. Introduction

After the Fukushima Daiichi accident, the SG tube integrity may be challenged by high temperature and high pressure conditions and may have a potential to fail due to creep rupture in a broad category of station blackout severe accident scenarios. Recently, SG tube material has been replacing by Alloy 690 which has high corrosion resistant on high temperature condition. However, there is a lack of research on creep characteristics of Alloy 690 SG tube. In this study, a number of creep tests were performed for alloy 690 SG tube, and creep life prediction was conducted using carious creep life prediction methods.

2. Creep Test

Fig. 1 shows the geometry of creep specimen. Real tube was used for the specimen, the tube was not flattened for having the residual stress of the tube during manufacturing process. Reduced section of the specimen is 19mm and the width is 4mm. A series of creep test was performed under different stress levels and temperatures. Creep strain data and elapsed times were recorded automatically by using data acquisition system. Time to rupture, steady-state creep rate was obtained by analyzing experimental creep curves. The creep properties such as the creep rupture time (hour, t_r), creep strain rate (steady-state creep rate, SSCR) and test conditions (temperature (T) and stress (σ)) are summarized in Table 1. Due to the lack of alloy 690 creep data in the related researches, some data reported by manufacturer were collected [1]. Total of 63 data points were collected by adding the 18 test data (so far) obtained from the experiment.

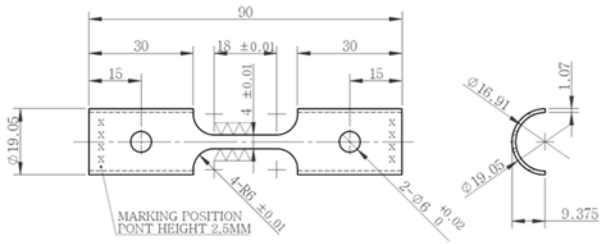


Fig. 1. Geometry of creep specimen

Table 1 Experimental condition and results of creep tests

T(°C)	σ (MPa)	T_r (hr)	$SSCR$(1/hr)
700	120	214.6	1.130.E-03
700	110	303.0	7.272.E-04
700	100	386.0	5.580.E-04
700	90	644.1	2.707.E-04
700	80	865.6	1.717.E-04
750	100	39.1	3.550.E-03
750	80	98.1	1.730.E-03
750	70	177.6	9.252.E-04
750	50	575.6	1.462.E-04
750	40	779.1	7.468.E-05
800	60	43.0	3.610.E-03
800	50	78.1	1.790.E-03
800	40	194.6	5.436.E-04
800	30	507.7	1.974.E-04
850	60	10.0	2.010.E-02
850	50	24.6	8.590.E-03
850	40	35.3	4.080.E-03
850	30	93	1.400.E-03

Rupture time decreases with increasing stress, and more loads are required as the temperature decreases at same rupture time as summarized in Table 1. Based on the data set, parameters of each creep life prediction model were determined.

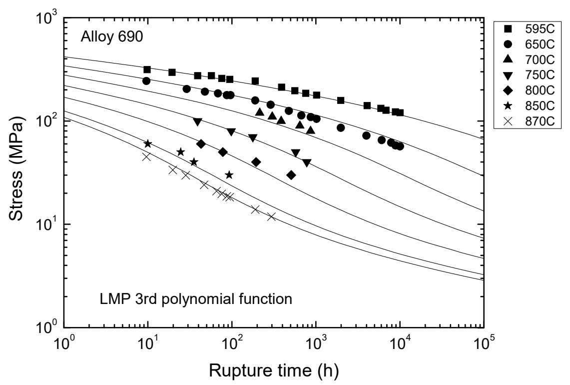
3. Creep Life Prediction

Various method to predict creep life such as Lason-Miller Parameter(LMP), Orr-Sherby-Dorn(OSD), and Manson-Haferd Parameter (MHP) known as a time-temperature parameter(TTP) have been proposed[2, 3]. Recently, Wilshire et al. proposed a new method to predict long-term creep life using short term creep data simply [4]. In this study, 4 types of creep life prediction methods were applied to the experimental data and collected data set.

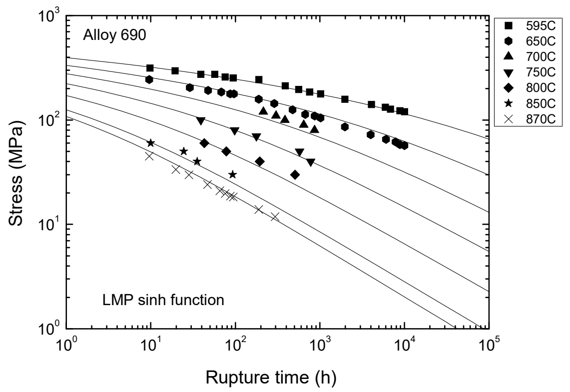
The parameter of LMP method given by

$$\mathrm{LMP} = \mathrm{T}(\log t_r + C) \qquad (1)$$

where, T is the absolute temperature (Kelvin), t_r is the rupture time and C is a material specific constant.



(a) Polynomial equation



(b) Sinh function

Fig. 2. LMP Creep life prediction using master curve of polynomial and sinh function

An optimum material specific constant, *C*, in the master curve was investigated to be *C*=13.

The OSD parameter given by

$$\mathrm{OSD} = \log t_r - \frac{Q}{2.3RT} \qquad (2)$$

where, Q is the activation energy, and R is the universal gas constant. Average of $Q/2.3R$ was determined to 15739.96.

The MHP equation can be given as,

$$\mathrm{MHP} = \frac{(log t_r - log t_a)}{T - T_a} \qquad (3)$$

where, T_a and t_a values are material constant. T_a=646.159 K and $log(t_a)$=6.989 were determined in an average value of the linear slopes.

The Wilshire equation is given as follow:

$$\ln\left(\frac{\sigma}{\sigma_{TS}}\right) = -k\left[t_r exp\left(-\frac{Q^*}{RT}\right)\right]^u \qquad (4)$$

where, σ_{TS} is the ultimate tensile strength (UTS) at a given temperature of material, and Q* is different from the activation energy in creep. Here, it was obtained for Q*=230 kJ/mol.

The LMP and OSD method showed better prediction results than MHP among TTP methods.

In determining the master curves to predict creep life, LMP, OSD and MHP methods usually use third (3rd) order polynomial equation. However, polynomial fit causes the unreasonable prediction of creep behavior at lower stress and higher temperatures so that a “sinh (hyperbolic sine)” function was also used [5].

As a results of applying the master curve of the “sinh” function, the prediction results was improved at high temperature for a long term creep prediction. Although the Wilshire results is not provided here, it shows better results than the TTP methods. Wilshire method can be used as the best method to predict the creep rupture life of Alloy 690 SG tube.

In this study, creep life was predicted using various creep life prediction models However, the number of creep data is insufficient to predict creep life so far, limitation exist to predict the accurate creep life. In the future, a larger number of creep tests will be carried out to improve accuracy of creep life prediction.

4. Conclusions

In this study, the creep test was performed to predict the creep life of Alloy 690, which is the material of SG tube, and the test data for creep life prediction were prepared by adding the data reported by the manufacturer. Using these limited test data, LMP, OSD, and MHP methods which are widely used in creep life prediction are applied. In addition, Wilshire model which was recently reported as an excellent method, was applied to find optimal creep life prediction model.

The application of TTP method for predicting the creep life of Alloy 690 tube showed that LMP and OSD method were superior to MHP method. In the case of the TTP method, it was confirmed that the use of the sinh function as mater curve improves the life prediction results rather than the use of polynomial master curve. The Wilshire model showed better creep life prediction results than the TTP method.

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