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Creep Life Prediction for P91/12Cr1MoV Dissimilar Joint Based on the Omega Method

H. Chen[a]*, G.R. Zhu[a], J.M. Gong[b]

[a]Ningbo Special Equipment Inspection and Research Institute, Ningbo 315048, China
[b]Nanjing Tech University, Nanjing 210009, China

Abstract

P91/12Cr1MoV dissimilar steel welded joints are widely used in the superheater and reheater tubes at elevated temperature. Therefore, it is of great significance to predict the creep rupture life of the P91/12Cr1MoV dissimilar joint for safe operation. In this paper, Omega method was used to predict the creep curve of T91/12Cr1MoV dissimilar joint based on the creep test results. The predicted life was found to be invariably above the experimental result, and was in close relationship with the Omega value. A larger value can be obtained from lower stress, and the results obtained from lower stress are more close to the experimental ones.

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Keywords: Dissimilar joint; Creep behaviour; Omega method

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1. Introduction

Premature failure of dissimilar joints in superheater steam pipes and furnace tubes always occurs during service [1], and the need for life assessment of components in the creep range is thus of great concern. To ensure the safety at elevated temperatures, various life prediction methods have been developed [2-7]. In these methods, the measured creep strain with time variations of critical components are used to extrapolate the rupture life. However, different creep equations can be applied to quantify these creep curves, which including Theta project, Kachanov approach, Omega method and so on [2-4].

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* Corresponding author. Tel.: + 86-574-55121377; fax: + 86-574-55121377.
*E-mail address:*chh025@163.com

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The Omega methodology, which is established by MPC Petroleum and Chemical Committee, has been widely applied in USA for the life assessment of petroleum and power companies [4]. The recognition of this method has been justified in API RP579 fitness-for-service. This model extended the descriptions of simple creep model such as Larson-Miller approach, Monkman Grant relationship and Norton's theory [5-7], providing a more accurate description of the material behaviour of components operating at high temperatures.

In this research, creep tests were carried out on cross weld specimens, and Omega method was subsequently applied to predict creep behaviours of this dissimilar joint. Comparisons were made between the actual and predicted creep data.

2. Experimental procedure

The P91 and 12Cr1MoV metals were joined together by metal inert-gas (MIG) method using welding electrode type of GTR-2CM, and postweld heat treatment (PWHT) was conducted at 700 °C for 90 minutes after welding. Chemical compositions of the base metals (P91 and 12Cr1MoV) and weld metal (GTR-2CM) are listed in Table 1. The P91/GTR-2CM/12Cr1MoV dissimilar joint used in the creep tests was cut from super steam piping with a diameter of 273 mm and thickness of 20 mm without service. Tests were carried out by CSS-3905 type creep machine as shown in Fig. 1, which contains main part of apparatus as well as data recorder device. The temperature and stress of creep were conducted at 550 and 570 °C ranging from 130 to 220 MPa, respectively. The dimensions of a creep specimen for constant load tests are 100 mm in gage section and 9 mm in diameter as shown in Fig. 2.

Table 1. Compositions of base and weld metals (wt %).

Material	C	Si	Mn	P	S	Ni	Cr	Mo	V
P91	0.109	0.295	0.428	0.038	0.0071	0.166	9.12	0.88	0.28
12Cr1MoV	0.143	0.24	0.55	0.009	0.008	0.003	1.11	0.31	0.22
GTR-2CM	0.09	0.49	0.62	0.023	0.009	0.18	2.69	1.02	/

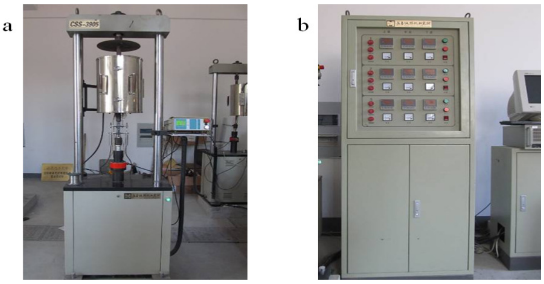

Fig. 1. CSS-3905 constant load creep machine: (a) main part of apparatus; (b) system of date acquiring and processing.

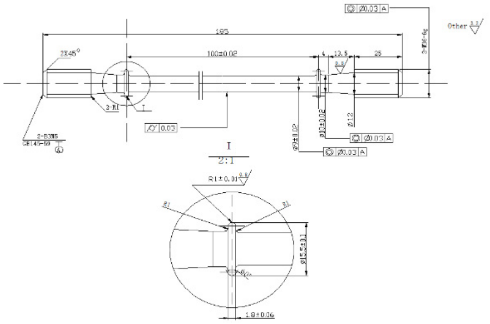

Fig. 2. Configuration and dimension of the creep specimen.

3. Results and discussion

3.1. Results of creep tests

The creep curves of P91/GTR-2CM/12Cr1MoV dissimilar joint at 550 ºC and 570 ºC are given in Fig. 3 with various loads. It can be observed that the creep strain vs time curves have the three typical stages, i.e. are primary, secondary and tertiary stages. The primary regions are very short with decreasing creep rate under the test conditions of varying temperatures and stresses. The secondary creep, also called as steady state creep, is of constant creep speed and takes the longest time of the creep process. In the tertiary stage, the creep rate increases until the final fracture occurs.

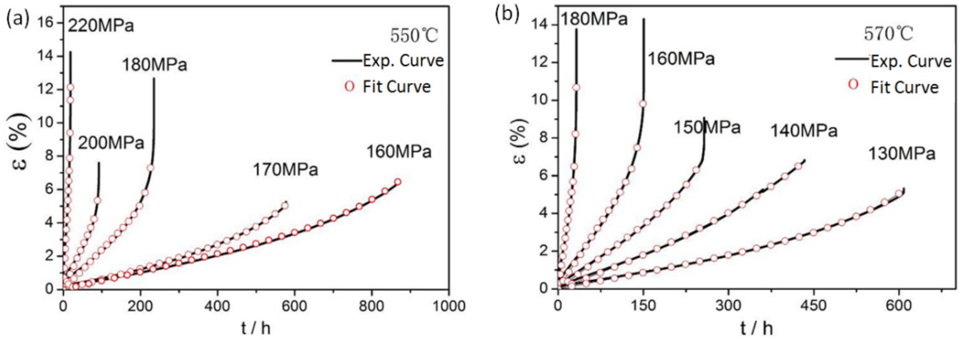

Fig. 3 Creep curves of P91/GTR-2CM/12Cr1MoV dissimilar weld joint: (a) at 550 ºC; (b) at 570 ºC.

The rupture time and minimum creep rate obtained from the cross weld specimen tests are presented in Table 2. As the decreasing of tested stress, the minimum creep rate decreases while rupture time increases under the same temperature. On the other hand, the minimum creep rate increases while rupture time decreases as the increasing of temperature under the same stress.

Table 2 Creep test results of P91/GTR-2CM/12Cr1MoVdissimilar weld joint.

Temperature T/ ºC	Stresses σ/MPa	Rupture time τ/h	Minimum creep rate (10^{-3} h^{-1})
550	220	18.54	301.5
	200	92.08	81.75
	180	234.93	22.17
	170	577.63	11.54
	160	844.12	5.67
570	180	32.09	251.7
	160	150.78	54.39
	150	256.88	25.28
	140	433.53	11.75
	130	608.32	5.46

3.2. Results predicted by Omega method

Omega method [4] was proposed for predicting rupture life using creep strain vs time curves without the primary and secondary regimes. This method was based on linear relation between logarithm of creep strain rate ($\dot{\varepsilon}$) and strain (ε). Their relationship, which is irrespective of stress and temperature, is well expressed by the following equation:

$$ln\dot{\varepsilon} = ln\,\dot{\varepsilon}_o + \Omega\varepsilon \tag{1}$$

where $\acute{\varepsilon}_0$ is initial creep strain rate. When the primary creep region is small, $\acute{\varepsilon}_0$ is very close to the minimum creep rate $\acute{\varepsilon}_{\text{min}}$. Ω is the strain rate acceleration factor, which can be defined as equation (2).

$$dln\left(\dot{\varepsilon}\right) / d\varepsilon = \Omega \tag{2}$$

The initial strain rate ($\acute{\varepsilon}_0$) and Omega (Ω) value are dependent upon stress and temperature, and they can be expressed by the power creep law as shown in equations (3) and (4), respectively.

$$\dot{\varepsilon}_0 = A_0\sigma^{n_0} exp\left(-\frac{Q_0}{RT}\right) \tag{3}$$

$$\Omega = A_\Omega\sigma^{n_\Omega} exp\left(-\frac{Q_\Omega}{RT}\right) \tag{4}$$

where A_0, A_Ω are stress coefficients, n_0, n_Ω are stress exponents, and Q_0 is the apparent activation energy, Q_Ω is a value indicating the temperature dependence of Ω.

Equation (1) is integrated into a function containing strain and time, which is shown as follows:

$$t = \frac{1}{\Omega\dot{\varepsilon}_0}\left(1 - e^{-\Omega\cdot\varepsilon_c}\right) \tag{5}$$

Thus, the creep rupture life and creep strain can be respectively expressed by the following equations (6) and (7):

$$t_f = \frac{1}{\Omega\dot{\varepsilon}_o} \tag{6}$$

$$\varepsilon = \left(1/\Omega\right) ln\left(1 - \left(1 - \frac{t}{t_f}\right)\right) \tag{7}$$

In summary, creep strain *vs.* time curves at a given stress and temperature can be expressed using only two coefficients, which are $\acute{\varepsilon}_0$ and Ω. Values of $\acute{\varepsilon}_0$ and Ω can be obtained through plotting the natural logarithm of creep strain rate *vs.* creep strain curves. The slope of line is Ω and the intercept is $\acute{\varepsilon}_0$, and their values under varying temperatures and stresses are shown in Table 3. In addition, the predicted creep rupture life using equation (6) are also shown in this Table.

It can be seen that the magnitude of the Ω value increases with the decreasing of both stress and temperature, which is in corresponding to the descriptions by Ohgeon *et al* [8]. On the other hand, the predicted rupture times become much more close to the actual values, as the decreasing of stress. For example, the error is 12.7 % at stress of 160 MPa and is up to 75.4 % at 220 MPa under the same tested temperature of 550 °C. Thus, it can be concluded that Omega method is more accurate in predicting rupture time at lower stress level. It is also believed that more accurate predictions can be made especially at lower temperature, *i.e.* the error is 25.3 % under the temperature of 550 °C and is up to 47.1 % under 570 °C when tested at the same stress level 180 MPa.

Table 3 $\acute{\varepsilon}_0$ and Ω obtained from creep tests, and the comparison between predicted and actual rupture time.

Temperature *T*/ ºC	Stress *σ*/MPa	$\acute{\varepsilon}_0$	Ω	Predicted rupture time *t*/h	Actual rupture time *t*/h	Error %
550	220	1.88×10-3	16.34	32.51	18.54	75.4
	200	4.36×10-4	16.81	136.26	92.08	48.0
	180	1.97×10-4	17.24	294.35	234.93	25.3
	170	7.87×10-5	18.16	669.70	577.63	15.9
	160	4.97×10-5	20.54	978.67	868.12	12.7
570	180	3.09×10-4	16.63	194.34	132.09	47.1
	160	2.92×10-4	17.11	200.06	150.78	32.7
	150	1.76×10-4	17.52	324.22	256.89	26.2
	140	9.92×10-5	20.03	502.81	433.53	16.0
	130	7.09×10-5	20.81	677.41	608.32	11.4

4. Conclusions

In this paper, creep tests were conducted on the P91/GTR-2CM/12Cr1MoV dissimilar joint under 550 and 570 ºC at different stress levels. The magnitudes of actual rupture time had been compared with the predicted results using Omega method. Some conclusions can be obtained as follows:

(1) Typical creep curves can be observed under varying temperatures and stresses. The primary region is very short with decreasing creep rate, the secondary region is of constant creep speed and takes the longest time of the creep process, and the creep rate increases until the final fracture in the tertiary stage.

(2) Omega method can be used to predict the rupture life of the dissimilar joint under different conditions. This method becomes much more accurate as the decreasing of stress and temperature, which is in close relationship with the Ω value variations.

Acknowledgements

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