

High-temperature Creep Behavior of 12Cr1MoVG Steel

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Abstract. Heat-resistant steels are key materials for the construction of boilers and high-temperature pipes. Herein, high-temperature creep behavior of 12Cr1MoVG steel has been studied. Creep tests over a long period of time were carried out for 12Cr1MoVG steel samples at varied temperatures. The activation energy for the creep of 12Cr1MoVG steel was evaluated based on the changes of creep rate with temperature when the steel was subject to various stresses. The creep mechanism of the steel has been elucidated by analyzing the relations between the minimum creep rate and the stress. In addition, continuum damage mechanics (CDM) model-based calculation agree well with the strain versus creep time curves obtained from the creep tests. The creep behavior of the 12Cr1MoVG steel at high temperatures has been perfectly described by means of long-time creep tests and mathematical modelling.

1. Introduction

Ultra-super critical (USC) power plants have been developing rapidly due to urgent demands for clean energy and global environment protection [1]. Heat-resistant steels are frequently used for fabricating high-temperature boilers in USC power plants [2, 3]. 12Cr1MoVG steel is a class of high-performance steels frequently used for structural components in boilers. The environment in which the steel works is always harsh. Therefore, a sound understanding of creep behavior of the 12Cr1MoVG steel at high temperatures is fairly important for safe and economical operations of power plants [4, 5]. In this study, the high-temperature creep behavior of the 12Cr1MoVG steel was investigated by creep experiments at selected temperatures and stresses in combination with continuum damage mechanics (CDM) modeling [6]. The creep activation energy of the steel was estimated, and the relevant mechanism of creep was also elucidated.

2. Experimental

2.1. Materials

The 12Cr1MoVG steel samples studied were provided by a power station. The elementary composition was measured using an Optical Emission Spectrometer (ARL 4460, Thermo Scientific). The results are listed in Table 1.

Table 1. Chemical composition of 12Cr1MoVG steel (at. %)

C	Si	Mn	Cr	Mo	V	P	S
0.106	0.255	0.451	1.107	0.286	0.187	0.021	0.012



2.2. Creep Tests

Tensile creep tests at various temperatures were carried out on an electronic high temperature creep & rupture testing machine (GWT2105, MTS) with predetermined loads to examine the creep behavior, using rectangular specimen with the size of 50*15*3 mm.

3. Results and Discussion

3.1. Creep Activation Energy

Creep activation energy plays pivotal roles in the study of creep behavior of materials at high temperatures [7]. Arrhenius equation is often used to calculate the creep activation energy. For most steel materials, Arrhenius equation can be expressed as:

$$\dot{\epsilon}_m = A\sigma^n \exp [-Q_c/(RT)] \quad (1)$$

Where $\dot{\epsilon}_m$ denotes the minimum creep rate; A is a material-dependent constant; σ represents the applied stress (MPa); n is the stress exponent; Q_c is the creep activation energy (kJ/mol); R is the gas constant; T is the absolute temperature (K).

If a constant stress is applied, the creep activation energy can be calculated using the equation as follows:

$$Q_c = -R[\partial \ln \dot{\epsilon}_m / \partial (1/T)]_\sigma \quad (2)$$

The $\dot{\epsilon}_m$ of 12Cr1MoVG steel can be determined from creep tests under different conditions (changing temperature and stress), where by the creep activation energy was calculated. The results under appropriate conditions are shown in Table 2.

Table 2. Values of Creep Activation Energy for 12Cr1MoVG Steel at Different Temperatures and Stresses

T (°C)	σ (MPa)					
	200	180	160	130	100	80
500-550	815.4	745.6	666.0	580.2	--	--
550-600	--	749.2	685.3	599.7	534.8	--
600-650	--	--	--	616.4	557.5	465.9

In many cases, creep activation energy equals self-diffusion activation energy, as the creep rate is dominated by climbing of dislocations. For most of the heat-resistant alloys, however, such relation does not apply. From Table 2, it can be seen that the creep activation energy increased with reduced enhanced temperature at the same stress level. When the temperature kept constant, the creep activation energy decreased with reduced stress. These results demonstrate the complex creep behavior characteristic of heat-resistant steels. Besides, the following equation is obtained by deriving the equation (1):

$$n = (\partial \ln \dot{\epsilon}_m / \partial \ln \sigma)_T \quad (3)$$

The n value indicates the sensitivity of the material to the applied stress. In the next section, the creep mechanism related to the stress exponent n will be discussed.

3.2. Creep Mechanism

For steel materials strengthened by second-phase particles, the double logarithmic plots of minimum creep rate versus stress can be divided into three regions on the basis of the stress exponent n value [8], which has been defined by the above-mentioned equation (3). It was reported that the n value is near 1 at low stress levels and relatively high temperatures [9]. As the stress grows, the n exceeds 1, and the glide of dislocations dominates the creep [10]. This region is named “power-law-breakdown” (PLB) region where the second-phase particles are bypassed by the Orowan mechanism with n value larger than 7.

The changes of the minimum creep rate with the stress at different temperatures are shown in Figure 1. The experimental data were linearly fit well in the whole stress range. The stress exponent n increased with decreasing temperature. At each temperature, the n value kept constant despite the changes of stress, the decrease in the n value was not attributed to the breakdown of creep strength. Furthermore, the n values were larger than 7 in all the cases, implying that the Orowan mechanism accounts for the by-pass of second-phase particles.

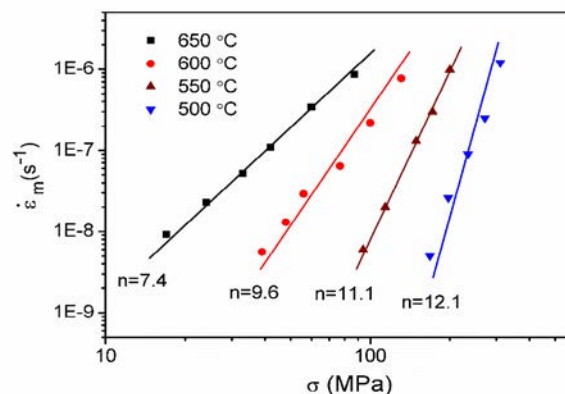


Figure 1. Minimum Creep Rate Versus Applied Stress for 12Cr1MoVG Steel at Different Temperatures. The data is linearly fitted and the n values represent the slopes of the fitting lines.

3.3. Strain-creep Time Analysis

The creep curves from the experiments as well as the predicted creep curves by CDM modeling for the 12Cr1MoVG steel under selected testing conditions are demonstrated in Figure 2. A primary creep region can be clearly observed for both experimental curves. Beyond 15000 h, the strain increased more rapidly for both curves. In the data range, the steel sample measured at 200 MPa and 550 °C exhibited larger strains. The creep curves obtained by CDM modeling were in good accordance with the experimental creep data in both cases, showing the high applicability of the CDM model for describing the creep behavior and predicting the creep life of the 12Cr1MoVG steel.

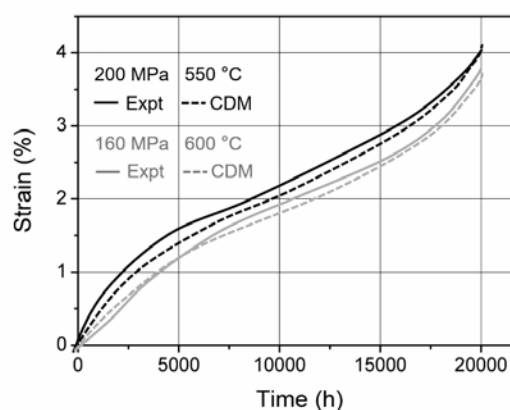


Figure 2. Experimental and CDM Prediction Creep Curves for 12Cr1MoVG Steel under two Testing Conditions

4. Conclusions

To sum up, the high-temperature creep behavior of 12Cr1MoVG steel has been studied. The creep activation energy has been estimated by analyzing the data of creep tests, the results of which show

typical creep behavior of a heat-resistant steel. The creep mechanism of the steel proves to be the Orowan mechanism by which dislocations pass by the second-phase particles. Finally, the CDM model has been found to agree well with the experimental creep curves of the 12Cr1MoVG steel over a period of 20000 h, indicating that the CDM model is suitable for describing the creep behavior and predicting the creep life of the 12Cr1MoVG steel.

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6. References

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