Creep Properties of 12Cr1MoVG Material at High Temperatures

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Abstract. Heat-resistant steels play a pivotal role in the construction of boilers and high-temperature pipes. Herein, the creep properties of 12Cr1MoVG steel at high temperatures have been studied. Creep tests at high temperatures over a 20000 h period were done for 12Cr1MoVG steel samples. Creep curves were examined to unveil the creep properties of the 12Cr1MoVG steel. Moreover, Manson-Haferd model (M-H model) was chosen to study the creep behavior, whose results showed that the model prediction data were in perfect accordance with those from creep experiments. This work provides a new perspective for modeling and evaluation of long-lasting creep properties under the condition of high temperatures.

1. Introduction
Heat-resistant steels with superior resistance to hot corrosion are key materials for smooth operation of modern power plants [1, 2]. 12Cr1MoVG steel is frequently used for critical components of power plants that operate at the temperatures of 500–600 °C. The environment in which the steel works is usually harsh. Therefore, a sound understanding of creep properties of the 12Cr1MoVG steel at high temperatures is significantly meaningful for smooth and efficient operations of power plants [3, 4]. In this study, 12Cr1MoVG steel samples were obtained from a new boiler of a power station. On the basis of the data from the creep tests, the creep properties of the 12Cr1MoVG steel were investigated. In addition, we managed to predict the creep life of the steel in service by Manson-Haferd (M-H) modeling.

2. Experimental
2.1. Materials
The 12Cr1MoVG steel samples studied herein were provided by a power station. The elementary composition was measured by an ARL 4460 Optical Emission Spectrometer (Thermo Scientific, US). Table 1 shows the results.

| Table 1. Elementary composition of the 12Cr1MoVG samples (at %). |
|------------------|---|---|---|---|---|---|---|
| C | Si | Mn | Cr | Mo | V | P | S  |
| 0.108 | 0.254 | 0.451 | 1.111 | 0.289 | 0.186 | 0.021 | 0.013 |
2.2. Creep Tests
At various temperatures, creep experiments for the 12Cr1MoVG steel samples were done on a GWT2105 electronic high temperature creep and rupture testing machine (MTS, US) with fixed loads to examine creep behavior, using 50*15*3 mm rectangular specimen.

3. Results and Discussion

3.1. Mechanisms of Creep
We have plotted the changes of creep rate with time and strain at 550 °C under conditions of various stresses applied, as shown in Figure 1. The initial creep rate decreased with prolonged time and strain to a minimum in the primary (transient) creep region. When the applied stress was 100 MPa or 130 MPa, secondary (steady-state) creep region in which the creep rate kept almost unchanged was observed right after the transient creep region. The creep rate then grew remarkably with increasing strain and time, characteristic of tertiary (accelerated) creep [5]. As the stress applied was beyond 130 MPa (160 MPa and 180 MPa), by contrast, steady-state creep could hardly be identified, and the creep rate increased rapidly immediately after achieving the minimal value. Increasing the stress seemed to decrease the steady-state creep region and made the accelerated creep region occur earlier. It was also found that the creep behavior in short-term region differed significantly from that in long-term region.

When the stress was enhanced from 100 MPa to 180 MPa, the minimal creep rate increased from ca. $10^{-8}$ s$^{-1}$ to ca. $10^{-6}$ s$^{-1}$, as can be seen in figure 1a. The time to rupture decreased with the increase of applied stress. In figure 1b, we found that the strains where the creep properties changed depended little on the stress when the stress lay between 130 MPa to 180 MPa. In all the cases, the primary creep region was limited below the strain of 3%. At the strains beyond 3%, the 12Cr1MoVG steel went into the tertiary creep region. Additionally, the ductility of the steel samples in the long-time region reduced as the stress decreased.

![Figure 1](image-url)

**Figure 1.** Changes of creep rate with time (a) and with strain (b) at 550 °C and varied stresses.

3.2. Manson-Haferd Model
M-H model has proved a powerful tool for predicting the life of high-chromium steels [6]. For the 12Cr1MoVG steel studied in this work, it is also expected as an effective model in assessing the creep rupture life. The description of M-H model can be achieved by the equation as follows:

$$P_{MH}(\sigma) = (\lg t_r - \lg t_a)/(T - T_a)$$

in which $\sigma$ denotes the stress applied during the creep; $T_a$ and $\lg t_a$ are parameters characteristic of the model. A linear relationship between T and $\lg t_c$ can be found when a fixed $\sigma$ is applied. It is critical to gain the optimal values of T and $\lg t_c$ in order to predict the creep rupture life. Herein, the T and $\lg t_c$ could
be calculated through determining the point having the shortest distance from the isostress lines. The equation used for calculation is as follows:

\[
d = \min \left( \sum_{i=1}^{g} (a_i x_i + b_i y_i + c_i) / \sqrt{a_i^2 + b_i^2} \right)
\]

(2)

in which \(d\) denotes the distance between the most suitable point and the isostress lines; \((x, y)\) represents the most suitable point; The coefficients describing the isostress lines include \(a_i, b_i\) and \(c_i\). We limited the \(x\) and \(y\) values in a certain range. The software MatLab was utilized to construct the model. Table 2 shows the optimal values of the parameters.

| Table 2. Parameters for the M-H model. |
|----------------------------------------|
| \(a_0\) | \(a_1\) | \(a_2\) | \(a_3\) | \(\text{lg}T_a\) | \(T_a\) |
|--------|--------|--------|--------|----------------|--------|
| 0.2458 | -0.5002 | 0.2793 | -0.06402 | 13.90          | 705.38 |

3.3. Creep Curves

The creep stress was recorded over a period of 20000 h and was plotted against creep time at different temperatures, as depicted in figure 2. On the other hand, the theoretical prediction curves based on M-H model are also shown in figure 2. With the increase of temperature, the stress decreased, as expected. It was found that the experimental creep data were perfectly fitted by the M-H curves at all the applied temperatures, demonstrating that the M-H model is suitable for describing the creep properties of 12Cr1MoVG steels at high-temperatures.

![Figure 2. Stress versus creep time (scatter) data and the M-H prediction data (curve) for the 12Cr1MoVG steel at different temperatures.](image)

4. Conclusions

In summary, the creep properties of 12Cr1MoVG steel at high temperatures have been investigated. Creep tests over a 20000 h period were carried out at several temperatures, whose results uncovered the creep behavior characteristic of the 12Cr1MoVG steel. M-H model was adopted to evaluate the creep life. The stress versus creep time data were in good accordance with the M-H modeling. Therefore, the M-H model is useful for simulating and predicting the creep properties of the 12Cr1MoVG steel at elevated temperatures.
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