Experimental Investigation of Creep Behaviour of 35CrMo Steel at High-temperature

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Abstract. The creep behaviour of 35CrMo steel have been investigated by high temperature creep experiments. It shows that the steady-state creep rate of 35CrMo steel under 450℃ (400 MPa, 450 MPa, 500 MPa), 500℃ (400 MPa, 450 MPa, 500 MPa) are 8.3980×10^{-5} h^{-1}, 1.2223×10^{-4} h^{-1}, 1.5749×10^{-4} h^{-1}, 6.2995×10^{-4} h^{-1}, 9.7457×10^{-4} h^{-1}, 1.1975×10^{-3} h-1, respectively. The stress index of 35CrMo steel during creep is 2.8599. And the apparent activation energy of 35CrMo steel is 189.57 kJ/mol. The results of this study can provide some technical references for the safety management of 35CrMo steel at high-temperature.

Keywords: 35CrMo steel; creep rate; stress index; apparent activation energy.

1. Introduction

35CrMo steel is a kind of medium carbon low-alloy structural steel. It has high creep resistance and strong rupture strength at high temperature. It can be used under 500 ℃ for a long time. At the same time, 35CrMo steel has large fatigue limit, high static load strength, and good resistance to impact load. So it is often used to make parts endure impact resistance, bending resistance and high load. 35CrMo steel is widely used in machinery manufacturing, vehicle assembly, mining and other industries [1].

In view of the mechanical properties such as room temperature strength, corrosion resistance and thermal strength of 35CrMo steel, the current research is relatively thorough and many beneficial results have been obtained. However, there are few reports on the performance changes of 35CrMo steel at high temperature, especially the creep behaviour under high temperature and high stress. Creep is one of the important factors that affect its high temperature safety and lifetime. Therefore, it is of great practical significance to study the creep behaviour of 35CrMo steel at high temperature.

In this paper, the creep behaviour of 35CrMo steel at high temperature are studied by means of high temperature creep test method, in order to obtain the creep performance parameters (long-term mechanical properties) under different working conditions. It can provide certain technical reference for the safety management of the material.

2. 35CrMo steel

The chemical composition and room temperature mechanical property parameters of 35CrMo steel are shown in Table 1 and table 2 respectively [1 ~ 3].

Table 1. Composition of 35CrMo steel (m%)

C	Si	Mn	S	P	Cr	Ni	Cu	Mo
0.32~ 0.4	0.17~ 0.37	0.40~ 0.70	≤ 0.035	≤ 0.035	0.08~ 1.10	≤ 0.030	≤ 0.30	0.15~ 0.25

Table 2. Mechanical properties of 35CrMo under room temperature

Steel	Tensile Strength σ_b/MPa	Yield Strength σ_s/MPa	Elongation δ_5/%	Reduction of area ψ/%	Impact Energy A_{KU2}/J
35CrMo	≥980	≥835	12	45	63

3. Experiments

In this paper, the high temperature creep tests of 35CrMo steel are conducted by using the RPL50-type high temperature electronic creep-fatigue testing machine produced by Sinotest Equipment Co., Ltd. The accuracy grade of the test machine is 0.5, the maximum loading capacity is 50 kN, and the measurement error is ±0.5% of the indicated values. The temperature range of high-temperature atmosphere furnace is 300 ℃ ~ 1100 ℃, and the measurement error is within ±2℃. This test machine can be subjected to creep tests, relaxation tests, as well as complex tests such as draw-compression fatigue, low cycle fatigue and creep-fatigue.

The specimen of high temperature creep should meet the requirements of standard GB/T 2039-2012 [4]. The specimen drawing is shown in figure 1. The gauge distance and diameter of creep specimen are 100 mm and 10 mm, respectively. During the tests, the specimens should be protected to avoid smudge, corrosion or mechanical damage.

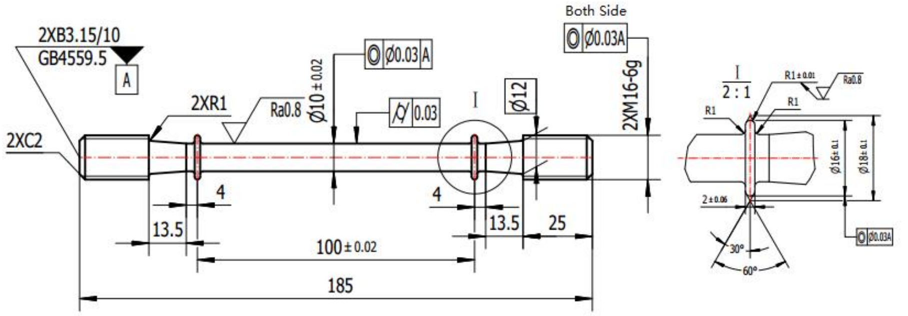

Figure 1. Sketch of the high temperature creep specimen

According to the design characteristics of the testing machine, each specimen should be subjected preload 0.5 kN at the right beginning of testing. The actual load of each specimen is subjected by slope mode, and the loading rate is 8.5 kN/min.

The loading conditions of these specimens are sorted into six group, 450℃(400MPa, 450MPa, 500MPa)、500℃(400MPa, 450MPa, 500MPa). There are more than five standard specimens for each loading condition.

4. Results

The creep curves of 35CrMo steel under various working conditions are shown in figure 2. The curves accord with the typical creep law of metal materials. Due to the limited test time, the curve only presents the first and second stages of creep, and the slope of the second stage of the creep curve is just the steady-state creep rate of the material under specific conditions. It can be seen from the figure that with the increase of temperature, the steady creep rate of the second stage increases obviously, that is, the creep curve is steeper.

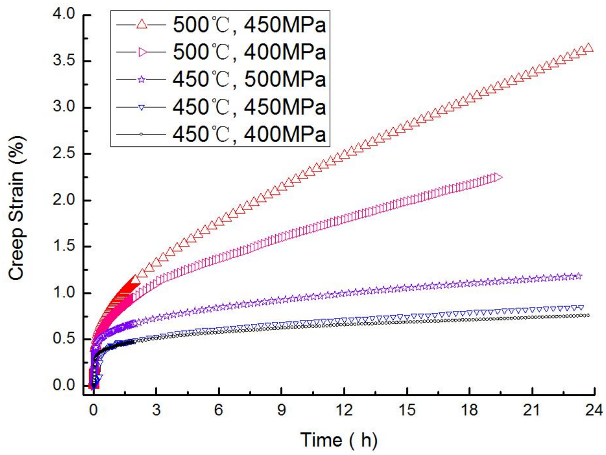

Figure 2. Creep curves of 35CrMo specimen under several loading conditions

The steady-state creep rate of 35CrMo steel under each loading condition is obtained by the average of creep rates of specimen extracted from each testing. And the steady-state creep rate under different loading conditions are shown in table 3.

Table 3. The steady-state creep rates of 35CrMo under various loading conditions

Conditions	400 MPa	450 MPa	500 MPa
500 ℃	6.2995×10^{-4} /h^{-1}	9.7457×10^{-4} /h^{-1}	1.1975×10^{-3} /h^{-1}
450 ℃	8.3980×10^{-5} /h^{-1}	1.2223×10^{-4} /h^{-1}	1.5749×10^{-4} /h^{-1}

It is shown that the steady-state creep rate of 35CrMo steel increases as the increase of temperature under certain stress loading, and increases as the increase of stress under certain temperature.

5. Discussion

A large number of theoretical and experimental studies have shown that the steady-state creep rate, during the second stage, meet the following power index constitution equation [5, 6].

$$\dot{\varepsilon}_c = A\sigma^n e^{-\frac{Q_c}{RT}} \qquad (1)$$

Where, σ is the applied stress, n is the stress index of material, A is the parameters related to the material microstructure, Q_c is the apparent creep activation energy of the material, R=$8.314\,J/(mol\cdot K)$ is the gas constant, T is the thermodynamic temperature.

For equation (1), take the natural log of both sides, and get equation (2)

$$ln(\dot{\varepsilon}_c) = lnA + nln\sigma - \frac{Q_c}{R}\frac{1}{T} \qquad (2)$$

By drawing the data gained from equation (2), and setting $ln\sigma$ as abscissa, $ln(\dot{\varepsilon}_c)$ as ordinate, respectively, the slope is just the stress index n. By setting $1/T$ as abscissa, $ln(\dot{\varepsilon}_c)$ as ordinate, respectively, the slope is just $-Q_c/R$, and the apparent creep activation energy can be gained.

5.1 Stress index of 35CrMo steel

The drawing of relationship between $ln\sigma$ and $ln\dot{\varepsilon}$ of 35CrMo steel is shown in figure 3. The slopes at 723K, 773K are 2.8250, 2.89481, respectively. The average value is 2.8599. The creep stress index of 35CrMo is 2.8599.

The stress index of 35CrMo steel is less than 5, which indicates that 35CrMo steel is more resistant to high temperature creep than pure metal or ordinary low carbon steel [5]. Because, at the same temperature, the smaller the stress index is, the higher the load stress is needed to achieve the same steady-state creep rate, that is, the higher the high-temperature creep resistance is, so that the endurance strength of the high-temperature operation is more durable.

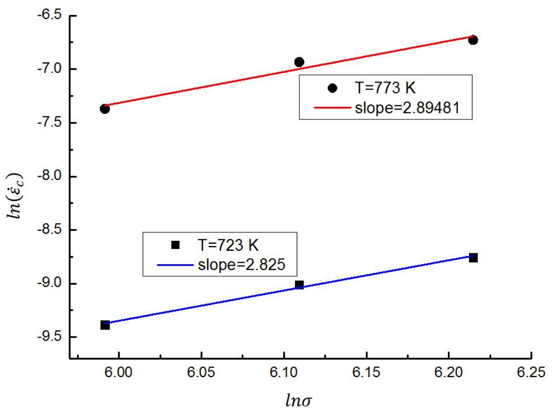

Figure 3. The relationship between $ln\sigma$ and $ln\dot{\varepsilon}$

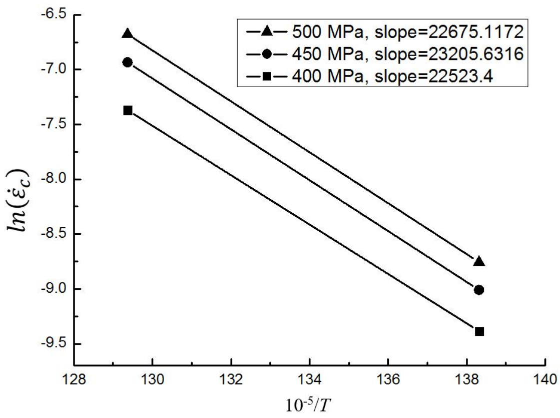

Figure 4. The relationship between $1/T$ and $ln\dot{\varepsilon}$

5.2 Apparent creep activation energy of 35CrMo steel

The drawing of relationship of between $1/T$ and $ln\dot{\varepsilon}$ of 35CrMo steel is shown in figure 4. The slopes at 400MPa, 450MPa, 500MPa are -22523.4, -23205.6316, -22675.1172, respectively. And the average of them is -22801.38. Thus the apparent creep activation energy of 35CrMo steel is 189.57 kJ/mol.

5.3 Evaluation of creep lifetime

A large number of high temperature creep experiments have shown that the relationship between the creep fracture lifetime and the steady-state creep rate meets the following equation [5].

$$\dot{\varepsilon}_c t_f = C$$

Where, C is the material constant independent of temperature and stress.

All the testing of specimens in this paper have not last until the creep fracture due to the time limits. More 35CrMo steel specimens shall be tested in the future. The constant C can be obtained once all specimens testing last to the fracture. Then, the creep lifetime of 35CrMo steel under various loading conditions can be evaluated.

Creep testing under more operation conditions will be performed subsequently. And the short-term mechanical properties and microstructure after creep condition will be analyzed, in order to obtain more comprehensive properties degradation of 35CrMo steel under high temperature operation conditions, helpful to the safety management of 35CrMo steel.

6. Conclusion

In this paper, the creep behaviour of 35CrMo steel have been investigated by high temperature creep experiments. The results show that the steady-state creep rates of 35CrMo steel under 450°C(400 MPa, 450 MPa, 500 MPa), 500°C(400 MPa, 450 MPa, 500 MPa) conditions are 8.3980×10^{-5} h^{-1}, 1.2223×10^{-4} h^{-1}, 1.5749×10^{-4} h^{-1}, 6.2995×10^{-4} h^{-1}, 9.7457×10^{-4} h^{-1}, 1.1975×10^{-3} h^{-1}, respectively. The stress index of 35CrMo steel is 2.8599. And the apparent activation energy of 35CrMo steel is 189.57 kJ/mol. The results can provide some technical references for the safety management of 35CrMo steel at high-temperature.

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References

[1] Yuanchun Huang, Sanxing Wang, Zhengbing Xiao, et al. Microstructure of 35CrMo steel after high temperature compression deformation under different conditions, Materials for Mechanical Engineering, 2017, 41(06): 84-89.

[2] Benguo Zhang, Jian Zhao, Jiansheng Xia, et al. Fracture reason of 35CrMo steel bolt during reducing diameter, Materials for Mechanical Engineering, 2017, 41(06): 95-98.

[3] Siyu Zhang. The Latest Practical Manual for Quick Search of Metal Material Brands, Properties, Uses and Domestic and Foreign Brands, Beijing, China Scientific & Cultural Press, 2005, pp. 328-332.

[4] GB/T 2039-2012 Test method for single axial tensile creep of metal materials, Beijing, China Standard Press, 2012.

[5] Junshan Zhang, High Temperature Deformation and Fracture of Materials, Beijing, China Science Press, 2007, pp. 1-7+282.

[6] Shandong Tu, Structural Integrity Principle under Elevated Temperature, Beijing, China Science Press, 2003, pp. 59-61.