Experimental investigation of high-temperature creep properties parameters in 2520 steel

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Abstract. The creep properties parameters of 2520 steel have been investigated by high temperature creep experiments. It shows that the steady-state creep rate of 2520 steel under 700℃ (150MPa, 170MPa, 180MPa), 725℃ (150MPa, 170MPa, 180MPa), 750℃ (150MPa, 170MPa, 180MPa) are 2.34339×10^-3 h^-1, 2.8203×10^-3 h^-1, 3.0559×10^-3 h^-1, 3.84×10^-3 h^-1, 8.2678×10^-3 h^-1, 1.215×10^-2 h^-1, 3.58376×10^-2 h^-1, 5.23867×10^-2 h^-1, 6.48349×10^-2 h^-1, respectively. The stress index of 2520 steel under 700℃, 725℃, 750℃ are 1.459, 6.2866, 3.216, respectively. And the apparent activation energy of 2520 steel is 478.81 kJ/mol. The results of this study can provide some technical references for the safety management of 2520 steel.

1. Introduction

2520 steel (Grade 06Cr25Ni20, also known as 310S steel) is a kind of high chromium nickel austenite heat-resistant stainless steel [1]. The chemical composition of the composite is based on Cr, Ni and Mo, W, Nb and Ti elements, and other elements are added to obtain the BCC lattice. Therefore, it has excellent corrosion resistance, oxidation resistance and high temperature mechanical properties [2, 3], and its performance is better than 18-8 type stainless steel and zirconium alloy [3~5]. The maximum working temperature of 2520 steel is 1200℃, and the continuous working temperature is 1150℃ [2, 5]. 2520 steel is widely used for pipes, valve bodies, gas turbine blades and other parts under high-temperature, high-pressure, highly corrosive conditions in nuclear power, aerospace, military, petrochemical and other industries [6, 7].

The mechanical properties such as room temperature strength, corrosion resistance and thermal strength of 2520 steel have been studied thoroughly, and many beneficial results have been obtained. However, there are few reports on the performance changes of 2520 steel under high temperature, especially the creep properties under high temperature and high pressure. 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 behavior of 2520 steel at high temperature.

In this paper, the high temperature creep test method is used to study the creep properties of 2520 steel at high temperature, in order to obtain the creep performance parameters under different working conditions. It can provide certain technical reference for the safety management of 2520 steel.
2. 2520 steel
2520 steel is a kind of chromium nickel austenitic heat-resistant stainless steel with excellent corrosion resistance, oxidation resistance and high-temperature mechanical properties. Its chemical composition and room temperature mechanical properties are shown in Table 1 and table 2 respectively [8].

| Table 1. Composition of 2520 steel (m%) |
|------------------|------|-----|-----|-----|     |
| C    | Si  | Mn  | S   | P   | Cr  | Ni  |
| ≤0.08  | ≤1.00  | ≤2.00  | ≤0.030  | ≤0.035  | 24~26  | 19~22  |

| Table 2. Mechanical properties of 2520 steel under room temperature |
|-------------------|-------------------|-------------------|-------------------|
| Steel         | Tensile Strength | Yield Strength | Elongation |
| 2520          | ≥520 MPa           | ≥205 MPa           | ≥40%     | ≥50% |

3. Experiments
In this paper, the high temperature creep tests of 2520 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 [9]. 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.

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 nine group, 700℃ (150MPa, 170MPa, 180MPa), 725℃ (150MPa, 170MPa, 180MPa), 750℃ (150MPa, 170MPa, 180MPa). There are five standard specimens for each loading condition.
4. Results
The creep curves of 2520 steel under five typical 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.

![Creep curves of 2520 steel specimen under five loading conditions](image)

**Figure 2.** Creep curves of 2520 steel specimen under five loading conditions

The steady-state creep rate of 2520 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 is shown in table 3.

| Conditions | 150 MPa  | 170 MPa  | 180 MPa  |
|------------|----------|----------|----------|
| 750°C      | 3.58367×10⁻² h⁻¹ | 5.23867×10⁻² h⁻¹ | 6.48349×10⁻² h⁻¹ |
| 725°C      | 3.84×10⁻³ h⁻¹    | 8.2678×10⁻³ h⁻¹  | 1.215×10⁻² h⁻¹  |
| 700°C      | 2.34339×10⁻³ h⁻¹ | 2.8203×10⁻³ h⁻¹  | 3.0559×10⁻³ h⁻¹  |

It is shown that the steady-state creep rate of 2520 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 [10, 11].

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

Where, \( \sigma \) 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, \( R=8.314 \text{ J/(mol \cdot K)} \) is the gas constant, \( T \) is the thermodynamic temperature.

For equation (1), take the natural log of both sides, and get equation (2)
\[ \ln(\dot{\varepsilon}) = \ln A + n \ln \sigma - \frac{Qc}{R T} \]  

(2)

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

5.1. Stress index of 2520 steel
The drawing of relationship between \( \ln \sigma \) and \( \ln(\dot{\varepsilon}) \) of 2520 steel is shown in figure 3. The slopes at 973k, 998k and 1023k are 1.459, 6.2866 and 3.216, respectively. The results show that the creep stress index of 2520 steel increases first and then decrease with the increase of service temperature. The inflection point of stress index corresponds to the most sensitive temperature point of high temperature creep, which is related to the microstructure of the material. However, the specific temperature of the inflection point of stress index needs to be determined by more detailed experimental analysis.

5.2. Apparent creep activation energy of 2520 steel
The drawing of relationship of between \( 1/T \) and \( \ln(\dot{\varepsilon}) \) of 2520 steel is shown in figure 4. The slopes at 150 MPa, 175 MPa, 200 MPa are -53995.58, -58026, -60751.62, respectively. And the average of them is -57591.07. Thus, the apparent creep activation energy of 2520 steel is 478.81 kJ/mol.

![Figure 3. The relationship between \( \ln \sigma \) and \( \ln(\dot{\varepsilon}) \)]
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 [10].

$$\varepsilon_{sf} = Ct_f = C$$

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

Not all the testing of specimens in this paper last until the creep fracture due to the time limits. More 2520 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 2520 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 2520 steel under high temperature operation conditions, helpful to the safety management of 2520 steel.

6. Conclusion

In this paper, the creep properties parameters of 2520 steel have been investigated by high temperature creep experiments. The results show that the steady-state creep rates of 2520 steel under 700℃ (150MPa, 170MPa, 180MPa), 725℃ (150MPa, 170MPa, 180MPa), 750℃ (150MPa, 170MPa, 180MPa) conditions are $2.34339 \times 10^{-3}$ h$^{-1}$, $2.8203 \times 10^{-3}$ h$^{-1}$, $3.0559 \times 10^{-3}$ h$^{-1}$, $3.84 \times 10^{-3}$ h$^{-1}$, $8.2678 \times 10^{-3}$ h$^{-1}$, 1.215$ \times 10^{-2}$ h$^{-1}$, $3.58376 \times 10^{-2}$ h$^{-1}$, $5.23867 \times 10^{-2}$ h$^{-1}$, $6.48349 \times 10^{-2}$ h$^{-1}$, respectively. The stress index of 2520 steel under 700℃, 725, 750 are 1.459, 6.2866, 3.216, respectively. And the apparent activation energy of 2520 steel is 478.81 kJ/mol. The results can provide some technical references for the safety management of 2520 steel.

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