

Experimental Investigation of Creep Properties Parameters of 10MoWVNb Steel

Hongliang Wu

School of Electromechanical and Architectural Engineering, Jiangnan University,
Wuhan 430056, China

hongliang0913@163.com

Abstract. The creep properties parameters of 10MoWVNb steel have been investigated by high temperature creep experiments. It shows that the steady-state creep rate of 10MoWVNb steel under 175 MPa (400 °C, 450 °C, 500 °C), 200 MPa (400 °C, 450 °C, 500 °C) are $3.60 \times 10^{-5} \text{ h}^{-1}$, $2.17 \times 10^{-4} \text{ h}^{-1}$, $4.57 \times 10^{-3} \text{ h}^{-1}$, $5.59 \times 10^{-5} \text{ h}^{-1}$, $3.34 \times 10^{-4} \text{ h}^{-1}$, $7.02 \times 10^{-3} \text{ h}^{-1}$, respectively. The stress index of 10MoWVNb steel during creep is 3.2474. And the apparent activation energy of 10MoWVNb steel is 198.73 kJ/mol. The results of this study can provide some technical references for the safety management of 10MoWVNb steel.

1. Introduction

10MoWVNb is one kind of low carbon low alloy steel with high resistance to hydrogen, nitrogen, and ammonia corrosion under high temperature, high pressure conditions, which is successfully developed by China [1, 2]. The main development thought of 10MoWVNb was that the right amount of Nb, Mo, W, V addition atoms in steel can form stable carbides with the carbon atoms. And the carbides scattered in the ferritic matrix provide dispersion strengthening effect, thus improve the mechanical properties of steel at room temperature and high temperature and corrosion resistance. The Nb element can simplify the heat treatment process, improve the comprehensive mechanical properties of steel, and cold & hot working and welding performances. While, by controlling the V/C element rate at around 4, V_4C_3 forms which can improve the anti-hydrogen performance at high temperature. Besides fixing the carbon atoms, Mo and W atoms are partially dissolved in ferritic matrix strengthening the solid solution and enhancing the thermal strength and tempering stability of steel. And the probability of generating NbN between Nb and N atoms is very small [2].

The main applications of 10MoWVNb steel are in the areas of synthetic ammonia, partial valve and partial high temperature, high pressure equipment. For example, the main medium in synthesis ammonia tube section are hydrogen, nitrogen, ammonia, which are inflammable, explosive and toxic. Therefore much great emphasis must be on all the steps of design, manufacture, installation, operation and so on. According to the standards of GB 150-2010 and GB 6479, the pipe material in synthetic ammonia shall be 16Mn, while 20# steel was used before. And the operation temperature of waste heat inlet pipes is 350 °C or so. The import stainless steel was used for the waste heat inlet pipes. But since the successful development of 10MoWVNb steel, it is starting use the excellent hydrogen-resistance steel 10MoWVNb from 1984 replace of import stainless steel. The 10MoWVNb steels are usually used for the furnace tube (350 °C) in large chemical fertilizer plant, central or rear waste heat boiler tube (<400 °C) of synthesis



ammonia tower in medium and small nitrogen plant, and satisfactory results have been achieved. 10MoWVNb steel has become the preferred material for waste heat inlet pipeline due to its high resistance to hydrogen, nitrogen, and ammonia corrosion and high thermal strength, which are better than stainless steel [1, 2].

The current researches have been thoroughly studied on the mechanical properties such as room temperature strength, corrosion resistance, and thermal properties, and many beneficial results have been obtained. However, the performance changes of 10MoWVNb steel under high temperature condition, especially the specific creep performance under high temperature and pressure, are less reported. And creep is one of the important factors that affect the safety and lifetime of high temperature high pressure equipment. In this article, the high temperature creep test method are used to study the creep properties of 10MoWVNb steel. And the creep parameters under different conditions will be gained. It can provide certain technical reference for the safety management of 10MoWVNb steel.

2. 10MoWVNb steel

Table 1. Composition of 10MoWVNb steel (*m %*) [2]

C	Si	Mn	Mo	W	V	Nb	P	S
0.07~0.1	0.50~0.8	0.50~0.8	0.60~0.9	0.50~0.9	0.30~0.5	0.06~0.1	≤0.03	≤0.03
3	0	0	0	0	0	2	0	0

Table 2. Mechanical properties of 10MoWVNb under room temperature [2]

Steel	Tensile Strength /MPa	Yield Strength /MPa	Elongation /%	Impact Energy /J
10MoWVNb	461~657	≥289	≥19	78

Table 3. Short term mechanical properties of 10MoWVNb at high temperature [5]

Temperature / °C	29	400	450	500	550	600	650	700
Tensile Strength σ_s /MPa	309	235	211	196	176	167	/	78.4
Yield Strength σ_b /MPa	475	446	412	353	274	250	/	123
Elongation δ_5 /%	36	24	26	28	/	34.5	/	45
Reduction of area ψ /%	79	65.5	72	76.5	/	84.5	/	93.5

10MoWVNb is one kind of low carbon low alloy steel with high resistance to hydrogen, nitrogen, and ammonia corrosion. The chemical composition of 10MoWVNb steel is shown in table 1. The short-term mechanical property parameters at room temperature and high temperature of 10MoWVNb steel are shown in table 2 and table 3, respectively.

3. Experiments

In this paper, the high temperature creep test of 10MoWVNb steel are conducted by using the RPL50-type high temperature electronic creep-fatigue testing machine produced by Changchun Research Institute for Testing Machines. The accuracy grade of the test machine is 0.5, the maximum loading capacity is 50kN, and the measurement error is ±0.5% of the indicated values. The temperature range of high-temperature atmosphere furnace is 300 °C~1100 °C, and the measurement error is within ±2 °C. 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 [6]. The specimen objects and drawings are shown in figure 1 and figure 2, respectively. The gauge distance and diameter of creep specimen are 100mm and 10mm, 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 $0.5kN$ 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, 175 MPa ($400\text{ }^{\circ}\text{C}$, $450\text{ }^{\circ}\text{C}$, and $500\text{ }^{\circ}\text{C}$), 200 MPa ($400\text{ }^{\circ}\text{C}$, $450\text{ }^{\circ}\text{C}$, $500\text{ }^{\circ}\text{C}$). There are five standard specimens for each loading condition.



Figure 1. High temperature creep specimen of 10MoWVNb steel

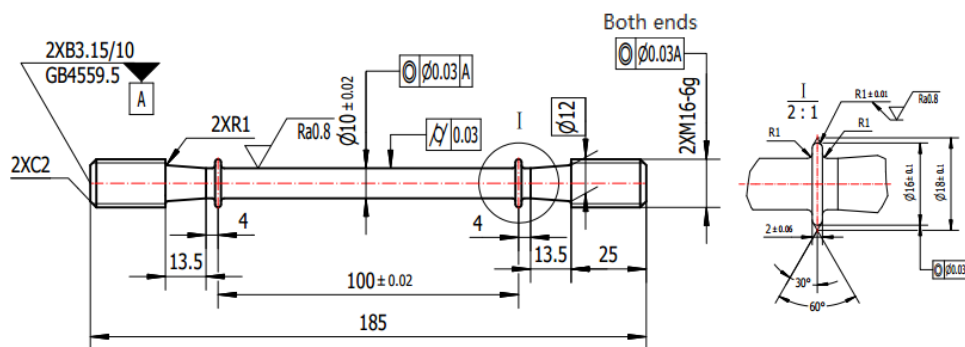


Figure 2. Sketch of the high temperature creep specimen

4. Results

The creep curves of 10MoWVNb specimens under 175 MPa ($450\text{ }^{\circ}\text{C}$, $500\text{ }^{\circ}\text{C}$) are shown in figure 3. These curves conform to the typical creep law in metal materials. As the testing time limited, only the first and second stages of creep are shown. And the slope of curve during the second stage is just the steady-state creep rate of 10MoWVNb steel under certain operation condition. It is shown that the steady-state creep rate increases significantly as the temperature increases, and the curve is steeper at higher temperature.

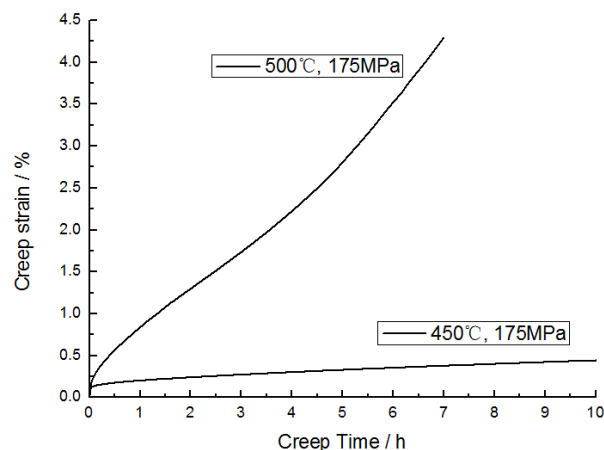


Figure 3. Creep curves of 10MoWVNb specimen under two kinds of loading condition

The steady-state creep rate of 10MoWVNb 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 4.

Table 4. Steady-state creep rates of 10MoWVNb under various loading conditions

	400 °C	450 °C	500 °C
200MPa	$5.59 \times 10^{-5} /h^{-1}$	$3.34 \times 10^{-4} /h^{-1}$	$7.02 \times 10^{-3} /h^{-1}$
175MPa	$3.60 \times 10^{-5} /h^{-1}$	$2.17 \times 10^{-4} /h^{-1}$	$4.57 \times 10^{-3} /h^{-1}$

It is shown that the steady-state creep rate of 10MoWVNb 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 [7, 8].

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

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)

$$\ln(\dot{\epsilon}_c) = \ln A + n \ln \sigma - \frac{Q_c}{R} \frac{1}{T} \quad (2)$$

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

5.1. Stress index of 10MoWVNb steel

The drawing of relationship of between $\ln \sigma$ and $\ln \dot{\epsilon}$ in 10MoWVNb steel is shown in figure 4. The slopes at 673K, 723K, and 773K are 3.2966, 3.2300, and 3.2157, respectively. And the average of them is 3.2474. Thus the stress index of 10MoWVNb steel is 3.2474 under high temperature creep conditions.

The stress index is less than 5, indicating that 10MoWVNb material is more resistant to creep than pure metal and low carbon steel [7]. Because, at the same temperature, the smaller the stress index is, the higher the load stress is required to achieve the same steady-state creep rate, that is, the creep resistance is higher. This is also the original intention of the development of 10MoWVNb steel that its high temperature strength is more durable.

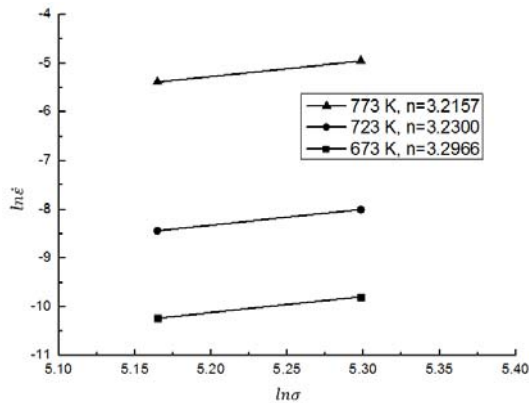


Figure 4. The relationship between $\ln\sigma$ & $\ln\dot{\epsilon}$

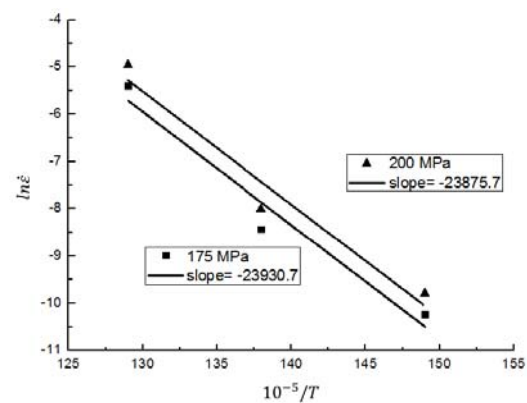


Figure 5. The relationship between $1/T$ & $\ln\dot{\epsilon}$

5.2. Apparent creep activation energy of 10MoWVNb steel

The drawing of relationship of between $1/T$ and $\ln\dot{\epsilon}$ in 10MoWVNb steel is shown in figure 5. The slopes at 175 MPa, 200 MPa are -23930.7, -23875.7, respectively. And the average of them is -23903.2. Thus the apparent creep activation energy of 10MoWVNb steel is 198.73 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 [7].

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

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

The testing of specimens in this paper have not last until the creep fracture due to the time limits. More 10MoWVNb 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 10MoWVNb 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 10MoWVNb steel under high temperature operation conditions, helpful to the safety management of 10MoWVNb steel.

6. Conclusion

In this paper, the creep properties parameters of 10MoWVNb steel, one kind of low carbon low alloy steel with high resistance to hydrogen, nitrogen, and ammonia corrosion, have been investigated by high temperature creep experiments. The results show that the steady-state creep rates of 10MoWVNb steel under 175MPa (400 °C, 450 °C, 500 °C), 200MPa (400 °C, 450 °C, 500 °C) conditions are $3.60 \times 10^{-5} h^{-1}$, $2.17 \times 10^{-4} h^{-1}$, $4.57 \times 10^{-3} h^{-1}$, $5.59 \times 10^{-5} h^{-1}$, $3.34 \times 10^{-4} h^{-1}$, $7.02 \times 10^{-3} h^{-1}$, respectively. The stress index of 10MoWVNb steel during creep is 3.2474. And the apparent activation energy of 10MoWVNb steel is 198.73 kJ/mol. The results can provide some technical references for the safety management of 10MoWVNb steel.

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