Mechanical properties of Grade 91 steel at high temperatures

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Abstract. The tensile and short-term creep rupture properties of Grade 91 steel at high temperatures were investigated. The tensile tests were conducted at room temperature, 565°C and 650°C. The short-term creep tests were conducted at 565°C and 650°C with stress ranging from 125 to 250MPa. The creep rupture life of Grade 91 steel was found to increase with the decreasing of applied stress. The creep rupture morphology was investigated based on the scanning electron microscope analysis.

1. Introduction
Grade 91 steel is widely used in the power plants because of its lower coefficient of thermal expansion and high thermal conductivity. The high temperature mechanical properties, such as tensile and creep rupture properties, are very important to the secure application of material. In the past, some researchers investigated the high temperature mechanical properties of different materials.

Heidarpour et al. [1] investigated the mechanical properties of very high strength steel tubes at elevated temperatures. The results show that the manufacturing process causes a greater reduction in strength at high temperatures. Cai et al. [2] investigated the tensile properties at elevated temperatures and the thermo-physical properties after thermal cycling of Al-50Si alloy. The results show that the tensile strength decreases gradually with the increase of temperature. Hajiloo et al. [3] studied the mechanical properties of glass fibre reinforced polymer bars from different manufacturers at high temperatures. The results show that the strength of glass fibre reinforced polymer bars is influenced by the thermal properties and resin content. Ma et al. [4] reviewed the mechanical properties, physical and chemical changes of concrete at high temperature. The results show that the strength of glass fibre reinforced polymer bars is influenced by the thermal properties and resin content. He et al. [5] studied the microstructure and high temperature mechanical properties of as-cast FeCrAl alloys at temperatures from 700°C to 1200°C. The results show that the occurrence of continuous dynamic recrystallization plays an important role in increasing the hot ductility of FeCrAl alloys. Taherishargh et al. [6] investigated the mechanical properties of expanded perlite-metal syntactic foam at elevated temperatures. The results show that the mechanical properties of the foams at elevated temperatures are influenced by the softening of the matrix material and the improved ductility of the foam.

In this paper, the mechanical properties of Grade 91 steel at elevated temperatures were investigated. The effects of different parameters on the tensile and creep rupture properties were analyzed.

2. Material and Experimental
The hot rolled Grade 91 plates were obtained in normalized and tempered condition with the size of 6720mm*2400mm*85mm. The chemical composition of Grade 91 steel is shown in Table 1.

| Element | C   | Mn  | Si  | Ni  | Cr  | Mo  | Cu  | Al  | S   | Sn  | V   | Nb  | N   | Ti  | Zr  | P   | N/A | Ti  | N/A |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Amount  | 0.10| 0.40| 0.23| 0.13| 8.34| 0.98| 0.06| 0.009| 0.002| 0.005| 0.229| 0.079| 0.044| 0.002| 0.001| 0.0101| 4.9 |

2.1. Tensile test
The geometry and dimensions of tensile test specimen are shown in Fig. 1. The diameter of the test specimen is 5mm. The tensile tests were conducted at room temperature, 565°C and 650°C using the Z250 electronic universal testing machine. The tensile tests refer to GB/T228.1-2010 Metallic materials-tensile testing-part 1: method of test at room temperature and GB/T228.2-2015 Metallic materials-tensile testing-part 2: method of test at elevated temperature.

![Figure 1. Geometry and dimensions of the tensile test specimen.](image)

2.2. Creep test
The geometry and dimensions of uniaxial creep test specimen are shown in Fig. 2. The gauge length and diameter of the test specimen are 100mm and 10mm, respectively. The uniaxial creep tests were conducted at 923K with the stress ranging from 125 to 200MPa using the high temperature creep and stress-rupture testing machines. The creep tests refer to GB/T2039-2002 Metallic material-creep and stress-rupture test in tension.
3. Results and Discussions

3.1. Tensile properties
The tensile properties of Grade 91 steel is shown in Table 2. The yield strength and tensile strength at room temperature provided by the manufacturer are 534MPa and 697MPa, respectively. The test results of this study are in good agreement with these data. The tensile test at 650°C was repeated and the results have a good repeatability.

Table 2 Tensile properties of Grade 91 steel

| Test temperature (°C) | Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) | Reduction (%) |
|-----------------------|----------------------|------------------------|----------------|--------------|
| 650                   | 244.916              | 283.441                | 41.26          | 94.88        |
| 650                   | 250.650              | 289.164                | 36.64          | 94.02        |
| 565                   | 352.757              | 390.226                | 31.04          | 89.47        |
| 25                    | 533.779              | 682.991                | 23.24          | 71.57        |

3.2. Short-term creep properties
The creep strain-time curves of Grade 91 steel at 650°C and 565°C under the stress ranging from 125 to 250MPa are shown in Fig. 3. It can be seen that the curves show typical primary, steady-state and tertiary creep stages. The creep rupture life was found to decrease with the increase of stress level.
Figure 3. Creep strain-time curves of Grade 91 heat-resistant steel at 650 ℃ and 565 ℃.

The fracture morphologies of Grade 91 steel crept at 650 ℃ under stress level of 125MPa are shown in Fig. 4. It can be seen from Fig. 4(a) that the fracture show the typical cup and cone type appearance. This means that Grade 91 steel has good plasticity under this test condition. The size of dimples has little difference as shown in Fig. 4(b).

Figure 4. Fracture morphology crept at 650 ℃ and 125MPa.

The fracture morphologies of Grade 91 steel crept at 565 ℃ under stress level of 250MPa are shown in Fig. 5. It can be seen from Fig. 5(a) that the fracture also show the typical cup and cone type appearance. The dimples have different size as shown in Fig. 5(b) and the maximum diameter is about 50μm.

Figure 5. Fracture morphology crept at 565 ℃ and 250MPa.
4. Conclusion
The tensile and creep rupture properties of Grade 91 steel have been studied by test and scanning electron microscope analysis. The results show that the Grade 91 steel has good plasticity under this test conditions.

References
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