Effect of High Temperature on Mechanical Properties of 13MnNiMoR

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Abstract. 13MnNiMoR is a low-alloy high-strength steel. It is a medium-temperature medium-pressure boiler and pressure vessel steel. It has been used in the manufacture of high-pressure heater, nuclear energy vessels and other high-pressure resistant vessels. In this paper, the mechanical properties of 13MnNiMoR at different temperatures are systematically studied. It is shown that the yield strength of the material decreases with the increase of temperature. The mechanical properties of the material have little difference after 200 °C. The prediction formula of the material in the range of 20–350 °C is obtained by double-fold line, which could be effectively predicted. It is useful to improve the accuracy of the analytical design consequences, and provides a data basis for the revision of subsequent material standards.

1. Introduction
13MnNiMoR is a low-alloy high-strength steel. It is a medium-temperature medium-pressure boiler and pressure vessel steel\textsuperscript{1-6}. It has been used in the manufacture of high-pressure heater, the nuclear energy containers and other high-pressure containers. Compared with traditional container materials, it has high temperature yield strength, excellent crack resistance, good welding and processing properties, etc. which could be provided in broad application prospects. The maximum applied design temperature of 13MnNiMoR under static load is 400 °C in GB 150-2011. With the improvement of smelting process, the material performance is getting better and better, and the performance given in the existing material standard is too conservative to meet the analytical design accuracy requirements. Therefore, in this paper, the mechanical properties of 15NiCuMoNb at different temperatures are studied systematically to improve the performance of the container steel analysis design method. It could be useful to further improve the accuracy of the analysis design and provide the basis for the revision of China’s material standards.
2. Test

2.1. Purpose of the test
The purpose of the experiment is to obtain the mechanical properties and the stress-strain curve of 13MnNiMoR at different temperatures. According to the experimental results, the influence of temperature on the mechanical properties of 13MnNiMoR at different temperatures was analyzed to further judge the static performance and safety of 13MnNiMoR material at high temperatures.

2.2. Process of the test
The high temperature furnace is used to raise the temperature to the specified temperature according to the designed heating rate (20 °C/min), and the temperature is maintained for 30 minutes. The temperature and the heat preservation process test load are 0, which should allow the specimen to expand naturally. Secondly, according to the requirements of GB/T228.2-2015 "Metal material tensile test part 2: high temperature test method", the loading method of the test piece in the steady state test is the same as the loading method of the tensile test piece at normal temperature. The loading rate is 0.1 mm/min until the specimen strain is 2.0 mm during the first stage. The loading rate is 1.0 mm/min during the second stage until the specimen is broken. The constant temperature is always constant during the loading process. The test temperatures were 100 °C, 150 °C, 200 °C, 250 °C, 300 °C, 350 °C. Since the constant temperature time at each temperature point is short, the influence of creep is not fully considered.

2.3. Equipment of the test
The instrument used in the high temperature tensile test is the INSTRON 8801. The measuring device is a high temperature extensometer UTM5305 with 5 Hz sampling frequency and 50 mm measuring range for measuring the tensile strain.

2.4. Speciment of the test
The dimensions of the test piece are in accordance with GB/T 228.1-2010 "Metal material tensile test part 1: Room temperature test method" and GB/T 228.2-2015 "Metal material tensile test part 2: High temperature test method". The design is performed, and the exact dimensions are shown in Fig. 1. In order to avoid the influence of stress concentration, the surface roughness should be as much as possible little, the gauge length of the tensile specimen was polished by 5000# German Warrior sandpaper before the experiment.

![Figure 1 The size of specimen](image)

3. Results
The tensile curves of the materials at different temperatures are shown in Figure 2.
The mechanical properties of the material are shown in Table 1.

Table 1 Mechanical properties of 13MnNiMoR under high temperature conditions

| Serial number | Temperature t, °C | Tensile strength, MPa | Yield strength, MPa |
|---------------|-------------------|-----------------------|---------------------|
| A-1           | 100               | 756                   | 630                 |
| A-2           | 100               | 778                   | 652                 |
| A-3           | 100               | 778                   | 667                 |
| average       |                   | 770.6667              | 649.6666667         |
| B-1           | 150               | 738                   | 611                 |
| B-2           | 150               | 749                   | 622                 |
4. Discussion
Take the average value of yield strength and tensile strength, and plot the yield strength and tensile strength versus temperature of the material. As shown in the figure 1, Both the yield strength and tensile strength of the material appear obviously the downward trend with increasing temperature. But the material properties tend to be stable after 200 °C. It is indicated that the difference of mechanical properties of the materials exceeding 200 °C are not obvious.

As could be seen from the figure 3, the two curves are approximated by two straight lines:

\[
\sigma_y = a_1 + b_1 T \quad (T \leq 200)
\]

\[
\sigma_y = c_1 \quad (200 < T \leq 350)
\]

\[
\sigma_s = a_2 + b_2 T \quad (T \leq 200)
\]

\[
\sigma_s = c_2 \quad (200 < T \leq 350)
\]

After fitting
The formula could be used to predict the mechanical properties of the material in the range of 20–350 °C, and provide data for the analysis and design of the subsequent equipment.

5. Conclusion
In this paper, the mechanical properties of 13MnNiMoR at different temperatures were systematically analyzed. It is demonstrated that the yield strength of the material decreases with the increase of temperature. The mechanical properties of the material have little change after 200 °C. The material obtained by double-fold line is 20–350 °C. The interval material prediction formula could effectively predict the mechanical properties of the material, which is useful to improve the accuracy of the analysis design results and provides a data basis for the revision of subsequent material standards.

Acknowledgments
This study has received funding by Scientific Research Projects of Shanghai Quality and Technical Supervision (2017-32), Youth Project of Shanghai Quality and Technical Supervision Bureau and Shanghai Science and Technology Talents Program (19XD1432600). The authors are grateful for the financial supports provided by Shanghai engineering research center of pressure pipeline intelligent inspection.

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