Analysis of Mechanical Properties of 15NiCuMoNb at Different Temperatures

Du Yannan¹,², Ren Bin¹, Liu Longxian³, Tang Xiaoying¹,², Xue Xiaolong¹,², Zhu Weiping¹, Ouyang Weiping¹

¹ Shanghai Inst. of Special Equip. Inspection & Tech. Res., Putuo, Shanghai, 200062, China
² Shanghai engineering research center of pressure pipeline intelligent inspection, Putuo, Shanghai, 200062, China
³ Petrochina Kunlun Gas of Gansu, Liquefied Natural Gas Company, Lanzhou, Gansu, 730094, China

Abstract. 15NiCuMoNb has good mechanical properties, which is widely used in high-end equipment. However, the performance of existing material standards has been conservative in the past. In this paper the mechanical properties of 15NiCuMoNb at different temperatures are systematically studied. It is shown that the yield strength of the material decreases with the increase of temperature. The decrease tends would be slow after 200 °C, and the tensile strength of the material has similar characteristics. The least square method is used to obtain the prediction formula of the material in the range of 20~350 °C, which could be effectively predicted the mechanical properties of material. It could be useful to improve the accuracy of analytical design results, and provide a data basis for the revision of subsequent material standards.

1. Introduction

15NiCuMoNb steel was first developed by Mannesmann Company of Germany, and Ni-Cu-Mo-Nb alloy elements were added on the basis of carbon-manganese steel. Since alloying elements such as Ni, Cu, Mo, and Nb have the effects of fine grain strengthening and precipitation strengthening, the high temperature strength and the long-lasting strength of the steel species are greatly improved, and the addition of Cu does not lower the permanent plasticity of the steel[1-3]. Therefore, the material has high strength and high yield limit ratio, more than 40% steel yield limit is higher than 20G, and the applied temperature reaches 465 °C, which could be used for the water supply pipeline of the nuclear power unit and the high-parameter thermal power unit, the start-up steam separator, and the water cooling. Medium-temperature and high-voltage components such as pipe headers are the materials of choice for nuclear power plants and high-parameter generator sets. However, with the improvement of the smelting process, the material performance is getting better and better. The performances existing in material standards are too conservative to meet the analytical design accuracy requirements. Therefore, 15NiCuMoNb is used as the research object to study the mechanics of 15NiCuMoNb at different temperatures. It could be helpful to further improve the accuracy of analytical design, and provide a basis for the revision of China’s material standards.
2. Test

2.1. Process of the test
The normal temperature tensile test is loaded by displacement control and loaded in two stages refer to the requirements of GB/T228.1-2010 "Metal material tensile test Part 1: room temperature test method": The first stage loading process is mainly used to measure the initial elastic modulus and the nominal yield strength of materials with a loading rate of 0.6 mm/min. The elastic modulus and strain data are obtained by an extensometer in the gauge length range; The second stage loading process is mainly used to measure the material resistance. The tensile strength was stretched to a fracture rate of the test piece at a loading rate of 5 mm/min, and the elongation of the test piece at break was measured using a vernier caliper.

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 is 0, which allows 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 first stage The loading rate is 0.1 mm/min until the specimen strain is 2.0 mm; the second phase loading rate is 1.0 mm/min, and the specimen is broken until the specimen is broken. The constant temperature is always constant during the loading process. The test temperatures were 20°C, 100 °C, 150 °C, 200 °C, 300 °C, and 350 °C.

2.2. Equipment of the test
The instrument used in the high temperature tensile test is an electronic universal testing machine. The measuring device is a high temperature extensometer UTM5305 for measuring the tensile strain, the sampling frequency is 5 Hz, and the measuring range is 50 mm.

2.3. Speciment of the test
The dimensions of the test piece are refer to 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 carried out, and the specific dimensions are shown in Fig. 1. In order to avoid the influence of stress concentration and 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.
Figure 2. Tensile Curves of Materials at Different Temperatures

The mechanical properties of the material are shown in Table 1.

| Temperature °C | Yield strength MPa | Tensile strength MPa | Temperature °C | Yield strength MPa | Tensile strength MPa |
|----------------|--------------------|----------------------|----------------|--------------------|----------------------|
| 20             | 639                | 790                  | 200            | 562                | 709                  |
| 20             | 624                | 773                  | 200            | 568                | 721                  |
| 20             | 610                | 756                  | 200            | 545                | 679                  |
| 100            | 624                | 756                  | 300            | 549                | 715                  |
| 100            | 594                | 746                  | 300            | 546                | 721                  |
| 100            | 600                | 737                  | 300            | 536                | 728                  |
| 150            | 603                | 731                  | 350            | 522                | 746                  |
| Temperature °C | Yield strength MPa | Tensile strength MPa | Temperature °C | Yield strength MPa | Tensile strength MPa |
|---------------|--------------------|----------------------|---------------|--------------------|---------------------|
| 150           | 594                | 734                  | 350           | 530                | 721                 |
| 150           | 571                | 702                  | 350           | 530                | 721                 |

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 3, the yield strength and tensile strength of the material may appear obviously downward trend with increasing temperature. But the decline in material properties slowed down after reaching 200 °C.

![Figure 3. Yield and tensile strength versus temperature](image)

It is assumed that the yield strength and tensile strength of the material satisfy the following relationship:

\[
\sigma_y = a_1 + b_1 t + c_1 t^2
\]

\[
\sigma_s = a_2 + b_2 t + c_2 t^2
\]

After fitting:

| a₁       | 633.99296 | b₁      | -0.35097 | c₁      | 0.00012308 | R² | 0.95578. |
|----------------|------------|---------|----------|---------|------------|----|----------|
| a₂       | 790.15578 | b₂      | -0.68641 | c₂      | 0.00149    | R² | 0.88254. |

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 15NiCuMoNb at different temperatures are systematically studied. It is shown that the yield strength of the material decreases with the increase of temperature. The tensile strength of the material also has similar characteristics after 200 °C. The material prediction formula of the material range of 20~350 °C is obtained by multiplication, which could effectively predict the mechanical properties of the material. The results contribute to improving the accuracy of the analysis design results and providing 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.

References
[1] Kander L, Matocha K, Sobotka J. Relationships between Microstructural Parameters and Properties of 15NiCuMoNb5 Grade Steel Used for Special Industry Applications[J], Materials Science Forum, 2007, 567-568: 381-384.
[2] Schmauder S, Uhlmann D, Zies G. Experimental and numerical investigations of two material states of the material 15 NiCuMoNb5 (WB 36)[J], Computational Materials Science, 2002, 25(1): 174-192.
[3] Le XB. Research on Heat Treatment of 15NiCuMoNb5-6-4 Steel Pipes [J], Chemical Equipment Technology, 2017, 38(3): 64-66.
[4] Liu YL, Liu JM, Yin XF, et al. Research and Development of 15NiCuMoNb5-6-4 Hot Rolled Seamless Pipe [J], Tianjin Metallurgy, 2010, (5): 13-15.
[5] Qiu KQ, Xu Q. Experimental Research on 15NiCuMoNb5 (WB36) steel for 600MW Supercritical Boiler [J], Boiler Technology, 1992, (10): 5-13.
[6] Yang YQ. Determination And Application Of Welding And Heat Treatment Process For 15NiCuMoNb5 Steel [J], Ningxia Electric Power, 2008, (c00): 188-190.
[7] Zheng ZB, Wang B, Zhang B, et al. Research on Post-weld Heat treatment and Property of Welded Joint of 15NiCuMoNb5-6-4 Steel [J], Hot Working Technology, 2010, 39(23): 208-209.