Mechanical property analysis of stainless steel bolt

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Abstract. Tensile property test, hardness test, chemical composition test, metallographic analysis and solution treatment analysis were carried out for stainless steel bolt. The results show that the Cr content is slightly lower than the requirements of relevant standards, and the tensile properties and hardness meet the requirements. Comparing the microstructure of the original sample with that of the sample after solution treatment, it can be seen that there are a lot of acicular martensite phase in the original sample, and there are a lot of carbide precipitation at the grain boundary, but no carbide precipitation is found at the grain boundary of the sample after solution treatment.

1. Introduction
Bolt connection is simple, replaceable, fatigue resistant, not loose and safe. Special equipment requires higher strength performance of bolts for connection. Ordinary high strength bolts may have stress corrosion and corrosion fatigue in the process of use, which has the risk of sudden brittle fracture and low stress failure. High strength bolts are not resistant to atmospheric corrosion, even if they are phosphated, there will still be serious uniform corrosion, crevice corrosion and other corrosion phenomena. In recent years, more attention has been paid to the study of bolt performance.

Duan et al. [1] studied the microstructure and mechanical properties of GH783 alloy bolts in 1000MW Ultra Supercritical Units aged at 650°C at different aging stages. The results show that the tensile strength and impact toughness of the bolts decrease with the aging time. Bosch et al. [2] studied the cold working performance of 316 stainless steel diaphragm bolts for pressurized-water reactor. The results show that the bolt material is easily affected by irradiation assisted stress corrosion cracking and presents intergranular fracture morphology. Liu et al. [3] studied the tensile properties of aluminum alloy plate bolted connections at room temperature and high temperature, and analyzed the effects of different parameters on bolted connections at high temperature. Ketabdari et al. [4] studied the performance of high strength steel bolt under fire, and put forward the practical calculation formula of ultimate strength, yield strength and elastic modulus. The results show that the relative error based on Gene Expression Programming model is less than 10%. Kodur et al. [5] studied the residual mechanical properties of grade 8.8 bolts at high temperature and evaluated their failure modes. The results show that the carbon content in the steel and the tempering temperature in the bolt production process have significant effects on the residual mechanical properties. Li et al. [6] studied the effect of fiber preform structure on the mechanical properties of C/SiC nuts and bolts, and the failure behavior of threaded joints. The results show that the shear strength of C/SiC nut made of 3K carbon fiber is the highest.

In this paper, the mechanical properties and microstructure of a stainless steel bolt before and after solid solution treatment are tested and analyzed.
2. Material and Experimental
The material of this test is flange bolts connecting valve body and valve stem in supercritical ethylene transmission pipeline, as shown in Figure 1. Relevant documents show that the bolt material is 304 stainless steel.

![Stainless steel bolt](image1)

Figure 1. Stainless steel bolt.

The dimension of tensile specimen is shown in Fig. 2. The gauge distance is 25mm, the length of parallel section is 30mm, and the thread of clamping end is M8. The test equipment is Instron 8800 tensile testing machine. The loading rate is 1mm/min before 2% strain and 1.5mm/min after 2% strain.

![Geometry and dimensions of tensile specimens](image2)

Figure 2. Geometry and dimensions of tensile specimens.

3. Results and Discussions

3.1. Tensile properties
The macro morphology of the specimen after tensile fracture is shown in Fig. 3. It can be seen that the sample shows obvious elongation and necking after breaking, indicating that the plasticity of the bolt is very good.

![Macro morphology of tensile fracture specimens](image3)

Figure 3. Macro morphology of tensile fracture specimens.
The tensile properties of the tested bolts are shown in Table 1. Since the valve is a cryogenic valve, the bolts used in the valve should meet the requirements of cryogenic bolt standard, namely ASTM A320 <Standard Specification for Alloy-Steel and Stainless Steel Bolting Materials for Low-Temperature Service>. It can be seen from the table that the tensile properties of the two test samples of the bolt meet the requirements of the standard.

|          | Yield strength (MPa) | Tensile strength (MPa) | Elongation (%) | Reduction (%) |
|----------|----------------------|------------------------|----------------|---------------|
| No. 1    | 756.19               | 870.12                 | 38.08          | 69.33         |
| No. 2    | 641.28               | 836.20                 | 41.2           | 59.69         |
| ASTM A320 B8 M27 | 450                 | 725                    | ≥20            | ≥35           |

### 3.2. Chemical composition analysis

The chemical composition of the stainless steel bolt is shown in Table 2. The results show that the Cr content of the bolt is 17.09, which is lower than the requirements of 18.0-20.0, and other elements meet the requirements of the specification.

| Element | C   | Mn  | Si  | Ni  | Cr   | S    | P    |
|---------|-----|-----|-----|-----|------|------|------|
| Sample  | 0.068 | 1.15 | 0.42 | 8.24 | 17.09 | 0.005 | 0.032 |
| ASTM A320 B8  | ≤0.08 | ≤2.00 | ≤1.00 | 8.0-11.0 | 18.0-20.0 | ≤0.03 | ≤0.045 |

### 3.3. Microhardness analysis

The hardness of bolt section is tested according to the standard, and the Brinell hardness value of stainless steel bolt is shown in Table 3. The results show that the Brinell hardness of the bolt meets the specification requirements.

| Points | 1   | 2   | 3   |
|--------|-----|-----|-----|
| Sample | 274 | 284 | 286 |
| ASTM A320 | ≤321 |

### 3.4. Microstructure analysis

Fig. 4 shows the metallographic structure of stainless steel bolts. As shown in Fig. 4(a), the grain size grade is 13 after statistical analysis. A large number of needle martensite phases can be seen from Fig. 4(b), and a large amount of carbide precipitates at the grain boundary.

Figure 4. Microstructure of stainless steel bolt section.
The metallographic structure of stainless steel bolt after solution treatment is shown in Fig. 5. By statistical analysis, the grade of grain size is 12. It can be seen that there is no carbide precipitation at the grain boundary after solution treatment.

![Figure 5. Microstructure of stainless steel bolt section after solution treatment.](image)

4. Conclusion
According to the requirements of austenitic stainless steel solution treatment, 304 stainless steel after solution treatment should not contain any carbide precipitation. However, carbide precipitates at the grain boundary of 304 stainless steel bolt, which indicates that the bolt has not undergone solution treatment or the solution treatment is not perfect.

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