Experimental study on mechanical behavior of welded joints of strain strengthening austenitic stainless steel under 77K

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Abstract. With the development of economy and technology, people's demand for material properties is developing towards the extreme direction of cryogenic temperature and high pressure. The development of materials with better properties has been widely studied. Austenitic stainless steel S30408 is a typical transformation induced plastic steel, that is, part of austenite transforms into martensite in the process of plastic deformation. Because of this characteristic, the martensite produced after strain affects the mechanical properties of the material to a great extent, which makes austenitic stainless steel maintain high strength and high toughness at low temperature [2-5].

At present, it has been widely used in many countries to improve the yield strength of austenitic stainless steel by means of strain strengthening. The basic principle is to make part of austenite lattice in metastable austenite stainless steel into martensite through a certain degree of pre-strain, so as to improve the yield strength of the material, effectively reduce the wall thickness and improve the fatigue resistance [6].

Compared with the base metal, the welded joint is very uneven in structure and performance, which is easy to produce welding defects. It is the weakest link in the structure of the whole pressure vessel, and its performance is directly related to the normal and safe operation of the equipment. Therefore, the research on the mechanical properties of the welded joint of strain strengthening austenitic stainless steel can effectively ensure the safety and reliability of the welded joint in the strain strengthening pressure vessel.

1. Introduction
With the development of economy and technology, people's demand for material properties is developing towards the extreme direction of cryogenic temperature and high pressure. The development of materials with better properties has been widely studied, and the application of new technologies and new processes to improve the properties of existing materials has been a research hotspot in the world in recent 20 years [1].

Austenitic stainless steel S30408 is a typical transformation induced plastic steel, that is, part of austenite transforms into martensite in the process of plastic deformation. Because of this characteristic, the martensite produced after strain affects the mechanical properties of the material to a great extent, which makes austenitic stainless steel maintain high strength and high toughness at low temperature [2-5].

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vessel. In this paper, the mechanical properties of austenitic stainless steel welded joints with strain strengthening were studied.

2. Material and Experimental

Based on the requirement of GB/T 24511-2017, the 16mm domestic austenitic stainless steel S30408 plate was used as the research object, and the chemical composition of the base metal has been analyzed. The analyses results are shown in Table 1.

| Element | C  | Si  | Mn  | Cr  | Ni  | P   | S   |
|---------|----|-----|-----|-----|-----|-----|-----|
| The standard value of S30408 | ≤0.08 | ≤0.75 | ≤2.00 | 18.00–20.00 | 8.00–12.00 | ≤0.035 | ≤0.015 |
| The measured value of S30408 | 0.06 | 0.37 | 1.10 | 18.18 | 8.07 | 0.028 | 0.002 |

The steel plates were butt welded by submerged-arc welding, and the welding is carried out according to the welding procedure that can pass the strain strengthening procedure qualification, and 9% pretensile strain is applied to some welding test plates, as shown in the Fig.1.

![Figure 1. Pre-tensile testing](image1)

Then, the welding test plate is processed into a series of tensile specimens, which are rod-shaped standard specimens with diameter of \(\Phi 6\) mm and clamping end of M12, as shown in the Fig.2. The initial gauge distance \(L_0\) of the specimen is 30mm, and the parallel length \(L_c\) of the specimen is 40mm.

![Figure 2. Tensile specimens](image2)
immersed in liquid nitrogen (under 77K environment) for tensile test, and the stress-strain curve of the material was obtained.

In order to ensure sufficient strain, the strain rate $\varepsilon_{L_c}$ is set to 0.00025s$^{-1}$ in the experiment. The strain rate is transformed into the beam displacement rate $v_c$. The expression is as follows.

$$v_c = L_c \times \varepsilon_{L_c} = 40 \times 0.00025 = 0.01 \text{mm/s} = 0.6 \text{mm/min}$$  \hspace{1cm} (1)

3. Results and Discussion

The stress-strain curves of base metal and welded joint of austenitic stainless steel S30408 no-strain strengthening specimens and 9% pre-strain strengthening specimens at room temperature and 77K, respectively, as shown in Fig.4.

![Figure 4. Tensile stress-strain curves of base metal of non-strain strengthening and strain strengthening under room temperature and 77K](image)

It can be observed from Fig.4 (a) that the yield strength and tensile strength of the no-strain strengthening S30408 base metal are significantly improved under 77K environment. The tensile strength under 77K environment is more than twice that at room temperature, and the yield strength
under 77K environment is also significantly improved compared with that at room temperature. The main reason is that more martensite is produced by plastic deformation under 77K environment than at room temperature, which leads to a significant increase in the strength of the material. However, it can also be seen that the elongation after fracture or the reduction of area of the material under 77K environment decreases to a certain extent, but it can still maintain at a relatively high level.

It can be seen from Fig. 4 (b) that the tensile strength of 9% strain strengthening S30408 base metal is significantly improved under 77K environment. However, the yield strength under the two temperatures is basically the same, and the elongation or reduction of area after fracture also has little change.

![Tensile stress-strain curves of welded joint of no-strain strengthening under 77K](image)

**Figure 5.** Tensile stress-strain curves of welded joint of no-strain strengthening under 77K

### 4. Conclusion

In this paper, austenitic stainless steel S30408 is taken as the research object. The typical submerged arc welding method is used to prefabricate the welding test plate and make the welded joint. The mechanical tests of the base metal and the welded joint after 9% pre strain at room temperature are carried out. The test results show that the yield strength and tensile strength of S30408 are greatly improved under 77K environment, whether it is base metal or welded joint. At the same time, the yield strength and tensile strength of S30408 can be significantly improved by strain strengthening. Therefore, the wall thickness of the pressure vessel can be effectively reduced and materials can be saved by using strain strengthening technology.

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