Study on Microstructure and Fatigue Properties of Q960 High Strength Steel

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Abstract. The microstructure and fatigue properties of Q960 high strength steel were studied by optical microscope, conventional mechanical properties and fatigue tests. The results showed that the microstructure of Q960 high strength steel was tempered sorbite, the grain size grade 9, and the internal inclusions A1 and B1.5. The brinell hardness of Q960 high strength steel was 326.5HBW10/3000, the tensile strength more than 1000MPa, the impact energy 86.5J, which indicated good strength and toughness. In the case of high fatigue strength, the dispersion of fatigue life was low. The dispersion of fatigue life increased with the decrease of fatigue strength.

Keywords: Q960, Fatigue Properties, Tensile Strength, High Strength Steel.

1. Introduction

High strength steel had the advantages of high strength, good toughness and weldability; it could bear large dynamic and static loads, had light weight and high safety. It was widely used in machinery, mining, coal and other engineering equipment [1]. With the development of large-scale projects, Q960 high strength steel with good comprehensive properties and high added value had gradually become the key steel for construction machinery [2]. At present, the research on Q960 was divided into two categories. One was to study the microstructure and properties of Q960 by heat treatment, such as the effect of different tempering temperatures on the microstructure and properties of Q960 [3-7]. The other was to study the weldability of Q960 High strength steel. Based on the simulated welding thermal cycle test and fatigue crack growth test, the fatigue life of Q960 high strength structural steel Q960 under various stress amplitudes was studied by Zhang Nan [8]. Liu Qiming [9] analyzed the crack sensitivity of welded joint of Q960 steel by using inclined Y-groove welding crack test, and studied the influence of welding process on the properties and microstructure of welded joint. In this paper, the microstructure and properties of Q960 were analyzed, and the uniaxial tensile fatigue test of Q960 was carried out in order to guide the practical use of Q960.

2. Material and Experimental Procedures

The chemical composition of Q960 was analyzed by direct reading spectrometer. The results were shown in Table 1. The samples were cut into 10mm×10mm×20mm metallographic samples,
55mm×10 mm×10mm charpy V-notch impact specimens and 50mm gauge distance tensile samples respectively. Then they were tested on optical microscope, impact testing machine and universal tensile testing machine. The uniaxial axial tension fatigue test was carried out on a fatigue testing machine. The stress ratio was 0.1 and the frequency 10Hz. At last, the morphology of fatigue fracture was observed by SEM.

| Table. 1 | The result of Q960 high strength steel element content/wt% |
|----------|----------------------------------------------------------|
| C        | 0.098                                                   |
| Si       | 0.288                                                   |
| Mn       | 1.124                                                   |
| Ni       | 0.284                                                   |
| Mo       | 0.469                                                   |
| B        | 0.001                                                   |
| Cr       | 0.479                                                   |
| P        | 0.014                                                   |

3. Results and discussion

3.1. Research on Microstructure of Q960

It could be seen from Fig.1a that the microstructure of Q960 high strength steel was tempered sorbate. Fine dispersed carbides precipitated between and within the lath, which ensured the strength and toughness of Q960 high strength steel. The average grain diameter of Q960 high strength steel was 13μm. The grain size grade was 9, which indicated that the grain is fine and had good strength and toughness. The reason was that Q960 high strength steel contained carbide forming elements such as Ni, Ti and Mo, which strongly slowed down the diffusion rate of carbon in steel, and then restrained the process of austenization. In addition, the second phase particles formed by them reduced the original grain boundary area and the total interface energy, which could inhibit the grain growth [10]. During the process of quenching and heating, the carbides of these alloying elements could be more and more evenly dissolved into austenite. After quenching, the supersaturation of carbon and alloy elements in the microstructure increased, and the amount and uniformity of carbides precipitated after high temperature tempering treatment increased correspondingly, which was conducive to the improvement of strength and toughness of steel.

![Fig. 1 The microstructure of Q960 high strength steel](image)

For high strength steel, the higher the strength, the more stringent the inclusion requirements were. The results showed that, compared with low and medium strength alloy steel, high strength alloy steel was more prone to internal fatigue failure caused by inclusions [11]. The inclusion grade of Q960 steel was A1 and B1.5.

![Fig. 2 The inclusion of Q960 high strength steel](image)
3.2. Research on mechanical properties of Q960
According to GB/T 231.1-2018, GB/T 228.1-2010, GB/T 232-2010 and GB/T 229-2007, brinell hardness test, tensile test, bending test and impact test (normal temperature) were carried out for Q960 high strength steel. It could be seen from Table 2 that the mechanical properties of Q960 were higher than the requirements of national standard. Q960 was tempered at high temperature, and its internal dislocation density was reduced, its configuration was more stable. In particular, the number of movable dislocations was reduced by counteracting or entangled with other dislocations, and the carbide precipitation in Q960 effectively pinned the dislocations, which required higher stress to fracture Q960 during tensile and impact tests.

Table. 2 The conventional mechanical properties of Q960 high strength steel

|       | Brinell hardness /HBW10/3000 | Tensile strength Rm/MPa | Yield strength Re/MPa | Elongation /% | Impact energy /KV2 |
|-------|-----------------------------|-------------------------|-----------------------|---------------|-------------------|
| Q960  | 326.5                       | 1028                    | 978                   | 13.5          | 86.5              |
| GB/T16270 | /                           | 980-1150               | ≥960                  | ≥10           | ≥34               |

The uniaxial fatigue test of Q960 was carried out. It could be seen from Fig.3 that under high fatigue strength, the dispersion of fatigue life of materials was low, and with the decrease of fatigue strength, the dispersion of fatigue life of materials gradually increased. The S-N curve of Q960 was obtained by fitting the Q960 fatigue data with small sample statistical method.

![Fig. 3](image)

Fig. 3 The fatigue S-N curve of Q960 high strength steel

3.3. Fatigue properties of Q960
According to the observation and analysis of the fatigue fracture surface, it can be seen from Fig.3a and 3b that the morphology of the radiation zone was composed of typical quasi cleavage fracture river like pattern, tongue like pattern and cleavage step. There were some ductile ridges in the radiation area, which can delay the crack growth and improve the toughness. From Fig. 3c and 3d that the fiber zone and shear lip were composed of a large number of shallow dimples, which indicated that the fiber zone and shear lip still have good plasticity and toughness under high strength.
4. Conclusions

1) The microstructure of Q960 high strength steel is tempered sorbite, the grain size grade 9, and the internal inclusions A1 and B1.5.

2) The brinell hardness of Q960 high strength steel is 326.5HBW10/3000, the tensile strength more than 1000MPa, the impact energy 86.5J, which indicate good strength and toughness.

3) In the case of high fatigue strength, the dispersion of fatigue life is low. The dispersion of fatigue life increases with the decrease of fatigue strength.

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