Research on High Cycle Fatigue Performance of Q345B

Pengxiao Zhu1,2, Jun Wen1,2, Yi Li1,2, Dongya Zhang1,2, Xuejiao Ma1,2
1State Key Laboratory of Intelligent Manufacturing of Advanced Construction Machinery, Xuzhou Construction Machinery Group, Xuzhou 221004
2Jiangsu Xuzhou Construction Machinery Research Institute, Xuzhou Construction Machinery Group, Xuzhou 221004
*Corresponding author: LB19040027@cumt.deu.cn

Abstract. The high cycle fatigue properties of Q345B were studied by optical microscope, conventional mechanical properties and fatigue tests. The results showed that the microstructure of hot-rolled Q345B was ferrite + pearlite, and the inclusions were MnS. In the case of high fatigue strength, the dispersion of fatigue life was low. With the decrease of fatigue strength, the dispersion of fatigue life gradually increased. The fatigue crack initiated at the MnS inclusion on the subsurface.

1. Introduction
Q345B low alloy high strength steel was widely used in mechanical manufacturing and engineering construction due to its high strength, plasticity and toughness, good weldability and cold forming ability. For example, Q345B was used as common raw materials for boom, hydraulic cylinder and scraper of grader. These construction machinery and equipment bore the action of alternating load in use, and fatigue fracture was the main failure mode.

At present, the research on fatigue behavior of Q345B was mainly focused on the fatigue properties of welded joints. Luo Yunrong [1] and Pu Yumei [2] studied the low cycle fatigue behavior of Q345 structural steel, and concluded that the fatigue failure was mainly caused by plastic strain. The low cycle fatigue behavior of Q345B base metal and its welded joint was studied by you Xiang [3]. The relationship between strain amplitude fatigue life and energy life was established. The increase of cyclic hardening caused by mechanical inhomogeneity was the main reason for the decrease of low cycle fatigue property of welded joints. However, little research has been done on the high cycle fatigue properties of Q345B base metal. The research methods of high cycle fatigue mostly used small sample fatigue test method. The principle to fit P-S-N curve with small sample test data was investigated by Xie Liyang [4], which related with information fusion techniques, and the method to establish P-S-N equation. Lv Zhen [5] proposed a method for determining fatigue life distribution. The bootstrap method of expanded sample statistical was applied to determine the P-S-N curve from small sample test, and corresponding calculation procedure was established which solved the instability of the probabilistic characteristic value of the small sample size by Chen Xiangyu [6]. In this paper, the high cycle fatigue properties of Q345B were studied by small sample fatigue test method. The fatigue life curve of Q345B was obtained, which was of great significance to the structural design analysis and life prediction of Q345B.
2. Material and Experimental Procedures
The sample was taken from hot rolled Q345B plate produced by a steel plant, and its chemical composition was shown in Table 1. The high cycle fatigue specimens are of smooth rectangular cross-section. The dimensions are designed according to Metallic materials-Fatigue testing-Axial-force-controlled method [7]. The samples were processed by WEDM, and then the surface was polished with sandpaper and abrasive paste.

| C   | Si  | Mn  | Ni  | Cr  | S  | P  |
|-----|-----|-----|-----|-----|----|----|
| 0.147 | 0.210 | 0.966 | 0.015 | 0.017 | 0.006 | 0.010 |

The metallographic samples were taken from the cross section of the plate by wire cutting, and then the samples were etched with 4% nitric acid alcohol solution after grinding and polishing. The microstructure was observed under the metallographic microscope. The Brinell hardness, strength and impact energy of Q345B were tested by digital Brinell hardness tester, universal tensile testing machine and low temperature pendulum impact testing machine respectively. Q345B fatigue test was carried out by Instron 8802 fatigue testing machine. The stress ratio was 0.1 and the frequency 10Hz. The fatigue fracture was observed by SEM.

3. Results and discussion

3.1. Research on Microstructure of Q345B

![Fig 1. the microstructure of Q345B](image1)

![Fig 2. the inclusion of Q345B](image2)
It can be seen from Fig.1 that the microstructure of Q345B was banded ferrite + pearlite. According to GB /T13299-1991, the banded structure grade was 4A. The conventional delivery state of Q345B was hot-rolled state. After rolling, its microstructure would be parallel to the rolling direction, distributed in layers and in the shape of strip ferrite + pearlite. The banded structure is generally caused by the inhomogeneity of alloying elements, mainly Mn content [8]. During the cooling process, ferrite preferentially forms in the strip formed by dendrite segregation and nonmetallic inclusions. The inclusions were observed in Q345B polished state. Q345B inclusions were mainly elongated MnS inclusions with a length of 50-120 μm from Fig.2. In the process of rolling deformation, inclusions were distributed along the rolling direction due to rolling force. The existence of strip MnS inclusions could destroy the continuity of steel matrix and cause stress concentration in different degrees [9].

3.2. Research on mechanical properties of Q345B

The brinell hardness, tensile strength, yield strength, elongation after fracture and impact energy of Q345B met the standard requirements from Table2.

| Parameter             | Value       |
|-----------------------|-------------|
| Brinell hardness      | 155.1       |
| Tensile strength      | 500         |
| Yield strength        | 358         |
| Elongation            | 33.0        |
| Impact energy         | 137.5       |

The uniaxial fatigue test of Q345B was carried out. It can be seen from Fig.3 that under high fatigue strength, the dispersion degree of fatigue life of materials was low, and with the decrease of fatigue strength, the dispersion degree of fatigue life of materials gradually increased. The S-N curve and equation of Q345B were obtained by fitting Q345B data according to the small sample statistical method.
3.3. Fatigue properties of Q345B

The fracture position of the specimen was at the junction of gauge length and arc transition zone, which was due to the stress concentration at the transition point of circular arc. A universal tensile testing machine was used to snap the incompletely fractured specimens, and the fracture surfaces were observed. It can be seen from Fig. 4a that there was no obvious macroscopic plastic deformation on the fatigue fracture surface, and the fracture morphology was a typical axial loading high cycle fatigue fracture, showing brittle fracture. The fatigue source was located on the surface defect or MnS inclusion in the fan handle. The propagation region was flat and had radial stripes. The fatigue crack originated from the defects on the surface of the specimen during machining, which had a large stress concentration arc transition [10].

From Fig. 4b, it could be deduced that the cracks may initiate at the MnS impurities on the sub surface, resulting in large stress concentration in these areas. With the cyclic stress loading, the stress on the defect was much larger than that in other regions, and the fatigue microcracks initiated in these regions. Surface defects and inclusions played a role of sharp notch on the material, resulting in stress concentration, which was easy to cause uneven local slip and micro cracking, accelerating the initiation of fatigue cracks. After fatigue crack initiation, the fatigue crack propagated to the material along the direction perpendicular to the maximum normal stress until the fatigue crack reached its adjacent crack size. Typical fatigue striations could be seen in Fig. 4c and 4d, indicating that the specimen was fractured after fatigue.

4. Conclusions
1) The microstructure of hot-rolled Q345B was ferrite + pearlite, and the inclusions were MnS.
2) In the case of high fatigue strength, the dispersion of fatigue life was low. With the decrease of fatigue strength, the dispersion of fatigue life gradually increased.
3) The fatigue crack initiated at the MnS inclusion on the subsurface. There was no obvious macroscopic plastic deformation on the fatigue fracture surface.

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