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Research on Microstructure and Mechanical Properties of High Strength Steel

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Abstract. The microstructure and properties of Q460C high strength steel were studied in this paper. The results show that the margin microstructure of the test steel Q460C is banded ferrite + pearlite. The internal microstructure is banded ferrite + pearlite + bainite, the grade of banded microstructure is 2.5. The tensile strength, yield strength, post-fracture elongation and Brinell hardness of Q460C steel are 620MPa, 502MPa, 22% and 175HBW10/3000 respectively. The impact energy of -40℃ is above 50J, and a large number of equiaxed dimples are evenly distributed in the impact fracture. The conditional fatigue strength of test steel Q460C under 10^7 is 250MPa.

1. Introduction
Low alloy high strength steel has the advantages of high strength, high toughness, good weldability and corrosion resistance. It was widely used in construction machinery, special vehicles, oil and gas pipelines and other fields. Gao Ya [1] studied the law of continuous cooling transformation of Q460C steel. Ferrite (F) zone, pearlite zone, bainite zone and martensite zone were found on both CCT diagrams. The deformation moves CCT curve to left and up direction. The cooling transformation initiating temperature of austenite increases more with the increase of cooling rate. The F and P zone enlarge and the B and M zone diminish. Hao Xiaoqiang [2] studied the effect of normalizing and controlled cooling on microstructure and properties of Q460C steel plate. The strength of the steel plate increases with the increase of water cooling rate and the decrease of final cooling temperature. The strength values of the steel plate are not influenced when then cooling rate is less than 3 ℃/s; the strength values of the steel plate increase with the increase of cooling rate when the cooling rate is more than 3 ℃/s. The impact toughness at 0 ℃ increases with the increase of temperature when the normalizing temperature is less than 920 ℃; the impact toughness gradually deteriorates when the normalizing temperature is more than 920 ℃. Wang Yuanqing [3] studied the fracture toughness of Q460C at low temperature. The fracture of the 3-point bending specimen of steel Q460C shows an obvious brittle fracture mechanism. The δm value of steel Q460C tends to decrease with the temperature reduction. In this paper, we analyze the organization and performance of Q460C in order to lay a foundation for the popularization and application of Q460C.
2. Material and Experimental Procedures
The chemical composition of hot rolled Q460C was analyzed by ARL-4340 direct reading spectrometer. The results were shown in Table 1. The specimens were cut into (10*10*20) mm metallographic specimens, (55*10*10) mm Charpy V notched impact specimens, tensile specimens with a standard distance of 50 mm by wire cutting and fatigue specimens. The fatigue specimen size is shown in Fig.1 with a frequency of 10Hz and a stress ratio of R of 0.1. They were tested on DMI500M metallographic microscope, THBS-3000 digital brinell hardness tester, PTM2200 impact tester, AGS-X100kN tensile tester and INSTRON8802 fatigue tester. Finally, the impact fracture morphology was observed by Inspect550 scanning electron microscope.

| C    | Si   | Mn   | S     | P     | Cr | V  | Ni | Cu | Al |
|------|------|------|-------|-------|----|----|----|----|----|
| 0.162| 0.286| 1.437| 0.005 | 0.008 | 0.073  | 0.026  | 0.021  | 0.062 | 0.058 |

![Figure 1. Q460C fatigue specimen size](image)

3. Results and discussion

3.1. Research on Microstructure of Q460C

It can be seen from Fig.2 that the margin microstructure of Q460C after hot rolling was banded ferrite + pearlite. The internal microstructure was banded ferrite + pearlite + bainite. According to GB/T13299-1991, the grade of banded microstructure was 2.5. Banded microstructure was a common morphology in hot rolled steel. It was considered [4, 5] that banded microstructure is caused by uneven distribution of alloying elements (mainly Mn). The liquid steel was crystallized selectively during the casting process and formed the dendrite microstructure with uneven chemical composition. During the rolling process, dendrites were elongated along the rolling direction, forming an alternately distributed alloy element enrichment and depletion zone. The Mn element can reduce the Ar3 temperature. Proeutectoid ferrite was precipitated from Mn-poor zone during Austenite Cooling and excess C element is discharged into Mn-rich zone on both sides. Austenite eutectoid was transformed...
to pearlite in Mn rich zone. Ferrite and pearlite were alternatively distributed to form banded microstructure.

The formation of banded bainite in the steel sheet was due to severe central segregation of continuous casting slab and excessive cooling rate of the steel sheet after rolling [6]. The serious central segregation made the content of alloy and impurity elements in the core of the continuous casting billet higher than that of the matrix. The segregation elements such as C, Mn, S and P are concentrated in the heart. During the subsequent heating process, the segregation still existed because of the low diffusion coefficient of alloy elements and the difficulty of homogenization. The heterogeneity of alloying elements (mainly Mn) and magazine elements lead to segregation of plastic inclusions such as MnS. In addition, strip-like morphology appeared in the thickness direction of steel sheet due to the elongation of dendritic structure along the rolling direction. The Mn element reduced the Ar3 temperature and increased the austenite stability. Therefore serious Mn segregation lead to medium temperature transformation of austenite during cooling and form bainite microstructure.

3.2. Research on mechanical properties of Q460C

As can be seen from Table 2, the tensile strength, yield strength, post-fracture elongation and Brinell hardness of Q460C are 620 MPa, 502 MPa, 22% and 175 HBW10/3000 respectively. Because the microstructure of Q460C after hot rolling was mainly ferrite + pearlite, the hardness and strength of these two kinds of structures were lower and plasticity was better. The results of tensile and hardness tests showed that a small amount of bainite in the center had little effect on the strength and hardness of Q460C.

| Rm/MPa | RM/MPa | A/% | HBW10/3000 |
|--------|--------|-----|------------|
| 620    | 502    | 22  | 175        |

Table 3. The bending test results of Q460C

| Bending head diameter/mm | Bending angle/° | Defect |
|--------------------------|-----------------|--------|
| 50                       | 180             | None   |

It can be seen from Fig. 3 that the ballistic work of Q460C decreased with the decreasing of temperature. When the temperature changed from -20°C to -40°C, the ballistic work decreased rapidly. However the ballistic work KV2 of Q460C was still above 501 at -40°C, indicating that Q460C had excellent low temperature toughness. Fig.4 showed the fracture located in the center of the V notch. The fracture morphology of this part can accurately reflected the fracture mode of the entire impact fracture [7]. It can be seen from Fig.4 that a large number of equiaxed dimples were evenly distributed in the impact fracture. The impact fracture dimples of Q460C were large and deep at 20°C. There were many small dimples around the dimples. The size of large dimple gradually decreased, and the depth was gradually shallower, but there were still small dimples around it at 0°C. The fracture dimple was larger, and there was no small dimple at -20°C. The dimple size and depth were small at -40°C, and there were a few cleavage fracture planes, which indicated that the impact toughness of the dimple was further decreased.
3.3. Fatigue properties of Q460C

Because the yield strength of Q460C was 502 MPa, the maximum load of fatigue test was 500 MPa, and then the load decreased in turn. The fatigue datas were fitted [8], and the result was shown in Fig.5. With the load decreased, the number of fatigue cycles increased. At 250MPa the cycle number of Q460C reached $10^7$, indicating that it’s conditional fatigue strength was 250MPa. The fatigue specimens are broken at the transition from circular arc to parallel section. This was because the cross-sections varied greatly, causing stress concentration and fatigue damage.
4. Conclusion
1) The margin microstructure of the test steel Q460C is banded ferrite + pearlite. The internal microstructure is banded ferrite + pearlite + bainite, the grade of banded microstructure is 2.5.
2) The tensile strength, yield strength, post-fracture elongation and Brinell hardness of Q460C steel are 620MPa, 502MPa, 22% and 175HBW10/3000 respectively. The impact energy of -40°C is above 50J, and a large number of equiaxed dimples are evenly distributed in the impact fracture.
3) The conditional fatigue strength of test steel Q460C under $10^7$ is 250MPa.

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