Angle expanding fracture analysis of Q420B angle steel

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Abstract. The cracking angle steel is analyzed by chemical composition analysis, tensile test, impact strength, bending test, metallographic structure and other physical and chemical test methods and all indicators meet the requirements of the standard, so material quality is not the cause of crack of angle steel. The stress distribution of Q420B angle steel in the process of expanding angle in cold working is analyzed by numerical simulation. Three dimensional simulation results show that when the angle of expansion reaches 92° and the maximum principal stress exceeds the tensile strength of the material, the angle steel breaks; The results of plane strain calculation show that when the angle of expansion reaches 92.6° and the maximum principal stress exceeds the tensile strength of the material, the angle steel breaks.

1. Introduction

At present, China is vigorously developing ultra high voltage (UHV) transmission lines. In order to make some ultra high voltage and double circuit ultra high voltage tower types bear more load, as the main material of the power tower, the angle steel should be assembled in the form of double or multi splicing. This will lead to the complexity of the tower structure, greatly increasing the weight of the tower. Q420B low-alloy high strength steel has been widely used in high-voltage transmission line tower due to its excellent performance. Studies have shown that the strength and bearing capacity of Q420B steel are 23% and 18% higher than those of Q345 steel. Using Q420B angle steel can reduce the material weight by 4.9%-7.8% [1]. Using Q420B high strength and large size angle steel instead of Q345 and Q390 angle steel can effectively reduce the weight of tower body and reduce the cost [2]. In the past years, a large number of researchers have studied angle steel in many aspects [3-6].

In the steel structure enterprises, it is usually necessary to expand the angle of large-scale, high-strength low alloy steel for assembly or welding with other workpieces. When Q420B angle steel is processed by cold expanding angle, it often cracks along the transverse direction. This paper studies this problem and puts forward solutions.

2. Macroscopic morphology

The macroscopic morphology of cracked angle steel is shown in Fig. 1. The crack position is about 12mm away from the root as shown in Fig. 1(a). It can be seen that the cracking property is penetrating cracking as shown in Fig. 1(b). The size of angle steel is \( \angle 200\text{mm} \times 200\text{mm} \times 20\text{mm} \times 8000\text{mm} \).
Figure 1. Macroscopic morphology of cracked angle steel.

3. Results and Discussions

3.1. Chemical composition analysis
The chemical composition analysis results of Q420B angle steel are shown in Table 1. The chemical composition of Q420B angle steel meets the technical requirements of standard GB/T 1591-2018 <High strength low alloy structural steels>.

| Element | C  | Si  | Mn  | P   | S   | Ni  | Cu  | Cr  | V   | CEV |
|---------|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Sample  | 0.16 | 0.32 | 1.54 | 0.025 | 0.010 | 0.008 | 0.004 | 0.019 | 0.062 | 0.43 |
| Standard | ≤0.20 | ≤0.55 | ≤0.70 | ≤0.035 | ≤0.035 | ≤0.80 | ≤0.40 | ≤0.30 | ≤0.13 | ≤0.45 |

3.2. Mechanical properties analysis
The tensile test results of Q420B angle steel are shown in Table 2. The tensile test meets the standard requirements of GB/T 1591-2018 <High strength low alloy structural steels>.

| Upper yield strength (R_{0.2}) | Tensile strength (R_m) | Elongation |
|---------------------------------|------------------------|------------|
| Sample No. 1                   | 458MPa                 | 633MPa     | 30%        |
| Sample No. 2                   | 458MPa                 | 633MPa     | 30%        |
| Standard                       | ≥420MPa                | 520MPa-680MPa | ≥20%       |

3.3. Metallographic microstructure analysis
The sampling position for metallographic analysis is shown in Fig. 2.
The micromorphology of A1 surface crack is shown in Fig. 3. It can be seen from Fig. 3 (a) that the crack propagation direction is perpendicular to the banded microstructure. It can be inferred that the banded structure produced in the rolling process is not the main cause of cracks. The crack tip passes through the ferrite grain, which is a transgranular fracture mode. The ferrite deformation can effectively absorb the fracture energy and hinder the propagation of crack tip. It can also be seen from Fig. 3 (b) that the crack propagates through the grain along the direction perpendicular to the banded distribution.

The micromorphology of A2 surface is shown in Fig. 4. It can be seen that the metallographic structure of A2 surface is typical ferrite and pearlite structure, and the grain size is uniform and distributed in strip shape.
The micromorphology of B1 and B2 surface are shown in Fig. 5 and Fig. 6, respectively. It can be seen that the banded distribution of metallographic structure from the outer top angle to the inner span arc is more obvious, which is related to the different deformation during the rolling process of the outer top angle and the inner span arc. The deformation of the outer top angle is larger during the rolling process, and the microstructure is more uniform than that at the inner span arc.

Figure 5. Micromorphology of B1 surface.

Figure 6. Micromorphology of B2 surface.

3.4. Numerical simulation analysis
In the numerical simulation of this paper, Q420B angle steel adopts elastic-plastic material model. According to the standard GB/T 22315-2008 <Metallic materials-Determination of modulus of elasticity and poisson's ratio>, the elastic modulus of Q420B angle steel is 206GPa and poisson's ratio is 0.3. The tensile test results show that the yield strength and tensile strength of Q420B are 458MPa and 633MPa respectively.

The numerical simulation in this paper adopts two methods: three-dimensional (3D) deformation calculation and plane strain calculation. In order to simulate the angle expanding process of angle steel, in the calculation process, the bottom angle steel limb is fixed and constrained, and one rigid push rod is used to push the other angle steel limb to the left at the speed of 1mm/s. The friction coefficient between the rigid push rod and the angle steel is 0.3. According to the actual angle expanding equipment, the contact point between rigid body and angle steel limb is 100mm away from the root.

The stress distribution obtained by 3D deformation calculation is shown in Fig. 7. It can be seen that when the maximum principal stress in the model exceeds 633MPa, the angle of angle steel is 92° at this time, that is, when the angle is not up to 95°, the angle steel will crack. The crack first occurs at point A in Fig. 7, which is 11.92mm away from the root of angle steel.
Figure 7. Stress distribution obtained from 3D deformation calculation.

Considering the length of angle steel is 8m, the stress state can be simplified to plane strain state. Extract the stress distribution map when the maximum principal stress exceeds the tensile strength, as shown in Fig. 8. At this time, when the angle angle is 92.6°, that is, the angle steel will crack when the angle is less than 95°. The crack first occurs at point a shown in Fig. 8, which is 11.80mm away from the root of angle steel.

Figure 8. Stress distribution obtained from plane strain calculation.

4. Conclusion
Q420B angle steel is a typical ferrite and pearlite structure. Although it is banded distribution, the crack propagation direction is perpendicular to the banded distribution direction, and the generation and propagation of cracks have nothing to do with the banded structure. Through the finite element numerical simulation analysis, it can be concluded that under the cold working deformation condition, when the expansion angle is less than 95°, the local stress has exceeded the tensile strength of the material, resulting in cracks. Therefore, it is suggested to expand the angle of angle steel under heating condition.

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