The Influence of Annealing Process on Microstructure of Welded Joint of Weathering Steel

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Abstract. In this paper, the structure and properties of Q355NH weathering steel welded joints were studied. Through the analysis of the micro-structure of welded joint, the results showed that the fine grain area, columnar crystal and equiaxial crystal existed both before and after the annealing, and the grain size at the bottom of the cover welds was larger than that of the bottom welds. After annealing, the grain size became uniform and the size was reduced. Moreover, the fusion line became less obvious. After annealing treatment, the distribution of martensite inside the welds was more uniform than that of untreated ones.

1. Introduction
In the process of mechanical and material processing, residual stress will generate in the work piece to different degrees. But the causes of residual stress is complex, including both the internal causes of uneven structure and the external factors of processing [1]. On the one hand, the existence of residual stress will affect the yield strength of the work piece, and on the other hand, it will change the machining accuracy of the work piece in the manufacturing process or after manufacturing [2].

The residual tensile stress affects the mechanical properties of the work piece, involving fatigue strength, yield limit. In the process of using work pieces, the destructive accidents, are mostly caused by the influence of the residual stress [3]. Therefore, the removal of residual stress is very important to ensure the machining accuracy, safety and reliability of work pieces [4].

In this study, through the stress relief annealing process of welding specimen after welding, we observed the metallographic structure characteristics of the welded specimens, and furtherly studied the change of microstructure and grain before and after annealing.

2. Test materials and procedures

2.1. Test materials
The test material is Q355NH weathering steel (12 mm thickness), whose chemical composition and mechanical properties are listed in table 1 and 2 respectively.
### Table 1. Chemical compositions of Q355NH

| Elements | C    | Si   | Mn    | P    | S    | Cu   | Cr   | Ni   |
|----------|------|------|-------|------|------|------|------|------|
| W (%)    | ≤0.16| ≤0.50| 0.50~1.5| ≤0.030| ≤0.020| 0.25~0.55| 0.4~0.8| ≤0.65 |

### Table 2. Mechanical properties of Q355NH

| Mechanical property | The yield strength N/mm² | Tensile strength N/mm² | fracture elongation% | 180°Bending | Impact energy(KV₂, J) |
|---------------------|--------------------------|------------------------|----------------------|-------------|----------------------|
| Requirements        | ≥355                     | 490~630                | ≥22                  | a           | -20°C ≥34            |

#### 2.2. Annealing process

In the process of annealing, the NS-86-102-650°C car type resistance furnace was used as annealing equipment. The annealing temperature of the workpiece is 570±10°C, and the holding time is 90-120 min.

#### 3. Influence of annealing on the forming and microstructure of the joint

##### 3.1. Metallographic analysis of joints

The metallographic specimens were prepared for the welded parts before and after annealing. After corrosion, the macroscopic morphology and microstructure were observed respectively, and the effects of annealing process on the microstructure were analyzed. Figure. 1 is the macroscopic morphology before and after the annealing.

![Figure 1](image)

(a) Before the annealing  
(b) after the annealing

**Figure 1.** Macroscopic metallography before and after annealing.

Through macroscopic metallographic observation, the grain size was not uniform in the fusion zone before annealing, and the fusion line was clearly visible. In the weld zone, the grain size was larger, and the cover was wider. Besides that, the temperature gradient of the pool center was gentle, and the growth of grains was fast, which formed large grains.

After annealing, the grain size of the fusion zone changed little, but the fusion line was not clear. The grain of the weld zone was thinning but not significant. The range of heat affected zone after annealing was significantly reduced by nearly 40% compared with that before annealing.

##### 3.2. Analysis of joint microstructure

Figure 2 is the microstructure of metallographic specimen before annealing. By metallographic experiment, it was observed that the microstructure of base metal was ferrite and pearlite before annealing.
In the fusion zone, the grains grew in the form of columnar crystals toward the weld center. The grain size was not uniform, and some grains were obviously thick near the side of the heat affected zone, while the grains on the side of the weld were small. In the weld zone, the grains were large, with similar chemical composition, and the organization was still in the state of regional equilibrium.

Figure 2. Metallographic microstructure before annealing

Figure 3. Metallographic microstructure after annealing
The fusion zone was homogeneous, which resulted in an unclear fusion line. The pearlite in the weld zone was slightly diffused. After annealing treatment, the distribution of martensite inside the welds was more uniform than that of untreated ones.

3.3. EBSD analysis of joints

Figure 4 is a reverse polar diagram of EBSD analysis of metallographic experiments before and after annealing. (a) And (b) is the weld zone. (c) And (d) is the heat affected zone.

![Figure 4. EBSD analysis of metallographic samples before and after annealing](image)

(a) Weld area before annealing (b) Weld area after annealing (c) Heat affected zone before annealing (d) Heat affected zone after annealing

Through observing (a) and (b), we can find that the grain size of the weld zone after annealing is slightly smaller than that before annealing, but the difference is not significant. However, the grain size of both of them is extremely uneven. By compared (c) with (d), it is found that the grain size of the heat affected zone is more uniform and smaller than that in the weld zone, and the size of most grains, which tend to homogenization, is obviously smaller after annealing than that before annealing.

Figure 5 is the analysis of grain boundary angle of metallographic sample before and after annealing. (a) And (b) are the weld zone, (c) and (d) are the heat affected zone.

Compared Figure 5 (a) with (b), the statistical results showed that the percentage of the high-angle grain boundary ($\theta > 15$) in the weld zone before annealing was 46.1%, and the number of high-angle grain boundaries increased after annealing, accounting for 57.6%, which rose nearly 10%.
Compared Figure 5 (c) and (d), the statistical results showed that the percentage of the high-angle grain boundary ($\theta > 15$) in the heat affected zone before annealing was 45.6%, and the number of high-angle grain boundaries increased after annealing, accounting for 55.4%.

4. Conclusion

By comparing and analyzing the structure changes of Q355N resistant steel before and after annealing, the following conclusions are obtained:

1. After annealing of the weld, the grain size of the fusion zone is not very different, and the grain of the weld zone is somewhat refined but not significant. The range of heat affected zone after annealing is smaller than that before annealing, and the range is reduced by nearly 40%.

2. After annealing process, the structure of the parent material is still composed of ferrite and pearlite, and the grain is refined but not obvious. After annealing, the martensite inside the welded parts is more evenly distributed than the untreated sample.

3. The EBSD analysis shows that the grain size of the heat affected zone is more uniform and smaller after annealing, and the annealing process has a certain refinement effect on the grain size of the weld zone. In addition, the number of high-angle grain boundary in the weld zone is increased and the toughness of the weld zone was enhanced.

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