

Effect of Welding Process on Microstructure and Properties of High Strength Steel Joints

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Abstract. S900MC high strength steel was selected as the research object, and different MAG welding processes were designed according to the practical application of construction machinery. The microstructure, tensile test and impact test of the welded joints were carried out under different conditions. The effects of welding heat input, preheating temperature and cooling time $t_{8/5}$ on the tensile strength and impact toughness of welded joints were studied. The results show that the microstructure of the welded joint is composed of weld, fusion zone, superheated zone, fine grain zone and incomplete recrystallization zone. When the welding line energy or preheating temperature is increased, the cooling rate decreases, the strength of the welded joint decreases. The impact absorption energy of the weld is about 50% higher than that of HAZ. With the increase of $t_{8/5}$, the impact absorption energy of the weld and HAZ increases first and then decreases. When $t_{8/5}$ is 15-20s, the impact absorption energy is the largest.

1. Introduction

Construction machinery is developing towards large-scale, lightweight and high parameter with the progress of science and the increasing demand for construction. The higher the requirement for the structural steel used, not only need to ensure high strength, but also take into account the good plastic toughness and welding performance.

The premise of large-scale and lightweight of construction machinery is that the development of high-strength weldable structural steel. At present, the yield strength of low alloy high strength structural steel has developed from the original 550Mpa to the present 960MPa. At present, high strength steel has been widely used in construction machinery products such as large tonnage crane, rice concrete pump truck and aerial platform truck at home and abroad.

However, the welding performance of steel will gradually deteriorate with the increase of its strength, and it is easy to form more welding defects, especially cold cracks, at the same time, the heat input in the welding process will lead to the softening and embrittlement of the heat affected zone.



This paper takes S900MC imported high strength steel as the research object, analyzes the microstructure and properties of welded joints under different welding parameters, and provides guidance for the production of key structural parts of construction machinery.

2. Test Materials and Methods

In this paper, the welding process of S900MC high strength steel is tested by using the method of molten pole active gas shielded welding. The welding wire is Bohler T-Union GM 120. The thickness of welded test plate is 10mm, and the type of joint is butt joint. Sixteen groups of experiments were carried out under the conditions: 0.6KJ/mm (E1), 0.9KJ/mm (E2), 1.2KJ/mm (E3) and 1.5KJ/mm (E4) as four kinds of heat input, and the four preheating conditions is that no preheating (T1), preheating 50°C (T2), preheating 100°C (T3) and preheating 150°C (T4) respectively.

Table 1. Welding Parameters.

| Experimental Group | I(A) | U(V) | Welding Speed(cm/min) | Preheat(°C) | Theoretical Heat Input(KJ/mm) | Cooling Time T ₈₅ (s) |
|--------------------|------|------|-----------------------|-------------|-------------------------------|----------------------------------|
| E1T1 | 220 | 24 | 50 | — | 0.6 | 7 |
| E2T1 | 230 | 25 | 40 | — | 0.9 | 11 |
| E3T1 | 250 | 27 | 35 | — | 1.2 | 15 |
| E4T1 | 280 | 30 | 33 | — | 1.5 | 20 |
| E1T2 | 220 | 24 | 50 | 50 | 0.6 | 8 |
| E2T2 | 230 | 25 | 40 | 50 | 0.9 | 13 |
| E3T2 | 250 | 27 | 35 | 50 | 1.2 | 19 |
| E4T2 | 280 | 30 | 33 | 50 | 1.5 | 25 |
| E1T3 | 220 | 24 | 50 | 100 | 0.6 | 10 |
| E2T3 | 230 | 25 | 40 | 100 | 0.9 | 16 |
| E3T3 | 250 | 27 | 35 | 100 | 1.2 | 23 |
| E4T3 | 280 | 30 | 33 | 100 | 1.5 | 32 |
| E1T4 | 220 | 24 | 50 | 150 | 0.6 | 14 |
| E2T4 | 230 | 25 | 40 | 150 | 0.9 | 21 |
| E3T4 | 250 | 27 | 35 | 150 | 1.2 | 31 |
| E4T4 | 280 | 30 | 33 | 150 | 1.5 | 42 |

After the test plate is welded, ultrasonic testing is carried out, and the welding plate is processed by wire cutting. The chemical composition of base metal was analyzed by direct reading spectrometer, the microstructure of welded joint was analyzed by metallographic microscope, the strength of welded joint was tested by universal testing machine, and the toughness of welded joint was tested by impact testing machine.

3. Test Results and Analysis

3.1. Component Analysis

The chemical composition of S900MC high strength steel and Bohler T-Union GM 120 welding wire is shown in Table 2.

Table 2. Chemical Composition (wt. %).

| Element | C | Si | Mn | P | S | Cr | Ni | Mo | Cu | V |
|------------------|------|---------|---------|-------|-------|----------|---------|----------|------|------|
| Base Metal | 0.08 | 0.14 | 1.63 | 0.007 | 0.004 | 0.70 | 0.03 | 0.19 | 0.01 | 0.10 |
| Welding Material | 0.12 | 0.6-0.9 | 1.6-2.1 | 0.015 | 0.018 | 0.2-0.45 | 1.6-2.2 | 0.45-0.7 | 0.30 | 0.03 |

3.2. Microstructure Analysis

Due to the thermal effect of welding arc during welding, the different parts of the joint have quite different thermal cycles because of the different distance from the center of the heat source, so the

microstructure is different. The typical structure of S900MC high strength steel is shown in figure 1 and 2.

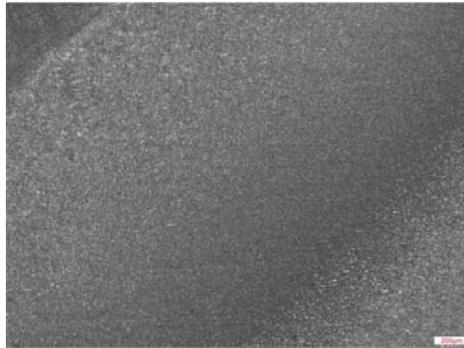
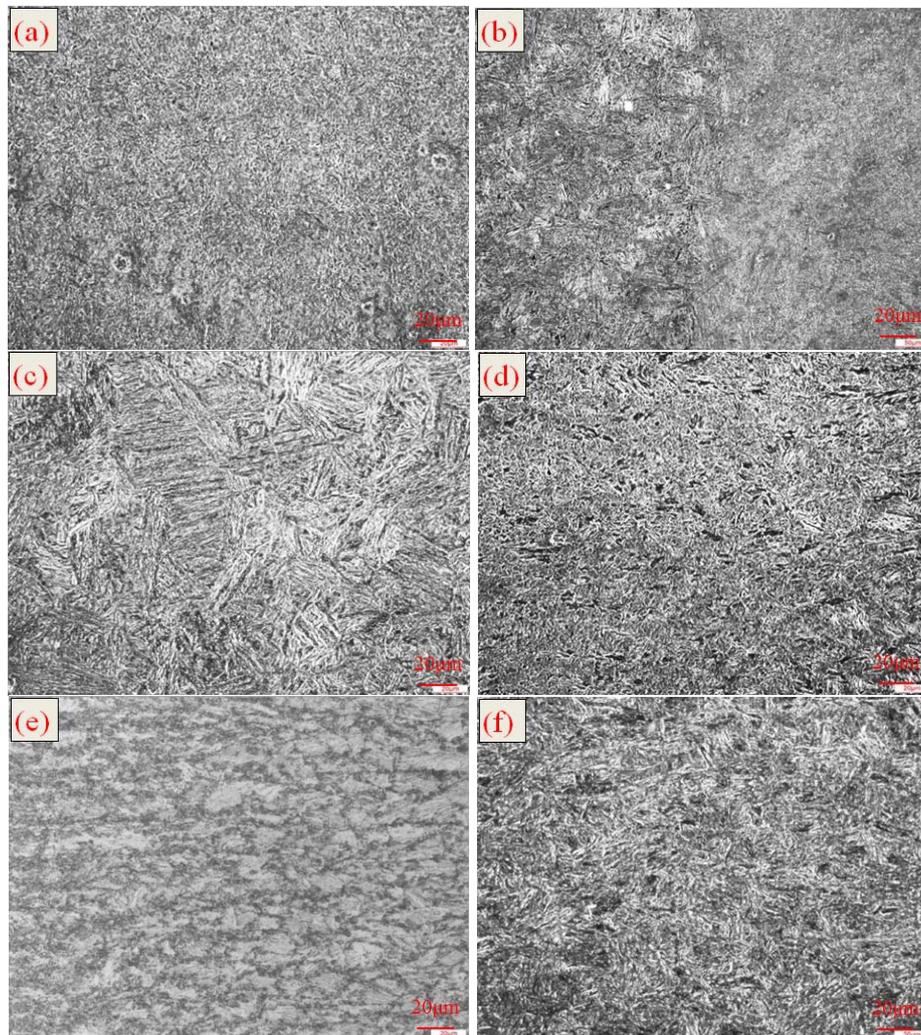


Figure 1. Microstructure of Welded Joint (50×).



(a) Weld Zone, (b) Fusion Zone, (c) Coarse-grained Region, (d) Fine Crystal Region, (e) Incomplete Recrystallization Zone, (f) Parent Material Area

Figure 2. Microstructure of Welded Joints in Different Regions (500×).

It can be seen from the figure that the total width of the heat affected zone is about 10 mm, and the microstructure varies greatly from weld to base metal. (1) The weld zone is mainly composed of welding wire and part of base metal. During welding, the arc will melt part of the base metal while melting the welding wire and form the weld. The proportion of the base metal in the weld metal is called dilution rate. The dilution ratio affects the performance of the welding wire melting metal. From the figure, the weld zone is mainly composed of lath ferrite, granular cementite and a little troostite. (2) The fusion zone is heat affected zone on the left and weld seam on the right. The fusion zone is the bonding zone between the base metal and the weld. The composition is uneven, the width is very small, and it is not easy to be observed. From the diagram, the weld and base metal are bonded well, but the grain size and microstructure are different greatly, so the properties of fusion zone are unstable, and the failure of welded joint often begins here. (3) The coarse-grained region is close to the weld seam. The temperature of the zone reaches 1100°C during the welding process, the austenite grain grows seriously, and the coarse microstructure is formed after cooling as shown in the diagram which leads to poor impact toughness. Welding heat input has the greatest influence on the area. From the diagram, the coarse-grained region is mainly composed of ferrite with a consistent orientation and bainite in the shape of a plate. One grain contains 1-2 bainite lath groups. (4) The fine grain region is also called the phase transformation recrystallization zone or the normalizing zone. During the welding process, the temperature of the region reaches above Ac3 line to 1000 °C, the base metal austenitized and recrystallized, forming uniform and fine microstructure, which is equivalent to a normalizing heat treatment. Therefore, the area has good mechanical comprehensive properties. From the diagram, the fine grain region is homogeneous and the grain size is smaller than that of the base metal, which is mainly composed of ferrite and granular cementite. (5) The region of incomplete recrystallization is different from the completely recrystallization of fine crystal region. The temperature range of the region Ac1-Ac3 can only make some of the microstructures undergo phase transformation recrystallization and form fine microstructure, while the phase that can not be austenitized will continue to grow up and form coarse grains which have an effect on the toughness of welded joints.

3.3. Mechanical Property Analysis

The following is a comparison of the influence of welding line energy and preheating temperature on the tensile strength of welded joints.

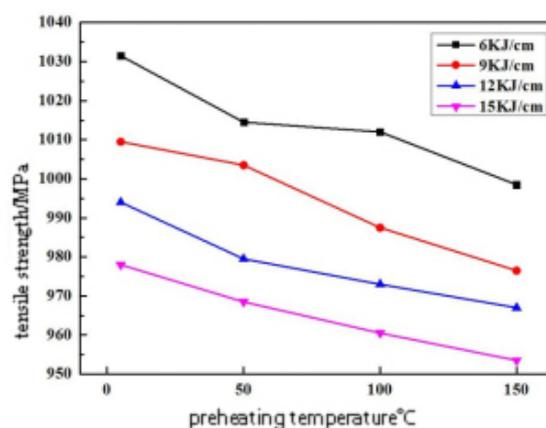


Figure 3. Strength Contrast of Welded Joints.

It can be seen from figure that the lowest tensile strength of welded joint is 948 MPa, which is higher than the minimum required value of base metal 940 MPa, which satisfies the performance index.

From figure 3, when the preheating temperature is constant, the tensile strength of the welded joint gradually decreases with the increase of the line energy; when the line energy is constant, the tensile strength of the welded joint is also gradually decreased as the preheating temperature increases. The alloy composition and cooling rate of the weld are the fundamental factors affecting the properties of the weld. The welding process parameters have a small effect on the alloy composition of the weld, but have a great effect on the cooling rate. When other conditions are fixed, the increase of the welding line energy will lead to an increase in the fusion ratio, which in turn leads to an increase in the dilution ratio of the weld metal, a decrease in the alloying element concentration in the weld metal, a decrease in hardenability and a decrease in strength. At the same time, the increase in welding line energy and preheating temperature reduces the cooling rate, and the possibility of producing hardened structure in the weld is reduced, so the strength is lowered.

The following figure 4 is about the relationship between weld and HAZ impact absorbing power and cooling time $t_{8/5}$.

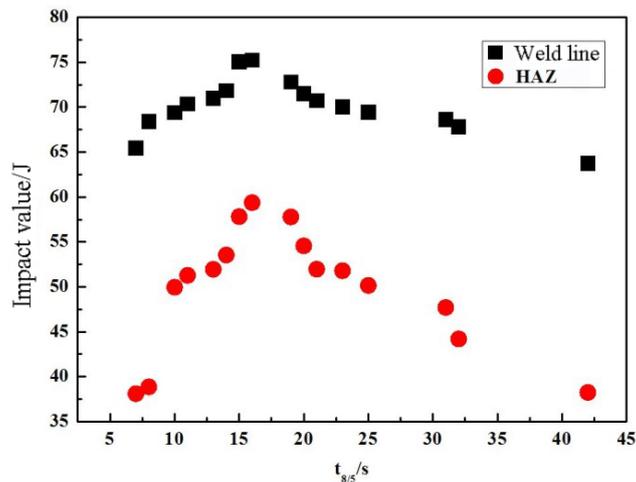


Figure 4. Relationship between Impact Absorbing Power and Cooling Time.

In Figure 4, the impact absorption energy of the weld position is between 65J and 75J, the impact absorption energy of the HAZ position is between 35 and 55J, and the impact absorption energy of the weld position is about 50% higher than that of the HAZ position.

When the cooling time $t_{8/5}$ increases, the impact absorption energy of weld and HAZ increases first and then decreases. When $t_{8/5}$ is 15-20s, the impact absorption energy reaches the maximum value. The impact absorption function of welded joints is sensitive enough to reflect the changes of microstructure and micro-defects of welded joints. In the welding process of test steel, the change of welding current, voltage, welding speed and preheating temperature will lead to the difference of cooling rate, and the difference of cooling rate will lead to the change of microstructure. When the cooling rate is fast, the hardened microstructure with higher hardness and lower toughness is easy to be produced in the weld and HAZ, resulting in lower impact toughness. With the decrease of cooling rate, the hardened structure decreases, and the impact toughness reaches the highest value when $t_{8/5}$ reaches 15-20s. Subsequently, as the cooling rate continues to decrease, the grain size grows and the microstructure coarsens, especially in the coarse grain area of HAZ, ferrite aggregates and grows, the toughness decreases, and the impact toughness decreases.

4. Conclusion

(1) The microstructure of welded joints consists of weld, fusion zone, superheated zone, fine grain zone and incomplete recrystallization zone. The microstructure of welded joints varies greatly due to the different thermal cycles experienced by each zone.

(2) The tensile strength of welded joints is higher than 950MPa, which is higher than the minimum requirement 940MPa, and meets the performance requirements. When the welding line energy or preheating temperature is increased, the cooling rate decreases, the strength of welded joint decreases.

(3) The impact absorption energy of the weld is about 50% higher than that of HAZ. With the increase of $t_{8/5}$, the impact absorption energy of the weld and HAZ increases first and then decreases. When $t_{8/5}$ is 15-20s, the impact absorption energy is the largest.

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