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Effect of Strength Matching on Mechanical Properties of WELDOX 960 Steel Welded Joint

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Abstract. In this paper, WELDOX960 high strength steel sheet was used as the research object, and the welding method was adopted with Ar-CO2 mixed gas welding method. The change of microstructure and properties under different strength matching was studied by changing the strength matching method of welded joint. The main research contents are as follows: The comprehensive mechanical properties of the weld are tested, including the tensile, impact and microhardness tests. The changes of the comprehensive mechanical properties of the welds under different strength matching are obtained, and the selection of the best strength matching under different application conditions is put forward.

1. Introduction

Along with the automobile crane lifting capacity and reliability improvement, as far as possible, reduce the boom weight increase the lifting capacity of crane, so with the strength of steel is also more and more high. Welding in the strength is higher than that of high strength steel of 700 MPa, the stress concentration is serious backing weld position will often appear fracture [1]. So far, the high strength steel crane production, in order to get good toughness, often at the expense of the weld metal strength, selection of welding material with low matching, this method makes the weld is guaranteed in flexibility, but has greatly reduced the weight of crane.

The tensile strength of the automobile crane used for WELDOX960 steel 985 MPa as the research object, using Ar ten C02 mixed gas welding and tensile strength were 840MPa (80), 880 MPa (85), 950MPa (90) of 3 kinds of wire, for multi-layer welding. In the stress concentration layer is serious, considering the influence of backing welding on the properties of welding joint, design of each layer all adopt high strength wire 3 and the strength of 525MPa (50) of 3 groups of low strength welding backing, a total of 6 groups of strength matching form, i.e. 50-80, 80-80, 50-85, 85-85, 50-90, 90-90, matching of welding strength affect the microstructure and properties of welded joint of WELDOX960 steel.

2. The experimental materials and specimen preparation

In this study, WELDOX960 low alloy high strength steel sheet was used as the research object, and the effects of different strength matching welds on the microstructure and properties of low alloy high strength steel were studied by adopting different intensity matching methods. In the six groups of 50-80, 80-80, 50-85, 85-85, 50-90, 90-90, one sample was tested in each group. The test load was 4.9035N and the packing time was 10s.In this experiment, four kinds of welding wires with different tensile strength are used. Their grades are: ER50-6, T union GM100, T union GM110, T union GM120, and their chemical composition and mechanical properties are shown in table 1 and table 2.

Table 1. The Chemical composition of four kinds of welding wire.

Wire grade	C	Si	Mn	Cr	Mo	Ni
ER50-6	0.1	0.9	1.54	-	-	-
Tunion GM100	0.08	0.6	1.7	0.2	0.5	1.5
Tunion GM110	0.09	0.7	1.7	0.3	0.6	1.65
Tunion GM120	0.1	0.8	1.8	0.35	0.6	2.3

Table 2. The Mechanical properties of four kinds of welding wire.

Wire grade	Yield strength/MPa	Tensile strength/MPa
ER50-6	440	525
T union GM100	780	840
T union GM110	790	880
T union GM120	890	950

It can be seen from table 2 that the tensile strength of the ER50-6 is 525 MPa, which is lower than that of the base metal, but has good toughness and is used as a primer. Because in the low-alloy high-strength steel multi-layer welding process, the backing welding shall bear the welding stress of the rear weld bead, and if the plastic toughness of the bottom is not good, especially in the tip of the groove, it is easier to cause the stress concentration of the backing layer, resulting in cracking of the weld [2]. The welding groove form is shown in figure 1. Especially in the larger thickness conditions, the relative residual stress produced by welding is larger, the occurrence of cracks is more serious, the use of less strength ER50-6 can effectively reduce the occurrence of this situation.

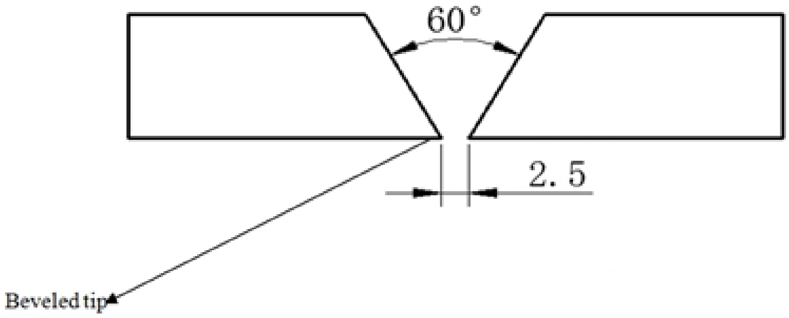

Figure 1. The weld groove form.

The tensile strength of Tunion GM100, T union GM110 and T union GM120 is 840MPa, 880MPa and 950MPa respectively, and these three kinds of welding wire are incremented step by step and are used as main welding materials to achieve different strength matching with the base metal and reach the expected intensity match effect.

The experiment was divided into 6 groups, which were welded by 6 pairs of 300mm*150mm*12mm WELDOX960 steel plate (yield strength of 960MPa) into 6 steel plates with specifications of about 300mm*302.5mm*12mm. Each group was subjected to different intensity matching for welding, and the specific strength matching form can be seen in table 3.

Table 3. Welding Material Tensile Strength Matching Form.

Groups		50-80	80-80	50-85	88-85	50-90	90-90
Backing welding	σb/MPa	525	840	525	880	525	950
Fill and cover welding	σb/MPa	840	840	880	880	950	950

As shown in Table 3, in the group 50-80, the backing welding uses a wire with a tensile strength of 525MPa (hereinafter referred to as 50 wire), and a welding wire with a tensile strength of 840MPa is used to fill and cover the surface (hereinafter referred to as 80 wire); n the group 80-80, the bottom and cover welding both use 80 wire. In group 50-85, the backing welding uses a 50 wire with the filler and cover wire using a tensile strength of 880MPa (hereinafter referred to as 85 wire). And as such, the last set of welding wires use a yield strength of 950MPa (hereinafter referred to as 90 wire). In this way, 6 sets of welds with increasing strength are obtained, namely, six sets including 50-80, 80-80, 50-85, 85-85, 50-90 and 90-90. The following experiments are classified according to this method.

This experiment uses the active gas protection welding (MAG); the protection gas is 86%Ar+14%CO2; the joint form is the butt joint, the plate thickness 12mm; the weld form is 60 degrees V shaped groove and the groove gap is 2.5mm. In order to reduce the influence of welding parameters on different groups, the current, voltage and so on should be kept in a smaller range as much as possible during welding. Therefore, the welding parameters of the different groups are similar and change within the same range. Table 4 shows the welding process parameters used in the experiment. The bead level is 3 layers, 6 passes welding, preheating 100℃ before welding.

Table 4. Welding parameter.

Program	Welding current(A)	Voltage(V)	Welding speed mm/min	Gas flow L/min
Cover welding	110-130	16.7~17.0	61	15
Filling welding	110-130	16.7~17.0	67	15
Backing welding	110-110	16.5~16.8	80	15

3. Experimental results analysis

3.1. The tensile properties of the welded joint

The tensile test results of welded joints are shown in table 1. In the 6 sets of experiments, there are obvious yield outside, and the fracture condition is ductile fracture. As can be seen from the table, the tensile strength of these three groups of 50-80, 50-85, 50-90 is gradually increasing. Although the backing welding material is the same, its influence is small, because the main part of the welding force is filling welding. Under normal circumstances, the mechanical properties of thick plate welds are determined by filling welding, and the role of backing welding as the connection and prevention of cracks is much smaller than that of filling welding [3]. For the plate used in the paper, the 12mm thickness welding proportion is not too large, generally not more than 2mm, but the cover welding and filling welding material is the same, which can play the same role as filling welding, and can withstand greater tension to ensure welding performance. In table 5, the tensile strength of 50-80 is 860.54MPa while the tensile strength of 50-85 is 872.08MPa. The difference between these 2 groups is small, only 11.54MPa, indicating that in terms of the tensile strength, the group of 50-85 did not highlight the corresponding advantages while in the group of 50-90, the tensile strength advantage was most obvious, reaching 946.3MPa. At the same time, the tensile strength of 90-90 reached 973.40MPa, 27.1MPa higher than that of 50-90. This might be due to the higher tensile force, when the 50 welding wire was broken first, the crack source was formed, and then it expanded to the filling and cover surface welding parts, which leads to fracture when the tensile force is relatively low.

Table 5. The tensile strength and elongation of welded joints.

Number	Tensile strength /MPa	Elongation /%
50-80	860.5	12.75
80-80	922.0	10.70
50-85	872.1	12.50
85-85	960. 0	9.30
50-90	946.3	12.33
90-90	973.4	9.20

It can be seen from table 5, the arrangement from large to small of the elongation is just in adverse to that of the tensile strength, that is, the higher the strength of the weld, the lower the elongation, and the lower the plasticity. As can be seen from the table, the elongation in 50-80 was 12.75% while in 50-85, it was 12.50%. There is little difference between the two groups, indicating that the low matching primer layer has little effect on the strength of the plasticity. Considering that the tensile strength of 50-85 is only 11.54MPa higher than that of 50-80, the conclusion is that the overall mechanical performance of 50-80 is better than that of 50-85. The tensile strength of 90-90 is the highest, but its elongation is only 9.20%, nearly half of that of 50-90, which is 12.33%. This shows that the bottom of the 50 welding wire can improve the overall plasticity of the weld, and the difference between the two elongation reached 3.13%. Therefore, the weld strength of 50-90 and 90-90 is relatively higher, especially in the group of 50-90, the plasticity is close to the base metal. The strength of the 50-80 is relatively low, and the plasticity is better. In the group of 50-85, it appears moderate, the strength and plasticity of which are between 50-90 and 50-80, so its comprehensive performance is better.

3.2. The impact testing results and analysis

The impact test is carried out on the JBN-300 pendulum impact test machine, and the results of the absorbing energy of weld center impact are shown in table 6.

Table 6. The absorbing energy of weld center impact.

Groups	Area	Average value AKV/J
50-80	Welds	129.39
80-80	Welds	130.35
50-85	Welds	142.46
85-85	Welds	147.83
50-90	Welds	120.02
90-90	Welds	104.79

Table 6 is the absorbing energy of weld center impact. As can be seen from the table, the weld center impact absorption energy (Akv) in 50-80, 80-80 are 129.39J and 130.35J. The value is basically the same, but there is no difference due to different welding materials. In the same case, there are 50-85 and 85-85. The impact absorption work (Akv) of the two groups are 142.46J and 147.38J respectively. The difference between the two is less than 5J, but the two groups of 50-90 and 90-90 are completely different. The Akv value of 50-90 is 120.02J, and the Akv value of 90-90 is 104.78J, and the difference between the two is 15.24J, which shows that the impact property of the 90 welding seam is improved due to the existence of the 50 welding wire backing layer. We note that in the 50-90 and 90-90, these two groups of weld have the highest tensile strength and lowest elongation, which shows that for high strength, low plasticity of weld, the soft layer will improve the impact property of weld seam, while for weld bead of low strength and better plasticity, such as 80-80 and 85-85, low strength rendering welding has less impact on impact properties, and can even be neglected. Therefore, the Akv value of the two groups of 50-85, 85-85 is the highest, which is to say, its impact toughness is the best, followed by 50-80 and 80-80, and 50-90, 90-90 is the worst.

3.3. Analysis of micro hardness test results

The experimental results of microhardness are shown in figure 2, 3 and 4.

3.3.1 Cover and filling welding hardness. As shown in figure 2, all of the cosmetic welding hardness curves follow the same law: In the weld zone, all the curves are basically paralleled. After entering the fusion zone, the hardness rises suddenly and varies in amplitude, then the curve enters the quenching zone, the hardness decreases greatly, and finally enters the base metal zone, and the hardness rises or falls to reach the hardness of the base metal. As shown in the weld zone, the hardness of the weld is different due to the different welding materials. The change range of 50-80 cosmetic welding hardness is about 300-310HV; the hardness of 80-80 is about 320HV -330HV, and although 50-80 is using the same welding material of cosmetic welding (80 wire), there is still a difference of 10HV-20HV, which is due to small differences in the welding parameters. 50-85, 85-85 welding hardness of the cosmetic welding can be considered the same, and their range of change is smaller than the first two groups, and are at around 270HV -280HV, but it's about 30HV smaller than 50-80 and 80-80. From the previous tensile test data, we can see that the tensile strength of 50-85 is 872MPa, 860MPa greater than 50-80, that is to say, although the micro-hardness of 50-85 is lower by nearly 30HV, it does not mean that its tensile strength is less than that of 50-80. The cosmetic welding hardness of 50-90 is relatively high, reaching about 380HV, and the cosmetic welding hardness of 90-90 is relatively high too, between 360HV-370HV. The difference between the two groups is about 10HV, and the reason is the same as that of the first and second groups, which is the slight difference in welding process.

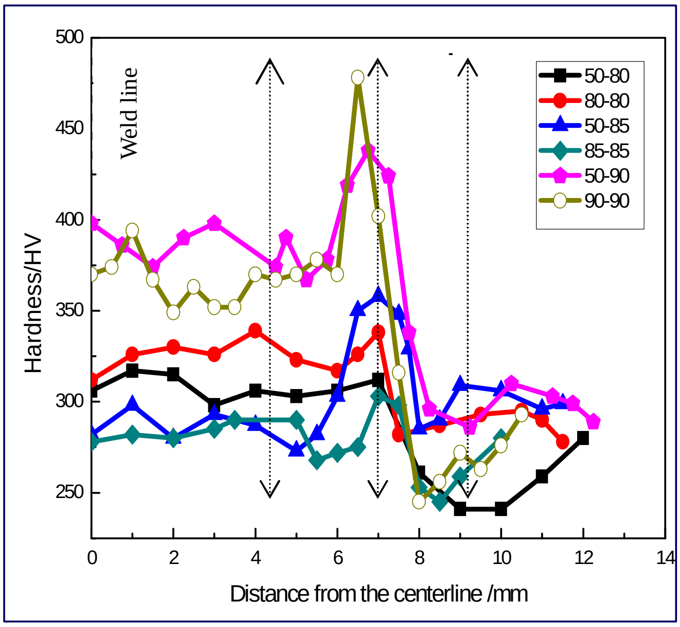

Figure 2. The distribution curve of Cover weld hardness.

In the fusion zone, the hardness of all the basic groups has an upward trend, but the rates of increase are different, in which 90-90 curve is the most sharp, and the highest hardness reaches more than 450HV, followed by 50-90, which is about 440HV. The hardness of the remaining group here is much smaller than that of the two groups. Following 50-90, the group of 50-85 is 350HV; 80-80 is about 340HV; 50-80 is about 320; and 85-85 is the minimum, at around 300HV. The fusion zone is the junction of the weld and the base metal. The part is an incomplete mixing zone, the micro-structure and properties being uneven, and there are a lot of dislocations, so the hardness is relatively higher. However, higher hardness results in embrittlement of heat affected zone, which results in the increase of cold cracking tendency of welded joint and the reduction of impact toughness of heat affected zone. Therefore, the cold cracking resistance of 90-90 and 50-90 is the worst, and the cold cracking resistance of 85-85 and 50-80 is the best, and 50-85 and 80-80 are between them.

In the quenching zone, the hardness values of each group are decreased, and the hardness of the quenching zone will decrease to about 280HV regardless of the hardness of the fusion zone. This is because the quenching zone in the heat affected zone of each group is basically the same, This is because the quenching zone in the heat affected zone of each group is basically the same, which are carbide, ferrite and austenite decomposition products, and this hybrid tissue has lower hardness and less resistance to plastic deformation [4]. In the base metal zone, the hardness of each group has not changed much. The hardness of the base metal is gradually transited from the quenching zone to the base metal, and the hardness of the base metal is about 300HV.

3.3.2 Hardness of filling welding. Figure 3 shows the hardness distribution of the filling welding. Its change rule is basically similar to that of cosmetic welding hardness. From the welding center to the fusion line, the hardness value remains basically unchanged, and the hardness decreases sharply after the curve enters the heat affected zone, and then slowly rises to the base metal region.

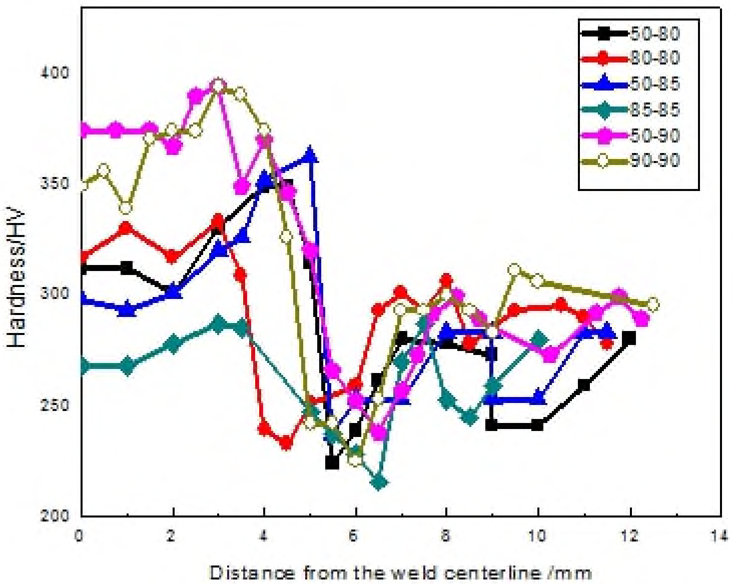

Figure 3. The distribution curve of filling welding hardness.

Unlike cosmetic welding, the hardness of the filling welding does not rise significantly at the fusion line, or let's say, at a very small increase. This is because when the cover welding is carried out, the welding heat input carries out an annealing treatment of the filling welding, so that the non-uniformity of the micro-structure and the performance of the fuse line is greatly improved. Thus, the hardness value is reduced to approximately equal to that of the weld zone. Also, it reduces the hardness of the fusion line and improves the cold cracking resistance of the heat affected zone. In figure 3, the hardness strength of weld zone status are filled and cover welding. 50-90 and 90-90 are the highest, at about 370HV-390HV; 80-80, 50-80 in the middle, the hardness is about 310HV-320HV; and the lowest hardness is the two groups of 50-85, and 85-85, with the hardness respectively 300HV and 280HV. In the heat affected zone, the lowest hardness decreased to less than 250HV, 30HV less than the cosmetic welding, which is 280HV. This is also because the amount of heat on the cosmetic welding softens the annealing process of the filling welding. The hardness curve passes to the base metal zone, and the hardness is about 300HV, which is the hardness of the base metal.

3.3.3 Backing welding hardness of the wire priming in 50-90 and 90-90. The hardness of the backing weld in the group of 50-90 in figure 4 is about 260HV, and the hardness value of the deposited metal is almost 100HV higher than that of the ER50-6 wire deposited metal, which is 159HV. This is because the softer 50 wire metal is attached to the harder 90 wire metal, and the higher the strength of the latter, the higher the restraint on the former, resulting in higher hardness. It can also be explained that the higher the strength of filling and cosmetic welding, the worse the plasticity and toughness. The smaller the stress released by the plastic deformation after welding, the higher the residual stress and the higher the hardness of the backing welding. At the junction of the weld and the heat affected zone, the hardness starts to rise substantially, and the high-point of hardness is higher than the hardness of the base metal because of the uneven number of dislocations in the fusion zone.

The hardness of the backing welding in the 90-90 groups is about 415HV, much higher than that of the 90-90 filling welding (360-370HV) and the hardness of the cover welding (about 380 HV). The main reason is the influence of the backing bead on the welding bead, which leads to the increase of hardness. But in the fusion zone and the heat affected zone, the hardness change law of the 90-90 backing welding and filling welding is similar. In the heat affected zone, the hardness does not rise significantly, then decreases directly, and then smoothly transfers to the base metal.

The higher hardness will lead to embrittlement of the weld, which results in the increase of cold cracking tendency of the welded joint and the decrease of the shock toughness of the weld metal. Thus, the cold cracking resistance of 90-90 and 50-90 is the worst, and the cold cracking resistance of 85-85 and 50-80 is the best, and 50-85 and 80-80 are between them.

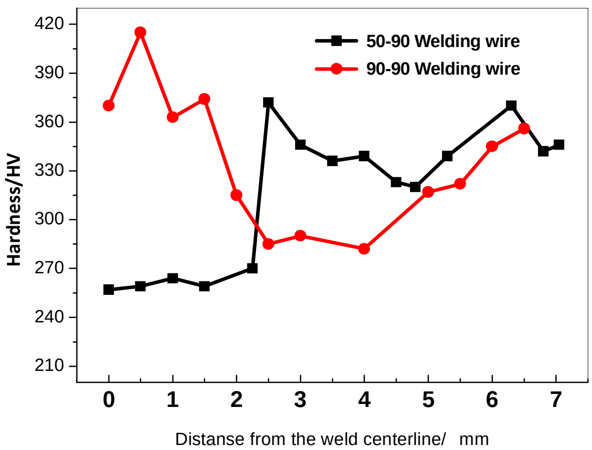

Figure 4. The hardness of backing welding substrate of 50-90 and 90-90 groups.

4. Summary

Except for 50-80, the tensile specimens of each group have obvious deformation after breaking, and there is a certain yield in tensile process, which belongs to ductile fracture.

The tensile strength of welds in the two groups of 50-90, 90-90 is the highest, but the plasticity and weld impact toughness are the worst; the weld strength in 50-80 is the lowest, but the plasticity and weld impact toughness are better; the strength and plasticity of 50-85 are between that of 50-90 and 50-80; the toughness of welding seam is the best, and the comprehensive mechanical property is better.

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For high strength and low plasticity welds, low strength backing layers can significantly improve the impact properties of welds; but for low strength and better plasticity welding bead; low strength backing welding has little impact on impact properties, which could even be ignored.

The micro-hardness of all welds in the two groups of 85-85, 50-85 is the lowest; that of 50-80 and 80-80 are slightly higher, and that of 50-90 and 90-90 are the highest hardness.

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