Study on the Flash Butt Welding of 400 MPa Ultra-Fine Grain Steel

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A 400 MPa ultra-fine grain steel possesses high strength and toughness. Due to its fine grain size, the heat affect zone (HAZ) of the weld joint will soften during welding. The weldability of 400 MPa ultra-fine reinforced steel bar of flash butt welding is investigated by using the micro metallographical examination and macro-mechanical-property tests. The joint of flash butt welding has a superior mechanical property. The HAZ in the weld joint does not show apparent softening. There is only a localized softening spot inside the weld seam, which does not affect the property of the whole joint. Therefore, flash butt welding is appropriate for joining the 400 MPa ultra-fine grain reinforced steel bars. The resulting weld joint has excellent mechanical properties.

Keywords flash butt welding, mechanical property, ultra-fine grain reinforce steel bar

1. Introduction

With the development of industry, more and more types of steel are used in construction and manufacturing. Many countries are trying to develop new types of steel. In 1997, Japanese scientists started the super steel project.[1] In the same year, the project of 21st century structure steel began in Korea. The great fundamental study of new-generation steel known as Projects 973 began in China in 1999. Research into the flash butt welding of 400 MPa ultra-fine grain steel is part of that elemental study. The 400 MPa ultra-fine grain steel is a new-generation steel, which is made of general Q235 steel by the process of grain size fining. Due to its super fine grain and super pure character, the steel has excellent general mechanical properties.[2] The so-called super fine grain denotes grain sizes that range from 0.1-10 um. Super purity is such that impurities found in steel, such as S, P, O, N, and H, are kept <50 ppm. Super purity is the crucial feature of the new generation of steel. When the steel's grain is extraordinarily fine, it ensures an obvious grain growth when undergoing the welding process. Grain growth gives rise to brittleness in the weld joint and HAZ. In addition, the welding heat may lead to softening in the heat affect zone (HAZ).[3,4] These processes directly affect the mechanical properties of the weld joint. Therefore, scientists have been studying the weldability of 400 MPa ultra-fine grain steel ever since the research into the new-generation steel began.

When ultra-fine grain steel is welded, the HAZ will soften because the microstructure softens and re-crystallization softens. When the softened area is narrow, the restriction-strengthening factor may reduce or avoid its negative effect on the joint's mechanical property. If we use high energy density heat source to weld quickly, the width of softened zone will be reduced, which is conducive to maintaining the mechanical property.[5]

A recent study[6] shows that weld joints will not soften, even though the grain of HAZ is greatly enlarged, when we use pulse metal active gas (MAG) arc welding to weld 400 MPa ultra-fine grain steel. The weld joints of deep rolling steel by laser welding will re-crystallize the softened area. But when the area is relatively narrow, the strength of the whole joint will not be affected.

Flash butt welding is a type of resistance welding. Due to its strong points of high speed, high efficiency, no pre-treatment for the base materials, high strength in weld joints, and wide-ranging materials for welding, flash butt welding has recently been applied to locomotives, pipes for long distance transport, steel structures for construction, and other fields of engineering. Resistance welding differs substantially from melt welding process by heating up rapidly at the butts of the weld piece and being self-protective during the flash. So it is essential to in-

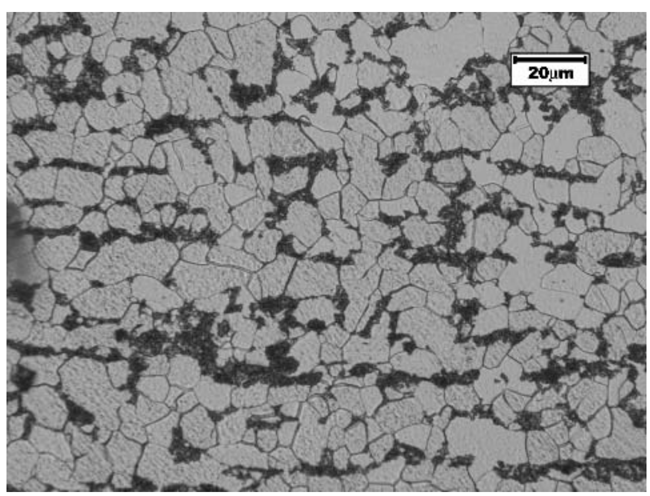

Fig. 1 Microstructure of 400 MPa ultra fine grain reinforcing steel bar

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vestigate the application of 400 MPa ultra-fine grain steel by flash butt welding. The research is instrumental in improving our understanding of the new generation materials.

In this paper, we present our study on the feasibility of applying flash butt welding to the 400 MPa ultra-fine grain steel, our analysis of the microstructure, as well as the change of hardness of HAZ, and our discoveries regarding flash butt welding and its effect on the softening of HAZ.

2. Experimental Materials and Experimental Method

The experimental materials, reinforced steel bars rolled by thermo-mechanical control process (TMCP), and distortion inducible ferrite transformation (DIFT) based on the Q235C, are made in the Huaiyin Steel Factory, Jiangsu Province, China. The diameter of each bar is 20 mm and the average grain size is approximately 7 um. The microstructure is made up of ferrite and pearlite. Figure 1 and Table 1 show the chemical composition and mechanical properties of 400 MPa ultra-fine grain reinforce steel bar, respectively.

An electric cam-welding machine is used in the experiment. We used continual flash welding to weld. Elongation L is 25 mm and flash time is 11 s.

After welding, we obtained the metallographic specimens and hardness specimens, which are placed in a 3% solution of nitric acid alcohol. We then analyzed the microstructure under an optical microscope and mapped the distribution of the microhardness.

3. Results and Discussion

3.1 Metallographic Structure

The ultra-fine grain steel used in the experiment is made by refining the ferrite grain through deformation inducing coales-

Table 1 The Chemical Composition (wt.%) and Mechanical Property of 400 MPa Ultra-Fine Grain Reinforcing Steel

C	Si	Mn	P	S	Cr, Ni	Cu	σ_b, MPa
0.18	0.19	0.60	0.015	0.009	≤0.3	0.17	526.4

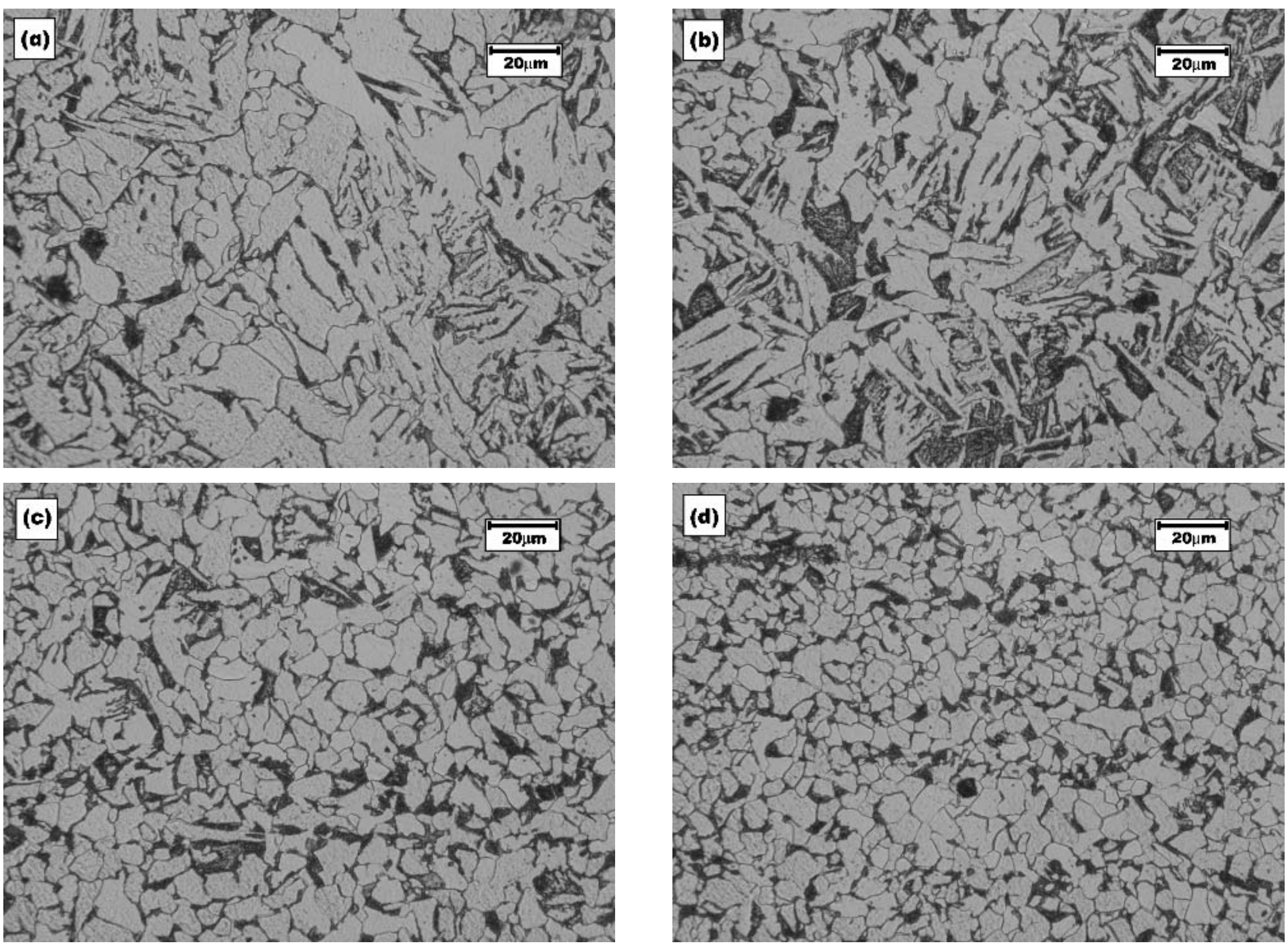

Fig. 2 Microstructures in different zones of flash butt weld joint using 400 MPa ultra-fine grain reinforcing steel bar: **(a)** weld seam ×200; **(b)** fusion zone; **(c)** coarse grain zone and fine grain zone; **(d)** fine grain zone

cence. As no micro alloy ingredients are added to the steel to form stable particulates under high temperatures, the grains in the HAZ show obvious grain growth when subject to flash welding, but the expansion is not severe.

Figure 2 shows microstructures in different zones of flash butt weld joint using 400 MPa ultra-fine grain reinforcing steel bar. The weld joint is made up of decarbonized microstructure, which is mainly ferrite. Its grain size is 6-7 um. As the figure shows, the fusion area is made up of ferrite and wiedmanstatten structure; in the over-heated area, fine grain area and parent material are all made up of ferrite and pearlite.

3.2 Mechanical Property

The tensile and bending experiments are made of weld joints with flash butt welding. The results are listed in Table 2.

Tensile and bending results are satisfactory. All the tensile specimens are ruptured at the parent materials. The average tensile strength is 529 MPa. Results show that flash butt welding using ultra-fine grain steel guarantees good mechanical properties of weld joints.

A hardness test of the central area and the margin area of a ϕ20 mm flash butt welding joint are shown in Fig. 3.

As Fig. 3 shows, the hardness at the edge of the joint is less than that at the edge of HAZ, and also less than that at the central area. The hardness at the edge of the joint is almost equal to the hardness at the central part of the parent material. However, HAZ is not softened, compared with the parent material.

Table 2 The Results of Tensile and Bending With Flash Butt Welding

Specimens	Load, kn	σ_b, MPa	Location of Fracture and Character of Rupture Surface	Bending Angle 90°
No. 1	166	528.4	Ductile rupture in the parent material	No crack
No. 2	166	528.4	Ductile rupture in the parent material	No crack
No. 3	167	531	Ductile rupture in the parent material	No crack

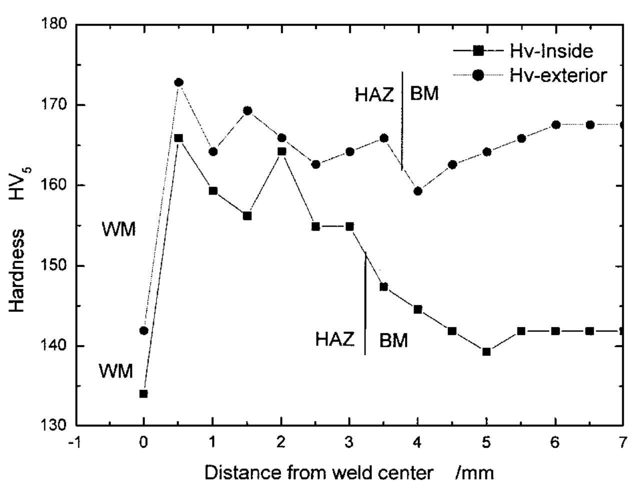

Fig. 3 Hardness distribution of flash butt welding joint

From the hardness distribution curve of the joint's core part, we can easily see that the hardness of HAZ is more than that of central parent material. No softened area could be found in HAZ.

The hardness of both HAZ and the parent material at the edge of the steel bar is obviously more than the hardness of HAZ and the parent material at the core. This is related to the rolling process of ultra-fine grain steel bar. As Fig. 2 shows, though the parent material is composed of ferrite and pearlite, hardness distribution of ultra-fine grain steel manifests the above characteristics because the quantity of pearlite keeps increasing steadily from the center to the margin along its path.

Through tests of draw and bend, we found that the strength of the weld joint is relatively high. The plasticity of the joint is good, and the whole joint is not softened.

The extent to which local softness in the weld joint affects the joint's overall strength is controlled by other factors such as the width of local softening area, the size of welding, and the strength matching of the joint. The local softening of flash butt welding occurs only at the core part of the joint. Due to the narrowness of the softened area and the increase of "restriction intensifying" effect in the case of undermatching, the entire weld joint retains its strong mechanical property.

4. Conclusion

(1) In the case of choosing the proper weld parameters, flash butt welding is suitable for 400 MPa ultra-fine grain steel bar, and the joints thus made by flash butt welding turn out to have excellent properties.
(2) During the welding process using 400 MPa ultra-fine grain steel bar, coarse grains will appear, but the joint is not softened obviously.
(3) The joint of flash butt welding by using 400 MPa ultra-fine grain steel bar demonstrates good draw, bend, and plasticity properties.
(4) The locally softened core part of the joint of flash butt welding does not affect the overall property of the joint.

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