Flash butt welding on microstructures and mechanical properties of joints for high strength acid resistant steel

Hongyan Wang, Xiuhua Gao*, Chi Yu, Wang Li, Tong Li, Linxiu Du

The State Key Laboratory of Rolling and Automation, Northeastern University, Shenyang 110819, China;

Abstract—In this research, the 600 MPa acid resistant steel was used as flash butt welding base material, to study the effect of different upset allowance on the microstructure and mechanical properties of the joints. The results can be obtained as follows: with the increase of the upset allowance, it has a significant effect on the elongation, the ferrite content in the heat affected zone increases, and the joint strength first increases and then slowly decreases. When the upset allowance is bigger than 4mm, there are wide and large bainitic ferrites in the coarse grained zone, the joint strength deteriorates sharply. When the upset allowance is 3-4mm, the mechanical properties of the welded sample are the best, the tensile strength is 686-708MPa, the yield strength is 610-636MPa, the elongation is higher than 13.77%. The steel matrix can be strengthened effectively by forming grain refinement and dispersed granular bainite with proper upset allowance. The different hardness distributions of welded joints to display the difference of microstructure in different regions.

1. Introduction

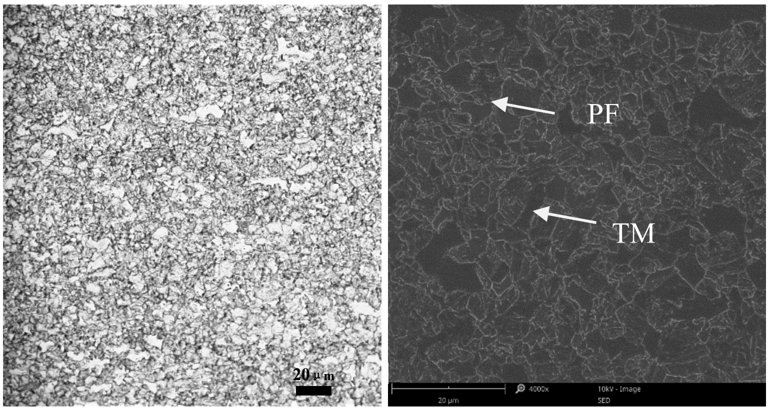
Nowadays, the marine flexible risers used to transport oil and gas in the exploitation of deep-sea oil fields mainly rely on imports, which seriously restricts the exploitation of deep-sea oil and gas resources[1]. In order to accelerate the pace of deep sea or ultra-deep sea oilfield exploitation, some researchers have carried out basic research on acid-resistant steel for marine flexible risers, including the strengthening mechanism, fatigue property and corrosion resistance mechanism of acid resistant steel were investigated[2]. However, there are relatively few literature reports on welding of acid-resistant steel in marine flexible risers. In the process of offshore oil exploitation, the marine flexible risers withstands high pressure and high concentration of H_2S and CO_2 corrosion gas in crude oil during the transportation process. The long-term service of internal corrosion gas can penetrate through the sealing layer, which will cause high strength acid resistant steel produced many unexpected corrosion[3, 4]. Compared with the base material, welding joints are very easy to cause corrosion failure, causing marine environmental pollution and significant economic losses. Therefore, in order to ensure the safety of flexible risers service process, it is necessary to study the basic research on the welding of acid resistant steel for high strength marine flexible risers, which can be applied to the welding process of low alloy and high strength steel in acid environment. Flash butt welding has the advantages of high thermal efficiency, no need to add welding rod metal, short welding cycle and so on. After matching welding parameters, high quality joints can be obtained[5]. However, the flash butt welding process of quantifying multiple process parameters is complicated[6]. Different parameters changes will lead to differences structure and performance of welded joints[7, 8]. Therefore, it is necessary to study the influence of single parameter on the structure and performance of high-strength acid-resistant steel respectively, in order to provide a theoretical basis for the systematic study of flash butt welding process parameters in the later stage.

In this paper, the 600 MPa high strength acid resistant steel was used as flash butt welding base material to study the effect of different upset allowance on the microstructure and mechanical properties of welded joints. The emphasis was placed on the influence of different upset allowance on the microstructure evolution of heat-affected zone and hardness properties of welded joints.

2. Experimental materials and methods

The chemical composition of 600 MPa high-strength acid steel (wt.%) is 0.06C, 0.002S, 0.005P, 0.9Cr, 0.9(Mn+Mo), 0.18Si, 0.03(Nb+Ti), 0.02Al, and balanced by Fe. After hot rolling, cold rolling and heat treatment, the final microstructure of the welded base metal is polygonal ferrite (PF) and tempered martensite (TM), as is shown in Fig.1. This kind of high strength acid steel tensile strength and yield strength can reach about 732 MPa and 659 MPa.

*E-mail: gaoxiuhua@126.com



(a) OM (b) SEM

Fig. 1 Microstructure of base metal.

Before the welding experiment, the welded base metal with dimensions of 70 mm×10 mm×4 mm was employed. In order to obtain a good welding effect, the surface of the welded sample was polished to remove the oxide film. During the welding process, UN-100A pneumatic flash butt welder is selected for welding experiment equipment, The primary voltage is 380 V and the rated power is 150 kVA. The welding process is divided into three stages: flash, upset and rest. The flash stage, the two end faces of the test steel are slowly approached and then two end faces touch each other, meanwhile, the large current goes through the touching point, heating metal and burning away the uneven and dirty dirt at the contact point of two parts. In the upset stage, a certain upset force is applied to the weldment to ensure the two parts are joined connection, and the molten metal with oxide slag or impurities are extruded. Through several flash butt welding experiments, determine the welding parameters: flash current 400A, welding current 270A, flash allowance 7mm, extension length 20mm. The flash butt welding experiment of test steel are studied by different parameters of the upset allowance, and the upset allowance was set as 3mm, 4mm and 5mm respectively.

The scanning electron microscope (Supra55 Sapphire) and metallographic microscope (DMI 5000M) is used to observe the microstructure of the welded joint. The electrinic universal testing machine (WDW-3100) is used for tensile test of welded joint samples, the tensile strain rate is set as 1mm/min. The hardness of different areas of the welded joint is measured using a digital vickers hardness meter (MHV-50Z), during the tests, in the direction perpendicular to the welding interface, the load was 24.5N and the loading time was 10 s, the distance between each sampling point is 0.5mm, each sample was measured three times and then averaged.

3. Test Results and Discussions

3.1. Microstructural characterization of HAZ

the OM microstructure at low magnification of the welded joint are shown in Fig 2. According to the characteristics, the section of welded joint can be divided into three parts: weld zone (WZ), heat affected zone (HAZ) and base metal (BM). The heat affected zone is very wide, which has great influence on properties of the joints, it can be divided into coarse grain zone (CGHAZ), mixed grain zone (CFGHAZ) and fine grain zone (FGHAZ). The microstructure of the CGHAZ has large grain size, the microstructure of FGHAZ has more uniform and fine, The CFGHAZ is a transition zone between the CGHAZ and the FGHAZ. Compared with the structure of CGHAZ, the FGHAZ is slowly heated up to more than Ac_3 in the welding process, and the duration time is relatively short. This region is equivalent to normalizing heat treatment, and the grain size is the smallest.

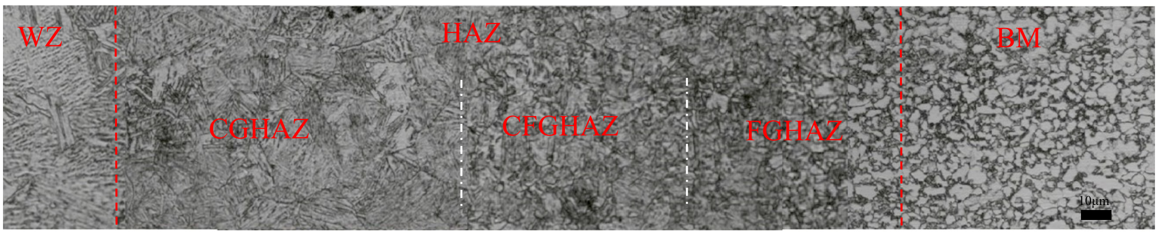
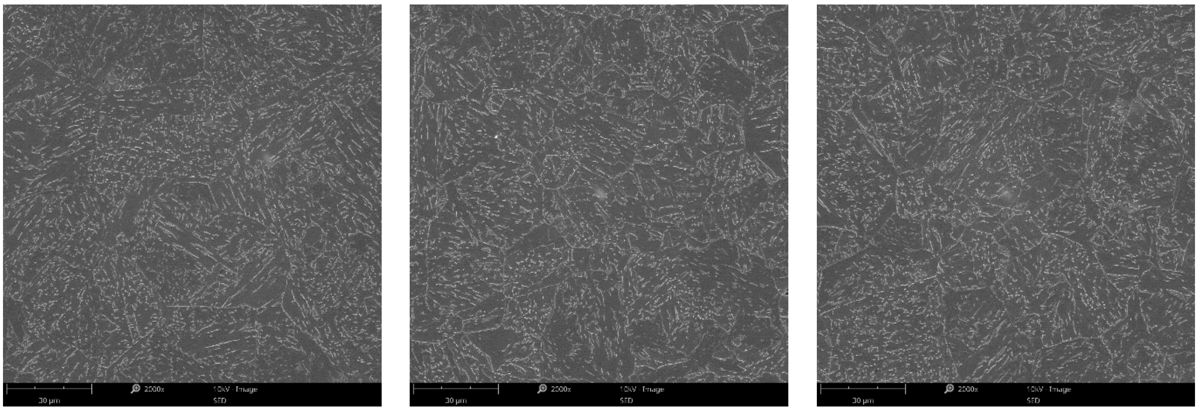
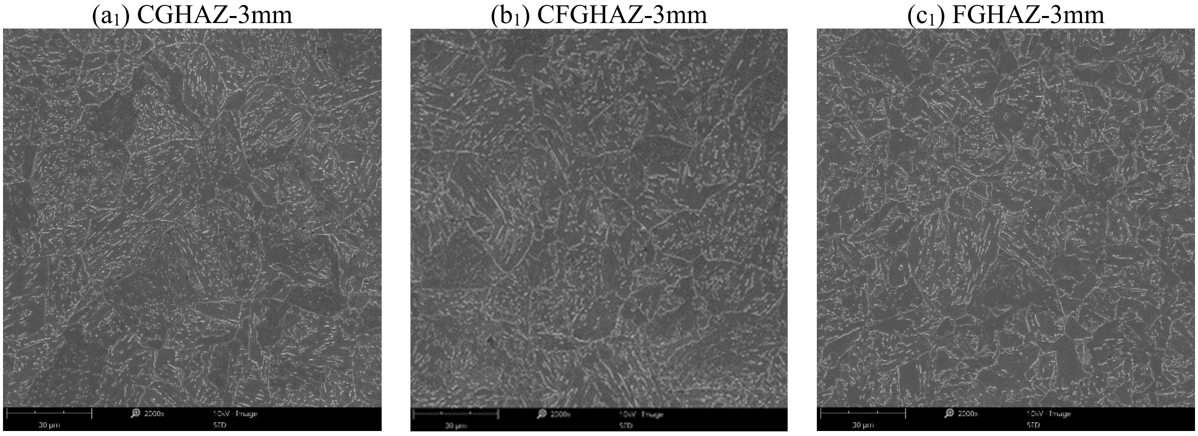


Fig.2 the OM microstructures of welded joint

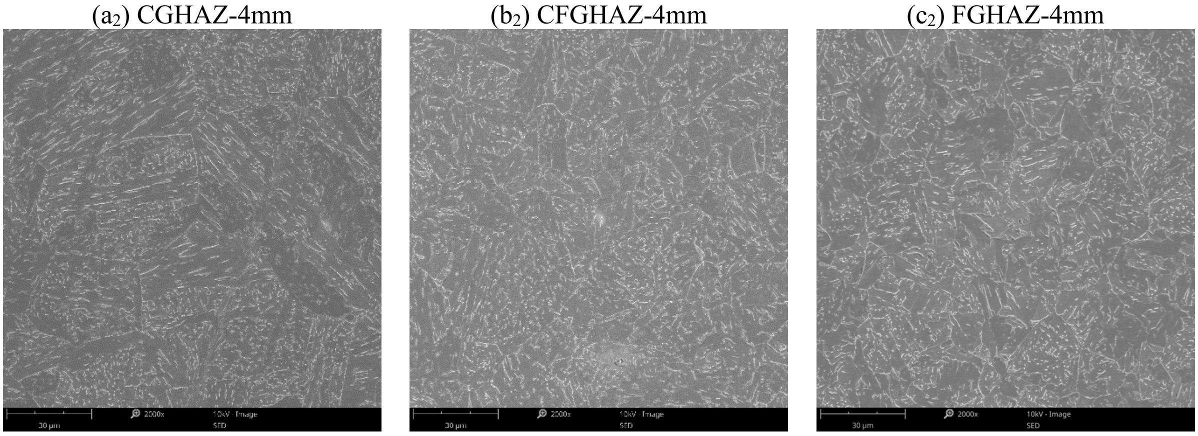
The microstructure of HAZ under different upset allowance are shown in Fig.3. It can be found the microstructure of the heat affected zone is a mixture of ferrite and bainite, but there are obvious differences between the grain size of ferrite and the morphology of bainite. under the condition of 5mm upset allowance, a lot of wide bainitic ferrite structure appeared in the CGHAZ, as shown in Fig.3(a_3). When upset allowance is 4mm, more fine acicular ferrite and fine bainite ferrite have been found in the CGHAZ in Fig.3(a_2). The upset allowance 4mm ensures sufficient plastic deformation, partial dynamic recrystallization be occurred during the upset process, to obtain a good match between strength and plasticity. From Fig.3(a_1) we can see that a lot of wide bainitic ferrite and polygonal ferrite with coarse grains structure appeared in the CGHAZ. As can be seen from FGHAZ of the joints under different upset allowance, acicular ferrite gradually disappears and polygonal ferrite increases with the increase of upset allowance, its structure is fine and uniform ferrite and bainite. The upset allowance affects the ferrite grain morphology, precipitated phase size and distribution.



(a_1) CGHAZ-3mm (b_1) CFGHAZ-3mm (c_1) FGHAZ-3mm



(a_2) CGHAZ-4mm (b_2) CFGHAZ-4mm (c_2) FGHAZ-4mm



(a_3) CGHAZ-5mm (b_3) CFGHAZ-5mm (c_3) FGHAZ-5mm

Fig.3 Microstructures of HAZ of joints under different upset allowance

3.2. Tensile properties of joints

Fig.4 shows the changes of tensile strength, yield strength and elongation under different upset allowance conditions. As can be seen from Fig.5, the mechanical properties of welded samples are significantly different. When the upset allowance is 5mm, the tensile strength and the yield strength of the joints is up to 631MPa and 573 MPa, respectively. Combined with Fig.3(a_3), due to the presence structure of hard phase bainitic ferrite, the CGHAZ has a large number of lamellar bainite with obvious directionality, ferrite elongation and granular bainite uneven distribution, the strength and plasticity of the joint decrease. When the upset allowance reaches3-4mm, the tensile strength of the joints is up to 686-708MPa, and the yield strength is 610-636MPa, the elongation is higher than 13.77%. According to Fig.3(a_1-c_2), the appropriate upset allowance is conducive to the formation of more fine polygonal ferrite and granular bainite in the HAZ under thermal influence, ensuring sufficient plastic deformation and partial dynamic recrystallization during the upset process to obtain good mechanical properties of the joint. Fig.5 shows the fracture position of the tensile test specimen, upset allowance is 5mm, the fracture position is in the HAZ, the upset allowance is 3-4mm, and the fracture position is in the BM. It can be seen from Fig.3, the upset allowance affects the ferrite grain morphology, precipitate size and distribution, resulting in strength of joints have major changes, and the joints elongation increases with the increase of the upset allowance.

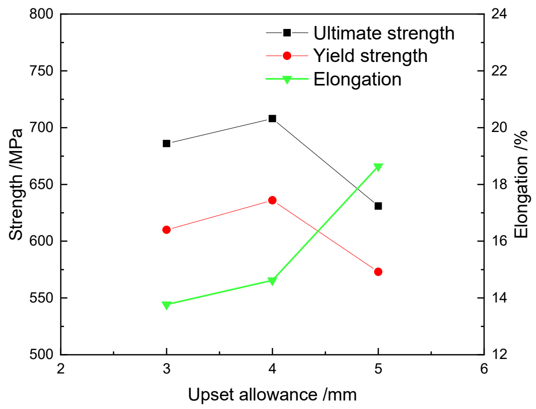


Fig.4 effect of upset allowance on the properties of welded joints

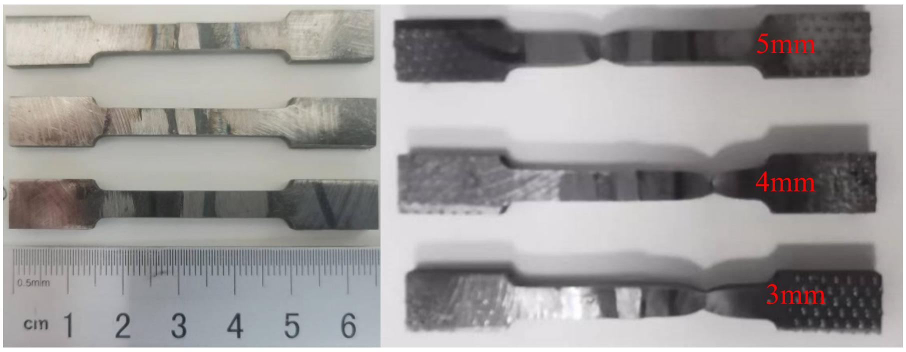


Fig.5 tensile test specimen of welded joints

3.3. Vickers hardness of joints

As observed in Fig.6, the hardness distribution of the welded joint under different upset allowance processes. It can be divided into three parts: WZ, HAZ and BM.

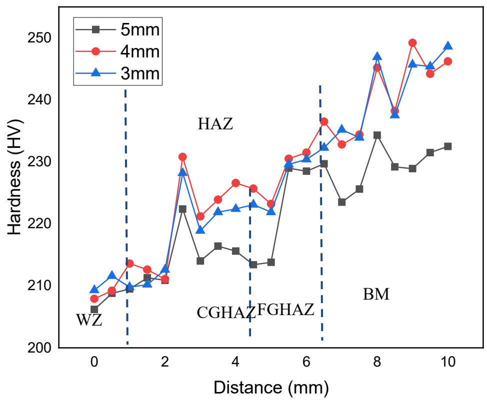


Fig.6 Welded joints hardness distribution of sample

The hardness increases slowly with the increase of the distance from the WZ. When the upset allowance is 5mm, the HAZ has obvious softening occurs and the hardness curve presents a double trough. It can be observed from Fig.5. The softening of HAZ will lead to the fracture at the HAZ, combined with Fig.4, its strength is also lower than the base material. The main reason may be that the influence of welding thermal cycle on toughness and microstructure, the irregular temperature gradient distribution in the HAZ leads to changes in the microstructure, the lamellar bainite and ferrite grains in the CGHAZ are coarse, resulting in softening phenomenon in the region. The temperature gradient distribution on FGHAZ is gently, because this zone far away from WZ, which is equivalent to normalizing. The structure type and grain size changes a little and second phase strengthening effect, the hardness of the FGHAZ and the BM distribution is relatively uniform.

4. Conclusion

Detailed structural characterizations and mechanical properties of joints of high strength acid resistant steel are made. The main conclusions of research can be drawn:

(1) When the upset allowance is 4 mm, the structure of HAZ of welded joint is composed of polygonal ferrite and granular bainite, the tensile strength and yield strength are 708 MPa and 636 MPa, reached the required standard of 600 MPa acid-resistant steel. Compared with the base material, the yield strength decreases by 3.5% and the average tensile strength decreases by 3.3%.

(2) When the upset allowance greater then 4mm, the wide bainitic ferrite structure is found in HAZ , grain size increases, the granular bainite structure is reduced and distributed unevenly, which weakens the joint mechanical property.

(3) The hardness distribution of welded joints shows that WZ has the owest hardness value. The HAZ microscopic structure is wide and inhomogeneity, resulting in large fluctuations in hardness. The FGHAZ and BM has the highest hardness and stable hardness distribution due to its uniform organization.

Acknowledgments

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