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Rijun Zhang[1], Qiyou Wu[2], Lin Wang[3], Chao Zeng[4], Xiangjiang Wang[5*]

[1]China Nuclear Industry Maintenance CO, LTD, Shanghai City, 201103, China

[2]School of Mechanical Engineering, University of South China, Hengyang City, Hunan Provice, 421001China

[3]China Nuclear Industry Maintenance CO, LTD, Shanghai City, 201103, China

[4]College of Innovation and Entrepreneurship, University of South China, Hengyang City, Hunan Provice,421001 China

[5]College of Innovation and Entrepreneurship, University of South China, Hengyang City, Hunan Provice, 421001China

[*]Corresponding author's e-mail: wangxiangjiang72@163.com

Abstract: This paper mainly studies the welding of stainless steel 321 and carbon steel Q245R dissimilar steel. Welding tests of stainless steel 321 and carbon steel Q245R are carried out by A-TIG welding method. The effect of active agent on weld penetration, weld formation and inner hole slag inclusion is studied. The mechanical properties of welded joints is measured by tensile and bending mechanics tests, and the macroscopic and microscopic structures are observed. Furthermore, these tests and research results are compared with conventional TIG welding. The results show that the welding of dissimilar steel with A-TIG welding method is well formed, and there are no pores, cracks and slag inclusion in the weld. The weld microstructure of the two welding methods is mainly austenite and ferrite. In the Q245R side heat affected zone (HAZ), the migration of carbon elements is obvious, but the A-TIG welding joint is superior to the conventional TIG welding in strength and toughness.

1. Introduction

As a new energy source of development potential and development value, nuclear energy has been paid more and more attention to its lasting, safe, economic and clean advantages. Up to now, China has become the world's largest country in the construction of nuclear power projects. The construction of the whole nuclear power project involves a variety of materials, technologies and equipment, and the construction is extremely complex. There are many kinds of materials used, and all kinds of materials are connected together through welding. The interaction is greatly influenced, and the principle of action is more complex. At the same time, some problems will be produced. In the welding process of heterogeneous metals, there are great differences in the physical properties, chemical properties and chemical composition of base metal, these differences will lead to many defects in the welding process, such as carbon migration, residual stress of weld, non fusion of different species of gold, and corrosion of different metals. These are the main reasons for the failure of key facilities and equipment in nuclear power projects.

Many welding experts and scholars at home and abroad have done much experimental research on dissimilar steel welding and achieved good achievement. Bensheng Huang et al.[2] Studied the microstructure and mechanical properties of Q345/316L dissimilar steel welded joints. The results show that the welded joint obtained by welding wire with high Cr and Ni content has excellent comprehensive properties, and the weld seam of the joint are mainly austenite and vermicular or skeletal delta ferrite distributed on the austenite matrix. On the side of Q345, the carbon element migrates and diffuse toward the weld, but the migration of other alloy elements is not obvious, the alloy element dilution is not obvious, and there is no alloy element segregation phenomenon, which ensures the corrosion resistance of the metal. The microstructure and properties of the welded joint of Q345R and S30408 dissimilar steel are analyzed by Wei Xin[3]. It is found that with the increase of heat treatment temperature, carbon increase from the side weld of Q345, which wide the decarburization layer and the weld seam at the Q345R side, and the best heat treatment temperature after welding is 550℃. The microstructure and mechanical properties of the welded joint of T92/Super304H dissimilar steel are studied by Qi Zhang[4]. It is found that the HAZ on the T92 side is composed of massive delta ferrite and carbide particles along the grain boundary of the original y, and the fine crystal area is a fine Soxhlet structure. The grain size of y in Super304H side HAZ is obvious, and a lot of fine second phase particles are distributed in the fine-grained zone.

So far, few studies have been made on the welding of Q245R/321 dissimilar steel, especially for the welding of dissimilar steel by A-TIG welding. Yan Yin and others have studied the weld ability of A-TIG welding for high end cutters[1]. It is found that compared with the conventional TIG welding, A-TIG welding can effectively reduce the weld width and significantly increase the penetration. There are no defects in the weld, such as porosity and inclusion, and the addition of active agent does not affect the tensile mechanical properties and corrosion resistance of the welded joint. In this paper, A-TIG welding and conventional TIG welding are used to compare the Q245R/321 dissimilar steel (in which the conventional TIG welding wire is ER309L). The microstructure of the welded joint, the fusion part of the joint and the mechanical properties of the joint are mainly studied. It will provide a theoretical basis for the implementation of nuclear power construction projects in the future.

2. Test method

2.1. test material

Base metal carbon steel Q245R and stainless steel 321, specifications are 400mm * 130mm * 5mm. The wire is ER309L, and the diameter is 1.9mm. In order to prevent the corrosion of halide elements to stainless steel, the active agents in this test are all oxides: SiO_2, Al_2O_3, MnO_2, Cr_2O_3, Fe_2O_3 and B_2O_3. The effect of the same oxide on the weld penetration of carbon steel and stainless steel is different. The effect of different oxides on the weld penetration of the same kind of base metal is also different. Some oxides increase the weld penetration depth, but make the weld width larger, such as SiO_2, Some oxides have little effect on weld penetration, but their deposited properties are better, such as Cr2O3. A large number of experiments were carried out in the early stage to study the effect of these oxides on weld. In order to integrate their good characteristics, It is matched in proportion and verified by experiments. The formula of active agent of good welding effect for both Q245R and 321 welding is found out.

Table 1. Chemical composition of the parent material and welding wire (mass fraction,%)

Material	C	Si	Mn	S	P	Ni	Cr	Ti	Mo	Cu
Q245R	0.16	0.14	0.60	0.003	0.011	0.01	0.02	0.002	0.0017	0.01
321	0.08	0.75	2.00	0.02	0.035	11.00	18.00	0.40	-	-
ER309L	0.026	0.38	2.11	0.008	0.017	12.50	23.56	-	0.20	0.07

Table 2. Mechanical properties of Q245R and 321 at normal temperature

Material	tensile strength （σ_b/MPa）	Yield strength （σ_s/MPa）	elongation δ/%
Q245R	465	321	30
321	620	280	46

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2.2. test equipment and methods

The welding equipment adopts WSM-315D type all digital DC pulsed argon arc welding machine, and the welding method is manual tungsten inert gas arc welding. Before the formal welding test is carried out, the Q235R and 321 surface of the welded steel plate were first worn out with the grinding machine, the oxide film on the surface is removed, the metallic luster is exposed, and then the surface is wiped with alcohol to remove the surface oil. The Q245R and 321 test plates are butted seamlessly, and spot welding is fixed at both ends of the plate. The powder is made to be sticky with anhydrous ethanol. At the same time, it is evenly coated with a flat nylon brush on the surface of the metal to be welded. The coating thickness is about $0.013g/cm^2$ and the coating width is about 20mm. After the volatile ethanol is completely volatilized, the sample is fixed on the platform to be welded. Because there is stainless steel in the sample to be welded, the argon filling device is needed on the back of the weld, so as to prevent the back of the weld from being oxidized during welding.

Table 3. welding condition

welding method		welding current I/A	Welding voltage U/V	Welding arc length L/mm	welding speed $v/(m \cdot h^{-1})$	shield gas flow rate $q/(L \cdot min^{-1})$
A-TIG	Bottom welding	110	12.0～14.0	1	3	15
	cosmetic welding	100	11.0～13.0	1	3	15
Conventional TIG	Bottom welding	90	10.0～12.0	1	3	15
	Filling welding	100	11.0～13.0	1	3	15
	cosmetic welding	100	11.0～13.0	1	3	15

2.3. test process

In the welding process, avoiding the influence of non-human factors on the test results as far as possible. In order to study the influence of activating agent on the penetration depth, weld width and weld microstructure, A-TIG welding and conventional TIG welding adopt the same welding standard. The thickness of the test plate is large, A-TIG welding makes the back of the weld penetrated, and at the same time, there will be a certain degree of sag in the weld face. In order to successfully pass NDT, the welding wire cover should be treated on the front of the weld. Therefore, A-TIG welding single side welding and double-sided molding is only aimed at thinner plates. When the thickness of the sheet is relatively thick, the surface treatment is required to achieve the standard.

It is difficult to evenly coat the pads on the surface to be coated with brush. In the welding process, it is found that the are shrinkage is obvious, the weld pool is opened rapidly and the sink will spread around the weld, which will make the weld weld wider. when the active agent is thicker; the are shrinks slightly, the weld pool opens, the pool water sinks, and it does not spread around When the coating is thinner. By comparison, when the active agent is thinner, the welding effect will be better.

3. Test results and analysis

3.1. Macroscopic Comparison of conventional TIG (bevel) welding and A-TIG welding seam

The Q245R/321 dissimilar steel A-TIG welding is better applied to the specific engineering projects that can be used later. This test uses manual argon arc welding, so the weld formation is not very uniform, but all meet the requirements of the welding standard. Figure 1.(a) and Figure 1.(b) are the macroscopic morphology of the front of the weld of the A-TIG and the conventional TIG. It can be seen that the A-TIG welding is larger than the conventional TIG weld weld, and the heat affected zone of the weld seam of the A-TIG welding is also larger. This is due to the large welding current in the A-TIG welding process, which is equivalent to the greater heat input of the welding, so the heat affected zone of the weld is larger. At the same time, with the welding ground, the temperature of the weld zone is getting higher and higher, there is a tendency to increase in the heat affected zone. Figure 1.(c) and Figure 1.(d) are macroscopic morphology on the back of A-TIG and conventional TIG welds. It can be clearly seen that the back of the weld of A-TIG weld is completely penetrated, without slag, unfusion and edge bite. Compared with conventional TIG welding, the back forming of the weld is not uniform, and the metal is black and bright yellow. After analysis, it is found that the welding wire is welded on the cover surface and the back of the weld is filled with argon gas, which causes the heat of the weld on the back of the weld to be oxidized by oxygen in the air, which causes the back of the weld to be black and then polished to show the bright color of the metal.

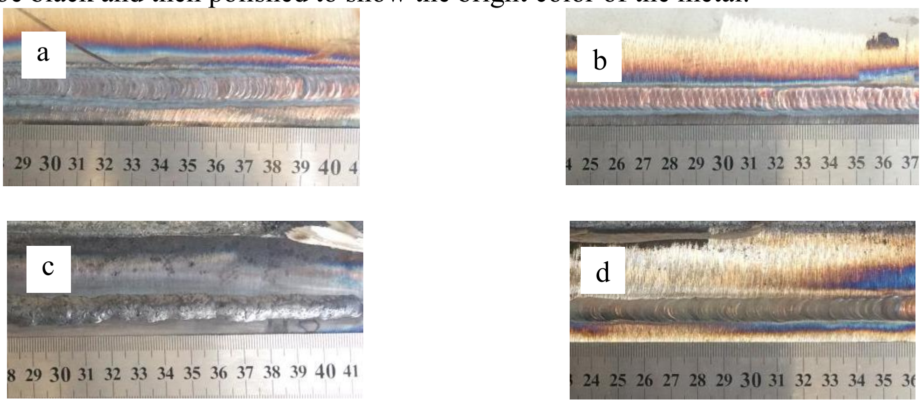

Figure 1. Macro morphology of weld surface. (a) The front of A-TIG welding (b) The front of the conventional TIG welding (c) The back of A-TIG welding (d) The back of conventional TIG welding

3.2. Macroscopic metallographic and microscopic metallography of welded joints

3.2.1. Macroscopic metallography of welded joints

The welding joint specimen is grinded until the surface is smooth and the metallic luster appears. Then it is put into the corrosion inhibitor of ferric chloride hydrochloric acid solution. After 10min, it is taken out, rinsed with hot water immediately, rinsed with alcohol, and dried with hot air, then the macroscopic observation of gold phase is carried out.

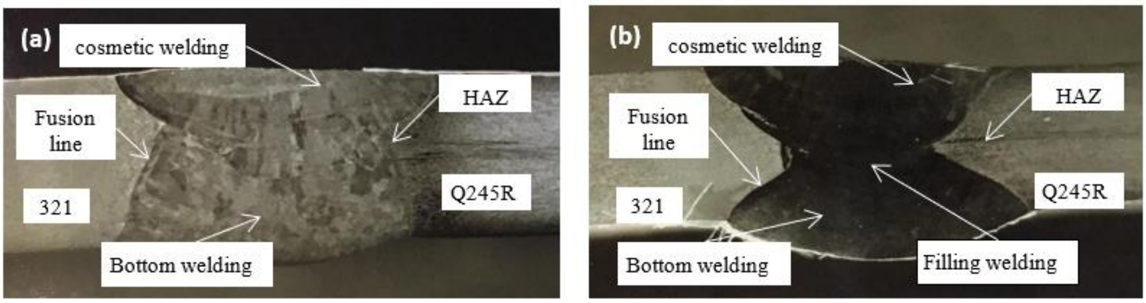

Figure 2. Macroscopic metallographic diagram of welded joint. (a) Macroscopical metallography of A-TIG welding joint (b) Macroscopic metallography of conventional TIG welding joint.

Figure 2.(a) is macroscopic gold phase diagrams of A-TIG welded joints. Figure 2.(b) is the macroscopic metallographic diagrams of conventional TIG welded joints. The fusion line, heat affected zone (HAZ) and welding procedure of the welded joint and the base metal can be clearly seen from the diagram. A-TIG welding and conventional TIG welding have obvious "blackening" phenomenon on the Q245R side of heat affected zone, and A-TIG welding is more obvious. This area is called superheated zone, which is called coarse crystal area. When heated to more than 1100 degrees Celsius, the austenite grain in the region begins to grow rapidly, especially at 1300 degrees centigrade, and the grain is very coarse. Because of the coarse grain size, the welchween structure appears in the condition of cooling after welding, which greatly reduces plasticity and toughness. But it has little

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effect on strength.

3.2.2. Microstructure of welded joint
In order to better study the microstructure and properties of the weld, we observe the microstructure of the weld joint, the heat affects zone on the Q245R side, and the 321 side heat affected zones. The welding seam and the 321 side heat affect zone are etched by the ferric chloride solution, so that the weld microstructure of the 321 austenitic stainless steel can be better displayed. The Q245R side heat affected zone is eroded with nitric acid and alcohol solution, which could make the pearlite black, increase the lining of the pearlite region, display the grain boundary of ferrite, and distinguish the ferrite and martensite.

Figure 3. Microstructure of A-TIG welding joint. (a) HAV structure of 321 sides of stainless steel (b) Microstructure of weld (c) HAV structure of Q245R side of carbon steel.

The microstructure of A-TIG welded joint Q245R/321 dissimilar steel joint weld, fusion line and base metal heat affected zone (HAZ) on both sides is shown in Figure 3. As can be seen from Figure 3.(a), the fusion zone between the weld and the 321 side is about 50μm, which is made up of a small, discontinuous and discontinuous ferrite distributed on the austenite matrix. At the same time, it is obvious that there are some ferrite inclusions between austenite and solid solution near the 321 side. The analysis shows that, because of the high heat input of A-TIG welding, the fluidity of the molten pool is strong and the temperature of the 321 edge is high, some ferrite will be precipitated in the austenite grain boundary during the cooling process after welding. Figure 3.(b) shows that the microstructure of the weld is austenite and vermicular or skeletal delta ferrite, and the white austenite is distributed with black delta ferrite, which separates the intergranular relation between the austenite. In the process of welding, the ferrite is changed to austenite slowly, and the cooling rate of the weld after welding is faster. This leads to incomplete transformation of ferrite to austenite and the formation of delta ferrite in the remaining delta ferrite nuclei[10,12,13]. According to the pseudo two phase diagram of the solidification crystallization of the weld metal, it is found that when the ratio of chromium and nickel is between 1.5 and 2 is the FA solidification mode, the ferrite is the initial precipitate, and some austenite is formed before the end of solidification. Figure 3.(c) is the microscopic metallographic phase in the heat affected zone of the Q245R side. It can be seen that the boundary between the heat affected zone of the Q245R side and the weld line is distinct, made up of pearlite and ferrite, and the grain near the weld side is obviously grown up, which is mainly caused by the close proximity of the weld to the weld, the large heat input and the higher temperature. At the near interface of the Q245R side, the pearlite decreased obviously, almost all of the ferrite, and the black carburized layer appeared on the side of the weld, which is generally called the carbon migration overlayer. Due to the influence of the alloy elements in the weld and fusion zone, carbon atoms begin to diffuse during the welding process. The carbon content of HAZ in the Q245R side decreases, the microstructure of pearlite decreases, and the content of ferrite increases, until the pearlite in HAZ vanishes and turns into ferrite.

Figure 4. Microstructure of conventional TIG welding joint. (a) HAV structure of 321 sides of stainless steel (b) Microstructure of weld (c) HAV structure of Q245R side of carbon steel.

Figure 4. is the microscopic metallographic structure of weld joint, fusion line and heat affected zone (HAZ) of Q245R/321 dissimilar steel joints in conventional TIG welding joints. In Figure 4.(a), the relative Figure 3.(a) between the 321 sides and the weld seam does not form a wider zone of fusion, and the boundary between the weld and the heat affected zone is obviously visible. The analysis shows that during the conventional TIG welding process, the heat input is smaller than that of the A-TIG welding. The ferrite in the austenite structure in the 321 parent material is also less during the post weld cooling process, which leads to the obvious dividing line between the 321 side HAZ and the weld seam. Figure 4.(b) shows that the welds of conventional TIG welding are uniform, ferrite is typical vermicular, and the orientation is basically the same, similar to that of columnar crystal growth. The interface between weld and Q245R heat affected zone in Figure 4.(c) is clear. There is an obvious decarburization zone near HAZ on the Q245R side, and the migration of carbon element is obviously enhanced.

In the welding process of Q245R and 321 dissimilar steel, the phenomenon of carbon diffusion and migration on both sides of the weld fusion line is called "upper slope diffusion". The driving force of the diffusion is the chemical position gradient of carbon, which is caused by the large difference in the mass fraction of the alloy elements such as Cr and Ni between the Q245R low alloy steel and the weld seam. In iron carbon alloy system, Ni, Mn, N and other elements can promote Austenite Formation, Cr, Si, Al, Mo, Ti and other elements are ferrite forming elements. The active agents used in A-TIG welding contain a large number of alloy elements such as Cr, Si, Al, Ti and other alloy elements. Compared with conventional TIG welding, dense ferrite is distributed in the weld structure of A-TIG welding, such as Figure 3.(b) and Figure 4.(b). In conventional TIG welding, there are more austenites and a small amount of ferrite in the weld microstructure obtained by using ER309L welding wire. There are a small number of dendrites and finer grains in the weld. This is because the wire contains a lot of Cr, Ni and a small amount of Mo. During welding, Cr and Mo reduce the diffusion rate of carbon in austenite, slow down the formation of austenite, while Ni has opposite effect[5,7,9]. The Cr content in the welding wire is about two times the content of Ni, so the austenite growth is inhibited, and the austenite microstructure of the obtained weld is small. Due to the rapid cooling rate after welding, the carbon can not be fully integrated into the austenite, and Cr promotes the formation of ferrite, so a small amount of ferrite is distributed in the weld.

From the kinetic point of view, the diffusion of carbon in the welding of 321 austenitic stainless steel and Q245R low alloy steel is a reaction diffusion process. In the diffusion process, the solubility of carbon in the solid metal and the liquid metal is very different. When the low alloy steel and the weld pool contact each other during the crystallization process, the diffusion conditions are formed around the weld pool area. Because the solubility of C in Q245R and stainless steel welds is different, the carbon atoms will be diffused from the Q245R base material with higher carbon content to the weld with lower carbon content. At the same time, it will be accompanied by the diffusion of carbides in the Q245R steel to the side of the stainless steel weld and the formation of chromium carbide on the side of the weld. The final result is that the more stable carbides are produced at the joint fusion line.

In the initial stage of carbon diffusion, carbon is diffused outward from the weld area of low alloy steel with high carbon content. The stainless steel welds contain a large number of chromium elements with strong affinity for C, resulting in the diffusion of carbon to the weld under the affinity of chromium and the production of C-Cr compounds on the side of the weld. To achieve equilibrium, the carbide in Q245R low alloy steel is continuously dissolved to supplement the absence of C. The result is that after a period of migration and diffusion, the decarburization zone will be produced near the fusion line at the Q245R side, and the carbon element is enriched continuously on the weld side, eventually producing the carbon increasing zone. This is the reason why there is obvious "blackening" phenomenon in the macro metallography, A-TIG welding and conventional TIG welding on the Q245R side of the heat affected zone.

4. conclusion

(1) The welded joint with good performance can be obtained by using A-TIG welding and conventional TIG welding for Q245R/321 dissimilar steel. The weld structure of the joint is mainly austenite and the worm like or skeletal delta ferrite distributed on the austenite matrix.

(2) Welding of Q245R/321 dissimilar steel with A-TIG welding. The activating agent has a solid solution strengthening effect on the weld microstructure, thereby improving the strength and toughness of the weld.

(3) A-TIG welding of Q245R/321 dissimilar steel can significantly increase the weld penetration, and the welding joint has no defects such as gas holes, inclusions and cracks. It is superior to conventional TIG welding in economic, process and other aspects. At the same time, the welding joint is superior to conventional TIG welding in strength and toughness.

(4) When Q245R/321 dissimilar steel is welded, there is a phenomenon of migration of carbon to weld line on the Q245R side, which has a certain effect on the performance of welded joint.

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