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Effect of Ni on microstructure and mechanical properties of underwater wet welding joint

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ABSTRACT

Underwater wet welding was performed in the present work, and different Ni contents from 0.19 to 5.18 wt.% in underwater weld metal are obtained by the addition of Ni into the covering of electrodes. The joints are welded in fresh water by welding diver in the experimental pool with the water depth of 3 m, and then analyzed by OM, XRF, SEM and EDS. The emphasis is placed on studying the effect of the Ni content on the variation regulation of the microstructure, tensile strength and low-temperature toughness of the underwater wet welding joint. Base on the experimental results, the relation of Ni content and the joint quality of underwater wet welding is established, and the optimal Ni content is determined.

1. Introduction

In underwater wet welding, the mechanical properties deterioration of weld metal is the most important problem that must be solved, which is induced by the rapid cooling rate and high hydrogen content [1,2]. To adjust the slag-system and alloy-system of welding materials is deemed to be one of the most effective methods [3,4]. Ni plays an important role in solid solution strengthening and fine grain strengthening in the steel. The lattice constant of γ-Fe is 3.64 Å. The alloying elements, such as Ni, Mn, Si and Cr, can replace Fe atom from γ-Fe, which results in the lattice distortion and the increasing of lattice constant. Subsequently, the strength of weld metal will be increased [5,6]. Ni is one of the elements which are beneficial for the stabilization of austenite. It can enlarge austenitic area and lower the transformation temperature from austenite to ferrite. So a certain addition of Ni can help suppress the formation of coarse pro-eutectoid ferrite (PF) in the weld metal, which can improve the mechanical properties of the weld metal [7,8]. In addition, good low-temperature toughness and corrosion resistance are important for weld reliability when steel serves in the underwater environment. Ni, as an important element of low-temperature steel, has significant effect on the weld impact toughness [9,10]. The addition of Ni can decrease the brittle transition temperature and make the weld more suitable for underwater conditions.

Ni and O can promote the nucleation of second phase. The dispersive distribution of small second phase particles can promote the formation of acicular ferrite (AF), refine the grain and improve the microstructure and mechanical properties of the weld metal. Studies suggested that the excellent low temperature impact toughness could be guaranteed by a certain content of Ni and Mo in the weld [11]. If the Ni content in weld metal is increased from 0 to 2.5 wt.%, the weld bending angle can be increased from 70° to 180°. However, the Ni content should not be more than 2.5 wt.%, otherwise bainite and martensite trends to be formed and reduces plastic toughness. Keehan found that the critical point of the Ni content depended on the Mn content [12]. If the critical point was exceeded, −40 °C Charpy impact energy could be reduced significantly. Evans pointed out that the addition of Ni could increase the AF content in weld when Mn content was below 1.0 wt.%. However, if Mn content was higher (about 1.4 wt.%), the weld toughness reduced when the Ni content was more than 2.25 wt.% [13]. Ni, is different from Mn and Si, has limited oxidation and burning loss in the process of underwater welding and can achieve a higher transfer coefficient (the transfer coefficient is not affected by factors such as water depth, pressure and so on). So Ni should be focused on during the design of welding material.

In the process of underwater welding, the crystallization time of molten pool is short because of faster cooling rate. So the original austenite grain cannot grow fully. Because the original austenite grain size directly affects PF content after solid-state phase transformation, the smaller austenitic grain can induce more PF content. This is inconsistent with the purpose of getting more AF [14,15].

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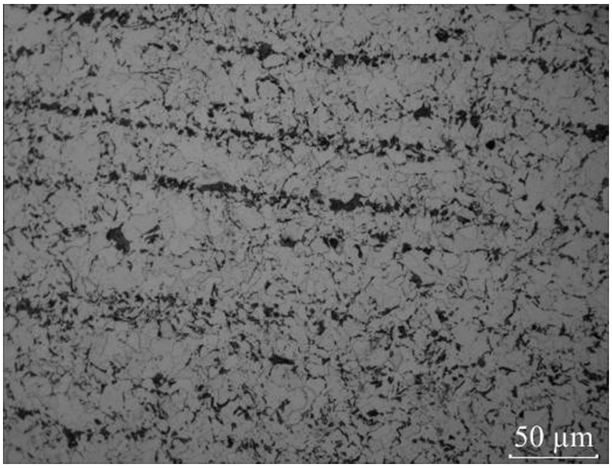

Fig. 1. Optical micrograph of the base metal E40 steel.

The adding of element Ni can reduce austenitic transformation temperature and inhibit nucleation of high temperature eutectoid products so as to increase mechanical properties of the weld. Until now, the effect of Ni on microstructure and mechanical properties of underwater wet welding joint is rarely reported. In this paper, the relationship of the Ni content and the joint quality of underwater wet welding is explored.

2. Experimental procedures

As the optical micrograph shown in Fig. 1, the base metal EH40 steel dominantly consists of fine granular ferrite and pearlite. Chemical compositions of the base metal and the electrodes rod metal are given in Table 1. Eight kinds of self-developed electrodes with different contents of Ni added in covering are manufactured, which are named A0–A7.

The base materials are machined into V-groove with groove angle of 45°, root opening of 7 mm and thickness of 14 mm. The plates are restrained by a backing plate to simulate actual high restraint fabrication conditions. Multipass welds are deposited using the shielded metal arc welding (SMAW) process. The welding process is carried out with a welding power source operating on direct current electrode negative at a nominal 190 A. Welding trials are performed in fresh water with depth of 3 m in the experimental pool.

The tensile tests are conducted on a universal testing machine (UTM5000, China) with capacity of 500 kN at room temperature. For preparing the tensile test specimens, the backing plate is removed and the root and face of the welds are ground. Vickers hardness test is also conducted on the across section to study the transition in microstructure of the joint. A diamond pyramid indenter is used with a 50 gf load for 15 s. Impact toughness of weld metal is measured using standard Charpy V-notch impact test at room temperature and 0 °C. For microstructural examinations, specimens' cross-sections are ground with 1500-grit emery papers and final polished by diamond paste. Microstructural observation is performed using optical metallography (Olympus GX51, Japan), scanning electron microscope (Hitachi S-4700) and attached energy dispersive X-ray spectroscopy (EDS). The tests and preparation of the specimens mentioned above are carried out according to the Specification for Underwater Welding ANSI/AWS D3.6-2010.

Table 2
Chemical composition of underwater weld metal (wt.%).

	C	Mn	Si	S	P	Al	Ni	Fe
A0	<0.2	0.692	0.37	0.014	0.02	0.014	0.19	Rest
A1	<0.2	0.83	0.47	0.014	0.01	0.013	1.52	Rest
A2	<0.2	0.729	0.38	0.017	0.028	0.004	2.04	Rest
A3	<0.2	0.683	0.27	0.006	0.007	0.021	2.45	Rest
A4	<0.2	0.689	0.42	0.013	0.025	0.029	2.81	Rest
A5	<0.2	0.748	0.395	0.018	0.038	0.021	3.16	Rest
A6	<0.2	0.734	0.36	0.0015	0.041	0.02	4.26	Rest
A7	<0.2	0.718	0.39	0.0014	0.039	0.019	5.08	Rest

3. Results and discussion

3.1. Influence on microstructure

The chemical compositions of underwater weld metal achieved from manufactured electrodes with different Ni contents in the covering are shown in Table 2.

The microstructures of weld metal with different Ni concentration are shown in Fig. 2. It can be seen from Fig. 2(a) that some coarse granular PF with the width of 10–30 μm distribute on the boundary of columnar grain, which will induce the degradation of toughness of weld metal [16]. The coarse PF on the grain boundary will provide a path for crack growth. So it has great effect on the mechanical properties. The microstructure in the weld metal varies prominently with the Ni content variation. The temperature of ferrite transformation is decreased to suppress the formation of PF with the increase of the Ni content in the weld metal. The microstructure is transformed from coarse granular PF with the width of 10–30 μm to strip PF with width of 3–5 μm. The quantity of side plate ferrite (SPF) increases in the weld metal with the Ni content of 1.52 wt.% as shown in Fig. 2(b), and 20–30% acicular ferrite exists in the weld metal with the Ni content of 2.45 wt.%, as shown in Fig. 2(d). With further increase of the Ni content, ingrown upper bainite along the prior austenite grain boundary exists in the weld metal with the Ni content of 3.16 wt.% and 4.26 wt.%, while the quantity of hard and brittle phase of martensite–austenite (M–A) component increase. With the highest Ni content of 5.08 wt.%, ferrite almost disappears and is replaced by the coarse lath martensite and bainite. Low temperature eutectic forms on the grain boundary because of the segregation of Ni, which induces a crack with length of over 100 μm, as shown in Fig. 2(i).

According to the preliminary analysis of metallographic photos, the quantity of ferrite nucleation increases in the prior austenite grain in the weld metal with the Ni content of 2.04 wt.% and 2.45 wt.% due to the refinement of PF. Furthermore, a certain amount of AF is obtained, which is regarded as an ideal weld microstructure. AF is a transformation product at intermediate temperatures, whose formation temperature range is between 650 °C and 500 °C. With the addition of Ni, the stabilization of austenite increases and the undercooling of austenite transformation enlarges, which are beneficial for the formation of AF [17,18]. The microstructure of AF in the weld metal with the Ni

Table 1
Chemical compositions of base and electrodes rod metal (wt.%).

	C	Si	Mn	Cr	Al	Mo	Ti	Cu	Ni
Base metal	0.14	0.33	1.5	0.04	0.043	0.011	0.002	0.06	0.025
Electrodes rod	0.1	0.03	0.4	0.02	–	–	–	0.1	0.03