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Application on Welding Technology of Thick Pump Pipes

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Abstract: 15NiCuMoNb5-6-4 steel is Cu-Ni-Mo alloy; it has been widely used in power station industry such as boiler steam drum and pipes of the water supply system. Welding of 15NiCuMoNb5-6-4 thickness pipes is needed in the pressure pipes installation. The pipe system works under the condition of high pressure and temperature, in addition to the inner surface of pipes will be overlaid the stainless steel that helps the pipes to resist corrosion. Thus, the welding procedure becomes the key point for the installation quality-control. By using GTAW and SMAW method, the proper welding procedure is carried out, and welding procedure qualification test has been passed and metallographic microstructures analyses of welding joints are conducted. The results show that this procedure can ensure the mechanical property and corrosion resistant performance of weld joints.

1. Introduction

The pump test platform is to be built, the design temperature for the piping system of the test platform is 350℃, the design pressure is 180 bars, the maximum flow is 30000m3/h, inner working medium is deionized water. 15NiCuMoNb5-6-4 steel is used as the main loop pipes, while the inner surface of pipes will be overlaid the stainless steel that resist corrosion. The purpose of overlaying stainless steel on the inner surface are to decrease the pipe thickness and the system weight, also to reduce the system cost and to meet the high cleanliness requirement for main pump piping system.

In Germany material standards VdTÜV 377/3, this steel is named 15NiCuMoNb5 (WB36), material number is 1.6368; According to Europe Union standard EN10216.2 (2002), the material nameplate is 15NiCuMoNb5-6-4; In ASME code cases, this steel is called 1.15Ni-0.65Cu-Mo-Nb; In Chinese national standards GB5310, it is named 15Ni1MnMoNbCu. Because of its excellent yield strength and tensile strength, it has been used at the environment temperature of below 450℃; in addition the good machining performance and welding property allow it to be applied in power station industry worldwide [1-3].

Welding of 15NiCuMoNb5-6-4 forged and bored thickness pipes is needed in the pressure pipes installation project, the maximum pipe diameter is up to 1321mm, the minimum thickness is up to 65 mm. Special dimensions of pipes and high performance requirement for weld joints determine the importance and complexity of welding procedure. Thus, it’s necessary to establish the reasonable weld procedure for ensuring the quality of joints.

2. Experimental work

2.1 Chemical Compositions

Table 1 shows the standard value and re-check value of material chemical composition. Table 2 lists the mechanical property.

Table 1: Chemical Composition of 15NiCuMoNb5-6-4

Element	C	Mn	Si	S	P	Cr	Mo	Ni	Cu	Nb
Standard value	0.10~0.17	0.80~1.20	0.25~0.50	0.015	≤0.025	≤0.30	0.25~0.50	1.00~1.30	0.50~0.80	0.020~0.080
Re-check value	0.15	0.96	0.34	0.006	0.007	0.2	0.28	1.05	-	0.022

Table 2: Mechanical Property of 15NiCuMoNb5-6-4

Item	$R_m/N•mm^{-2}$	$R_{eL}/N•mm^{-2}$
Standard value	620~780	≥440
Re-check value	669	590

2.2 Welding Performances

(1) 15NiCuMoNb5-6-4 performance analysis

As showed in Table 1, 15NiCuMoNb5-6-4 is bainite steel that containing metallic elements Ni, Cu, Mo and trace Nb. The element components and material smelting process have been optimized that are helpful for improving material application performance [4]. Nb element that exiting make the grain of steel more finer; Cu element precipitates that contribute in strengthening the matrix as well as increase steels strength at high temperature, but Cu is red hot brittleness, adding the Ni element aims to eliminate its effect that Cu element caused. Usually, the ratio of Cu and Ni is controlled on the average that is 1:2, this aspect should be considered when choose the welding material.

(2) Sensitivity of cold crack and reheat crack

Weldability of 15NiCuMoNb5-6-4 is good, but this steel has certain tendency for cold crack, so preheating before welding and tempering treatment that eliminates the stress after welding are needed. At the same time, this steel has the possibility of generating the reheat crack. 15NiCuMoNb5-6-4 steel, therefore, should be conducted heat treatment after welding, and welding material must be chosen at the same strength level [5].

2.3 Welding Material

Based on application experiences and pipes technical conditions, welding materials are chosen and shown in Table 3.

Table 3: Welding Material

Product	Trade designation	Size/mm
Welding rod	T Union GT Mo	Φ2.4
Welding rod	GTS-309MoL	Φ2.4
Welding rod	GTS-316L	Φ2.4
Welding electrode	T Phoneix 3K Ni	Φ3.2/Φ4.0

2.4 Sample Preparation

Clear the rust and greasy dirt on sample's surface via polishing should be required before welding. Unfitness of the butt joint is controlled below 3mm and weld groove takes "V" shape, as drew in Figure 1.

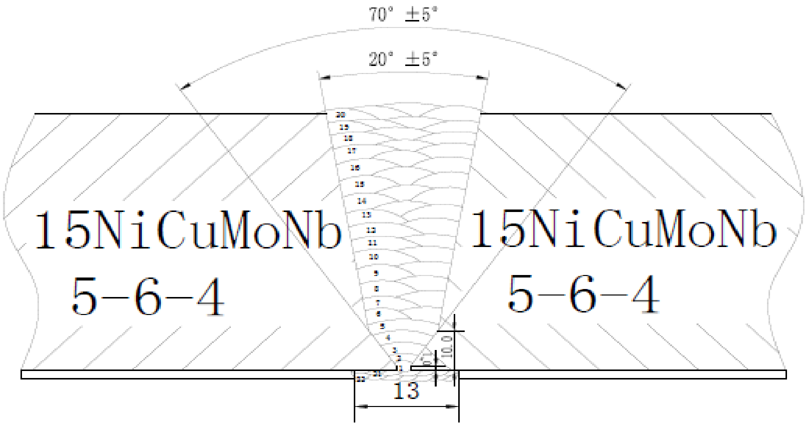


Figure 1: Weld Groove Shape

3. Welding process

3.1 Welding Method

On the basis of material property, applied condition and experiences, this test chooses argon-arc welding (TIG) as base welding and shielded metal arc welding as filled layers' welding; the filled layer use multi-layer and multi-pass welding technology. For ensuring the good welding quality, the sample should be preheated to above 120℃. The maximum temperature difference between the weld pass is controlled at 350℃.

After welding, the weld should undergo heat treatment that the temperature is at 350℃ for 3h. UT/MT will be conducted in 48h after cooling. During the welding, the transition layer of inner corrosion-resistant surface should be preheated the temperature being controlled between 120℃ and 150℃, then take PT in 48h after cooling action; When the final covered corrosion-resistant layer is welded, PT should be performed; the heat treatment of the whole welding sample will be carried out. For post-weld heat treatment parameter is at 550℃ for 3h, then UT/PT/MT check the welding and heat treatment quality.

The welding process parameters are listed in Table 4.

Table 4: Welding Details

Welding method	Filler material	Size of Filler Material/mm	Type of current/Polarity	Current/A	Voltage/V	Wire Feed Speed/mm min^{-1}	Heat input /kJ cm^{-1}
Gas Tungsten Arc Welding(GTAW)	T Union GT Mo GTS-309MoL GTS-316L	Φ2.4	DCEN	120~140 140~160 100~120	12~14 16~18 10~12	45~55	15.7~26.1 24.4~38.4 10.9~19.2
Shielded Metal Arc Welding STAW)	T Phoneix3K Ni	Φ3.2/Φ4.0	DCEP	110~130/140~150/140~160	20~25/25~30	60~70/70~80/80~100	18.9~41.1

4. Welding procedure qualification test

According to NB/T47014-2011 and the project technology requirements, the welding process is conducted, after completing the corresponding heat treatment and non-destructive testing above described. Tensile test, bending test, intergranular corrosion test, chemical composition analysis of welding, high temperature tensile test and metallographic observation are carried out [6-7].

4.1 Non-destructive Testing

In accordance with NB/T47013-2015<Nondestructive Testing of Pressure Equipments>, welding seam should be performed UT and MT after welding and post-heat treatment. The test results show that there are no defect and nonbonding parts for the weld seam. PT is conducted in the transition layer and corrosion-resistant layer. The test result indicates there is no crack.

4.2 Tensile Test

On the basis of GB/T228 -2021, the test requires the specimen to be cut in two different locations of the welding seam, every welding joint specimen is divided into three samples along the thickness direction, and this test has six samples in total. Tensile test results are listed in Table 5.

4.3 Bending Test

Sample should be conducted side-bend test according to NB/T47014-2011; the thickness of test sample is 10mm. Bending diameter is 4a and bending angle is 180°. There is no crack for the test samples. The result shows the plasticity of overlayer meet the requirements.

Table 5: Tensile Test

Sample No.	Tensile Strength /N ·mm^{-2}	Crack Location
1-1-1	645	Base metal
1-1-2	610	Base metal
1-1-3	645	Base metal
1-2-1	645	Base metal
1-2-2	625	Base metal
1-2-3	640	Base metal

4.4 Chemical Composition Analysis

In accordance with NB/T47014-2011, the chemical content on where 0.5~1mm distance away from surfacing layer is measured. The results are listed in Table 6.

Table 6: Chemical Composition of Corrosion-resistance Layer

Elements	C	Mn	Si	S	P	Cr	Ni	Mo
ER309MoL	0.018	1.76	0.55	0.007	0.02	23.5	13.7	2.12
ER316L	0.013	1.62	0.45	0.011	0.017	18.5	12.2	2.62

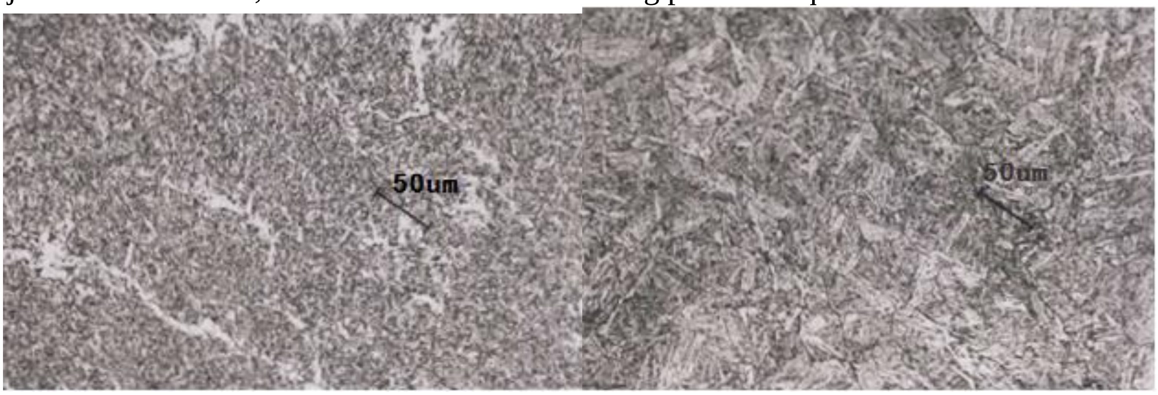
4.5 Inter-granular Corrosion Test

Inter granular corrosion is one form of corrosion where corrosion develops along the grain boundaries of metal or alloy, but the grain has slightly corrosion. Inter granular corrosion greatly weakened the binding force between the grains, even mechanical strength of the material has been completely lost in some serious situation.

For testing the corrosion resistance capacity of Ni-based alloy welding layer, the inter granular corrosion test is conducted according to GB/T4334-2020 (Corrosion of metals and alloys-Test methods for intergranular corrosion of stainless steels).The result shows no corrosion tendency for welding layer.

4.6 Metallographic Microstructures of Welding Joints

To understand the welding procedure impacts on joints, macro-metallographic and micro-metallographic tests are conducted. The results show there is no gas pores, slag inclusion, cracks, and incomplete fusion in the cross section of the joint. The micro-metallographic of weld seam and heat-affected zone are seen in the Figure 2. The weld metal zone consists of proeutectoid ferrite, needle-like ferrite, pearlite, sorbite and slightly granular bainite; The heat-affected zone is composed of sorbite and bainite. It's clear that no nocuousness appeared and the microstructure of weld joints looks refined, and that indicates this welding process is qualified.



Welding Seam 200× Heat-affected Zone 200×

Figure 2: Micro-metallographic of Weld Metal Zone and Heat-affected Zone

5. Conclusions

(1) 15NiCuMoNb5-6-4 steel is alloy of Cu-Ni-Mo type, which is sensitive to cold crack and hot crack. By using this welding procedure, the qualified welding joints can be obtained.

(2) This procedure takes argon-arc welding as backing welding and shield metal arc welding as filled layers welding; The filled layer used multi-layer and multi-pass welding technology, and cleared the rust and greasy dirt on the surface before welding, controlling the input energy and weld-pass temperature. The welding procedure qualification indicates tension test, bend test and intergranular corrosion test can meet the corresponding requirements.

(3) The weld metal zone consists of proeutectoid ferrite, needle-like ferrite, pearlite, sorbite and slightly granular bainite and heat-affected zone is composed of sorbite and bainite. The result shows that no nocuousness appeared and the microstructure of weld joints looks refined, and that indicates this welding process is qualified.

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