Welding of Gas-Tight Pipe Walls Made of Composite Pipes of 3R12/4L7 Steel

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Abstract. The paper presents the results of macro and microstructure testing, hardness measurements and tensile test of submerged arc welded joints of composite pipes made of two grades of steel with X6CrNi18-10 steel flat bars intended for operation in elevated temperature. The outer part of the composite pipe is made of Sandvik 3R12 steel (grade ASME 304L/SA) and has austenitic microstructure, whereas the inner pipe – of Sandvik 4L7 steel (grade ASME SA-210A1) and has ferritic pearlitic microstructure. The results of the tests were used as a base to elaborate the Welding Procedure Specification allowing to obtain high quality joints with correct structure and high mechanical properties.

Introduction

So far, seamless pipes intended for operation in elevated temperature in the power industry have been produced of non-alloy steel and high-temperature creep resisting steels and alloys. Applying composite pipes made of two types of steel connected with each other by rolling in such temperatures is an innovative solution. Their production is beneficial both for economic and technical reasons. Composite pipes are applied when external and internal conditions, in which the pipe is used, extremely differ from each other and require such material properties that cannot be met by one material. As the composite pipes can withstand such severe conditions while maintaining required properties they can be used as an alternative for non-alloy steel. The results prove that after longer time of operation at the correct parameters, the microstructure does not change and shows no significant signs of corrosion [1, 2].

Composite pipes are also used for manufacturing more critical elements, such us elements of recovery boilers. These elements are to increase the stress corrosion cracking resistance, raise the fatigue resistance and improve the structural stability. In order to obtain a corrosion-resistant weld having optimal mechanical properties, the mechanical welding of composite pipes is performed by using non-alloy filler metal for welding normal quality carbon steel and austenitic filler metal for welding that part of the pipe, which is made of stainless steel. Properly made welds of the composite pipes are resistant to stress corrosion cracking (SCC) and do not have a tendency to brittle cracking [3-9].

Material for tests

The material for test were pipe-flat bar fillet joints with composite pipes with the dimensions of ∅ 50.80 x 5.08 mm made of two grades of steel. The outer pipe is made of Sandvik 3R12 steel (grade ASME 304L/SA) and has austenitic microstructure, whereas the inner pipe – of Sandvik 4L7 steel (grade ASME SA-210A1) and has ferritic pearlitic microstructure. The flat bar with a thickness of 6 mm is made of X6CrNi18-10 steel and has austenitic microstructure. The chemical composition of the steels used to make the tested joints is shown in the Table 1. Submerged arc welding (SAW 121) was performed using LNS 304L welding wire (ISO 14343: S 199L) ∅ 2 mm and P2007 Lincoln flux (ISO 14174: SA AF2 64 AC H5 2-20).

Table 1. Chemical composition of the composite pipe and flat bar [mass %]

Steel	C	Si	Mn	P	C	Cr	Ni	Mo
3R12 (304L/SA)	0.012	0.36	1.19	0.023	0.0052	18.47	10.12	0.29
	V	Ti	Cu	Al	Nb	N		
	0.050	0.009	0.35	0.003	0.01	0.052		
4L7 (SA-210A1)	C	Si	Mn	P	C	Cr	Ni	Mo
	0.192	0.29	0.696	0.007	0.010	0.076	0.050	0.018
	Cu	Al	V	Ti	N			
	0.086	0.009	0.002	0.005	0.0069			
X6CrNi18-10	C	Si	Mn	P	C	Cr	Ni	Mo
	0.05	0.35	1.35	0.018	0.007	18.20	10.02	0.11

Tests results

Metallographic tests. The macro- and microstructure tests were performed on welded joints cut from a section of a membrane wall. The welded joints were selectively etched. Pipes of 3R12 steel, flat bar of X6CrNi18-10 steel and welds were electrolytically etched in 10% water solution of oxalic acid at the voltage of 4 V. Pipes made of 4L7 steel were chemically etched in 3% solution of HNO_3 in C_2H_5OH. The results of tests of the macrostructure of welded joints subjected to heat treatment are presented in Fig. 1 and of the microstructure in Figs. 2-4.

Macro- and microscopic tests of welded joints confirmed the correct structure of the joints that are free from welding non-conformities. All welds are fused into the outer pipe only (Fig. 1). The flat bar has austenitic microstructure with NbC carbide bands. A slight growth of austenite grains in the flat bar HAZ as well as partial dissolution of NbC carbides in the matrix at the fusion boundary of the weld have occurred (Fig. 2). Austenite grains with larger size (Fig. 3) than in native material are present in the HAZ microstructure of pipes made of 3R12 steel. The HAZ of the inner pipe of 4L7 steel has fine-grained ferritic pearlitic microstructure with decarburization of the 4L7 pipe surface occurred in the metallurgical process of composite pipe production (Fig. 4). Tested welds have austenitic microstructure with dendritic nature.

Mechanical properties of welded joints. To determine the tensile strength of welded joints of composite pipes with flat bars, the tensile test was performed on the membrane wall panel section. Tested samples were 20 mm wide. The rupture in the wall of the pipe occurred at 90 kN load. The view of the sample after rupture and the microstructure at this place are presented in the Figs. 5, 6. It was found that the sample rupture occurred beyond the welded joint and the delamination between the components of the composite pipe did not take place.

Hardness test. The Vickers hardness test was performed at a load of 49 N (HV5), in accordance with standards PN-EN ISO 6507-1 and PN-EN ISO 9015-1. The summary of hardness test results for welded joints is presented in Table 2. Heat affected zone of the pipe made of 4L7 steel is the place with the highest increase of hardness as compared to the native material. Hardness in the tested joints does not exceed 237 HV5, and thus it meets the requirements of PN-EN ISO 15614-1.

Fig. 1. Macrostructure of the welded joint

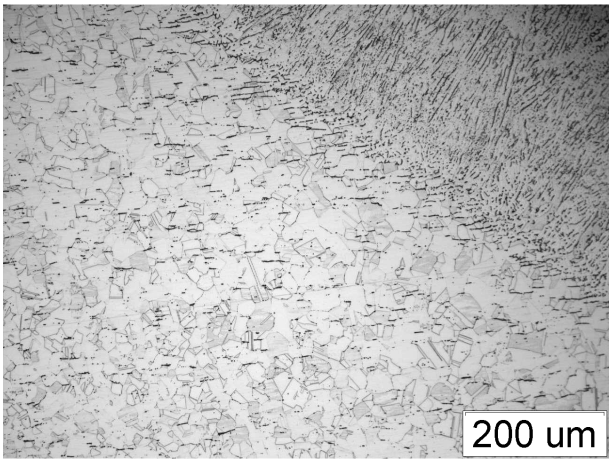

Fig. 2. HAZ microstructure of the flat bar made of X6CrNi18-10 steel

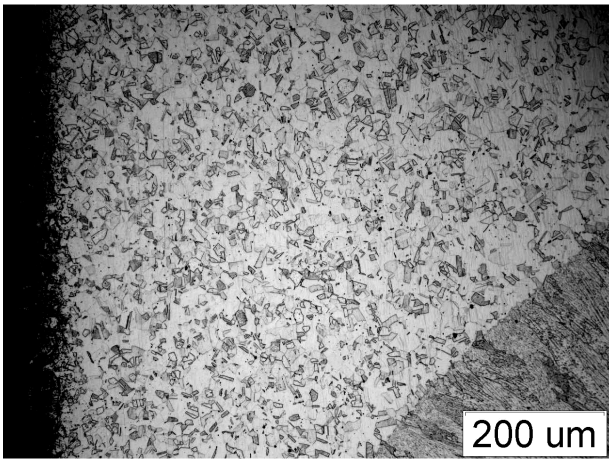

Fig. 3. HAZ microstructure of the 3R12 pipe

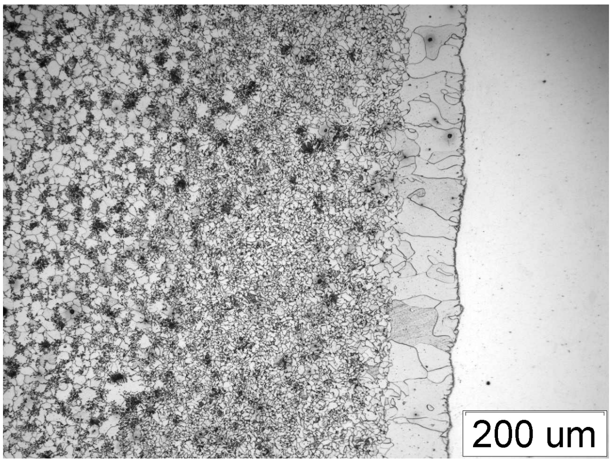

Fig. 4. HAZ microstructure of the 4L7 pipe

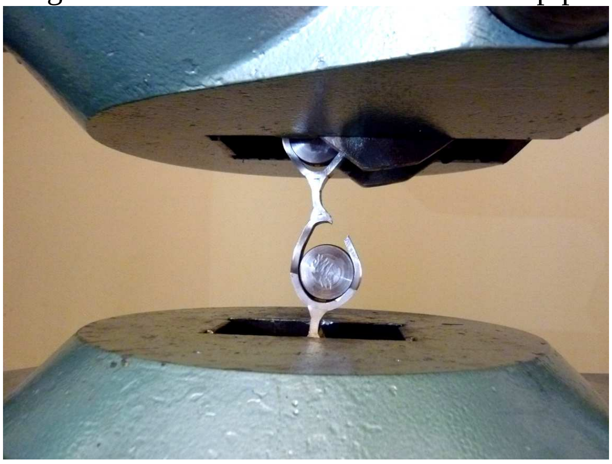

Fig. 5. View of the sample after rupture in the wall of the pipe

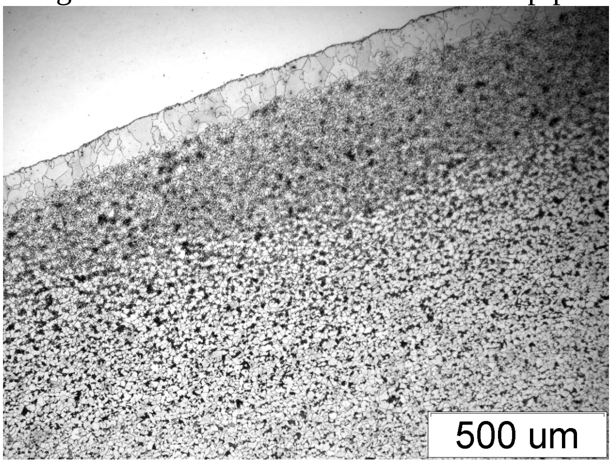

Fig. 6. Microstructure of the pipe in the area of the sample rupture

Summary

Tests of the composite pipes composed of outer pipe with austenitic microstructure made of Sandvik 3R12 steel (grade ASME 304L/SA), and of inner pipe with ferritic pearlitic microstructure made of Sandvik 4L7 steel (grade ASME SA-210A1) proved high quality of these pipes. Considering the results of performed tests one may conclude that the developed technology of submerged arc welding of gas-tight pipe walls made of composite pipes of 3R12/4L7 steel and flat bars of X6CrNi18-10 steel ensures that the required properties will be obtained. Macro- and microscopic tests of welded joints confirmed the correct structure of the joints that are free from welding non-conformities. All welds are fused into the outer pipe only. Welding thermal cycle caused a slight increase of hardness in the HZA, which did not exceed 215 HV5. A high resistance of tested welded joints and resistance of pipes to delamination when exposed to tensile stress were proved.

Table 2. Results of HV5 measurements

Place of measurement	Weld 1	Weld 2	Weld 3	Weld 4
BM X6CrNi18-10	213, 214, 223			
HAZ X6CrNi18-10	203, 214, 227	208, 212, 215	211, 224, 226	221, 223, 232
Weld	173, 176, 178	165, 169, 176	173, 175, 176	178, 178, 183
BM 3R12	164, 169, 173			
HAZ 3R12	188, 194, 206	182, 187, 212	191, 208, 215	193, 194, 196
BM 4L7	139, 140, 146			
HAZ 4L7	188, 191, 198	197, 198, 203	185, 187, 187	186, 189, 193

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