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Influence of various welding methods on the structure and properties of welded austenite steel joints with nitrogen content ~ 0,5%

V S Kostina, M V Kostina and S O Muradian

A.A. Baikov Institute of Metallurgy and Materials Science, Russian academy of Sciences, Moscow, 119334, Russia

E-mail: vskostina@yandex.ru

Abstract. The analysis of literature data on the weldability of nitrogen-containing austenitic steels with high equilibrium nitrogen concentrations (0.4-0.6) is performed, and the results of studies of the structure and phase composition and mechanical properties are given for Cr-Mn-Ni-Mo-N welded joints with nitrogen concentration ~ 0.5% obtained by laser welding (for thin sheet metal) and argon arc and manual arc welding (for hot rolled metal with a thickness of up to 20 mm)

1. Introduction

According to the ISO standard: “Steels or metals can be considered weldable if the continuity of the welded joint is achieved during the welding process. At the same time, welding methods are used to obtain a joint that satisfies the requirements for their local properties and the effect on the structure of which they are part”. An important indicator of the weldability of austenitic corrosion-resistant nitrogen-containing steels with high nitrogen concentrations is the absence in the welded joints (WJ) of overheating sites, gas pores and / or release of chromium nitrides in the heat affected zone (HAZ), reducing the level of performance properties of the welded product, including the reduction of mechanical strength, viscosity of the weld (W), and its corrosion resistance [1-4].

It is known that one of the causes of gas pores is a partial burnout of the main alloying elements, such as chromium and manganese (elements that contribute to the solubility of nitrogen) [5]. Due to the decrease in their concentration in the molten metal zone, the solubility of nitrogen is limited, withal, the crystallizing metal prevents the release of undissolved nitrogen, leaving it in the W as gas pores. M. Raffi et al. [6] investigated the microstructure and corrosion resistance of welded joints of high-nitrogen steel (~ 0.5% N), welded with Cr-Mn-N filler material by argon-arc welding in a protective gas. WJ showed a high level of properties due to the complete solubility of nitrogen in the metal of W. The authors recommend carefully choosing a filler material so that its composition contains enough chromium and manganese for nitrogen solubility. It is also necessary to achieve equal strength of the W in comparison with the base metal (BM). Equal strength of the WJ can be achieved by using as a filler material a metal corresponding in its chemical composition to the base metal. Such studies were carried out for steels Х22АГ16Н8М [7] and 05Х22АГ15Н8М2Ф [8]. WJ were obtained using argon arc welding and submerged arc welding ANK-67. It was found that, compared with BM, the content of nitrogen, chromium, and manganese in the metal of the W is lower. However, the WJ showed high

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strength, the metal of W remained austenitic, nitrogen was evenly distributed in W and HAZ, and there were no pores in the metal of W.

In general, the issues of weldability of austenitic steels with high equilibrium nitrogen concentrations are resolved; however, the development of welding process technology is required for each specific steel.

2. Materials and Methods

We studied the WJ of two grades of austenitic steels: 04Х20Н6Г11М2АФБ [9] and 05Х22АГ15Н8М2Ф [10] with an equilibrium nitrogen concentration ~ 0.5% (find chemical composition in Table 1) obtained by several methods of fusion welding. Taking into account the analysis of the literature data, for their welding the methods and modes given in Table 2 were selected, which allow to obtain high-quality non-porous WJ [11, 12]. Steels for which WJ have been investigated:

1) hot rolled sheet steel 04Kh20N6G11M2AFB (thickness 10 and 20 mm), obtained using filler materials S_{v1}-09Kh16N25M6AFS, S_{v2}-10Kh20N18M3APS and EA-868/20 (10Kh19N23G2M5FAT) [12] (WJ-1, WJ-2, WJ-3);

2) 05Kh22AG15N8M2F steel - hot rolled and cast (WJ-4, WJ-5), thickness - 3 mm (chemical composition is presented in Table 1), welded without the use of filler materials.

Welding modes are shown in Table 2.

Table 1. The chemical composition of the base metal and filler materials

Grade	Chemical composition, mass% (Fe - and impurities - the rest)								
	C	N	Si	Cr+Mo	Ni+Mn	V	Nb	S	P
04Kh20N6G11M2AFB	0,05	0,47	0,15	20,3	17,8	0,13	0,15	0,004	0,014
S_{v1}-09Kh16N25M6AFS	0,12	0,15	0,9	21,8	26,8	0,80	-	0,007	≤0,015
S_{v2}-10Kh20N18M3APS	0,12	0,15	0,9	22,8	19,3	0,80	-	0,007	≤0,015
EA-868/20 (10Kh19N23G2M5FAT)	0,12	0,25	0,47	23,1	25,3	1,85	-	0,005	0,015
05Х22АГ15Н8М2Ф	0,04	0,47	0,2	24,0	23,2	0,2	-	0,008	0,01

Table 2. Modes and methods of welding

Welded Joint	Structural condition /thickness	Filler material	Welding method	Edging
WJ-1	hot-rolled /20 mm	S_{v1}-09Kh16N25M6AFS	TIG: I_w=200-220 A, U_a=24-28 B	X-shaped
WJ-2		S_{v2}-10Kh20N18M3APS		
WJ-3	hot-rolled /10 mm	EA-868/20 (10Kh19N23G2M5FAT)	MMA: I_w = 110-140 A, U_a= 24 ÷ 28B.	
WJ-4	hot-rolled /3 mm	No	Laser welding: power P = 1 … 6, kW; welding rate V= 1…7 m/min, depth of focus from the surface +3 … -3 mm[a]	No
WJ-5	cast /3 mm			

[a] Development of IPG IRE-Polus (Ytterbium Fiber Laser)

The microstructure of WJ was examined on an Olympus light microscope and a LEO-1420 scanning electron microscope with an Oxford Instruments X-ray Microscope Analysis Unit (MRSA). The nitrogen content in samples from different zones of WJ was determined on the Eltra ONH-2000 gas analyzer (“Venta Lab”). Tensile tests were carried out according to GOST 1497-84 on Instron 3382 equipment; (test speed 1 mm / min). Impact bending tests were carried out according to GOST 9454-78

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on Amsler RKP-450 (copra energy - 300 J). The microhardness of the various structural components of the WJ (fusion line — FL, weld — W, base metal — BM, and heat-affected zone of weld — HAZ) was determined according to GOST 9450-76 on Volpert 402MVD hardness meter (load 50g for 10 s). Ferritometry was performed using IMP-2M ferritometer.

3. Results and Discussions

As a result of welding according to the specified modes, defect-free (according to X-ray inspection data) WJ were obtained from the flat rolled steel 04Kh20N6G11M2AFB with thickness 10 and 20 mm.

Zones of noticeable porosity were found along the austenite grain boundaries (pore size 20-100 nm, length of zones up to 7-10 microns) in the WJ-1 (with the use of S_{v1}-09Kh16N25M6AFS). Sometimes the appearance of pores is accompanied by the appearance of particles of excess nitride or carbonitride of the type Cr2N. Porosity was absent in the WJ-2 (using S_{v2}-10Kh20N18M3APS).

There is no pronounced HAZ of the weld in WJ-3. The zone of relatively small grains (10-40 microns) having a width of 100-200 microns adjoins the FL. At WJ-1 (Figure 1, a) and WJ-2 (Figure 1, b), the HAZ of the weld is observed wherein primary recrystallization took place with the formation of small equiaxed grains, and directly near the FL a collective recrystallization took place. In this part of the HAZ larger equiaxed austenite grains were formed.

WJ-4 and WJ-5 (thickness - 3 mm) are characterized by the presence in the central part of W of a clear vertical line of joining dendrites with size from ~ 5 to 150 ± 30 μm of each of the two halves of WJ; this is especially noticeable in WJ-4 (Figure 1, c). WJ-5 is characterized by the presence of ferrite in BM in the amount of ~ 2.86% (Figure 1, d), ~ 0.3% of ferrite is contained in BM of welded joints of hot rolled steel. Ferrite and σ-phase precipitates in the weld metal of WJ-5 were not observed. In WJ-4 and WJ-5 the metal microstructure in the heat affected zone of the weld did not differ from the microstructure of the base metal.

The MRSA method was used to determine the content of basic metal alloying elements. In WJ-1 and WJ-2 the chemical composition of the base metal (BM) at a distance of 8–10 μm from the FL corresponds to the grade composition of steel 04Kh20N6G11M2AFB. In some areas of the metal of the melted grains on the FL small changes in the concentration of Cr, Mn, Ni are noted. In welds, at a distance of 10–30 μm from the FL, a gradual approximation of the chemical composition of the metal to the composition of the welding wire begins (the content of Mn decreases, the content of Ni and Mo increases, in WJ-1the content of Cr also decreases). At a distance of ~ 130 and ~ 240 μm from the FL, the compliance of the composition of the metal WJ with the chemical composition of the welding wire was recorded. In WJ-4 and WJ-5 in BM the content of the main alloying elements corresponds to the grade composition of steel 05Kh22AG15N8M2F. In the weld there is a slight decrease of the concentration of Mn (on average, 14.5% versus 15.3% in BM), the content of the remaining alloying elements is almost the same as in BM. According to the gas fractional analysis of the WJ metal of hot-rolled steel, the nitrogen concentration in BM is 0.47, and in the weld it is 0.39.

Measurements of microhardness in various zones of WJ-3 showed that the highest hardness is observed for the metal on the fusion line (HV_{50} = 345), then it decreases in the series: HAZ → BM (310 → 280). Metal of weld has the lowest hardness (260). The average values of microhardness in the WJ-4 are as follows: in BM - 329, in the W - 324. For the WJ-5 lower values were obtained: in BM - 312, in the weld - 318.

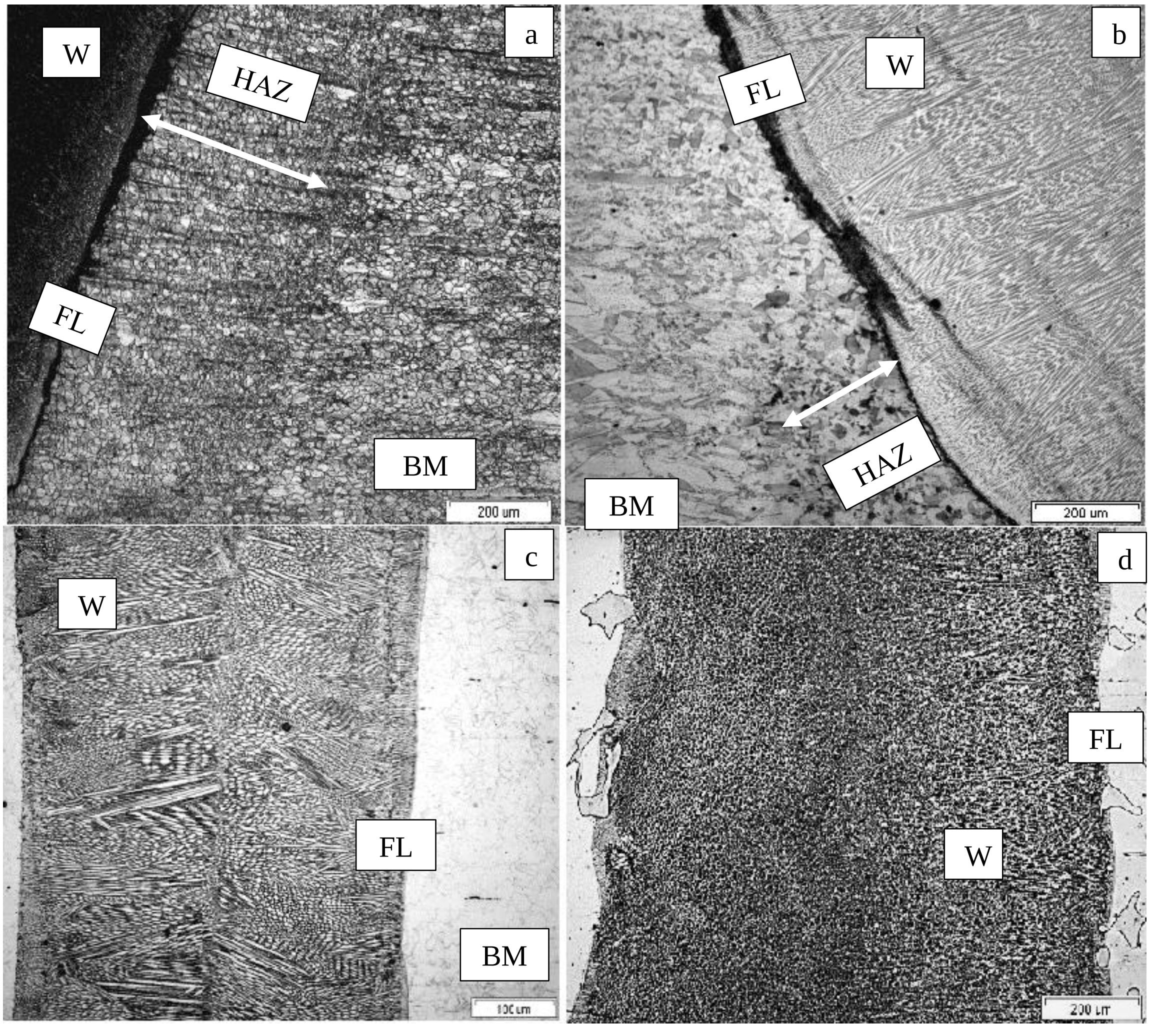

Figure 1. Microstructure of various zones of welded joints: WJ-1 (a), WJ-2 (b), WJ-4 (c) and WJ-5 (d).

Tests on the mechanical properties of WL-3 and base metal 04Kh20N6G11M2AFB were carried out on cylindrical samples. The yield strength of tensile samples WJ-3 is higher than the yield strength of BM (thickness 10 mm) and of the metal of the welding wire (Table 3). Higher strength of the metal WJ is probably achieved due to a significant refinement of the structure in the zone of fusion line (the size of the cast grains on the FL is 4 μm, whereas in BM it is from 50 to 100 μm). The ductility characteristics of the WJ-3 specimens are lower than the ductility characteristics, determined separately on the BM (thickness 10 mm), and the metal of the welding wire. This is concerned with the presence of inclusions, first of all - large particles in the metal of the weld.

Table 3. Mechanical properties of WJ-3, filler material and steel 04Kh20N6G11M2AFB at 20 °C.

Type of metal	$\sigma_{0,2}$, MPa	σ_u, MPa	δ, %	ψ, %	KCV, J/cm^2
WJ-3	597	800	21	29	≥ 200
EA-868/20 (10Kh19N23G2M5FAT)	530	770	33	55	107,5
BM, rolled 10 mm	540	854	57	71	250

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Tensile tests were carried out on flat samples of WJ-4 and WJ-5 and base metal 05Kh22AG15N8M2F in a cast state, thickness - 3 mm (find in Table 4).

Table 4. Mechanical tensile properties at 20 °C of samples WJ-4 and WJ-5 and base metal 05Kh22AG15N8M2F (not welded samples of cast steel).

Type of metal	$\sigma_{0,2}$, MPa	σ_{u}, MPa	δ, %	ψ, %	Comments	
WJ-4	375	914	31	18	FL	Region of breakage
	336	920	36	17	W	
WJ-5	308	657	51	45	BM	
	268	625	39	35	FL	
05Kh22AG15N8M2F (cast steel without welding)	355	650	49	33	With edge treatment	
	321	648	47	45	Without edge treatment	

The WJ samples were flat, without smooth edges, and the sharp edges of the samples were stress concentrators. When testing the cast metal a comparison was made: flat samples of BM were tested with treated edges (smoothed out and not treated). On the tested specimens the WJ region in which the specimen was destroyed was detected by the metallographic method, identifying zones of the weld, FL, HAZ, BM.

The tensile strength of WJ-4 is about 900 MPa, which is typical for non-welded samples of this steel after hot plastic deformation and short-term annealing at 1000-1050 ° C with cooling in water [13]. It indicates an equal strength of WJ and BM is observed. This correlates with the results of microhardness measurements. At the same time, the yield strength of these WJs, especially those destroyed in the weld zone, is at the level inherent in the cast state of 05Kh22AG15N8M2F nitrogen-hardened steel.

The destruction of WJ-5 samples occurred both in BM and in FL. Samples destroyed in the BM zone naturally had a level of strength similar to that of the cast non-welded metal samples (~ 650 MPa). Slightly smaller values of strength and yield strength among WJ-5 samples had samples destroyed in FL. Tests of cast non-welded metal (BM) samples showed that flat BM samples with non-smoothed edges have a slightly lower yield strength than samples with treated edges.

4. Conclusion

1. High-quality welded joints obtained by various methods of fusion welding, using and without welding filler materials.
2. The influence of the modes and methods of welding on the structure and properties of welded joints of high-nitrogen austenitic stainless steels (~ 0.5% N) in hot-rolled and cast states was established.
3. For welded joints (WJ-1, WJ-2 and WJ-3) made using the filler material, it has been established: the higher the welding current, the larger the HAZ size at a comparable rolled thickness. In WJ-4 and WJ-5. thickness 3 mm, welded with an ytterbium fiber laser (developed by IPG IRE-Polus), the HAZ is absent.
4. The content of basic chemical elements corresponds to the grade composition of steels and filler materials, however, in the zone of fusion line, the content of Mn and Cr slightly decreased in some samples.
5. At WJ-1, WJ-2 and WJ-3, the metal on the fusion line has the highest hardness, then it decreases in the series: HAZ → BM → W.
6. WJ-1, WJ-2 and WJ-3 have high toughness and strength, including based on the release of nanoscale particles of chromium nitrides, which are an obstacle to the movement of dislocations.
7. WJ-4 and WJ-5 can be considered equal-strength to the base metal, which correlates with the data of microhardness measurements of BM and weld. The yield strength of the studied WJ as a whole is at the level inherent in the cast state of the 05Kh22AG15N8M2F steel strengthened by nitrogen; it also depends on the zone in which the destruction occurred.

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