REPAIR OF PIPELINES USING ORBITAL TIG WELDING INSIDE INHABITED SPACE OBJECTS

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Investigations on application of equipment and technology for orbital TIG welding to repair pipelines inside functioning space objects were carried out. Properties and structural peculiarities of 12Kh18N12T steel tubular joints made by auto-pressing under conditions of decreased effect of the Earth gravitation were studied.

Keywords: *orbital TIG welding, pipelines, stainless steel, position welds, decreased gravitation, microchamber, tubular joints, mechanical properties, macro- and microstrucutre, microhardness*

In performance of repair works on the board of International Space Station (ISS) under space conditions the problem of welding of position welds of different-purpose pipelines has become challenging. The analysis of service of space objects, operating for a long time under conditions of orbital flight, in particular, the Russian complex «Mir», proves that one of the most vulnerable units are technological pipelines. It is supposed that after 6–10 years from the beginning of operation of ISS the need in their repair, as well as in methods and equipment for its realization, can arise.

In the opinion of authors of the works [1, 2] the argon arc welding with non-consumable tungsten electrode (TIG) is one of the basic methods of welding and repair of pipelines under space conditions using specialized captive chambers with a controllable atmosphere. TIG method both with filler materials feeding and also without it found wide application in manufacturing structures in different fields of industry [3–5].

Without filler material the auto-pressing method is usually used for welding of butt joints with edges flanging, overlap joints, and also butt joints without edges flanging (mainly tubular ones) [6–9]. In this method the multipass welding is applied which is performed in continuous and pulsed mode and also with activating additions [10–13]. In spite of existing opinion about detrimental influence of reheats in multipass TIG welding, the increase in strength of joints is observed in comparison with welds, welded with feeding of filler wire whose composition corresponds to that of the base metal [14]. Different enterprises of CIS and also many international companies are dealing with the development of technology and equipment for these purposes. However, there are no equipment and technologies for welding and repair of pipelines directly in space.

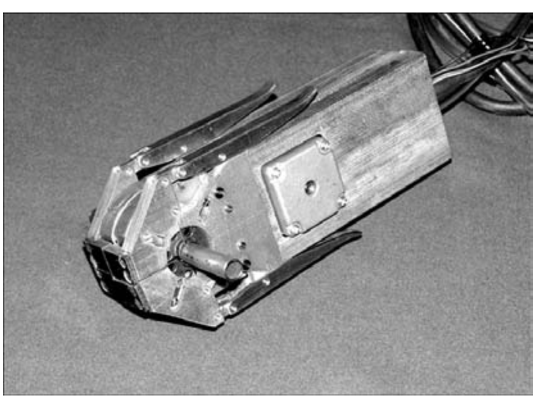


Figure 1. Appearance of captive microchamber for orbital TIG welding of pipelines under microgravity conditions

In this work the application of method of orbital TIG welding for repair of pipelines inside functioning space stations is considered and properties of multipass butt tubular joints, produced during testing the preliminary technology as applied to the conditions of microgravity, are studied.

During experiments the inverter power source GUSMI-160 for TIG welding was applied. As specimens, the steel 12Kh18N12T pipes of 10 mm diameter and 1 mm wall thickness were butt welded without filler materials. Here, the tungsten electrode of WT20 grade of «Binzel» company of 1.6 mm diameter with 60° sharpening angle and 0.5 mm blunting was used. As the shielding gas, the argon of the highest quality (GOST 10157–79) was used, the consumption of which was 4–6 l/min.

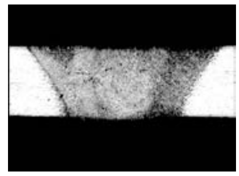
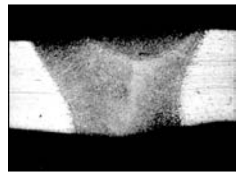
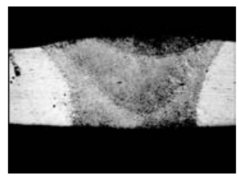
At the first stage the downhill welding at stationary arc heating source and horizontally positioned rotating tube was performed. Such choice of spatial position and method of performance of welding process assumes minimal influence of gravitation field of the Earth on molten weld pool [15–18].

At the second stage the orbital welding by horizontal welds in vertically positioned stationary pipe using captive chamber was performed (Figure 1).

As a result of carried out works the optimal welding modes of single- and multipass welding for both variants, properties and structural peculiarities of joints produced without feeding of a filler wire were defined.

The quality of produced butt joints were estimated by visual inspection, as well as according to macro and microsections. The chemical composition of base

Table 1. Conditions of TIG welding of butt joints of 12Kh18N12T steel tubes of ∅ 10 × 1 mm (welding speed is 15 m/h)

Number of specimen	Number of passes	Arc current, A, in making a pass				Macrosection of joint
		One	Two	Three	Four	
30	One	28	–	–	–	
41	Two	28	22	–	–	
56	Three	28	22	18	–	
58	Four	28	22	18	15	

metal (BM) and weld metal were studied by a spectral analysis using spectrometer DFS-36. Tensile strength of welded joints was determined by mechanical tests of tubular specimens in rupture machine TsDM-4 at temperature +20 °C. Metallographic examinations, photographing of geometry and structure of metal both of the whole joint, and also of its single areas were performed in optical microscope «Neophot 32». Size of grains was measured by visual comparison with references of scales in accordance with GOST 5639–82. Vickers hardness of joints at 1 N load was measured on tubular transverse microsections using the LECO microhardness meter M-400 at 0.3 mm pitch. The structural components were revealed by electrochemical etching in 20 % water solution of chromic acid at the voltage 20 V during 10 s.

To set welding conditions of butt tubular joints the penetrations on solid tubular specimens of steel 12Kh18N12T was initially performed. Then, the butt joints were welded by single- and then multipass welds.

The TIG downhill and orbital welding conditions of butt tubular joints were similar (Table 1). Here the first pass was performed by a through penetration and next depositing passes on the first weld were made without through penetrations. It was established as a result of conducted experiments that selected TIG welding conditions with through penetration of butt tubular joints of steel 12Kh18N12T allow producing circumferential welds for one pass with reinforced root bead and negligible weakening of a face part of the weld (see macrosection of specimen 30 in Table 1). The next pressing passes allow producing of welds with reinforcement of an upper part of the weld, which is seen on macrosections of specimens 41, 56, 58 in Table 1.

The analysis of macrosections of joints showed that by selection of main and pressing modes of welding one

Table 2. Chemical composition (wt.%) of base and weld metal produced by orbital TIG multipass welding on 12Kh18N12T steel tubes

Number of specimen	Number of passes	Si	Mn	Cr	Ni	Ti	Cu
1 (BM)	–	0.63	1.15	18.0	11.6	0.85	0.22
27	One	0.62	1.14	18.0	11.4	0.86	0.21
42	Two	0.62	1.13	17.8	11.5	0.85	0.21
50	Three	0.62	1.12	18.0	11.4	0.85	0.22
57	Four	0.62	1.12	17.8	11.6	0.85	0.22

Table 3. Results of tensile tests of BM and joints of 12Kh18N12T steel tubes of ∅ 10 × 1 mm produced by orbital TIG welding and downhill welding

Number of specimen	Number of passes	Site of fracture	Test results σ_t, MPa	
			BM	Welded joint
1, 2, 3	–	BM	782–788	–
72, 76, 79 28, 29, 31	One	Weld	–	605–635 610*–630*
82, 84, 85 43, 44, 45	Two	HAZ	–	638–657 635*–660*
87, 89, 90 51, 52, 53	Three	Same	–	635–647 638*–650*
92, 93, 98 60, 61, 62	Four	»	–	612–637 608*–642*

*Specimens were made by downhill welding.

can achieve optimum geometry and satisfactory formation of upper and root reinforcing beads both for downhill welding and also for the orbital one. The uniformity of penetration of root weld and its reinforcement are achieved as a result of stable welding speed which is provided by step motor KRS392S-4015-Z121-W60, controlled by a drive KRD1250i and stabilization of welding current of inverter power source GUSMI-160. A metal of the first pass and HAZ are repeatedly heated by next (pressing) passes which were performed by the arc of a lower capacity. Here the metal is subjected to local plastic deformation (buckling) under the influence of inner compressveg stresses up to the temperatures of plastic and elastic-plastic state of metal in heating zone. Thus, the weld reinforcement is obtained without applying the external compressive forces and filler material for both variants.

The chemical composition of weld metal of joints produced for one, two, three and four passes without filler material is not almost differed from BM (Table 2).

Having compared the values of tensile strength of butt joints of pipes of ∅ 10 × 1 mm of steel 12Kh18N12T produced for variants of downhill and orbital welding, at different amount of welding passes (Table 3), it is necessary to note that the smallest value of strength was obtained after the first and fourth passes.

The most suitable results were obtained after second and third passes — $(0.80–0.84)\sigma_t$ of BM.

Investigations of nonmetallic inclusions in 12Kh18N12T steel joints produced without filler wire for variants of downhill and orbital welding showed that single and line oxides are observed in BM (Figure 2, *a, b*), and in weld metal after the first pas — single inclusions of corundum and tiny silicates of a globular shape (Figure 2, *c*).

It is also necessary to note the presence of inclusions of titanium nitrites in weld metal after the first pass and in the fusion zone.

After the second and next passes the nonmetallic inclusions in welds and in the fusion zone were observed more rarely.

Macrostrucutre of weld metal produced in orbital welding for four passes is given in Table 1 (specimen 58), where weld has a reinforcement both on the external surface, and also in its root part. The weld metal is dense, without pores, cracks and other defects, weld shape is symmetric, microstructure of this joint is shown in Figure 3.

The cast weld structure represents a two-phase system: austenite and δ-ferrite. Weld metal structure after the first pass is dispersed. The contents of δ-ferrite in weld metal is about 1.0–1.5 %. After the second pass the austenite grain is increased and amount of δ-ferrite is reduced (down to 0.5–1.0 %). After the third and fourth passes the weld metal structure is more fine-dispersed than after the first pass. Nonmetallic inclusions in a weld and fusion zone are observed more rarely than in weld metal after the first pass.

In HAZ metal the typical austenite structure is observed on the both sides of a weld (Figure 4).

Small amount of δ-ferrite (up to 0.5 %) was revealed at the areas adjacent to fusion line. Size of grain at the area of coarse grain of HAZ on the both sides is the same and corresponds to the size No.5 (line 3). At the area of fine grain the size of grains corresponds to the size No.8 (line 3). Microstrucutre of BM is composed of austenite grains of size No.6 (line 3) and represents austenite and δ-ferrite with distinctly expressed texture of rolling. Along the fibers of rolling the nonmetallic inclusions and also carbide particles are observed. Grain size at the bound-

Figure 2. Microstructures (×500) of base and weld metal with nonmetallic inclusions in them: *a* — chains of oxides in BM along the rolling; *b* — sulphides in BM elongated along the rolling; *c* — inclusions of corundum and silicates in a single-pass metal

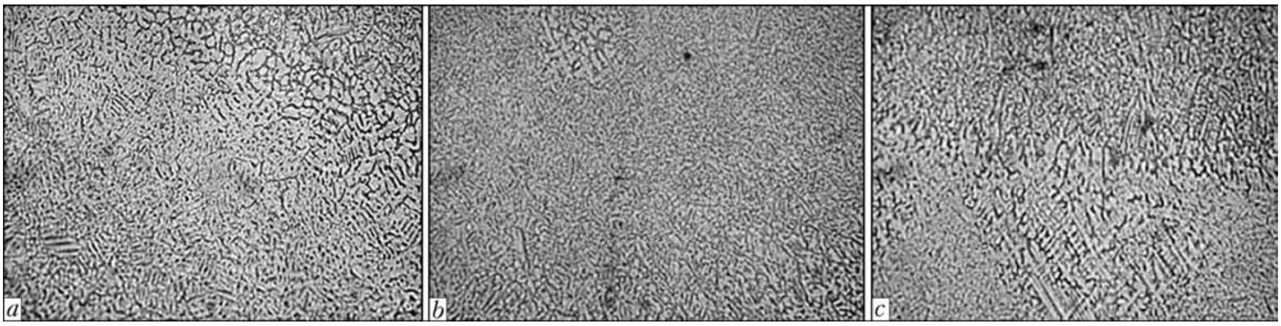


Figure 3. Microstructure (×320) of weld metal of 12Kh18N12T steel tubular joint produced by orbital TIG welding for four passes: *a*, *b* — weld metal, respectively, after the first and second passes; *c* — at the boundary of the third and fourth passes

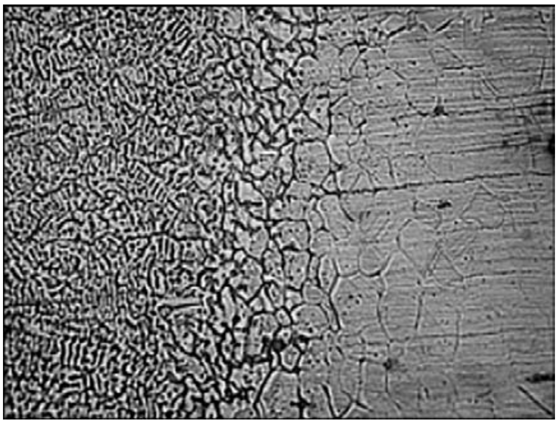


Figure 4. Microstructure (×500) of HAZ metal of 12Kh18N12T steel joint made by TIG welding for four passes

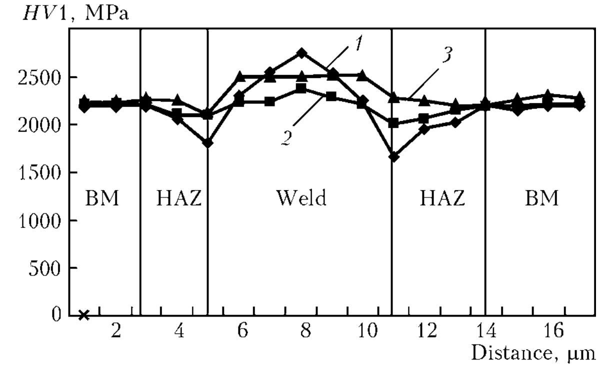


Figure 5. Distribution of microhardness of 12Kh18N12T steel tubular joints (specimen 47) made by orbital TIG welding for one (*1*), two (*2*) and three (*3*) passes

ary of BM, i.e. the area of incomplete recrystallization, corresponds to size No.7 (line 3).

Microhardness of joints was measured in upper cuts of external surfaces of pipes in perpendicular direction towards the weld.

The values of hardness of weld metal, HAZ and BM are differed between each other. Besides, the number of welding passes also influences the values of hardness. Figure 5 shows distribution of microhardness for welded tubular joints produced for one, two, four passes, where maximum microhardness is 2750 MPa in the center of a single-pass weld and minimum value in the same joint at the region of a coarse grain is 1650 MPa in HAZ metal. In welds with two passes the character of distribution of microhardness remained the same as after the first pass, however the values of microhardness become somewhat lower. And after third and especially fourth passes the distribution of microhardness is more stable along the whole weld section and reaches the value of 2500 MPa.

Thus, the feasibility of producing quality welded joints of thin-wall pipes of stainless steel 12Kh18N12T at repair of pipelines using orbital TIG welding was experimentally shown.

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