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DEVELOPMENT OF WELDING CONSUMABLES FOR WET UNDERWATER WELDING OF HIGH-ALLOY CORROSION-RESISTANT STEEL

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Abstract. This paper discusses a technology of mechanized wet underwater welding of high-alloy corrosion-resistance steel. The main aim of the investigation is development of self-shielded flux-cored wire for wet underwater welding for the first time in the world practice. A mathematical method of experiment design was used for determination of quantity and quality characteristics. Besides, quantitive and qualitative indices of welding-technological characteristics such as weld metal gas saturation, stability of arc burning in water medium, and optimum composition of gas-slag-forming components of flux-cored wire charge were determined. Problems of this branch and current ways of performance of welding – repair operations on objects of high-alloy corrosion-resistance steel were outlined. Application of experimental self-shielded flux-cored wire in mechanized wet underwater welding of high-alloy corrosion-resistance steel allows increasing efficiency and quality of underwater welding-repair operations and receiving economical effect due to reduction of production downtime of object under repair. Usage of present technology provides for the possibility of complete elimination or partial reduction of human participation in welding process under extreme conditions in radioactive environment (in the case of NPP) and in welding at greit depth. The results of researches can be used for welding-repair operations in nuclear power plants, for ship repair and ship-raising operations and on hydraulic structures. Proposed innovation technology allows complete replacement of wet underwater welding using coated electrodes as well as eliminating human participation in welding-repair operations of critical structures under especially dangerous conditions such as underwater welding.

1. Introduction

Underwater welding is widely used for welding-repair operations and maintenance of pipelines for gas and oil recovery from sea bottom, for ship repair and ship-raising operations, manufacture of elements of hydraulic and port constructions as well as elements of power equipment. Most of the elements are made form low-alloy structural steels. However, since the latter has low corrosion resistance properties, high-alloy corrosion-resistance steel finds more and more application.

2. Problem description

One of the main objects for application of wet underwater welding of indicated steel is spent-fuel pools at NPP. After unloading of fuel elements from a reactor core, they are held in a spent-fuel pool for 2-5 years for reduction of decay heat. The pools are concrete structures of around 25 m depth lined with high-alloy chromium-nickel corrosion-resistance steel of 18-10 type of 3-5 mm thickness which are filled with fresh water (Fig. 1). Mechanical damages of the pool body plating often take place during loading/unloading operations of the fuel elements. Tardy repair results in outflow of radioactive water to environment that can promote ecological disaster.

High level of radiation restricts access of maintenance staff to equipment being in the direct vicinity to NPP reactor. Equipment with remote control is tried to be used in the most cases for repair or scheduled operations. In other case, when it is necessary to use human labor, the task becomes more complex.

3. Analysis of current information resources corresponding to paper subject

The first attempts on solving the given problem were made in the middle of the 80^{th}, after scheduled inspection of some USA nuclear electric plans determined cracks in the pool plating [1, 2]. NPP production run was stopped for repair performance, water was drained and corresponding repair operations using non-consumable electrode were carried out.

Fig. 1. Pool for storage of spent nuclear fuel at NPP

It was necessary to replace present technology for more operative and less dangerous taking into account significant time loss and detriments due to NPP stop as well as negative effect of radioactive environment on welder-diver health.

The E. O. Paton Electric Welding Institute of the NAS of Ukraine developed special coated electrodes for wet underwater welding of high-alloy corrosion-resistant steel. Novel coated electrodes allowed quicker performance of welding-repair operations, without wasting time for draining of water and using its physical properties for protection from radiation and reduction of effect of radioactive environment on diver-welder health.

However, manual arc welding using coated electrodes in comparisons with mechanized and automated methods of welding is characterized by lower efficiency in performance of welding-repair operations and comparatively lower quality of welds. Besides, world tendencies of development of welding equipment move in the direction of mechanization and automation (Fig. 2) for providing the possibility of complete elimination of human presence in specially dangerous conditions such as underwater welding and radioactive environment [3, 4].

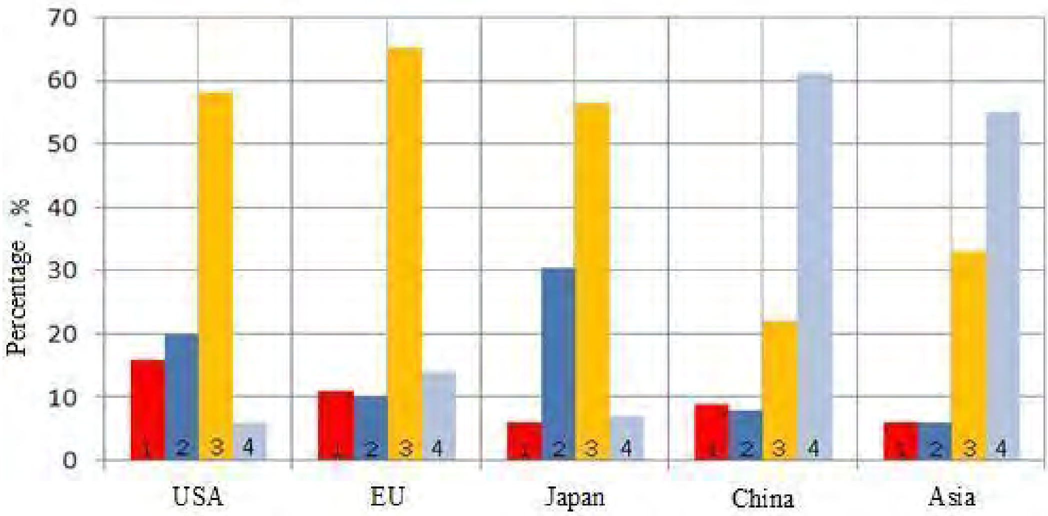


Fig. 2. Structure of application of welding methods in world production: 1 – submerged-arc; 2 – flux-cored wires in shielding gases; 3 – solid wire in shielding gases; 4 – stick electrodes

Gradual transfer of most of the world on equipment for automatic and mechanized welding is based on economic concepts of current time and struggle of plant-manufacturers for reduction of products prime cost. Application of such equipment has positive effect on quality of welded products, speed of product manufacture as well as allows around-the-clock work of production lines. This significantly rises productivity due to nonstop production.

4. Aim and tasks of the research

Development of technology for mechanized underwater welding of high-alloy corrosion-resistant steel using self-shielded flux-cored wire is very relevant taking into account mentioned above as well as economic constituent of nuclear power engineering, where one hour of NPP downtime can cost half million of dollars [2].

Aim of the research is development of self-shielded flux-cored wire for wet underwater welding of high-alloy corrosion-resistant chromium-nickel steel of 18-10 type.

The following tasks are to be fulfilled in order to realize stated aim:

1. Study the level of weld gas saturation, analyze oxidizing and hydrogenization effect of water medium;

2. Study the type of wire slag system and determine optimum relationship of gas-slag-forming components of wire charge;

3. Study the stability of arc burning process in water medium;

4. Receive satisfactory mechanical characteristics of welded joints and necessary composition of weld metal.

It should be noted that now there are no self-shielded flux-cored wires for underwater welding of high-alloy corrosion-resistance steel and this development is the first in the world practice.

5. Description of main material

Wet underwater welding has series of difference from welding in air. In wet under water welding the arc burns in closed vapor-gas bubble which is formed due to water dissociation products [5, 6]. Hydrogen supersaturation of the deposited metal in low-alloy steels results in formation of weld defects and reduction of mechanical properties of the weld. At the same time, hydrogen solubility in austenite metal is sufficiently high (55-60 cm^3/100g) and lies, as a rule, in solubility range [7, 8]. The priority direction in wet underwater welding of high-alloy corrosion-resistant steels is reduction of oxygen content. Its interaction with molten metal promotes for burning out of high active volatile components and can appear in form of oxide inclusions having negative effect on mechanical properties of the deposited metal as well as in form of defects such as pores [9, 10].

MI-99 specimens cut out from the deposit top layer were used for determination of content of hydrogen, oxygen and nitrogen in development of pilot wire. Table 1 gives the results on gas content in the deposited metal.

Table 1

Content of gases in the deposited metal in wet underwater welding and in welding in air

Welding medium	Content of gases in the deposited metal		
	wt.%		cm^3/100 g
	[N]	[O]	[H]
Air	0.06	0.05	10.5
Water	0.03	0.07	27.0

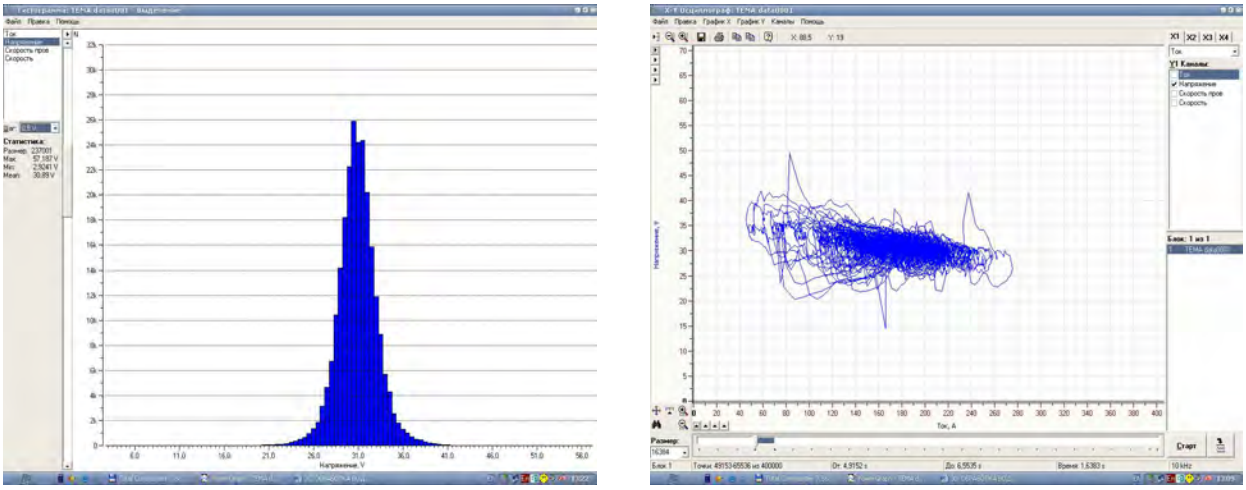
Fig. 3 shows a view of the deposits made on 12Kh18N10T steel in wet underwater welding using pilot wire of ∅1.6 mm diameter at reversed polarity direct current. Rectifier VDU-601 (constant voltage) having U_a = 32-34 V ; I_w = 140-160 A mode was used as power supply.

Estimation of stability of arc burning process and characteristics of process of melting and transfer of electrode metal were carried out with the help of ASP-19 welding process analyzer. It can be seen from

Fig. 4 that welding process takes place without short-circuits and has satisfactory stability of arc burning process.

a) *b)*

Fig. 3. One-pass (a) and multi-pass (b) deposit produced using pilot wire



a) *b)*

Fig. 4. Histograms of welding process voltage (a) and volt-ampere characteristic (b)

Results of chemical analysis of composition of deposited metal show correspondence to set type of alloying 06Kh20N9G2B according to GOST 10052-75 (Table 2).

Table 2

Results of analysis of chemical composition of metal deposited in wet underwater welding and in welding in air

Medium	Composition of deposited metal, wt.%							
	C	Si	Mn	Cr	Ni	Nb	S	P
Air	0,06	0,52	1,83	21,83	9,5	0,30	0,015	0,025
Water	0,05	0,32	1,23	20,90	9,4	0,21	0,018	0,022
GOST 10052-75	0,05… 0,12	< 1,3	1,00… 2,50	18,00… 22,00	8,00… 10,50	0.70-1.30 but not less than 8·C	< 0,020	< 0,030

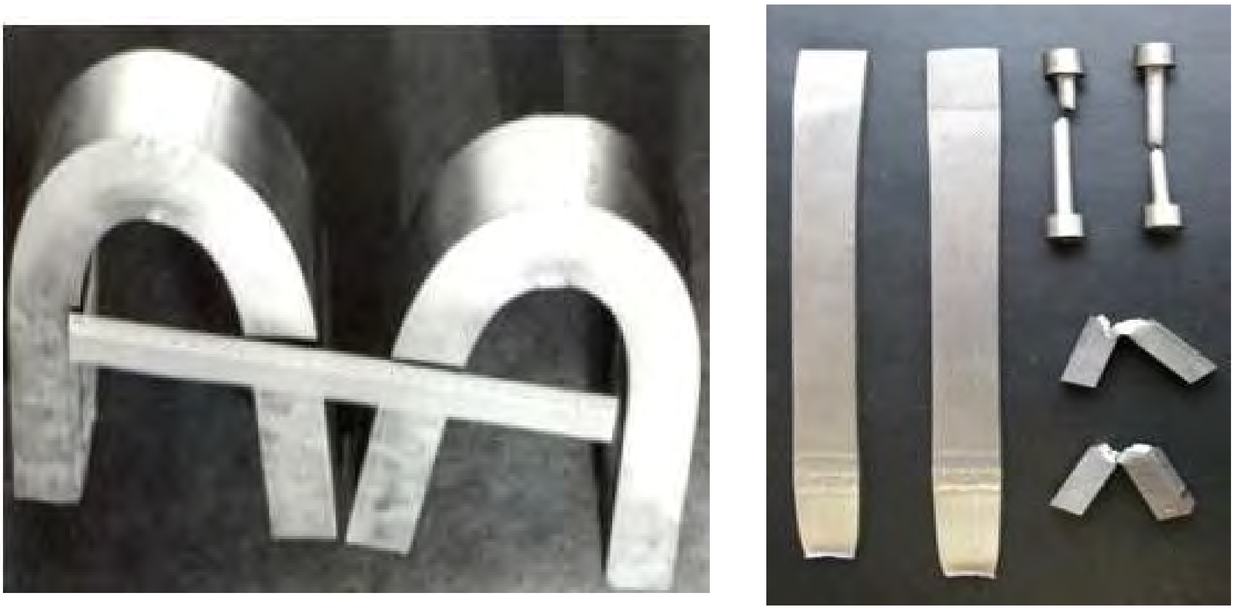
Estimation of content of ferrite phase in the deposited metal was carried out by volumetric magnetic procedure using "MF-10i" grade ferrite meter. Content of ferrite constituent in weld metal of 06Kh10N9g2B type according to GOST 9466-75 shall be in the range of 4-10 wt.%. Research of ferrite phase portion was performed with the help of "Ferrtgehaltmesser 1.053" grade ferrite meter, which showed austenite + 6% of α-phase structure of the deposited metal. Susceptibility of welded joints to intercrystalline corrosion was tested by "AM" method according to GOST 6032-2003. Analysis of the specimens after testing showed complete absence of ICC.

Results of mechanical tests completely fulfill the requirements of class "B" of international special standard on underwater welding ANSI/AWS D3.6-92 (Table 3) and (Fig. 5).

Table 3

Results of analysis of chemical composition of metal deposited in wet underwater welding and in welding in air

Yield point $\sigma_{0.2}$, MPa	Ultimate tensile strength σ_t, MPa	Relative elongation δ, %	Relative contraction ψ, %	Impact toughness a_k, J/cm^2	Bending angle, degree R = t
350.8	623.3	25.7	28.7	90.3	68-103



a) *b)*

Fig. 5. View of specimens after mechanical tests

Metallographic examinations of the weld metal showed that quantity of non-metallic inclusions increases almost 2 times in wet underwater welding, but they are dispersed and equally distributed across the weld section. Weld metal structure is refined and at that size of grains decreases almost in 2 times (Fig. 6 and 7).

Application of technology of mechanized underwater welding using developed self-shielded flux-cored wire of PP-ANV-25 grade in comparison with coated electrodes allows reducing the time for welding-repair operations as well as total cost of repair in 2.6 times [11].

Conclusions

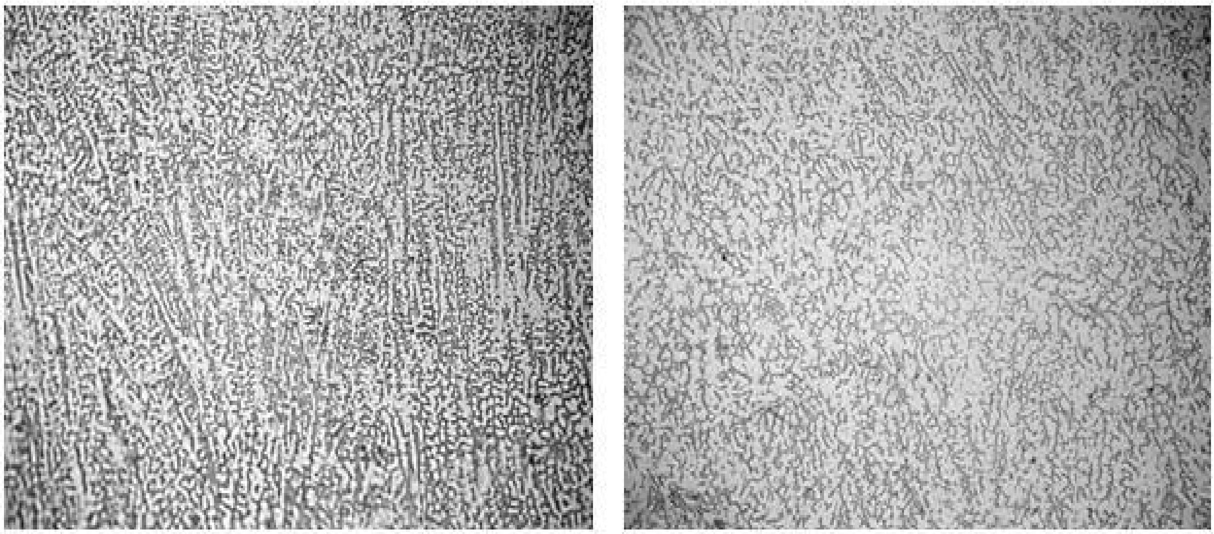
Results of the carried out investigations and tests have showen that:

1. The developed welding wire gives us the possibility to increase the quality and efficiency of welding-repair operations in water medium as well as to receive significant economical effect due to reduction of production downtime of object under repair.

2. Results of the researches have showen that self-shielded flux cored wire of PP-ANV-25 grade, which is developed for the first time in world practice, gives us the necessary composition and mechanical

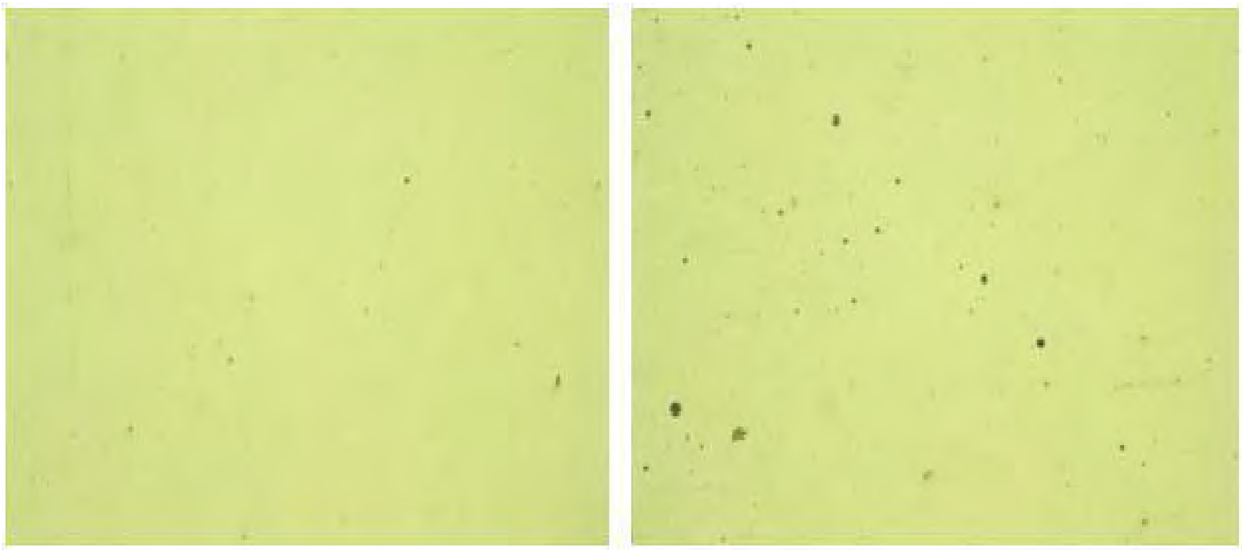
properties according to GOST 10052-75 and meets “B” class requirements of ANSI/AWS D 3.6-92 international standard on underwater welding.

3. Application of technology of mechanized wet underwater welding with using pilot self-shielded flux-cored wire makes a basis for development of automated equipment that allows reducing harmful effect on diver-welder health due to decrease of time of staying in radioactive medium, and later on eliminating human participation in welding-repair operations of critical structures under especially dangerous conditions.



a) *b)*

Fig. 6. View of microstructure of weld metal produced in air (a) and under water (b) x 200



a) *b)*

Fig. 7. Non-metallic inclusions in weld produced in welding using pilot wire in air (a) and in wet underwater welding (b)

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