INNOVATIVE TECHNOLOGIES IN THE FIELD OF STRUCTURAL STEELS AND THEIR WELDING

I.V. GORYNIN
Central Research Institute of Structural Materials «Prometey»
49 Shpalernaya Str., 191015, St. Petersburg, Russia. E-mail: mail@crism.ru

The retrospective review of cooperation between the Central Research Institute of Structural Materials «Prometey» and the E.O. Paton Electric Welding Institute in the field of development of super reliable metallic materials and industrial technologies for special engineering, development of covered electrodes, agglomerated fluxes, flux-cored wires, welding technologies and equipment was studied. The common approach was used to the developments of technology of metallurgy and welding with the final aim to provide the high service reliability of modern structures manufactured on the basis of new materials. The joint works on evaluation of resistance of materials to brittle fractures, development of methods for evaluation of cyclic life of welded structures, improvement of methods for certification tests of metal were outlined. 2 Tables, 4 Figures.

Keywords: *innovative technologies, structural steels, welding consumables, service reliability, nanotechnologies and nanomaterials, cooperation*

The joint works with the E.O. Paton Electric Welding Institute in the Soviet years and in the post-Soviet period laid grounds to research directions of works which found their further progress at the Central Research Institute of Structural Materials «Prometey» in the development of super reliable materials and industrial technologies for special engineering, applied under the extreme conditions. The most significant of them are devoted to the developments of electroslag remelting (ESR) technologies of high-strength weldable steels, development of high-quality welding consumables and also providing operation reliability of large-size welded structures.

The ESR method was developed at the beginning of the 1970s of the past century in collaboration between the scientists of the E.O. Paton Electric Welding Institute, the Central Research Institute of Structural Materials «Prometey», the I.P. Bardin Central Research Institute of Ferrous Metallurgy and specialists of metallurgical plants of Ukraine. The main task, requiring solution, was to increase the metallurgical quality and eliminate the anisotropy of properties of thick-plate rolled metal of high-strength steels for prevention of brittle fractures. The new technology allowed considerable reduction in the content of sulfur, oxygen, non-metallic inclusions (Figure 1), providing 2–3 times increase in ductility and impact toughness values (Table 1); decrease of critical temperatures of brittleness, increase of resistance to crack propagation; maximum restriction of carbon content, regulating the content of alloying elements within the narrow limits.

Table 1. Mechanical properties of high-strength steels

Method of melting	δ_5, %	ψ, %	KCV, J/cm^2	ψ_z, %
ESR	17.0–21.5	64–70	128–300	50–55
Ladle refining	17.0–20.5	64–68	124–235	40–55

This allowed widening the assortment and providing production of large-size sheet rolled metal, high uniformity of structure and mechanical properties along the area of a large-size sheet and in the direction of its thickness, improving weldability and increasing stability of mechanical properties in the heat-affected zone of welded joints. The steel turned in principle into the isotropic material.

The transition of Russian enterprises to the market relations required the new methods of melting, i.e. those applying the complex of ladle treatment (ladle refining and degassing). The

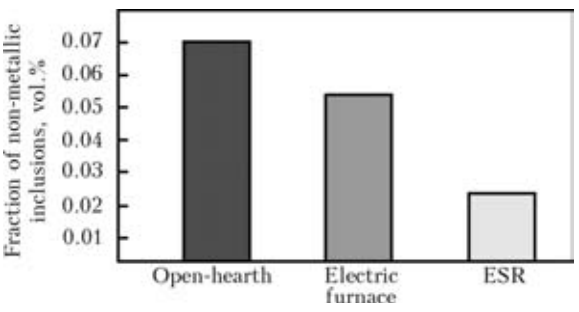

Figure 1. Content of non-metallic inclusions in high-strength steel of different melting

Table 2. Service characteristics of weld metal in flux-cored wire welding

Grade of flux-cored wire	R_m, MPa	R_e, MPa	A_5, %	KV, J
48PP-8N	510–650	440–480	22–28	75–90 (–20 °C)
48PP-11N	610–770	500–530	20–24	60–80 (–40 °C)
PP-SVP1	650–710	500–550	23–27	75–90 (–40 °C)
48PP-10T	545–560	460–480	22–25	60–80 (–60 °C)

experience of application of ESR technology allowed transition to radically new scheme of production of metal with the quality not inferior to the metal produced by ESR (Table 1). It should be noted that ESR method allows producing new high-quality products (for example, during production of nitrogen steels) developed in the Central Research Institute of Structural Materials «Prometey».

The Central Research Institute of Structural Materials «Prometey» together with the E.O. Paton Electric Welding Institute carried out the joint works on the development of covered electrodes, agglomerated fluxes for automatic welding, flux-cored wires of small diameter and also welding technologies and equipment. The new challenging welding consumables are developed on the basis of optimization of systems of alloying, microalloying and modifying of weld metal to provide the required operating efficiency of welded joints (including those at the negative temperatures), high weldability and crack resistance.

The new highly-technological flux-cored wires of small diameters for welding of steels with the yield strength from 360 to 550 MPa with the level of operation characteristics not inferior to the best foreign analogues were created and the industrial technology of their manufacture was developed (Table 2).

The series of developed covered electrodes of fluorite-calcium type allows providing a low content of diffusion hydrogen in the deposited metal, stable high service characteristics, preset level of strength and ductile properties of weld metal in welding of cold-resistant steels.

For automatic submerged arc welding the agglomerated fluxes in combination with different wires were developed providing complex of necessary service characteristics. The industrial production of fluxes was mastered on the production facility of the Central Research Institute of Structural Materials «Prometey», Figure 2. The distinctive feature of the developed fluxes is their high competitiveness based on the high technological efficiency of welding process and cost-effectiveness.

The principally new technology of welding flux production using laser granulation was developed to provide the low hygroscopic properties of the flux; possibility of deoxidation, alloying and modifying of weld metal through the flux; low content of diffusion hydrogen in the deposited metal and also relatively high strength of flux granules. The implementation of a new flux in the production allows decreasing the temperature of preliminary and concurrent heating in welding; performing welding of high-strength steels with the yield strength of more than 800 MPa; considerably increasing the service characteristics of welded joints.

The submerged multiarc welding, widely used in the pipe industry, with the developed new welding consumables during its implementation in the ship building allows considerable increasing of labor efficiency and maximum automation of production cycle in plane sections manufacture.

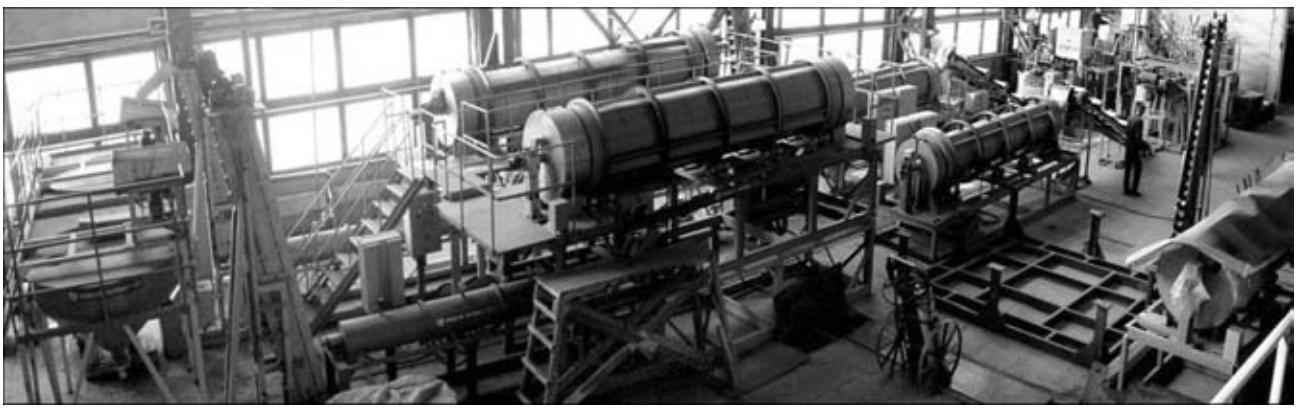

Figure 2. Technological line for production of agglomerated fluxes

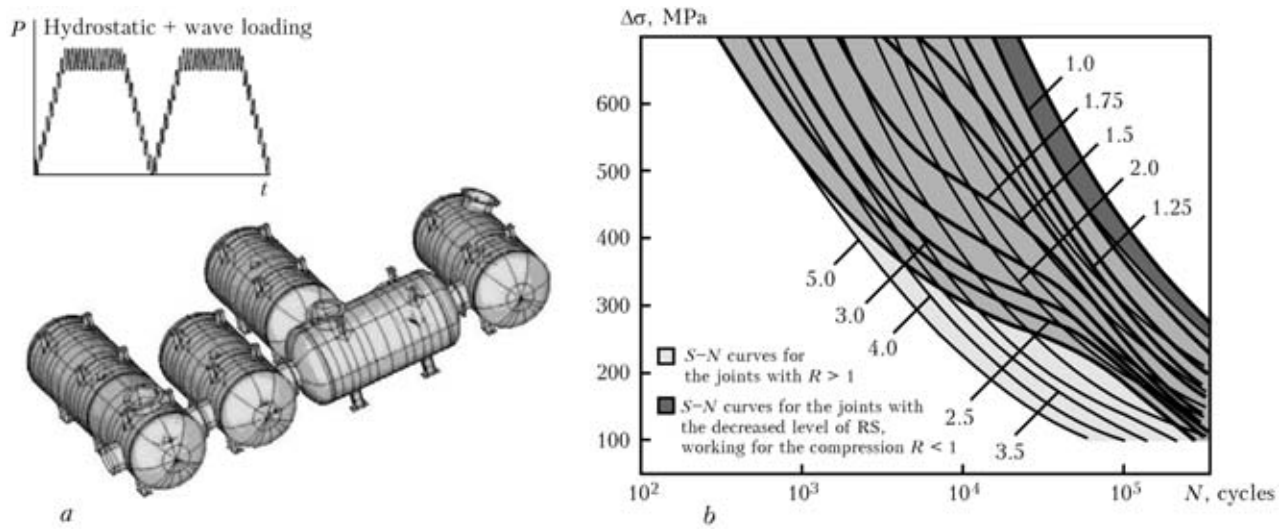

Figure 3. Calculated evaluations for selection of design of a barocomplex units: *a* — system of barochambers; *b* — calculation curves of admissible fatigue damages

The high-efficient electrogas welding along the slot groove till now remains unsurpassed in producing slot welds of structures of high-strength steels. The mentioned technology provides possibility of welding the high-strength steels without preheating using low-alloyed wires, high quality of metal of welded joints and process efficiency.

Over the period of cooperation between the Central Research Institute of Structural Materials «Prometey» and the E.O. Paton Electric Welding Institute the common approach to the developments of metallurgy and welding technologies was applied. The aim of the developments was not only the creation of new materials, but also providing a high operation reliability of structures made of these materials. The set aim requires the solution of three problems: development of scientifically-grounded requirements to the materials, their comprehensive certification, and also works directed on «fitting» of structures to the material. To solve the first and the third problems the development of calculation methods for evaluation of strength and life is necessary from which both the grounds of requirements to the material as well as grounds of requirements to the design of welded elements should result.

To provide the reliability of structures operating under the arctic conditions, the development of methods for evaluation of resistance to brittle fracture is challenging. Its task consists not only in determination of requirements to cold resistance of metal of welded joints but also in the efficiency and volumes of non-destructive testing methods. Namely such an «inverse» problem had to be solved evaluating the possibility of operation of a structure manufactured for the higher calculation temperatures under the arctic conditions.

The development of methods of evaluation of cyclic life of welded structures was also beginning from the joint works with the E.O. Paton Electric Welding Institute: the influence of two-frequency loading on fatigue strength of the structures was investigated. The example of similar task solved at the moment is implied in selection of design of units of a barocomplex, installed on the deck of a ship, using calculated evaluations (Figure 3). Here, the low-cycle loads due to changes of internal pressure in barochambers are added by the second frequency loads connected with the wave loads to the deck.

The new tasks connected with the construction of pipelines of high reliability in the arctic regions require also the updating of methods of certification tests of metal. To control the energy capacity of metal fracture of main pipelines the methods for determination of energy of plastic deformation during crack propagation at dynamic tests on the unique as to its energy capacity vertical impact tester of 60 kJ were mastered, the necessity in conduction of tests on crack resistance of metal of welded joints at different schemes of loads was shown, the methods of control of a new parameter, i.e. critical angle of crack opening (CTOD), was offered.

To investigate the life of new pipe products the stand was created (Figure 4) allowing simulating the real spectrum of loading of pipes, used in gas- and oil pipelines. The results of full-scale tests prove the necessity of their use in the critical structures, i.e. the integral verification of the whole technological line of production allows revealing the «weak spots» which are not detected during tests of standard specimens.

Figure 4. Stand for service life tests of pipe elements of up to 6 m length

The mutually-developed welding consumables, technological processes and methods of strength evaluation allow manufacturing the metal structures with guaranteed high service characteristics (from the regions of the Extreme North to the highly-aggressive conditions of tropical latitudes).

One of the further directions of radical increase of consumer qualities of materials are nanotechnologies and nanomaterials developed at the E.O. Paton Electric Welding Institute and also application of surface engineering. Developed are the technologies of evaporation condensation (magnetron, ion-plasma and atomic-ion spraying) with the controlled plasma flow, supersonic «cold» gas-dynamic and microplasma spraying, electrolytic modifying of nanostructured surface, laser prototyping of nanocomposite powders, controllable crystallization from the amorphous state.

The further development of hull materials will take place due to synergetic effect on the basis of new scientific knowledge in the physics of strength, plasticity, materials science, physical-chemical processes of welding and nanotechnologies. Such is the way of the challenging cooperation.

Received 12.04.2013