CONCLUSIONS

1. Such energy parameters as efficiency, power factor, coefficient of utilization of power in the working range of current and voltage for butt welding are higher in a.c. machines than in d.c. machine.

2. Main advantage of three-phase power sources compared to single-phase machines is related to better characteristics of electromagnetic compatibility, here uniform load is applied to mains phases and phase current decreases by 18 % at the same consumed power.

3. Lowering of the reactive component of secondary circuit resistance practically to zero when a rectifier is used in the secondary circuit does not lead to lowering of secondary circuit impedance, because of the features of machine design. Application of diodes introduces additional electrical resistance into the circuit.

4. Cost of power components of single-phase source is at lest 12 times lower compared to the considered rectifier source.

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RESEARCH AND DEVELOPMENTS OF THE E.O. PATON ELECTRIC WELDING INSTITUTE IN THE FIELD OF ELECTRIC ARC WELDING AND SURFACING USING FLUX-CORED WIRE (Review)

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The results of works performed by the E.O. Paton Electric Welding Institute in the field of welding and surfacing using flux-cored wire are generalized.

Keywords: *electric arc welding, surfacing, low-alloyed steels, flux-cored wire, production of flux-cored wire*

The flux-cored wire is high-efficient electrode material allowing solution of wide range of tasks connected with manufacturing of welded structures at the modern level.

At the beginning of the 1950s I.I. Frumin offered the application of flux-cored wire for automatic submerged surfacing of mill rolls [1]. The production of surfacing flux-cored wire was organized at Magnitogorsk Metal Wares and Metallurgical Plant.

The idea of application of flux-cored wire as welding consumable appeared to be very fruitful. At the second half of the XX century the investigations of electric-physical, metallurgical and technological processes of welding and surfacing using flux-cored wire were carried out. As a result a large number of different types of flux-cored wires of different purpose was developed, technologies of welding and surfacing and also industrial equipment and technology of production of flux-cored wires were also developed and tested. The materials for welding and surfacing in shielding gases, materials without additional shielding (self-shielding flux-cored wires), flux-cored wires for underwater, arc (electric gas) and electric slag welding with a forced weld metal formation and also for desulphuration and alloying of metal melts were developed.

At present, welding and surfacing using flux-cored wire, widely applied in many countries of the world, are the most challenging arc processes for joining metals, restoration of products or to impart them the necessary properties.

In the present article the review of works of the staff of the E.O. Paton Electric Welding Institute in this field was made.

Development of welding using flux-cored wire. The first industrial samples of flux-cored wire were developed and tested under the industrial conditions in 1959–1961 [2–4]. Their successful tests in welding

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of different-purpose metal structures became the start of opening of a new effective direction in the field of mechanization and automation of the arc welding.

Since that period the integrated investigations were carried out at the E.O. Paton Electric Welding Institute, which resulted in the establishment of the fundamentals of metallurgy and technology of the flux-cored wire welding, development of new consumables and methods of welding with their application.

The investigation of peculiarities of processes of heat and mass exchange in heating and melting of powder compositions, development of reactions at welding speeds of heating and melting of steel sheath and flux core allowed determination of kinetics of proceeding of processes and offer methods of control of melting the composite material, development of reactions of gas evolution, oxidation, complex formation, which are accompanied in arc welding with a formation of interacting phases (metallic, gas, slag) [5–7].

The considerable volume of investigations combining calculation, experimental methods and mathematics modeling is devoted to the study of physical-metallurgical processes in the metal–gas–slag system. Basing on the obtained results the basic principles of design of compositions of the core of flux-cored wire for welding in shielding gases and without additional shielding were defined [8–10]. The establishment of regularities of absorption and desorption of gases in arc fusion welding gave possibility to elucidate the mechanism of porosity formation from the new positions. The study of hydrogen behavior in steels allowed determination of influence on the resistance to embrittlement (delayed fracture) of a number of factors, including distribution of hydrogen in metal, composition and structure of metal, stress, rate of deformations and temperature [5, 11–13].

The development of flux-cored wires for welding metal structures of steels of high strength required the conductance of profound investigations in the field of physical metals science of welded joints. In these investigations except of modern experimental methods (scanning electron microscopy, local X-ray spectral analysis, quantitative metallographic analysis and others) the methods of mathematical modeling were widely used [14–17].

The carried out investigations allowed the obtaining of new data about distribution of elements in the metal of welded joint, composition and distribution of non-metallic inclusions, developing the conceptions about effect of composition and structure of metal on micromechanisms of fracture and cold resistance. In the works [14, 18] new data about the influence of alloying, modifying and complex microalloying on the formation of structure components of weld metal and characteristics of mechanical properties of weld metal and welded joint are contained.

Important scientific information, having a large practical significance, was obtained as a result of investigations of stability of arc burning, melting and electrode metal transfer using modern information-measuring systems and computer processing of data about welding process [17, 19]. The investigations of thermodynamic properties of metal and slag in the process of their melting and crystallization served as a basis for control and optimization of technological in-process properties of flux-cored wires used in welding in different spatial positions with free and forced weld formation [20–22]. The methods were developed and works were carried out on evaluation of sanitary-hygienic characteristics of welding using flux-cored wires with different types of a core [23]. The E.O. Paton Electric Welding Institute with the participation of Ministry of Ferrous Metallurgy of the USSR worked out the national standard 26271 «Flux-cored wire for arc welding of carbon and low-alloy steels», which was put in force in 1984 and is acting nowadays (in the edition of 1992) at the territory of CIS countries [24]. The monographs [5, 25–30] are devoted to the problems of theory and practice of the flux-cored wire welding.

The priority of the E.O. Paton Electric Welding Institute in the development of flux-cored wires, methods of welding with their use and equipment is protected by more than 100 patents and Author's Certificates.

Welding using self-shielding flux-cored wires. The conditions of application of flux-cored wires without additional shielding from the air atmosphere define main requirements to their properties, in particular, to provide gas-slag protection of molten metal and application of metallurgical means of nitrogen binding into stable nitrides, to obtain favorable welding-technological characteristics, to provide high resistance to formation of cracks and pores, sufficient level of deoxidation and alloying of metal, which allows achieving the required level of mechanical properties of weld metal and welded joint. For non-alloyed carbon steels the required level of properties is provided due to application of tubular flux-cored wires with a flux core of a rutile-organic type [3, 31]. Such wires are produced since 1959, and till now they are applied mainly during repair-renovation welding and manufacturing of simple metal structures.

Tubular self-shielding wires with application of nitride-forming elements in the core (aluminium, titanium, zirconium) were developed in the 1960s [3, 32]. Considering the specifics of alloying their application was limited by certain classes of steels, which was determined by the difference in chemical composition of weld metal and base metal and possible unfavorable influence on the properties of welded joint metal. Later the compositions of wires with a core of fluoride and fluoride-oxide types were modified, which gave a possibility to obtain high values of mechanical properties of welded joints of carbon and low-alloyed steels of ordinary and increased strength.

A special place among the self-shielding flux-cored wires is occupied by the wires of a double-layer design, developed by the E.O. Paton Electric Welding Institute [4, 33, 34]. Such wires with a core of a carbon-fluoride type mainly provide reliable gas-slag protection of molten metal from the air and have no almost restrictions in the selection of type of the weld metal alloying. They are used in manufacturing of many welded different-purpose metal structures of low carbon and low-alloy steels of increased strength.

The welding using self-shielding flux-cored wires started its mass application since 1960 mainly in manufacturing and assembly of building, technological structures and equipment. Further the field of their application widened to other branches of industry and building. Mechanized welding using self-shielding flux-cored wires as a rule is performed by means of semi-automatic machines with a modernized feed mechanism (four- or two-roller of gear type). In site semi-automatic machines of a light type a wire of 1.6–2.0 mm diameter is used, and in stationary or semi-stationary (suspended) machines the wire of 2.4–3.0 mm diameter is used.

Welding using gas-shielding flux-cored wires. The development of welding using gas-shielding flux-cored wires was performed under the conditions of beginning of mass application of arc welding by silicon-manganese wire of solid section of the type Sv-08G2S and others in CO_2, and later — in gas mixtures. The conditions of their application, requirements to welding equipment, types-sizes of flux-cored wires of 1.0–2.0 mm diameter created no difficulties in mastering mechanized welding under the industrial conditions. The main tasks, solved during development of flux-cored wires, were focused on development of core types, alloying systems as applied to the class of steels being welded to achieve the best technological and engineering-economic values than in use of wires of solid section [26, 35–38]. The additional treatment of metal with a slag, control of welding-technological properties using a powder core, additional filler metal in a form of metallic constituents of a core provided such advantages in the application of gas-shielding flux-cored wires, as compared with wires of solid section, as high stability of welding process, small losses on spattering, considerable improvement of quality of welds deformation, high values of mechanical properties of weld metal, in particular plastic characteristics. The achieved increase of labor productivity amounts from 15 to 30 % [27, 39, 40].

In the last decade the development of automatic and robotic welding gave an impetus to the development of gas-shielding flux-cored wires with a metal core, whose content of non-metallic materials does not exceed 1 %. Such flux-cored wires are characterized by high speed and efficiency of melting (by 30–40 % higher than in welding using wire of solid section), due to their application the losses of electric energy are cut due to high fraction of filler electrode metal in the powder core [23, 41, 42]. The lack of a slag on the surface of a weld allows performing multilayer welding without cleaning from slag. High in-process properties in welding in gas mixtures are achieved due to fine-drop or spray electrode metal transfer. High level of values of mechanical properties (strength and tough-plasticity) was also obtained.

Gas-shielding flux-cored wires are applied in the most branches of industry where metal structures of carbon and low-alloy steels of increased and high strength are welded (in machine building, ship building, power engineering construction, etc.)

Specialized methods of welding using flux-cored wire. The specialized methods include methods of automatic welding, requiring application of special welding equipment, technologies and wires, which are characterized by peculiar properties in accordance with requirements specified to the conditions of welding and quality of welded joints. They include arc welding with a forced (electric gas) and semi-forced weld formation, automatic welding of circumferential welds with a pre-forming, welding using electric rivets and other [5, 43].

The electric arc welding of vertical butt joints of sheet structures (tanks, spans of bridges, ship sections on the bed, bodies of converters, blast furnaces, silo towers, etc.) foresees performance of process with a single — or two-sided forming of weld surface using movable (copper water-cooled shoe) or immovable means (ceramic or copper water-cooled backing) [44, 45].

Welding of horizontal welds in vertical plane is carried out using a pre-forming of a lateral surface of a weld pool by a special moving shoe, providing a «semi-forced» weld formation and required shape of its surface [5, 45, 46]. A large volume of a weld pool, necessity of obtaining of specific properties of a slag, forming the interlayer between a shoe and weld surface, absence of postweld heat treatment of a single-pass weld required creation of special flux-cored wires. For welding under site conditions at a designed position of the structures the self-shielding flux-cored wires of two-layer design were developed [9, 46].

The important step in the development of welding using flux-cored wire with a forced weld formation is the creation of method of welding, equipment and flux-cored wires to perform circumferential welds of butt joints of pipes in construction of main pipelines of large diameter [47–50]. The tasks of welding technology in all spatial positions providing stable high quality of welded joints of pipe steels of classes of strength from X50 to X80 were solved [29, 51]. The equipment and welding technology provide continuous monitoring of heat input and programmed control of welding process.

Flux-cored wires for underwater welding. The first half of the 1960s was characterized by beginning of intensive mastering of oil and gas deposits in Siberia and construction of main pipelines for transportation of gas to the European part of the USSR and countries of Europe. Considering a big number of water barriers on the way of lying down of pipelines and necessity to provide reliable service of the latter there appeared the demand for the development of technology of repair using underwater welding. Mechanical welding using solid wire in shielding gases and manual welding applied for this purpose did not provide the required quality of welded joints. According to the proposal of B.E. Paton the mechanized welding using flux-cored wires was decided to be used.

Since 1965 the fundamental investigations of metallurgical peculiarities of wet underwater welding and physical characteristics of the arc burning under water are carried out at the E.O. Paton Electric Welding Institute. The result of these works was creation in 1967 of flux-cored wire PPS-AN1 of rutile-ore-acid type for welding of non-alloyed structural steels at the depth of up to 20 m [52]. Metal of welds performed using mechanized welding by flux-cored wire as compared to manual welding was characterized by resistance against pores formation and had increased mechanical properties. New process allowed the increase of efficiency of welding, provide convenience and safety of work of a welder-diver, improve visibility of the zone of arc burning almost by 3 times.

Further, the investigations were directed on the determination of salinity of water, depth of works performance, search of the methods of optimization of gas-slag component of the charge of flux-cored wire and alloying systems [53–61], as a result the flux-cored wires were created for welding low-alloy steels with a yield strength of up to 400 MPa at the depth of up to 30 m, providing the weld metal with a required level of mechanical properties.

From the beginning of the 2000s the elements of structures of nuclear power stations began to be welded of stainless steels of the type 18-10. The application of developed flux-cored wires facilitated producing of welds, which according to the values of mechanical properties were superior to the welds produced on the air by electrodes of E-08Kh20N9G2B type, for example TsL-11 [62].

Since 1972 the E.O. Paton Electric Welding Institute carries out investigations on development of technology of mechanized arc cutting using flux-cored wire instead of manual electric oxygen cutting. The application of this method increased efficiency of the process and allowed refusing the supply of oxygen into the cutting zone, which is very important during performance of works under highly explosive conditions. The developed flux-cored wires allow performing technological and dividing cutting of low-alloy and stainless steels, aluminium, copper, titanium and their alloys of up to 40 mm thickness at the depths of up to 60 m [63, 64].

The practical application of developments of the E.O. Paton Electric Welding Institute began in 1969 during repair of water conduit of ∅1020 × 12 mm of steel 09G2, laid across the river Dnieper at the depth of 12 m [65]. In 1971 a repair of underwater part of the body of mid-size fishing trawler-refrigerator was for the first time performed using flux-cored wire [66]. Marine Register of the USSR allowed trawler to be admitted to the further navigation without docking. One of the examples of application of welding using flux-cored wire in building can be joining of four sections of floating platform «Prirazlomnaya» of 126 m length with overall length of three-pass fillet weld of about 1800 m afloat [67] and welding of underwater part of the supports of Podolsk-Voskresensk bridge across the Dnieper river in Kiev, the overall length of three-pass fillet weld was 5000 m.

The flux-cored wires for cutting were applied during works on cleaning offshore area from sunken ships, disassembling of underwater supports of stationary basements, performance of emergency-rescue operations. They were applied for the works on lifting submarine in the area of Petropavlovsk-Kamchatsky [68], repair of wharf walls in St. Petersburg, on the island Dikson, etc.

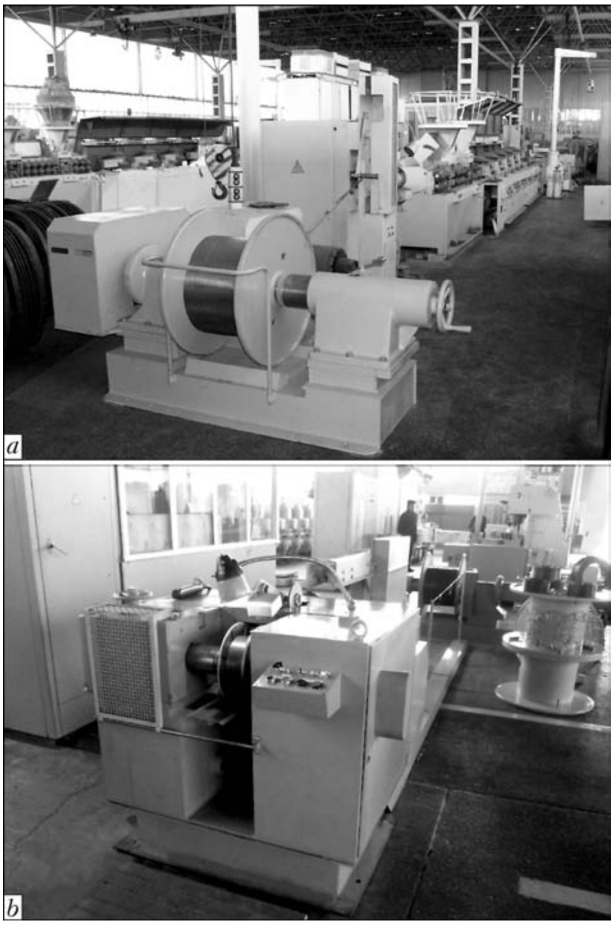
The technology of underwater wet welding and cutting using flux-cored wire developed at the E.O. Paton Electric Welding Institute is successfully applied in restoration of pipelines with maximal diameter of up to 1020 mm and working pressure of up to 5 MPa, liquidation of navigation and corrosion damages of ships afloat without further docking, repair of structure elements of hydro power stations, wharf walls, sea platforms, performance of emergency-rescue operations, etc.

The developments of the E.O. Paton Electric Welding Institute in the field of underwater wet welding using flux-cored wire are protected by 10 patents.

Flux-cored wires for electric arc surfacing. Nowadays the flux-cored wires are the most applied electrode material for automatic and mechanized electric arc surfacing of parts of machines and mechanisms in different branches of industry. As compared to the wires of large section the flux-cored wires provide great opportunities for alloying of deposited metal.

The first flux-cored wire PP-3Kh2V8 developed at the E.O. Paton Electric Welding Institute was designed for the surfacing of mill rolls. The composition of this wire was so successfully selected that it is still widely used in the industry under the designation PP-Np-35V9Kh3GSF.

The welding-technological properties of new surfacing electrode material were investigated, conditions of surfacing using wires providing quality deposited metal were developed [1, 69]. The first flux-cored wires were designed for surfacing under the flux.



Automatic line on manufacture of flux-cored wire (forming, filling, drawing) (*a*) and installation for coiling of flux-cored wire on framed spools K-300 (BS-300) (*b*)

As a result of investigations of interaction of slag melt with alloying elements [1, 69–73] the level of their oxidation or recovery from a slag was established which allowed calculating composition of a charge of flux-cored wires for surfacing with a sufficient level of accuracy.

In the works [1, 74–77] the mechanism of formation of crystalline cracks at surfacing and welding was investigated and measures of their prevention were offered. It was established that ledeburite low-melt eutectics forming during surfacing of high-carbon high-chromium steels at specified carbon content can cure discontinuities which are formed during solidification of these steels.

During surfacing of parts of low- and high-carbon steels it happens almost all the time to encounter the problem of cold crack formation. The most widely spread method of cold crack prevention is preheating of parts before surfacing and tempering after surfacing. To surface these parts without or with minimal heating the flux-cored wires PP-AN193, PP-AN195, PP-AN196 and PP-AN202 were developed at the E.O. Paton Electric Welding Institute providing the deposited metal with a high crack resistance [78].

Adding of additional mineral and metallic components to the charge of flux-cored wires gave possibility to struggle against such defect of the deposited metal as pores. To prevent hydrogen porosity I.I. Frumin offered to introduce tetrafluorine of alkaline metals into the core of flux-cored wire.

For mechanized arc surfacing using an open arc the gas- and slag forming components and different additions stabilizing the process of arc burning and preventing pores formation in surfaced metal are introduced into the charge of flux-cored wires. A number of self-shielding flux-cored wires for surfacing different wear-resistant alloys were developed [79, 80].

The investigations of peculiarities and character types of wear of parts of different machines and mechanisms were conducted and corresponding flux-cored wires were designed. To surface mill rolls and dies of different purpose a range of flux-cored wires was designed, such as PP-Np-35V9Kh3SF, PP-Np-25Kh5FMS, PP-AN132, PP-AN140, PP-AN147, PP-AN148, the application of which allows repeated restoration of worn-out parts. To restore and strengthen parts of metallurgical equipment the flux-cored wires PP-AN158, PP-AN159 and PP-AN147, providing the deposited metal of the type of high-chromium stainless steel with different hardness and wear resistance, were designed [81].

To surface parts operating under the conditions of abrasive wear with impact load of different intensity the flux-cored wires PP-AN125, PP-AN135, PP-AN170, PP-AN192, PP-AN197 and PP-AN105 are recommended.

To surface rods of mine hydrolinings of heading machines, pistons of hydraulic presses and other similar parts in manufacturing and restoration the flux-cored wire PP-AN165 was designed. A metal, deposited using this wire, is characterized by sufficiently high corrosion resistance in water-saline solutions and wear resistance in metal-against-metal friction. The application of surfacing allows excluding the ecologically harmful operation: chrome-plating of parts.

To surface shafts, axes, crane wheels and other parts operating under the conditions of friction of metal against metal with or without abrasive interlayer, it is recommended to apply flux-cored wires PP-AN120, PP-AN126, PP-AN194 and PP-AN198.

Till nowadays the E.O. Paton Electric Welding Institute develops and produces flux-core wire for submerged arc surfacing using open arc and also parts of different machines and mechanisms in shielding gases which are operated under conditions of almost all known kinds of wear [82]. The original compositions of flux-cored wires for surfacing are protected by five patents.

Creation of production of flux-cored wires. In the 1950s and beginning of the 1960s the flux-cored wires were manufactured at small areas equipped in shops of electrode production. The works on designing and organization of full-scale production of flux-cored wire and also development and realization of corresponding industrial technology were developed at the

E.O. Paton Electric Welding Institute attracting the organizations and enterprises with experience in creation of electrode productions, among which there were Institutes «Giprometiz» (Leningrad), NIIMetiz (Magnitogorsk), Alma-Ata Heavy Machine-Building Plant, organizations and enterprises of Minmontazhspetsstroj, etc. Head organization and coordinator of all works was the E.O. Paton Electric Welding Institute. The Institute performed the investigations of the technology of manufacture of flux-cored wire of different types. The study of combined deformation of solid and bulky bodies, load conditions at different schemes of treatment and organizing of technological process allowed developing the scientific and engineering bases of the industrial technology of manufacture. The designs of machines, devices and instruments for furnishing the production lines, in particular forming devices, charge batchers of continuous operation, units of degreasing, welding and coiling of steel strip, installations of continuous release of wire, devices of control and monitoring of filling wire with a charge.

The Design Bureau of the E.O. Paton Electric Welding Institute developed designs of specialized types of the equipment for forming of different flux-cored wires, batchers for filling steel sheath with a charge, devices for continuous release of flux-cored wire from the drawing mills, installations and outfit for degreasing of cold-rolled strip and other technological equipment. The pilot models of the equipment and main industrial machines were manufactured by the Pilot Plant of Welding Equipment of the E.O. Paton Electric Welding Institute. The developments of the Institute were transferred to the enterprises-manufacturers of the equipment. At the Alma-Ata Heavy Machine-Building Plant the industrial production of complete technological lines on manufacturing flux-cored wires was mastered. These production lines were used for productions being under construction (Nizhnedneprovskoe Metal Ware Production, Cherepovets Steel Rolling Plant, Dnepropetrovsk Plant of Welding Consumables, etc.). In 1978 the work of the staff of the E.O. Paton Electric Welding Institute on creation, organization of mass production and implementation of new materials (flux-cored wires) for mechanized welding, providing the increase of work efficiency and quality of welded structures was awarded the State prize of the USSR. The authors' staff included I.K. Pokhodnya, I.I. Frumin, A.M. Suptel, V.N. Shlepakov, V.F. Alter, and also the members of organizations and plants mentioned above.

In 1978 the Boiler-Welding Plant of Minchermet of the Ukr. SSR was transferred to the E.O. Paton Electric Welding Institute. In a short term the plant was considerably reconstructed and equipped with modern equipment. At present, the State Enterprise «Pilot Plant of Welding Consumables of the E.O. Paton Electric Welding Institute» is a leading enterprise in Ukraine on the production of welding consumables: electrodes, flux-cored wires (Figure), welding fluxes.

High level of developments of welding flux-cored wires, technologies of their manufacture and production equipment was recognized in many countries throughout the world. The transfer of documentation, delivery of equipment and mastering of technologies on the developments of the E.O. Paton Electric Welding Institute were performed on the base of license agreements and contracts with enterprises of France, Germany, USA, China, Japan, Argentina, etc.

The problems of theory and practice of manufacturing of flux-cored wires are generalized in the work [83]. The priority of developments of the E.O. Paton Electric Welding Institute in the field of technologies of manufacturing of wires and appropriate equipment is protected by more than 50 patents.

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JAPANESE WELDING FABRICATION DURING 2009 ECONOMIC CRISIS

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The paper presents statistical data characterizing the condition of the Japanese market of welding equipment at the final stage of the world financial-economic crisis of 2009.

Keywords: *welding fabrication, market of equipment and materials, action plan, priority areas*

Market of the main structural materials. In 2009 the world financial crisis resulted in a considerable reduction of production of the main structural materials in Japan. Compared to 2008, production of raw steel was reduced to 26.3 % and was equal to 87.5 mln t. This is the lowest level of productions since 1969. Output of all kinds of finished steel products was also greatly reduced. Table 1 gives the data on hot-rolled stock production for the period of 2007–2009 [1].

Metal working industries reduced their orders by 30 % (to 37.5 mln t). Steel consumption in construction decreased by 26.1 % (to 9.6 mln t), in mechanical engineering by 29.8 % (to 18.2 mln t), and in shipbuilding by 2.8 % (to 5.5 mln t). Automotive companies reduced their orders for steel products to the greatest degree (by 35.5 %, to 7.3 mln t). As predicted by JFF Holdings, in 2010 an increase of the volume of orders in automotive and mechanical engineering industries is anticipated.

Production of primary aluminium in 2009 decreased by 23.2 % (to 5.1 thou t), secondary aluminium — by 36.9 % (to 666.0 thou t), aluminium rolled stock — by 21.4 % (to 1.062.8 thou t), and that of extruded sections — by 24.2 % (to 673.1 thou t). Domestic consumption of aluminium in 2009 was equal to 3250.1 thou t (by 23.4 % less than in 2008). Table 2 gives the pattern of consumption of aluminium rolled stock and extruded sections in Japan by individual industries and in construction [2].

Welding consumables market. Welding consumables market in Japan is closely related to structural metal market, particularly, that of steel [3]. Reduced consumption of finished steel products by the main metal working industries led to a considerable reduction of welding consumables market. For instance, consumption of welding consumables in shipbuilding

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