DOI: http://dx.doi.org/10.15407/tpwj2019.03.05

APPLICATION OF FLUX-CORED WIRES AT SURFACING, REMELTING AND IN METALLURGY

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The paper presents the history of flux-cored wires appearance and their application as remelted material, both in micrometallurgy (surfacing), and in large-scale metallurgy (electroslag remelting and foundry). Features of technological processes with flux-cored wire application in each of the considered branches are shown. At present technologies ensuring improvement of metal quality in foundry are developing the most actively. Prospects for flux-cored wires application in surfacing from the viewpoint of improvement of their production technology and development of new compositions of deposited metal have largely been exhausted. Technologies of surfacing in a current-supplying mould have certain potential for a wider application, particularly in the field of producing composite layers. Electroslag remelting of metal, as in the years of its development, is mainly focused on producing ingots of a large mass and diameter with application of monolithic electrodes of a large cross-section. 37 Ref., 1 Table, 5 Figures.

Keywords: *flux-cored wire, arc surfacing, electroslag remelting, ladle treatment*

Flux-cored wire is a structure in form of hollow tube filled with charge of various dispersion and composition. Depending on determined tasks it can be of different diameter and length.

Applicable to welding the first mention of possibility of flux-cored wires use, apparently, shall be considered a proposal of N.N. Benardos on manufacture of electrodes of different design, including in form of «tubular electrodes with a core of various powders» [1]. Beginning of practical application of welding flux-cored wires refers to 1930th.

A series of reasons promoted distribution of arc welding and surfacing using flux-cored wires in comparison with seamless ones:

• need in performance of welding and surfacing of high-alloy and high-carbon steels and alloys, when corresponding doped wires cannot be manufactured in general or believed to be too expensive [1];

• application of self-shielded flux-cored wires allows performing welding without additional expenses for shielding gases and flux;

• surfacing, as well as welding, with self-shielded flux-cored wires is characterized by simplicity, manoeuvrability and low sensitivity to change of external welding conditions [2].

Nevertheless, today in Ukraine portion of flux-cored wires in the structure of production of welding consumables (electrodes, wires, fluxes) makes only 2 % [3].

Such low volumes of flux-cored wires refer particularly to wires designed for performance of welding operations. For arc surfacing, as type of welding technology, their application is more significant. Primary it is related with the need to get wear-resistant deposited metal, operation properties of which improve at its increased alloying. In this case, as it was mentioned above, in manufacture of seamless wire there are problems of technological as well as economical order. Some types of surfacing flux-cored wires are presented in Table [4].

Peculiarities of production and technical characteristics of flux-cored wire to a larger extent are determined by design of its cross-section [5]. Designs of tubular, with lap, edge bending, complex section types have found commercial application. The wires of complex section are mainly used as self-shielded. Tubular design with lap is oftenly used in manufacture of surfacing wires. A coefficient of filling (value of core portion in wire) is assumed to calculate in percent. The value of this coefficient for surfacing wires is in the 15–45 % limits.

Solid wire of 3 mm diameter is used as a rule in electroslag welding and surfacing as electrode metal. However, in some cases wire of other diameters (1–2 or 5–6 mm) [6] find application. Common welding equipment allows feeding electrode wires of 3–5 mm diameter. Nevertheless, in the beginning of active investigation and implementation of electroslag process in 1950th there were still different areas using surfacing flux-cored wires. This tendency of limited application of flux-cored wires was preserved in the next years, mainly, in 1970–1980th. Hardfacing with flux-cored wires was used in repair of steel rolls [7], strengthening of cams of pipe stripping machines [8], pressing tools of bearings production and different elements of stamps [9, 10], crushing hammers of aluminum production and grooves of pipe cold rolling mills [11], cutting edges of knives of hot cutting of metal

Flux-cored wires for hardfacing

Type of deposited metal	Typical composition of deposited metal, wt.%							Hardness after hardfacing *HRC*
	C	Mn	Si	Cr	W	Mo	Other elements	
Open arc hardfacing								
70Kh4M3G4FTR	0.7	3.5	0.5	4.0	–	3.0	1.0V; 0.7B; 0.1Ti	57–62
30Kh4V3M3FS	0.35	0.6	0.9	3.8	2.8	2.8	0.5V	47–50
30Kh5G2SM	0.3	1.6	0.8	5.0	–	0.6	0.2Ti	50–56
90G13N4	0.9	13.0	0.5	–	–	–	4.0Ni	≤ 20
200KhGSR	2.1	1.1	0.9	0.4	–	–	0.8B; 0.1T; 0.17Al	48–56
80Kh20RZT	0.8	–	–	20.0	–	–	3.0B; 0.6Ti	58–67
Submerged-arc hardfacing								
200Kh12M	1.8	0.6	0.6	12.0	–	0.8	–	40–44
10Kh17N9S6GT	0.1	1.8	5.5	17.6	–	–	9.2Ni; 0.15Ti	27–33
25Kh5FMS	0.25	0.6	1.0	5.0	–	1.1	0.4V	42–46
35V9Kh3SF	0.3	0.8	0.9	2.8	9.5	–	0.3V	44–50
30Kh2N2G	0.3	1.2	0.6	1.8	–	–	1.4Ni	42–48
100Kh4G2AR	1.0	2.2	1.3	4.0	–	–	0.2N	55
CO_2 hardfacing								
80Kh12K4F3V2M2NR	0.8	–	–	12.0	2.0	2.0	4.0Co; 3.0V; 1.0Ni; 0.1B	57–60

and plug noses of pipe rolling plants [12], sealing surfaces of parts of shut-off valves.

Some technologies of electroslag surfacing (ESS) formally can also be considered as one using flux-cored wires of any design as electrodes. Thus, for example, for circumferential surfacing of mill rolls it is proposed to use flux-cored electrode of circular section, in which charge is located not in rolled from strip tube, but between two concentric steel casings [13]. In essence, such a design can be presented as continuous series of tightly mating between themselves separate flux-cored wires.

Regardless the presented above examples of application of flux-cored wires in electroslag surfacing of parts of different designation, it is necessary to note that currently application of seamless wires [14] is preferred. Apparently, it is mainly related with a fear to violate continuous feed of flux-cored wires, having less rigidity in comparison with seamless, through the feeding mechanism of welding apparatus, particularly during long in time surfacings, partial pouring out of charge at low grade manufacture of wires. To some extent it is because of the wish of surfacers to get wear-resistant layers with more uniform distribution of alloying elements in the deposited metal and, respectively, properties. This is particularly important for the cases when insignificant wear of metal of working layer have more effect on product working capacity (for example, in metal to metal friction). Such a concept appeared based on existing opinion that «arc welding and surfacing with solid alloyed electrode provides sufficiently high homogeneity». However, investigations of macroinhomogeneity of metal, deposited with flux-cored wire using electroslag method, showed, that in this case its «sufficient homogeneity» is provided.

New possibilities of application in surfacing of flux-cored wires appeared due to development at E.O. Paton Electric Welding Institute a device representing itself sectional nonconsumable electrode, titled by the developers as current-supplying mould (CSM) [15]. One of the advantages of this device is open slag pool surface and possibility of regulation of its heat state. This allows using in surfacing current-conducting as well as non-current-conducting wires. The perspectives of application of CSM in surfacing with flux-cored wires are proved by works of Volgograd State Technical University [16]. Moreover, currently the main direction in these works is technology of production of composite layers, at which hollow graphite electrode (electrodes) of special design is located in a CSM working zone. Non-current-conducting composite flux-cored wire is supplied in the slag pool through its cavity. From point of view of authors the presence of such electrode allows developing in under-electrode space a local zone of increased temperatures, that promotes uniform melting of metallic shell and filler being a part of flux-cored wire. The filler contains refractory and fusible components in form of metallic powders and wires.

The similar investigations are carried out at the E.O. Paton Electric Welding Institute for the purpose of production of deposited face working layers of high-wear products, for example, mandrels for pipe production. At that it is possible to provide minimum and uniform penetration of base metal. Figure 1 presents the macrosection of billet deposited in CSM of 85 mm diameter using non-current-conducting flux-cored wire PP-Np-25Kh5FMS of 3 mm diameter.*

*Cand. of Tech. Sci. Osin V.V. took part in surfacing.

In ESS with flux-cored wires (at any type of surfacing) the main technological parameter determining the stability of electroslag process and depth of base metal penetration is electrode feed rate [17]. The rate itself depends on many factors, namely diameter and composition of flux-cored wires, slag composition, slag pool temperature, electrical mode of surfacing. It is also necessary to note the effect of surfacing method on process of wire melting. In particular, at ESS using CSM the current-less as well as electrode wires can be fed in the slag pool and, respectively, conditions of their melting will be different. From practical point of view the rate of wire feed shall be selected such as to provide from one side melting in the slag of all its constituents, and on the other, eliminate coming of wire tip in the metallic pool.

A predecessor of method of electroslag melting (ESR) is so-called Kellog process, proposed in the 1940 in USA by R.K. Hopkins (US patent No.2.191.479). The process was performed by means of arc remelting under layer of slag of tubular electrode, inside which dosed amounts of discrete filler were added in form of ferroalloys, foundry alloys and pure metals (Figure 2). In essence, a tubular electrode is an analogue of flux-cored wire. ESR directly was started from remelting of common welding wires with additional feed in the slag pool of charge materials. In the 1955–1956 works of D.A. Dudko, I.K. Pokhodnya and Yu.A. Sterenbogen showed the possibility of stable electroslag process using the electrodes of comparatively small sections (30–50 mm), later on larger and larger (more than 1000 mm). Remelting of flux-cored wires was used only in series of cases, for example, for evaluation of possibility in production of metal of different composition using electroslag process, in particular, cast irons for the purpose of further application of the results for manufacture of surfacing flux-cored wires [18].

With some assumption the technologies, in which seamless electrode strips (not folded in the tube) with additional feed to the surface of strip of discrete filler (charge) are melted in slag pool, can be referred to the processes of flux-cored wire remelting. At that the strip itself as well as filler shall be made of magnetic materials providing their magnetic adherence and simultaneous addition into the slag pool.

To such original technologies of ESR it is necessary to refer a technology proposed in 1960th by Belgian Cockerill S.A. and Electrotherm S.A. Companies (Figure 3). The main technical direction is the production of large round section ingots of low-alloy steels [19]. A strip of 75×2 mm section and powders with 0.5–3.0 mm particle size are used for surfacing. The

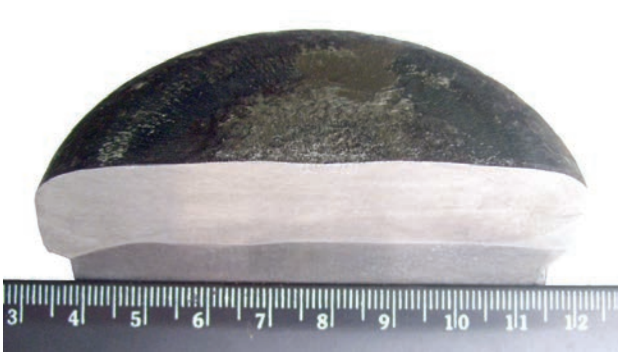

Figure 1. Macrosection of billet deposited with non-current-conducting wire PP-Np25Kh5FMS of 3 mm diameter in CSM of 85 mm diameter

powders can be produced by reduction of oxides of required metals or by means of spraying of a jet of liquid metal by air or water. Relationship of mass of remelted strips and powders makes 30 and 70 %, respectively.

Comparison of this remelting technology (process of CESR — continuous electroslag remelting of powders) with common ESR of electrodes of large section shows its next advantages:

• increase of remelting efficiency;

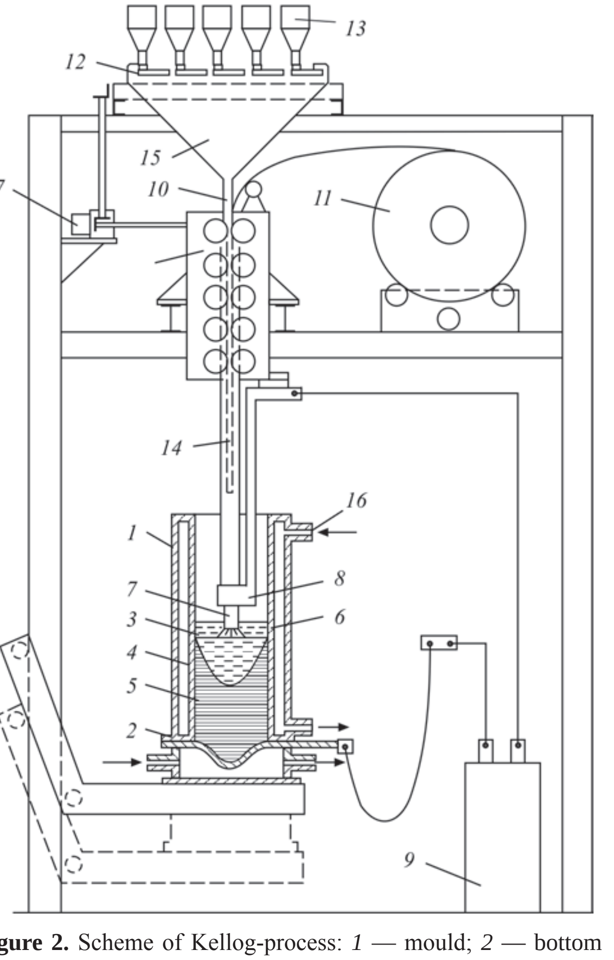

Figure 2. Scheme of Kellog-process: *1* — mould; *2* — bottom plate; *3* — liquid slag; *4* — liquid metal; *5* — ingot; *6* — electric arc; *7* — consumable tubular electrode; *8* — current lead; *9* — heat source; *10* — tube forming device; *11* — strip coil; *12* — dosage unit; *13* — measuring hopper; *14* — pour out tube; *15* — hopper; *16* — cooling water input; *17* — motor drive

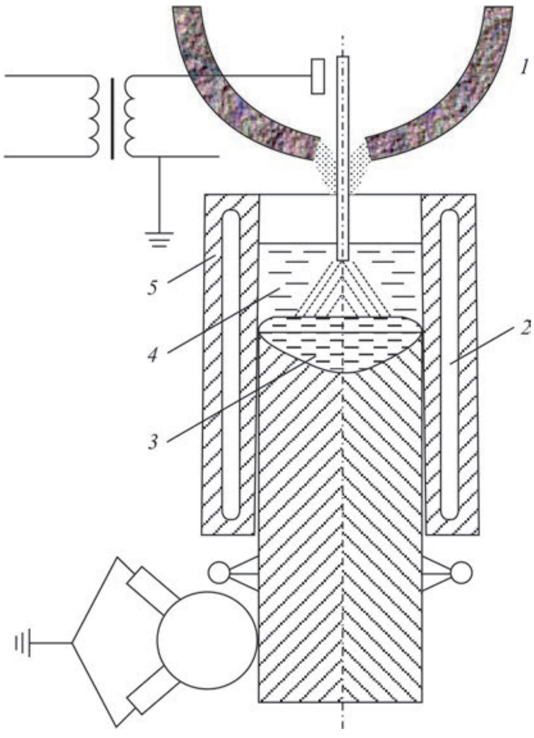

Figure 3. Scheme of CESR process: *1* — powder feeder; *2* — water cooling; *3* — liquid metal; *4* — slag pool; *5* — mould

• production of flatter metallic pool, that in many respects determines metal quality;

• reduction of expenses for production of materials being remelted;

• possibility of melting the ingots of virtually any length.

The perspectives of further application of this technology the authors connect also with the fact that, as practice of melting of 3 and 21 t ingots shows, economic efficiency of process rises with increase of mass of produced ingots [20]. Therefore, the real aim they consider achievement of melting of ingots of 40–50 t mass and more.

The similar technology of ESR with application of strips and powders is used by Electrotherm Corporation Company, USA [21]. The main product of remelting based on this technology is the small ingots of high-alloy steels, in particular, used in the USA tool steels. A scheme of remelting is presented on Figure 3.

This technology of remelting is characterized with some peculiarities. The process is started on a seed, transferring it from arc into electroslag due to strip melting and development of sufficient slag volume. After that, there is continuous feed into the slag pool of strip and powder. The particular requirements are made to strip electrodes and charge. The size of strip is selected taking into account its complete melting in the slag. Stick-out from current lead is of great importance, namely in the case of large stick-out the strip can be overheated (the same as powder) and lose its magnetic properties that effects the melting stability and metal quality. If charge contains nonmagnetic metals, for example Cu, Cr, Ti or some weak-magnetic ferroalloys there can be difficulties in its proper fixing on the strip surface. In this case it is necessary to provide good stirring of components in the mixer, moreover, total amount of nonmagnetic fraction shall not exceed 7–10 %.

There are peculiarities of remelting procedure. Thus, in production of ingots of 100×100 mm size the strip during melting has reciprocating motion in the slag pool. Besides, it is subjected to oscillations in plane normal to its surface.

Modern technology of steel production develops in the direction of application of new metallurgical aggregates (arc furnace, converter) only for melting of solid constituent of the charge and oxidation of carbon, silicon, manganese, i.e. semi-finished product manufacture. Virtually all operations on bringing of melt in accordance with grade requirements on properties and in whole on metal quality are carried out by the processes of ladle refining.

One of the most state-of-the-art and perspective methods of ladle treatment is addition of flux-cored wire in the liquid steel. Based on data from [22] in the beginning of the 1990th around 200 machines for modification with flux-cored wire were operated in the world metallurgical industry. Due to higher technical and economic efficiency of treatment of steel and cast iron by flux-cored wires in comparison with other known methods of liquid metal treatment the tendency to application of this technology in metallurgy continuously rises [23].

Start of application of flux-cored wires in the metallurgy was related with wide application of calcium and calcium-containing materials in steelmaking. Their addition into the liquid metal in form of flux-cored wire showed high efficiency of metal refining from detrimental impurities and nonmetallic inclusions. The First International Symposium on treatment of liquid metal with calcium [24] was held on June 30, 1988 in Great Britain (Glasgow). It was sponsored by Affival Company (France), which entered mass production of flux-cored wires and devices for their addition into the melt.

In the recent years other companies in addition to Affival Company started to expand the possibilities of application of flux-cored wires as a method, which is technologically convenient and economically profitable. At that alloying, microalloying, deoxidizing, refining and modifying additives [25] served as charge of flux-cored wires. Such additives became the elements characterizing with high oxygen affinity (Ca, Mg, Al, Ba, Ti, Si, Zr, Ce and other REM), small den-

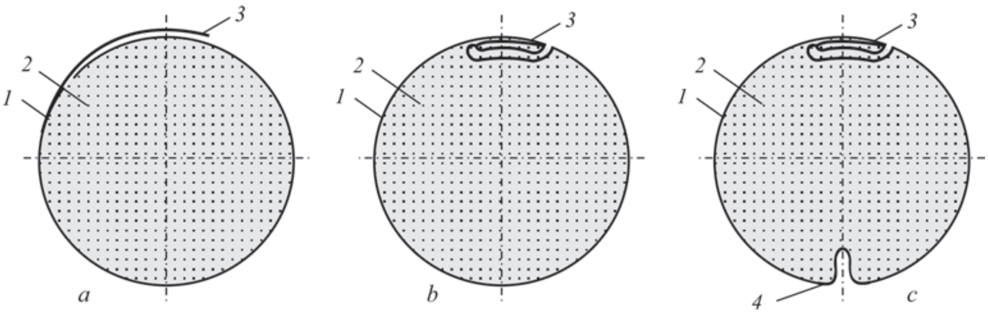

Figure 4. Types of using flux-cored wire joining: *a* — lap; *b, c* — finger (*1* — shell; *2* — filler; *3* — finger joint; *4* — compensator)

sity (C, B, S, Ca, Al, Mg etc.), relatively low melting and boiling temperatures (Ca, Mg, S, Se, etc.), high vapor pressure and small solubility in liquid metal (Ca, Mg, etc.). In a series of cases application of flux-cored wires is an alternative method for addition of calcium and other elements or compounds into liquid metal in comparison with method of injection in it of similar components in form of powders [26, 27].

In the former Soviet Union the most active work on improvement of elements of technology of wires production and methods of their addition to the melt were carried out by scientific institutes IPS, PWI, DonNII-CHERMET. For the period of 1986–1991 the development proceeded from issue of pilot batches of wires to their commercial production as well as special equipment for addition of wires into liquid metal at Donetsk production-implementation Company «Metall» (from 1989, OJSC «Zavod Universalnoe oborudovanie») [28]. Currently, flux-cored wire is manufactured by 20 more enterprises from former CIS countries [29].

The flux-cored wire used in this method of ladle treatment of liquid metal is a steel (steel 08Yu) shell of 0.2–0.5 mm thickness, filled with powder-like material, and reeled on coil. The length of wire in a coil is from 2000–4000 m and more. Wire diameter is 8–16 mm. At the first stage of mastering of wire production the ends of metallic shell were lap joined (overlapping 7–8 mm) with presence of longitudinal stiffening rib (compensator). Such a wire during its feed into liquid metal often opened that resulted in charge pouring out. In the future the flux-cored wires started to be manufactured using «finger» joint of the edges with or without compensator [29] (Figure 4). There are some requirements to powder-like chemical agents. They can be a metal, alloy or nonmetallic inclusions, milled to specific size. It was experimentally determined that the maximum fraction of powder particles shall not exceed 2.5 mm for 13 and 15 mm diameter and 2 mm for 10 mm diameter wire. From point of view of dense filling of section the pow-

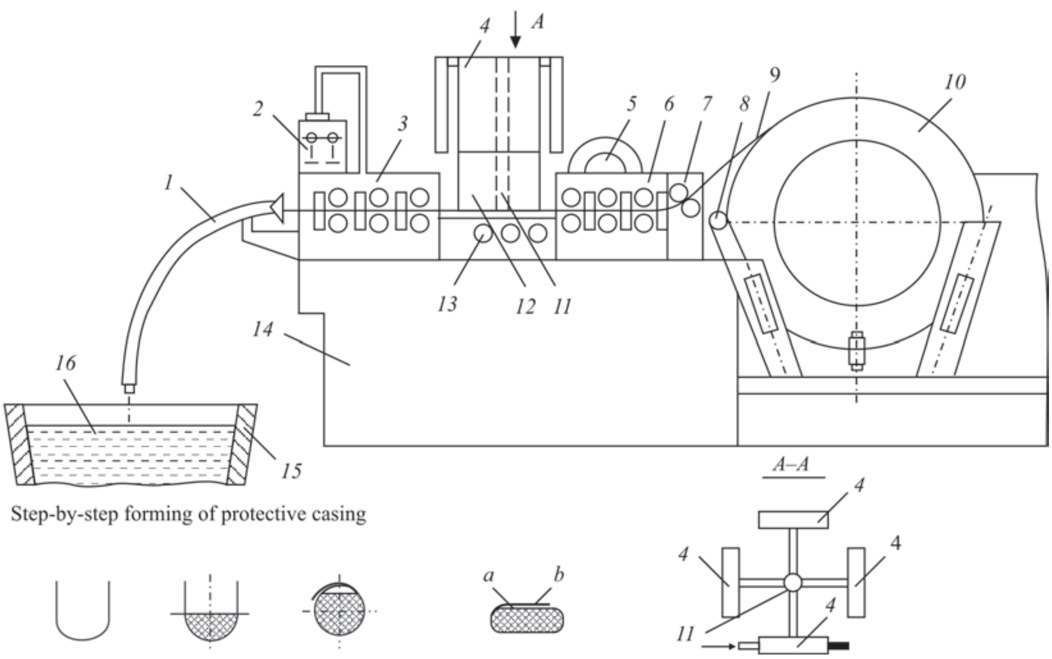

Figure 5. Technological complex of ladle treatment of melts using flux-cored wires: *1* — guide; *2* — control panel; *3* — forming-sizing stand; *4* — measuring hopper system; *5* — electromechanical group drive; *6* — forming stand; *7* — guide rollers; *8, 9* — tension device; *10* — decoiler with winded strip; *11* — rotating turret; *12* — protective casing; *13* — support rollers; *14* — frame; *15* — metallurgical capacity; *16* — melt; *a, c* — strip flanges overlapping

der-like material shall contain up to 25 % of dust-like fraction (particle size less than 0.2 mm) [29].

A technological line for production of flux-cored wire includes a series of devices, which provide uncoiling of strip, formation a channel in it, input of charge in it using the dosing machines, formation of closed profile, its calibration and row by row laying of wire in the coil.

The second main element of technology of secondary refinement of melt with flux-cored wires in ladle, tundish, mould is the presence in it of so-called pitch roll units. Their main task is to draw the wire with a set speed and create at the output a pushing force providing overcoming of wire friction forces on a guide pipe and at passing by it of metal melt as well as overcoming of friction forces in the pitch roll unit itself. The pitch roll units can be of single-, two- and multigroove design, i.e. for feeding into the melt of one, two or more types of wire [29, 30]. In a series of cases it is assumed to use technological complexes combining the processes of manufacture of flux-cored wire and its feeding into the liquid metal (Figure 5) [22]. Apparently, such technical solution still can not be recognized optimum one since any violation of wire manufacturing technology and its quality will have direct effect on quality of metal being treated. Besides, «lap» wire forming can result, as it was mentioned above, in its opening in the liquid metal.

Usually wire is fed vertically into the melt [29, 31], but some authors believe the wire feeding in the tundish at 40–70° is more reasonable, that significantly (1.5–3 times) increases the length of immersed part of wire and, respectively, allows varying its feed rate [32].

Thus, proposed at the end of the XIX century by N.N. Benardos welding consumable of special design, titled later on as a flux-cored wire, has found application not only in welding, but also in surfacing, remelting, and foundry. In each of these fields it was possible to show the main advantages, i.e. in surfacing it is a possibility of wide alloying of deposited metal; in remelting — continuous process of material melting; in foundry — improvement of quality of metal due to its refining, modifying and alloying.

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Received 12.11.2018