CLADDING FLUX-CORED STRIPS (Review)

A.P. ZHUDRA and **A.P. VORONCHUK**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

The history of development of a cladding electrode consumable in the form of flux-cored strip is presented. Various designs of the strips, compositions and application fields are considered. Equipment for manufacture of flux-cored strips and technological advantages of cladding using this consumable are described.

Keywords: *flux-cored strip, compositions, cladding, equipment, technology, deposition efficiency, application*

Flux-cored strip is now a well-known cladding consumable, which is extensively applied for manufacture and hard-facing of a wide range of parts in metallurgical industry, power engineering, mining, road construction and other industries. In contrast to flux-cored wire, the key advantages of the flux-cored strips are high deposition efficiency, possibility of alloying the deposited metal, and relative simplicity of manufacture.

The first to offer the flux-cored strip electrodes in the former USSR in 1959–1960 were O.A. Bakshi, E.F. Belousov and G.P. Klekovkin, associates of the Scientific Research Institute of Machine-Building Technology of the Chelyabinsk Sovnarkhoz (Council of National Economy) [1, 2]. The author's certificate [1] received by these specialists confirmed originality of this development not only for the USSR but also for the world welding industry. Initially, the flux-cored strips were manufactured from two strips, which were formed into a sheath directly by using the cladding device, the charge being made from the stalinite B powder. To prevent spilling of the core charge, the lower part of the sheath comprised corrugations, which formed separate cells (Figure 1, *a*).

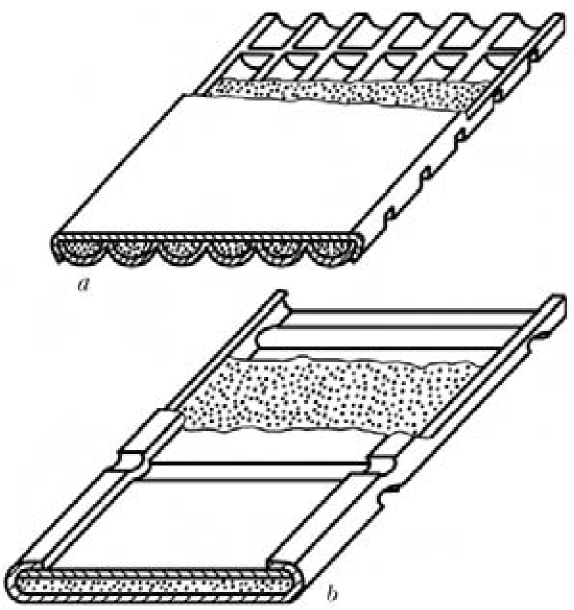

Figure 1. Schematic of flux-cored strip according to the author's certificate [1] (*a*) and of the design of Chelyabinsk NPTIAM-MASh (*b*)

Combining the electrode manufacture operation with subsequent cladding process made the design of the device much more complicated. Later on the flux-cored strip electrodes were manufactured separately by using the special equipment. The drawbacks of such flux-cored electrodes include high rigidity due to the presence of coarse cells, faulty sealing of locks, low compaction of the core charge, and non-uniform distribution of the sheath in width of the electrodes. Excessive rigidity of the flux-cored electrodes made it difficult to wind them into spools and feed to the arc zone during cladding. Faulty sealing of the locks did not allow a long-time storage of flux-cored electrodes and led to spilling of the core charge during transportation, loading into spools and cladding. This resulted in chemical heterogeneity of the deposited metal and decrease in its wear resistance.

Later on the Chelyabinsk Design Institute NPTIAM-MASh suggested a simpler design of the flux-cored strip (Figure 1, *b*). Transverse corrugations in this design imparted flexibility to the flux-cored strip, thus providing simplicity of its winding into spools. At the same time, the deep transverse grooves in the flux-cored strip sheath caused variations in its cross section, thus hampering the process of melting of the strip in the arc. Moreover, a serious drawback of this flux-cored strip was an insufficient density of the locks.

G.P. Klekovkin offered a flux-cored electrode for welding and cladding [3] which, physically, was made from one strip twisted into a spiral (Figure 2). Rigidity was ensured by using a shaped strip that formed a lock overlap joint along a spiral. To compact the lock material, a wick impregnated with ionising salts to stabilise the welding arc was put into its cavity. A powdered core material was located inside the spiral sheath.

Compaction of the powdered material was achieved by pressing the electrode. Twisted ribs of the sheath and recesses on its surface provided the uniform distribution of the core and the required longitudinal flexibility. Drawbacks of such flux-cored electrodes were complexity in manufacture and insufficient sealing of locks.

The stalinite B powder was used as a charge in the majority of the above designs of flux-cored strip electrodes, and cladding was performed by the submerged-arc

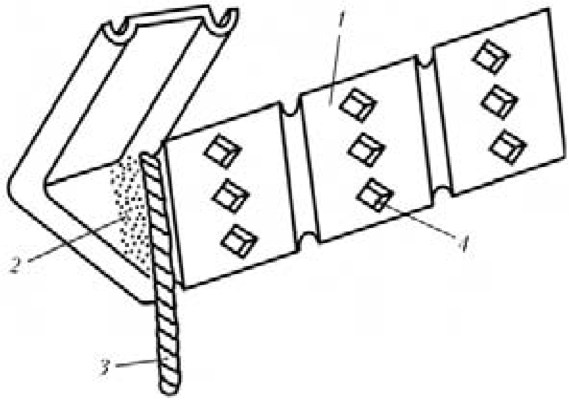

Figure 2. Schematic of Klekovkin's electrode: *1* — shaped strip; *2* — core material; *3* — wick; *4* — recess on the sheath surface

method under a layer of flux AN-60. Owing to the efforts of VPTIstroidormash, at the initial stage the flux-cored strip electrodes found application for hard-facing of many parts of construction and road machines [3–7].

At the E.O. Paton Electric Welding Institute the work on development of cladding flux-cored strips was initiated in 1960 by Yu.A. Yuzvenko and V.P. Shimanovsky [8]. One of the variants of production of alkaline accumulator segments was used to manufacture the first samples of the flux-cored strips. In contrast to developments of the above authors who offered 30–50 mm wide strips [1–3, 5, 7], all developments of the E.O. Paton Electric Welding Institute were aimed at manufacture of strips of a small width (10–22 mm) designed to provide high fill factors, thus allowing solution to the alloying problems which can hardly be solved by using flux-cored wire.

Comparatively small width of the flux-cored strip allowed the more uniform distribution of the core materials across the section and the maximum possible prevention of their spilling. The required width of the deposited layer was achieved due to oscillations of the electrode. Advantages of such a strip were especially pronounced in decreasing chemical macroheterogeneity of the deposited layer.

Based on these developments, in 1965 the E.O. Paton Electric Welding Institute made the first such strip PL-AN101 [9] of the universal type, which was intended for open- and submerged-arc cladding. Then a wide commercial application of open-arc cladding by using the flux-cored strip was started in the USSR. Composition and design of flux-cored strip PL-AN101 were patented in eight countries of the world, e.g. Germany, France, Italy, etc. Design of this strip is shown in Figure 3.

Tight locks and fine-cell corrugations on the sheath provided good compaction of the flux-cored strip core, which resulted in substantial improvement of metal transfer in the arc and elimination of spilling of the charge materials into the weld pool. Several modifications of mills were developed to manufacture this design of the strip. The latest of these mills, i.e. OB 2240, is still in operation (Figure 4).

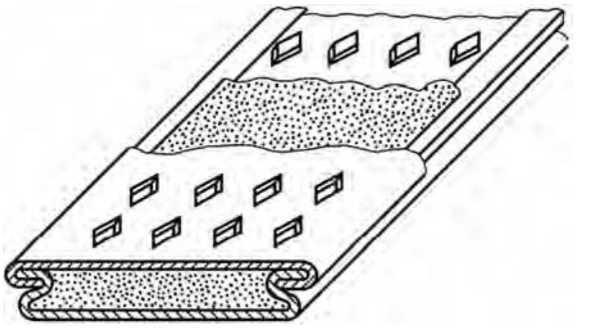

Figure 3. Schematic of double-lock flux-cored strip designed by the E.O. Paton Electric Welding Institute

Mass production of flux-cored strips of this design on industrial scales was mastered by the Torez Plant for Surfacing Hard Alloys and Research and Production Association «Tulachermet». Drawbacks of this strip include non-uniform distribution of the sheath in its width. The welding current had the highest density in cladding at locations of the locks, where the maximal amount of the strip sheath was concentrated. This led to non-uniform melting of the sheath and formation of a protrusion in the central part of the pressed core, which, while periodically breaking off, got into the weld pool in the non-melted state.

The flux-cored strip with one overlap lock (Figure 5, *a*) was developed to provide a high fill factor, which is especially important for the case when materials with a low apparent density (carbides, chromium borides, etc.) are used as a core charge. This strip had a simple design, and was characterised by a simple manufacture technology and a high fill factor. In addition, location of the lock in the central part of cross section of the flux-core strip provided a more uniform melting of the core. Its drawbacks included leakage of the overlap lock, as a result of which the charge material of the core spilled out both during transportation and during cladding.

To eliminate the above drawbacks, in 1981 the E.O. Paton Electric Welding Institute offered a design of the flux-cored strip with a tight lock [10] (Figure 5, *b*). Replacement of the flat overlap lock by the tight one made it possible to compact densely the flux-cored strip core by rolling it in rolls and simultaneously make on the sheath the small hollows 0.6 mm deep and (2–4) × (2–4) mm in size, having a rhombic or square shape and arranged in large diagonals along the strip. Compaction provided removal of air from

Figure 4. Mill OB 2240 for manufacture of double-lock flux-cored strip

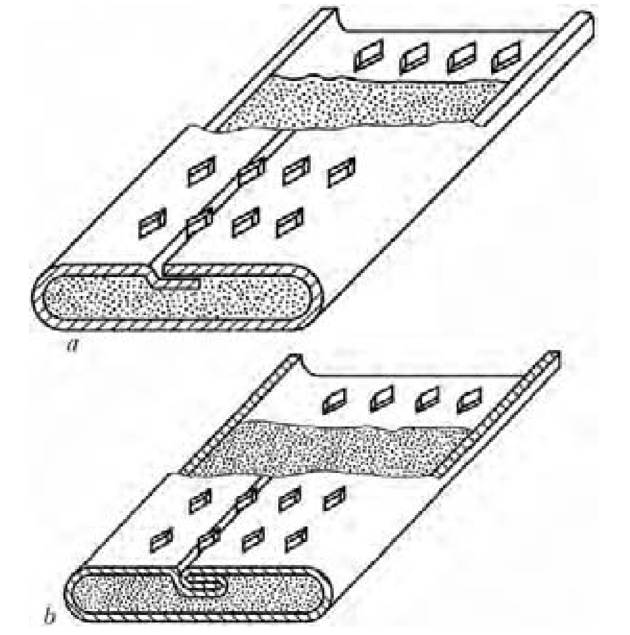

Figure 5. Schematic of design of single-lock flux-cored strip with overlap (*a*) and tight (*b*) lock

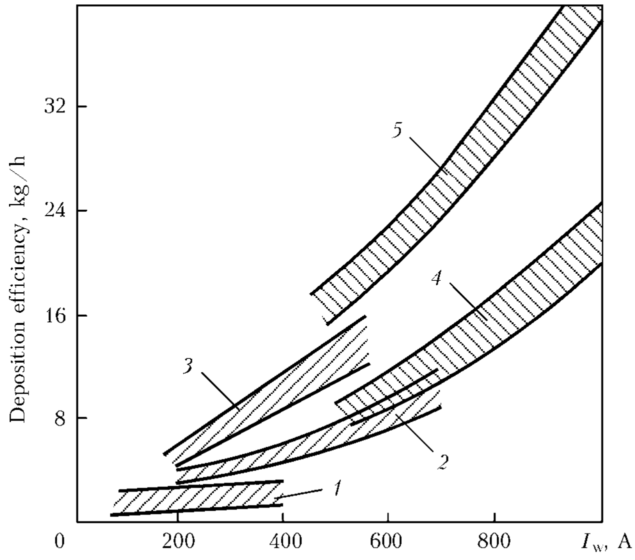

Figure 7. Deposition efficiency: *1* — stick electrodes: *2* — submerged-arc all-drawn wire; *3* — flux-cored wire; *4*, *5* — open-arc flux-core strip (one and two electrodes, respectively)

the core and prevented spilling of the core material. Small hollows on the sheath caused almost no deterioration in supply of current to the flux-cored strip sheath during cladding.

The tight lock was located in the central part of the flux-cored strip across its section. Hence, in cladding the current density per unit section of the flux-cored strip within the lock zone was higher than in its peripheral regions. This provided a more stable burning of the arc, improvement of metal transfer through the arc, uniform melting of the core, higher chemical homogeneity of the deposited metal and increase in its wear resistance.

Several modifications of the mill were developed to manufacture this design of the flux-cored strip. The latest modification was designated as OB 2324 (Figure 6). Mass production of this design of the flux-cored strips on industrial scales was arranged with participation of associates of the E.O. Paton Electric Welding Institute at Production Association «Dneprometiz» and «Tulachermet».

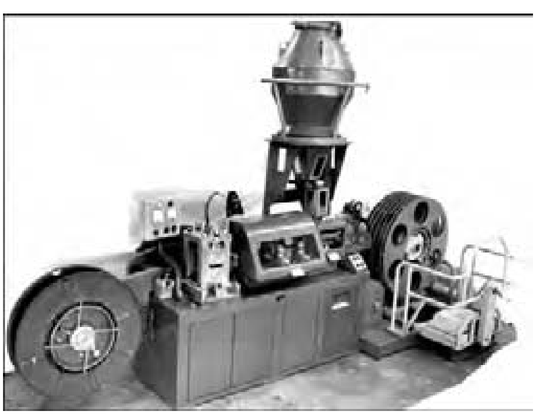

Figure 6. Mill OB 2324 for manufacture of single-lock flux-cored strip with tight lock

In 1985, associates of the E.O. Paton Electric Welding Institute worked out GOST 26467–85 «Cladding Flux-Cored Strip. General Technical Requirements», which is in force up to now. A short list of the developed and mass produced flux-cored strips is given in the Table.

At present two designs of the flux-cored strips are commercially manufactured — double- and single-lock strip with a tight lock, the latter being subdivided into two standard sizes — 16.5 × 4.0 and 10.0 × × 3.0 mm.

Standard size of the flux-cored strip, parameters of cladding and strip design are chosen depending on the size of the surface to be hard-faced. Cladding can be performed in one, two or more layers. It can be done with separate beads and can be of the wide-layer type, with oscillation amplitude ranging from 50 to 400 mm. The cladding currents can be varied from 300 to 1200 A, arc voltage — from 25 to 38 V, and electrode movement speed — from 5 to 100 m/h. Twin- and multi-arc cladding is applied with the specially developed equipment to increase the deposition efficiency. Deposition of a wear-resistant layer 2 to 8 mm thick is provided in one pass with one-arc cladding. The deposition efficiency in one-arc cladding using the flux-cored strip amounts to 25–30 kg/h (Figure 7).

Consumption of the flux-cored strip per kilo of the deposited metal is 1.1–1.2 kg at the presence of volatile components and 1.20–1.35 kg at the presence of mineral components in the filling powder. The flux-cored strip is supplied in bundles with row-organised layout, 400–460 mm in inner diameter, up to 850 mm in outer diameter and 115–130 mm wide. Weight of one bundle is 80–150 kg. Figures 8 and 9 show the general view of the flux-cored strip and the bundle with a row-organised layout.

The commercial welding equipment is utilised for cladding with flux-cored strips. This equipment is ad-

Flux-cored strip for cladding

Flux-cored strip grade	Chemical composition of deposited metal, wt.%									
	C	Cr	Mn	Si	Ni	Nb	Mo	V	W	B	Ti
PL-AN-101	3.0	25	2.0	3.0	2.0	–	–	–	–	–	–
PL-AN-171	1.2	25	2.2	1.0	–	–	–	–	–	3.5	–
PL-AN-180	4.5	30	–	–	–	–	1.0	–	–	–	–
PL-AN-181	4.5	30	3.0	–	–	–	–	–	–	–	–
PL-AN-111	5.0	38	1.0	2.5	38.0	–	–	–	–	0.3	–
PL-AN-179	5.0	22	–	–	–	7.0	6.0	1.0	2.0	–	–
PL-AN-185	5.0	22	–	–	–	7.0	–	–	–	–	–
PL-AN-186	4.5	30	–	–	–	–	–	–	–	0.7	–
PL-AN-132-1	0.10	4	1.5	1.0	–	–	2.0	–	2.5	–	–
PL-AN-132-2	0.15	4	1.5	1.0	–	–	2.0	–	2.5	–	–
PL-AN-132-3	0.20	4	1.5	1.0	–	–	2.0	–	2.5	–	–
PL-AN-187	0.2	11	10.0	–	–	–	–	–	–	–	0.8
PL-AN-115	0.1	–	1.5	0.8	–	–	–	–	–	–	0.5
PL-AN-189	0.35	3	0.8	0.6	–	–	–	0.3	9.0	–	–
PL-AN-190	0.40	3	0.8	0.6	–	–	–	0.3	9.0	–	–
PL-AN-191	0.25	5	0.7	1.0	–	–	1.2	0.4	–	–	–
PL-AN-183	0.4	2	1.6	1.6	5.5	0.6	1.8	0.5	–	–	–
PL-AN-150	0.12	16	2.0	5.0	9.0	–	–	–	–	–	–
PL-AN-151	0.12	16	4.0	5.0	8.0	1.0	6.0	–	–	–	–

Tabl. (cont.)

Flux-cored strip grade	Hardness *HRC*	Application
PL-AN-101 PL-AN-171 PL-AN-180 PL-AN-181	50–56 54–59 58–62 58–60	Cladding of parts operating under abrasive wear conditions (bulldozer and grab knives, excavator ladle teeth, coke mill rolls, plough disks, protective surfaces of caps and bells, etc.)
PL-AN-111 PL-AN-179 PL-AN-185 PL-AN-186	50–58 58–62 56–60 57–62	Cladding of parts operating under intensive abrasive and gas-abrasive were conditions at normal and elevated temperatures (caps and bells of blast furnace charging equipment, chutes, hoppers, etc.)
PL-AN-132-1 PL-AN-132-2 PL-AN-132-3	18–28 28–34 35–45	Cladding of parts operating under contact load conditions at elevated temperatures (rollers of gravity roll carriers, rolls, etc.)
PL-AN-187	18–26	Cladding of parts operating under high contact load conditions (crane wheels, guides, etc.)
PL-AN-115	18–26	Cladding of large-size steel parts to restore their geometric dimensions (caps and bells of blast furnace charging devices, agglomachine carriages, etc.)
PL-AN-189 PL-AN-190 PL-AN-191	44–50 44–50 46–52	Cladding of metal hot rolling rolls
PL-AN-183	47–54	Cladding of metal hot cutting knives
PL-AN-150 PL-AN-151	27–34 38–50	Submerged-arc cladding of stop valve components operating at an environment temperature of up to 545 °C

ditionally fitted with special contact tubes and feeding rollers, which provide a reliable feed of the electrode material.

Flux-cored strips are most successfully applied for cladding of blast furnace charging devices [11–14], cap-free charging devices [12, 13], coal mill beaters [12, 13], bimetal wear-resistant plates [13, 15], road construction machines [16–18], metal hot cutting knives [13], stop valves at heat and nuclear power plants [19, 20] and many other parts in metallurgical industry, mining and power engineering.

No data on development of compositions and mass production of flux-cored strips to be used as electrode materials are available in foreign literature. However, promotion materials of an Argentine company contain data on a material in the form of a flux-cored strip used to add deoxidisers in steel casting.

Therefore, the world priority in development of the flux-cored strips as an electrode material belongs to the USSR. Development of the majority of compositions, arrangement of commercial manufacture and wide application of the flux-cored strips — all

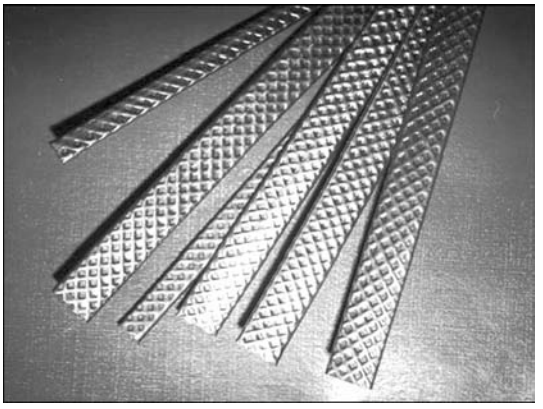

Figure 8. General view of flux-cored strip

Figure 9. Flux-cored strip bundle

this is a merit of associates of the E.O. Paton Electric Welding Institute. Great contribution to development of flux-cored strip compositions and cladding technologies was made in different years by specialists of such institutions as TsNTI VNIIST (Scientific-and-Technical Information Centre of All-Russian Research Institute for Construction and Operation of Pipelines) (Moscow) [21, 22], National Technical University of Ukraine «Kiev Polytechnic Institute» [23–26], Priazovsky State Technical University, Open Joint Stock Company «Azovmash» (Mariupol, Ukraine) [27, 28], Dnepropetrovsk State University (Ukraine) and many others.

Before 1991 the USSR manufactured up to 1000 t of flux-cored strips a year. At present the flux-cored strips are manufactured in Ukraine by Open Joint Stock Company «Toreztverdosplav» (Torez) and Limited Liability Company «PLAN-T», and in Russia — by Limited Liability Company «Rosnamis» (Taganrog) and Research and Production Association «Polema» (Tula). Today the total output of the flux-cored strips of different grades is above 700 t a year. There is a stable trend to increase in production of these electrode materials, which is attributed to a growing demand in the industry for new types of products with increased wear resistance.

1. Klekovkin, G.P., Bakshi, O.A., Sumina, T.V. et al. *Flux-cored strip electrode*. USSR author's cert. 132271. Priority 30.01.1959.
2. Bakshi, O.A., Belousov, E.F., Klekovkin, G.P. et al. (1960) Wear-resistant cladding with flux-cored strip electrode. *Svarochn. Proizvodstvo*, **3**, 30–33.
3. Klekovkin, G.P. *Klekovkin's flux-cored electrode*. USSR author's cert. 143180. Publ. 1960.
4. Kortelev, G.A., Cherepakhin, A.V., Nikolaenko, M.R. et al. (1968) Wear-resistant flux-cored strip cladding of operating elements of earth-moving machines. *Stroit. i Dorozhn. Mashiny*, **7**, 35–37.
5. Kortelev, G.A. (1971) *Specifics of wear-resistant mechanised cladding with high-chromium cast iron of parts of road and construction machines and development of filler materials*: Syn. of Thesis for Cand. of Techn. Sci. Degree. Bryansk.
6. Nikolaenko, M.R. (1972) *Investigation and development of filler materials and technology for cladding of earth-moving machine parts*: Syn. of Thesis for Cand. of Techn. Sci. Degree. Bryansk.
7. Nikolaenko, M.R., Kortelev, G.A. (1972) *Strip electrode cladding of machine parts*. Series 5. Moscow: TsNIITEstrojmash.
8. Yuzvenko, Yu.A. (1960) Flux-cored electrode strip. *Avtomatich. Svarka*, **9**, 86–87.
9. Yuzvenko, Yu.A., Shimanovsky, V.P., Kopylets, I.P. (1967) Flux-cored strip PL-AN101. USSR author's cert. 200075. Publ. 1967.
10. Danilchenko, B.V., Shimanovsky, V.P., Kopylets, I.P. et al. *Flux-cored strip electrode for cladding of high-chromium alloys*. USSR author's cert. 1152159. Publ. 1984.
11. Shimanovsky, V.P., Voronchuk, A.P., Zvezdin, S.M. (1990) Materials and equipment for cladding of bells and cups of blast furnaces. In: *Equipment and consumables for surfacing*. Kiev: PWI.
12. Danilchenko, B.V., Shimanovsky, V.P., Voronchuk, A.P. et al. (1989) Cladding of rapidly wearing parts with self-shielding flux-cored strips. *Avtomatich. Svarka*, **5**, 38–41.
13. Zhudra, A.P., Voronchuk, A.P. (2010) Wear-resistant flux-cored wire cladding. *Svarshchik*, **6**, 6–10.
14. Zhudra, A.P., Voronchuk, A.P., Fomakin, A.A. et al. (2009) New equipment for hard-facing of charging device bells and cups. *The Paton Welding J.*, **9**, 44–46.
15. Zhudra, A.P., Voronchuk, A.P., Veliky, S.I. (2009) Equipment and consumables for hard-facing of lining plate elements. *Ibid.*, **6**, 44–46.
16. Kortelev, G.A., Nikolaenko, M.R., Litvinov, B.A. et al. (1973) Automatic wear-resistant cladding with flux-cored strip PL-AN 101 of loader bucket teeth. *Svarochn. Proizvodstvo*, **11**, 38–39.
17. Kortelev, G.A., Spektor, L.M., Nosov, I.M. et al. (1975) Automatic cladding of screw blades using flux-cored strip PL-AN-101. *Avtomatich. Svarka*, **2**, 49–50.
18. Kortelev, G.A., Zheravkov, V.P., Cherepakhin, A.A. (1972) Automatic cladding of bucket teeth of E-652 excavator using flux-cored strip PL-U30Kh30G3TYu. *Svarochn. Proizvodstvo*, **12**, 32–34.
19. Eremeev, V.B., Strelyany, Yu.Z., Frumin, I.I. (1978) Development of flux-cored wire and strip for cladding of pipe fittings. In: *Theoretical and technological principles of surfacing. Filler materials*. Kiev: PWI.
20. Eremeev, V.B. (1985) Mechanised cladding of worn-out fittings of thermoelectric power stations. In: *Surfacing. Experience and efficiency of application*. Kiev: PWI.
21. Nikolaenko, M.P., Grinberg, N.A. (1976) Heterogeneity of metal deposited with flux-cored strip electrode. In: *Technology and equipment of welding and surfacing operations*. Tula.
22. Nikolaenko, K.R., Kortelev, G.A., Grinberg, N.A. (1973) Effect of boron, vanadium and nickel on structure and properties of high-chromium cast irons deposited with flux-cored strip. *Svarochn. Proizvodstvo*, **4**, 32–34.
23. Patskevich, I.R. (1973) Experience of application and prospects for development of flux-cored strip cladding. In: *Proc. of All-Union Meeting on High-Efficient Processes of Surfacing and Filler Materials* (Kommunarsk). Kiev: PWI, 14–18.
24. Patskevich, I.R., Rykov, A.M. (1973) Static characteristics of arc in flux-cored strip cladding. *Svarochn. Proizvodstvo*, **2**, 9–11.
25. Patskevich, I.R., Rykov, A.M. (1972) Heat balance of arc in flux-cored strip cladding. *Ibid.*, **2**, 7–9.
26. Patskevich, I.R., Khejfets, L.A. (1971) About chemical heterogeneity of layer deposited with flux-cored strip in CO_2. *Avtomatich. Svarka*, **11**, 66–67.
27. Chigarev, V.V. (1994) Manufacture and application of flux-cored strips for cladding of wear-resistant alloys. *Ibid.*, **2**, 51–52.
28. Chigarev, V.V., Belik, A.G. (2011) Flux-cored strips for cladding. *Svarochn. Proizvodstvo*, **8**, 38–44.