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# Flux-Cored Strips – the Deposition and Application Range of Abrasion-Resistant Layers

**Abstract:** The article presents the structure and chemical composition of flux-cored electrode strips used for the deposition of abrasion-resistant layers involving the use of non-submerged arc and flux, analyses technologies used during the surfacing involving the use of flux-cored strips as well as presents exemplary applications, related welding (surfacing) equipment and advantages resulting from the use of the above-named filler metals.

**Keywords:** flux-cored strip, surfacing, equipment, technology, surfacing efficiency, resistance to wear

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## Introduction

Flux-cored strips are popular surfacing consumables in Ukraine, Russia and many other countries. The strips are applied in the making and refurbishment of numerous elements used in the metallurgical, power engineering and extractive industries as well as in civil engineering and other industrial sectors. Presently, the annual production of flux-cored strips exceeds 1000 tons and is characterised by a growing tendency.

In comparison with flux-cored wires, flux-cored strips enable the obtainment of a high (restricted within the range of 60 % to 70%) filling coefficient, high surfacing efficiency and a relatively simple manufacturing technology, eliminating the process of drawing. The formation of the coating and the consolidation of the flux filling the coating are obtained through rolling, which consumes less energy and enables the use of a coating characterised by lower plastic properties. Figure 1 presents the flux-cored strip enjoying the most extensive industrial applications [1, 2].

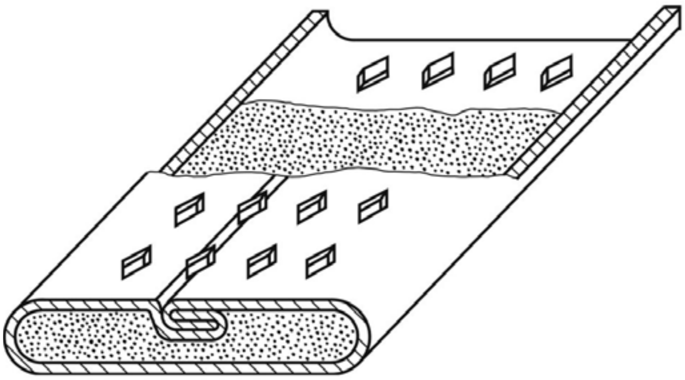

Fig. 1. Design of a single-lock flux-cored strip with a tight lock

The reliable tightness of the flux-cored strip lock prevents the spilling of the flux transport and surfacing as well as against the penetration of humidity to the core. Machines used in the production of flux-cored strips enable the production of two standard cross-sectional sizes of strips, i.e. 16.5 mm × 4.0 mm and 10.0 mm × 3.0 mm (Fig. 2).

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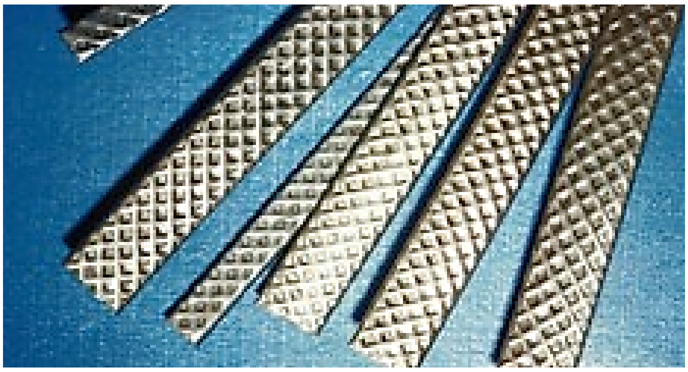


Fig. 2. Main view of flux-cored strips

Flux-cored strips are delivered in coils, wound in series, where the internal diameter of a coil is restricted within the range of 400 mm to 460 mm, the external diameter amounts up to 850 mm and the width is restricted within the range of 115 mm to 130 mm (Fig. 3). Supplying flux-cored strips in heavy coils, the weight of which is restricted within the range of 80 kg to 160 kg, ensures continuous and highly efficient surfacing. This is of particular importance during the surfacing of large-sized elements having large work surface areas.

Fig. 3. Coil of a flux-cored strip

## Surfacing with flux-cored strips

Surfacing with flux-cored strips can be performed using unsubmerged welding arc (arc burning in air; the process being referred to as surfacing with the self-shielded flux-cored strip) and under flux. The process involving the use of the flux-cored strip and submerged arc does not differ from the process of submerged arc welding involving the use of other electrode materials.

The size of an element to be subjected to surfacing affects the size of a flux-cored strip, surfacing parameters and surfacing scheme. Surfacing can be performed using one, two or more layers, single or wide beads and with the amplitude of transverse movements restricted within the range of 50 mm to 400 mm. Surfacing current can be restricted within the range of 300 A to 1200 A, arc voltage can be restricted within the range of 25 V to 38 V, whereas the rate of surfacing can be restricted within the range of 5 m/h to o 100 m/h. The consumption of the flux-cored strip per 1 kg of weld deposit is restricted within the range of 1.1 kg to 1.2 kg when using volatile ingredients in the core mixture and 1.2 kg to 1.35 kg when using mineral ingredients [2].

Surfacing with flux-cored strips involves the use of mass-produced welding machines, additionally equipped with guides and feeding reels [3, 4]. Increased efficiency involves the application of two-arc or multi-arc surfacing, requiring the use of special welding machines. In one run of arc it is possible to deposit an abrasion-resistant layer having a thickness restricted within the range of 2 mm to 8 mm. The efficiency of surfacing is restricted within the range of 25 kg to 30 kg of weld deposit per hour (Fig. 4).

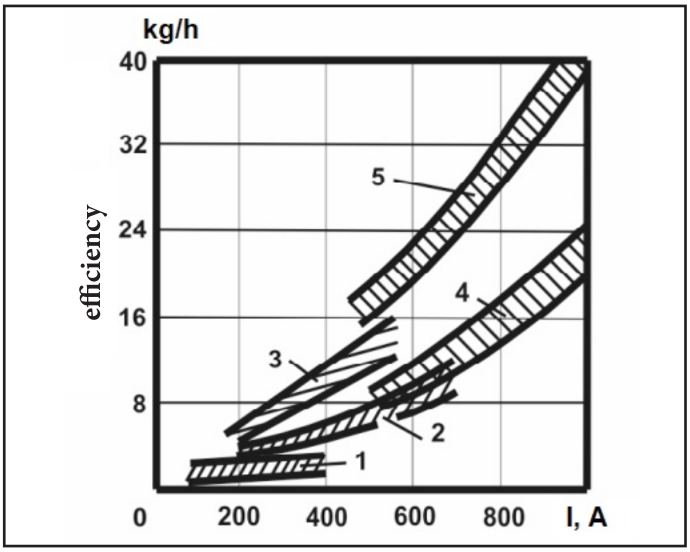



Fig. 4. Process efficiency: 1 – manual surfacing with the covered electrode, 2 – surfacing involving submerged arc and the solid electrode wire, 3 – surfacing with the self-shielded flux-cored wire, 4 – surfacing with the single self-shielded flux-cored strip, 5 – surfacing with the double self-shielded flux-cored strip

Table 1. Grades, chemical compositions and applications of flux-cored strip

| Flux-cored strip grade | Chemical composition of weld deposit, % | | | | | | | | | | | Hardness HRC | Application |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | Cr | Mn | Si | Ni | Nb | Mo | V | W | B | Ti | | |
| PL-AN -101 | 3.0 | 25.0 | 2.0 | 3.0 | 2.0 | - | - | - | - | - | - | 50 - 56 | Surfacing of elements subjected to abrasive wear (cutters of bulldozers and graders, excavator bucket teeth, coke crusher rollers, plough discs, protective surfaces of cones and pans of blast furnace charging elements, pipeline elements etc.) |
| PL-AN -171 | 1.2 | 25.0 | 2.2 | 1.0 | - | - | - | - | - | 3.5 | - | 54 - 59 | |
| PL-AN -180 | 4.5 | 30.0 | - | - | - | - | 1.0 | - | - | - | - | 58 - 62 | |
| PL-AN -181 | 4.5 | 30.0 | 3.0 | - | - | - | - | - | - | - | - | 58 – 60 | |
| PL-AN -201 | 4.5 | 30.0 | - | - | - | - | - | - | - | - | - | 58 - 62 | |
| PL-AN -111 | 5.0 | 38.0 | 1.0 | 2.5 | 38.0 | - | - | - | - | 0.3 | - | 50 - 58 | Surfacing of elements subjected to intensive abrasive wear and gas-abrasion wear at normal and higher temperature (cones and pans of blast furnace charging elements, chutes, containers for bulk materials etc.) |
| PL-AN -179 | 5.0 | 22.0 | - | - | - | 7.0 | 6.0 | 1.0 | 2.0 | - | - | 58 - 62 | |
| PL-AN -185 | 5.0 | 22.0 | - | - | - | 7.0 | - | - | - | - | - | 56 - 60 | |
| PL-AN -186 | 4.5 | 30.0 | - | - | - | - | - | - | - | 0.7 | - | 57 - 62 | |
| PL-AN -132-1 | 0.1 | 4.0 | 1.5 | 1.0 | - | - | 2.0 | - | 2.5 | - | - | 18 – 28 | Surfacing of elements exposed to surface pressure at higher temperature (rollers of roller conveyors etc.) |
| PL-AN -132-2 | 0.15 | 4.0 | 1.5 | 1.0 | - | - | 2.0 | - | 2.5 | - | - | 28 – 34 | |
| PL-AN -132-3 | 0.2 | 4.0 | 1.5 | 1.0 | - | - | 2.0 | - | 2.5 | - | - | 35 - 45 | |
| PL-AN -187 | 0.2 | 11.0 | 10.0 | - | - | - | - | - | - | - | 0.8 | 18 - 26 | Surfacing of elements exposed to high surface pressure (crane wheels, guides etc.) |
| PL-AN -189 | 0.35 | 3.0 | 0.8 | 0.6 | - | - | - | 0.3 | 9.0 | - | - | 44 -50 | Surfacing of rollers for hot rolling |
| PL-AN -190 | 0.4 | 3.0 | 0.8 | 0.6 | - | - | - | 0.3 | 9.0 | - | - | 44 -50 | |
| PL-AN -191 | 0.25 | 5.0 | 0.7 | 1.0 | - | - | 1.2 | 0.4 | - | - | - | 46 -52 | |
| PL-AN -183 | 0.4 | 2.0 | 1.6 | 1.6 | 5.5 | 0.6 | 1.8 | 0.5 | - | - | - | 47 - 54 | Surfacing of cutters for hot metal cutting |
| PL-AN -150 | 0.12 | 16.0 | 2.0 | 5.0 | 9.0 | - | - | - | - | - | - | 27 – 34 | Submerged arc surfacing of fixtures elements exposed to temperature restricted within the range of ambient temperature to 545°C |
| PL-AN -151 | 0.12 | 16.0 | 4.0 | 5.0 | 8.0 | 1.0 | 6.0 | - | - | - | - | 38 – 50 | |

Table 1 presents grades of manufactured flux-cored strips.

## Exemplary applications of flux-cored strips

A typical example related to the application flux-cored strips in the hard surfacing of metallurgical machinery elements is the surfacing of charging elements of blast furnaces. Unique charging machines U-50, U-75 and U-125 (Fig. 5) are composed of manipulators characterised by a lifting capacity of 50 tons or 75 ton and a moving column, to which highly specialised surfacing heads are attached [2, 3, 4, 5] (Fig. 6).

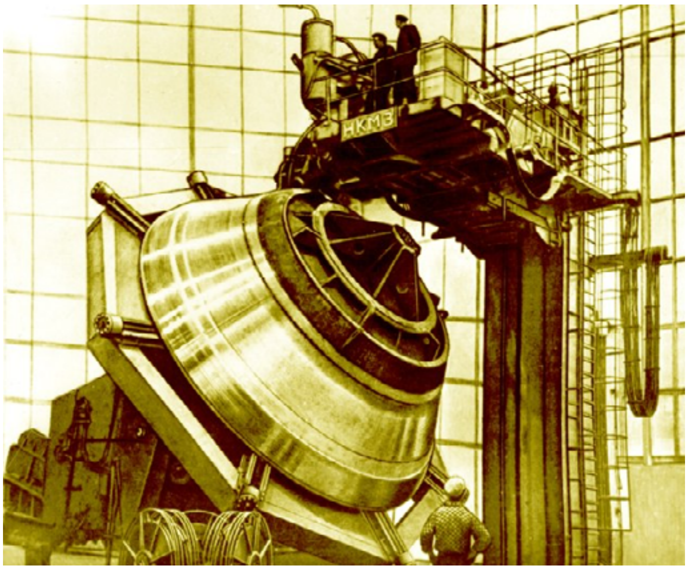


Fig. 5. Machine U-75-8000 for the surfacing of charging elements of blast furnaces

In recent years, the above-named machines have been equipped with asynchronous DC motors with frequency converters as well as with new modernised surfacing heads A1812M. The head enables the deposition of a wide layer using two arcs in the tandem system (the second arc is used to deposit the second layer) or in the parallel system (two beads side by side) as well as the transverse oscillation (having an amplitude restricted within the range of 50 mm to 500 mm) of the flux-cored strip. The design of the machines also provides for girth surfacing and the welding of large-sized elements using unsubmerged arc, flux-cored or solid wires and under flux. The SU-320 type control system [5] controlling the machine for the surfacing of charging elements is based on a microcontroller and supports all technological surfacing programmes in the automatic mode.

The surfacing of the cone and the pan of the blast furnace charging element involves the simultaneous application of two self-shielded flux-cored strips powered by two separate power sources. The process is continuous and involves the making of beads located along the generating line, with weaving movements having a width restricted within the range of 120 mm to 300 mm and a shift by a surfacing step. The above-presented method is referred to as "band surfacing". It provides the minimum number and width (opening) of cracks located along the generating line of the cone or pan, adversely affecting the service life of elements subjected to surfacing.

The work surface of blast furnace charging elements, i.e. cones and pans, is surfaced using self-shielded flux-cored strips PL-AN 101 and PL-AN 180. Contact surfaces are usually surfaced using self-shielded flux-cored strip PL-AN 111, enabling the deposition of a hard nickel-carbide-chromium alloy (at higher temperature) characterised by increased resistance under gas-abrasion wear conditions. The mechanised surfacing of cones and pans using the self-shielded flux-cored strip is 4 times more efficient than flux-cored wire-based surfacing.

New equipment and control systems have been successfully implemented at PJSC Arcelor Mittal Kryvyi Rih, PJSC Azovmash, Mariupol, Ukraine and at the OJSC West-Siberian Metallurgical Industrial Complex in, Novokuznieck, Russia.

One of examples related to the complex solution of issues concerning the extension of the service life of machine elements is the production of bimetallic structural materials made of plates (basic plate) provided with a layer resistant to abrasive wear. In terms of flat elements (containers for bulk materials, chutes, dump

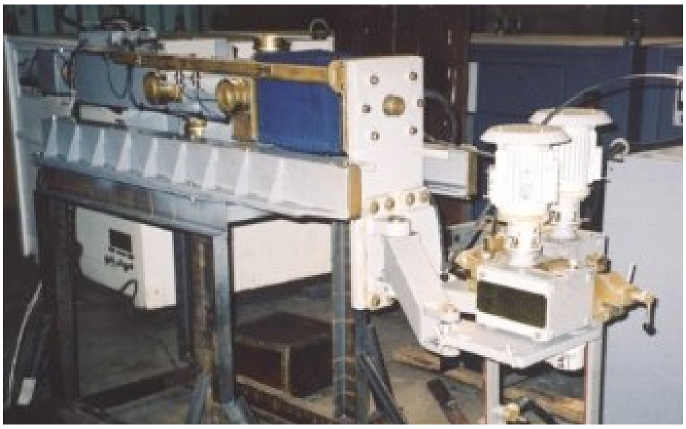


Fig. 6. Welding head A1812M

bodies, sieves, blast furnace chutes etc.) exposed to intensive abrasive wear conditions, it is economically and technically justified to protect quick-wearing surfaces by covering them with abrasion-resistant plates. Over the past 10 to 15 years, the above-named lining elements have become increasingly popular abroad. The TRITEN CORPORATION, USA developed a technology enabling the surfacing using a solid wire on a chromium carbide-based layer. A similar technology is also widely used by VAUTID GmbH and EIPA Eisen Palmen GmbH, Germany, ERGOTEM S.A., Greece and other companies. In CASTOLIN EUTECTIC, abrasion-resistant plates are surfaced using flux-cored wires, unsubmerged arc and under flux. DURUM GmbH, Germany, has mastered the plasma-powder surfacing of plates involving the hardening of a deposited layer with particles of cast tungsten carbide. Each year, industrial companies in Europe and America use hundreds of thousands of tons of deposited sheets/plates.

In contrast with overseas technologies, the E. O. Paton Electric Welding Institute, the National Academy of Sciences of Ukraine has developed a technology enabling the production of bimetallic abrasion-resistant plates, the thickness of which is restricted within the range of 5.0 mm to 20.0 mm, with the abrasion-resistant layer having a thickness restricted within the range of 3.0 mm to 17.0 mm [4, 6, 7, 8, 9], surfaced using a self-shielded flux-cored strip. The process is characterised by high surfacing efficiency and the good quality of deposited layers. The process involves the use of dedicated surfacing machine AD-380 (Fig. 7) [8]. The machine is composed of a carriage (moving along a running rail) with two surfacing heads and two tables for fixing steel plates/sheets. The carriage can move at a working or set-up travel rate. The machine is provided with two power sources of rigid external characteristics.

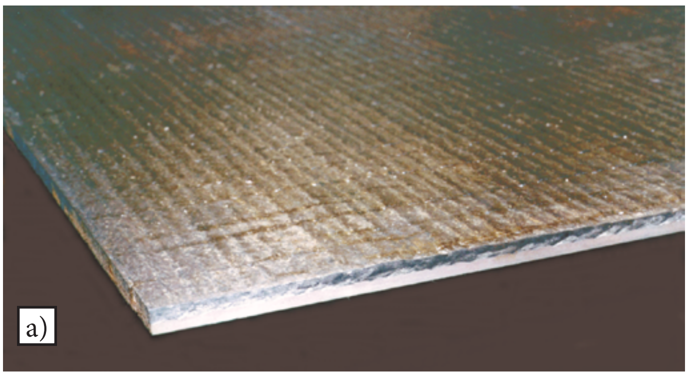
Fig. 7. Machine AD-380 for the surfacing of abrasion -resistant plates

The machine enables the performance of automatic two-arc surfacing (in accordance with dedicated developed software) on two tables interchangeably, with the efficiency amounting to one sheet (3000 mm x 1500 mm) per shift. The technology involves the use of self-shielded flux-cored strips PL-AN 179, PL-AN 180, PL-AN 185, PL-AN 201 etc., ensuring the obtainment of weld deposit characterised by hardness restricted within the range of 58 HRC to 62 HRC. The deposited layer of abrasion-resistant metal contains cracks which do not pass into the base material or affect its operational properties. Figure 8 presents bimetallic abrasion-resistant plates.

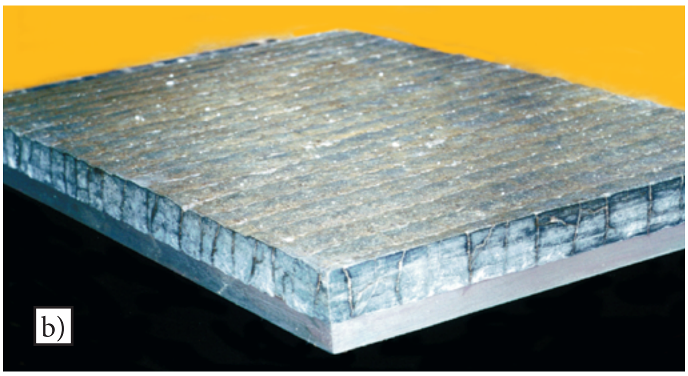
Plates of thicknesses restricted within the range of 5 mm to 7 mm are surfaced using a flux-cored strip having cross-sectional dimensions of 10.0 mm × 3.0 mm, whereas plates having a thickness of 8 mm and above are surfaced using a strip having dimensions 16.5 mm × 4.0 mm. Obtained bimetallic plates can be easily transformed, through cutting and bending, into many various a elements for metal structures, increasing the service life of the latter several times.

Positive results were also obtained during the hard surfacing of elements of blast furnace charging devices with a flux-cored strip. One of technological processes involved automated arc surfacing performed using self-shielded flux-cored strip PL-AN 179; the process was used to surface quick-wearing elements of the charging spout and other structural elements of a charging device (Paul Wurth), Luxemburg [4, 10]. Another example of the extensive application of a flux-cored strip is the surfacing of coal pulveriser hammers [2, 3, 4, 11]. The aforesaid process is performed using specialist machines U-877 (Fig. 9). Machine U-877 consists of a surfacing head, turntable and five water-cooled moulds fixed on the table; hammers to be surfaced are placed in the aforesaid moulds. The surfacing process is automatic, with the electrode oscillating across the entire width of an element subjected to surfacing. One machine can surface between 100 and 120 hammers per shift.

Rough castings of hammers made of low-carbon steel are surfaced using flux-cored strip



a)



b)

Fig. 8. Surfaced bimetallic plates: a) 5 + 5 mm thick and b) 12 + 17 mm thick

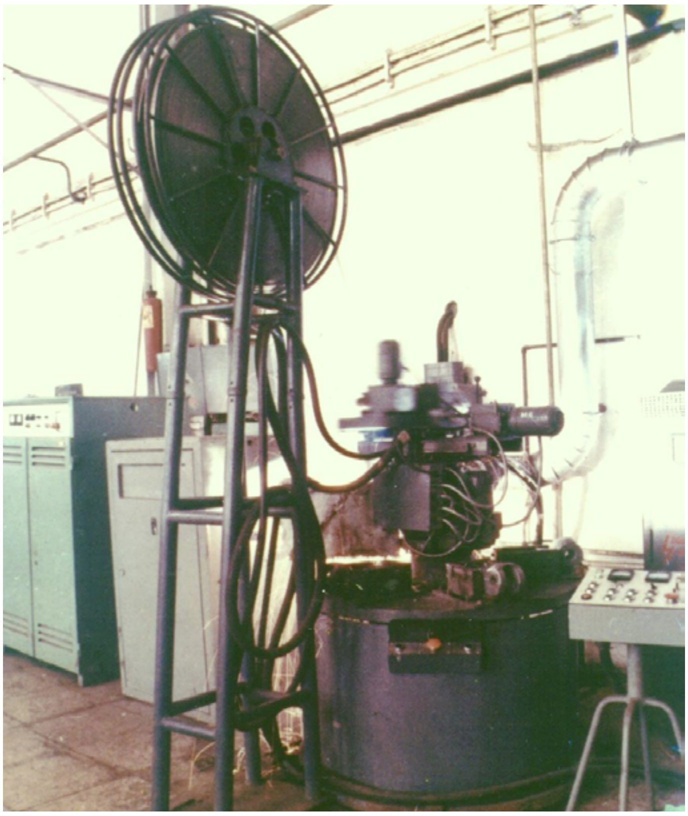


Fig. 9. Machine U-877 for the surfacing of coal pulveriser hammers

Fig. 10. Machine UD298M for the surfacing of the cutting edges of cutters used in hot metal cutting

PL-AN-101, making it possible to obtain the crack-free deposited layer having hardness restricted within the range of 52 HRC ÷ 56 HRC. One hammer is surfaced with between 1.6 kg and 1.8 kg of wear-resistant alloy. The use of the above-named technology and the flux-cored strip makes it possible to double the service life of hardened elements in comparison with that characteristic of hammers cast in whole and made of Hadfield cast steel.

Another technology, involving the use of machine UD298M (Fig. 10), was developed to surface cutters for hot metal cutting. The solution involves the use of a flux-cored strip and self-shielded arc. The technology enables the automatic surfacing of the cutting edges of cutters [2, 12], significantly increasing the efficiency of the surfacing process. Flux-cored strip PL-AN 183, developed for the surfacing of cutters, increases the service life of surfaced elements by between 1.5 and 2 times in comparison with that obtained using flux-cored wire PP-Np 35W9H3SF (ПП-Нп 35В9Х3СФ). In addition, the efficiency of the surfacing process performed using the above-named flux-cored strip is between 2 and 3 times higher.

Flux-cored strips are also commonly used for the hard surfacing of many various elements of mining machinery, such as dozer cutters, cone crusher lining, blades of fans of coal pulverisers and many other elements operated under intensive wear (e.g. abrasion) conditions.

One of Ukraine's largest manufacturers of flux-cored strips is the LLC PLAN-T company, with the annual production of various grades of flux-cored strips exceeding 400 tons. Most of the steelworks in Ukraine use flux-cored strips for the hard surfacing and repair of closures as well as gas and dust fixtures of blast furnaces. In addition, a significant amount of flux-cored strips is used in the production of bimetallic abrasion-resistant plates, the production of which tends to grow on an annual basis.

## References

[1] 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. 22.12.1984.

[2] Zhudra A.P., Voronchuk A.P.: Cladding flux-cored strips (Review). The Paton

Welding Journal, 2012, N 1, pp. 34-38.
[3] Данильченко Б.В., Шимановский В.П., Ворончук А.П., Копылец И.П.: Наплавка быстроизнашивающихся деталей самозащитными порошковыми лентами. Автоматическая сварка no. 5, 1989, pp. 38 - 41.
[4] Рябцев И.А., Сенченков И.К., Турык Э.В.: Наплавка, материалы, технологии, математическое моделирование. Wydawnictwo Politechniki Śląskiej, Gliwice, 2015. pp. 362-365, 398-406.
[5] Zhudra A.P., Voronchuk A.P., Fomakin A.A., Veliky S.I.: New equipment for hard-facing of charging device bells and cups. The Paton Welding Journal, 2009, no. 9, pp. 44-46.
[6] Жудра А.П., Ворончук А.П.: Износостойкая наплавка порошковыми лентами. Сварщик, 2010 no. 6, pp. 6-10.
[7] Жудра А.П., Ворончук А.П., Кочура В.О., Петров А.В.: Технология, оборудование и материалы для производства листовых футеровочных элементов. Сварочное производство no. 11, 2012, pp. 40 – 43.
[8] Zhudra A.P., Voronchuk A.P., Veliky S.I.: Equipment and consumables for hard-facing of lining plate elements. The Paton Welding Journal, 2009, no. 6, pp. 44-46.
[9] Жудра А.П., Ворончук А.П., Петров А.В., Кочура В.О.: Футеровочные элементы из износостойких наплавленных листов. Проблеми ресурсу і безпеки експлуатації конструкцій, споруд та машин. Зб. ст. Київ: ІЕЗ ім. Є.о. Патона, 2012. pp. 595-601.
[10] Шимановский В.П., Ворончук А.П., Звездин С.М.: Материалы и оборудование для наплавки конусов и чаш доменных печей. Оборудование и материалы для наплавки. Сб. научн. тр., Киев, ИЭС им. Е.О. Патона, 1990, pp. 71-73.
[11] Данильченко Б.В., Шимановский В.П., Копылец И.П.: Технология и оборудование для износостойкой наплавки деталей углеприготовлення тепловых электростанций. Современные способы наплавки и их применение. Киев, ИЭС им. Е.О. Патона, 1982. pp. 7-12.
[12] Zhudra A.P., Voronchuk A.P., Fomakin A.A., Veliky S.I.: Materials and equipment for surfacing of metal hot cutting knives. The Paton Welding Journal, 2015, no. 5-6, pp. 93-95. https://doi.org/10.15407/tpwj2015.06.21
*https://patonpublishinghouse.com/eng/journals/tpwj/2015/06/21/*