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The content of the Journal includes articles received from authors from around the world in the field of welding, cutting, cladding, soldering, brazing, coating, 3D additive technologies, electrometallurgy, material science, NDT and selectively includes translations into English of articles from the following journals, published in Ukrainian:
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DEAR COLLEAGUES, READERS OF "THE PATON WELDING JOURNAL"!

This is the August issue of "The Paton Welding Journal" of the current year 2023. The journal has been published since 1989 in UK with interruptions, and since 2000 it has been published monthly by the E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine (PWI). What is this issue noteworthy for?

First, it contains articles reflecting a wide range of relevant areas of activity of the PWI — the largest R&D centre in Ukraine in the field of welding and related technologies. On the pages of this issue you will also find works performed within the framework of scientific and technical cooperation of PWI with profile organizations of Ukraine and other countries as well as the articles by some of our numerous partners. In particular, this issue of the Journal provides readers the opportunity to learn about the results of research works, scientific and technical developments of Ukrainian scientists and specialists in such fields as: advanced technologies of welding and joining of materials; mathematical modeling of welding and related processes; strength, reliability and life of welded structures; additive technologies; technical diagnostics and non-destructive testing; equipment for welding and related technologies.

Secondly, most of the research results, published in this issue of the Journal, were obtained in the recent, very difficult time for Ukraine, in the conditions of a large-scale war unleashed by the russian federation. This means that Ukrainian scientists and specialists in the field of welding and related technologies continue to work actively, develop new technologies and equipment, introduce them into industrial production, including for the purpose of solving the problems of improving the defence capability of our country.

Finally, this issue of the Journal provides an opportunity to learn about the activities of some industrial enterprises, research institutes and organizations of both in Ukraine as well as in foreign countries, with which PWI is connected by many years of scientific and technical cooperation.

Prof. Igor Krivtsun
Editor-in-Chief,
Director of PWI

MODERN FLUX-CORED WIRES FOR ARC WELDING OF METAL STRUCTURES FROM LOW-ALLOYED STEELS, DEVELOPED AT THE E.O. PATON ELECTRIC WELDING INSTITUTE AND OJSC "TM.WELTEC"

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Flux-cored wire arc welding is becoming more and more popular due to its efficiency and ease of use. PWI specialists, who initiated development of such an electrode material as flux-cored wire and its application technology, have more than sixty years of experience, both in the field of fundamental investigations on metallurgy of flux-cored wire welding, and of problems of its manufacture and use [1–4]. The accumulated experience shows that at selection of a specific technology of flux-cored wire welding all its advantages and disadvantages should be taken into account. Taking a correct well-balanced decision requires deep knowledge and extensive practical experience for evaluation of both the positive aspects of a particular technology or certain wire grade, and also the possible negative consequences. Choice made on the basis of previous experience, guarantees that the flux-cored wire welding technology will be the best variant in a specific situation.

The growth in the popularity of this technology of flux-cored wire arc welding was based on a number of essential advantages, inherent to the welding technology proper. Scientifically substantiated selection of the core composition opens up wide possibilities for controlling the kinetics of metallurgical processes in the welding arc. That is why the flux-cored wires can be used for welding practically any type of metal, making this technology more versatile, compared to other methods.

Flux-cored wires, which are released to the market by certified manufacturers, owing to their high efficiency and productivity allow reducing the labour costs for auxiliary operations, providing an economic substantiation for their application. The flux-cored wires themselves are a high-tech welding consumable, and their quality is guaranteed by a complex of special technological operations of their manufacture and quality control. High-quality flux-cored wires can only be produced by competent specialized companies. In Ukraine OJSC "TM.WELTEC" is the leading manufacturer of flux-cored wires for welding and surfacing. PWI experience on development and use of flux-cored wires, gained over many years, is finding practical implementation in cooperation with such a manufacturer of welding consumables as OJSC "TM. WELTEC". Flux-cored wire production is located in a specially designed for this purpose shop of more than 3 thou m^2 area in the city of Dnipro. This is one of the most technologically sophisticated enterprises on welding consumables manufacture in the country. In addition to several automated lines for wire manufacture, the production facility includes a laboratory, where engineers and technical specialists continuously monitor compliance with the technological parameters of equipment operation, and product quality indices. Research and development is continuously carried on, which is aimed at improvement of the technological operations of manufacture, and creation of new grades of flux-cored wires, in keeping with the user inquiries and needs.

OJSC "TM.WELTEC" and PWI specialists are constantly working to improve the currently available and develop new compositions of flux-cored wires, in order to guarantee the high quality of welded joints by increasing the stability indices of the arc process, as well as improving the technological and sanitary-hygienic characteristics of the wires.

Assessment of the danger of the generated welding fumes is conducted in the entire range of welding modes, as the toxic impact of the fumes depends not only on the particle composition and dispersity, but also on the degree of their agglomeration during emission and a number of other factors. The volumes of welding fumes emission are influenced both by the type of the flux-cored wire, and the composition of the shielding gas atmosphere, as well as the welding mode parameters.

In welding in an argon-based gas mixture the level of gross emissions of the fumes and of their toxic component is significantly lower. Use of flux-cored wires

of metal-core type allows lowering the total level of gross fume emissions to the level characteristic for solid wire application. The total level of gross emissions is higher in the case of application of flux-cored wires with slag-forming core, than at application of solid wires or wires filled with metal powder filler. When using such wires, it is necessary to particularly strictly follow the respective recommendations on safety as regards cleanliness of the air in the working area of welding. However, presence of the slag melt leads to lowering of the overall level of burnout of deoxidizing and alloying elements, which eventually allows lowering the level of fume toxicity [5].

Presence of special stabilizers in the core composition allows significantly increasing the welding process efficiency, and lowering the level of molten metal

Table 1. Some characteristics of commercial flux-cored wires, proposed by OJSC "TM.WELTEC" for electric arc welding of low-alloyed steels

Wire grade, diameter and type, in keeping with the standards	Mechanical properties and chemical composition of weld metal	Purpose	Typical applications
FCWw-TMW1 ISO 17632-A: T 35 A Z N3 1.0–2.8 mm diameter	*UTS* ~ 460–550 MPa; *YS* ~ 330 MPa; $A_5 \geq 16$ %; $KCV_{+20\,°C} \sim 40$ J/cm^2 C ~ 0.08; Si ~ 0.1; Mn ~ 0.8; S ≤ 0.035; P ≤ 0.035 wt.%	Semi-automatic arc welding of metal structures from general purpose low-alloyed steels, also of contaminated metal	Building metal structures, technological containers, parts of agricultural machinery, railway equipment and machines
FCWw-TMW3 ISO 17632-A: T 42 2 1Ni Y N 3 1.6–2.4 mm diameter	*UTS* ~ 490–660 MPa; *YS* ~ 400 MPa; $A_5 \geq 20$ %; $KCV_{+20\,°C} > 80$ J/cm^2; $KCV_{-20\,°C} > 35$ J/cm^2 C ~ 0.12; Si ~ 0.2; Mn ~ 1.2; Ni ~ 1.0; Al ~ 0.85; S ≤ 0.02; P ≤ 0.02 wt.%	Mechanized arc welding in the field of metal structures from general purpose low-carbon and low-alloyed steels	
FCWw-TMW -mk5A ISO 17632-A: T 42 2 M M 1 H10 AWS A5.18 E70T-6C 1.2–1.6 mm diameter	*UTS* ≥ 520 MPa; *YS* ≥ 430 MPa; $A_5 > 24$ %; $KCV_{+20\,°C} \geq 160$ J/cm^2; $KCV_{-20\,°C} \geq 110$ J/cm^2; $KCV_{-50\,°C} \geq 40$ J/cm^2 C ~ 0.06; Si ~ 0.45; Mn ~ 1,5; S ≤ 0.02; P ≤ 0.02 (wt.%)	Automatic and semiautomatic high-speed single- and multipass gas-shielded welding of metal structures from carbon and low-alloyed structural and shipbuilding steels	Special-purpose structures, of which higher requirements are made to weld ductility characteristics at low temperatures (down to minus 60 °C)
FCWw-TMW29 ISO 17632-A: T 42 3 1.2 – 2.4 mm diameter	*UTS* ≥ 490 MPa; *YS* ≥ 420 MPa; $A_5 > 22$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-40\,°C} \geq 35$ J/cm^2 C ~ 0.12; Si ~ 0.4; Mn ~ 1.3; S ≤ 0.03; P ≤ 0.03 wt.%	Welding of metal structures from low-carbon and medium-strength steels. Multipass welding without intermediate slag removal is possible, due to its small quantity and easy detachalility of the crust. High efficiency of welding operations and good appearance of the welds	General mechanical engineering, metal structure plants, transport and lifting machinery
FCWw-TMW7 ISO 17632 A: T 42 4 P C 1 H5 AWS A5.18 E71T1-C1A4-CS2-H4 1.2–2.4 mm diameter	*UTS* ≥ 490 MPa; *YS* ≥ 400 MPa; $A_5 > 22$ %; $KCV_{+20\,°C} \geq 120$ J/cm^2; $KCV_{-20\,°C} \geq 90$ J/cm^2; $KCV_{-40\,°C} \geq 70$ J/cm^2 C ~ 0.08; Si ~ 0.3; Mn ~ 1.3; S ≤ 0.03; P ≤ 0.03 wt.%	Gas-shielded welding of metal structures from low-carbon and low-alloyed steels, including D32-E40 shipbuilding steels, unalloyed S235, S355 structural steels. Excellent welding-technological properties. Deposited bead has a smooth surface with easily detachable slag crust	Manufacture of metal structures, with higher requirements to low-temperature ductility characteristics of weld metal
FCWw-TMW57 ISO 18276-A: T 55 2 R C 2 1.2 – 2.4 mm diameter	*UTS* ~ 650–800 MPa; *YS* ≥ 590 MPa; $A_5 \geq 16$ %; $KCV_{+20\,°C} \geq$ 65 J/cm^2; $KCV_{-30\,°C} \geq 35$ J/cm^2 C ≤ 0.12; Mn ~ 1.3; Si ~ 0.3; Cr ~ 0.30; Mo ~ 1.2; V ~ 0.3; S ≤ 0.03; P ≤ 0.03	Gas-shielded welding of critical metal structures from low-alloyed high-strength steels, as well as alloyed structural steels with not less than 580 MPa yield limit	Repair welding of castings from higher-strength steels, repair of various-purpose equipment, building metal structures, mechanical engineering, metallurgical industry units
FCWw-TMW14 ISO 17634-A: T CrMo R C 1 1.2–2.4 mm diameter	*UTS* ~ 500 MPa; *YS* ≥ 430 MPa; $A_5 \geq 22$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-20\,°C} \geq 50$ J/cm^2 C ≤ 0.06; Mn ~ 0.8; Si ~ 0.3; Cr ~ 1.0; Mo ~ 0.5; S ≤ 0.014; P ≤ 0.012	Mechanized gas-shielded welding of metal structures, building-up and repair of defects in castings from high-alloyed steels and corrosion-resistant, heat-resistant and high-temperature alloys operating at up to 545 °C temperature	Transport engineering, technological containers, vessels, tanks and pipelines, metal structures, etc.
FCWw-TMW11 ISO 17633-A: T55 2 R C 2 2.4–3.0 mm diameter	*UTS* ~ 520 MPa; *YS* ≥ 400 MPa; $A_5 \geq 30$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-20\,°C} \geq 50$ J/cm^2 C ≤ 0.12; Mn ~ 14.0; Si ~ 0.2; Cr ~ 10.0; Ni ~ 9.0; S ≤ 0.025; P ≤ 0.025	Mechanized open-arc or gas-shielded welding and surfacing of low-carbon and low-alloyed steels, as well as welding alloyed structural steels to austenitic steels	Welding pearlitic steels to high-manganese steels, as well as welding and repair of mining excavator buckets

spatter [6]. The slag phase, forming at core melting, allows not only protecting the molten metal from undesirable interaction with the environment, but also realizing the necessary metallurgical reactions to improve the performance of the metal of the weld and the welded joint as a whole.

The main difference of the process of flux-cored wire welding in the spray transfer mode from solid wire welding consists in that the electrode metal transfer takes place on the wire edges (over the sheath cross-section), and not in the central zone, focused on the center of the arc burning. Presence in the flux-cored wire core of slag-forming materials and metal powders, as well as chemical compounds with a low ionization potential, influences the surface tension of molten metal of the weld pool, which allows regulation of the weld surface shape. For gas-shielded arc welding flux-cored wires with the following types of powder core are mainly used. Mineral-powder (slag-forming) core provides slag protection and performs metallurgical processing of the melt of the respective type (rutile or basic type). Metal-powder core, based on powders of iron and alloys with a small fraction of active chemical compounds (usually less than 1.5 % by weight), ensures active alloying and microalloying, as well as modifying of the weld metal structure. Here, the composition of the shielding gas atmosphere has a key role, determining the thermal conductivity of the arc gap, and degree of oxidizing process development at electrode metal transfer and in the weld pool.

As a rule, the cost of welding consumable for making a certain welded joint is higher in the case of using semi-automatic flux-cored wire welding, than in the case of coated-electrode manual arc welding or semi-automatic gas-shielded solid wire welding. However, even without allowing for a higher welding efficiency, the real cost of welding operations also includes the labour costs for postweld heat-treatment of the produced joint, and metal stripping along the weld. They take up from 50 up to 55 % of the total operation cost. The efficiency of the electric arc welding process, assessed by the quantity of the deposited metal, does not fully reflect the actual productivity of making the welds during metal structure fabrication. The influence of the possible deviation of weld dimensions from the design ones, in particular surface shape (reinforcement), and extent of the possible losses of electrode metal for spatter under the actual conditions should be also taken into account. For instance, the time spent for making welds of equivalent design size increases by 5–15 % in the case of application of a gas mixture of M21 type instead of carbon dioxide gas in gas-shielded welding. This is achieved not only due to reduction of burnout and spattering losses, but also due to a more accurate correspondence of the reinforcement dimensions and shape to the design values, which influences the cost indices of fabrication of welded metal structures. Additional economic advantages can be also achieved at application of flux-cored wires instead of solid wires owing to reduction of the weld metal volume, for instance in welding single-pass fillet joints.

Higher cost of welding consumables (flux-cored wires, gas mixtures of argon with carbon dioxide gas) is compensated not only by increase of welding process efficiency, but also by lowering of overall costs for making the welded joints due to elimination of electrode metal losses, as well as improvement of the shape and more complete compliance of the weld shape and dimensions with the design values. All this allows lowering the cost of fabrication of welded metal structures and improving their quality.

The main properties of some commercial flux-cored wires, manufactured by “TM.WELTEC” are shown in the Table 1.

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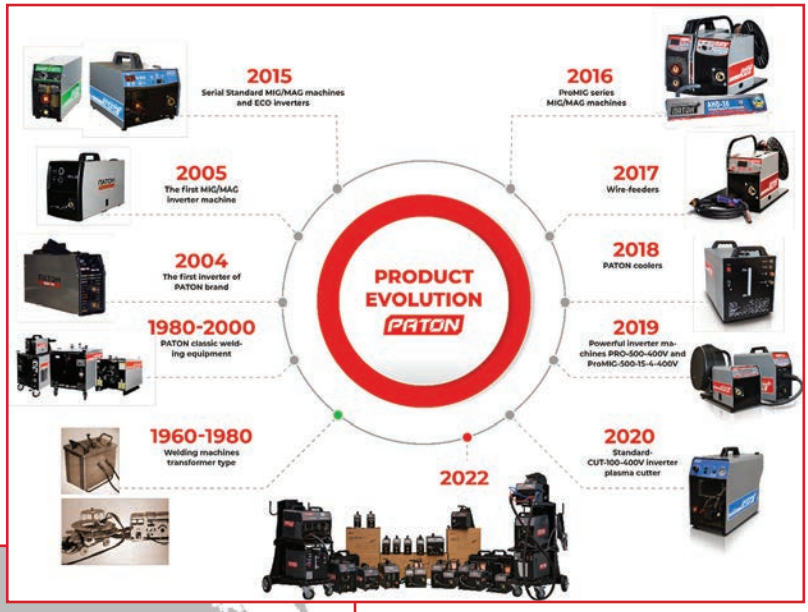
PATON INTERNATIONAL — EVOLUTIONS IN YEARS

The history of development of welding equipment production in Ukraine has been almost hundreds of years. 64 years of them are closely related to the activities of the PATON INTERNATIONAL Company, which was created at the Electric Welding Institute in 1959 for the implementation of new developments of specialists from the Institute and EDTB. For the whole period from the date of its creation to this day, at the production facilities of the Company, hundreds of thousands of units of welding equipment for various enterprises from almost all continents of the world have been manufactured. Today, PATON INTERNATIONAL is a leading manufacturer of welding equipment and materials in Ukraine and one of the leaders at the market of the CIS countries.

The Company has two production sites at the very heart of Ukraine — in Kyiv, which closely interact with the scientific potential of a leading institution in the field of welding — the E.O. Paton Electric Welding Institute. The own complex of design laboratories performs a full range of works related to the development of welding equipment, starting from bodies of machines and ending with the design of unique electronic circuits and software development. The mentioned design and production resources allow the Company to produce more than 60 models of equipment in such categories as:

- inverters for manual arc welding (MMA) with the current range from 150 to 630 A;
- MIG/MAG welding semi-automatic machines — from 150 to 630 A;
- argon-arc inverters (TIG) — from 200 to 350 A;
- machines for air-plasma cutting (CUT) — from 40 to 100 A;
- multimode welding inverters — from 250 to 350 A.



In the production, the most advanced components from such world's leading manufacturers as INFINEON, VISHAY, KENDEIL, NXP, TOSHIBA, TEXAS INSTRUMENTS etc. are used. The equipment is completed with high-quality welding accessories of German and Ukrainian production. All this allows the Company to manufacture extra-class products, the high quality of which was reflected in an increased guarantee term — up to 5 years.

Except of welding equipment, PATON INTERNATIONAL develops and manufactures a wide range of

accessories for welding and 10 most popular grades of electrodes in such categories as AWS 5.1:E6013, AWS 5.1:E7015, AWS 5.1:E7018, AWS A5.4:E347-16, AWS 5.15:ESt and EN 14700: E Z Fe14. PATON electrodes are produced by improved modern recipes from raw materials of well-known Ukrainian and world manufacturers, they are featured by high quality and excellent consumer characteristics, meet the necessary requirements, which is confirmed by the presence of appropriate certificates from international certification companies.

Thanks to the own developments, high production culture and considerable experience of the Company, welding machines and electrodes under PATON brand are honoured by welding specialists both in Ukraine and far beyond its borders.

The development of export markets for products is one of the most priority directions of the Company development strategy. Today, PATON products are shipped in more than 50 countries around the world — from Latin America to the Far East and Australia.

A separate vector of development is the strengthening of PATON brand positions at the European market of welding equipment and materials. The Company offers European consumers a unique combination of high quality, functionality, efficiency and compactness of PATON welding equipment, whereby it can compete at the market with equipment from well-known European and world brands.

To provide deliveries and organize service for products, the official representation of the Company PATON Europe was created in Poland, whose team can respond promptly to the request from customers and provide delivery of products to consumers in the shortest possible term. And today, thanks to the work of the team, PATON welding equipment and materials are present at the market of almost every EU country and the United Kingdom. Due to the wide network of official dealers and partners of the Company, the work of the own local online stores and the availability of products at the largest European online marketplaces, each European consumer can get acquainted with PATON products and order them on the most favourable terms with the minimum delivery period.

PATON INTERNATIONAL Company has an impeccable reputation of a reliable manufacturer and a supplier of high-quality welding equipment and materials and makes everything necessary to maintain it at such a high level. The Company continues its movement to the set goals — providing the sustainable development of its research and production potential, increasing production of high-quality welding equipment and materials, promotion of PATON products among as many welding specialists from different countries as possible.

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