CONTRIBUTION OF PROFESSOR EVGENY O. PATON TO THE DEVELOPMENT OF WELDING MATERIALS SCIENCE AND PRODUCTION OF HIGH-QUALITY STEEL

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The activity of Professor Evgeny O. Paton is analyzed in investigations of metallurgical processes of submerged arc welding, development of welding consumables and improvement of quality of welded joints. The results of these works were used in development of electroslag technologies. 37 Ref.

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In 1929, Evgeny O. Paton, the famous scientist in the field of bridge construction, academician of the All-Ukranian Academy of Sciences (AUAS, now NASU — the National Academy of Sciences of Ukraine) decided to apply welding in the bridge construction. Over centuries the metal structures were constructed by using riveted or bolted joints. Each of bridges, designed by E.O. Paton, was characterized by unique architecture, optimum costs for materials and construction works. And academician-amateur began to work with a project of the new bridge across the Dnieper river in Kiev. Evgeny Paton decided to create the radically new design of bridge and started the designing and testing of welded subassemblies. During the period of three year a cycle of investigations of service characteristics of welded structures was fulfilled, the comparative tests of a number of full-scale riveted and welded products were made, the recommendations were worked out for designing the welded structures [1, 2].

After finding out that the quality of welds is not stable and depends on skill of the worker, welding consumables and condition parameters, he put forward the task to mechanize and automate the arc welding technology. In 1933, the Presidium of the AUAS took a decision about establishment of the Institute of Electric Welding (now the E.O. Paton Electric Welding Institute) approved by the Ukr.SSR government in January 1934 [3–5].

Investigations of factors, influencing the quality of welds, and development of welding consumables were started. By understanding that unlike the other methods of permanent joining the metallurgical processes in welding are proceeding in a molten pool, E.O. Paton started in 1935 to organizer the laboratory of welding technology, headed by V.I. Dyatlov, graduated from the metallurgical faculty of Kiev Politechnic Institute and worked three years at the plant in Zlatoust (RF), where the high-quality armor steels were produced. Investigations in the field of welding materials science started from study of structure peculiarities of low-carbon steel welded joints. At the first stage of development of the welding materials science the main attention was paid to the establishment of interaction between parameters of thermal cycles and weld structure, as well as heat-affected zone [6–8].

At the same time, a welding head for the automatic consumable-electrode arc welding (P.P. Bushtedt) and methods of welding zone protection (V.I. Dyatlov) were developed at the Institute of Electric Welding under supervision of E.O. Paton. The problems of placing mixture on the electrode wire surface were solving for welding zone shielding and current connection to welding heads. In short terms several variants of mixture composition and designs of wires were developed: with grooves, cruciform section with recesses, filled with charge, etc. However, it was not managed to attain the stable good quality [8].

E.O. Paton took a decision to concentrate efforts to investigation of processes of submerged arc welding. Flux for weld pool shielding was earlier developed by N.G. Slavyanov [9], however, the conventional metallurgical fluxes did not guarantee the required quality. His idea was used by associates of the Linde company (USA), who developed the composition of granulated flux for welding of steels and technique of automatic consumable-electrode submerged arc welding [10, 11].

To develop the new domestic type of welding, E.O. Paton organized the group of welding metallurgy, including V.I. Dyatlov, A.M. Lapin, and V.S. Shirin. The main volume of investigations fell at the processes of melting and metallurgical processes proceeding in the weld pool [12].

In 1938–1939, the welding under the flux layer with non-consumable (carbon) electrode of up to 18 mm thick low-alloy steels was developed at the Institute of Electric Welding. By continuing to attain the achievements in mechanization and automation of arc welding processes, the specialists of the Institute could finalize independently the solution of all the problems remaining on the way of application of welding with consumable electrode under the flux layer [13].

In 1993, the first domestic fused flux (AN-1), electrode wire (10GS type) with increased content of deoxidizers (silicon and manganese), unique designs of welding head and welding transformers were developed. A year later, the highly-manganese flux for welding with low-carbon wire was suggested. The new method of welding occurred to be 11 times more efficient than the manual welding.

The results of search works were generalized by E.O. Paton in the first in the world monograph on submerged arc welding, published in 1940. In addition to other things it laid the foundations of the new scientific direction — welding materials science [14].

For the first time in the world, E.O. Paton disclosed dependence of microstructure of weld metal and heat-affected zone on welding conditions, systematized the data on peculiar features of microstructure of welded joints. In the third edition of the manuscript on automatic arc welding E.O. Paton outlined: «Weld, produced in submerged arc welding, greatly differed from conventional weld, produced by the open arc. In spite of the columnar structure, the weld metal is characterized by high toughness (elongation up to 25 % and impact toughness up to 150 J/cm^2). This result disproved the existing until now theory about the fact that metal brittleness, i.e. low elongation and impact toughness, are caused first of all by the columnar structure. The submerged arc welding proved that the decisive factor, causing the weld metal brittleness, is the contamination with nitrogen and oxygen, penetrating into the molten metal» [15].

All the further development of welding confirmed brilliantly the point of view of E.O. Paton. The effect of these factors was also confirmed in the new process, namely, electroslag casting, developed at the E.O. Paton Electric Welding Institute in the 1960s [16].

The Paton's principle in development of the new technologies was subjected to the severe testing in the years of the World War II. In Nizhny Tagil at the Ural Tank Plant after the name of Comintern (RF) it was managed for the first time in the world to create equipment and technology of automatic welding of tanks and other armored ammunition under the supervision of Paton E.O. The main problem was the prevention of crack formation in welded joints of armored low-alloy steels.

The causes of weld metal cracking were found (V.I. Dyatlov, T.M. Slutskaya, A.I. Ivanov), fluxes from local raw material were developed (V.I. Dyatlov, T.M. Slutskaya, A.I. Korennoj); the nature of process in the zone of submerged arc welding was studied and the presence of arc discharge here was experimentally proved for the first time in the world (B.E. Paton and A.M. Makara), unique automatic welding heads with constant rate of electrode feeding and control systems, etc. were designed [17, 18]. During the period of 1941–1945 the hardening hypothesis of formation of cold cracks was confirmed in investigations of weld and HAZ metal on the armored steels [18]. During the war years the further development of works of the Institute on study of fundamentals of submerged arc welding (B.E. Paton and A.M. Makara), development of new consumables (fluxes AN-2, ASh, AShMA) and wide implementation of this advanced process in production of defense equipment were progressing [18–21].

One more peak in history of automatic submerged arc welding was the development of devices and technologies for the first time in the world for fulfillment of vertical and horizontal welds. Thus, the task of full-scale application of submerged arc welding was solved in construction of large objects (blast furnaces, gas-holders, thick-walled pipelines) and buildings [19].

In spite of large programs of implementation tasks, work in shops of the restoration enterprises, the research work at the Institute was carried out on 35 subjects. E.O. Paton was the initiator of purposeful fundamental studies. At the end of the 1940s and at the beginning of the 1950s, the theoretical and experimental investigations were carried out, without results of which it was not even possible to develop the new technologies and welding equipment and the results of which became the basis of development of new scientific directions. Specialists of the Electric Welding Institute, N.E. Bauman MVTU, TsNI-

ITMASh, NIAT and others studied the processes of electrode melting, solidification of weld pool, define the causes of formation of pores, cracks, etc. The metals science of welding, distinguished from the metallurgy of welding into the independent direction, became progressing. In similar directions the investigations were carried out also by specialists of the USA, Great Britain and France. Discussions were organized in journals, recommendations were formulated for improving the weld metal quality, development of welding and surfacing consumables [20–26]. Investigations of primary solidification and microscopic heterogeneity of welds, made in the 1940–50s, had the great importance for improvement of welding consumables and technologies.

In the first post-war years, a number of high-silicon fused fluxes was developed, containing 40–50 % SiO_2, and also up to 20 % MnO (AN-3) or up to 35–40 % MnO (AN-348, AN-348Sh, AN-348A), etc. In welding of carbon steels by low-alloy wire using these fluxes the silicon recovery from flux takes place. At the same time, manganese is recovered from flux into the weld metal.

In the middle of the 1940s at the Electric Welding Institute, it was found (Medovar B.I.) that cracks are initiated in welding of corrosion-resistant chrome-nickel steels using electrodes with niobium content of 0.9 % and higher at content of silicon and manganese of more than 1.5 % and carbon of 0.09 %. For welding of niobium steel the welding wires of new types, such as EI605 and EI606, EP75, EP87, EI793 and also fluxes AN-26, BKF-5, KhNK-66 were developed [27].

By the beginning of the 1950s, the comprehensive experimental information on the problem of cracking in welds was collected. Studied were physical-chemical properties of molten fluxes and slags at high temperatures (viscosity, electric conductivity, surface properties, thermodynamic activity of oxides). The important process is the interaction of molten slag with solidified weld metal.

As a result of investigations of weldability of the low-alloy steel, carried out under the supervision of E.O. Paton, it was found that the increase in steel tendency to transition into a brittle state in the process of welding thermal cycle depends on chemical composition, method of steel deoxidation in melting and grain size. The low-carbon steel, killed by silicon and aluminium and rolled at optimum temperature, possesses the lowest threshold of cold brittleness in the heat-affected zone [28, 29]. As to the weld metal, then to avoid the cracks it is necessary that the amount of impurities, contributing to crack formation, did not exceed the definite value and were distributed uniformly in the rolled metal section.

The main result of these investigations was the working out of requirements to steels for welded structures. Evgeny O. Paton had a meeting with I.F. Tevosyan, Ministrer of Ferrous Metallurgy, and asked him to assist in making experimental samples of steels according to the technical specifications of the Institute. The request was immediately satisfied and steel, melted in Mariupol (Ukraine), possessed a good weldability at the absence of defects. Metallurgists had to support the point of view of E.O. Paton, such as «in steel production it is necessary to take into account the requirements of welders» (and ten years later the technologies of production of metals and alloys were developed at — PWI and implemented by metallurgists in many countries).

In 1948–1949, Voloshkevich G.Z. found during testing of technology of submerged arc welding with forced formation of vertical weld that the electrode wire is melted at arcless discharge in the fused flux, i.e. in slag pool. The new type of welding appeared — electroslag welding (ESW), based on electric conductivity of the molten slag. The problems of providing the stability of electroslag process and also designing of devices for maintaining of metal and slag pools, etc. were solved (B.E. Paton, G.Z. Voloshkevich, V.E. Paton, et al.) [30, 31].

The development of ESW process allowed solving the problems of production of the new class of massive metal structures: cast-welded, forged-welded, and rolled-welded. ESW «opened the way» for technologies, acquiring the general name «electroslag technologies».

In 1952, the first ingot was produced at the PWI and study of ways of application of welding metallurgy, welding physics-chemistry, welding technique in producing of ingots for rolling and forging started. The electroslag remelting (ESR) initiated the beginning of the special electrometallurgy. Due to a number of ESR peculiar features it was necessary to develop special fluxes using the experience of development of fluxes for the ESW of steel [32, 33].

The molten electrically-conductive slag is not only heat source, but also contributes to refining of metal being remelted from harmful impurities (sulphur, non-metallic inclusions), protects the molten metal from the effect of atmosphere.

A laboratory furnace, designed at the PWI in 1956 and put into operation at «Dneprospetsstal» Works in Zaporozhie (Ukraine) in May 1958, was the first in the world industrial electroslag furnace. Soon at the same Works the first in the world practice specialized ESR shop was constructed. At the beginning of 1958 the first in the world three-phase furnace for producing 12 % chromium heat-resistant steel was put into service [34–37] at Novo-Kramatorsk Machine-Building Works (Ukraine).

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