# AGGLOMERATED FLUXES IN LOCAL WELDING PRODUCTION (Review)

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USSR priority in development of agglomerated (ceramic) fluxes is noted. Stages of development of investigations on their improvement and widening of their application areas are described.

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Agglomerated fluxes are a mechanical mixture of powder-like components made in the form of grit of appropriate granulation, cemented by a binder or sintering. Each granule of agglomerated flux consisting of strongly bound fine particles is characterized by a constant ratio of all ingredients. Granules of different size are close by specific weight that ensures absence of flux separation at its application. In this respect agglomerated fluxes differ favourably from other non-fused fluxes (mechanical mixtures).

A certain similarity in fabrication of granulated non-fused fluxes and ceramic products (material grinding, forming together with binder, subsequent heat treatment) formed the basis for calling these fluxes ceramic fluxes in Soviet scientific-technical and normative publications [1]. In foreign literature fluxes of this type are called agglomerated fluxes, and in IIW and ISO documents they are classified as bonded fluxes.

The priority of development of ceramic (agglomerated) fluxes belongs to the Soviet Union. A prerequisite for development of ceramic fluxes were experiments on automatic welding with feeding of non-fused flux into the arcing zone conducted as far back as in 1937 in the welding laboratory of N.E. Bauman MHTU [2]. As proposed by K.K. Khrenov granulated non-fused flux made from electrode coating charge was used in these experiments for the first time. Flux was fed in a small amount and open-arc welding was performed. This work was not taken further at that time, it, however, demonstrated the technological advantages of granulated flux compared to powder-like fluxes-mixtures.

More profound studies on development of ceramic flux composition for submerged-arc welding, investigation of metallurgical and technological features of this kind of welding consumables, development of the technology of their manufacture and application in the USSR were begun as far back as in 1948 by D.M. Kushneryov under the guidance of Prof. K.K. Khrenov in the Welding Production Chair of Kiev Polytechnic Institute, and starting from 1949 — in the Laboratory of Electrothermics of the Institute of Structural Mechanics of the Academy of Sciences of Ukr. SSR.

Registration Certificate of USSR Gostekhnika #2981-51-8 with priority of February 3, 1951 for ceramic fluxes was issued to K.K. Khrenov and D.M. Kushneryov.

Already the first works demonstrated the basic possibility of application in ceramic flux composition of ferroalloys, metals, carbon materials, carbonates, higher oxides of iron and manganese, alongside the regular slag-forming components [3, 4]. During the same period the broad possibilities offered by ceramic fluxes in terms of deposited metal alloying at application of low-carbon electrode wire, and improvement of weld resistance to porosity, were determined [4].

It should be noted that by the beginning of 1950s USSR already had centralized commercial production of fused fluxes which became widely accepted in many industries. However, the range of welding wires produced by local industry at that time was very limited, and did not satisfy the need of many users. In addition to limited possibilities of metallurgical impact on the weld metal, fused fluxes also featured a high sensitivity to the presence of moisture or rust on the edges being welded. Under the conditions, when low-carbon rimmed or semi-killed steel was the main material for welded metal structure fabrication, rust presence in the groove caused weld porosity [5].

Broad possibilities of variation of the composition of ceramic flux charge allowed successfully overcoming these problems. Moreover, at addition of various ferroalloys, alloying metal additives, and master alloys ceramic fluxes ensured an increase of weld strength, toughness, hardness and wear resistance, owing to weld metal alloying [6–9].

Submerged-arc welding was a new highly efficient process, which not only provided an increase of efficiency (by several times), but also guaranteed a high reproducibility of the results, while requirements to qualifications of workers-welders were significantly lowered. At the initial stage of development welding fluxes were regarded as a means for protection of the arcing zone from air and electrode metal losses, as well as for protection of the surrounding personnel from arc radiation.

Adequate realization of unique capabilities of the new welding process required an in-depth study, and conducting scientific research. Work performed in this direction, is systematized in a number of monographs [10–12]. Realization of fundamental postulates set forth in them, enabled development of ceramic fluxes increasing resistance to porosity by 2–3 times [13].

With improvement of steel quality the priorities in the field of welding consumables changed. It became necessary to develop fluxes with a low content of impurities, high refining ability, and rational alloying. The Academy of Sciences of Ukr. SSR deployed systematic studies of metallurgical features of welding with ceramic fluxes, allowing for increased requirements to welded joint quality and widening of the range of welded steels. As a result of this work, coefficients of alloying element transition from the flux into the deposited metal were established experimentally, as well as the degree of influence of welding parameters on alloying element transition, that allowed calculation of the composition of flux alloying part by the specified composition of deposited metal with accuracy sufficient for practical purposes. Conducted studies showed that ceramic fluxes not only can alloy the deposited metal, but can also essentially lower its content of impurities, and improve the structure by modifying. These features are realized, for instance, at development of higher basicity fluxes, providing minimum oxidation of alloying elements in the weld pool, and improved cracking resistance of weld metal [14–16].

Mastering of the technology of mass production of increased and high-strength low-alloyed (HSLA) steels by local industry and widening of the scope of their application in welded metal structure fabrication brought to the forefront the problem of lowering of hydrogen content in the weld metal. Postulates defined by V.I. Dyatlov [17] on the predominant running of metallurgical reactions in the gas phase in submerged-arc welding were further elaborated in the field of development of fluxes designed for welding low-alloyed steels. As a result of investigation of the features of running of metallurgical reactions in welding with ceramic fluxes, systematized in the work by D.M. Kushneryov, it is established that application of a certain quantity of carbonates and higher iron oxides in the slag-forming base of the fluxes allows lowering both partial pressure of hydrogen in the arc atmosphere, and its content in the metal of welds and HAZ, and, due to that, ensuring a high resistance to cracking in thick steel welding. These developments were realized in practice in the form of fluxes for welding chromium-nickel stainless steels [18]. TsNIITMash under the guidance of K.V. Lyubavsky developed oxygen-free ceramic fluxes of FTsK type for welding high-alloyed steels [19], and at Zhdanov Metallurgical Institute K.V. Bagryansky developed a series of ceramic fluxes for surfacing parts of metallurgical equipment [20].

Beginning from 1960s, PWI deployed systematic investigations on development of ceramic flux compositions, technology of welding and surfacing with their application, as well as technology of mechanized commercial manufacture of fluxes of this type. Results of investigation in the field of metallurgy of welding with ceramic fluxes [21, 22], generalized in dissertation works of V.G. Svetsinsky [23], and V.M. Kiriakov, were realized at mastering of the technology of commercial production of ceramic fluxes at Nizhnedneprovsky Metalware Plant [24].

Appearance of new grades of low-alloyed steels, providing as a result of thermomechanical treatment ultimate tensile strength of not lower than 650 MPa and high impact toughness at low climatic temperatures, posed a new problem for the developers — producing cast metal of welds, which would be equivalent to base metal by the level of their mechanical properties. Solution of this problem required performance of investigations to study the possibility of controlling the weld metal structure by variation of welding flux composition. As a result of such work performance at PWI under the guidance of Prof. I.K. Pokhodnya, a new concept of structuring the ceramic flux composition was formulated, according to which the main alloying of weld metal should be performed at the expense of electrode wire (solid or flux-cored), while the flux has to fulfill the functions of providing the refining, microalloying and modifying of weld pool metal. The above approaches were used to develop ceramic fluxes for welding structures from low-alloyed steels in chemical engineering, at prefabrication of bridge metal structures [25, 26]. Volume of ceramic flux production in the USSR during this period of time was up to 2000 t per year.

An essential improvement of the quality of rolled stock for welded structure fabrication in the last quarter of the XX century led to the need of creation of new generation welding consumables developed on the basis of fundamental investigations of metallurgy of arc welding processes, physico-chemical processes in slag and metal systems, and metals science of low-alloyed steels. PWI staff performed a large scope of investigations aimed at elaboration of scientific approaches to solution of problems of formation of optimum structure of welded joint metal, required level of indices of weld metal formation, ensuring the specified characteristics of welded structures from low-alloyed steels of increased and high strength. As a result of performed research, generalized in dissertation works by V.V. Golovko and S.D. Ustinov, positive influence of certain non-metallic inclusions on initiation and development of ferrite components of metal of HSLA steels was established, providing an increase of both strength and toughness of welded joints [27–29]. Agglomerated fluxes, developed during this period, were accepted in welding in general and special shipbuilding, in fabrication of stationary and semisumbersible platforms for work performance on the World Ocean shelf [30].

Beginning from the end of 1990s PWI has conducted systematic investigations to study the possible influence of welding flux on the conditions of formation of weld metal microstructure. The possibility of forming non-metallic inclusions of specified composition in the weld metal by controlling the flux oxygen potential and alloying ability of welding consumable composition and ensuring strengthening of weld metal structure by solid solution alloying was shown.

In modern materials science non-metallic inclusions are regarded as active centers of formation of the required microstructure, without which it would be impossible to produce welded joints of HSLA steels with the level of mechanical properties equivalent to base metal. In foreign publications such a direction was called «oxide metallurgy», and technology of producing inclusions of a certain composition, morphology and size distribution in the metal — «inclusion engineering» [31, 32]. Performed thermodynamic calculations, numerical simulation of the processes of non-metallic inclusion formation both in the liquid metal of weld pool, and in the region of its solid-liquid condition, systematized in [33], allow taking development of modern local agglomerated fluxes to a new level, ensuring their high competiveness, compared to developments of leading world manufacturers of welding consumables.

Consideration of processes differing by their metallurgy, which are applied for manufacturing of welding fluxes, as one technological package, allowed suggesting a new process for flux manufacturing, which combined such advantages of fused fluxes, as lower susceptibility to atmospheric moisture absorption, high resistance of flux granules to breaking up during flux application with broad capabilities of controlling the metallurgical processes in the arcing zone and in the weld pool, characteristic for agglomerated fluxes [34]. The new technology envisages refining low-grade raw materials by their melting in open gas furnace with subsequent processing in electric-arc furnace and use as charge components in agglomerated fluxes. During flame processing as a result of high oxidation ability of gas medium an essential lowering of sulphur content in the slag is achieved, and features of metallurgical processes in electric-arc furnace allow refining the melt as to phosphorus. During agglomerated flux manufacture the charge materials, included into its composition, are not subjected to any heat treatment, which would allow performing such refinement, so that higher requirements are made to their composition as to impurity content. Application of higher purity synthetic slags in agglomerated flux composition widens the range of high-quality raw materials, and also improves such consumer characteristics of the flux, as resistance to atmospheric moisture absorption and granule breaking up during flux application due to presence of fused products in their composition. Here the possibility of flexible influence on welding process metallurgy, typical for agglomerated fluxes, is preserved. Introduction of such a technology of welding flux manufacturing in industry showed that local agglomerated fluxes, not inferior by their regulated characteristics to foreign analogs, are superior to them in terms of cost-effectiveness of application.


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