Relationship between quality, manufacturing technology and structure of welding fluxes

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Abstract. Technology for manufacturing of fused fluxes of the AN-67 grade (preparation of charge, melting of flux in electric arc furnace, granulation (pouring of melt into water), drying, screening and packing) was developed in such a way that the resulting granulated welding flux had a fully amorphous structure. However, production of such fluxes involves enormous power expenditures. Therefore, the trend with flux manufacturers is to reduction in time and decrease in ultimate temperatures of the processes, which makes it impossible to remelt high-temperature components of the flux charge. Some welding fluxes of the AN-67 series were examined by the X-ray diffraction method. It is established that certain fluxes produced in the last years contain crystalline components with a high melting point, such as Al₂O₃ and CaF₂, in addition to the amorphous phase. The paper shows the negative effect by this factor on properties of the fluxes.

1. Introduction

Properties of a welding flux are known to depend not only upon its chemical composition, but also upon the technology used to manufacture it [1]. However, as evidenced sometimes, a flux may meet requirements imposed on it (homogeneity, structure and colour of grains, chemical composition, moisture content and volume weight), but, at the same time, it may cause customers’ complaints [1]. This is related to violation of the manufacturing technology, which leads to partial crystallisation of flux during the melting process.
2. Structure and properties of welding fluxes

All granulated fused fluxes in the solid state, which were produced before 1991, give a diffraction pattern that is characteristic of the amorphous or glassy state [2-3]. One of the purposes of the present study was to reveal the effect of amorphisation of flux on improvement of its quality.

It is a known fact that reactivity of a slag depends upon the size of its particles: the coarser the particles, the lower the interaction. Particles of the liquid type have size of about one nanometre. This size is larger than that in the gas phase, which consists of atoms or molecules. At the same time, it is much smaller than an elementary crystalline grain, the size of which is over 10 nm. Therefore, formation of crystalline grains decreases the probability of interaction of metal and slag particles. To provide melting of crystals in slag, it is necessary to consume an extra energy and time to destroy the crystalline lattice, which is better to do in melting of slag than in the weld pool, as welding is a fast non-equilibrium process.

As shown by our data we generated for the majority of welding fluxes [2-3] in the molten state, they are characterized by the presence of atom groups of nanometric sizes, which are substantially different from their crystalline analogues. Such particles are close in structure to a colloidal micelle [4]. They are formed during remelting of the slag charge, and a generalized diffuse layer is formed around them [3]. Micelles slightly interact between each other, but the particles are in equilibrium exchange with the diffuse environment. Oxide nanomicelles are formed on the base of closely packed oxygen atoms. Some octa- and tetra-voids of the oxygen matrix are filled with cations. Nanomicelles are in a dynamic equilibrium with the diffuse environment. Figure 1 schematically shows the structure of the melt based on nanomicelles of closely packed oxygen atoms at low (a) and high (b) temperatures. Filling of the diffuse layer is not shown.

![Figure 1. Structure of oxide melt based on micelles of closely packed oxygen atoms (only oxygen atoms are shown) at low (a) and high (b) temperatures](image)

3. Results and discussions

We investigated different batches of welding fluxes of series AN-67B. Solid granulated fluxes were examined using diffractomer DRON-3 in CuKα-radiation, and molten fluxes – using diffractomer θ-θ in MoKα-radiation. Figure 2 shows diffraction patterns of different batches of fused fluxes AN-67B. Batch numbers 137, 2, 3, 4, 5, 6 and 71 are shown in Figure 2 on the left. Diffraction patterns of fluxes AN-67U and AN-67A made approximately 20 years ago are shown in the top part of the Figure. As
expected, they had an amorphous structure. Comparison of diffraction patterns of fluxes AN-67B at room temperature and at 1350 °C is given in Figure 3. As can be seen, crystalline peaks do not fully disappear even at high temperatures.

As follows from Figure 2, most welding fluxes of series AN-67B, which have been produced lately (except for batch 71, Fig. 2), are not amorphous. Almost all the fluxes with crystalline peaks were criticised by customers. Crystalline peaks in diffraction patterns are identified as two phases: one phase based on aluminate spinel (melting point is over 1520 °C), and the other – fluorite CaF₂ (melting point is about 1418 °C).

**Figure 2.** Diffraction patterns of different batches of fused fluxes AN-67B. Batch numbers 137, 2, 3, 4, 5, 6 and 71 are indicated on the left. Diffraction patterns of fluxes AN-67U and AN-67A made approximately 20 years ago are shown on the top.

Aluminate spinel alone is identified only in batch 137. Figure 4 shows structural factors of molten fluxes in a temperature range of 1300-1450 °C. Crystalline peaks of CaF₂ disappear after reaching a temperature of 1450 °C and isothermal holding at this temperature for 40-60 min, and they are not restored after cooling. Although at 1400 °C no crystalline peaks can be seen in structural factor curves of a molten flux (Figure 4), they are restored after cooling. The attempts to conduct experiments with a higher-temperature phase of the spinel type failed because of boiling of the slag melt, which distorted the surface of reflection of X-rays. Presumably, however, the fully amorphous flux can be produced by isothermal holding at 1600-1650 °C and subsequent quenching of the slag melt. Atom groups in such a flux will be close in size and structure to nanomicelles of the melt, which will make it possible to avoid extra energy consumption in melting of the flux and maximize on utilization of the possibilities of a molten slag.
Fused welding fluxes of the AN-67B grade were examined by the X-ray diffraction method. It is established that some fluxes have an amorphous structure, while the others (criticized by customers because of their poor quality) have a partially crystallized structure.

![Graph](image1.png)

**Figure 3.** Comparison of X-ray patterns of flux AN-67B at 1350 °C (line) and at room temperature (points). $S=4\pi\sin(\theta/\lambda)$ and $\lambda$ is the wavelength of the incident X-rays.

![Graph](image2.png)

**Figure 4.** Structural factor of molten flux AN-67B at temperatures of 1300, 1350, 1400 and 1450 °C

**Conclusions**

Because of violations of the temperature and time parameters of the melting process, part of the source material (melted at high temperatures) has no time to be melted. That is, no homogeneous slag melt is formed prior to granulation in furnace. Crystalline phases of a flux are identified as aluminate spinel and calcium fluoride. Therefore, the method of X-ray analysis allows controlling the quality of fluxes and explaining deterioration of the quality in the cases where all the process requirements are met.

**References**

[1] Podgaetsky V, Lyuborets I 1984 *Welding fluxes* (Kyev: Tekhnika) p 167
[2] Sokolsky V 2002 *Structure of melts of multi-component oxide systems* Thesis for Doctor of Chemical Sciences Degree (Kiev) p 351
[3] Shpak A, Sokolsky V, Kazimirov V, Smyk S, Kunitsky Yu 2003 *Structural features of melts of oxide systems* (Kyev: Akademperiodika) p 138
[4] Ezikov V, Sheludko M, Chukmarev S, Voznuk V 1986 High-temperature centrifuging of oxide melts *Izv. VUZov. Ferrous Metallurgy* 3, 4