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ANALYSIS OF APPLICABILITY OF SLAG CRUST IN PRODUCTION OF AGGLOMERATED FLUXES

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The use of wastes of fused and agglomerated fluxes is an urgent task. But as-applied to agglomerated fluxes the data on the effective use of slag crust are absent in the literature. In this work the analysis of possibility of using a slag crust of agglomerated fluxes for production of fluxes, providing the quality formation and high mechanical properties of weld metal at high-speed multi-arc welding of cold-resistant low-alloy steels was carried out. The comparative investigation of welding and technological properties of original flux OK 10.74 and experimental fluxes based on the crushed slag crust in single- and four-arc welding was carried out. Using the method of spectral analysis the chemical composition of weld metal was studied. The method of optical metallography was used to investigate the distribution of nonmetallic inclusions in them and characteristics of microstructure. The impact toughness of weld metal was determined by tests on impact bending. It was established that the flux, produced by the method of agglomeration with addition of 5 wt.% of metallic manganese into the composition of charge, was close to original flux OK 10.74 according to all the investigated indicators, and as to the level of impact toughness met the requirements for welded joints of cold-resistant gas-pipeline steel up to strength category X80 inclusive. The results represent interest to the consumers of flux from the point of view of improving the efficiency of its use in multi-arc welding of large-diameter pipes. 10 Ref., 4 Tables, 3 Figures.

Keywords: *submerged arc welding, agglomeration, regeneration, nonmetallic inclusions, microstructure, impact toughness of weld metal*

In submerged arc welding the wastes are formed, including the non-fused part of flux and slag crust (SC), which is characterized by a low content of hydrogen dissolved in the form of OH^- [1], sulfur and phosphorus. These wastes related to the III class of hazard, and should be stored in the closed containers. The volumes of SC at a number of enterprises, for example, pipe plants, are estimated in thousands tons, therefore, the works on their recovery are very relevant.

The issue of using wastes of fused fluxes (of the molten flux and SC) has been long time standing before the researchers [2]. The known technology of regeneration of a part of non-fused flux [3], which is at advanced pipe mills is realized directly in the process of welding. SC is used in melting of fluxes [4], or by adding it in a powdered form to the original flux. The investigations showed that during welding a significant change in the structure and composition of slag excluding the possibility of its application directly in the form of flux does not occur [5]. Therefore, its application as the charge component for melting flux is irrational in cases when there is no need in obtaining fluxes with bulk mass of <1.1 kg/dm^3, being commonly used in multi-arc welding at high speed. The technology of production of regenerated welding fluxes was offered, consisting in SC crushing followed by magnetic separation and sieving into fractions [6]. Such fluxes provide the increased resistance of welds to the pore formation [7].

All the investigations described above concerned the fused welding fluxes. To agglomerated fluxes considering their high cost the increased requirements are specified for strength of the granules in order to increase the fraction of the wastes of non-fused flux in welding after separation.

There are not many works in the literature devoted to application of SC of agglomerated flux. In work [8] it was established that the agglomerated flux produced of SC reduces the weld alloying and, respectively, the strength properties, while its impact toughness depends on the specific conditions. Therefore, its application requires carrying out the control of quality of welded joints and technology of production of regenerated flux [9].

Our investigations [10] showed the possibility of using SC formed during multi-arc welding under the mixture of agglomerated aluminate-basic flux OR-132 and fused manganese-silicate flux AN-60 taken in ratio 1:4 in production of regenerated flux. Such flux had good forming properties in single-arc welding of low-carbon and low-alloy steels at speed up to 40 m/h. The mechanical properties of weld metal in welding using wire Sv-08G1NMA of 4 mm diameter were as follows: σ_y = 530.7 MPa; σ_t = 649.4 MPa; δ = 25.3 %;

Table 1. Chemical composition (wt.%) of weld metal in welding of steel 10G2FB under different fluxes using welding wire Sv-08G1NMA

Flux	Number of arcs	Number of weld	C	Si	Mn	Ni	Mo	Al	Nb	V	Ti	S	P
OK 10.74	1	401	0.084	0.50	1.71	0.25	0.28	0.028	N/D	0.060	0.010	N/D	N/D
OK 10.74	4	386	0.085	0.43	1.64	0.20	0.20	0.025	0.021	0.059	0.012	0.009	0.019
A	1	400	0.090	0.34	1.57	0.20	0.23	0.026	N/D	0.064	0.006	N/D	N/D
B	4	405	0.088	0.30	1.68	0.19	0.22	0.024	0.024	0.059	0.007	N/D	N/D
BM: 10G2FB steel			0.103	0.25	1.57	0.20	<0.01	0.030	0.030	0.081	0.013	0.005	0.013

Table 2. Physical properties of fluxes used

Flux	Flux granular size, mm	Bulk mass, kg/dm^3	Note
A	0.315–4.0	1.72	Predominance fraction 0.315–1.6 mm
B	0.2–4.0	1.26	Predominance fraction 0.2–1.6 mm
OK 10.74	0.2–1.6	1.02	–

ψ = 63.7 %; KCV_{-20} = 35.3–40.3/37.7, KCV_0 = 41.2–47.1/44.9 and KCV_{20} = 54.9–82.4/71.8 J/cm^2.

However, this flux was not suitable for high-speed multi-arc welding because of high bulk weight, which is the cause of weld defects formation. In addition, the level of impact toughness of weld metal does not satisfy the requirements for welded joints of cold-resistant steels.

The aim of this work is the analysis of possibility of using SC of agglomerated fluxes for production of fluxes, providing the quality formation of high mechanical properties of weld metal at high-speed multi-arc welding of cold-resistant low-alloyed steels.

Nowadays the pipe plants use agglomerated imported fluxes predominantly of aluminate-basic type according to the classification EN 760 of grades OR 132 (Oerlikon), OK 10.74 (ESAB), 995N, 998 (Lincoln) and others. Considering the high cost of these fluxes, the practical interest was represented by evaluation of possibility of producing the fluxes of SC formed during welding. As the object of investigations the SC of flux OK 10.74 was taken, formed in multi-arc welding of pipe steels using wire Sv-08G1NM A.

Below the procedure of work on production of regenerated flux is described. From the crushed SC of flux OK 10.74 two factions of 0.315–4 and ≤0.315 mm were selected.

Then, the thorough magnetic separation was carried out, as a result of which the drops of electrode metal and scale were removed from SC fractions of 0.315–4 mm. As a result the product was made corresponding to granulometric composition of fused flux of AN-60 grade. The similar technology was used in works [6, 7] in production of regenerated flux. Therefore, the material mentioned above we designated conditionally as a regenerated flux according to variant «A». Its bulk mass amounted to 1.72 kg/dm^3, which significantly exceeds recommended values of 0.9–1.2 kg/dm^3 in multi-arc welding. The grain of flux had size of 0.315–4 mm with a predominance of fraction of 0.315–1.6 mm size. It should be noted that this fraction is the most typical for a number of agglomerated and fused fluxes. Before welding the fluxes were calcinated at 400 °C for 2 h.

From the data on chemical composition of weld metal, produced under flux OK 10.74 (welds 386 and 401) and under regenerated flux according to and variant A (weld 400), it is seen that when using the regenerated flux the alloying of weld metal as to the number of elements is significantly reduced (Table 1),

Table 3. Modes of welding modes using wire Sv-08G1NMA of 4 mm diameter

Flux	Number of arcs	Number of weld	*I*/*U*, A/V	v_w, m/h	q/v_w, kJ/mm	*B*, mm
A	1	400	720–750/39–40	23.5	4.4	21
B	1	403	850–880/36–37	24.0	4.7	25
	1	402	820–850/38–39	24.0	4.8	27–28
B	1	405	1150/35–36	99.2	4.5	25
	2		800–850/35			
	3		650–700/38			
	4		700/38–40			
OK 10.74	1	401	820–830/37	23.5	4.7	30
OK 10.74	1	386	1150/33	98.0	4.5	25
	2		900/35			
	3		700/40			
	4		600/43			

Notes. Inter-electrode distance in four-arc welding amounted to 15–21 mm; q/v_w — energy input of welding process; *B* — weld width.

Figure 1. Appearance of welds produced using single- (*a*) and four-arc (*b*) process under flux B of the flux OK 10.74 SC (×1.5)

the most significant is the decrease in manganese content.

Considering the data obtained after magnetic separation and calcination, 5 % of metallic manganese of grade Mn-98 (fraction of 0.2–0.4 mm) was added to the milled SC of <0.315 mm fraction obtaining a uniform dry mixture in the intensive mixer. Then, based on Na–K liquid glass binder according to the known technology the batch of agglomerated flux was produced. Bulk mass of the produced flux, hereinafter designated as B, amounted to 1.26 kg/dm^3 (Table 2).

The fluxes were evaluated according to formation of deposits, as well as to the chemical composition and impact toughness of control welds produced on one-sided butt joints of steel 10G2FBYu of 19 mm thickness with V-shaped edge preparation of 5 mm×90°. The modes of single- and twin-arc welding using wire Sv-08G1NMA of 4 mm diameter are given in Table 3.

The process of welding under flux A was unstable with splashes and formation of high narrow ridge of SC. Produced weld 400 had a high reinforcement with non-smooth transition to the base metal and small undercuts. Such a weld formation is connected apparently with increased bulk mass of the flux (1.72 kg/dm^3).

In welding under flux B the process stability and quality of the formation of welds, produced using single- and four-arc welding, were satisfactory. The photos of welds are shown in Figure 1.

Weld 400 produced using single-arc process under regenerated flux A showed a rather high impact

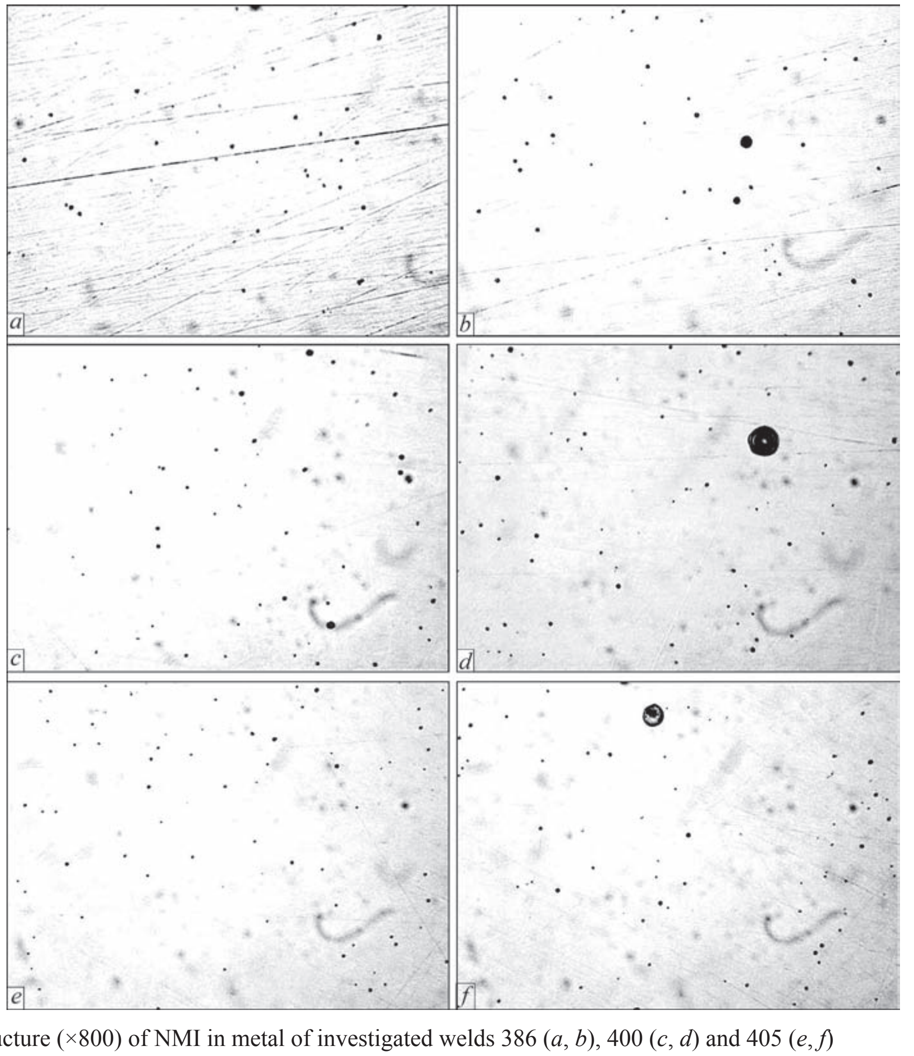

Figure 2. Microstructure (×800) of NMI in metal of investigated welds 386 (*a*, *b*), 400 (*c*, *d*) and 405 (*e*, *f*)

Table 4. Impact toughness of weld metal in welding of steel 10G2FB

Flux	Number of arcs	Number of weld	*KCV*, J/cm², at		
			–20 °C	–40 °C	–60 °C
OK 10.74	4	386	106.2–203.7 / 162.9	77.1–101.2 / 92.9	43.5–77.3 / 60.6
A	1	400	95.2–109.1 / 100.7	53.7–69.5 / 62.6	33.4–55.5 / 44.0
B	4	405	85.1–162.0 / 115.7	60.8–96.8 / 81.8	30.3–71.1 / 54.6

strength (KCV_{-40} = 62.6 J/cm²), but, as was mentioned, the weld had drawbacks as to its appearance.

Weld 405, produced using four-arc welding under agglomerated flux B, had satisfactory properties. According to chemical composition except of silicon it is close to weld 386, produced using four-arc welding with original flux OK 10.74 (see Table 1), and impact toughness (Table 4) is only slightly inferior to it. Average value for weld according to variant B (KCV_{-40} = 81.8 J/cm²) is quite acceptable. The possible reserve to provide higher impact toughness of welds at –40 °C, and lower is Ti–B alloying.

The morphology and features of distribution of nonmetallic inclusions (NMI) in the welds were investigated for not etched sections with the polished surface at magnification of 800. It was established that the NMI basic mass is located relatively uniform and represents small globular oxides of complex composition consisting of Mn, Al, Si, Ti, Ca, Fe in different ratios.

In weld 386, made under flux OK 10.74, size of the greater part of NMI is 1.0–1.2 μm (Figure 2, *a*). In some fields of view 1–2 larger inclusions of about 1.5 μm size are observed (Figure 2, *b*). In welding under the regenerated flux according to variant A (weld 400) the total number of NMI is slightly increased. Their size amounts mostly to 1.0–1.6 μm (Figure 2, *c*). At the same time, the number and size of large (more than 1.5 μm) inclusions with higher content of silicon (Figure 2, *d*) also increases.

In weld 405 produced under the agglomerated flux according to variant B, the number, distribution and sizes of NMI are close to weld 386 produced under original flux OK 10.74, while silicate inclusions observed in weld 400 are absent (Figure 2, *e*, *f*).

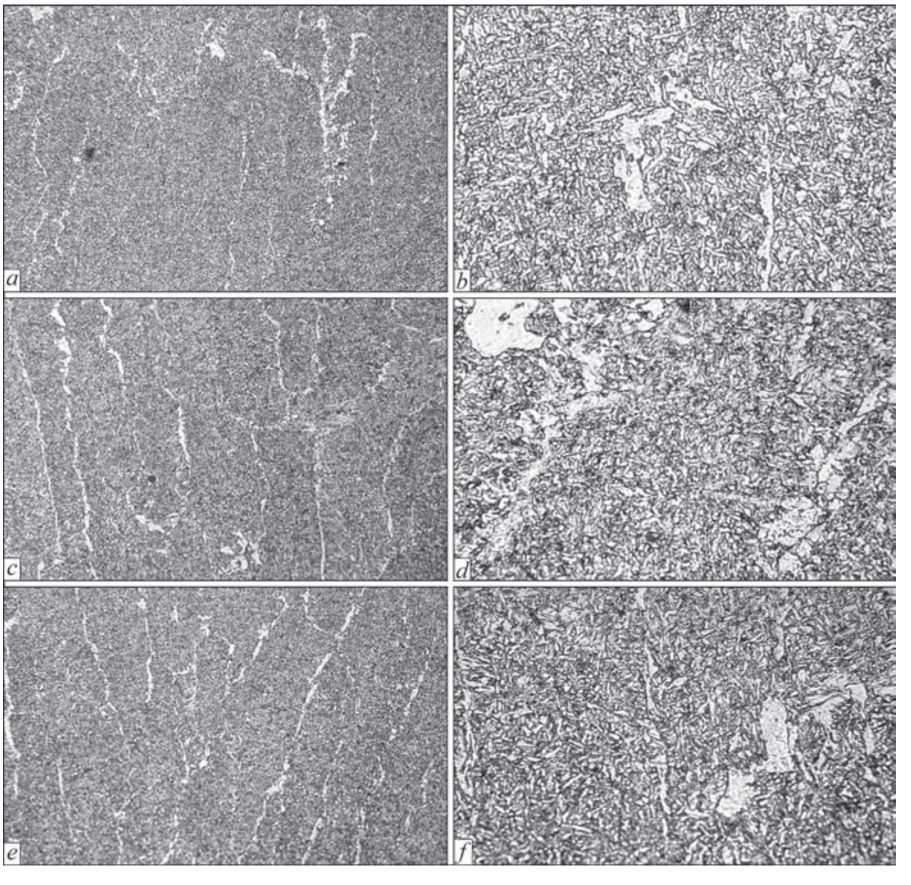

Figure 3. Microstructure of metal of investigated weld 386 (*a*, *b*), 400 (*c*, *d*) and 405 (*e*, *f*) (*a*, *c*, *e* — ×100; *b*, *d*, *f* — ×500)

The features of composition and morphology of structural components of welds were investigated on the sections after their etching in 4 % alcoholic solution of nitric acid at magnification of 100 and 500. The microstructure of welds consists of a mixture of different forms of ferrite in their different proportions. Thus, in weld 386 (flux OK 10.74) the main structural component is acicular ferrite. The share of grain boundary polygonal ferrite, evolved in the form of layers of width from 6 to 16 μm, or chains of separate grains does, not exceed 6 % (Figure 3, *a*, *b*). The single sections of intragranular polygonal ferrite are also observed, including the relatively large formations of massive ferrite with disordered MAC-phase (Figure 3, *b*), which is evolved also along the boundaries of the larger formations of grain boundary and intragranular polygonal ferrite.

In weld 400, produced under the regenerated flux according to variant A, the fraction of grain boundary polygonal ferrite is increased to 12 % (Figure 3, *c*). The sizes of formations of intragranular massive polygonal ferrite are also increased, and the width of layers of intergranular polygonal ferrite increases to 18–20 μm (Figure 3, *d*), due to which the number of MAC-phase clusters on their boundaries increases.

The microstructure of weld 405, produced under the agglomerated flux according to variant B, is close to the microstructure of weld 386 (flux OK 10.74). The fraction of grain boundary polygonal ferrite is slightly higher and amounts to 7–9 %, and the width of its layers does not exceed 18 μm (Figure 3, *e*, *f*). The dimensions of formations of massive intragranular ferrite with precipitation of MAC-phase slightly exceed the dimensions of this structural component in weld 386 (Figure 3, *f*).

The microhardness of investigated welds 386, 400 and 405 was approximately at the same level and amounted to *HV*5-227–230, *HV*5-219–221 and *HV*5-221–227, respectively.

Thus, the metallographic examination showed that the use of regenerated flux according to variant A produced of SC, as compared to the original flux, leads to deterioration of weld structure. At the same time, the weld structure, produced under agglomerated flux of the flux OK 10.74 SC with additional charging with 5 % of metallic manganese (variant B), is close to the structure of weld produced under the original flux according to all the investigated parameters.

Conclusions

The investigation of the possibility of using SC, formed in multi-arc welding under the agglomerated aluminate-basic flux, for production of welding fluxes was carried out. On the basis of the flux OK 10.74 SC the experimental fluxes were prepared according to the technology of regeneration (SC crushing followed by sieving and magnetic separation) and technology of agglomeration with additional charging with 5 % of metallic manganese.

A comparative investigation of welding and technological properties of original flux OK 10.74 and experimental fluxes in single- and four-arc welding was made. The chemical composition of weld metal, distribution of NMI in them, especially microstructure and indicators of impact toughness of weld metal were determined.

It was established that the flux, produced according to the method of agglomeration with addition of 5 wt.% of metallic manganese into the charge according to all of these indicators including the impact strength of weld metal, is close to original flux OK 10.74 and meets the requirements for welded joints of cold-resistant gas-pipeline steel up to strength category of X80 inclusively.

Application of flux produced from SC according to regeneration technology is accompanied by a certain reduction in the level of impact toughness of weld metal and some deterioration of the weld appearance original as compared to welding under flux OK 10.74. Therefore, a decision on the possibility of using regenerated flux in welding should be taken in each case taking into account the requirements for the quality of welded joints.

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