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Study of Welding Properties of Fused Weld Flux Produced by Electric Arc Granulation

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Abstract. The article outlines comparative analysis of surfacing under granulated flux cover produced using the developed technology and under AN-348 flux cover. Visual inspection, hardness tests, photoelectric spectral analysis, and studying of geometric characteristics of weld beads are carried out. The results of the comparative analysis and studying of welding properties of fused fluxes are comparable or in some cases identical, and in terms of geometric characteristics of weld beads, outperform the well-known analog of surfacing under flux cover.

1. Introduction

Modern market for arc welding materials offers a large range and variety for welding and surfacing of various metals and alloys. The main directions for increasing competitiveness and quality of welding materials are the development of new flux compositions and improvement of production technology [1-6].

At present, the authors of the article have developed a fundamentally new technology for production of welded fused fluxes using electric arc granulation technology[7], which lies in passing a fine-dispersed charge through a coal arc to fuse and then to solidify it, in a state of weightlessness during falling, into granules of a fused welding flux. However, the welding properties of flux produced using developed technology have not been studied yet and that does not allow fully positioning it as a welding material.

In this connection, the aim of the work is to study the welding properties of a fused welding flux produced using electric arc granulation, namely, mechanical properties, visual inspection results, chemical composition and obtaining the required geometric characteristics of weld beads produced using granulated flux.

2. Experiments

To achieve this goal, a comparative surfacing (figure 1) was carried out under granulated flux cover produced using the developed technology and under AN-348 flux cover (a common Ukrainian welding fused flux widely used by Russian machine-building enterprises and defense industry) in two modes: welding current $I = 550$ A (mode 1) and 400 A (mode 2), welding voltage $U = 34$ V, welding speed $V = 55$ cm/min, diameter of the wire Sv-08G2S 4 mm, material - Steel grade 20 with plate thickness of 12



mm [8]. The only difference in the comparative analysis apart from production method is the different type of flux, AN-348 has manganese-silicate base MS ($\text{CaO} + \text{MgO}\%$, 19, $\text{Al}_2\text{O}_3 + \text{MnO}\%$, 47.5, $\text{SiO}_2 + \text{MnO}\%$, 76), while the granulated flux has silicate base ($\text{CaO} + \text{MgO}\%$, 19, $\text{Al}_2\text{O}_3 + \text{SiO}_2\%$, 57.5). Granulated flux is produced from hornblendite of Pervouralsk deposit in Ural region as its slag base has shown good efficiency in submerged arc welding [9, 10].

Weld beads obtained from the control surfacing were prepared as samples for studying its geometric characteristics, chemical analysis and hardness tests. The numbering of the prepared samples is shown in table 1.

Table 1. Studied sample lot.

Sample №	Flux	Surfacing mode			Study type
		I (A)	U (V)	V (cm/min)	
111	Granulated flux	400	34	55	geometric characteristics of weld beads
211	AN 348	400	34	55	geometric characteristics of weld beads
121	Granulated flux	550	34	55	geometric characteristics of weld beads
221	AN 348	550	34	55	geometric characteristics of weld beads
112	Granulated flux	400	34	55	chemical analysis and hardness
212	AN 348	400	34	55	chemical analysis and hardness
122	Granulated flux	550	34	55	chemical analysis and hardness
222	AN 348	550	34	55	chemical analysis and hardness

Note: Flux: 1. Granulated flux; 2. AN 348;

Modes: 1. 400 A, 34 V, 55 cm/min; 2. 550 A, 34 V, 55 cm/min;

Study type: 1. geometric characteristics of weld beads (end face); 2. chemical analysis and hardness (weld bead is taken off evenly to base metal).

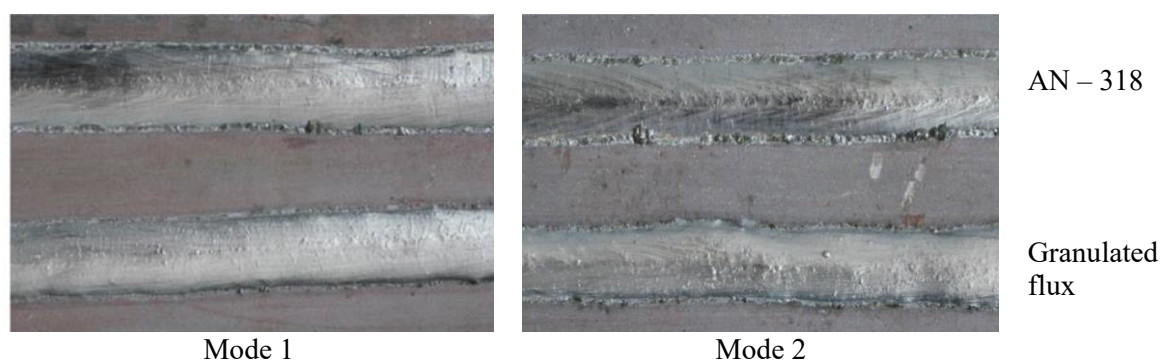


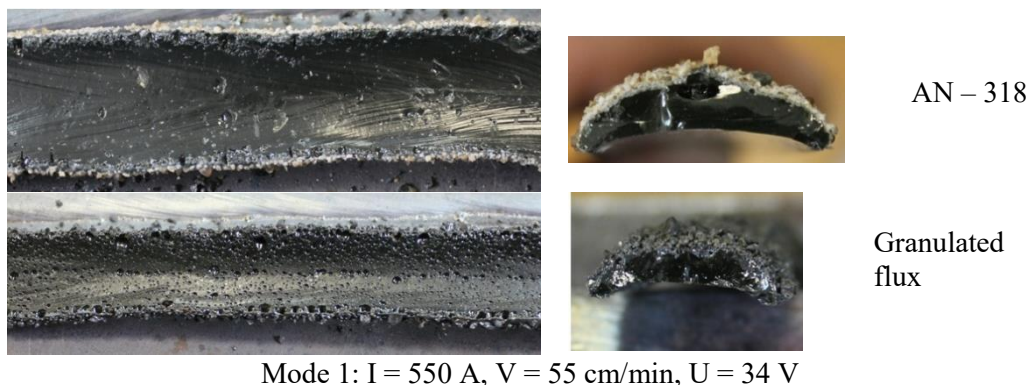
Figure 1. Comparative surfacing with visual inspection, carried out under granulated and AN-348 flux cover.

During visual inspection of weld beads it was established that AN-348 flux and granulated flux produced using the developed technology have equally satisfactory properties of beads formation, separation of slag crust after surfacing, absence of external pores and cracks; at the same time weld beads deposited under granulated flux cover have smaller ripple (table2).

Comparing AN-348 and granulated flux produced using the developed technology slag crusts, it is seen (figure 2) that they have similar density, but granulated flux slag crust has greater porosity, which may indicate a better passing of gases from the weld metal to the slag and promote better slag crust reparability [11].

Table 2. The main parameters of welding properties of granulated flux in accordance with the guidance documents 03-613-03 [12].

Test parameter	Score (1-5)	Parameter brief description
Arc starting	5	Easy. Starting right after touching of electrode and work piece
Arc stability	4	Good. Evenly burning arc with a slight vibration and crunchy noise (sputtering)
Weld formation quality	4	Good. The bead is finely scaly with a few small irregularities in height and small exceedings along weld edges.
Slag crust separability	5	High. Separates after welding without additional mechanical action

**Figure 2.** Inner surface of granulated flux and AN-348 flux slag crusts.

2.1. A photoelectric spectral analysis of deposited metal.

Photoelectric spectral method was used to determine the percentage mass fraction of elements in weld beads metal. Photoelectric spectral analysis was performed using Oxford Instruments PMI-Master Pro spectrometer. In this case, bulging of weld beads was milled flush with base metal. Three measurements for each sample were made on the flat area formed after milling and then the average value was found.

Data on chemical composition of the metal was received by means of photoelectric spectral analysis of beads deposited under a granulated flux, as well as under AN-348 flux, that is shown in table 3.

The metal deposited under the AN-348 has a decrease in C and an increase in Mn, whereas a metal deposited under granulated flux has an increase in Si and an insignificant increase in Cr and Cu. No other changes in other elements are observed.

Table 3. Results of photoelectric spectral analysis of deposited metal.

Studied metal	Chemical composition [mass%]									
	Fe	C	Si	Mn	P	S	Cr	Mo	Ni	Cu
Base metal	98.3	0.159	0.196	0.500	<0.005	<0.003	0.084	0.040	0.310	0.244
Bead metal (Sample 112)	98.2	0.151	0.471	0.307	<0.005	<0.003	0.133	0.029	0.241	0.355
Bead metal (Sample 212)	98.0	0.119	0.282	0.940	<0.005	<0.003	0.0621	0.027	0.232	0.228
Bead metal (Sample 122)	98.1	0.152	0.503	0.350	<0.005	<0.003	0.125	0.032	0.260	0.346
Bead metal (Sample 222)	98.0	0.116	0.278	0.928	<0.005	<0.003	0.063	0.030	0.242	0.228

The increase in Mn or Si is determined by the type of the flux. It is evident that due to the increased content of manganese oxide in AN-348 flux composition (type MS), its content is also increased in deposited metal. Similarly, with silicate-based granulated flux, the deposited metal produced under this flux has increased Si content. It is found that the chemical analysis of the metal deposited under the

granulated flux in terms of harmful impurities content presents low S (<0.003 mass%) and P (<0.005% by weight) content. This corresponds to the results obtained during welding under the widespread analog fused welding flux AN-348, which indicates the purity of weld metal.

2.2. The hardness of weld beads.

Measuring the hardness of beads fused under a granulated flux, as well as under an AN-348 flux was carried out using Brinell method, received data on weld metal is shown in table 4.

Table 4. The main parameters of welding properties of granulated flux in accordance with the guidance documents 03-613-03 [12].

Studied metal	HB1	HB2	HB3	HB _{average}
Base metal	143	156	143	147.3
Bead metal(Sample 112)	187	196	196	193
Bead metal(Sample 212)	163	170	163	165.3
Bead metal(Sample 122)	187	179	170	178.6
Bead metal(Sample 222)	143	156	146	148.3

The beads produced during surfacing under granulated flux have an increased hardness compared to the base metal, which may result from: an increased Si or Cr content; C content close to the base metal; change in the structure of weld metal; presence of nonmetallic inclusions in weld metal; increased stress in the weld bead.

Bead metal produced from surfacing under AN-348 flux has hardness close in value to hardness of the base metal. The reason for this can be a reduced carbon content in the weld metal of weld beads compared to content of carbon in the base metal, which significantly reduces its hardness, despite welding stress, leading to a significant increase in hardness of weld beads compared to hardness of the base metal.

2.3. Geometric characteristics of weld beads.

Studying geometric characteristics of weld beads was carried out using Olympus SZX16 microscope and the Olympus Stream Motion1.8 program that allows calculating of sectional area of the bead when tracing its contour. Before studying geometric characteristics, micro polished sections of the samples were etched by rubbing with a 4% alcohol solution of nitric acid.

An example of images of micro polished sections with dimensions obtained in Olympus Stream Motion1.8 program is shown in figure 3. The results of geometric characteristics measurements of the samples are given in table 5.

Table 5. The main parameters of welding properties of granulated flux in accordance with the guidance documents 03-613-03 [12].

Measurement place	Sample 111	Sample 211	Sample 121	Sample 221
Area (mm ²)	57.96	59.81	103.62	98.15
Fusion depth (mm)	4.24	4.41	7.20	5.95
Bead width (mm)	13.33	13.58	16.44	17.19
HAZ (mm)	1.60	1.24	3.12	2.46

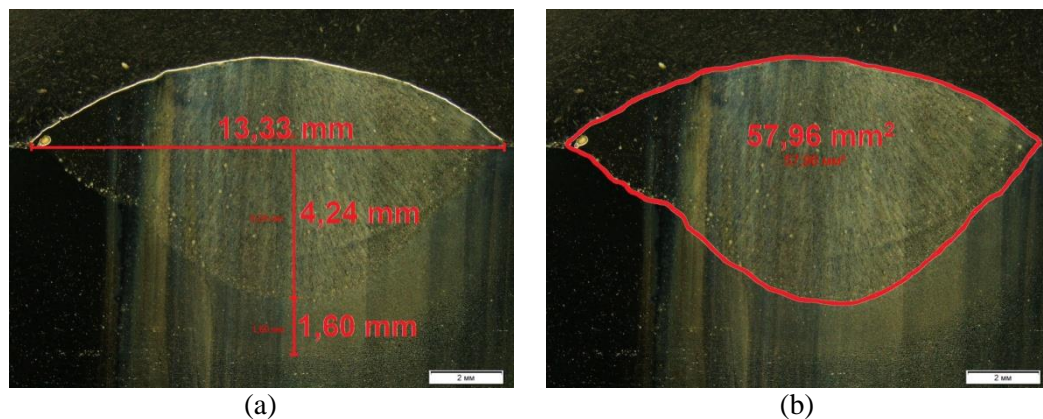


Figure 3. Geometric parameters of sample 111.(a)bead width, fusion depth, HAZ.(b)area of weld bead.

Analysis of geometric characteristics of the samples makes it possible to make the following observations:

- During surfacing under current of value $I = 400\text{A}$, geometric characteristics of the beads deposited under granulated flux and under AN-348 flux practically do not differ. Current of value $I = 400\text{ A}$ is relatively small for selected welding speeds for chosen wire diameter and welding method;
- During surfacing under current of value $I = 550\text{ A}$, beads welded under the granulated flux have an 22% greater fusion depth and 5% smaller width than beads welded under AN-348 flux. It enables to draw a conclusion about better technological properties of granulated flux in comparison with AN-348, since it is possible to obtain a penetration in lower modes and, therefore, lower thermal effect on the base metal;
- bead width and HAZ welded under granulated flux cover is 19.52 mm, which is practically equal to the width value of beads and HAZ welded under the AN-348, that amounts 19.65 mm. Consequently, the width of the zone with a modified structure during surfacing under either flux is practically the same.

3. Conclusion

According to welding and geometric characteristics, chemical composition and hardness of weld beads, deposited under granulated flux comply with quality to those deposited under widespread fused welding flux widely used by Russian machine-building enterprises and defense industry. However, there is a significant decrease in welding properties of granulated flux when using it at relatively low current. Therefore, there is a need to research for optimal welding modes under granulated flux that allows producing high-quality welding and welded joints.

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