Capability enhancement of production of activating fluxes for arc welding using ultradispersed products of silicon waste processing

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Abstract. Experimental results on welding with the help of activating flux are presented. It includes nanosilica obtained from metallurgical wastes. As a result of the use of the developed composition of the activating flux, melting capacity of the welding arc increased by 1.5-3 times, energy intensity of the process decreased by 30-50%.

1. Introduction
To achieve an increase in welding productivity the melting capacity of the arc by reducing the diameter of the electrode wire (increasing the current density and, as a consequence, melting rate of metal increases) [1], or using activating fluxes (activation of the arc-A TIG welding) [2-10].

2. Equipment and materials
To conduct researches, a DC welding arc of direct polarity with a current strength of 70-400 A, burned vertically between a non-consumable tungsten electrode (2.4-4 mm in diameter) and a metal surface in an argon shielding gas (TIG welding). Welding experiments were performed on plates with dimensions of 150*50*(2.4.6) mm from low-carbon steel 3. Before A-TIG welding, a uniform controlled layer of activating flux (SiO₂-silicon dioxide) with a width of 5 mm and a thickness of 20 μm was applied.

For the production of the activating flux, gas cleaning dust of the electrothermal silicon production was used. Dust contained components in the following ratio, %: SiO₂ 75÷95, SiC 4.0÷11.0, C_free 3.0÷7.0, MgO 0.4÷1.2, Al₂O₃ 0.5÷1.0, Fe₂O₃ 0.3÷0.9, CaO 1.0÷2.0, rest 0.8÷2.3.

Several activating granulometric compositions of the charge (table 1) were prepared for the study. The first composition had a particle size of 150-300 μm (macro silica) [2-10].

3. Results and discussion
Figure 1 shows the results of photographing the welding process without activating flux (figure 1, a) and with the activating flux of figure 1, b. Photographing the process shows that the front and tail parts of the welding pool surface at A-TIG welding with an activating flux have a shape with a clearly defined characteristic depression (cup) near the center of the crater (see figure 1, b). Such a significant depression is not observed at TIG welding without the activating flux (figure 1, a). On the contrary, we see a plain surface of the liquid pool in the area of the heating spot. With increase of the arc current...
during welding with activating fluxes, the depth of this cup increases using all the investigated thicknesses of the samples.

| Properties                      | Activating flux | Macroparticles SiO₂ | Microparticles SiO₂ | Nanoparticles SiO₂ |
|---------------------------------|-----------------|----------------------|---------------------|--------------------|
| Particle size                   |                 | 200-300, μm          | 30-70, μm           | 40-80, nm          |
| Bulk density (g/cm³)            |                 | 2.64                 | 2.42                | 2.10               |

**Figure 1.** Change in the structure of the welding arc during argon-arc welding of plates of steel 3 with a thickness of 4 mm. a – without flux; b, c – with the activating flux – SiO₂. DC power of direct polarity – 100 A. Arc length – 2 mm. Welding speed – 14 cm/min.

When the flux is melting, a screening slag phase is formed on the surface of the weld pool (figure 1, b) with low electrical conductivity, which reduces the surface tension of the molten metal and increases the deflection of the weld pool. Figure 2 shows the oscillograms which show an increase in the voltage during the welding with an activating flux at equal current values. These results indicate an increase in the effective thermal power of the welding arc during the welding with the use of an activating flux.

**Figure 2.** Oscillograms of current and voltage of the welding arc: a – without flux; b – with flux.
According to the thermal power, welding arc in argon with an activating flux approaches to the welding arc in a mixture of gases, but surpasses it by its melting capacity. The increase of the melting capacity of the arc during the welding with an activating flux changes the conditions for the formation of welds. The welds are formed narrow and deep, wedge-shaped (figure 3).

**Figure 3.** Cross section of the weld penetration zone during the welding in argon and current strength 80A Arc length 2 mm. Welding speed 18 cm/min. (a) without activating flux, (b) with activating flux (nanosilica), binder - ethyl alcohol, (c) with an activating flux (nanosilica), binder - heat-resistant varnish.

During the experiments it was established (figure 4) that the particle size of the activating flux plays a significant role in the melting capacity of the welding arc. All three studied compositions of activating fluxes show a positive effect on the melting capacity of the welding arc. Compared with macro and micro particles of SiO2, the SiO2 nanoparticle has a greater effect in melting capacity during the welding with an activating flux (figure 4, c). In the regime of arc heating and evaporation, thermal dissociation and decomposition of nanoparticles of silicone dioxide SiO2 occur much faster than thermal dissociation and decomposition of microparticles of silicone dioxide SiO2.

**Figure 4.** Cross section of the weld penetration zone during the welding in argon and current strength 90A Arc length 2 mm. Welding speed 25 cm/min. (a) activating flux (macrosilica) binder - heat-resistant varnish; (b) activating flux (microsilica); binder - heat-resistant varnish; (c) activating flux (nanosilica) binder - heat-resistant varnish.

As a result, nanoparticles of silicon dioxide SiO2 have a great influence on the arc melting properties during the welding in comparison with microparticles of silicon dioxide SiO2, which causes an increase in the weld penetration depth by 50-70%. Figure 5 shows the summarizing results of the positive effect of using an activating flux in welding low-carbon steel in argon service as compared to welding without an activating flux, both in argon and in a mixture of gases service (argon + helium). The positive effect of using an activating flux at high currents and with increasing thickness of the metal appeared considerably. From the standpoint of welding technology, we see (figure 5) that for welding metal with a thickness of 2.4 mm using an activating flux, it is possible to significantly reduce the electric power of the welding arc. The values obtained in figure 5 are in good qualitative
relationship with the results of the work of other authors who considered activating fluxes where the main component was metal oxides.

Figure 5. Experimental dependences of the depth of weld penetration of steel 3 of different thicknesses from the strength of the welding current at different welding regimes (welding in argon, in a mixture of gases, in argon with an activating flux).

4. Conclusions
1. The technology of obtaining the target final product of the activating flux for welding from secondary raw materials - wastes of metallurgical production
2. Compared with the traditional method, the use of activating fluxes provides a reduction in heat input for single-pass welding of metal of equal thickness up to 3-5 times in comparison with the traditional method.
3. It is shown that in the mode of arc welding heating, evaporation, thermal dissociation and decomposition of nanoparticles of silicone dioxide SiO2 occur much faster than thermal dissociation and decomposition of microparticles of silicone dioxide SiO2. This leads to the maximum melting capacity of the welding arc by increasing the effective thermal power of the welding heat source.
4. The use of an activating flux which has in its composition nano particles of silicon dioxide SiO2 during the welding in shielding gases, allows to increase the arc melting capacity by 2-4 times and increase the productivity of welding at low currents.

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