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Use of Complex Nanopowder (Al_2O_3, Si, Ni, Ti, W) in Production of Electrodes for Manual Arc Welding

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Abstract: One of the most essential characteristics of a weld is its strength. The mechanical properties of weld metal can be enhanced in a number of ways.One of them is to include nanopowder into weld metal. In this article, it is offered to add nanopowder to the components of a welding electrode through liquid glass at the stage of its production. This will help to enhance the arc stability and increase the strength of a weld joint, which will in its turn have a positive effect both on the quality of the weld joint and on the safety of the construction in general. There is not much information published on to the use of nanostructured materials in the welding production. However, for the recent years the research in using nanopowders in the welding industry has increased.

Key words: Nanopowder · Welding electrode · Liquid glass · Weld metal and fusion welding

INTRODUCTION

The beginning of the 21st century was marked by a revolutionary leap in the development of nanotechnologies and nanomaterials. They have already been used by all developed countries worldwide in the most significant human activities (industry, defense, IT, radio electronics, power engineering, transport, biotechnologies and medicine) in the production of ceramic and composite materials, superconductors, solar batteries, lubricant additives, coloring and magnetic pigments, components of low temperature high-strength solders, etc [1].

So, nanopowders are powders with characteristic nanosizes causing sharp changes of their properties [2].

In the welding industry, nanopowders are used to obtain a fine-grained structure of weld metal; and when crystallized these additives ensure grain refinement and in the end improve the mechanical properties practically without changing the chemical composition of the alloy [7]. Using nanostructured materials to stabilize the arc discharge in fusion welding has prospects as well.

For the last 3-5 years, there has been a tendency on the Russian market, as well as on the world market in general, to reduce the share of welding electrodes in the total amount of metal welding means used. Such tendency is related to an increased share of welding with welding wires, wolfram and contact welding as more efficient and qualitative. At the same time, due to an increasing demand for weld joints caused by a dynamic development of the construction industry, military and industrial complex, railways and oil and gas complex, the need for welding electrodes grows by 10–15 per cent every year in absolute terms. The share of welding electrodes in the overall production of welding materials amounts to some 20% [3].

The key advantage of using welding electrodes as compared to other welding materials and methods, in particular, powder wire and welding in shielding gases, is a low cost of equipment, a possibility of application in hard-to-reach places, when installing in field conditions, etc.

Adding of Nanopowder to Liquid Glass: One of the ways to enhance the mechanical properties of weld metal is applying nanodisperse materials (nanopowders).There are a number of methods of adding nanopowder to a weld pool, but the most effective one is to add nanopowder to liquid glass, that is at the stage of electrode production.

This method implies the following: complex nanopowder (Al_2O_3, Si, Ni, Ti, W) is added to liquid glass with the module of 3.13, the viscosity of 0.604 Pa*s and the density of 1.43 g/cm³ in the amount of 1.0% to the mass of liquid glass (Table 1).

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Table 1: Quality indicators of potassium and sodium glass

No.	Indicator	Serial	Experimental
1.	Module	3.13	3.20
2.	Viscosity (Pa*s)	0.604	0.292
3.	Density (g/cm³)	1.43	1.43

Nanopowder is introduced into the liquid glass on a cavitation mechanical activation unit for 2 minutes at 30–35°C.

According to Christopher Brennen: "When liquid is exposed to pressure below the threshold pressure (tensile stress), the integrity of its flow is infringed and vapor cavities are created. This phenomenon is called cavitation. When local liquid pressure in a certain point drops below the value corresponding to the saturation pressure at the given ambient temperature, liquid turns into another condition forming phase cavities called cavitation bubbles" [4].

Thus, when liquid glass and nanopowder pass through the cavitation mechanical activation unit, nanoparticles are "nailed" in the emerging bubbles, that is the nanopowder is evenly distributed throughout the whole volume of liquid glass.

As shown in Table 1, adding of nanopowder to liquid glass by way of cavitation reduced the glass viscosity two-fold.

Peculiarities of Using Liquid Glass: The silica module of liquid glass may be expressed through molar or mass (weight) content of the main components – SiO_2 and M_2O – in the system:

$$n = \frac{SiO_2^m\%}{M_2O^m\%};$$

$$n_w = \frac{SiO_2^w\%}{M_2O^w\%} \text{ [5]}$$

where n and n_W are molar and weight modules respectively;

$SiO_2^m\%$ and $M_2O^m\%$ mean the content of SiO_2 and alkali metal oxide, mole %;

$SiO_2^w\%$ and $M_2O^w\%$ mean the content of SiO_2 and alkali metal oxide, mole %.

The correlation between the weight and molar silica modules is expressed by the formula:

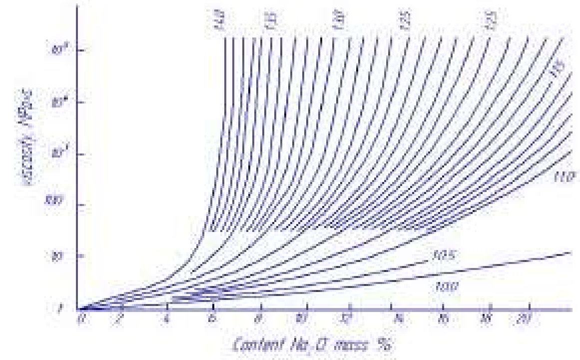

Fig. 1: Viscosity of sodium silicate solutions depending on the module and concentration at 20°C. [8]

$$n = n_w \cdot k,$$

where $k = \frac{M_{M_2O}}{M_{SiO_2}}$ [5].

Here M_{SiO2} and M_{M2O} are molar masses of SiO_2 and alkali oxide, g/mole. The k ratio is 1.032 and 1.568 respectively for the sodium and potassium systems [6].

It should be noted that in Russia the molar module is used more often, while the weight one is used abroad. The concentration of water alkali-silicate system (liquid glass) usually refers to the aggregate content of the main oxides SiO_2 and M_2O expressed in mass fractions and mass per cents.

The content of the main oxides in commercial sodium liquid glass varies approximately within the following range: SiO_2: 30–33, Na_2O: 10–13 mass %. The content of impurity oxides Al_2O_3+Fe_2O_3 does not exceed 0.25–0.4, CaO: 0.2–0.25 mass % [7].

Density and viscosity depend on the composition of liquid glass. Moreover, viscosity depends to a great extent on the solution temperature, impurities, way of generation, age and other secondary factors.

With increasing concentration of the solution, the viscosity grows not linearly (Fig.1). After reaching certain concentration values, the solution becomes so viscous that it is hard to use. For liquid glass with a 3 to 3.3 module, the threshold concentration value is about 40–45 mass % (10 mass % of Na_2O).

Often instead of concentration density is used which is a function of concentration, silica module and type of cation. In practice, it is quicker and easier to measure the solution density with sufficient accuracy than to determine its concentration.If you know the silica module and density, you can calculate the concentration using

Table 2: Mechanical properties of weld mental

MP3 electrodes of Ø4.0mm	$\sigma_{str.}$ (N/mm²)	δ (%)	KCU, at 20°C (J/cm²)
Serial	460	25	159
Experimental	492	28	192
GOST 9467-75 requirements	minimum		
	450	20	80

Table 3: Chemical composition of weld material

	Mass fraction of elements (%)				
MP3 electrodes of Ø4.0mm	C	Si	Mn	S	P
Serial	0.07	0.03	0.47	0.025	0.046
Experimental	0.07	0.5	0.61	0.025	0.044
GOST 9467-75 requirements	–	–	–	maximum	
				0.040	0.045

Table 4: Chemical composition of weld material welded with Omnia 46 electrodes from Lincoln Electric, %[9]

C	Mn	Si
0.06	0.5	0.45

Table 5: Mechanical properties of weld material welded with Omnia 46 electrodes from Lincoln Electric, % [9]

	Standards	$\sigma_{str.}$(N/mm²)	δ(%)	KCU, at 20°C (J/cm²)
Requirements	AWS A5.1	414	17	–
	EN ISO 2560-A	470	20	47
	GOST 9467-75	450	22	172
Typical values		480	26	60

special nomograms [8] and formulas and vice versa. Generally, the density of industrial liquid glass varies from 1.3 to 1.5 g/cm³.

Production of Welding Electrodes Using Nanopowder: To determine the possibility of using nanopowders in the production of welding electrodes (to enhance the quality characteristics of electrodes, first of all the welding and process features and mechanical properties of weld metal), MP3 electrodes of Ø4.0 mm were produced. It should be noted that less liquid glass was consumed than with the standard technology (22 kg of glass per 100 kg of dry batch against 24.5 kg of glass per 100 kg of batch in serial production, which is a 12% reduction in liquid glass consumption).

The mechanical properties of weld metal and the chemical composition of weld material welded using electrodes with nanopowder are provided in Tables 2 and 3.

As shown in Tables 2 and 3, the mechanical properties of weld metal and the chemical composition of weld material meet the requirements of GOST 9467-75.

It was determined that the structure of weld metal welded with experimental electrodes is more disperse and homogenous than the uneven structure of metal welded with serial electrodes.

The mechanical properties of weld metal and the chemical composition of weld material welded with Omnia 46 electrodes from Lincoln Electric are provided in Tables 4 and 5.

If we compare the obtained values of electrodes produced using complex nanopowder and Omnia 46 electrodes from Lincoln, we can see that the electrodes made using nanopowder have better indicators than similar electrodes from Lincoln. Namely: relative extension, ultimate strength, impact viscosity and higher content of deoxidizers (silicon and manganese) in electrode coating.

CONCLUSION

In today's world, nanopowders have already been used in such sectors as information technologies, chemical industry, medicine and pharmacology, material science, electronics and welding production. However, the welding production area is still new, therefore the publications in the field are not as numerous as can be expected.

The foregoing method of adding nanostructured materials to a weld pool is the most efficient and rational, due to no loss of nanopowder when introducing it into a weld pool and in view of significantly enhanced mechanical properties of weld metal and improved microstructure of a weld joint.

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