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INCREMENTO DE LAS PROPIEDADES OPERACIONALES EN RECUBRIMIENTOS POR SOLDADURA Y PLASMA MEDIANTE NANOPOLVOS

INCREASE OF THE OPERATIONAL PROPERTIES OF WELD AND PLASMA COATINGS USING NANOPOWDERS

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RESUMEN

En este trabajo se realizan estudios referentes a la determinación del efecto de nanopartículas de óxidos sobre la estructura y el desempeño de recubrimientos por soldadura y plasma. Se determinan las formas de introducir polvos refractarios nano dispersos en el baño de soldadura y como cubrirlo con polvos de nanopartículas desactivados. Los estudios estructurales de las soldaduras con adición de nano-óxidos en el baño de soldadura muestran la formación de una estructura dispersa con una microdureza desde 264 hasta 304 MPa. Se definen los valores medios de la cantidad de inclusiones no metálicas. Los ensayos mecánicos realizados a las soldaduras mostraron crecimiento de la tensión de rotura cuando son utilizados nano-óxidos de titanio y aluminio en el baño de soldadura. El efecto más significativo de estos parámetros con nano-óxidos de aluminio en una cantidad de 0,5 vol.% es el incremento de la tensión de fluencia en un 49 % y la tensión de rotura en un 23 %. La dureza es en su mayor parte afectada por el óxido de titanio en una cantidad de 1 vol.%., aumentando este valor aproximadamente 2 veces. A su vez, la introducción de nano polvo de la alúmina en los recubrimientos por plasma en cantidad de 1,5 vol.% muestran una reducción de la fricción e incrementa la resistencia de desgaste de los recubrimientos de 2 a 3 veces.

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Esto por supuesto se traduce en un ahorro de recursos no solo energéticos, disminuyendo el impacto ambiental.

Palabras clave: Soldadura, recubrimiento por plasma, nanopolvos

ABSTRACT

In this work, studies concerning determination of the oxide nanoparticles effect on structure and performance of the welds and plasma coatings were conducted. Ways of introducing nanodisperse refractory powders to the weld pool and how to cover with the deactivation of nanoparticles powder were determined. Introducing of the nanoparticles in the molten pool during the deposition and the coating was carried out by preparing a powder mixture by mechano-chemical processing in special high-energy intensive planetary mills. Structural studies of welds with nanooxides additives in the weld pool showed the formation of milled dispersed structure with microhardness 264-304 MPa. Statistical mean value of the number of non-metallic inclusions was defined. Mechanical testing of welds showed growth of the yield as well as tensile strength, when titanium and aluminum nanooxides were introduced into the weld pool. The most significant effect on these parameters has aluminum nanooxide in an amount of 0.5 vol.%, increasing the yield strength by 49 % and the tensile strength by 23 %. The toughness is mostly affected by titanium oxide in an amount of 1 vol.%., increasing its value by about 2 times. In turn, the introduction of alumina nanopowder in quantity 1,5 vol.% into the plasma coatings allowed to reduce friction and increase wear resistance of coatings by 2-3 times.

Key words: Welding, Plasma Coating, Nanopowders.

1. INTRODUCTION

The use of different welding techniques and the application of protective coatings is an integral component in the shipbuilding and ship repair. One effective way of controlling the structure, the increase of the welds' operational properties, weld and sprayed coatings are considered as an introduction to the matrix additives nanocomponents. Among the most promising, for the practical application, are the types of nano-oxides carbides, nitrides, which are offered by companies in a wide range. Depending on the type of nanoparticle morphology, size and introduction method in the material of weld or coating, may be produced composite materials with desired properties.

One of the major problems of the use of nanopowders in welding is the selection of types of refractory compounds and methods for their introduction into the weld pool. For example, (Cherepanov et al., 2009) studied the laser welding process nanopowder inoculators TiN, TiS, Y_2O_3, which are applied as slurry to the surface of the plate before welding. Sokolov (2011) presents a method of welding with the introduction of the microgranules nickel containing nanosized particles monocarbide tungsten in a coating of welding electrodes. In the work Parshin (2011), welding was also performed using consumable electrode with a composite coating that contains particles of the nanopowder with the additional protection of the welding pool by gas environment.

Author of the work Golovko (2011), injected nanoparticles into the welding pool through the cored wire in FCAW or placed (flux cored wire cuts) in the groove. Improvement of the arc properties, increasing of welding process productivity and enhancement of physical-mechanical properties of the welds are the results of such technologies usage.

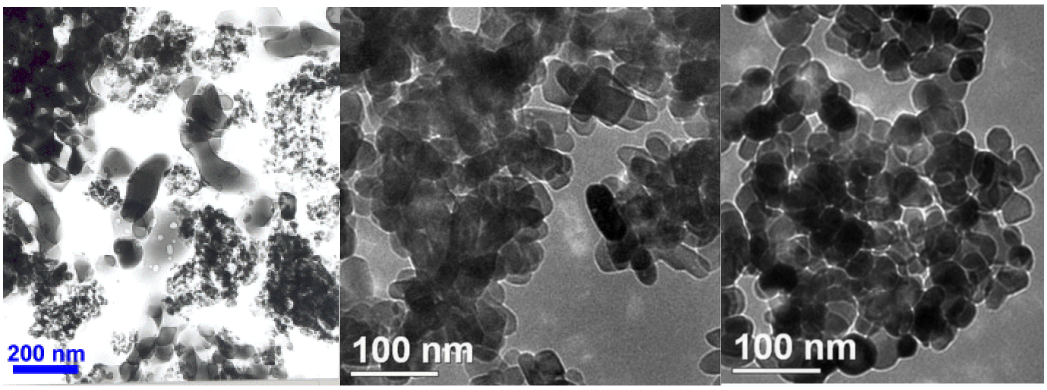
The current state of research in the field of thermal coatings using nanopowders is presented by Berndt (2001) and Levashov (2002). The main advantage of this approach is the possibility of applying thin wear-resistant composite coatings with improved tribological properties. According to the criteria of durability, score resistance and anti-friction resistance of nanostructured thermal coatings are more effective than solid electrolytic chromium plating, and economic performance in serial production and environmental compatibility (Smirnov et al., 2004). Thus, the main trends and prospects in the development of new welding and plasma powder materials and coatings are present in the estimation of most researchers, associated with the introduction of their composition nanoparticles.

The objective of this work was to study the influence of oxide nanoparticles on structure and performance of the welds and plasma coatings.

2. MATERIALS AND METHODS

To achieve this goal, it has been analyzed possible methods for the introduction of nano-dispersed refractory powders to the weld pool and cover with the fact that when passing through the high temperature zone of the plasma arc can occur deactivation of nanoparticle powder. To maintain activity, the nanoparticles must be attached to the microparticles, which can be made using mechanochemical processing of the powder mixture, in special high-energy intensive planetary mills. Mechanical energy, which is transferred to the powder in such processing, facilitates the formation of strong chemical bonds between the macro and nanoparticles. After treatment, the powder was pressed and sintered in the form of rods of a certain diameter and length, which are laid next to the edge to development before welding. Thus, during the welding process, nanopowder particles do not pass through the arc and fall into the weld pool without the high temperature exposure.

As nanopowders used oxides Al_2O_3, TiO_2, ZrO_2 fraction of 50 nm obtained cryochemical method (Figure 1). The main advantages of this method is the possibility of granular materials with strictly controlled particle size and a high degree of chemical homogeneity; obtaining powders with a high specific surface area and hydrophobic chemicals and materials with high stability in long-term storage.



a b c

Figure 1. Appearance of nanoparticles: a - Al_2O_3, b – TiO_2, c – ZrO_2

Preparation of a homogeneous powder mixture of macro- and nanoparticles for plasma spraying was carried out using as mechanochemical treatment in a planetary ball mill with optional evacuation of the working tanks. Nanoparticles of alumina and vacuum transferred to mechanochemical processing in the activated state and attached to particles of other elements forming a physical connection between the components of the coating.

The welding process is carried out using the welding set AD-231 and semiautomatic KP010-3 in a gas mixture of 72 % Ar + 28 % CO_2. Welding conditions: current I = 170-180 A, arc voltage U = 25-27 V, welding speed V = 12.5 m/h, the gas flow rate of 8-9 l/min.

3. RESULTS AND DISCUSSIONS

The results showed that in the initial conditions without adding nanooxides, in the weld metal was formed structure, the main component of which is polygonal, acicular and plate ferrite with disordered phases. A feature of this structure is the presence of large formations rugged plate-like predominantly acicular ferrite (IF) at the grain boundaries. Microhardness components varies accordingly from 145 to 187 MPa.

Introduction of the ZrO_2 nanopowders formed dispersed structure of acicular ferrite and ferrite with secondary disordered phases. Microhardness components varies accordingly from 189 to 202 MPa, Kuznetsov (2013).

The microstructure of the weld metal with the introduction oxide nanopowder Al_2O_3 and TiO_2 in an amount of 0.5vol. %, is milled dispersion structure mainly composed of upper bainite and lower part of acicular ferrite (Figure 2 c, d). Microhardness components of 264-304 MPa, Kuznetsov (2013).

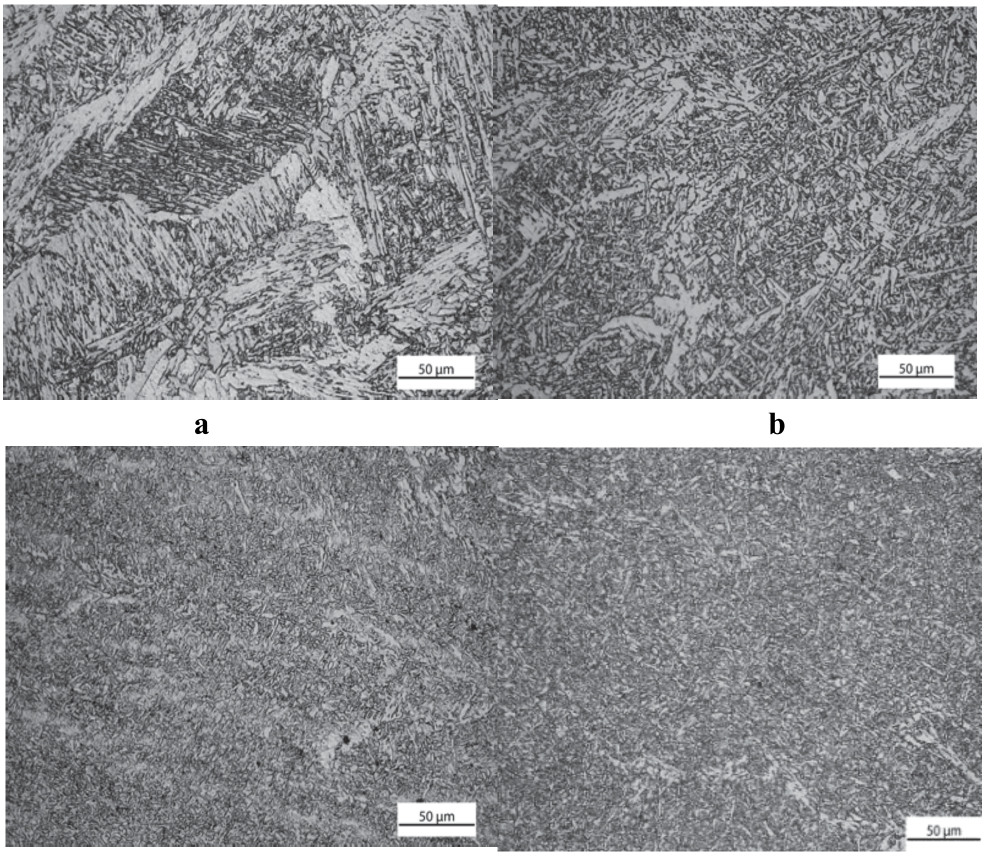


Figure 2. Microstructure of the weld metal with the introduction nanooxide powder in an amount of 0.5 vol. %

a - prior to the introduction; b - with the introduction of ZrO_2; c - with the introduction of Al_2O_3; d - with the introduction of TiO_2

An important characteristic that determines the possibility of obtaining a fine-grained microstructure with a high degree of IF is the quantity of impurities, which can serve as nucleation sites of ferrite in the steel. To assess the effect of inclusions on the formation of the structure of welds, special studies of the chemical composition, size and density of precipitates in a metal matrix were conducted. It was found that in the case of the introduction of nanooxides in the molten weld pool, the average value of the number of nonmetallic inclusions corresponds to 30 on square 324 μm, or 1 switching occurs on average segment length of 10 μm.

Thus, our studies indicate significant effects of nanooxides as on structure, and on the nature of the separation of the phases and their sizes. Introduction of the nanopowder in the weld varies nucleation process that occurs at the nanoscale particles at the interface of the three phases (nanoparticles - embryo - melt) and dramatically alters the structure and amount (morphology and dispersion) of grain grows. The structure of the deposited metal instead of needle-dendrite becomes a quasi-equilibrium and fine. It reduces the size of the nonmetallic inclusions, thus, it increases the mechanical properties (strength and ductility) of the weld metal, and increases several fold elongation, tensile strength and yield. Results of mechanical testing welds at welding steel A514 wire ER70S-6 shown in Table 1 below.

Table 1. Results of mechanical testing of welds

№	*Yield strength, σ_m (MPa)*	*Tensile strength, $\sigma_в$, (MPa)*	*Elongation, (%)*	*Reduction of area, (%)*	*Impact strength, KCV, (KJ/m^2)*
Without nanodopant	357	542	21	61	4.6
With nanooxide TiO_2	514	647	12	54	9.3
With nanooxide Al_2O_3	535	668	17	60	4.0

Data in Table 1 indicate an increase in both the yield strength and tensile strength, when titanium and aluminum nanooxides are introduced into the weld pool. The most significant impact on these indicators has nano alumina, increasing yield strength at 178 MPa (49 %) and a tensile strength of 126 MPa (23 %). The titanium most affects toughness, increasing its value in about 2 times.

As noted, the most effective, to enhance the performance properties of the thermal spray coating is the use of nanopowders. The presence of nanoparticles in the starting powder material increases the surface energy, which is positively reflected in the steps of coating formation, resulting in improving their performance properties, despite the fact that the proportion of nanoparticles in the coating is a few percent.

In plasma spraying, the wear-resistant coatings as by welding using nanopowder Al_2O_3.As the matrix used self-fluxing powder BoroTec 10009 fraction 40-63 μm, which is widely used for hard facing of thermal spraying with additional reflow.

During plasma spraying, the powder mixture coating was formed from the reaction products of components that interact during movement of the particles and the surface of the base. Coating sprayed with a special plasma torch partially imposition arc Figure 3.

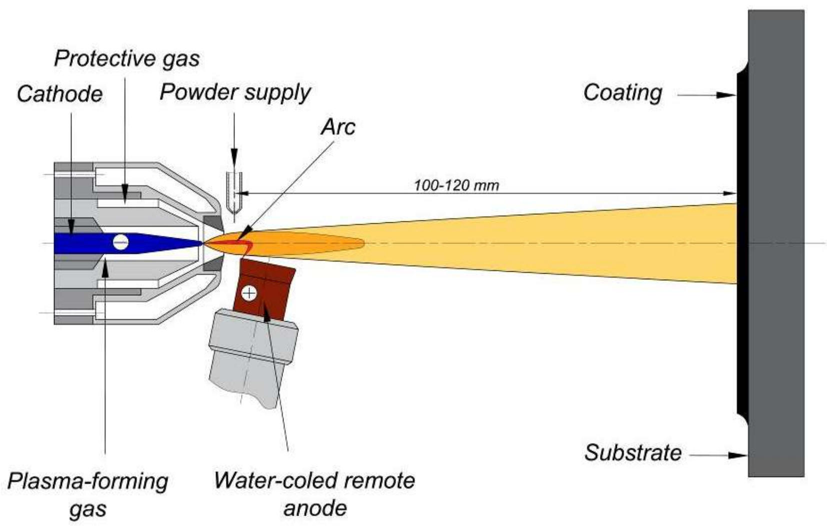


Figure 3. Scheme of plasma spraying with remote anode and laminar plasma jet

Due to structural features of the plasma torch and the modes of formation of the plasma jet, it reached the character near to laminar flow. An elongated high temperature portion of the plasma jet with the additional gas protection provides the best conditions for carrying nanoparticles in sprayed coatings. As the plasma forming and a protective gas is use dargon. Operating current is set within 80- 100 A, the voltage of 50-60 V, the gas flow rate of 2-3 l/min with a nozzle diameter of 2 mm. After, the spray coating is melted in a muffle furnace at 1050ºC for 5 min. The coating is applied to flat samples of size 10×5×20 mm made of steel A570. The coating thickness was in the range of 0.3-0.5 mm. The chemical composition of the surface plasma coating after the X-ray fluorescence in the absence of boron are given in Table 2.

Table 2. The chemical composition of the plasma coating system NiCrBSi and NiCrBSi + Al_2O_3

Elements, % / *Coating*	*Ni*	*Cr*	*Si*	*Fe*	*Al*
BoroTec 10009	70.350±0.349	7.200±0.149	1.030±0.355	21.420±0.089	–
BoroTec 10009+0,5%Al_2O_3	71.888±0.525	14.510±0.165	6.763±0.339	6.458±0.087	0.381±0.591
BoroTec 10009+1%Al_2O_3	73.240±0.489	15.259±0.154	4.584±0.248	6.046±0.082	0.871±0.561
BoroTec 10009+1,5%Al_2O_3	68.621±0.564	16.036±0.152	7.945±0.407	6,179±0.065	1.219±0.700
BoroTec 10009+5%Al_2O_3	69.544±0.525	14.510±0.165	6.763±0.339	5.973±0.087	3.210±0.591

The resulting coatings were investigated on the kinetics of deterioration in the condition of dry friction in the reciprocating motion of a plane counter face of hardened steel with a load of 3 kg. The test results are shown in Figure 4.

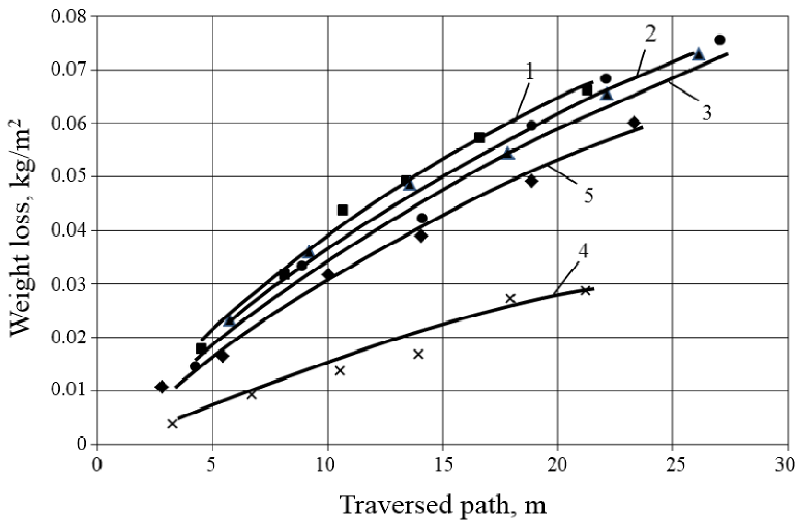


Figure 4. Kinetics of wear of plasma coatings obtained by spraying with melting powders: 1 - BoroTec 10009; 2, 3, 4 and 5 - BoroTec 10009 with the addition of Al_2O_3 nanopowder at 0.5, 1, 1.5 and 5 vol.%, respectively

From an analysis of the graphs shown in Fig.4, we can conclude that the highest wear resistance was observed for a coating based on a powder BoroTec 10009 with the addition of Al_2O_3 nanopowder in quantity 1,5 vol.% (curve 4). Increase in nanopowder to 5 vol.% leads to a deterioration in durability (curve 5). The presence of aluminum oxide nanoparticles in the coating in an amount of 1.5 %, as shown by the tests, also helps to reduce the coefficient of friction by 38 %. Further increase of concentration of nanooxides reduces the coefficient of friction, which is not substantially affected.

4. CONCLUSIONS

1. It has been established that the use of nanopowder oxides Al_2O_3 and TiO_2 is effective for controlling the structure and mechanical properties of both welds, and sprayed coatings.
2. Increasing the mechanical properties inherent in all research samples, the most significant influence nanooxide alumina in an amount of 0.5 vol.% increasing the yield strength of the weld of 49 % and a tensile strength of 23 %. Increasing toughness of welds is about 2 times better than titanium oxide in an amount of 1 vol.%.
3. Introduction of nanopowder alumina in an amount of 1.5 vol.% and in plasma coatings allowed to reduce friction by 38 % and increased wear resistance of coatings 2-3 times.

REFERENCES

Berndt, C., Thermal spray processing of nanoscale materials II – Extended abstracts., Journal of thermal spray technology, Vol. 10, No. 1, 2001, pp.147-182.

Cherepanov , A.N., Afonin, Y.V., Orishich, A. M., Laser welding steel with a titanium alloy using intermediate inserts and nanopowder inoculators., Heavy Machinery, Vol. 8, 2009, pp. 24-26.

Golovko, V.V., Influence of nanoinclusions on the structure of weld metal ferritic-bainitic steels (Review)., Collection of scientific works NUS, No. 4, 2011, pp. 42-49.

Kuznetsov, V.D., Effect of modifying oxide nanoparticles on structure welds low-alloy steels., Interuniversity collection "Research Notes", Lutsk, No, 41, Part 2, 2013, pp. 61-68.

Levashov, E.A., Prospects for the use of nanostructured materials in SHS technology and surface engineering., Abstracts of the 2^{nd} scientific and technical seminar Nanostructured Materials – 2002, Belarus, Russia, 2002, pp. 1-19.

Parshin, S.G., MIG-welding of steel using nanostructured electrode materials., Welding Engineering, Vol. 10, 2011, pp. 27-31.

Smirnov, N.I., Prozhega, M.V., Danilichev, M.A., International conference Nanotechnology and their influence on friction, wear and fatigue in machines, IMASH, 2004, Moscow, Russia, pp.1-11.

Sokolov, G.N., Influence of nano-dispersed carbides WC and nickel on the properties of the deposited metal., Welding and Diagnostics, Vol. 3, 2011, pp. 36-38.