Engineering Solid Mechanics 8 (2020) 41-48

Contents lists available at GrowingScience

Engineering Solid Mechanics

homepage: www.GrowingScience.com/esm

Effect of ultra-disperse powder in electrode coating on properties of welds in MMA welding

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A R T I C L E I N F O

Article history:
Received 9 July, 2019
Accepted 28 August 2019
Available online
28 August 2019

Keywords:
Nano-dispersed powders
Welding electrodes
Mechanical properties
Crystallization
Modification
Microstructure

A B S T R A C T

Growth of the volumes of dangerous and critical welded metal structures constructed under low temperatures imposes additional requirements on the mechanical properties of the weld joints, particularly, on the impact resistance of the weld joint and on the stability of its values. It can be achieved by using coated electrodes with ultradisperse powders of alloying elements in the coating. To develop new improved welding materials we need to optimize the systems of weld metal alloying to meet the increasingly stringent requirements to the welding-operational characteristics. Introduction of a complex ultradisperse powder (Al_2O_3, SiO_2, TiO_2, Ni) into the electrode coating applied for manual metal-arc welding ensures more stable process of electrode metal fusing and its transfer into the welding bath, improves the performance characteristics of the welded metal.

1. Introduction

Today, expanding manufacturing of important and critical welded constructions in low temperature conditions has posed additional requirements in respect of mechanical characteristics of welds, in particular, notch toughness of a weld and its stability. Traditionally, these characteristics have been controlled via alloying and modifying. The point of these methods is to ensure certain operational properties with the help of a structure formed in the material by means of introducing chemical elements.

Data provided by Analytical Agency (Electronic resource 2019) demonstrate that in 2018 the output of coated electrodes for manual metal arc (MMA) welding amounted to 90254.2 ton in Russia. The study on materials for welding (Mazur et al, 2014; Lozovoi et al., 2007; Votinova, 2016), available on the market in Russia, first of all, coated electrodes manufactured by domestic and foreign producers, has revealed a basic trend in this industry – improvement of tolerance to failure and operational properties of metal constructions welded in MMA welding, with the cost price kept stable. As a rule, different modifiers, e.g. nano-powders are used for this purpose (Chekanova, 2015; Il'yashenko & Makarov, 2016). Different methods to introduce modifying powders into a weld metal are suggested (Krushenko & Fil'kov, 2007; Wang et al., 2008; Sapozhkov & Burakova, 2016; Sokolov et al., 2011) – spraying in a

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doi: 10.5267/j.esm.2019.8.006

shielding gas (Kuznetsov & Zernin, 2012), in a fluxing agent via dipping an electrode into a mixture of ultra-disperse materials etc. Introduction of ultra-disperse powder into liquid glass when manufacturing electrodes is the most efficient method. Its efficiency can be attributed to

- minimal losses of a modifying powder;
- stable sanitary and hygienic characteristics of welding process;
- uniform distribution of a modifying powder along the length of an electrode;
- manufacturing technology of electrodes doesn't tend to become more difficult and complicated because of adding technological processes.

We believe that there is currently no integrated approach to determine an appropriate amount of modifying powders to be introduced into an electrode and predict properties of a joint welded in MMA welding with coated electrodes. The study aims at research on the effect of ultra-disperse powder with a complex chemical composition Al_2O_3, SiO_2, TiO_2, Ni introduced into cellulose and rutile coating of electrode on operational properties of a joint weld.

2. Methods of Research

For experiments electrodes MR-3E (GOST 9466-75) with a diameter of 4 mm were fabricated according to industrial standards. In the process of fabrication ultra-disperse powders Al_2O_3, SiO_2, TiO_2, Ni were introduced into liquid glass (Krushenko & Fil'kov, 2007). To compare and assess welding and operational properties of experimental electrodes and their industrial analogues MP-3 weld beds were built up on plate surfaces (09Г2С, 300x276x20 mm). A weld bed was deposited using a welding rectifier VD-306. Current oscillograms in a welding circuit and voltage of electrode and work piece were registered as energy parameters of weld deposition (Table 1) started changing (Fig. 1).

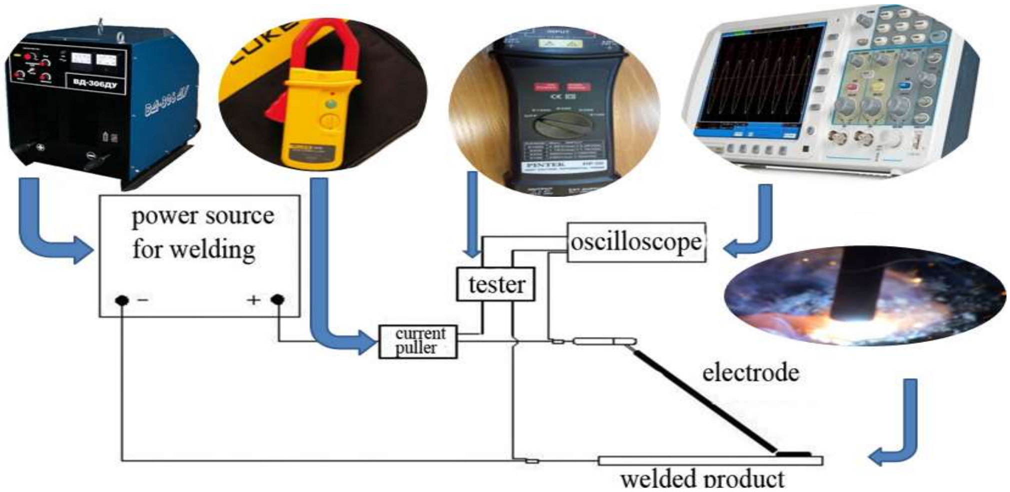

Fig. 1. Experimental procedure to determine stability criteria for MMA welding.

Table 1. Welding conditions for different electrodes and power sources

Power source	Electrode	Average values of parameters
Diode rectifier VD-306	MR-3	Current 113.1±2.7 A Voltage 243±0.6 V Welding velocity 0.25 m/min
	Experimental MR-3E	Current 110A±2.7 Voltage 24.9±0.6 B Welding velocity 0.25 m/min

Arc burning stability of the electrodes under consideration was analyzed via comparing current and voltage oscillograms traced by digital recording oscillograph «АКИП-4122/22»; differential tester «Pintek Electronics «DP-50»; current clamps «Fluke i1010»; software tool «OWON_Oscilloscope». Cross-sections were made on all samples to examine their micro-structure. Cross-sections were made via mechanical smoothing, mechanical polishing with diamond paste АСМ 10/7 НВЛ and chemical etching in concentrated «75% HCl + 25% HNO_3». Tests were carried out in optic metallography using a microscope Neophot-21, images recorded with a digital camera Genius VileaCam. Mechanical properties of welded metal were assessed according to GOST 6996-66 with the help of universal tension tester ЦДМУ-30, industrial № 2271/55/1 (measurement error 1%); impact testing machine МК, industrial № 32, (measurement error 3%). Fractography of welded metal fractures was carried out by an optic microscope Neophot-21, images recorded with a digital camera Genius VileaCam.

3. Results and Discussion

Current and voltage oscillograms in MMA welding with different electrodes are shown in Fig. 2. Experimental data on droplet transfer parameters of electrode metal are given in Table 2.

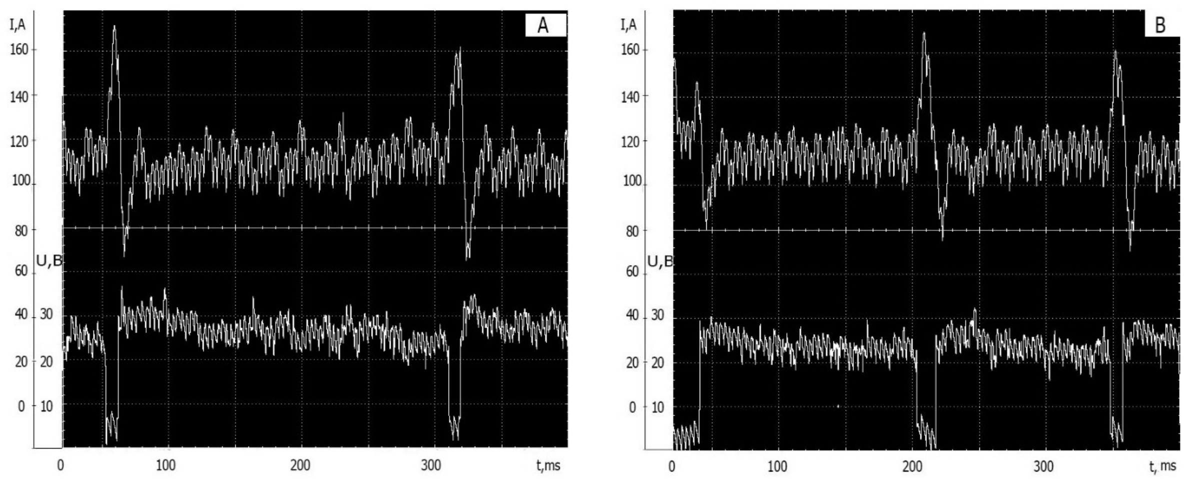

Fig. 2. Current and voltage oscillograms in MMA welding with coated electrodes:
a) MR-3; b) MR-3E

Table 2. Statistical data on parameters of electrode metals droplet transfer

Parameter	Electrode	
	MR-3	MR-3E
Arc gap period shortcut τsc, мs± mean root square deviation of period shortcut, στsc, ms	14.9±4.6	13.19±3.9
Period of cycle Tsc, мs± mean root square deviation of period of cycle σTsc, ms	200±79	177±64.8

Data in Table 2 point at decreasing time of droplet transfer and increasing number of shortcuts when using experimental electrodes MP-3 in comparison with standard electrodes MP-3; so, fine-droplet transfer of electrode metal (Makarov et al., 2017; Erohin, 1973) is possible due to modifying powders in electrode coating, which support stability of arc burning (Vaz, Bracarense, 2015; Varnauskas et al., 2004; Lazić et al., 2010).

Studies (Makarenko et al., 2001; Saraev et al., 2017) suggest that refinement of transferred electrode metal droplets furthers formation of a fine grained weld structure, improves plasticity and notch toughness. Comparative microstructural research on metal welded with different electrodes was carried out as shown in Fig. 3.

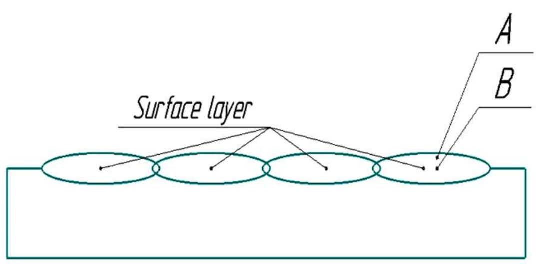

Fig. 3. Study on the surface layer micro-structure: A - upper sub-layer, B - lower sub-layer

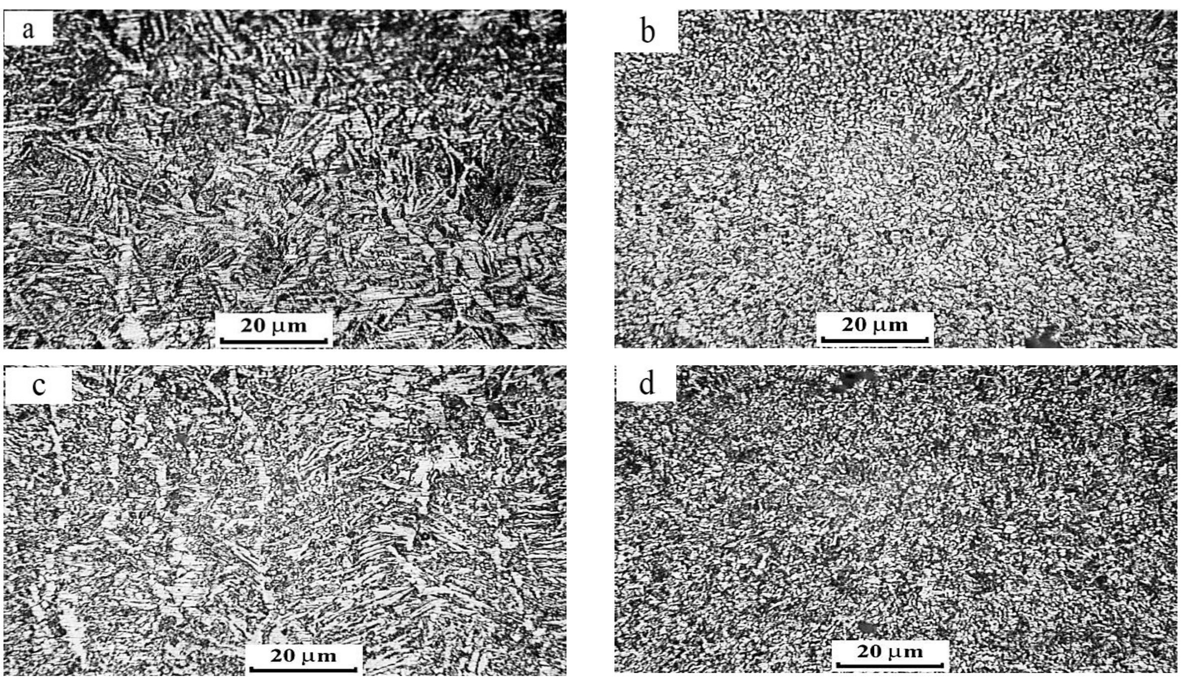

Fig. 4. Images of micro-structure in welded metal: a, b – upper layer (Fig. 3) standard MR-3 and experimental MR-3E, respectively; c, d – lower layer (Fig. 3)

Micro-structural analysis (Fig. 4) has determined

a) layer depth ≈ 1500 μm. Needle-shaped structure. Mean width and length of needles ≈ 1.8 ±0.06 μm and 9.0 ±0.28 μm.

b) layer depth ≈ 875 μm. Ultrafine-grained structure. Average dimension ≈ 1.2±0.08 μm.

c) layer depth ≈ 2875 μm. Branch-shaped structure. «Stem» – a primary ferrite, average cross dimension ≈ 2.8 ±0.08 μm. Average distance between «branches» ≈ 16.0±0.62 μm.

d) layer depth ≈ 3125 μm. Fine-grained structure. Average dimension ≈ 2.4±0.07 μm.

Micro-structures presented demonstrate that introduction of a modifying powder with a complex chemical composition improves micro-structure of welded metal and causes refinement of grains due to ultra-disperse powders in coatings (Kobernik et al., 2015; Boldyrev et al., 2014a; Golovko et al., 2015; Kuznecov, Stepanov, 2015; Boldyrev et al., 2014b; Boldyrev et al., 2012).

Table 3. Mechanical properties of welded metal

Parameter	Standard electrodes MR-3	Experimental electrodes on a component base MR-3E
σв, MPa	$\frac{458...464}{461}$	$\frac{480...510}{490}$
δ,%	$\frac{17...20}{18,5}$	$\frac{29...35}{32}$
KCU at + 20º C, J/cm² (notch in the center of a weld)	$\frac{75...85}{80}$	$\frac{90...110}{100}$

Differences found when investigating arc burning stability and analyzing micro-structure of welded metal are important for operational properties of a joint weld. In terms of methods above mechanical properties of welded metal were studied, their findings are given in Table 3. Data obtained (Table 3) show that introduction of ultra-disperse powder with a complex chemical composition into coating of electrode MP-3 results in 10% increase of ultimate stress limit, 43 % increase of relative elongation, and 20 % rise of notch toughness in comparison with characteristics of standard electrodes. Fractography of samples tested mechanically demonstrate brittle fractures (Fig. 5, 6).

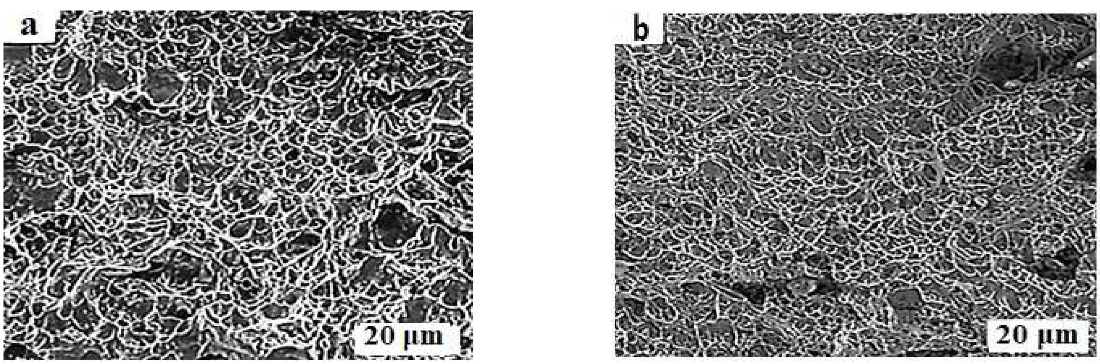

Fig. 5. Micro-photography of soft fracture on the sample surface when viscosity testing: (a) standard electrode MP-3; (b) experimental MP-3.

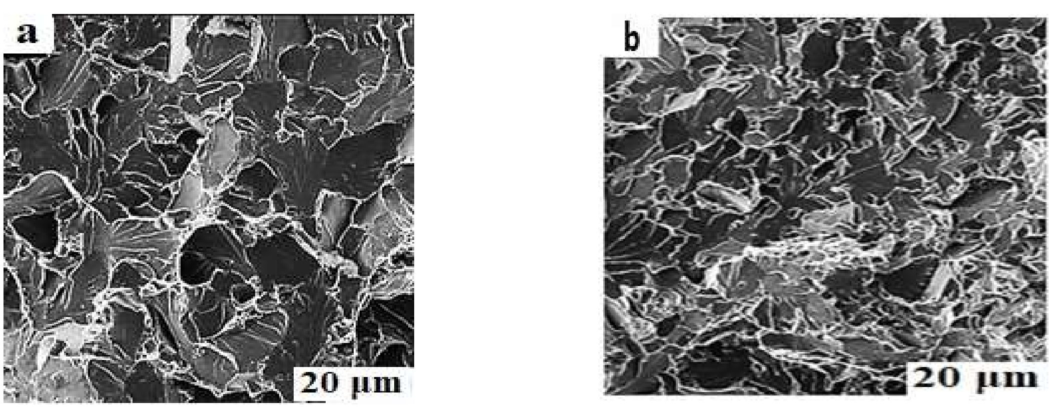

Fig. 6. Micro-photography of brittle fracture on the sample surface when notch toughness testing: (a) standard electrode MR-3; (b) MR-3E.

Dimensions of fracture facets dominate impact energy. It depends mainly on the package dimension. Size reduction of fracture facets results from formation of needle-shaped ferrite crystallized inside the grain. It was found out that high-peaked grain boundaries decrease concentration and stress intensity at the top of a crack. Furthermore, cracks tend to change their primary direction or split into a number of micro-cracks on the grain boundary with a sufficient crystallographic orientation and stream-like pattern on the fracture surface. Such components of a micro-structure as coarse-grained boundary allotrimorphic ferrite and Widmanstätten ferrite facilitate crack propagation and further brittle fracture.

4. Conclusions

Introduction of ultra-disperse modifying powder with a complex chemical composition (Al_2O_3, SiO_2, TiO_2, Ni) into coating of electrodes for MMA arc welding is advantageous over standard electrodes in some aspects:

- stability of melting process and electrode droplet transfer into a weld pool, i.e. 7 % reduction of shortcut period in the arc gap and 12 % decrease of cycle;
- improvement of operational properties of weld metal: 10% for ultimate stress limit, 43 % - relative elongation, and 20 % - notch toughness.

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