Corrosion and Mechanical Properties of Austenic Steel Weld Joints

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Abstract. This paper presents results of experiments on how tungsten, molybdenum and aluminum oxyhydroxide nanopowders, imbedded into the weld pool, affect corrosion resistance and mechanical properties of welded joints. It is shown that nanopowders have a significant effect on the intergranular corrosion of the weld.

1. Introduction

Most intensive corrosive damages occur in welded joints of high-alloyed, corrosion-resistant steels when compared with the base metal; this is due to the high electrochemical heterogeneity of weld metal chemical composition as well as its structure, properties and stress state.

The main difficulties of weldability of these steels are based on their multicomponent alloying and variety of operating conditions of welded products. The main disadvantage is the tendency to hot cracking, intergranular with character in the weld metal and heat affected zone (HAZ) [1]. This is the main cause of damage of pipelines, chemical, metallurgical, power, nuclear industry equipment, heat transfer fluids [2, 3].

The austenite phase is exposed to corrosion destruction. A corrosion attack develops in the weld zone more intensively if ferrite grains are larger and the austenite phase is smaller. Austenitic steels (chrome-nickel) are destroyed by corrosion along the fusion line [4]. This steel is unstable to local destructions in the HAZ and corrosive wear in comparison with other steels of this class [5, 6, 7]. In [8] it is confirmed that mechanism of HAZ metal embrittlement is associated with development of softening of the austenite grain boundaries, because this initial structure damages occur in the area of large grains during arc welding.

During operation, there is an active corrosion wear flowing particularly intense in the weld areas [9].There are several ways to improve the corrosion wear resistance of welded joints of austenitic steels as well as to restore the equipment operating in corrosive environments.

Intergranular corrosion (IGC) can be reduced if welding energy parameters are controlled by applying a high-frequency pulses [10], transition of droplets into the molten pool is

regulated using a pulsed wire feed [11], inverter power sources are applied [12], the weld pool is protected with gas [13].

Welds will have a high resistance to hot cracking and intergranular corrosion if the weld metal has a two-phase austenitic-ferrite structure. Weld metal alloying with elements-ferritizers was one of the first ways of control over intergranular corrosion; but experiments have shown that this alloying does not eliminate development of corrosion, if the metal is subjected to a prolonged heating [14].

Resistance to intergranular corrosion after prolonged heating can be saved by applying a stabilizing annealing [15] or, for example, weld metal alloying with rare earth and alkaline earth elements, nickel [16]. One more method of controlling over corrosion is a laser processing of welds. [17].

Also [1] presents researches on how electrode coating affects the corrosion resistance of the weld metal, which showed that the deposited weld metal, made with basic electrodes, has a higher corrosion resistance. This paper proposes a method to improve corrosion resistance of welded joints by dispensing nanostructured particles through the shielding gas to the weld pool by means of the device described in [18]. It is also necessary to evaluate the mechanical properties of welded joints, as they also depend on the efficiency of welded steel structures.

2. Research methods

Experimental study used nanopowders (NP) of oxide Al (Al_2O_3), tungsten (W) and molybdenum (Mo) produced in Institute of High Technology Physics of National Research Tomsk Polytechnic University. Powders are produced by electro-explosive technology which has been developed in the above Institute [19].

Conductor electric explosive (CEE) technology is a pulsed fast processes and has several advantages such as: ability to transfer a high-density energy of desired amount to the substance; energy supplied in a pulsed mode is used with great efficiency; high rate of system thermodynamic parameters change; ability of subtle influence on material structure and formation of the structure of individual particles.

Of particular interest are the NP, obtained by the CEE. Technique and fundamentals of technology for production of NP with controlled properties by CEE method are developed at the Institute of High Technology Physics of TPU (formerly High Voltage Research Institute) [19].

This method provides pure metal powders, and powders of various metal-based compounds (carbides, oxides, nitrides, sulfides, et al.). Particles have spherical shapes, particle sizes are distributed according to the normal-logarithmic law and an average particle size is in the range 100 - 500 nm. Particles are poly-crystals; the magnitude of structural fragments is in the range of 20-30 nm. Much of the material is in the X-ray amorphous state.

NP of aluminum (Al), tungsten (W), molybdenum (Mo), obtained by the of CEE technology, are among the most interesting representatives of this class of NP. At present a number of practical applications of Al NP has been successfully tested as: a starting material for nanoscale fibers of Al oxide-hydroxide phases as the main active components of filtration and sorption materials for purification of water [20]; active supports for catalysts in oil refining and petrochemical industries [21, 21]. NP of W and Mo are used as feedstocks for disulfides of the metals having high heat resistance and good tribological properties [21] as modifying additives for catalysts in oil refining and petrochemical industries [22-24]

To produce the metal NP, an aluminum wire of "AM" grade W=0.35 mm, a tungsten and a molybdenum wire of "VA" grade W=0.31 mm were used [20, 21]

The NP specific surface area W was 2.6 m2/g. That corresponds to the surface particle average diameter of 122 n. Al NP had primary 10 nm-sized particles, which combined into aggregates with dimensions up to 500 nm, and agglomerates up to 5 μm with weak coupling between the units. Average surface size of Al NP particles was 100 nm. Al NP was previously passivated in air wherein

the content of metallic aluminum was not less than 91% by weight. Then Al NP was subjected to thermal hydrolysis to produce Al oxyhydroxide (AlOOH) nanofibers. A procedure for preparation of AlOOH nanofibers, used in this work, is described in [25].

To obtain NP by electro-explosive method, pulse current of high density (1010A/m2) is passed through a metal wire, whereby the conductor explosively collapses; combustion products condense in an inert gas atmosphere to form nanoscale particles.

Powders obtained by this method have a particle size of 10 ÷ 150 nm (agglomerates of sizes up to 500 nm), the specific surface area of 2 ÷ 50 m2/g and have a high chemical activity. Depending on the kind of gas surrounding the conductor, it is possible to produce powders of metals and alloys, powders of chemical compounds and powders of composite structures [25]. Procedure for preparation of Al oxide-hydroxide phases, used in this work, is described in [25].

Steel plates of 5 mm in thickness (chemical composition of steel: 0.12% carbon, 18% chromium, 10% nickel, 1-15% titanium) were used to study corrosion resistance of welded joints;

Steel plates of 10 mm in thickness welded with consumable electrode, in argon, with welding wire (chemical composition of the wire: 0.12% carbon, 18% chromium, 9% nickel; 1-15% titanium) were used to study mechanical properties of the joints.

Equipment used: welding rectifier with rated current of 300A, a pendant welding head, an automatic control unit.

The samples were processed in four ways: №1 - welding in argon with solid section wire; №2 - welding in argon with solid section wire, with addition of tungsten nanopowder (W) to the protective gas; №3 - welding in argon with solid section wire, with addition of aluminum oxide nanopowder (Al2O3) to the protective gas; №4 - welding in argon with solid section wire, with addition of molybdenum nanopowder (Mo) to the protective gas.

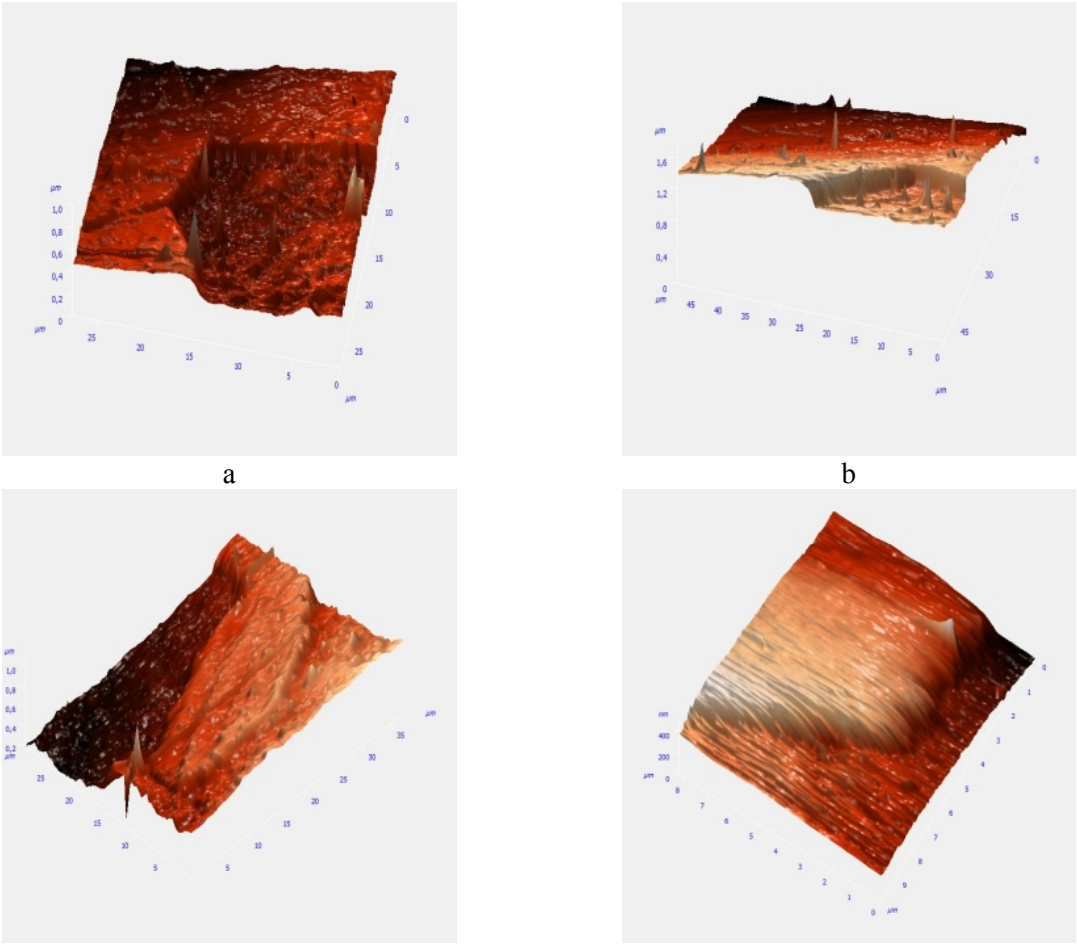
Control samples and test samples were selected from each group. Control samples were previously subjected to chemical etching at an ambient temperature in aqueous solution of nitric acid and ammonium fluoride to remove welding slag.

The corrosion resistance of samples was tested in a solution of sulfuric acid and copper sulfate in the presence of metallic copper and sodium fluoride or potassium fluoride. Reagent and mode of action was chosen according to the recommendations for this grade of steel. Test duration was 2 hours. Whereupon a condition of intergranular corrosion was tested by metallographic method; for this metallographic thin sections were prepared from control samples not subjected to the test and after the test samples. A plane of the section was perpendicular to the weld and included the weld metal, HAZ and the base metal. Microstructure was revealed by etching in an electrolyte until the grain boundaries. Optical microscope NEOPHOT-21 and confocal laser scanning microscope LEXTOLS4000 were used to record the results of metallographic examination.

Mechanical properties of welded joints were determined in accordance with generally accepted techniques. Such mechanical properties of welded joints were tested as tensile ultimate strength, yield strength and relative elongation. Equipment used: universal testing machine, at t +20°C and +500°C.

3. Results and Discussion

Microstructures analysis shows that all the samples have austenitic grain structure with a grain size approximately identical. However, at an equal heat-on period, grain boundaries of sample №1 were etched maximally, grain boundaries of sample №2 were etched minimally. Tendency to IGC was evaluated by determining the number of grains with clearly identified boundaries, the width of which could be up to 30 microns. Grain boundaries were not etched in the heat affected zone. This means that the standard test revealed no intergranular corrosion in any sample. The etching process occurred over the entire surface of grains, not only at grain boundaries. Depending on grains orientation their surfaces were etched stronger or weaker. Thus, some kinds of steps were formed between the grains (Fig. 1).



a b

c d

Figure 1. Microstructure of samples after test: a- sample №1; b - sample №2; c - sample №3; d - sample №4.

The average height of these steps on the samples: №1 - 320 nm, №2 - 200 nm, №3 - 275 nm, №4 - 250 nm. The finest grain boundaries were in sample №2, which also shows the greatest similarity between the reference sample and the microstructure of the sample after the test in a corrosive environment. When analyzing the weld metal, it was possible to evaluate the interdendritic spaces. They were strongly etched and grooves were formed as a result.

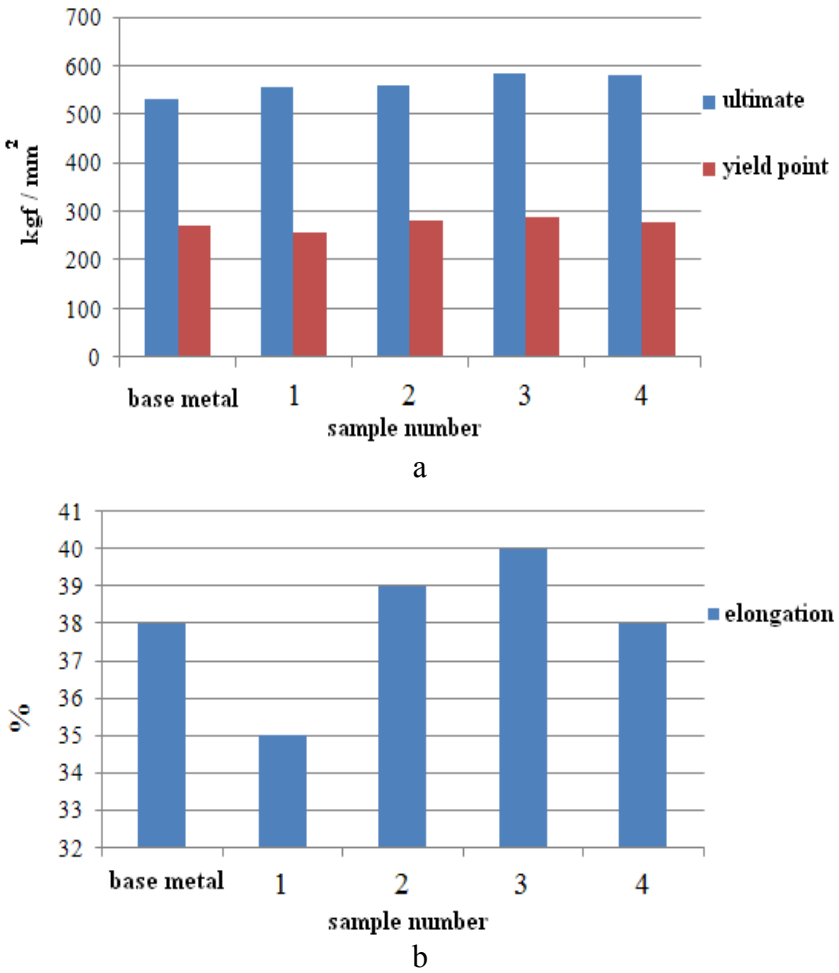


Figure 2. Mechanical properties of welded joints at +20°C:
a – tensile ultimate strength, yield strength; b – relative elongation.

Evaluation of mechanical properties (tensile ultimate strength, yield strength and relative elongation) of weld joints was made at a temperature of +20°C and +500°C. Mechanical properties of welded joints at +20°C are presented in Figure 2.

One of the characteristics of these steels is that they operate at higher temperatures, so studies were conducted at a temperature of +500°C. Mechanical properties of welded joints at +500°C are shown in Figure 3.

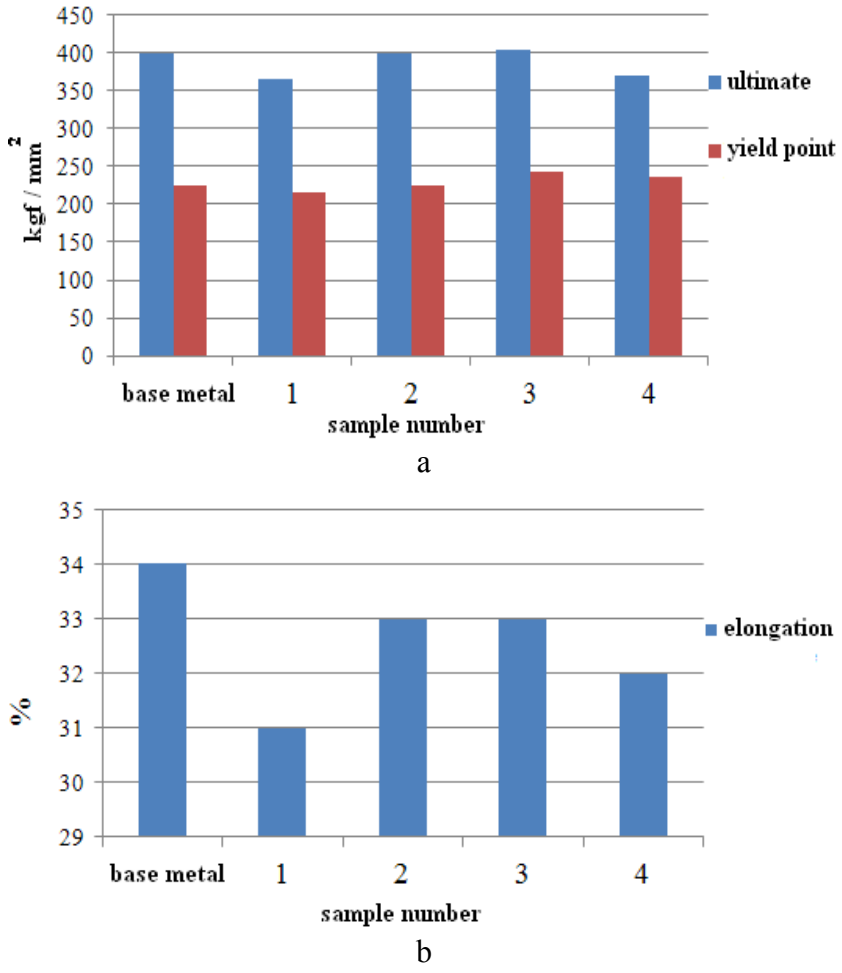


Figure 3. Mechanical properties of welded joints at +500°C:
a – tensile ultimate strength, yield strength; b – relative elongation.

Figures 2 and 3 show that introduction of nanostructured powder modifiers to the liquid weld pool increases the mechanical properties of welded joints; at t +20°C an average increase is 4 - 11%, at a temperature of +500°C an average increase is 3 - 10%. The sample with Al2O3 content showed the best mechanical properties. Study [26] proves that mechanical properties are better for weld metal samples with less dendrite structure and less coarse dendrite structure. The most equilibrium dendrite structure is achieved with the use of nanostructured powder Al2O3.

4. Conclusion

It is found that, if any of the abovementioned nanostructured powders is added into the liquid weld pool, intergranular corrosion does not occur in a single sample. Corrosion resistance of welded joints increases by 15-20%, mechanical properties of welded joints increases at +20°C by 7.5%, at +500°C by 6.5%, if compared with consumable electrode welding in argon without nano-agents.

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