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Materials Science

Microstructure and Thermal Conductivity Analysis of Metal-Polymer Composite Coatings Deposited by Electric Arc Spraying

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(Presented by Academy Member Tamaz Shilakadze)

The paper is devoted to the research of deposition possibility of metal-polymer composite coatings by electric arc spraying with using a polymer component in a powder state. As a result, coatings of the following compositions were obtained: steel wire ER70S-6 – polymer powder P-EP-219 and aluminium based alloy wire ER5356 – P-EP-219. The optimal spraying parameters like current, arc voltage, spraying distance, gas pressure and powder consumption rate have been determined. The phases in the coatings were identified by measuring the microhardness. It was found for the first time by metallographic analysis that microstructure of metal-polymer coatings are characterized by reduced porosity and maximal polymer phase content can be reached to 35…40% (vol.). The investigations shows for the first time, that sprayed composite coatings have reduced thermal conductivity, which is 38 ... 46% lower in comparison with conventional metal coatings. It has been shown that such coatings can be used not only as corrosion resistant, but also like heat-insulating on various structures and details. *© 2022 Bull. Georg. Natl. Acad. Sci.*

thermal sprayed coatings, metal-polymer composites, microstructure, thermal conductivity

The process of improving machines and mechanisms puts forward new requirements to ensure their workability in a wide range of temperatures, loads, speeds and various aggressive environments. One of the most perspective methods to provide these requirements is the deposition of protective coatings to the surface of parts and structures using thermal spray technology. Wire arc spraying is based on the feeding of two consumable conductive between which a direct current electric arc is established. This spraying method has a number of advantages. Firstly, electric arc spraying is the most technologically advanced and cheapest, both in terms of equipment and operating costs. It is also characterized by the absence of unmelted or semi-melted particles, a high deposition rate compared to other thermal spay methods, and a low thermal effect on the substrate. All these factors make wire arc spraying one of the perspective techniques [1]. In recent years, considerable attention has been paid specifically to composite coatings. Various properties can be achieved to such coatings by selecting appropriate functional fillers without changing the external shape of the products. This direction is very promising not only from the point of view of providing surfaces with new properties, but also in the direction of saving expensive alloyed stainless steels and non-ferrous metals in mechanical engineering, shipbuilding and other fields of technology.

Composite electric arc coatings are produced in several ways. One is to spray two or three dissimilar solid wires. Such composite coatings are characterized by high physical, mechanical and corrosive properties. Compositions of the nickel-aluminum [2], aluminum-stainless steel [3] are of the greatest interest. However, such coatings are characterized by high cost due to the use of non-ferrous metals, alloys and high-alloy steels. A promising direction is the spraying of flux-cored wires of various compositions [4, 5], which made it possible to widely vary the chemical composition of coatings, and to significantly expand the scope of their use. But, in this case, it is impossible to deposit metal-polymer coatings, since the polymer component destroys under the influence of high arc discharge temperatures.

Despite the fact that polymer-based materials have high strength and corrosion-resistance, low electrical conductivity, low operating temperatures and potential flammability significantly limit their use in various branches of industry. It is considered perspective to deposit metal coatings on a polymer base using thermal spray methods to increase heat and electrical conductivity, which can provide a wider use of polymer materials. So recently, the deposition of different metals and alloys on plastics by thermal spray methods has been implemented: copper on polyethylene, polycarbonate and polyurethane [6], aluminum on carbon fiber reinforced plastic [7] by cold spraying; aluminum alloy on polyurethane [8] and glass fiber-reinforced epoxy [9] by flame spraying; aluminum on polyester [10] and Co-Ni-Cr-Al-Y alloy on polyimide [11] by plasma spraying; aluminum and zinc on polyethylene by electric arc spraying [12]. However, may occur thermal degradation of the polymer-based substrate due the impact of temperature of the metal particles and high-temperature gases during thermal spraying. Conventional grit blasting operation before spraying may result in cracking and localized destruction of brittle polymeric materials under the influence of high-speed particles. This creates the need to use another surface preparation method and control: deposition of low-melting intermediate layers, grinding, cleaning with acetone and temperature control of the polymer during deposition, etc.

Therefore, the aim of this work is to investigate the possibility of deposition of various composite metal-polymer electric arc coatings using polymer in powder state, to analyze their microstructure and determine their physical and mechanical properties.

Materials and Methods

The object of research was selected electric arc metal-polymer coatings of two compositions deposited by atomization of steel wire ER70S-6 and polymer powder P-EP-219, as well as wire from aluminum-based alloy ER5356 with the same polymer powder. Electric arc spraying was carried out by KDM-2 unit with modernized spray gun which had powder feed unit to the high-temperature arc discharge zone [13]. Compressed air was used as the atomizing and carrier gas. To prevent the molten particles adhesion to the bronze working nozzle, a wire with a diameter of 1.2 mm was used. The surface preparation of the samples was carried out immediately before spraying using a 026-7 "Remdetal" device for grit blasting operation. The roughness of the treated surface was 50…90 μm.

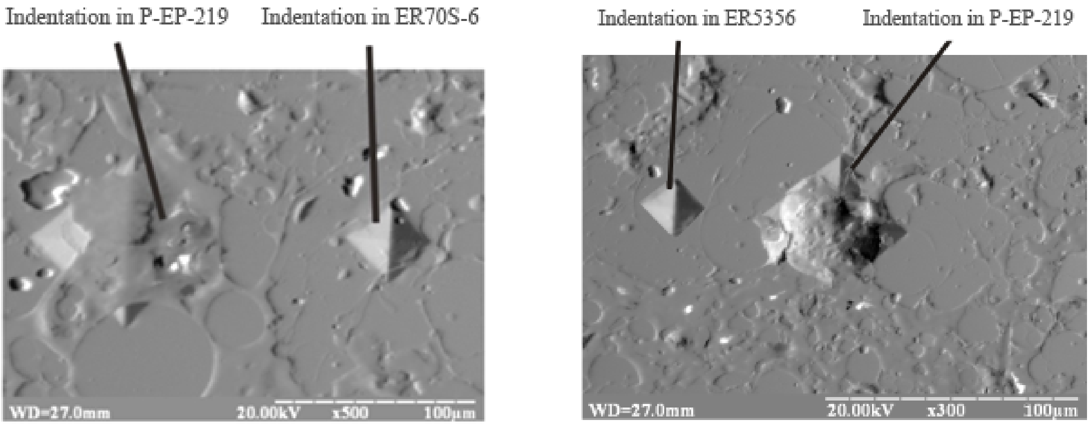

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Fig. 1. SEM micrographs (surface topography) of microhardness measurement results of different phases in composite coatings: a - ER70S-6 – P-EP-219; b - ER5356 – P-EP-219.

The spraying was carried out on steel plates made of high-quality carbon steel C45 (0.45% of C) with dimensions 50×20×5 mm and cylindrical samples with a 15 mm diameter. To prevent the particles of the polymer powder from burning out in the high-temperature zone of the arc discharge, it was fed before the arc discharge. With an increase in the power of the electric arc spraying gun and a decrease in the spraying distance, the temperature of the sprayed particles and their heat transfer to the substrate increase, this is accompanied by intense burnout of the polymer material. Based on this, the deposition modes of metal-polymer coatings were experimentally established that ensure the maximum content of the polymer phase: current 90-100 A, arc voltage 25 V, compressed air pressure 0.4…0.6 MPa, polymer powder consumption 25 g/min, spraying distance 100...120 mm. Polymer powder fed into a high-temperature jet, due to a short residence time in it, heats up to a viscous state and together with molten metal particles forms a composite metal-polymer coating. The phase identification and the microhardness determination in composite electric arc coatings were carried out using a PMT-3 microhardness tester on cross sections with a 50 g and 20 g load. The microstructure was analyzed using a scanning electron microscope (SEM) REMMA 102-02. The

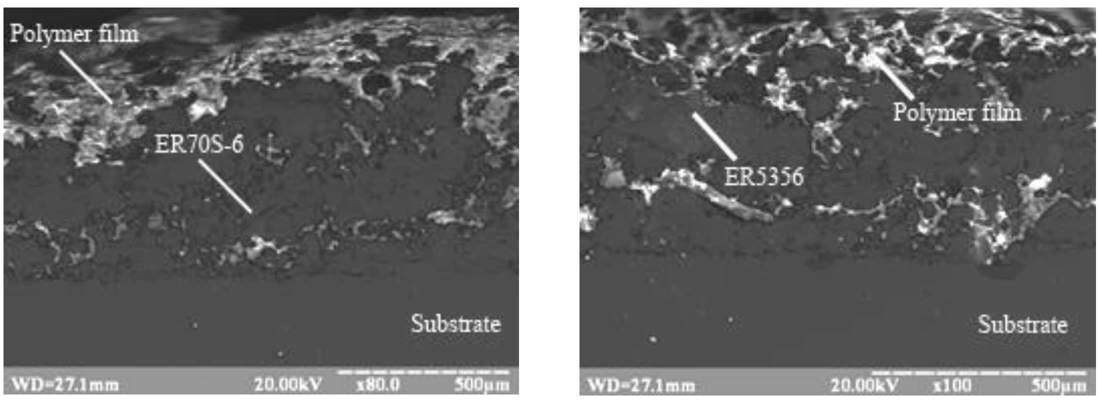

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Fig. 2. Cross section SEM micrographs of electric arc composite coatings: a - ER70S-6 - P-EP-219; b - ER5356 – P-EP-219.

thermal conductivity of sprayed coatings was analyzed using a IT-λ-400 device by dynamic calorimeter method.

Results and Discussion

The microhardness measurement results of the metal and polymer phases of composite coatings from the compositions ER70S-6 - P-EP-219 and ER5356 - P-EP-219 are shown in Fig. 1.

The indentation diagonal length in the ER70S-6 is 23 μm (load 50 g), which corresponds to the microhardness of 1716 Mpa. For the PEP-219 polymer is 85 μm (128 Mpa) (Fig. 1 a). The indentation in the polymer is poorly visible on convention SEM micrographs due to the fact that polymers do not have electrical conductivity, and after removing the load from the indenter, appears the effect of elastic deformation. Because of this we used surface topography regime.

porosity decreases from 13 to 7% compared to the convention metal coating, and the maximum polymer content (P-PE-219) reaches 40% (vol.). For the composition ER5356 – P-EP-219 (Fig 2b), the porosity decreases from 10 to 4% compared to the convention metal Al-based coating, and the maximum polymer content (P-PE-219) reaches 35% (vol.). The decrease in porosity in metal-polymer coatings is due to the fact that the polymer powder P-PE-219, which has good adhesion to metals, mixing with molten metal particles in a high-temperature jet, heats up to a viscous state and together with them forms a dense metal-polymer coating. Moreover, continuous polymer film with a thickness of 10 to 100 μm is formed on their surface after spraying because the polymer solidifies later than metal particles in metal-polymer coatings.

Thus, it can be assumed that such metal-polymer coatings can find their application as anti-corrosion coatings to protect various structures by

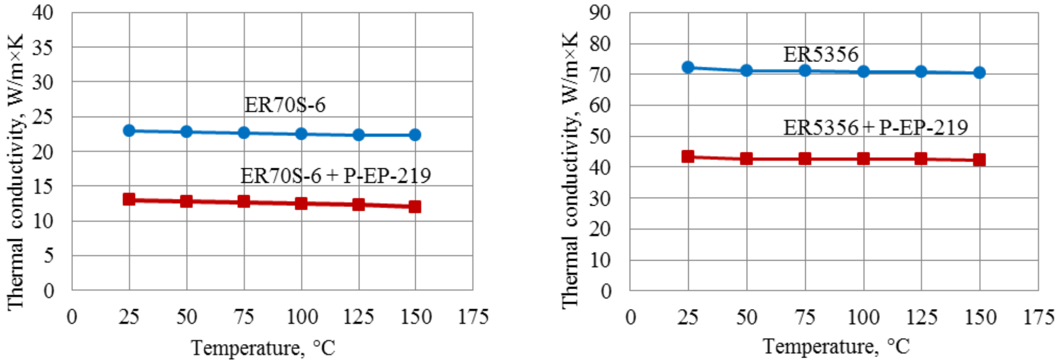

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Fig. 3. Thermal conductivity comparison between conventional metal (100% ER70S-6) and composite coatings ER70S-6 – P-EP-219 (a); conventional (100% ER5356) and ER5356 – P-EP-219 coating (b).

The indentation length in ER5356 is 28 μm (load 20g), which corresponds to the microhardness of 461 Mpa. For the PEP-219 polymer is 46 μm (147 Mpa) (Fig.1b). The measuring of polymer phase content and porosity was carried out using the planimetric method according to the obtained microstructures (Fig. 2).

It was found that in metal-polymer composite coatings (Fig. 2a) ER70S-6 – P-EP-219, the

reducing their porosity and the formation of a continuous polymer film on the surface.

The thermal conductivity measurement at different temperatures results of the sprayed composite coatings are shown in Fig. 3.

It is clear from Fig. 3 that when a polymer component with low thermal conductivity is added into the coating, a decrease in the thermal conductivity of the coating occurs (from 38 to 46%), which makes it possible to use such coatings not only as corrosion resistant, but also like heat-insulating coatings on various structures and details.

Conclusions

Approaches for using the electric arc spraying with powder feeding in deposition metal-polymer coatings have been demonstrated. Composite coatings of the following compositions were deposited: wire ER70S-6 – P-EP-219 and wire ER5356 – P-EP-219. The phases in the composite coating were identified by determining their microhardness. It was found that microhardness of metal phase is 1716 MPa, polymer phase – 128 MPa for composite coating ER70S-6 – P-EP-219; microhardness of metal phase is 461 MPa, polymer phase – 147 MPa for composite coating ER5356 –P-EP-219.

It was shown that in metal-polymer composite coatings (Fig. 3a) ER70S-6 – P-EP-219, the porosity decreases from 13 to 7% compared to the convention metal coating, and the maximum polymer content (P-PE-219) reaches 40% (vol.). For the composition ER5356 – P-EP-219, the porosity decreases from 10 to 4% compared to the convention metal Al-based coating, and the maximum polymer content (P-PE-219) reaches 35% (vol.). Sprayed metal-polymer coatings are characterized by reduced thermal conductivity, which is 38 ... 46% lower in comparison with conventional metal coatings from similar materials.

მასალათმცოდნეობა

ელექტრორკალური შეფრქვევის გზით დატანილი მეტალ-პოლიმერული კომპოზიციური საფარების მიკროსტრუქტურისა და თბოგამტარობის ანალიზი

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ნაშრომი ეძღვნება ფხვიერ მდგომარეობაში მყოფი პოლიმერული კომპონენტის გამოყენებით ელექტრორკალური შეფრქვევის გზით მეტალ-პოლიმერული კომპოზიციური საფარის დატანის შესაძლებლობის კვლევას. შედეგად მიღებულ იქნა შემდეგი საფარები: ფოლადის მავთული ER70S-6 – პოლიმერული ფხვნილი P-EP-219 და ალუმინის შენადნობის მავთული ER5356–P-EP-219. განისაზღვრა შეფრქვევის ოპტიმალური პარამეტრები, როგორიცაა: დენი,

რკალის ძაბვა, შეფრქვევის დისტანცია, აირის წნევა და ფხვნილის ხარჯვის მაჩვენებელი. შეფრქვევის ფაზების იდენტიფიკაცია მოხდა მიკროსიმყარის გაზომვის გზით. მეტალ-პოლიმერული ანალიზის შედეგად პირველად დადგინდა, რომ მეტალ-პოლიმერული საფარების მიკროსტრუქტურას ახასიათებს დაბალი ფორიანობა, ხოლო პოლიმერული ფაზის მაქსიმალური შემცველობა შეიძლება აღწევდეს 35-40%-ს. კვლევის შედეგად პირველად იქნა გამოვლენილი, რომ შეფრქვეულ კომპოზიციურ საფარებს გააჩნია დაბალი თბოგამტარობა – 38-46%-ით ნაკლები ჩვეულებრივ ლითონის საფარების მაჩვენებელთან შედარებით. ნაშრომში ასევე ნაჩვენებია, რომ ამგვარი საფარები, სხვადასხვა კონსტრუქციებსა და დეტალებზე, შეიძლება გამოყენებულ იქნეს არა მხოლოდ როგორც ანტიკოროზიული დაცვა, არამედ როგორც თბოიზოლაციაც.

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