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Elastic properties of the plasma sprayed Ni coating after the electromechanical treatment

A Yu Ivannikov[1,2], I N Lukina[1], V I Kalita[1], D I Komlev[1], A A Radyuk[1], N V Umnova[1], A S Baikin[1] and A V Alpatov[1]

[1] Baikov Institute of Metallurgy and Material Science, Russian Academy of Sciences, 49, Leninsky ave., 119334 Moscow, Russian Federation
[2] Moscow State University of Technology 'Stankin', 1, Vadkovsky per., 127055 Moscow, Russian Federation

E-mail: ivannikov-a@mail.ru

Abstract. The principal aim of this study was to evaluate the effect of the electromechanical treatment (EMT) on the elastic properties of the air plasma sprayed coating from Ni powder. During the EMT process the boundaries of the splats welded and the quantity of the pores decreased from 8.0 ± 1.5% to 2.5 ± 0.5%, thus the elastic modulus of the coating increased from 63 ± 5 GPa to 95 ± 5 GPa. The obtained results revealed the high potential of the EMT for post-treatment of the plasma sprayed coatings.

1. Introduction

Re-melting of coatings is a commonly used post-treatment technology of the plasma sprayed coatings [1], but it leads to disintegration of metastable structure with coarsening of second phases. For this reason, for amorphous and nanostructured coatings it is not recommended to use re-melting.

Another type of post-treatment is surface induction heating. The surface induction heating can help improve structure and mechanical properties of the surface [2-4]. However, this treatment has limits on form and size of the samples due to size and forms of the inductor. The surface induction heating is usually applied for treatment of cylindrical samples.

Hot isostatic pressing (HIPing) is another type of the post-treatment of the plasma sprayed coatings [5]. Low porosity level is obtained, and HIP treatment at increasing temperatures and pressures changes the microstructure and increases the microhardness of the coatings. The results show that the elastic modulus of the HIPed coatings is greater than the elastic modulus of the as-sprayed coatings, that can be related to plastic flow, interlamellar diffusion, and creep, that occur at increased temperatures and pressures. Two independent studies, performed by T. Chraska et al. [6], A. A. Almathami and M. Brochu [7], use the spark plasma sintering for post-treatment of amorphous and nanostructured coatings. The post-treated samples have microstructure that is best described as nanocomposite with very small crystallites, by the way near-zero porosity levels were obtained. Meanwhile, there are restrictions on the form and the size of specimens, which are treated by the spark plasma sintering technology, i.e., this method excludes large samples with complex shapes. For this reason, in the industry of the thermal spray coatings one of the actual tasks is determination of the new post-treatment methods of amorphous and nanostructured coatings.

The authors of this investigation used the electromechanically treatment to improve the structure and the properties of the plasma sprayed coatings [8-11]. This approach is based on the simultaneous

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resistive heating of the surface and the deformation of the coating by the electrode. In practice, equipment for the EMT can be mounted on lathes, milling machines, and robotic systems for post-treatment of thermal sprayed coatings. The EMT can replace traditional post-treatment processes, such as heat treatment and mechanical treatment. For this reason, the use of the EMT optimizes the production processes. Also, there is no machine waste, consequently, environmental risks are lower.

In this study feedstock powder of Ni is selected for investigation of the elastic properties of the plasma sprayed coating after the EMT. Nickel has good mechanical properties, which are favorable for the EMT of a plasma sprayed Ni coating, because they allow residual stresses to relax in the cooling cycle. Pure nickel is used as a protective layer for corrosion resistance and as a binder in the cemented tungsten carbide. In addition, nickel is used as a base of Ni-alloys, in which it typically increases tensile strength, toughness, and elastic limit [12]. In particular, T. S. Sidhu et al. [13] show that the Cr_3C_2-NiCr coating has imparted necessary resistance to hot corrosion, which has been attributed to the formation of oxides of nickel and chromium, and spinel of nickel-chromium. Hong-Bin Zhu et al. [14] show that coating deposited from agglomerated and sintered TiB_2–40Ni powder presents better tribological properties, i.e. low friction coefficient and wear rate. Jianbo Lei et al. [15] show that the carbon fibers enhanced the corrosion resistance and the wear resistance of Ni-based coatings. The analysis of the referenced articles show that nickel is an important and demanded material for coatings. Consequently, we can use nickel as a model material for our research. For this reason, it becomes relevant to investigate the effect of the electromechanical treatment on the properties of the plasma sprayed Ni coating.

The purpose of this study is to estimate the influence of the EMT on the elastic properties of the plasma sprayed Ni coating.

2. Materials and methods

Commercial feedstock powder of Ni (chemical composition of ≤ 0.003 wt.% N, ≤ 0.086 wt.% O, Ni constituted the balance) was chosen for plasma spraying. The powder was manufactured by a carbonyl process (Severonickel Combine). The powder particles had irregular shape and size range of 40-56 µm.

Substrates from low-carbon steel were used for plasma spraying of coating and subsequent post-treatment. The sample for determining the effect of the EMT modes was a cylinder 38 mm in diameter and 150 mm in length.

The plasma spraying equipment was the air plasma spray system UPU-3D (JSCo "Electromechanica", Rzhev, Russia) with the plasma spray gun PP-25. The maximum power of the plasma spray gun PP-25 is 25 kW.

Plasma spraying was carried out according to a protocol, which is presented below.

At the first stage, before spraying, the surface of the substrates was cleaned with acetone and roughened by grit blasting with SiC powder (grit size −900 + 700 µm). Further, the samples were placed alternately in a rotator, which was installed under the plasma spray gun, and they moved reciprocatively relative to the sprayed powder with a linear velocity of 1.2 m/min. The samples rotated with the speed of 200 rpm.

For the second stage, Ni powder was plasma sprayed on cylindrical samples. A mixture of Ar and N_2 gases was used as a plasma gas. The plasma gas consumption was 38 l/min. By plasma spraying process the arc current and the voltage were constantly 350 A and 50 V, respectively. The carrier gas was Ar and its feed rate was 3.5 l/min. The powder feed rate was 21 g/min.

The electromechanical treatment was chosen for post-treatment of the plasma sprayed Ni coating. The process of the electromechanical treatment was carried out on a lathe [16].

Three WC–6Co rollers were used for the EMT [16]. The first roller (number 1) had the following dimensions of the working part: 40 mm in diameter and ~1 mm in width. Two diametrically opposite rollers (numbers 2, 3) had the following dimensions of the working parts: 38 mm in diameter and ~4 mm in width. During the EMT process the area of contact between the first roller and the coating was about 1.8 ± 0.1 mm^2, and the area of contact between the second and the third rollers and the coating was about 7.2 ± 0.1 mm^2. Two pneumatic cylinders were used for transmitting efforts to the rollers. A toroid AC transformer with a capacity of 5 kW was used as a power source. The supply voltage to the

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primary winding of the transformer was limited by a laboratory autotransformer. The measurement of the electric current in the secondary circuit was carried out by a shunt.

The electromechanical treatment was carried out according to the following protocol. The cylindrical sample was installed in the lathe. The speed of the EMT, the density of the electric current, and the voltage were 1.57 m/min, 600 A/mm^2, and 0.5 V, respectively. The longitudinal movement of the roller was determined by the feed rate of the tool holder; in this experiment, the feed rate was constant (0.5 mm/rev). The transmitting efforts to the rollers was 100 kgf. Water was used for cooling of the contact zone during the EMT process, for this reason there was no overheating of the WC–6Co rollers and the samples.

For determining the properties of the coatings, the sample was sectioned to two parts. One part was cut from the areas treated by the EMT, one part had the plasma sprayed Ni coating, not treated by the EMT. Then each part was cut transversely, mounted in plastic, and polished to 1 mm diamond finish. The particles of the feedstock powder were mounted in resin and polished to 1 μm diamond finish, too.

The elastic modulus of the coating was obtained by means of nondestructive method. It was determined in cross-section of the plasma sprayed coating and the treated by means of the EMT coating. For the test a dynamic ultra micro hardness tester (SHIMADZU DUH 211S) with the Vickers indenter at the loads of 1 and 1.5 N were used. Minimum 15 indentations were applied to each sample. The indentation tests were made according to ISO 14577-1:2015 “Metallic materials -- Instrumented indentation test for hardness and materials parameters -- Part 1: Test method”.

3. Results and discussion

The analysis of the structure and the mechanical properties was described in the article [16]. The Rz parameter of the plasma sprayed Ni coating decreased from 30 ± 5 μm to 7 ± 3 μm after the EMT. The porosity of coatings decreased from 8.0 ± 1.5% to 2.5 ± 0.5% after the EMT. The tensile strength of the Ni coating was 105 ± 15 MPa, the tensile strength of the coating after the EMT with the load of 100 kgf was 305 ± 20 MPa. The tensile tests showed that the displacement increased from 0.22 ± 0.05 to 0.37 ± 0.05 mm after the EMT.

The indentation tests (Figure 1) show that the indentation depth under applied test force decreases from 5.29 ± 0.05 μm to 5.21 ± 0.05 μm, the elastic modulus of the coating increases from 63 ± 5 GPa to 95 ± 5 GPa, the average relation W_{elast}/W_{total} increases from 24.6 % to 49.3 % after the EMT.

The analysis of the elastic properties of the plasma sprayed Ni coating shows that the elastic modulus of the coating and the average relation W_{elast}/W_{total} are low because of large amount of the residual pores and the low cohesive strength between the splats. During the EMT process of the plasma sprayed Ni coating the combined action of pressure and local Joule heating deforms the splats and welds their boundaries. The amount of the residual pores decreases. For this reason, during the indentation process (Fig.1) the indentation depth (h_{max}) decreases and at the end of the process the permanent indentation depth decreases after removal of the test force (h_p). Thus, the elastic modulus and the average relation W_{elast}/W_{total} of the treated by the EMT coating increase, too.

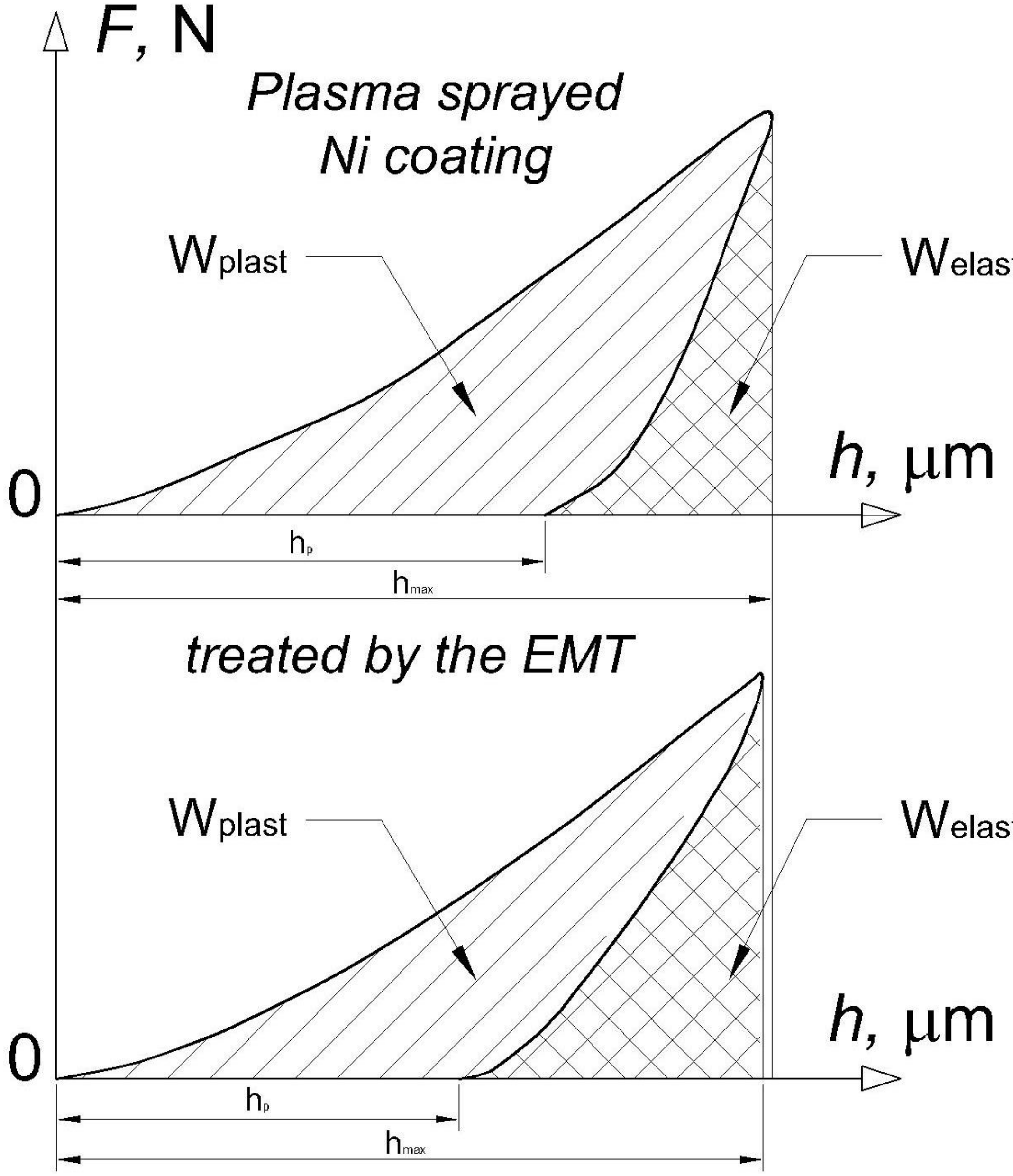

Figure 1. The indentation diagrams of the plasma sprayed Ni coating and of the treated by the EMT plasma sprayed Ni coating

4. Conclusion

1. After the EMT the elastic modulus of the plasma sprayed coating increases from 63 ± 5 GPa to 95 ± 5 GPa because of densification and increase of cohesive strength.
2. The average relation W_{elast}/W_{total} increases from 24.6 % to 49.3 %, this confirms welding processes.
3. During the EMT process the combined action of pressure and local Joule heating deforms the splats and welds their boundaries, for this reason, the EMT has a significant impact on the elastic properties of the treated coating.

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