INFLUENCE OF PECULIARITIES OF PLASMA SPRAY TECHNOLOGY ON EFFICIENCY OF Al_2O_3 COATINGS

Alexey STEPNOV[1], Igor BELYAEV[2], Viacheslav BAZHENOV[3], Artem PAVLOV[4], Andrei KIREEV[2]

[1] *Research and Production Enterprise "Center for Plasma Spraying" LLC, Vladimir,*
Russian Federation, stepnov86@mail.ru

[2] *Vladimir State University named after A.G. and N.G. Stoletovs, Vladimir,*
Russian Federation, belyaev-iv54@yandex.ru

[3] *National University of Science and Technology "MISiS", Casting Department, Moscow,*
Russian Federation, v.e.bagenov@gmail.com

[4] *"Coating Technologies", Vladimir, Russian Federation, pavlovaa@mail.ru*

Abstract

The adhesion strength of a plasma-sprayed Al_2O_3 coating with a steel surface was investigated. Various cooling options for this surface were used. It was found that the best result is achieved with active water supply to the spraying zone. The boundaries of the Al_2O_3 coating and the deposited surface were studied by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). No evidence of chemical interaction between the Al_2O_3 coating and the sprayed surface was found. At the same time, quantitative X-ray phase analysis showed that when the water is supplied to the sputtering zone, the phase composition of the Al_2O_3 coating significantly changes. The amount of α-Al_2O_3 and δ-Al_2O_3 decreases ~ 5-fold, and the amount of γ-Al_2O_3 increases more than 1.5-fold. Given the differences in the physicochemical properties of Al_2O_3 modifications, this is probably the main reason for the increase in adhesion strength of the Al_2O_3 coating with a sprayed surface. The technical solutions found were used to form a sublayer of γ-Al_2O_3, onto which the Al_2O_3 coating was applied already without water supply to the sputtering zone. The obtained coating had a hardness HV = 821 kgf / mm^2. The material of the underlayer and the coating material in the contact zone were a single whole.

Keywords: Plasma spraying, Al_2O_3 coating, adhesion strength, phase composition, structural modifications

1. INTRODUCTION

Al_2O_3 coatings are widely used in technology to increase the wear resistance of parts surfaces. The main way of applying such coatings is plasma spraying. At the same time, there is a problem of adhesion strength of Al_2O_3 coating to the material of the sprayed surface. Usually this problem is solved by applying a sublayer of expensive nickel or cobalt-based materials to the sprayed surface. This significantly complicates and increases the cost of technology for creating wear-resistant Al_2O_3 coatings [1,2].

The purpose of this work is to simplify and reduce the cost of the technology for creating Al_2O_3 coatings without significantly reducing their adhesion strength to the sprayed surface.

2. MATERIALS AND METHODS

For powder coating, α-Al_2O_3 powder grade 25A with an average grain size of 32 μm was used. The plasma deposition unit UPN-350 (Russia) was used. The design of the plasma torch realized a circuit with a rotating anode [1,3]. Plasma-forming gas was compressed air. The surface material for the sputtering was steel grade St.20 (analogue of Gr. A steel with carbon content 0.2 wt. %). The surface to be sprayed was previously sandblasted. The deposition process consisted in passing high-velocity particles α-Al_2O_3 through a plasma stream and applying these particles to a stationary steel sprayed surface. The sputtering modes were the same in all cases: the arc current of the plasma torch is 125-130 A; the voltage is 200-210 V; the pressure of the plasma-forming gas (air) is 0.5 MPa; distance of spraying - 200 mm; the speed of movement of the plasma torch relative to the sprayed surface is 20 mm / s. Four different technological variants of plasma spraying were investigated: 1) the sprayed surface was preheated to a temperature of 350 °C; 2) the sprayed surface has room temperature before the beginning of the deposition; 3) the sprayed surface according to the variant (2), but during the spraying it is cooled by air; 4) the sprayed surface according to the variant (2), but during the spraying it is cooled by water. The peculiarity of the technology was that in the implementation of variants (3) and (4) compressed air and water were supplied directly to the spraying zone.

To assess the adhesion strength of the coating to the sprayed surface, the "torn off pin" method was used [4.5]. The scheme of the method is shown in **Figure 1**.

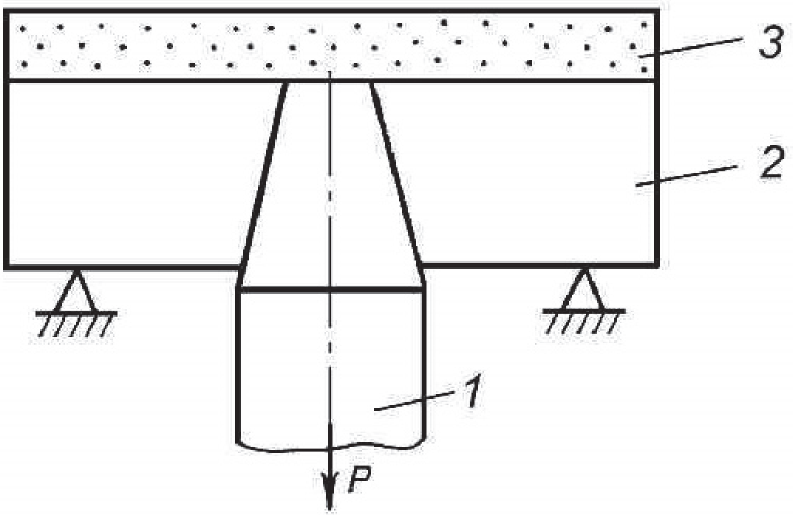

Figure 1 Scheme of the test method for adhesion strength of a coating with a sprayed surface: 1 - pin; 2 - a washer; 3 - ceramic coating

Using a WDW-100E tensile test machine, a steel cone pin 1, dusted to the surface of the washer 2, was torn off from ceramic coating 3. At the same time, the tearing force was fixed. The value of adhesive strength was determined through the ratio of the detachment force to the area of detachment of the destroyed coating. For each variant of the deposition, the experiment was repeated 3 times. The results were determined as the arithmetic mean.

The boundaries of the Al_2O_3 coating and the sprayed surface were investigated by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS) using a Tescan Vega 3 SBH (Czech Republic) microscope with EDS system Oxford (USA).

The phase composition of Al_2O_3 coatings was determined by quantitative X-ray diffraction analysis using a D8 Advance X-ray diffractometer from Bruker AXS (Germany). The volume fractions of the phases were determined by the method of autonomous pulse counting using a special data processing program. Studies were carried out in the radiation of CoKα.

3. RESULTS AND DISCUSSION

For each technological variant of sputtering, the adhesion strength of Al_2O_3 coatings with a sprayed surface was determined by the above procedure. The results are shown in **Table 1**.

Table 1 The results of determining the adhesion strength of Al_2O_3-coatings at different technological spraying options

No.	Technological regimes of plasma spraying of a coating of aluminum oxide.	Strength of adhesion, σ, MPa
1	The sprayed surface is preheated to a temperature of 350 °C	29.26
2	The surface to be sprayed before the beginning of deposition has a room temperature	27.35
3	The sprayed surface according to the variant (2), but during the spraying it is cooled by air	31.05
4	The sprayed surface according to the variant (2), but during the spraying it is cooled by water	63.12

It can be seen from **Table 1** that the best value of adhesive strength is achieved when implementing variant (4) ie. with an active supply of water to the spraying zone. To determine the reasons leading to such results, the interfaces of Al_2O_3 coatings with the material of the sprayed surface were investigated. SEM and EDS methods were used. Studies have shown that there are no signs of chemical interaction between the coating material and the material of the sprayed surface using these methods. **Figures 2 and 3** show the results of these studies.

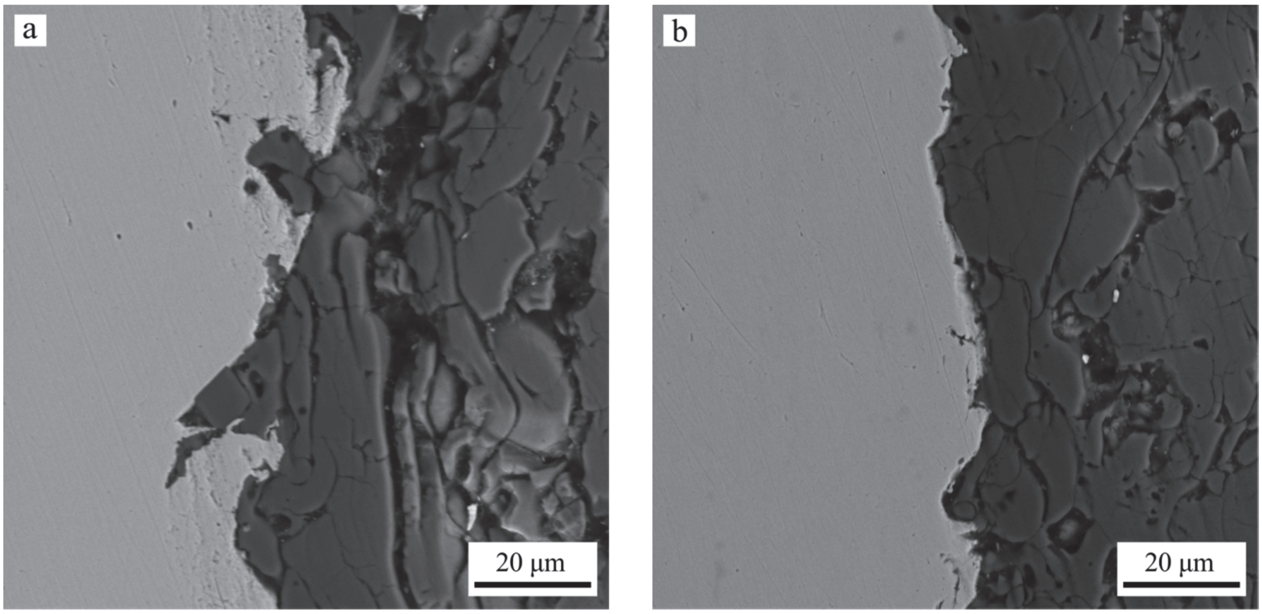

Figure 2 SEM micrographs of the interface of Al_2O_3 coatings with the material of the sprayed surface: (a) - spraying according to option 2; (b) - spraying according to the variant 4

It can be seen from the figures that there are no new chemical compounds on the boundary of Al_2O_3 coatings with a deposited surface. At the same time, it was established by quantitative X-ray phase analysis that when the water is fed into the sputtering zone, the phase composition of the Al_2O_3 coating significantly changes. Thus, in the implementation of variants (1), (2) and (3), the coating consists of the following set of modifications of Al_2O_3: 10-13% α-Al_2O_3, 25-31% δ-Al_2O_3, 59-62% γ-Al_2O_3 (wt. %). When implementing variant (4), the coating contains ~ 2.1% α-Al_2O_3, 4.5% δ-Al_2O_3 and 93.4% γ-Al_2O_3 (wt. %). As can be seen, the amount of α-Al_2O_3 and δ-Al_2O_3 decreases ~ 5-fold, and the amount of γ-Al_2O_3 increases by more than 1.5 times. Such a sharp shift in the phase composition of the Al_2O_3 coating toward increasing the amount of γ-Al_2O_3 modification and decreasing the amounts of α-Al_2O_3 and δ-Al_2O_3 modifications confirms the data presented in ref. [6] on the stabilizing action of water on γ-Al_2O_3 in plasma deposition. The high chemical activity of the modification of γ-Al_2O_3 was also noted in [6,7].

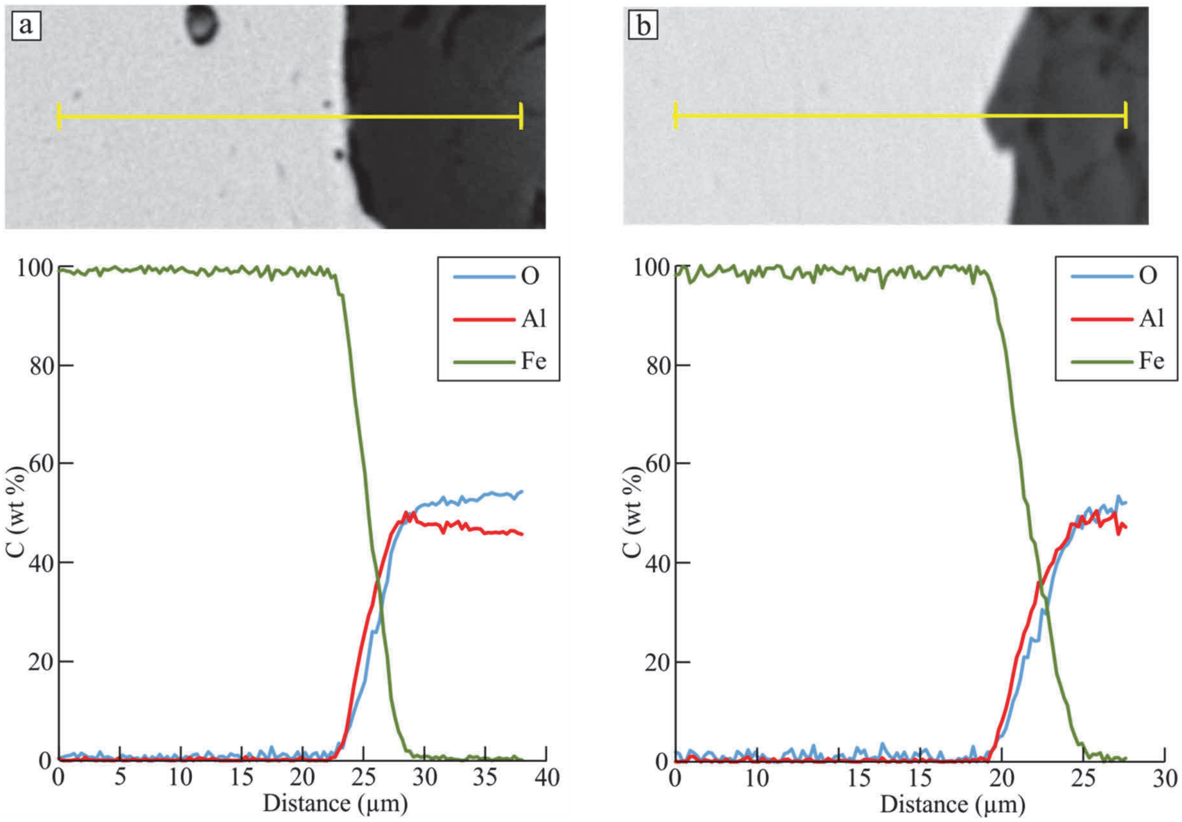

Figure 3 Results of EDS analysis of the interface of Al_2O_3-coatings with the material of the sprayed surface: (a) - spraying according to option 2; (b) - spraying according to the variant 4

It is known that the γ-Al_2O_3 modification formed in the presence of water can have the formula Al_2O_3 x $3H_2O$ or Al_2O_3 x H_2O. It is also known that water falling into the zone of plasma spraying dissociates to form active oxygen and hydrogen ions [6]. These ions interact with both the coating material and the material of the sputtered steel surface. As a result, FeO or Fe_2O_3 compounds are formed on the steel surface. In the process of plasma deposition, these compounds can interact with water-containing modifications of γ-Al_2O_3 to form spinels such as Al_2O_3 x FeO. These spinels are located on the boundary of the Al_2O_3 coating and the sprayed steel surface and can be the reason for the high adhesion strength of the Al_2O_3 coating obtained according to the variant (4). The processes at plasma deposition proceed at high speed and the time released for spinel formation is very small. Therefore, the formed spinel layer must be very thin and, apparently, is not detected by ESD and SEM methods used in the present work.

The sputtering technology of variant (4) was used to form a sublayer of γ-Al_2O_3, onto which the Al_2O_3 coating was applied already without water supply to the sputtering zone. With an undercoat thickness of ~ 100 μm, the resulting coating had a thickness of ~ 400 μm and a hardness HV = 821 kgf / mm^2. The material of the sublayer and the coating material in the contact zone were a single whole.

4. CONCLUSION

Adhesive strength of Al_2O_3-coating with steel sprayed surface significantly increases when water is supplied to the spraying zone. The most probable cause of this is the formation of a chemically active modification of γ-Al_2O_3, capable of interacting with the material of the sprayed surface. The observed effects are well reproduced and can be used to improve the current methods of applying Al_2O_3 coatings by plasma spraying. This makes it possible to simplify and reduce the cost of technology to create efficient Al_2O_3 coatings.

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