ELECTROSPARK TI-AL COATINGS: DEPOSITION, STRUCTURE AND PROPERTIES

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Abstract. Titanium coatings were deposited onto aluminum alloy substrates by means of electrospark deposition using different discharge parameters in argon and air, to create titanium aluminides. The microstructure and composition of the coatings were investigated by X-Ray diffraction and SEM microscopy. An Al_3Ti intermetallic was observed in the coatings deposited in argon. The electrospark coatings obtained in air also contained aluminum oxide and titanium nitride species. The modified surface layers have a higher microhardness and wear resistance than the substrate materials.
Keywords: intermetallic, electrospark deposition, coating

Introduction

Ti-Al intermetallics have many unique properties, such as high melting point, low specific weight, good oxidation resistance, thermal stability and excellent creep strength, which create favorable conditions for their use as construction materials in the aerospace and automotive industries [1]. In some cases, the entire object does not need to be produced completely from the intermetallic compounds, and it is sufficient to cover the surface of the object to achieve the required properties. The intermetallic coatings can be deposited by various methods, such as ion implantation [2], vacuum arc deposition [3], magnetron sputtering [4], laser alloying [5] and plasma spraying [6]. The majority of these methods require that the deposited coatings undergo an additional annealing procedure. In our work, the electrospark alloying (ESA) technique was utilized to create titanium aluminide coatings that allow for improved wear/corrosion-resistant properties due to the deposition of the anode material directly onto the surface of the metal [7]. ESA is a pulsed-arc process that uses short-duration, high-current electrical pulses. The main aim of our investigations was to study the influence of ESA processing parameters on the microstructure, composition, microhardness and wear resistance of Ti-Al coatings.

Experimental

The substrates employed were 10×10×5 mm^3 plates of an aluminum alloy, while 40×3×3 mm^3 rods of titanium (99 wt.%) were used as the alloying electrodes, i.e., the anodes. For electrospark deposition, we used a current pulse generator with a transistor key scheme in multiple regime. The interelectrode voltage during the pulses was maintained at 40 V. The discharge current amplitude was 100 A, while the frequency of pulses was 100, 200, 500 and 1000 Hz. The pulse duration varied from 20 to 400 μs. The total processing time was 2–20 min. The coatings were deposited in argon or air.

The microstructure and chemical composition of the coatings were analyzed using an optical microscope and a scanning electron microscope (SEM) EVO

40HV with an energy-dispersion spectrometer INCA Energy 350. The phase composition of the produced coatings was examined by an X-ray diffractometer (XRD) DRON-7 equipped with a Cu–K_α radiation source in the Bragg-Brentano geometry. The microhardness was measured by the Vickers method with a PMT-3M tester under a load of 50 N. The abrasive wear resistance of the electrospark coatings was measured by a friction machine CALOTEST using the "ball - plate" scheme. A ball with diameter of 30 mm was rotated at linear velocity of 0.27 m/s. An aluminum oxide powder in solar oil was employed as an abrasive material.

Results

Fig. 1 provides the X-ray diffraction patterns of aluminum alloy surfaces after the electrospark deposition in argon and air. It is demonstrated that various gases influence on the composition of titanium coatings differently. In the XRD spectra of coatings deposited in argon, the peaks of Al and Al_3Ti intermetallic were only observed, while the peaks of pure titanium and Al-Ti intermetallics with other stoichiometric ratios were absent. After electrospark treatment in air, the reflections of Al_3Ti intermetallic species were already visible in the XRD spectra. The peaks for titanium nitride and aluminium oxide that formed by the interaction of electrode materials with the components of an ambient environment (O_2 and moisture) were also detected. When the total processing time increased, the intensity of peaks corresponding to Al_2O_3 and TiN increased, in contrast to that of Al and Al_3Ti, which decreased.

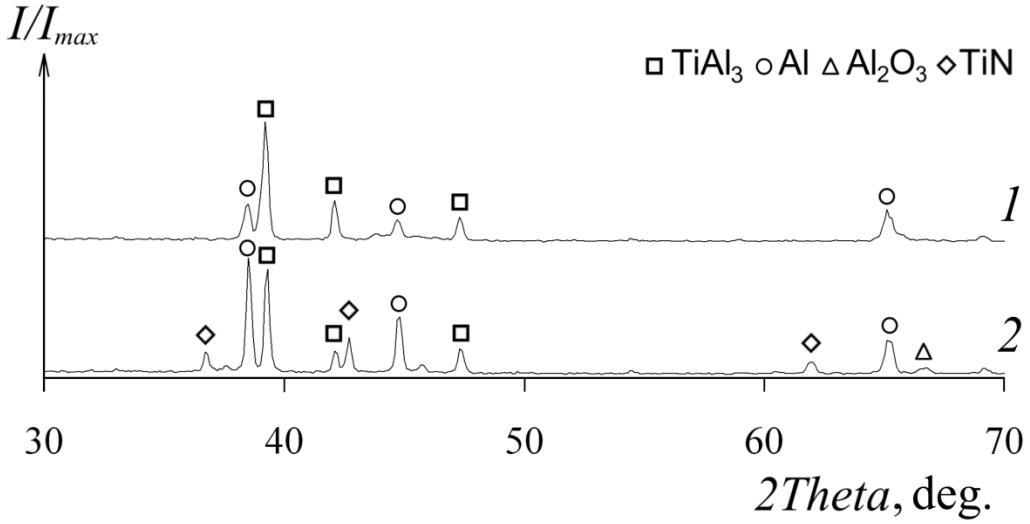

Fig. 1. XRD patterns of the titanium coatings deposited on aluminium in (*1*) argon and (*2*) air.

The aluminium coatings received on titanium in argon are uniform, and have less cracks and pores as compared with the titanium coatings on aluminium. Inclusions of TiAl with diameter less than 1 micron were found. Concentrations of titanium and aluminium on different depth are differing. The ration between concentrations of these elements in upper layers is close to $TiAl_3$ and to TiAl in

deeper layers. The XRD analysis showed, that the aluminium coatings received on titanium in argon consist of the set of phases such as Al, Ti and $TiAl_3$ (fig. 2). With the increasing of the common deposition time, the amount of $TiAl_3$ becomes more. The change of duration and discharge frequency did not influence on the qualitative composition of the coatings.

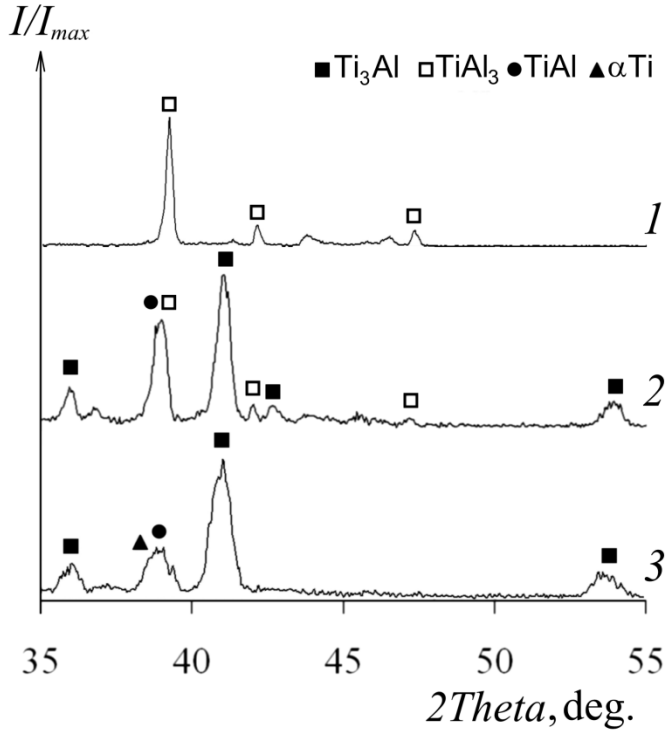

Fig. 2. XRD patterns of (*1*) the aluminum coatings deposited onto titanium in argon and the coatings produced by the sequential deposition during: (*2*) Al - 1 min and Ti - 1 min; (*3*) Al - 3 min and Ti - 1 min.

So long as the amount of titanium it is not enough for the formation of intermetallic Ti_3Al, therefore we offered to create combined coatings by the sequential deposition of aluminium and titanium. The first aluminium was deposited to titanium for different time from 1 to 4 min, and then the second titanium layer was deposited during 1-3 min. Despite two stages of the deposition of the combined coatings, the foliated structure is not visible that is explained by the active mixing of substance in molten state. The compositions of coating are characterized by the presence of the three main phases: Ti, $TiAl_3$, Ti Al and TiAl (Fig. 2). With the increase of the deposition duration of the first aluminium layer from 1 to 4 min, the titanium content decreases, and amount TiAl and $TiAl_3$ remains approximately on one level. With the growth of the deposition time of the second titanium layer, the Ti_3Al phase becomes prevailing. At the deposition of Ti for 3 min, the amount of α-titanium increased appreciably, and the concentrations of intermetallics decreased, therefore it is expedient to deposit the second titanium layer during less than 2 min.

At the micro-abrasive wear test, it was established that the coatings deposited in argon had microhardness that more in four times then the microhardness of

uncovered titanium. However, the wear coefficient decreased only on 20 % (Table 1). The titanium coatings obtained in air had the better tribological characteristics. The wear coefficient of these coatings reached $1.5 \cdot 10^{-13}$ due to the present of TiN and Al_2O_3. With increasing pulse duration and frequency, the Al_2O_3 content becomes higher as compared with TiN. The wear resistance of the coating obtained at pulse duration of 200 μs and frequency of 500 Hs was highest.

Table 1. Characteristics of combined coatings in argon.

Deposition time Al/Ti [min/min]	1/1	2/1	3/1	4/1	3/2	3/3	Uncovered Ti
Wear coefficient [m^3/(N·m)/]	3.4E-13	2.8E-13	3.9E-13	2.9E-13	3.4E-13	3.3E-13	3.6E-13
Average thickness [μm]	38	64	81	92	70	77	—
Microhardness [GPa]	10.4	9.3	10.6	10.3	10.7	11.4	2.4

Summary

The electrospark processing of aluminum and titanium was performed in argon and air in order to create the intermetallic coatings. The coatings deposited in air contain Al_3Ti intermetallic, aluminum oxide and titanium nitride. Changing the electrospark deposition durations of the first layer of aluminium and the second titanium layer, it is possible to receive the composite coating with the prevailing concentration of one of Ti-Al intermetallics.

Acknowledgements

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References

[1] D.M. Dimiduk: Mater. Sci. Eng. A 263 (1999) 281.
[2] Y. Setsuhara, H. Ohsako, Y. Makino, S. Miyake: Surf. Coat. Technol. 66 (1994) 495
[3] S. PalDey, S.C. Deevi, T.L. Alford: Intermetallics, 12 (2004) 985.
[4] C. Leyens, M. Peters, W.A. Kaysser: Surf. Coat. Technol. 94-95 (1997) 34.
[5] A. Hirose, T. Ueda, K.F. Kobayashi: Mater. Sci. Eng. A 160 (1993) 143.
[6] P. Staron, A. Bartels , H.-G. Brokmeier, R. Gerling, F.P. Schimansky, H. Clemens: Mater. Sci. Eng. A 416 (2006) 11.
[7] E.I. Zamulaeva, E.A. Levashov, A.E. Kudryashov, P.V. Vakaev, M.I. Petrzhik: Surf. Coat. Technol. 202 (2008) 3715.