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TRIBOLOGICAL BEHAVIOR OF A PLASMA-SPRAYED Al_2O_3-TiO_2-Cr_2O_3 COATING

TRIBOLOŠKO PONAŠANJE S PLAZMO NAPRŠENEGA Al_2O_3-TiO_2-Cr_2O_3 NANOSA

Yeşim Sert, Nil Toplan

Sakarya University, Department of Metallurgical and Materials Engineering, Esentepe Campus, 54187 Sakarya, Turkey
toplan@sakarya.edu.tr

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Alumina-titania, titania, chromia and chromia-titania coatings, deposited on aluminium substrates with atmospheric, plasma-spray, coating techniques (APSCTs), were tested on a low-frequency reciprocating-sliding tribometer. The surface wear of the coatings was investigated with SEM and optical microscopy. The denser Cr_2O_3 coatings showed a higher wear resistance than the more porous Al_2O_3-TiO_2 and TiO_2 coatings. An increase in the titania content diminishes the coating hardness and the wear resistance.

Keywords: Cr_2O_3-TiO_2, Al_2O_3-TiO_2 coatings, textile parts, plasma-spray coating, wear

Nanosi Al_2O_3-TiO_2, TiO_2, Cr_2O_3, Cr_2O_3-TiO_2 z atmosferskim plazemskim nanašanjem z brizganjem (APSCT) na podlago iz aluminija so bili preizkušeni na nizkofrekvenčnem protismernem drsnem tribometru. Obrabljena površina nanosa je bila preiskovana s SEM in svetlobno mikroskopijo. Gostejši nanos Cr_2O_3 je pokazal večjo odpornost proti obrabi kot bolj porozna nanosa Al_2O_3-TiO_2 in TiO_2. Povečanje vsebnosti TiO_2 zmanjšuje trdoto nanosa in zmanjša odpornost proti obrabi.

Ključne besede: nanosi Cr_2O_3-TiO_2, Al_2O_3-TiO_2, kosi tkanine, plazemski nanos z brizganjem, obraba

1 INTRODUCTION

It is well known that aluminum (Al) alloys have been considered to be some of the most useful and versatile materials because of their metallurgical characteristics, such as high strength-to-weight ratio, and high thermal conductivity. They are also easy to shape and relatively inexpensive. However, the low hardness results in poor tribological characteristics and prevents their wide use, especially in the situations where a hard surface is needed. To improve the wear resistance, many techniques, such as metal-matrix composites, plasma spraying, thermal spraying and hard anodizing have been explored[1].

The APSCT is an economical and effective method applied to various machine parts to improve the component performance in wear, corrosion, thermal barrier, and electric insulation. Plasma-sprayed Al_2O_3-TiO_2 has been widely used as a wear-resistant coating in textile, machinery and printing industries[2–5]. Cr_2O_3 has a wide range of applications such as green pigments, coating materials for thermal protection and wear resistance as well as refractory applications due to the high melting temperature (about 2435 °C)[3,6]. The present paper deals with the wear resistance of the plasma-sprayed alumina-titania, titania, chromia and chromia-titania coatings that increased the service life of the shutters (Al-based) used in the textile industry.

2 EXPERIMENTAL PROCEDURE

The commercial feedstock powders in the mass fractions 13 % TiO_2-Al_2O_3 (Metco 130), 40 % TiO_2-Al_2O_3 (Metco 131VF), 100 % TiO_2 (Metco 102) and 100 % Cr_2O_3 (Metco 106) were supplied by SULZER METCO Powder Technology. Al_2O_3, TiO_2 and Cr_2O_3 powders were premixed to form five different compositions (**Table 1**) and these were prepared on an aluminium alloy (AA1050). The mixtures were ball-milled for 2 h by using ZrO_2 balls and distilled water as the milling media to provide homogenous mixtures. After drying the powders were screened and sieved to

Table 1: Coating powders (*w*/%)
Tabela 1: Prahovi za nanašanje (*w*/%)

Composition	Al_2O_3	TiO_2	Cr_2O_3
1	87	13	–
2	60	40	–
3	–	100	–
4	–	50	50
5	–	–	100

Table 2: Plasma-spray parameters
Tabela 2: Parametri nabrizgavanja s plazmo

Coating parameters (for the 1–5 coded compositions)	
Primary-gas flow rate (Ar, L/min)	80
Secondary-gas flow rate (H_2, L/min)	15
Carrier-gas flow rate (Ar, L/min)	40
Spray distance (mm)	100
Current (A)	500
Voltage (V)	60–70

achieve the correct particle-size distribution needed for plasma spraying. Prior to the deposition process, aluminium substrates were grit blasted with Al_2O_3 particles and this was followed by ultrasonic cleaning in acetone for 15 min. A 40 kW plasma-spraying system (METCO 3MB) was utilized to produce the coatings using the parameters summarized in **Table 2**.

The surface roughness was measured with a surface-roughness tester (Perthometer M4P) and the average roughness Ra, defined as the arithmetic mean of the departures of the profile from the mean line, was used to quantify the coating-surface roughness. A scanning electron microscope (SEM) (JEOL JSM-6060LV) equipped with an energy dispersive X-ray spectrometer (EDS) was used to examine the microstructures and chemical compositions of the coatings. An X-ray diffraction analysis (XRD) was carried out on RIGAKU DMAX 2200 to determine the phases of the coating(s). The microhardness values of the specimens were taken from the cross-sections of the polished samples at the load of 200 g and after a loading time of 15 s using LEICA VMHT MOT microhardness equipment. The wear tests were performed using a low-frequency reciprocating-sliding tribometer, connected to a computer monitoring the dynamic coefficient of friction (in both sliding directions), relative humidity and temperature. The tests were performed by applying a load of 5 N to a single-crystal Al_2O_3 (sapphire) ball with a diameter of 6 mm. The wear specimens had the dimensions of 3 cm × 3 cm × 3 mm, the shear rate was 0.15 m/s and the sliding distance was 150 m. The values of the coefficient of friction were calculated from the normal load and the friction force was obtained from a digital oscilloscope. After the wear tests, the morphology of each wear scar was observed with SEM.

3 RESULTS AND DISCUSSION

Table 3 summarizes five different compositions of the coating-test results. While the TiO_2 coatings had the highest surface-roughness values, the values for the Cr_2O_3 coatings were found to be the lowest. Having a lower as-sprayed surface roughness is very important for technological applications because it reduces the number of post-deposition mechanical treatments necessary[7,8]. As a function of the substrate-surface roughness, the values of porosity and coating roughness increased, while the increase in the substrate-surface roughness grow up. The hardness values were also relatively reduced. The highest hardness, the lowest porosity and the lowest coating roughness were obtained at the value of the substrate roughness of 2.346 μm. The hardness values decrease with the increasing amounts of TiO_2 in the Al_2O_3-TiO_2 coatings. In the Cr_2O_3-TiO_2-based coatings, the hardness values increase with the amount of Cr_2O_3. An increase in the porosity amount will result in a decrease in the hardness of the coating. The lowest coefficient of friction (μ) was achieved in the 100 % Cr_2O_3 coatings. Hardness has a strong influence on wear resistance. The higher the hardness, the better is the wear resistance. It is well known that an addition of TiO_2 to an Al_2O_3 coating is to reduce the melting temperature of the oxide, thereby producing less porous and better performance coatings than the pure Al_2O_3 coatings. The melting temperature decreases due to the fact that TiO_2 has a lower melting temperature (1854 °C) than Al_2O_3 (2040 °C) and due to its ability to form a liquid solution with Al_2O_3. It is also noted that the trend displayed by the coating densities is consistent with that exhibited by the degree of melting, i.e., a high degree of melting (e.g., Cr_2O_3, 2435 °C) results in high density. Increasing the microhardness leads to the improvements in the wear resistance of the coatings. The grain size also has an effect on the wear resistance. The nanocoating has a higher wear resistance than the commercial coating although its hardness is lower than that of the commercial coating. A related study on the abrasive wear has revealed that nanocoatings could have a two-to-four-fold increase in the wear resistance in comparison with the commercial coatings[2,7].

Table 3: Surface roughness, hardness, density and friction coefficient of the coatings

Tabela 3: Hrapavost površine, trdota, gostota in koeficient trenja nanosa

Composition	1	2	3	4	5
R_a/μm	3.553	3.437	4.443	3.011	2.346
Hardness (HV)	1028	899	812	1010	1724
Relative density (%)	87.70	88.45	86.00	90.12	92.51
Average friction coefficient	0.142	0.190	0.223	0.144	0.074

The XRD analysis of the starting powders showed that the chromia powder consisted of an eskolaite phase (Cr_2O_3) and the alumina-titania powder of α-Al_2O_3 and anatase. It was also clear from XRD that the chromia coating consists of eskolaite, the chromia-titania coating consists of eskolaite and $Ti_2Cr_2O_7$ and the alumina-titania coating consists mainly of γ-Al_2O_3 with some α-Al_2O_3, Al_2TiO_5, a glassy phase and a small amount of rutile. A very low amount of crystalline TiO_2 indicates that it mostly dissolves in the molten Al_2O_3 [2,8].

The main wear mechanisms of plasma-sprayed ceramic coatings were reported to be a plastic deformation, crack formation and spalling due to fatigue, brittle fracture and material transfer. In the reciprocated dry sliding, wear debris was considerably involved in the wear process in the steady state. The worn surfaces of the Cr_2O_3 and TiO_2 coatings were observed with SEM at different magnitudes (**Figure 1**). In the SEM images the wear scar of the TiO_2 coating was much larger than that of the Cr_2O_3 coating. The Cr_2O_3 coating is the hardest and the most anisotropic among the plasma-sprayed ceramics due to its low interlamellar cohesion; the Al_2O_3-TiO_2 and TiO_2 coatings are the most isotropic but

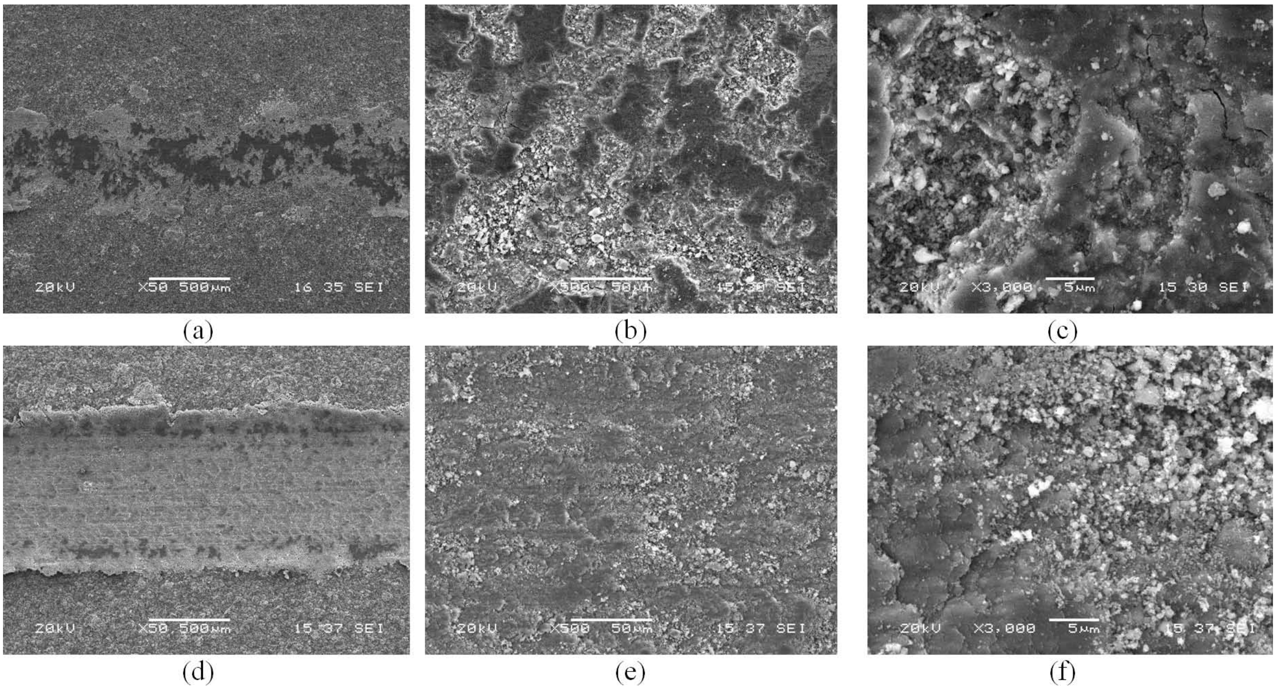

Figure 1: a), b), c) Worn surface morphologies of the Cr_2O_3 and d), e), f) TiO_2 coatings
Slika 1: a), b), c) Morfologija obrabljene površine nanosa Cr_2O_3 in d), e), f) TiO_2

also less hard and less tough due to the formation of an alumina-titania glassy phase which favors intersplat adhesion but turns out to be quite brittle[8]. The smooth film, formed due to a large plastic deformation of the adhered wear debris, strongly influenced the friction and wear behavior. For the plasma-sprayed Cr_2O_3 coatings, similar wear mechanisms were reported under dry sliding conditions and the role of the wear-protective film formed by a plastic deformation of the adhered and compacted debris particles was discussed[9]. The abrasive wear mechanism of the coatings does not only depend on the coating hardness and density, but also on the particle size, the type of the powder used, the coating microstructure, as well as on the microstructural change during a wear testing. The average coarser powder particle size causes an appearance of a significant number of unsmelted particles.

4 CONCLUSIONS

Alumina-titania, titania, chromia and chromia-titania coatings were deposited with APSCT to increase the wear behavior of the aluminium-based shutters. While the friction coefficient and the coating-surface roughness increased with an increase in the titania content, the coating density, hardness and wear resistance decreased.

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