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TRIBOLOGICAL PROPERTIES OF ALUMINA-ZIRCONIA COMPOSITE COATINGS PREPARED BY PLASMA SPRAYING

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Abstract: *The intent of this research was to determine the tribological trends of zirconia as an additive to a plasma-sprayed alumina coating matrix. For the deposition process, pure alumina and alumina-with-zirconia (5%, 10%) weight percentages were employed to be coated on steel substrates using an air-hydrogen plasma. The torch power was set to ~40 kW. The surface roughness for the alumina coatings were in the range from 2.6-3.2 µm and with additive percentages of zirconia, it was found to vary between 3.0-3.7 µm. XRD measurements indicated that the predominant phase in the alumina-zirconia coatings was tetragonal-ZrO_2 (t-ZrO_2) and with alumina, it was α-Al_2O_3 and γ-Al_2O_3. The tribological properties such as the friction coefficient and the wear-rate of the alumina-composite coatings had been inspected to evaluate its dependence on the type and concentration of the additive powders. An increase in friction-coefficient was observed with the addition of zirconia. The normalized wear rates were in the range of ~10^{-5} mm^3/Nm for the composite coatings with certain exceptions.*

Keywords: *Plasma Spraying, Zirconia, Alumina Composite Coating, Tribology.*

1. INTRODUCTION

Customarily, alumina is used as a ceramic coating due to its superior properties such as high hardness and strength, and prevailing wear resistance properties [1]. One of the more feasible ways to produce these coatings is by plasma spraying. The merits of using the plasma spraying technique are an increased flame temperature, proliferated particle velocity and a high degree of melting. This therefore, produces coatings with neat and expedient surface characteristics [2]. It was found that plasma-sprayed alumina had a friction coefficient ranging from 0.53 to 0.78 with varied counter-bodies and the normalized wear rates were found to span from 1.18 x 10^{-6} mm^3/Nm to 2.85 x 10^{-4} mm^3/Nm [3]. In another study it was obtained that the friction coefficient of alumina coatings had ranged from 0.6 to 0.8, the wear rates being from 1 x 10^{-5} to 3 x 10^{-5} mm^3/Nm [4]. In order to compliment the properties of alumina, it has been observed that a ceramic such as zirconia proliferates the toughness, dimensional stability as well the wear resistance, when added to the matrix [5]. It was estimated that with a 25 wt.% reinforcement of ZrO_2 into

Al_2O_3, the average friction coefficient was 0.45 for a vertical load of 30 N [6]. B. Liang et al. even demonstrated a condition wherein the friction dropped to ~0.2 with 70 wt.% of zirconia in the alumina-zirconia composite coating with a wear rate of ~3×10^{-5} mm^3/Nm, and in some other cases even half of the latter [5]. Therefore, to amalgamate both would be to derive at the least, a condition of superior hardness (alumina) and higher toughness (zirconia), which are imperative mechanical properties [5-6]. In this research here, we have employed zirconia additives into an alumina matrix to study the effect of the former's concentration on the tribological properties of the alumina-composite coatings.

2. EXPERIMENTAL

The coatings were deposited on stainless steel substrates (AISI 304L) using a direct current plasma torch operating at atmospheric pressure. The plasma torch herein was constructed at the Lithuanian Energy Institute [7]. The steel substrates *(s)* had dimensions of 40x10x1.5 mm. Additionally, they were subject to polishing and chemical-cleaning as a prerequisite. The steel substrates were positioned on a water-cooled sample holder. Air was employed as for both the primary gas with a total flow rate of 4.72 g/s, and the powder-carrier gas with a flow rate of 0.60 g/s. Hydrogen (0.1 g/s) was employed as the secondary gas. An Al bonding layer *(Al)* was employed to facilitate adhesion between the composite-coating and the substrate. The feedstock materials: Al_2O_3 *(A)* and ZrO_2 *(Z)* powders were from PRAXAIR Surface Technologies- USA, the specifications being ALO-101 and ZRO-113/114, respectively. The spraying distance was set at 70 mm. The coatings were deposited at a torch power of ~40 kW. The surface morphology was investigated by a scanning electron microscope (SEM) Hitachi S-3400N. The elemental composition of the coatings was determined by an energy dispersive X-ray spectroscopy (EDS) Bruker Quad 5040 spectrometer. The surface roughness was measured using a Mitutoyo Surftest-SJ-210-Ver2.00 profilometer. Structural characterization of the coatings was performed by X-ray diffractometry. Tribological properties of the samples were inspected using a CETR-UMT-2 ball-on-disc tribometer. For the tribological tests, an alumina ball of 10 mm diameter of grade 10 (99.5%), was used as a counter-body; the load being taken at 0.8 N. And, the wear was determined by a 3D-white light optical interferometer. We have herein employed three different types of coatings which are: pure alumina *(A)*, alumina with 5 wt.% of zirconia *(A5Z)* and alumina with 10 wt.% of zirconia *(A10Z)*, to gauge its tribological properties.

3. RESULTS AND DISCUSSIONS

The pure alumina coating had a morphology that was well spread but was rather wavy and disordered as seen from the figure 1a. It could be perceived that the coating was well adhered to the substrate with certain branch-like structures upholding it. The size of the irregular splat particles varied from 10-50 µm. With alumina-zirconia coating: *A5Z* (figure 1b), large globules could be observed with the addition of the additive, and the spread of the coating was rather non-uniform in nature. The size of the splats varied from 10-150 µm, and there was the presence of both fully-molten and semi-molten particles in the matrix. It could be seen with 10 wt.% of zirconia to the alumina matrix: *A10Z* (figure 1c), the globular formations had normalized. Nevertheless, both partially and fully-molten particle distributions could be discerned. Additionally, there were interfacial voids that could be perceived throughout the morphology of the composite matrix, and the size distribution was found to be close to the former case with the zirconia additive.

EDS analysis indicated that for *A5Z* and *A10Z* there was a 2-3 wt. % and 4-6 wt. % of zirconium, respectively after the plasma coating process. With the addition of zirconia to the alumina matrix with an R_a of 2.82 µm

(R_q= 3.54 µm), there was an overall increase in the surface roughness of the composite coatings. With *A5Z*, there was an increase up to 3.50 µm (R_q= 4.40 µm), and with *A10Z*, the value was recorded at 3.33 µm (R_q= 4.17 µm). With 10 wt.% of zirconia, there was a drop in the surface roughness (from 5 wt.%), due to the relatively uniform and finer morphology that was yielded.

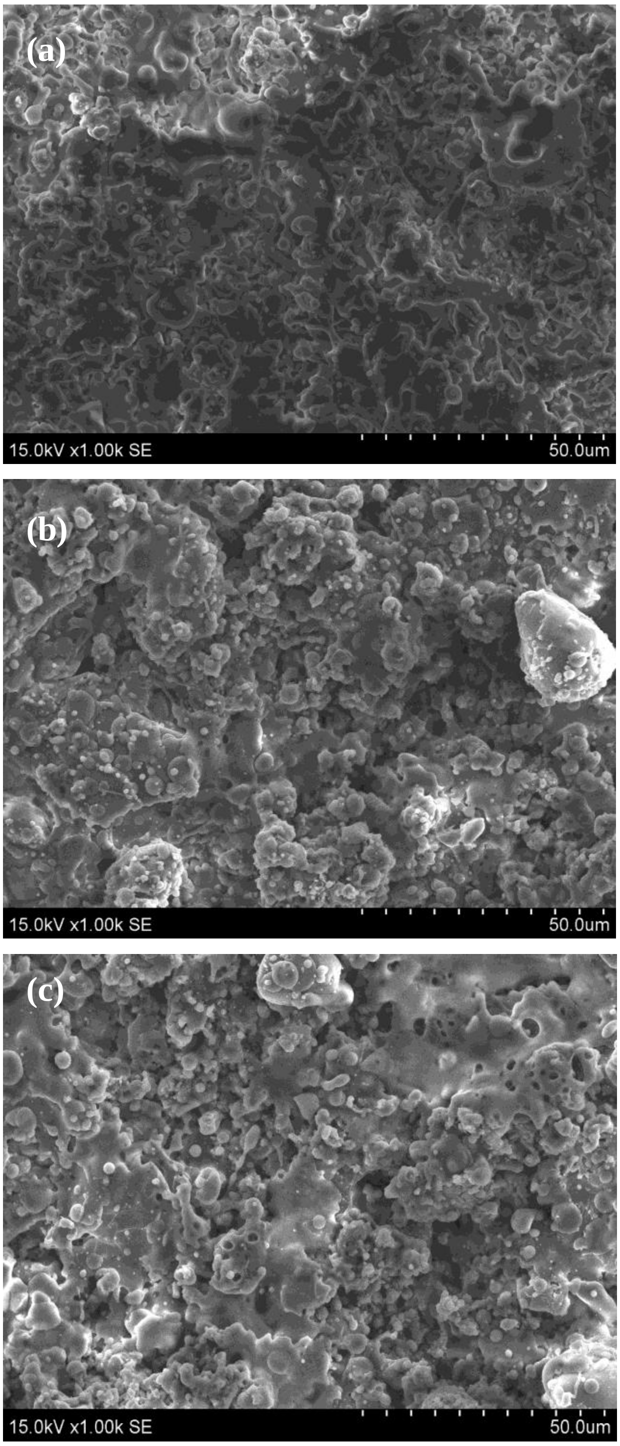

Figure 1. Surface morphology of (a) Al_2O_3, (b) Al_2O_3-5 wt.% ZrO_2 and, (c) Al_2O_3-10 wt.% ZrO_2 coatings

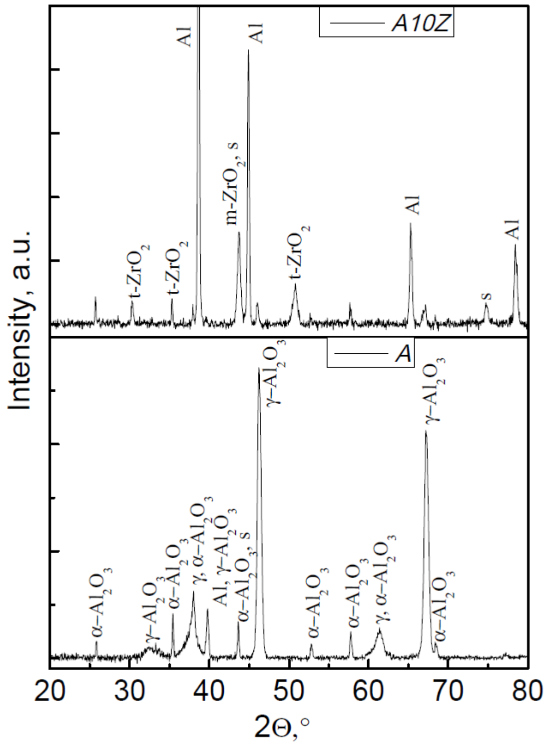

Figure 2. XRD pattern: Alumina *(A)* and Alumina-10 wt.% Zirconia coating *(A10Z)*

The XRD patterns pertaining to alumina *(A)* (see, figure 2) indicated predominantly the presence of rhombohedral α-Al_2O_3 and cubic γ-Al_2O_3 phases. The peaks at 25.84°, 35.42°, 43.63° etc., denoted the α-Al_2O_3 phase. The highest intensity peaks at 46.23° and 67.18° were found to be of γ-Al_2O_3. As regards the XRD pattern of the alumina-zirconia *A10Z* coatings: there was the presence of t-ZrO_2 (30.29°, 35.29°) and m-ZrO_2 (43.7°) phases, which was also similar to that of *A5Z*. Meanwhile, the intensities of the α-Al_2O_3 and γ-Al_2O_3 peaks were reduced with the additives.

As for the tribological properties of the coatings, the advancement of the friction coefficient with sliding distance for cases within the three types of coatings are presented herewith. As seen from the figure 3, alumina coatings *(A)* had the most stable steady-state and the lowest friction coefficient; for *A5Z* it was mid-level in terms of steady-state characteristics and the friction coefficient; with *A10Z* it was the highest. Gauging the average friction coefficient of the alumina coating *(A)*, it turned out to be 0.55 and for the cases with zirconia additives, it was found to be 0.65 and 0.74 for *A5Z* and *A10Z* coatings, respectively.

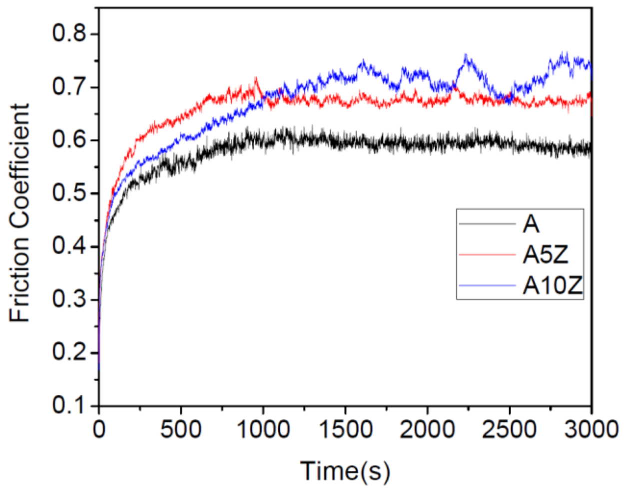

Figure 3. Friction coefficient curves for *A, A5Z* and *A10Z*

The normalized wear rate for *A* and *A5Z* coatings were found to be practically immeasurable, due to a mere plastic deformation, but with *A10Z*, it was found to be 2.64 x 10^{-5} mm^3/Nm. The reasons for the lowest friction coefficient and wear rate as in the pure alumina coatings could be mainly due to the presence of a strong phase: γ-Al_2O_3, brought forth due to the $\alpha \rightarrow \gamma$ transformations from well-melted particles aiding a better surface morphology subject to efficient substrate cooling [7]. With respect to the alumina-zirconia *A5Z* coatings, the well-spread tetragonal phase which aids in the formation of a stronger and tougher matrix, could have been seen in application here [6]. With *A10Z*, the negative effect of both interfacial-voids and crevices as seen from the morphology, could have outweighed the tetragonal-phase effect as observed in the former, leading to a measurable wear and the highest friction coefficient in comparison. Therefore, the ideal concentration of the additive zirconia was estimated to be 5 wt.%, depicting exemplary friction characteristics and a neat wear-resistance from among the composite coatings.

4. CONCLUSION

The work herewith studied the tribological effect of zirconia as an additive (5, 10 wt.%) to a plasma-sprayed alumina matrix. It was demonstrated that the friction coefficient of the pure alumina coating was the least (0.55), and with 10 wt.% of zirconia, it was the highest (0.74). The normalized wear rate was the least for the condition with 5 wt.% of zirconia, just as with the pure alumina, whereas with *A10Z* it was the highest (2.64 x 10^{-5} mm^3/Nm). The tangible effect of the phases: γ-Al_2O_3 and t-ZrO_2, could be observed for its contribution toward the superior tribological properties subject to plasma-spray parameters, in the alumina-composite coatings.

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