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Fracture toughness of $Al_2O_3/ZrSiO_4$ coatings obtained by multi-chamber gas-dynamic accelerator

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Fracture toughness of $Al_2O_3/ZrSiO_4$ coatings obtained by multi-chamber gas-dynamic accelerator

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Abstract. In the current work the research of fracture toughness of $Al_2O_3/xZrSiO_4$ composite coatings have been realized using automatic system for microhardness analysis. $Al_2O_3/xZrSiO_4$ (x = 0, 3, 25 wt. %) coatings were produced from a mixture of cheap raw materials (alumina and zircon $ZrSiO_4$) on the surface of stainless steels by a new multi-chamber gas-dynamic accelerator. It has been experimentally established that adding of $ZrSiO_4$ increases fracture toughness of alumina coatings.

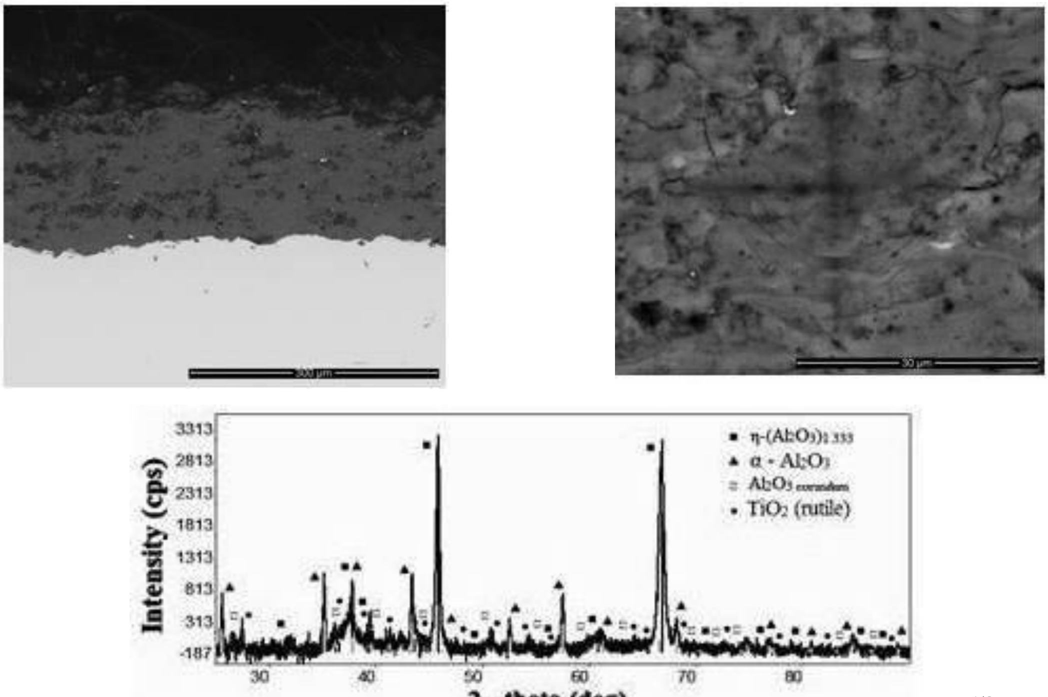
Zirconium silicate ($ZrSiO_4$) and aluminum oxide (Al_2O_3, alumina) are some of the most used and cheapest materials for coatings production on the heat-resistant surfaces [1]. Microhardness and fracture toughness of Al_2O_3 coatings can be improved by adding of other components with a goal to compensate decreasing of these properties owing to transformation of Al_2O_3 to metastable condition. For instance, an addition of $ZrSiO_4$ (zircon) increases fracture toughness of Al_2O_3 coatings [2]. In the current work influence of $ZrSiO_4$ addition to Al_2O_3 composite coatings (0, 3, 25, wt. %) on fracture toughness was investigated.

In the present work the mixture of alumina (average size of particles is 34.2 μm) and zircon (average size of particles is 18.3 μm) was used as feedstock materials for coatings deposition on the surfaces of 304L stainless steel. The powders were mixed and grinded during 3 h with ethanol in a ball mill. The alumina powder consists of γ-Al_2O_3 with a cubic lattice, α-Al_2O_3 with a trigonal lattice and TiO_2 (rutile) with a tetragonal lattice. The phase analysis has shown that the main phase in zircona powder is $ZrSiO_4$ with a tetragonal lattice. The phase composition of the powders and the coatings was investigated by X-Ray diffractometer Rigaku Ultima IV. $Al_2O_3/xZrSiO_4$ composite coatings (80–190 μm) were obtained by a multi-chamber gas-dynamic accelerator [3–5]. The porosity of the coatings is less than 1 % (0.30 ± 0.01 %). The investigation of fracture toughness was provided with using of an automatic system for a microhardness analysis on the base of a motorized microhardness tester DM-8 and scanning electron microscope Quanta 200 3D (SEM). Five imprints were made with the load of 300 g in a cross-section in the coating layer. Then, the imprints and cracks were photographed with help of SEM and the length of all cracks and imprints were measured. The magnitude of fracture toughness was calculated with the following formula:

$$K_C = 0.079\, P/a^{3/2} \log 4.5(a/c),$$

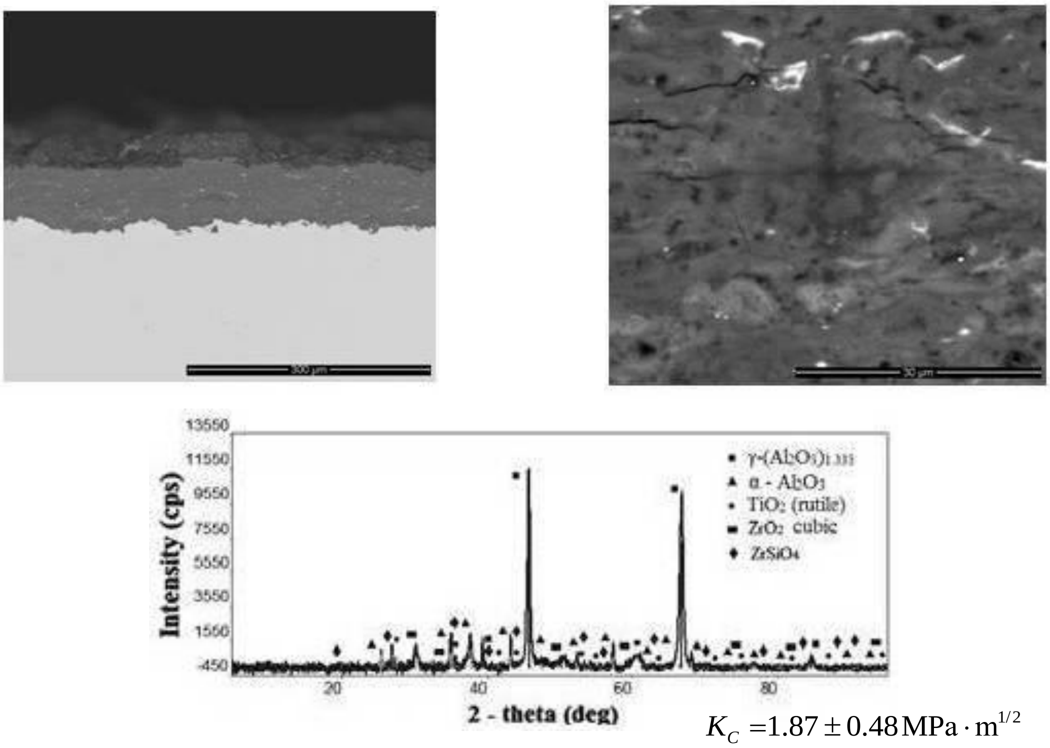
where P – the load of the indenter (μN); a – the average value of a half of the imprint length (μm); c – the sum of the average value of a crack length with a half of the imprint length (μm) [6, 7].

The type of cracks formation is determined as I type (longitudinal crack) (figure 1), where the dominating cracks occur parallel to a substrate and spring from one or two horizontal angles of the imprint.



$K_C = 1.68 \pm 0.54\,\mathrm{MPa} \cdot \mathrm{m}^{1/2}$

(a)

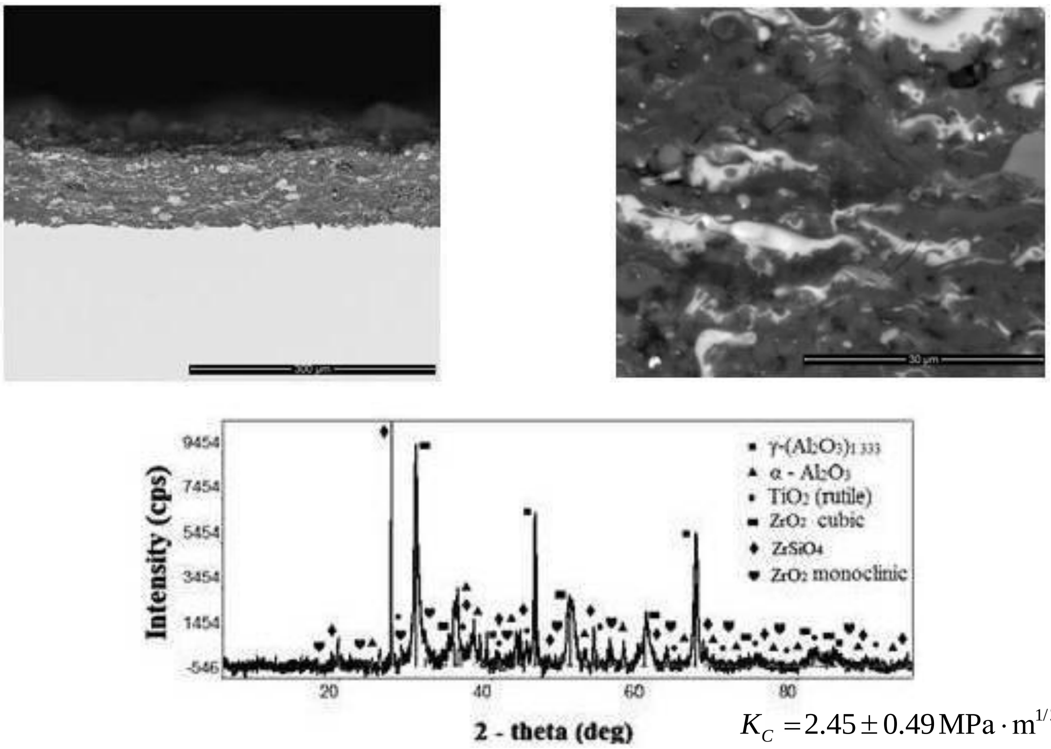


$K_C = 1.87 \pm 0.48\,\mathrm{MPa} \cdot \mathrm{m}^{1/2}$

(b)

Figure 1. SEM microphotographs, X-Ray pattern and typical views of imprints and cracks (cross-section) for: **(a)** – Al_2O_3; **(b)** – $Al_2O_3/3ZrSiO_4$.

The fracture toughness of the coatings on the base of alumina noticeably increases from 1.68 to 2.45 MPa·$m^{1/2}$ with $ZrSiO_4$ addition. A bigger zirconium dioxide grains was found in the structure of $Al_2O_3/25ZrSiO_4$ coating that lead to high content of monoclinic phase (figure 2). This mechanical strength can improve resistance to cracks propagation in zirconium dioxide owing to hardening mechanism as a result of transition of one modification to another [8, 9].



$K_C = 2.45 \pm 0.49\,\mathrm{MPa \cdot m^{1/2}}$

Figure 2. SEM microphotographs, X-Ray pattern and typical views of imprints and cracks (cross-section) for $Al_2O_3/25ZrSiO_4$.

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