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## DEVELOPMENT OF THE THERMAL BARRIER COATING FOR HEAT AFFECTED COMPONENTS OF AIRCRAFT GROUND SUPPORT EQUIPMENT

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**Abstract.** Heat protection properties of SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> components composite material in a result of high temperature oxidization at temperature close to ceramics melting point have been researched. The evidence of formation on the surface of wear- corrosive-proof three-layered protective scale with the outer layer of fine-grained fibrous structure of aluminium silicate in thickness of 180 micrometers has been established. Application advisability of specified composition material, both as the solid bulk, and as coating deposited for protection of heat bearing components of aircraft ground support equipment

**Keywords:** composition ceramics; high temperature oxidization; fibrous structure; thermal barrier coating.

### 1. Introduction

Components of aircraft ground support equipment closely contact with hot and chemically aggressive substances that may cause serious damage and substantially reduce their life time.

So, components thermal protection is now vital and already well researched for protective system made of elements which are rare and of high cost.

Investigation of the thermal behaviour of cheaper elements and compounds are of great scientific interest for development of application technology for thermal protection.

### 2. Review of the latest relevant publications

In the series of composites that perform at extreme loads and temperatures, SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics, possessing excellent tribotechnical and mechanical properties and adequate high-temperature corrosion resistance [1, 4], hold much promise.

Materials in this system are also efficiently used as powders for thermal-sprayed coatings.

In particular, a detonation-sprayed coating on steel 30XГCHA sprayed from a composite SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> powder has wear resistance four times as high as that of a conventional coating of hard alloy BK-15 [3].

The excellent mechanical properties of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics also promote their use as monolithic antifriction composites: sealing elements for oil transfer pumps, parts of high-loaded friction units, walls of boilers that decrease heat losses, refractory bricks, and rings through which rock moves in the mining industry.

In many applications of high-temperature materials, their thermal shock impact resistance is crucial.

One of the promising ways to benefit from this characteristic is to use concentrated light streams, particularly concentrated solar radiation (CSR).

Concentrated solar radiation is advantageous in that it is a natural heat source that is ecologically clean and economical; moreover, any materials can be treated by non-contact heating in prescribed environments.

The effect of CSR on the effective surface of materials involves a series of physicochemical processes that have common features with other types of concentrated energy flows (for example, laser radiation and spark discharge): rapid heating and cooling, cyclic thermal and mechanical impacts, concentration of substantial energy on small area, oxidation, and interaction between components. In particular, this relates to high-temperature oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite in air under the action of CSR. It is accompanied by the surface oxidation of the samples.

### 3. Objective

This article is devoted to study the high-temperature oxidation and variation in the composition and structure of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite both in steady oxidation conditions and under effect of the thermal flow of CSR.

### 4. Experimental procedure

The initial 10 mm × 10 mm × 10 mm ceramic samples of composition (wt. %) 50SiC–34Al<sub>2</sub>O<sub>3</sub>–16ZrO<sub>2</sub> were produced by powder metallurgy methods.

The samples were subjected to special mechanical treatment to remove the outer defect layer.

The samples with 2–3 % porosity were oxidized in air in a Setaram unit (France) by their gradual heating to 1600°C; the weight increment and thermal effects during interaction were recorded in respective temperature ranges with TG and DTA methods.

The same samples were also subjected to CSR in air using an CGY-2 unit [1] at 0.0856 W/cm<sup>2</sup> solar radiation, 1160 W/cm<sup>2</sup> thermal flow, and exposure time  $\tau = 15$  s.

The samples were exposed to solar radiation with the shutters being fully open ( $\theta = 90^\circ$ ), solar radiation was measured with a 138Д1104 instrument.

The initial sample was fixed in the focal plane of a special optical system in the holder so that the exposed surface was perpendicular to the axis of input heat flow.

The exposed surface of the sample was concave at the centre of the heating spot because the material has been evaporated in the fusion area.

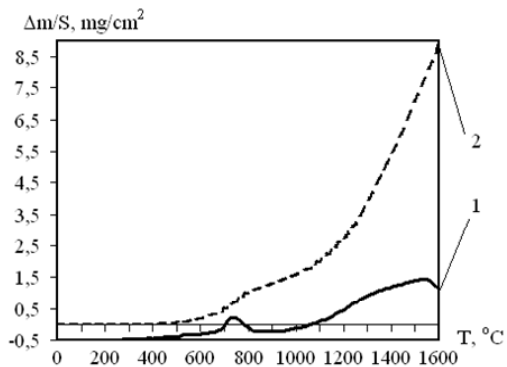
Fusion of the spot central part is due to the Gaussian distribution of flux power density in the plane of a focused solar beam 8 mm in diameter.

Metallography, microstructural analysis, and electron microprobe analysis of the samples exposed to solar radiation and oxidized in laboratory conditions were conducted on their cross-sections along the energy input axis, i.e., in the fused area, using ПМТ-3 and CAMEBAX SX-50 analyzers. Microhardness  $H\mu$  of the samples before and after oxidation was measured under a load of 1 N. X-ray diffraction of the oxidation products was carried out using a ДРОН-3 diffractometer in  $Cu-K\alpha$  radiation.

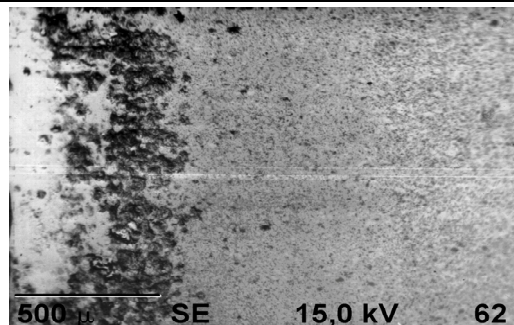
The formation of  $Al_2SiO_5$  on oxidized samples was identified by petrography using a МИН-7 mineralogical microscope and a set of standard immersion fluids with known refractive indices.

For the silicate  $Al_2SiO_5$  phase of (62 wt. %  $Al_2O_3$  and 37.1 wt.%  $SiO_2$ ), refractive indices were  $n_p = 1.659$ ,  $n_g = 1.680$ , and  $n_m = 1.660$ .

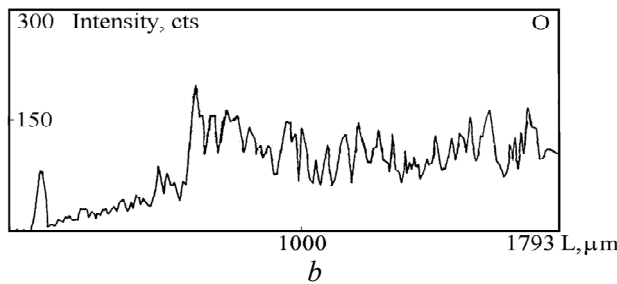
**4. Experimental results**



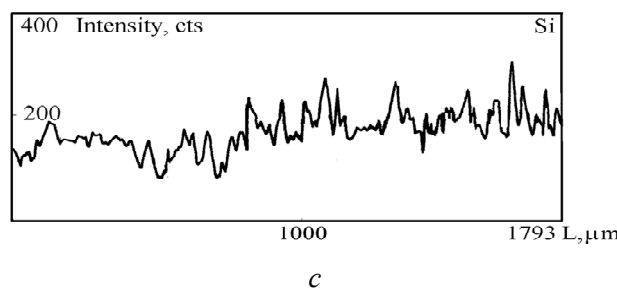
**Fig. 1.** Curves for high-temperature oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics in air: 1 – TG; 2 – DTA



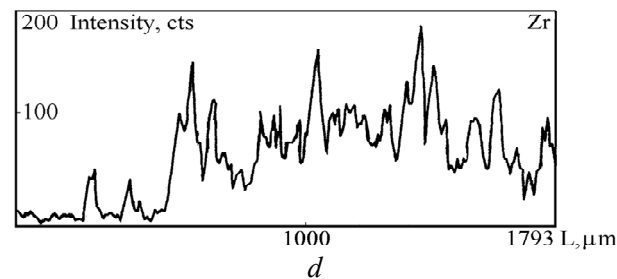
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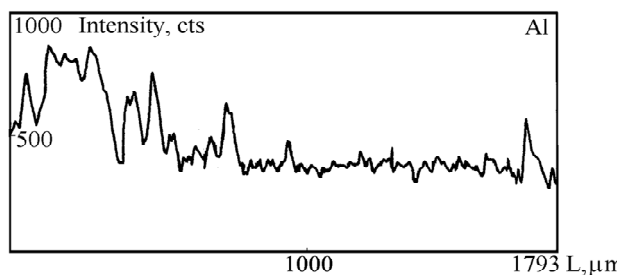
b



c



d



e

**Fig. 2.** Microstructure of the cross-section of the oxidation exposed sample (a) and distribution of elements b – oxygen; c – silicon; d – zirconium; e – aluminium

Nonisothermal oxidation to 1600°C at a heating rate of 20°/min confirms exceptionally rapid oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics (total value  $\Delta m/S = 8.9 \text{ mg/cm}^2$ ).

Results of TG and DTA analysis (Fig. 1) clearly

demonstrate that there are two different mechanisms: at 500 to 900°C, with a maximum rate of oxidation reaction at 760°C (first DTA peak) and at 900–1600°C (second maximum rate of reaction and second DTA peak at 1500°C).

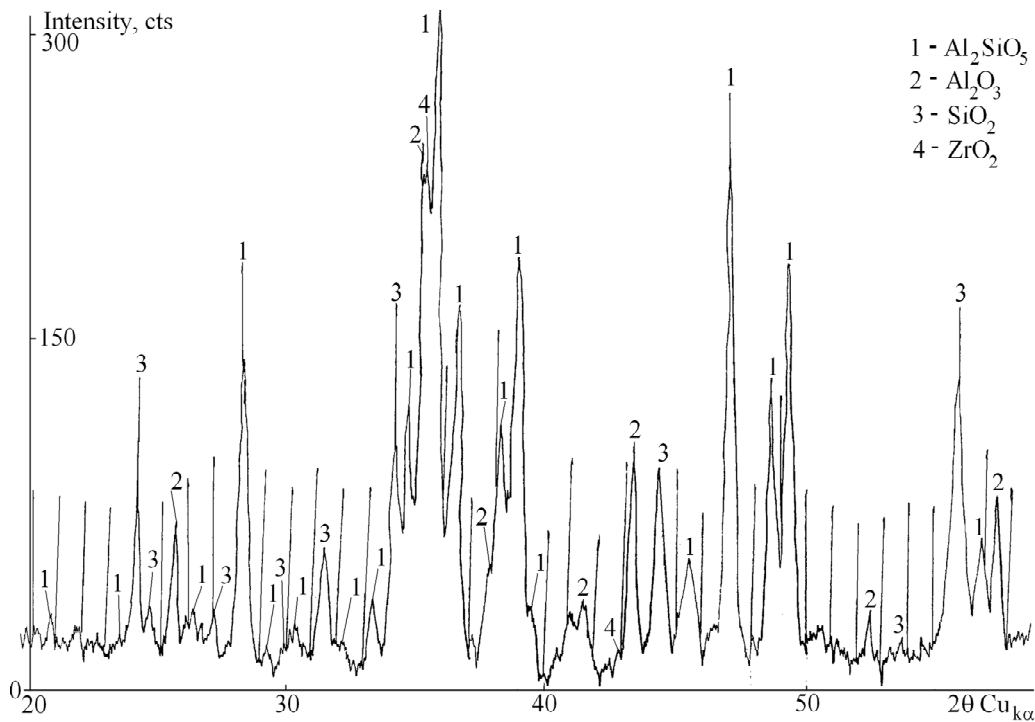


Fig. 3. X-ray diffraction pattern of the exposed surface of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> sample

We used X-ray diffraction and petrographic analyses of the scale on samples oxidized in isothermal conditions at 760 and 1500°C to establish two oxidation mechanisms.

The surface film on the sample oxidized to 1600°C includes four phases:  $\alpha$ -SiO<sub>2</sub>,  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, ZrO<sub>2</sub>, and Al<sub>2</sub>SiO<sub>5</sub>. This is confirmed by the distribution of O, Si, Al, and Zr in the oxide film formed (Fig. 2).

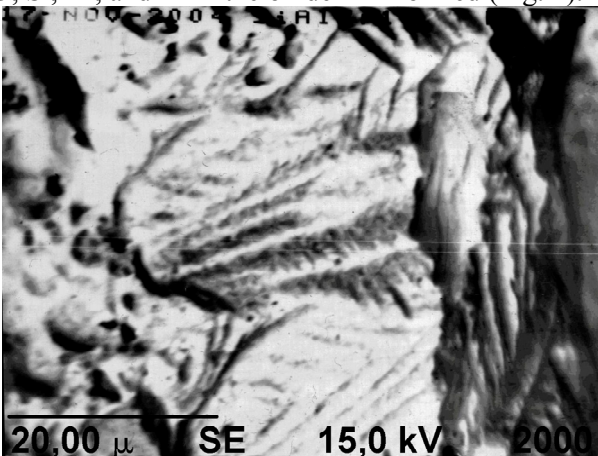


Fig. 4. Microstructure of outer scale layer  $\times 2000$

Concentrated solar radiation leads to high-temperature oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics to form composite materials based on Al<sub>2</sub>SiO<sub>5</sub> on its surface. Besides Al<sub>2</sub>SiO<sub>5</sub>, there is a smaller amount of oxides  $\alpha$ -SiO<sub>2</sub>,  $\alpha$ -Al<sub>2</sub>O<sub>3</sub>, and ZrO<sub>2</sub>. This composite has a layered structure; it is these structures that have increased mechanical properties. In particular, the oxide and silicate phases formed during high-temperature corrosion act as a barrier that prevents diffusion of oxygen deep into the sample. Therefore, the protective layer of aluminum silicate formed on the surface primarily ensures its excellent high-temperature corrosion resistance.

The cross-section of the exposed sample (Fig. 2) demonstrates a multilayer scale about 900  $\mu\text{m}$  in thickness, containing three layers that differ in structure, thickness, and composition. The outer layer about 180  $\mu\text{m}$  thick, without pores and cracks, has a fine discrete fibrous structure, typical of mullites and aluminum oxide (Fig. 2). Fibres 10–20  $\mu\text{m}$  in length are 1–5  $\mu\text{m}$  wide. The fibrous structure of the outer oxidized layer testifies that heating of

the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite in air to its melting point (~3000°C) leads to the diffusion of Al and Si from inside the material to its surface to form aluminum silicate.

The result agrees with X-ray diffraction (XRD) (Fig. 3) and electron microprobe analysis (EMPA) (Fig. 2).

The cross-sectional distribution of elements (Al, Si, Zr, O) in the exposed sample (Fig. 2) confirms the formation of a multilayer scale structure with three typical layers that differ in composition. The main changes in concentration profiles of elements occur at a depth of about 900 μm. The outer layer ~180 μm thick has an increased amount of Al and the lowest Zr content compared to the underlying layers. That the composition peaks of Al, O, and Si match testifies that there is an Al<sub>2</sub>SiO<sub>5</sub> phase in the layer, which is confirmed by XRD of the exposed surface (Fig. 3) and by microstructure of the outer layer in cross section (Fig. 4).

The intermediate layer of the oxidized sample ~200 μm thick is enriched with aluminum and silicon oxides. This layer is a porousless fusion zone with high microhardness (32.6 ± 0.6 GPa) probably because of the presence of the Al<sub>2</sub>O<sub>3</sub> and SiC phases.

The fusion, diffusion-controlled mass transfer, and oxidation of the carbide component of the composite lead to intensive formation of spherical pores in the internal layer (Fig.2). The high porosity of the internal scale layer seems to enhance thermal protection function of the starting sample.

At a depth of ~900 μm, corresponding to the base, concentration profiles of the elements stabilize at the level corresponding to the constitution of the composite. Noteworthy is that there are no cracks across the entire thickness of the changed zone, which is evidence of high fracture toughness of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite under thermal shock loads.

Therefore, impact fusion under CSR leads to the formation of crack-resistant three-layer scale on the composite with varying chemical and phase composition. A fine fibrous corrosion-protection zone as aluminium silicate Al<sub>2</sub>SiO<sub>5</sub> forms in the outer scale layer, acting as a solid lubricate and ensuring wear resistance. The latter is confirmed by high wear resistance of detonation-sprayed coatings in the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> system, which may be due to the formation of a tribological alumina film on the effective surface during dry friction [3].

The results indicate that there are similar mechanisms whereby phases form in the oxide layer both in steady conditions and under CSR. In addition, better service characteristics of the SiC–

Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite may be reached by its preliminary high-temperature oxidation during fusion under thermal impact of light, laser, or other flows of concentrated energy.

## 6. Conclusions

The high-temperature oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> ceramics forms a protective corrosion-resistance layer to about 1700°C both in steady conditions and under CSR.

We analyzed the structure and composition of the surface layer formed during high-temperature oxidation of the SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> composite in air under impact fusion in CSR conditions to establish the formation of a three-layer scale without cracks with composition and structure varying across depth. The outer scale layer ~180 μm in thickness, representing aluminium silicate Al<sub>2</sub>SiO<sub>5</sub>, has a fine fibrous structure and promotes wear and corrosion resistance. The intermediate porousless layer based on Al<sub>2</sub>O<sub>3</sub> and SiC exhibits high hardness (~32.6 GPa). The inner layer adjacent to the base is porous and makes a relevant contribution to the thermal function of the composite. The results indicate that application of the composites based on components SiC–Al<sub>2</sub>O<sub>3</sub>–ZrO<sub>2</sub> is reasonable both as the solid bulk, and as coating deposited for protection of heat bearing components of aircraft ground support equipment.

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**А. Г. Довгаль Розробка термобар'єрних покриттів для тепло навантажених деталей авіаційної наземної техніки.**

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Досліджені теплозахисні властивості композиту системи  $\text{SiC-Al}_2\text{O}_3\text{-ZrO}_2$  в результаті високотемпературного окислення при температурі, близькій до плавлення кераміки. Встановлено, що на поверхні відбувається формування зносо-корозійно-стійкої тришарової захисної окалини із зовнішнім шаром тонкодисперсної волоконної структури силікату алюмінію завтовшки 180 мкм. Встановлена доцільність застосування вказаного композиційного матеріалу, як в компактному вигляді, так і в якості покриття для захисту теплонавантажених деталей авіаційної наземної техніки.

**Ключові слова:** високотемпературне окислення; волокониста структура; композиційна кераміка; термобар'єрні покриття.

**А. Г. Довгаль Разработка термобарьерных покрытий для теплонагруженных деталей авиационной наземной техники**

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Исследованы теплозащитные свойства композита системы  $\text{SiC-Al}_2\text{O}_3\text{-ZrO}_2$  в результате высокотемпературного окисления при температуре, близкой к плавлению керамики. Установлено, что на поверхности происходит формирование износо-коррозионно-стойкой трехслойной защитной окалины с наружным слоем тонкодисперсной волокнистой структуры силиката алюминия толщиной 180 мкм. Установлена целесообразность применения указанного композиционного материала, как в компактном виде, так и в качестве покрытия для защиты теплонагруженных деталей авиационной наземной техники.

**Ключевые слова:** волокнистая структура; высокотемпературное окисление; композиционная керамика; термобарьерные покрытия.

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