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Non destructive monitoring of cavitation erosion of cordierite based coatings

Marko Pavlović [a], Marina Dojčinović [a], Sanja Martinović [b], Milica Vlahović [b, *], Zoran Stević [c], Tatjana Volkov Husović [a]

[a] University of Belgrade, Faculty of Technology and Metallurgy, 4 Karnegijeva St., Belgrade, Serbia
[b] University of Belgrade, Institute of Chemistry, Technology and Metallurgy, 12 Njegoševa St., Belgrade, Serbia
[c] University of Belgrade, Technical Faculty in Bor, 12 Vojske Jugoslavije St., Bor, Serbia

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ABSTRACT

Coating materials are widely used in refractory lining to prevent different deleterious effects such are reactions on the mold-metal contact surface, abrasion from liquid metal or alloy, gasses, slags, and other materials in contact with the coating. In this paper, behavior of cordierite based coating exposed to the cavitation erosion was investigated. Cordierite samples sintered at 1200 and 1400 °C were used for the tests. Mass loss, level of surface degradation obtained using image analysis and thermal imaging analysis were applied for the cavitation erosion evaluation. Results showed that the cordierite samples can be successfully used in conditions where the cavitation resistance is required.

1. Introduction

An extremely lightweight material, cordierite ($2MgO-2Al_2O_3-5SiO_2$), with low thermal expansion and excellent strength, rigidity and thermal shock resistance is an excellent candidate for different industrial applications [1–5].

Cordierite is mainly a structural ceramic material, often used for kiln furniture due to its extremely good thermal shock resistance. Like other structural ceramic materials, it also has good thermal and electrical insulating capabilities. In engineering practice, mechanical properties of materials play a major role in determining their suitability for specific applications. These mechanical properties are related to the crystalline phase and microstructure of the materials. Desirable properties of ceramic systems can be obtained by the proper selection of the stoichiometric composition required for the formation of the crystalline phases. Development of fine-grained microstructures in ceramics improves the thermo-mechanical properties [6]. The formation of ceramics is influenced by the composition, the choice of nucleating agents, and also by the performed treatment processes [7].

Cavitation involves the formation, growth, and collapse of bubbles in a liquid due to the local pressure changes. This phenomenon can occur if the pressure in a liquid is reduced sufficiently to cause formation of bubbles or vapor-filled voids. When a liquid is subsequently subjected to higher hydrostatic pressure, the bubbles can collapse and cause pressure waves and microjets. If these collapses are repeated, the solid surface in the liquid is subjected to the fatigue, which can cause the cavitation erosion. Cavitation erosion is a type of wear that occurs in many types of hydraulic structures such as pumps, valves, water turbines, ship propellers. Previous studies were occupied with the cavitation erosion of many kinds of materials: gray cast irons with graphite phase, stainless steels, coated materials and Ni–P–SiC composite coatings, and ceramic materials such are sialon, silicon carbide, and silicon nitride ceramics [8–18]. However, cavitation damage test is usually used for metallic materials. Recent studies are mainly based on designing and developing modern materials as well as replacing metallic components with composite and ceramic materials. Over the last few decades, considerable efforts have been devoted to enhancing the erosion resistances of different alloys and steel by deposition of protective coatings on their surfaces [9–14]. The coatings can be easily formed on the surface of steel, which can exhibit smooth surface and good mechanical properties; such are high hardness, high elastic modulus, and high oxidation resistance [13]. Many fluid

* Corresponding author. Tel.: +381 11 3303 698; fax: +381 11 3370 389.
E-mail address: milica.vlahovic@yahoo.com (M. Vlahović).

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machinery components are supplied with coatings to prolong their lifetime and to improve their work efficiency.

Nowadays, combined usage of modeling and nondestructive testing (NDT) is a consolidated practice in order to study the physical condition of a component, above all in the aeronautical and aerospace fields [19–22].

Image analysis of the sample surface degradation is an important non-destructive method for assessing damage of the materials. Namely, image analysis provides more objective characterization of materials from the aspect of their properties. Evaluation of various materials properties, as well as the effect of external influences on their microstructure, can be investigated using this methodology. The Image Pro Plus is a special program for processing and analysis of image [23].

Among the NDT techniques, the infrared thermography (IRT) is the only diagnostic technology allowing the operator to instantly visualize and verify the thermal material performance [24]. Active thermography represents a non-destructive technique and it is based on observing the temperature differences with an infrared camera after a thermal excitation, and can be analyzed by various methods: lock-in thermography (LT), pulse thermography (PT), and pulsed phase thermography (PPT) [25].

In order to estimate level of subsurface anomalies quantitatively, it is necessary to apply advanced algorithms to the raw curves [26,27]; in this way, it is possible to gather information, such as depth and dimensions of the subsurface anomalies [27,28] and also, in some cases, their nature [29,30].

In this study attention was focused on investigating the cavitation erosion resistance of the cordierite samples sintered at different temperatures. Accordingly, the idea was to investigate behavior and possible application of cordierite coatings under extreme conditions of the cavitation exposure. Level of cavitation damage was monitored by mass loss and surface erosion of the tested material. Coupling between properties and structure of the samples sintered at two different temperatures as well as their influence on damage level caused by cavitation was the main task of this study. The obtained results can be used for finding other possible applications of cordierite coatings.

2. Experimental

2.1. Materials

Cordierite ($2MgO{\cdot}2Al_2O_3{\cdot}5SiO_2$) as refractory coating is selected in accordance with the following properties: high refractoriness (16 SK/1470 °C), hardness by Mosh scale 7, density 1.9–2.2 g/cm^3; low coefficient of thermal conductivity (λ = 2.3–2.9 W/mK); low coefficient of linear thermal expansion ($\alpha = 1.7\cdot10^{-6}\,°C^{-1}$ (20–1000 °C)); high resistance to thermal shock; relatively high melting temperature with the possibility of application to 1380 °C; high inertness to the liquid metal (does not develop fumes in contact with liquid metal); low wettability with the liquid metal.

Cordierite used for the samples preparation was synthesized using the following materials: kaolin, alumina, and sepiolite, whose chemical composition is given in Table 1. The initial materials except kaolin, which was in powder form, were crushed to the upper limit of size 100% $-0.1\cdot10^{-3}$ m. Then, the components were mixed according to the following amounts: 35 mass% of alumina (maximum particle size of 0.1 mm), 28 mass% of sepiolite (maximum particle size of 0.1 mm), and 37 mass% of kaolin (<63 μm). After homogenization, the mixture powder was pressed under the pressure of 1 MPa and sintered at the temperature of 1200 and 1400 °C for 2 h in the laboratory furnace with an oxidation atmosphere.

Table 1
Composition of starting components for cordierite synthesis.

Composition (%)							
Precursor	SiO_2	MgO	Al_2O_3	Fe_2O_3	CaO (%)	$Na_2O + K_2O$	LOI
Alumina	0.14	0.01	95.96	0.09	0.16	0.05	3.20
Sepiolite	52.33	29.25	1.19	0.22	0.54	0.18	18.50
Kaolin	53.55	/	28.93	1.35	0.65	0.07	8.14

Composition of the synthesized cordierite samples is as follows: 51.11% SiO_2, 30.9% Al_2O_3, 13.5% MgO, 1.29% Fe_2O_3, and 3.2% CaO.

In order to determine size and shape factor of particles, which is important for preparation of coating materials, the obtained material was mechanically activated for 60 min in vibratory mill with the upper limit of size 100% $-40\cdot10^{-6}$ m to a grain size of 100% $-24\cdot10^{-6}$ m.

Size and shape factor of particles were measured using 3510 and 3240 grains, respectively. Average particle size was 24.45 μm (100% -24×10^{-6} m). Minimum and maximum measured grain sizes were 4.88 and 86.30 μm, respectively. The standard deviation was $\sigma = 16.44$. Middle shape factor was 0.67. Based on this data, the grain of the sample belongs to the category of rounded grains. Maximum and minimum shape factors were 0.85 and 0.29, respectively. The standard deviation was $\sigma = 0.15$.

Particle size distribution and grain shape factors of the sample before sintering are shown in histograms presented in Figs. 1 and 2.

XRD of sintered cordierite samples is given in Fig. 3.

In the Fig. 3 a), the sample sintered at 1200 °C exhibits typical pattern of cordierite with the following phases: cordierite, cristobalite, spinel, ortopyroxen, forsterite, garnet and silimanit. Diffraction pattern of cordierite sintered at 1400 °C, given in Fig. 3 b), shows the dominant presence of cordierite rich with iron and minor amount of ringwoodite.

SEM analysis of cordierite samples sintered at 1200 and 1400 °C is given in Fig. 4.

As can be seen, morphology of the samples is similar. The sample sintered at 1200 °C shows parts with the porosity (dark part at the surface). For the sample sintered at 1400 °C, the amount of pores is lower and their surface areas are smaller.

2.2. Methods

2.2.1. Cavitation erosion testing

Cavitation erosion testing was performed according to the

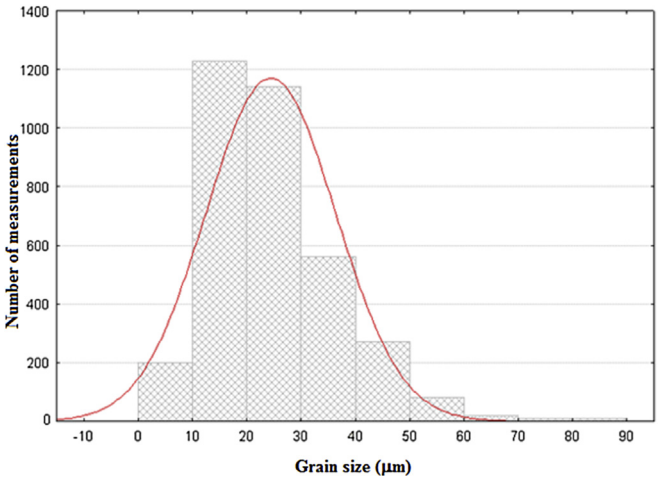

Fig. 1. Histogram of particle size distribution of the sample before sintering.