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Comparison of Morphological Parameters of Ceramic Materials Surface Damage Exposed to Thermal Shock and Cavitation Erosion

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Abstract:

The surface defects on the samples, which are based on alumina, exposed to thermal shocks and cavitations erosion were analyzed using image analysis. For both types of experimental testing, the samples are made of the same shape and size. The specimens contain different amounts of alumina fibers (samples without fiber and with of 1 and 2 wt.% of the fibers). The surface defects were characterized by their morphological parameters determined using image analysis procedure. Sixteen parameters are used for the image analysis. The results show that the damage caused by thermal shocks and cavitations were different and the greatest difference was in roundness and fractal dimension.

Keywords: *Alumina ceramics, Image analysis, Thermal shock, Cavitations resistance.*

1. Introduction

Alumina ceramics are used in many applications where low density, high temperature properties and high hardness are required, but alumina disadvantages are brittleness, low thermal shock resistance and low fracture toughness [1]. This drawback can be overcome by the addition of a secondary phase in the ceramic matrix, resulting in improvement of mechanical properties of the ceramics [2, 3]. The secondary phase can be a particle, fiber, etc. Hasselman was established the classic theory on the thermal shock resistance of brittle ceramics [4, 5].The thermal shock resistance of a material depends on a material properties including the fracture strength, elastic modulus, Poisson's ratio, thermal expansion coefficient, thermal conductivity, etc. [6].

Cavitation is a non-stationary process of creation, growth and condensation of the bubbles within the liquid [7, 9]. Start of cavitation is related to the magnitude of the pressure in the liquid. By reducing the pressure on the critical value or when the pressure causes the evaporation of liquid at a certain temperature, it comes to the appearance of blisters and that moment is considered the beginning of cavitation [10].

The process by which the material is separated from the solid surface is called cavitation erosion and the resulting damage is termed cavitation damage. Cavitation damage was observed on propellers and hidroprofils, the Bryansk sauces, valves, tunnels and other

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hydraulic structures, the hydraulic pumps and turbines. In hydrosistems, large narrowing in the passage of fluid causes cavitation damage downstream of the passages and the valves, fasteners, bearings and heat exchangers. Cavitation erosion rate is measured as a weight or volume loss of material per unit of time. For defining the rate of cavitation erosion, diagrams are used during the testing - weight loss vs. time [11].

Thermal shock resistance of refractory materials is one of the most important characteristics which determine their performance in many applications. The thermal shock resistance of refractory can be obtained by quenching appropriate specimens from an oven at elevated temperature into a medium such as water, liquid metal, oil, or fused salts maintained at a lower temperature. Thermal quenching leads to the crack nucleation and/or propagation of cracks resulting in a loss of strength [12, 13].

Thermal stability can be considered by the two approches: the heat transfer and fracture mechanics. Material resistance to sudden changes in temperature is based on the critical temperature interval difference which depends on the conditions of the heat transfer and not only on the material properties. This approach was used to avoid influence of samples size and geometry, and to make the results suitable for comparison [14, 15].

In this work, the morphological characteristics of damages were analyzed using image analysis tools. The aim of this paper was to investigate the possibility for damage monitoring in the ceramic materials exposed to the thermal shock and cavitation, by comparing the morphological parameters of the surface damage.

2. Experimental
2.1. Material

The samples consist of chamotte, bauxite, clay ("Šamot" Arandjelovac) and alumina fibers (manufactured by Thermal Ceramics, l/d ≈ 17). Three series of samples were prepared: the samples without the addition of alumina fibers, the samples with the addition of 1 wt.% of alumina fibers and samples with 2 wt.% of alumina fibers. The samples (cylinder of dimensions 30×9 mm) were pressed at a pressure of 36 MPa. After that, the samples were sintered at 1200 °C for 2h.

2.2. Thermal shock

Thermal stability of the refractories was determined experimentally by water quench test (ICS 81.080 SRPS B.D8.308 former JUS B. D8. 306). This experimental procedure is well described in the literature [16, 17].

The specimens' surface has been scanned after every 4 cycles and the image were used for further analysis. In this paper, the image after 4, 8 and 12 cycles of thermal shock were used for detailed analysis. The surface of specimens was colored using blue chalk to enable the contrast separation of the damaged and non-damaged part of the surface. The scanner was used to obtain the digital images of those surfaces. Image ProPlus 4.0 software package tools (Media Cybernetics, Rockville, MD) were used for image data processing and quantification of the morphological characteristics of selected objects.

The relation between preparation conditions and sample destruction pattern was previously studied and similar methodology resulted with the aim to compare different damage sources on their shape [18].

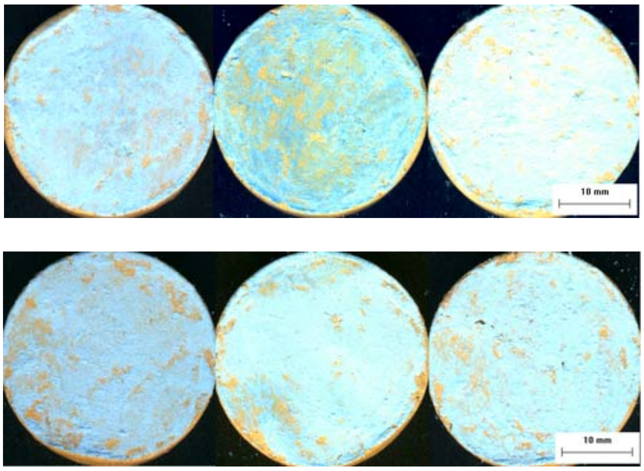

Fig. 1. a) Samples without fibers before and during testing, b) Samples with 2% of fibers before and during testing.

2.3. Cavitation

Cavitation was monitored using the mass loss measurements and by measuring corresponding surface degradation during the experiment. The surface of specimens was photographed using the scanner in order to minimize the influence of light conditions. The surface damage was determined from the photographs according to difference in gray level in the picture. Image analysis of the photographs of the sample surfaces was done using image analysis software that allowed to measure levels of the surface damage during cavitation erosion [19-21]. In this paper, the image after 0, 6 and 12 min of cavitation were used for detailed analysis. Results were presented as a surface erosion ratio [22].

Fig.2. a) Samples without fibers before and during testing, b) Samples with 2% of fibers before and during testing.

3. Results and discussion

The destruction of surface in specimens having no fibers and having the addition of fibers vs. number of cycles and time of cavitation was shown in Fig. 3.

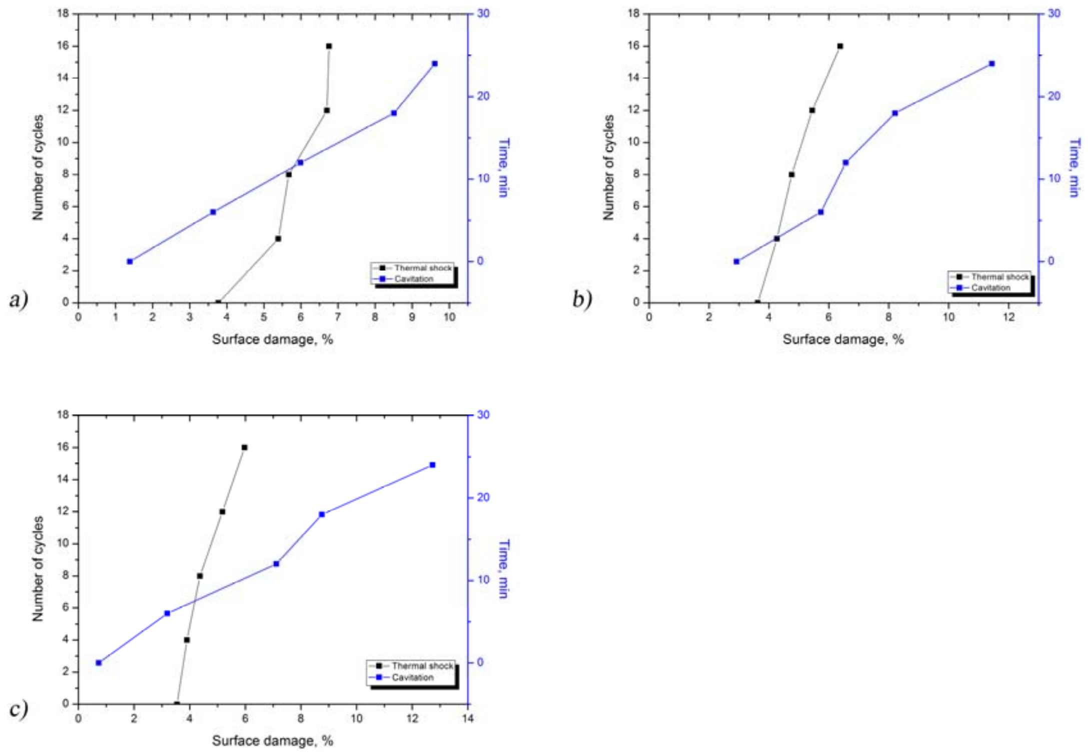

Fig. 3. The dependence of the share of damage vs. the number of cycles and time of cavitation for sample: a) without fibers, b) with 1 % of fibers and c) with 2 % of fibers.

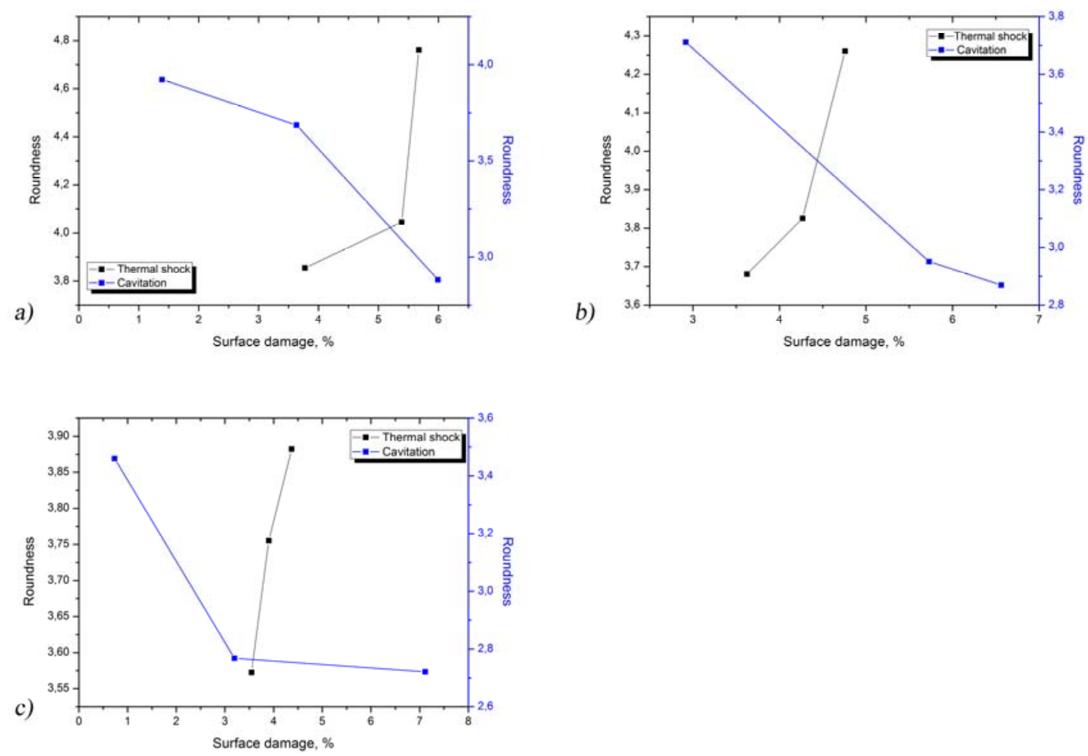

Fig. 4. The dependence of the share of damage vs. roundness for sample exposed to thermal shock and cavitation: a) without fibers, b) with 1 % of fibers and c) with 2 % of fibers.

The share of damage increases with the number of cycles and time of cavitation. Addition of fibers affects the increase in the share of damage. The surface damage grows faster in cavitation than thermal shocks.

The parameters, selected for morphological analysis of surface damage, were: *Area, Aspect, Density (mean), Density (min), Density (max), Axis (major), Axis (minor), Diameter (max), Diameter (min), Diameter (mean), Perimeter, Perimeter2, Roundness, Fractal Dimension, Box Width, Box Height*. Roundness and fractal dimension are significantly different in two groups of samples subjected to different sort of surface destruction.

Roundness of damage increases with increasing number of cycles in samples exposed thermal shocks. This dependence is more linear with increasing the addition of fibers. Roundness of damage decreases with increasing time of cavitation.

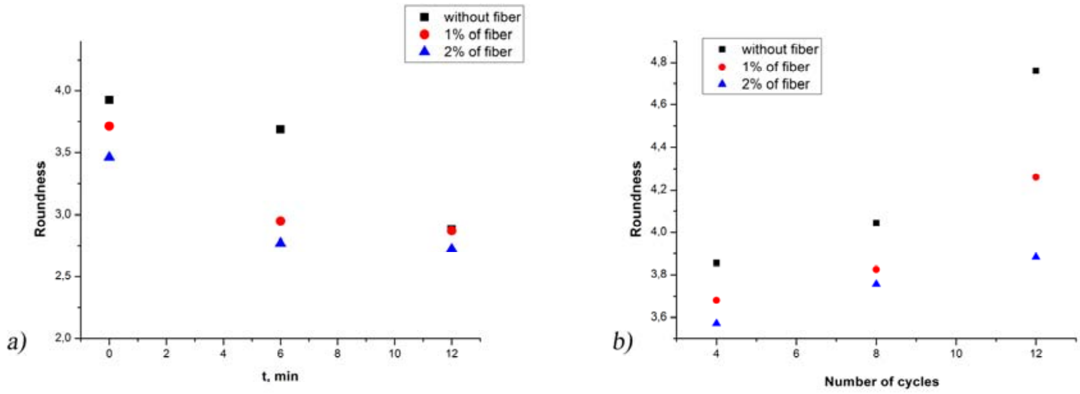

Fig. 5. Comparison a) roundness of surface erosion caused by cavitation vs time, b) roundness of surface damage caused by thermal shock vs number of cycles.

Results for dependence of roundness on duration of the surface erosion are presented in Fig. 5a. The roundness of damage decreases with time. The roundness of surface damage decreases with the addition of fiber, the samples with 2 % of the fiber had the lowest roundness. This means that the result of cavitation process on the shape of the damage is in form of spherical holes on the surface of the specimen.

On the other hand, the roundness of surface damage, observed in samples exposed to thermal shock, increased with the number of cycles. Giving the surface damage that has more stress concentration points and resulting in the loss of the surface layer of the sample. The addition of fiber affected the value of roundness. Samples with 2 % of the fibers had a lower roundness than samples without the addition of fibers and with 1 % of fibers. Results are presented in Fig. 5b.

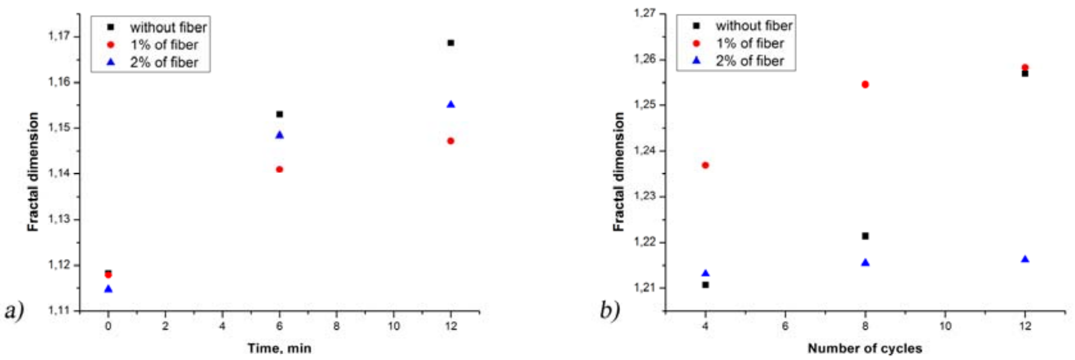

Fig. 6. Comparison a) fractal dimension of surface erosion caused by cavitation vs. time, b) fractal dimension of surface damage caused by thermal shock vs. number of cycles.

Results for fractal dimension of the surface erosion are presented in Fig. 6a. It can be observed that fractal dimension increases with time. The addition of fiber leads to the decrease of fractal dimension. The fractal dimension of surface damage caused by thermal shock also increases with the number of cycles, but these values are higher than the fractal dimension in samples caused by cavitation, Fig. 6b.

4. Conclusion

Synthesis of alumina based materials and characterization of surface damages morphology were investigated in this paper. Image analysis tools were used for quantification of the defects morphology data**.** The addition of fibers influences on the form of defects. Roundness of damage decreases in samples exposed to cavitation.The samples with 1 and 2 % of fibers has lower values of roundness than samples without fibers. In samples exposed to thermal shock, roundness of surface damage increases with the number of cycles but the addition of fiber reduces the value of roundness. Fractal dimension was growing in samples exposed to thermal shock and cavitation, but the value of fractal dimension was higher in samples exposed to thermal shock.

Acknowledgements

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Садржај: *Површинска оштећења на узорцима, који су базирана на алуминијум оксиду, изложена термошоку и кавитацији анализирана су анализом слике. За оба типа експерименталног тестирања, узорци су направљени истог облика и величине. Узорци садрже различите количине влакана (узорци без влакана и са додатком 1 и 2 % влакана). Површинска оштећења су окарактерисана морфолошким параметарима који су одређени коришћењем методе за анализу слике. Шеснаест параметара је коришћено за анализу слике и праћење нивоа оштећења узорака. Резултати показују да се оштећења проузрокована термошоком и кавитацијом разликују, а највећа разлика је у сферичности оштећења и фракталној димензији.*
Кључне речи: *керамика на бази алуминијум оксида, анализа слике, термошок, кавитација*