UNIVERSITY OF BELGRADE
TECHNICAL FACULTY IN BOR
CHAMBER OF COMMERCE AND
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PROCEEDINGS

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INTERNATIONAL MINERAL PROCESSING & RECYCLING CONFERENCE

XIII International MINERAL PROCESSING and RECYCLING CONFERENCE

Editors:

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Belgrade, Serbia, 8 – 10 May 2019

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DETERMINATION OF THE CAVITATION RESISTANCE OF GLASS-CERAMIC SAMPLES BASED ON RAW BASALT AND INDUSTRIAL WASTE RAW MATERIALS FOR USE IN METALLURGY

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ABSTRACT – The paper presents the results of the investigation of cavitation resistance of glass-ceramics based on basalt rocks from the Vrelo Kopaonik deposit and various waste industrial raw materials. The aim was to determine the possibility of using glass-ceramics as a substitute for metallic materials in the production of structural elements of mining and metallurgy equipment. The ultrasonic vibration method (with a stationary samples) was used for cavitation resistance testing, according to the ASTM G-32 standard. A change in the sample mass in function of the cavitation time was monitored for the evaluation of cavitation resistance. The level of degradation of the surface of the sample was quantified using the image analysis. The change in the morphology of the sample surface with the test time was followed by scanning electron microscopy.

Key words: basalt, cavitation resistance, mass loss, image analisis, constructions elements.

INTRODUCTION

Basalt is a cheap and wide spread raw material, which by melting and a certain cooling treatment can be used for the production of glass and glass ceramics with specific mechanical properties, high strength and low abrasiveness [1, 2]. It use for synthesis of new materials and products such as basalt wool, basalt fibers, armature, composite materials, which are used for the production of parts and equipment in the machinery industry, automotive industry, shipbuilding [3-6]. The basic properties of basalt, which influenced his choice for exploring cavitation resistance and assessing the possibilities of application in engineering practice, as substitutes for metallic materials, were: melting point 1300-1400 °C; high hardness 6.5 - 7 Mosh scale; density 2460 - 2960 kg/cm^3; wear resistance; high resistance to acids, alkalis and heat; ecological and hygienic quality [7]. Cavitation is a phenomenon that

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comprises formation, growth and implosion (collapse) of bubbles in a liquid flow. During cavitation, when the bubbles collapse, high temperature and pressure (approximately 5000 °C and 1000 bar) develop locally in the a very short time (less than 1 μs) [8-10]. According to the literature data, in the conditions of cavitation stresses, the most common are metallic materials (steel and alumininum alloys), while ceramic materials are used less. There are no data on the examination and application of basalt in conditions of cavitation loads. It was also a motive to examine the cavitation resistance of basalt for the purpose of application for the construction of parts of equipment in mining and metallurgy.

MATERIAL AND METHODS

Olivine-pyrroxene basalt from the Vrelo-Kopaonik deposit (sample design: RB) is used as the starting material for the synthesis of samples for testing. Basalt was crushed and ground on size 10-15mm, mixed with 10 % of industrial waste materials (metallurgical slag and waste from the ceramic industry) and melted at a temperature of 1250 °C. Test samples, plate of dimensions (200x150x15) mm are cast in sandy molds. In order to reduce the internal stresses of the cast test plates, they are thermally treated according to the regime: heating at a temperature of 850 °C/2.5 h and cooling in a furnace to room temperature. Samples for testing of cavitation resistance of dimensions (10x10x10) mm were cut from the plates. Designation of glass-ceramic sample: CB. Table 1 shows the composition of the starting materials and the obtained glass-ceramics.

Table 1. Chemical composition of raw materials and obtained glass-ceramics (%)

Compound	Raw basalt	Industrial waste	Basalt glass-ceramic (CB)
SiO_2	56.21	27.98	51.15
Al_2O_3	18.61	3.50	20.90
Fe_2O_3	1.15	9.98	2.80
FeO	2.97	3.10	4.90
MgO	3.40	0.98	3.55
CaO	7,78	5.90	9.20
Na_2O	4.73	1.10	3.45
K_2O	3.37	0.80	2.50
Cu+Zn+Pb	-	2.49	1.50

Basalt samples were analyzed using X-ray diffractometer, "Philips" model PW-1710. The microstructure of the samples was characterized with the scanning electronic microscope JEOL model JSM 6610 LV. In order to improve conductivity, the sample was vapoured with gold powder.

The ultrasonic vibration method (with a stationary samples) was used for cavitation resistance testing of samples. Characteristic parameters for this method (vibration frequency, amplitude at the top of the concentrator, distance between the tested sample and concentrator, water temperature, water flow) were selected according to ASTM G-32 standard and previous works [10, 11]. The water in the water bath cools the sample and keeps its temperature constant. A constant flow of water creates a pressure field that stimulates the implosion of cavitation bubbles on the surface of the test sample. In this way, the test sample is not exposed to mechanical strains during the test. Selected sample time (min) is: 15; 30; 60; 120. After each test interval, the mass loss of the sample was measured by an analytical balance of accuracy of 0.1 mg. Samples were photographed before, during and at the end of the test. The formation and development of damage to the surface of the tested samples during the cavitation test was followed in correlation with the structure and properties of the refractory materials. Software sample analysis was performed in Image Pro Plus [12]. The morphology of the damaged surfaces was analyzed by a scanning electron microscope (SEM) Joel JSM 6610 LV. The level of degradation of the sample surface P/P_0, % is determined, where P_0 represents the surface of the sample without defects, while P represents the surface of the samples with damages. The number of damage caused by the surface in the form of shallow pits, N_p, and the average surface of the formed pits P_{av}, mm^2 were determined. All obtained results of damage to the surface of the samples at the time of the cavitation activity are illustrated by the diagrams.

RESULTS AND DISCUSSION

The mineral composition of a glass-ceramics based on basalt (CB) is shown on Figure 1. The most prevalent minerals are pyroxene, basic plagioclases and olivines. In Figure 2, SEM microphotograph of the CB samples are shown before the cavitation process. The basic structure of the samples is cryptocrystalline with the appearance of fine crystals. Bubbles of different sizes, which are filled with gas or glass are present in the structure. The present bubbles on the surface of the samples cause surface roughness and the appearence of pits. During the cavitation test, the changes of the present bubbles contained in the basalt base, as well as the present pits on the surface of the sample CB were monitored.

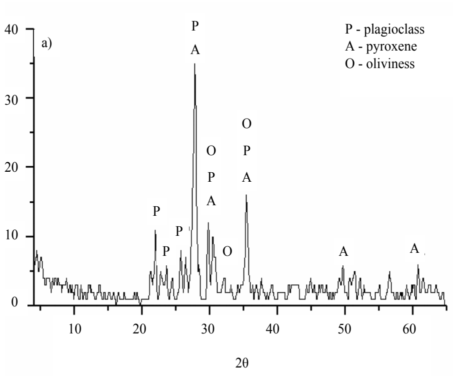


Figure 1. XRD of CB sample

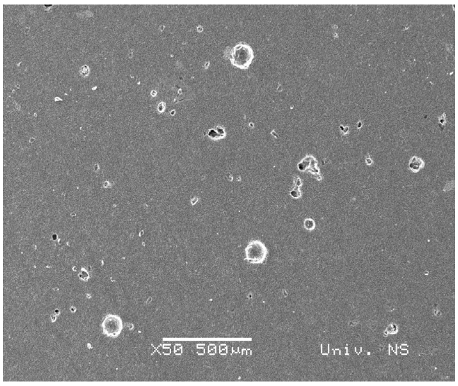
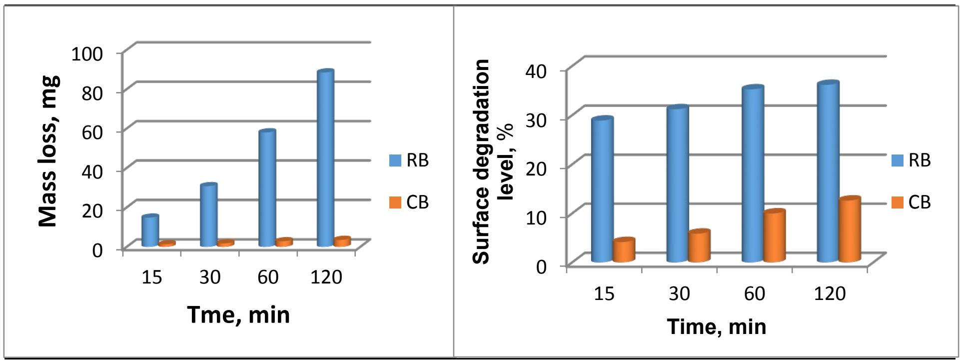


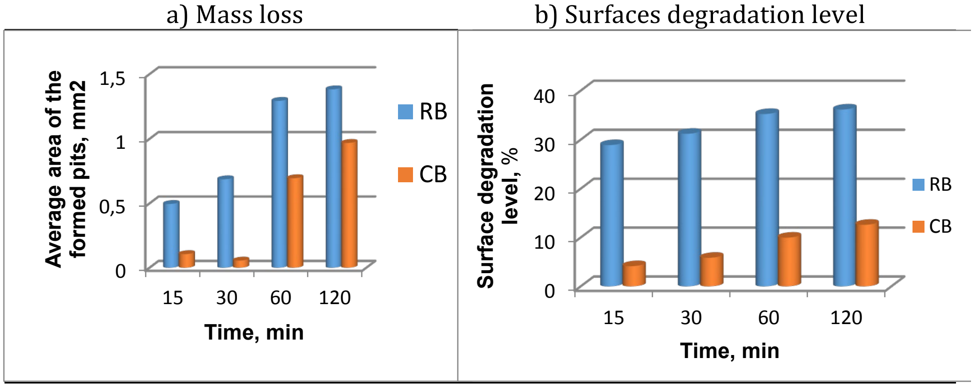
Figure 2. SEM microphotograph of CB sample

Figure 3 shows the results of the study of the formation and development of damage under the effect of cavitation for samples RB and CB using image analysis and Image Pro Plus software.

From figure 3a, it can be seen that the weight loss is expressed in samples of RB. A small weight loss of CB samples and a small level of surface damage under the effect of cavitation is characteristic of CB samples, figure 3a, b. The number of pits formed on the surface of the CB sample is considerably smaller than the formed pits in the sample RB, figure 3d. The average surface of the formed pits is significantly lower in the CB sample compared to the RB samples, figure 3c. At the end of cavitation exposure damage to the surface of CB sample is 12 %, while damage to RB samples is greater than 35 %, shown in Figure 3b. This corresponds the results of determining the average surface of the formed pits, Pav shown in Figure 3c.



a) Mass loss | b) Surfaces degradation level



c) Average area of formed pits | d) Number of formed pits

Figure 3. The formation and development of damage under the effect of cavitation for samples RB and CB

Figure 4 shows the appearance of the sample surface and profile lines obtained using the red filter, using Image Pro Plus software.

Calculated cavitation velocity as the ratio of total mass loss in relation to the time of cavitation is: for samples RB v=0.708 mg/min, while for CB samples v=0.058mg/min. From the results of the measurement of mass loss during the effect of cavitation and the result of image analysis, it can be concluded that glass-ceramics samples based on basalt have a satisfactory resistance to the effect of the cavitation.

The formation of pits is often found near the bubbles that exist in the basic mass of basalt. Further development of damage occurs at a low speed so that there is no danger of a greater loss of mass from the surface of the formed pits, which speaks in favor of greater safety in the work of glass ceramics (CB) samples compared to raw basalt samples (RB).

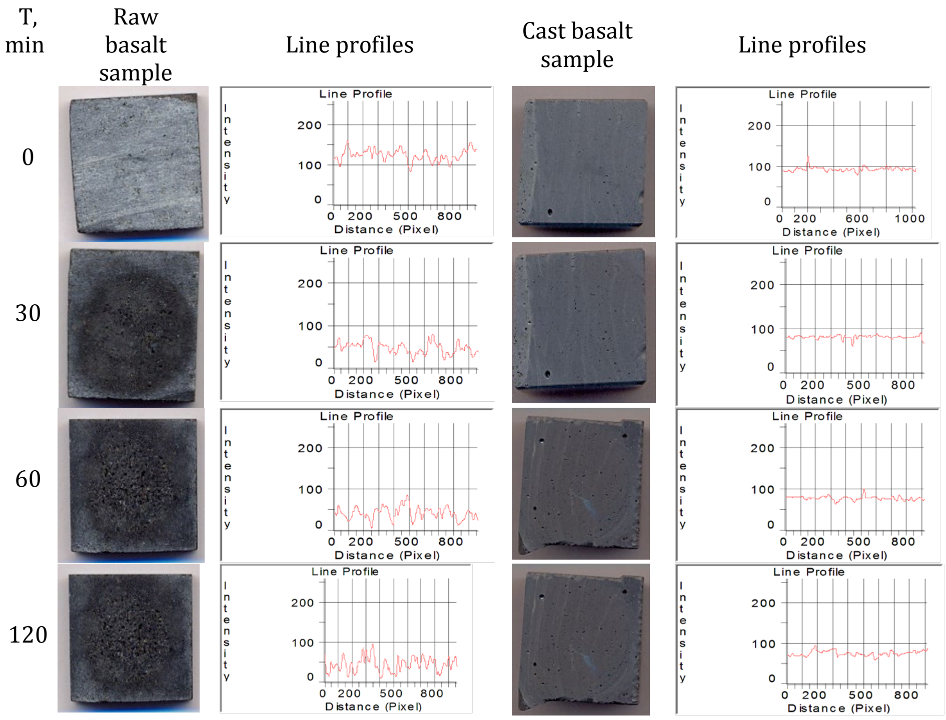


Figure 4. Photographs of RB and CB samples before and during the cavitation erosion testing after implementation of red filter and corresponding line profiles

The appearance of formed pits at the end of cavitation testing of RB and CB is shown on Figures 5 and 6. The mechanism of formation and growth of pits was monitored on an electronic microscope and shows a low rate of development of surface damage in CB samples and appearance of pits near the already existing bubble in the basic structure of glass-ceramics, Figure 6.

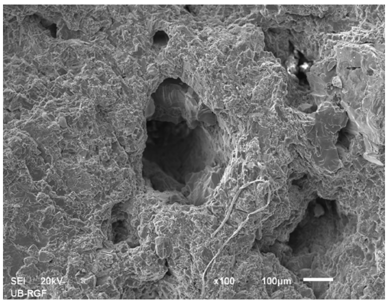


Figure 5. Deformed surface of RB sample

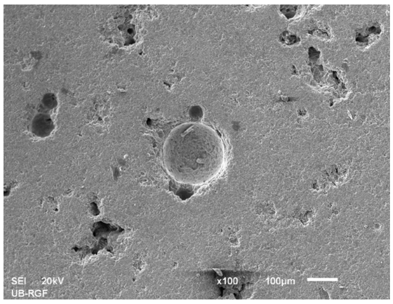


Figure 6. Deformed surface of CB sample

The profile lines indicate that the degradation is at the center of the sample surface, given the intensities of the edges of the profile lines that change and increase, from about 30 min exposure to 120 min, when significant surface area damage of the RB sample is present, Figure 4.

The results shown in Figure 4 correspond to the results of damage to the surface of RB and CB samples determined by applying image analysis on photographs of sample surfaces during the cavitation time, processed and analyzed using the Image Pro Plus software, shown in Figure 3b.

CONCLUSION

The paper investigated the formation and development of damage to the surface of the samples of the raw and cast basalt under the effect of cavitation. It has been shown that the structure of the glass-ceramics samples based on basalt (samples CB) is resistant to cavitation loads and can be applied in conditions of high temperatures and pressures that occur in a short period of time under cavitation conditions. The occurrence of shallow pits in the vicinity of already existing bubbles in the base of glass-ceramics does not damage the surface at cavitation velocity v=0.058mg/min in relation to the surface of raw basalt samples (RB) that are more damaged at cavitation speed of 0.708mg/min. The research has shown that increasing the content of waste materials in the basalt product supply contributes to the improvement of the economic, energy and ecological aspects of metallurgical and mining operations, as well as the waste recycling.

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