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CAVITATION EROSION RESISTANCE OF BASALT

Abstract

The cavitation erosion resistance of the basalt samples from Vrelo, Kopaonik deposit was investigated. The cavitation erosion test was performed using an ultrasonic vibratory cavitation testing method in accordance to the ASTM G32 standard. To measure the cavitation resistance, a change in the sample mass in function of the cavitation time was monitored. The alternations of the samples' surface morphology with the passing time were analyzed by scanning electron microscopy. The level of the surface degradation was quantified using image analysis software. The results indicate that basalt posses a good cavitation resistance, which implicates that this raw material can be utilized in extreme exploitation environment.

Key words

Mineral raw material; Level of cavitation damage; Mmicrostructural analysis; Image analysis.

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1. INTRODUCTION

Basalt from the Vrelo, Kopanik deposit is an extremely tough olivine-pyroxene rock of volcanic origin. This raw material is inexpensive and highly abundant. Processed basalt can be used for the production of glass and glass ceramics with specific mechanical properties such as high strength and low abrasiveness [1-3]. Melting and a certain cooling treatments can produce certain new products such as: basalt wool or basalt fibers for reinforcement of various composite materials. These componential materials are usually employed in the production of various parts and equipment in the machine and car industry, or even shipbuilding [4-6]. Good physico-mechanical properties enable the use of basalt as a raw material in civil engineering [7, 8]. It is primarily used as aggregate for road and rail shrouds [9], aggregate for special types of concretes, glaze for ceramic tiles [10], etc. Basalt is also used as architectural stone in exterior and interior design as well as for the industrial floors [11]. The basalt processing technology is environmentally clean and the obtained products are not carcinogenic.

The properties and microstructural characteristics of the basalt products are normally determined depending on the conditions of their application [1]. In order to assess the possibility of basalt utilization in extreme environment (high temperature and/or pressure, intensive wear, aggressive suspensions and liquids, corrosion) the cavitation resistance of basalt samples was investigated. In practice, testing of a material resistance to cavitation is usually conveyed in laboratory using an ultrasonic vibratory cavitation test method (with a stationary sample) according to procedure provided in the ASTM G-32 standard [12]. In this study, image analysis software Image Pro Plus 6.0 [13] was used for estimation of the cavitation resistance of basalt samples. The change in a sample’s mass was correlated to the cavitation interval (time) in order to determine parameters of the basalt structure and resistance of the observed samples. The samples were recorded by scanning electron microscope and determination of sample’ surface was analyzed upon exposure to the cavitation testing.

2. EXPERIMENTAL

The cavitation resistance was tested on the basalt rock samples. The testing specimens were cut from the selected rocks from the Vrelo, Kopaonik deposit. The basic properties of basalt, which influenced the choice for exploring cavitation resistance and assessing of the application possibilities in the engineering practice were: density 2460-2960 kg/m^3; glass content 10-15 %; melting point 1300 - 1400 ºC; hardness 6.5 - 7 Mosh’ scale; compressive strength 80 MPa; porosity 3.78 %; hygroscopicity 1 – 4 %; moisture content 1.2 %; high frost and wear resistance; high resistance to acids, alkalis and heat; good ecological and hygienic quality [1-4].

The mineralogical analysis of the basalt samples was conveyed using a Philips PW-1710 X-ray diffractometer. The microstructure of the samples was characterized with a JEOL scanning electronic microscope (JSM 6610 LV). In order to improve conductivity, the analyzed samples was coated with the gold powder.

An ultrasonic vibratory cavitation testing method (with a stationary sample) was used for the evaluation of cavitation resistance. The testing was conducted in accordance to the procedure provided in the ASTM G32 standard [12, 14]. The testing device consisted of a 360 W high frequency generator, electrostrictive transducer, transformer for mechanical vibrations and a water bath. The testing sample was placed in the water bath. Recommended standard values were used for the cavitation erosion test: vibration frequency - 20 ± 0.2 kHz; amplitude of vibrations at the top of the transformer - 50 µm; gap between the test specimen and the transformer - 0.5 mm; temperature of the water bath - 25 ± 1 °C; water flow - 5 – 10 ml/s.

The dimensions of brittle materials are not specified in the previously mentioned standard. In this experiment 15x15x15 mm cubic samples were used. The samples were immobilized during the cavitation test with holders located at the bottom of the water bath. Water in the water bath cools the sample and keeps its temperature constant. Three basalt specimens were used for the cavitation test and an average value of the measurements was adopted as the final results. These results were used for illustrations of correlations between the mass loss of samples and testing time. The cavitation rate of the material was calculated as the total mass loss of the sample after the total testing time. The testing periods were: 15; 30; 60; and 120 min. After each testing interval, the change in the mass loss of a sample was measured with the analytical weighing accuracy of 0.1 mg. In order to analyze the surface deterioration caused by cavitation, the samples were photographed before, during and at the end of each experiment.

The morphological sample analysis was performed via Image Pro Plus 6.0 software [13]. This analysis enabled the identification of the destruction mechanisms and monitoring of the indicators of the damage which appeared during cavitation testing: degradation level of sample' surface (P/P_0 in %; where P_0 is the area of the sample' surface without damage and P is the damaged area which occurred upon the cavitation testing); the number of formed individual pits (N_p), and average area of formed pits (P_{av} in mm^2).

3. RESULTS AND DISCUSSION

The chemical composition of the basalt is given in Table 1.

Table 1. Main oxides comprised in the average basalt sample.

Oxide	SiO_2	Al_2O_3	Fe_2O3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2
Content (%)	56.21	18.61	1.15	2.97	3.40	7,78	4.73	3.37	1.11

The X-ray diffraction analysis of the basalt is presented in Figure 1. As it can be seen, the basalt sample predominantly comprises plagioclase, pyroxene, and olivine. The most abundant minerals are basic plagioclases, while pyroxene and olivine are present in lesser amounts.

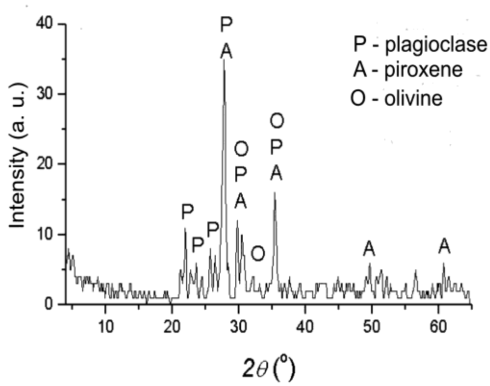

Figure 1. X-ray diffractogram of an average basalt sample.

Scanning electron microphotographs (SEM) of the basalt samples recorded before the cavitation testing are given in Figure 2a. and 2b. The observed basalt sample is mainly composed of microcrystalline plagioclase (Fig. 2a.). Phenocrysts distinct from the groundmass are identified. Granular olivine and rhombic pyroxene are also present in the investigated basalt samples.

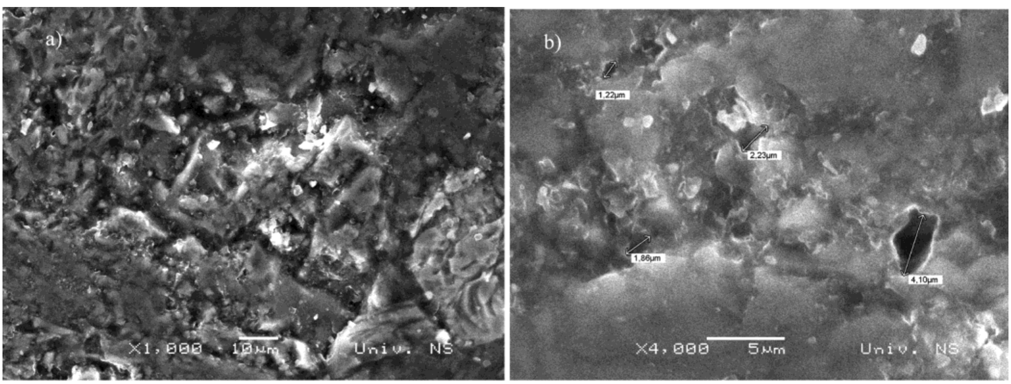

Figure 2. SEM microphotographs of basalt sample: a) the structure of olivine-pyroxene; b) bubbles present in the structure.

The structure of basalt contains bubbles of various sizes, which are filled with air or glass, as it can be seen in Figure 1b. On the surface of some samples, prior to the cavitation testing, cerain voids and pits were observed. These pits probably originate from the bubbles present in the basalt structure. During the cavitation testing, the changes in identified bubbles and pits present on the surface of the samples were spotted.

Measurements of the mass loss of the sample upon the cavitation (various testing periods) are illustrated in Figure 3. The total mass loss of the sample during the test defines the cavitation rate of the tested material. The calculated cavitation rate of basalt was: 0.738 mg/min.

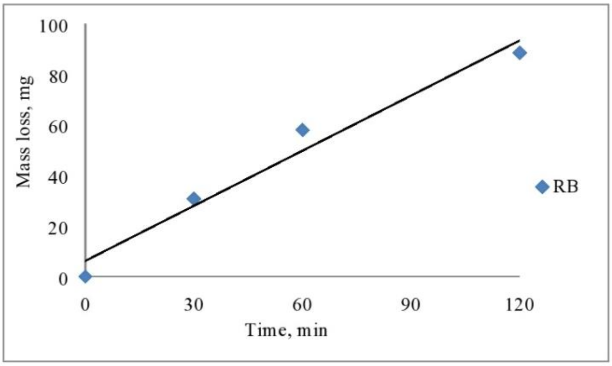

Figure 3. Cavitation rate calculated for the basalt samples.

By analyzing of the progression of erosion of basalt samples, it can be concluded that the incubation period at the early stage of the damage is short, because the period without mass loss is almost negligible. According to the selected test conditions, during the first 15 min the sample mass loss is up to 15 mg. As the exposure time increases, the cumulative mass loss of the sample gradually increases almost linearly to 88.5 mg for 120 min exposure. A relatively higher mass loss can be explained with the rough structure of olivine–pyroxene basalt, as well as by the presence of bubbles in the basalt structure (Fig. 2b).

Analysis of the basalt samples photographed before and during the cavitation erosion test is shown in Figure 4.

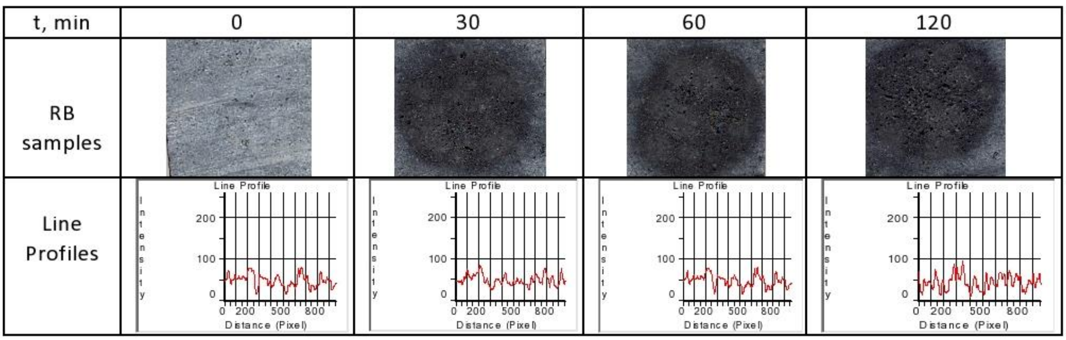

Figure 4. Photographs of basalt samples before and during the cavitation erosion testing after implementation of red filter and corresponding line profiles.

It was observed that the initial pits and the present roughness of the basalt surface (for time of t=0 min) are changing and dimensionally increasing during the exposure to the cavitation. This can be seen in the sample's profile lines recorded during testing. The profile lines indicate that the degradation is taking place at the center of the sample surface. The peaks of the recorded lines of the profile are intensifying when surface area damage is spreading at higher degree. The deterioration was increasing from 30 min of exposure to 120 min, and the highest degree of damage was observed upon 120 min of cavitation testing.

The results shown in Fig. 4 correspond to the results of damage that occurred on the surface of basalt samples determined via image analysis software. The results of the image analysis are illustrated in Figure 5.

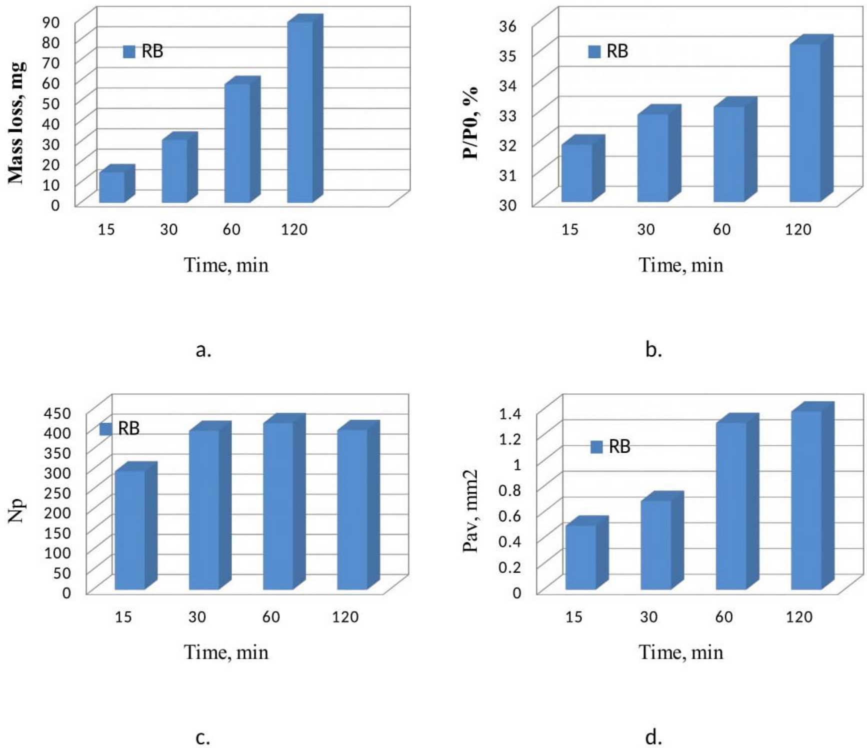

Figure 5. Results of image analysis: a) mass loss in mg; b) level of surface damage, P/P_0 in %; c) number of formed pits, Np; d) average surface of formed pits, P_{av} in mm^2.

Upon 120 min testing of cavitation erosion on basalt samples, the average mass loss of the investigated samples was 88.5 mg. The estimated change/degradation of the sample surface was about 35 %. Average number of formed pits was approximately 350. Estimated average surface of pits was 1.4 mm^2. It was confirmed that the formation and growth mechanism of pits on the surface of basalt samples can be successfully monitored by image analysis software, starting from the early phase of the cavitation process, throughout 15 min of exposure, up to the final testing interval (120 min).

The changes occurred in the morphology of basalt samples upon applied different cavitation intervals were additionally recorded with scanning electron microscopy. The resulting microphotographs are provided in Figure 6.

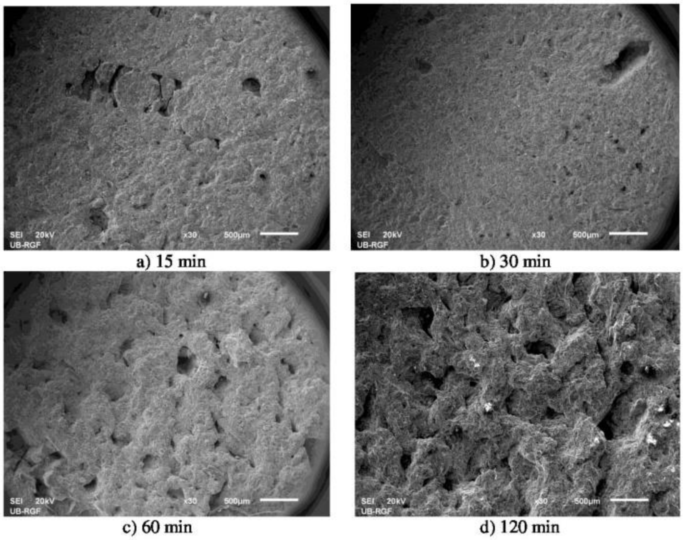

Figure 6. SEM microphotographs of the eroded surfaces of a basalt sample with the same magnification and different cavitation time: a) 15 min; b) 30 min; c) 60 min; d)120 min.

The 15 minute long cavitation process increases the existing roughness of the surface and forms shallow pits. A pit in the olivin-pyroxene basalt structure has sharp edges, most likely due to the eroding of the edges of the crystal around the existing bubble (Fig. 6a). The exposure during 30 min initiated the increase in the dimensions of the formed pits. The appearance of the pit with eroded surfaces due to ejection of grain and mass loss caused by cavitation is given in Fig. 6b. Sixty minutes long cavitation caused further degradation of a sample' surface. Numerous new pits were formed and existing pits increased due to the erosion of the pit surface and further loss of sample's mass (Fig. 6c). At the end of the cavitation erosion experiment, i.e. upon the 120 min long exposure, surface of the sample is highly deformed, larger in size and the interconnection connection of the pits is formed (Fig. 6d).

4. CONCLUSION

The results of the presented experimental research contributed to the understanding of the cavitation resistance of the basalt from the Vrelo, Kopaonik deposit. The methodology for the monitoring of the level of damage caused by cavitation and the estimation of the working life of this material on the basis of given parameters were developed: the change in mass loss during various cavitation exposure times, measurement of the level of degradation of the sample' surface, dynamics of the superficial pits formation as well as their grown and merging, the determination of the profile line.

Following the changes in the morphology of surface of the samples during the experiment, it was found that the erosion is taking place at the sample' surface due to the formation of a small pits, whose number was growing during the experiment, without the appearance of cracks that would cause the samples fracture. The pits were usually formed in the vicinity of already existing surface damage caused by the presence of bubbles in the basalt base. The results indicate that basalt from this deposit is suitable as a raw material for the production of various building materials that will be exposed to cavitation loads during their life-cycle.

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