The 56th International October Conference on Mining and Metallurgy
22-25 October 2025, Bor Lake, Bor, Serbia
www.ioc.tfbor.bg.ac.rs

DOI: 10.5937/IOC25490P *Original scientific paper*

CAVITATION RESISTANCE OF TALC-REINFORCED PYROPHYLLITE CERAMICS

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Abstract

The paper describes the effects of changing the properties of pyrophyllite ceramics reinforced with different proportions of talc (%): 10; 20; 30. Pyrophyllite powders with a grain size of 20 μm and talc powders with a grain size of 15 μm were homogenized, pressed and sintered at a temperature of 1200ºC. The cavitation resistance of the sintered samples was determined by the ultrasonic vibration method with a stationary sample according to the ASTM G32 standard. The evolution of surface morphology and damage was examined by scanning electron microscopy (SEM). The aim of the research was to obtain a compact ceramic with improved properties of resistance to wear and cavitation. The quality of the sintered samples was evaluated according to the values of cavitation rates and the analysis of the surface damage.

***Keywords**: pyrophyllite, talc, sintering, cavitation resistance*

1. INTRODUCTION

In the conditions of cavitation, damage occurs and develops on the surface of the material under the influence of shock waves, micro-jets, cavitation vortices, or some other cavitation structures. Cavitation is a type of wear and represents the appearance, growth, and implosion (collapse) of vapor or vapor-gas bubbles in a flowing liquid. During this, shock waves are created, high temperatures and pressures develop, and the released energy is absorbed by a solid surface that is in contact with the flowing liquid. Absorbed energy in the material causes elastic-plastic deformations or destruction of the material, which represents damage under the effect of cavitation (erosion) [1]. The extent of material degradation during cavitation depends on its type, microstructure, and mechanical properties-particularly its strength and hardness. According to the literature, cavitation in refractory materials results in surface damage and mass loss, typically without plastic deformation [2,3].

In our earlier research, the possibility of using pyrophyllite in cavitation conditions was investigated [4]. Small resistance properties were obtained, which gave the idea to investigate the possibility of using other materials as a reinforcement, and above all, talc, which is similar in properties to pyrophyllite. Pyrophyllite is a phyllosilicate mineral with the chemical formula $Al_2Si_4O_{10}(OH)_2$. The most important physical and chemical characteristics of pyrophyllite are: high melting point, high thermal conductivity, density (2,65 to 2,90 g/cm^3), softness (hardness according to Mohs scale 1 to 2), inertness, purity, and whiteness. Pyrophyllite has a layered structure, and the bonds between the layers are weak van der Waals bonds that can be easily broken, so the layers slide over each other. This property is important for the modification of pyrophyllite and the improvement of its physical and chemical characteristics (chemical modification, modification in the mill, as well as the application of physical methods, such as ultra sound, plasma and similar methods). Pyrophyllite is used in the paper industry, pharmacy, ceramics, environmental protection, cosmetics, agriculture, as well as for processing materials [5].

Talc is magnesium hydrosilicate with the general formula $3MgO \cdot 4SiO_2 \cdot H_2O$, containing impurities such as Al_2O_3, FeO, NiO, and CaO. Minerals commonly associated with talc include chlorite, tremplite, anthophyllite, and quartz. Talc has a leafy structure and low hardness. The most important physico-chemical and mineralogical properties of talc include a high melting point, chemical inertness (resistance to acids, alkalis and heat), low hardness and density, good grindability, low thermal conductivity, low coefficient of linear thermal expansion, and excellent adhesion and coating ability. It is used in the paint, pharmaceutical, chemical, and construction industries, as well as in medicine, cosmetics, rubber, and paper manufacturing, among other applications [6]. The goal of this research was to develop pyrophyllite ceramics with enhanced properties, particularly improved cavitation resistance, by incorporating talc as a reinforcing agent. To achieve the desired microstructure and properties, raw materials were prepared through crushing, grinding, and mechanical activation, followed by sample synthesis via sintering. These preparation and synthesis procedures were optimized and characterized to ensure quality samples.

2. EXPERIMENTAL

Three series of samples were used in the experiment: pyrophyllite 90% + talc 10% (label PT10); pyrophyllite 80% + talc 20% (PT20); pyrophyllite 70% + talc 30% (PT30). For the experiment, pyrophyllite (label: P) was obtained from the Parsovići – Konjic deposit, Bosnia and Herzegovina. The sample was prepared by crushing and grinding to a maximum grain size of 20 μm. The talc sample (label: T) was obtained by a combined procedure for the preparation of mineral raw materials (shredding, leaching) of raw talc. The sample was ground to a grain size of 15 μm for better compatibility with larger pyrophyllite particles. Table 1 shows the chemical composition of the initial pyrophyllite and talc fillers. The mixture of components of three series of samples was homogenized and pressed into tablets with a diameter of 30 mm and a thickness of 5 mm under a pressure of 10 MPa with the addition of carboxy methyl cellulose as a binding agent. For each series of samples, 10 tablets were made.

Table 1. Chemical composition of pyrophyllite and talc refractory fillers

Fillers	Oxide content, %							
	SiO_2	Al_2O_3	Fe_2O_3	MgO	CaO	Na_2O	K_2O	LoI*
P	63.55	14.85	1.24	1.46	7.53	0.29	0.3	5.90
T	60.88	4.14	0.85	32.50	1.07	-	-	6.90

*Loss on ignition at 1000 °C

After pressing, the tablets were sintered in a laboratory furnace at 1200 °C, according to the sintering regime: raising the temperature to 1000 ºC at a rate of 5 ºC/min for 250 min; 1000-1200 ºC with a heating rate of 2 ºC/min for 150 min; at 1200 ºC, the sintering of the samples lasted 60 min.

To determine the properties of the cavitation resistance of the tested samples, the ultrasonic vibration method was applied with a stationary ASTM G32 sample. The device and testing methodology were described in earlier works [3,7]. The samples were tested with different intervals of exposure to the effect of cavitation (min): 30; 60; 90 and 120. During the determination of the resistance to the effect of cavitation, the change in the mass of the samples as a function of the time of cavitation was monitored and the cavitation rate of the samples was determined. Measurements of the samples were made using an analytical balance with a precision of ± 0.1 mg. The formation and development of damage to the surface of the samples under the effect of cavitation were monitored by recording on an electron microscope brand MIRA3 FEG-SEM, Tescan (Brno, Czech Republic). The samples that were examined on the SEM were coated with gold before recording, the thickness of the layer was 5 nm.

3. RESULTS AND DISCUSSION

During the sintering process, a compact structure was achieved, which had a positive effect on the increased resistance of the samples during tests on the effect of cavitation. The sintering process contributed to a series of thermal transformations of phyrophyllite: removal of water present in the structure, dihydroxylation of pyrophyllite, decomposition of pyrophyllite into amorphous quartz and mullite, crystallization of cristobalite from amorphous quartz, and the resulting crystalline phases in the structure contributed to an increase in the hardness of sintered pyrophyllite [5]. The application of a mixture of pyrophyllite powder and talc of different grain sizes contributed to a better arrangement of the particles with each other, which contributed to the achievement of a higher density of the pressed samples. By inspecting the surfaces of the sintered P+T samples before and during the cavitation effect test, it is noted that there was no visible damage to the surface of the samples, nor breakage and degradation of the samples, as shown in Figure 1. The formation and development of damage to the surface of the samples took place at a low rate, and the loss of mass of the samples during exposure was small, Figure 2.

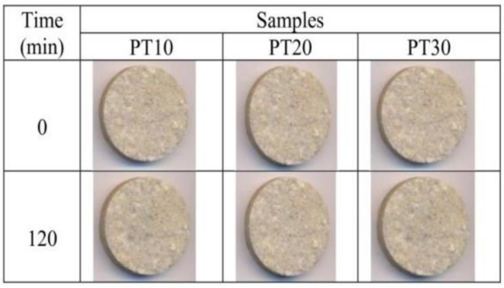

Figure 1. Photographs of the surfaces of sintered samples P+T before and after exposure.

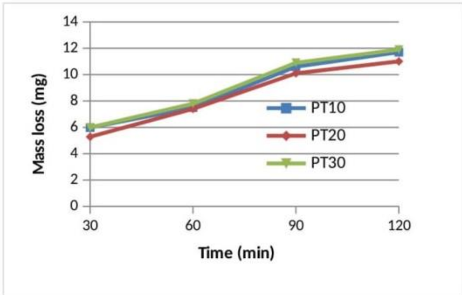

Figure 2. Cavitation rate of sintered samples P+T.

The process of surface damage takes place very slowly, without the appearance of cracks or a major loss of mass of the samples. The eroded surfaces are smooth, which indicates that the damage and loss of mass took place by removing particles from the surface without deformation, Figure 3.

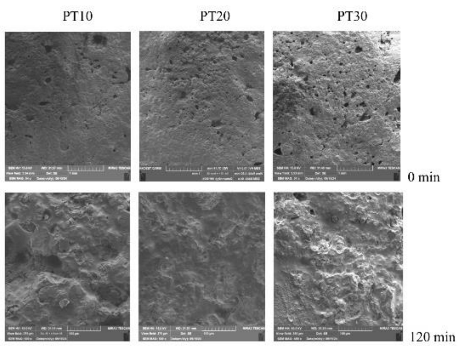

Figure 3. SEM microphotographs of the surface of P+T samples before cavitation and 120 min of exposure.

Figure 2 shows that all samples have low mass losses during exposure, and PT20 samples show the lowest mass loss and the lowest cavitation rate. The total mass loss at the end of the test lasting 120 min was: 11,70 mg (sample PT10); 11.01mg (sample PT20); 11.9 mg (sample PT30). The calculated cavitation rates of P+T samples were: V= 0.098 mg/min (PT10); V=0.092mg/min (PT20); V=0.099 mg/min (PT30), which indicates good cavitation resistance of all sintered samples.

4. CONCLUSION

Research on the effects of applying talc to improve the resistance properties of pyrophyllite-based ceramics has shown positive results. Pyrophyllite and talc are known to have low hardness, 2 and 1 on the Mohs scale, respectively. This affects the low cavitation resistance of sintered samples of pyrophyllite and talc, as shown by earlier research. With the addition of talc, which is similar to pyrophyllite and has high adhesion and surface coating properties, the cavitation resistance of the samples is significantly increased. The different sizes of pyrophyllite and talc grains, 20µm and 15µm, respectively, contributed to obtaining a compact structure of the samples, which improved mixing and stacking of particles with each other. By pressing and sintering the mixtures prepared in this way, compact structures of samples with improved properties of resistance to cavitation shocks were obtained. A series of crystalline phases created by sintering, primarily quartz, mullite, and cristobalite, contributed to the increase in the hardness of the samples, and thus to the increase in cavitation resistance. The cavitation resistance of the samples was determined based on the cavitation rate and analysis of the morphology of the damaged surface: the cavitation rates were low, from 0.092-0.099 mg/min, the erosion loss of the sample mass in 120 min was 1.9 mg, and the eroded surfaces of the samples were without visible damage. The obtained results showed that sintered samples based on pyrophyllite reinforced with talc have good resistance to cavitation impact and can be used in conditions where the presence of cavitation processes is expected.

ACKNOWLEDGEMENTS I

This work was supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia (Contract No. 451-03-136/2025-03/ 200213 and 451-03-136/2025-03/200135).

ACKNOWLEDGEMENTS II

The authors would like to thank AD Harbi-Sarajevo BiH for providing samples of pyrophyllite for experimental research.

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