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CAVITATION RESISTANCE OF BASALT-BASED PROTECTIVE COATINGS AND EPOXY SYSTEM

KAVITACIONA OTPORNOST ZAŠTITNIH PREMAZA NA BAZI BAZALTA I EPOKSI SISTEMA

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- cavitation resistance

Ključne reči
- premazi
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- bazalt
- epoksi sistem
- kavitaciona otpornost

Abstract

The paper presents the results of synthesis and characterization of new refractory coatings based on basalt and epoxy system. Coatings are intended to protect the surfaces of parts of equipment and various structures in civil and mechanical engineering and metallurgy which are exposed to wear, corrosion, or cavitation during exploitation. Coating composition, procedures for preparation of components from coating composition, synthesis procedures, and application of coatings are investigated. Several methods are used to characterize the coating: X-ray diffraction analysis (XRD), scanning electron microscopy (SEM), optical microscopy and ultrasonic vibration method with a stationary sample according to ASTM G32 standard. Material resistance to the action of cavitation is determined using the ultrasonic method. In order to monitor the formation and development of surface damage on samples under the effect of cavitation, the morphology of surface coating damage is analysed using scanning electron microscopy. Results show high resistance of the tested basalt-based coatings under the action of cavitation, with low cavitation rate (0.04 mg/min), low mass losses of coating and minor surface damage during exposure. This indicates the possibility of applying this type of refractory coating for the protection of various metallic and non-metallic structures in conditions of wear and cavitation.

Izvod

U radu su prikazani rezultati sinteze i karakterizacije novih vatrostalnih premaza na bazi bazalta i epoksi sistema. Premazi su namenjeni za zaštitu površina delova opreme i različitih konstrukcija u građevinarstvu, mašinstvu i metalurgiji, koji su tokom eksploatacije izloženi habanju, koroziji ili kavitaciji. Istražene su recepture premaza, postupci pripreme komponenata iz sastava premaza, postupci sinteze i primene premaza. Za karakterizaciju premaza primenjeno je više metoda: rendgenska difrakciona analiza (XRD), skenirajuća elektronska mikroskopija (SEM), optička mikroskopija i ultrazvučna vibraciona metoda sa stacionarnim uzorkom prema standardu ASTM G32. Primenom ultrazvučne metode određena je otpornost materijala prema dejstvu kavitacije. U cilju praćenja nastajanja i razvoja oštećenja površine uzoraka pod dejstvom kavitacije, analizirana je morfologija oštećenja površine premaza primenom skenirajuće elektronske mikroskopije. Rezultati su pokazali visoku otpornost ispitivanih premaza na bazi bazalta pod dejstvom kavitacije, sa malom kavitacionom brzinom (0,04 mg/min), malim gubicima mase premaza i manjim oštećenjima površine tokom ekspozicije. To ukazuje na mogućnost primene ove vrste vatrostalnih premaza za zaštitu različitih metalnih i nemetalnih konstrukcija u uslovima dejstva habanja i kavitacije.

INTRODUCTION

Basalt is a hard volcanic rock. As a mineral raw material, it is easily available and widely distributed. It is used for synthesis of glass and glass-ceramics /1, 2/, synthesis of new materials and products such as basalt wool, basalt fibres, basalt plastics, basalt reinforcement, /3-5/. Basalt-based composite materials are widely used for the manufacture of parts and equipment in the machine industry, automotive industry, shipbuilding, civil engineering, /6, 7/. A number of good technical properties that basalt possesses makes it an important raw material for application in civil engineering, road economy, for making curtains of high-speed railways, /5/. It is used as building stone for cladding external and internal horizontal and vertical surfaces, for making decorative furniture, dishes, glazes for decorating various ceramic and other products /8, 9/. Basalt is used for the obtaining of floor coverings in production plants and halls, coating devices, and wearing parts of mills, mixers, classifiers, silos for storage of mineral raw materials, for all types of hydraulic works, /3, 5/. The technology of basalt rock processing is ecologically clean, and the products obtained by technological processing of basalt are not carcinogenic, /3/.

In recent decades, extensive research has been conducted on the application of cast basalt for the manufacture of parts of equipment that are exposed to wear, corrosion, high temperature, aggressive fluids and suspensions, as a substitute for metallic materials, /3, 4, 8, 9/. Special attention is paid to the manufacture and application of basalt-based coatings for the protection of various structures and equipment under cavitation conditions, /10, 11/. According to the data from literature /12, 13/, it can be seen that the phenomena that occur in the process of cavitation in industrial conditions have been investigated. Research has shown that cavitation is a type of wear and represents the occurrence of the formation, growth, and implosion (collapse) of steam or steam-gas bubbles in a flowing liquid. Bubble implosions create shock waves and microjets - stress concentrators, whose energy is dissipated inside the liquid or absorbed by the solid surface with which the liquid is in contact. It has been shown that impact loads caused by the collapse of cavitation bubbles cause surface damage and mass loss of material which represents cavitation erosion. During cavitation, high temperatures and pressures (approximately 5000 °C and 1000 bar) occur locally during bubble collapse in a very short time interval (less than 1 μs), /13/. In order to select the material for application in conditions of cavitation action, it is necessary to study the correlation of hydrodynamic parameters of the cavitation process, the structure and properties of the material. It has been shown that the structure and mechanical properties of materials (primarily hardness and strength) have a dominant influence on cavitation resistance, /9, 10/.

EXPERIMENTS

Basalt-based refractory coatings are a novelty and have not been used in practice so far. As a basis for researching the composition of these coatings, the results from previously published works are used, /9-11/. Selected basalt rocks from the deposit 'Vrelo' Kopaonik (in Serbia) are used as a starting material for the production of coating fillers. Figures 1 and 2 show the XRD diffractogram and the SEM micrograph of the initial sample of basalt rocks used, in respect. Philips X-ray diffractometer, model PW-1710, is used to test the composition of basalt rocks. The most common minerals in the composition of basalt rocks are: plagioclase, pyroxene, and olivine, Fig. 1. A scanning electron microscope JOEL JSM-6390LV is used to characterize the microstructure of the examined samples. Microcrystalline plagioclase, phenocrystals of olivine, rhombic pyroxene and less often basic plagioclase are present in the structure, Fig. 2. The basic oxides that determine the quality of basalt as a filler of refractory coatings are present in the composition of basalt rocks, as follows: 55.90 % SiO_2; 18.49 % Al_2O_3; 7.78 % CaO; 3.5 % MgO; 2.99 % FeO; and 1.15 % Fe_2O_3.

Basalt rocks are crushed and ground to a powder granulation of 20 μm to obtain a filler, Fig. 3. During research, the composition of protective coatings is defined: 82-83 % basalt-based filler; 14-15 % binder based on epoxy system; 1.2-1.3 % organic additives and organic solvent to a suspension density of 2-2.5 g/cm^3, Fig. 4.

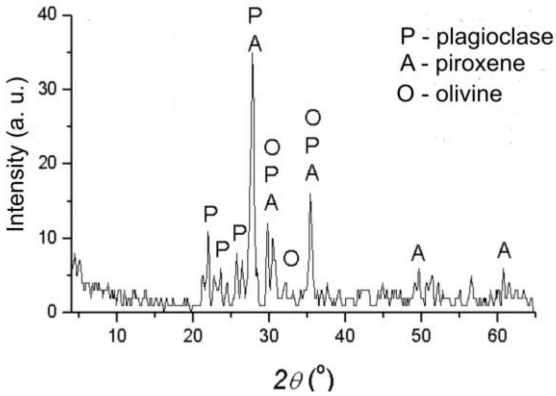


Figure 1. XRD diffractogram of the initial basalt rock sample.

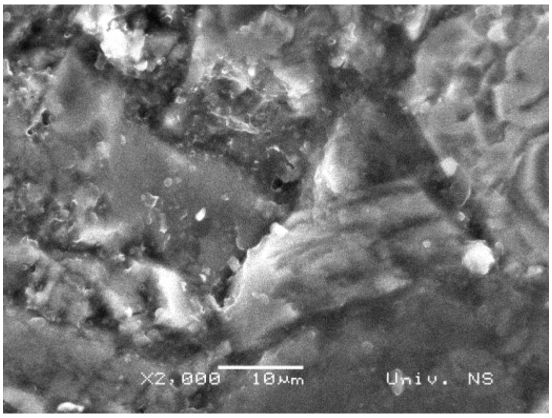


Figure 2. SEM micrograph of the initial basalt rock sample.

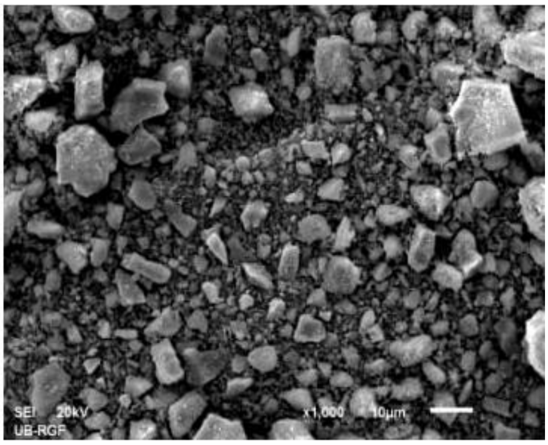


Figure 3. SEM micrograph of a basalt-based refractory filler.

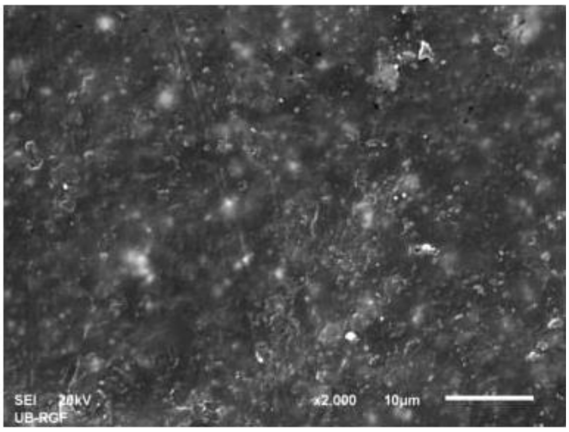
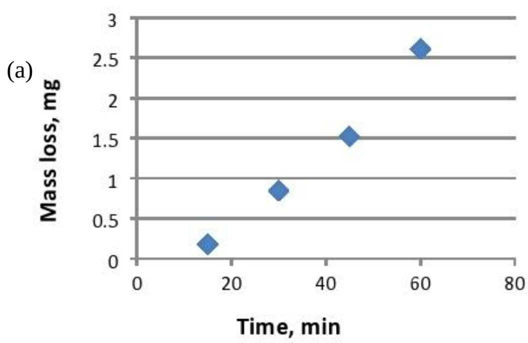


Figure 4. SEM micrograph of the coating surface.

During preparation of the coating, the refractory filler and additives are gradually added to the epoxy resin-based binder with constant stirring. To obtain the optimal density of the coating, an organic solvent (toluene) is gradually added with constant mixing. For testing under the action of cavitation, the obtained refractory coatings are applied with a brush in one layer on a polystyrene support measuring 16×16×7 mm. After drying the coating for 60 min, the resistance of the coating to the action of cavitation is tested using the ultrasonic vibration method with a stationary sample according to the ASTM G32 standard /14/, and the procedure described in previous works /9, 10, 15/. The selected test time of the coating samples under the action of cavitation was: 15; 30; 45; and 60 min. To assess the cavitation resistance of basalt-based coating samples, the change in sample mass as a function of cavitation time is monitored. Also, the change in surface area of the coating samples during exposure is monitored using scanning electron microscopy (SEM). Using the computer program for image analysis Image Pro Plus® /16/: the level of damage to the sample surface during exposure (P/P_0 %, where the value of P_0 represents the reference surface without damage, and the value of P represents damage to the sample surface during testing); number of formed individual pits N_p; mean area of formed pits P_{av} (mm^2); as well as the surface profile line of the samples is determined. Image analysis is performed on macroscopic photographs of the surface of samples taken at different times of cavitation. The cavitation rate for coating samples during exposure is determined as a quotient of the total mass loss during the test time in accordance with the standard, /14/. All the obtained results are shown in the corresponding diagrams.

RESULTS AND DISCUSSION

The mass loss of coating samples under the action of cavitation during test time and the results of image analysis obtained using the computer program Image Pro Plus® are shown in Fig. 5. Three samples are used for all tests and the mean value of the tested parameter during exposure is shown. The diagram in Fig. 6 shows the relation between mass loss and testing time, where the line is drawn by least-square method. The slope of the straight line represents the cavitation rate. The cavitation rate, v = 0.04 mg/min, is calculated as the total mass loss at the time of cavitation testing. The value of cavitation rate indicates high cavitation resistance of protective coatings and the possibility for application in rigorous operating conditions.



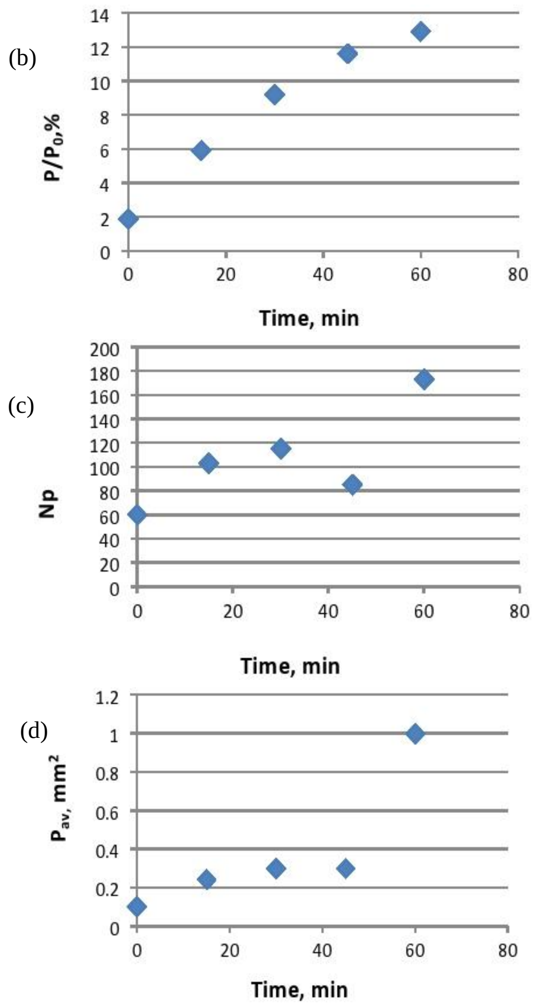


Figure 5. Test results of coatings: a) mass loss (mg); b) level of surface damage (%); c) number of formed pits; d) middle surface of formed pits (mm^2).

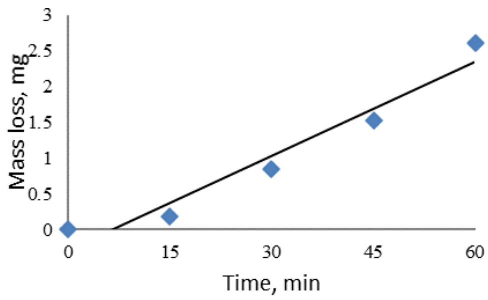


Figure 6. Cavitation rate of coating samples.

To evaluate the cavitation resistance, the sample surface is examined before and during testing. Figure 7 shows the results of testing the occurrence and development of damage to the coating surface before and during the test on the effect of cavitation with the corresponding lines of the profile obtained by applying the image analysis.

Morphology of surface damage of coating samples is monitored using scanning electron microscopy (Fig. 8). Before exposure to cavitation, small bubbles formed during the coating and brush application are present on the sample surface, as well as a number of small and shallow pits (Fig. 8), for time 0 min. The figures show the even distribution of the refractory filler in the coating. After 60 min of exposure the initial pits on the surface are dilated, a larger number of new pits are formed. These are small and shallow pits, that form at low speed and do not damage the surface much, which can be seen from the results of image analysis: the total surface damage of the samples at the end of the test is small, below 12 %, mass loss is below 2.6 mg, Figs. 5b and 5a, respectively. During exposure, a larger number of small pits are formed, that have inflicted less damaged to the surface of the coating, as shown in Figs. 5c and 5d. The results show the high resistance of this type of refractory coating to cavitation loads and the possibility of their application for the protection of work surfaces on equipment exposed to cavitation stresses during operation.

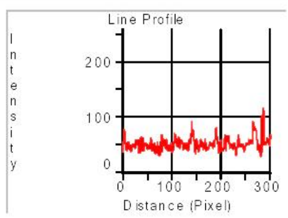
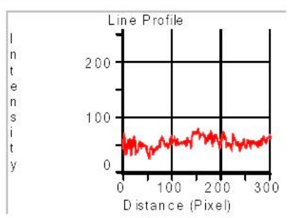
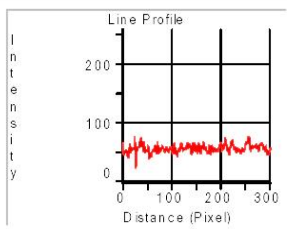
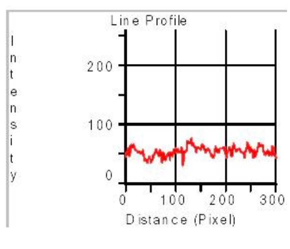
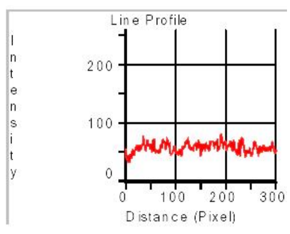
T, min	Coating surface	Line profile
0		
15		
30		
45		
60		

Figure 7. Photographs of coating samples before and during the test on the effect of cavitation with corresponding profile lines obtained by applying image analysis.

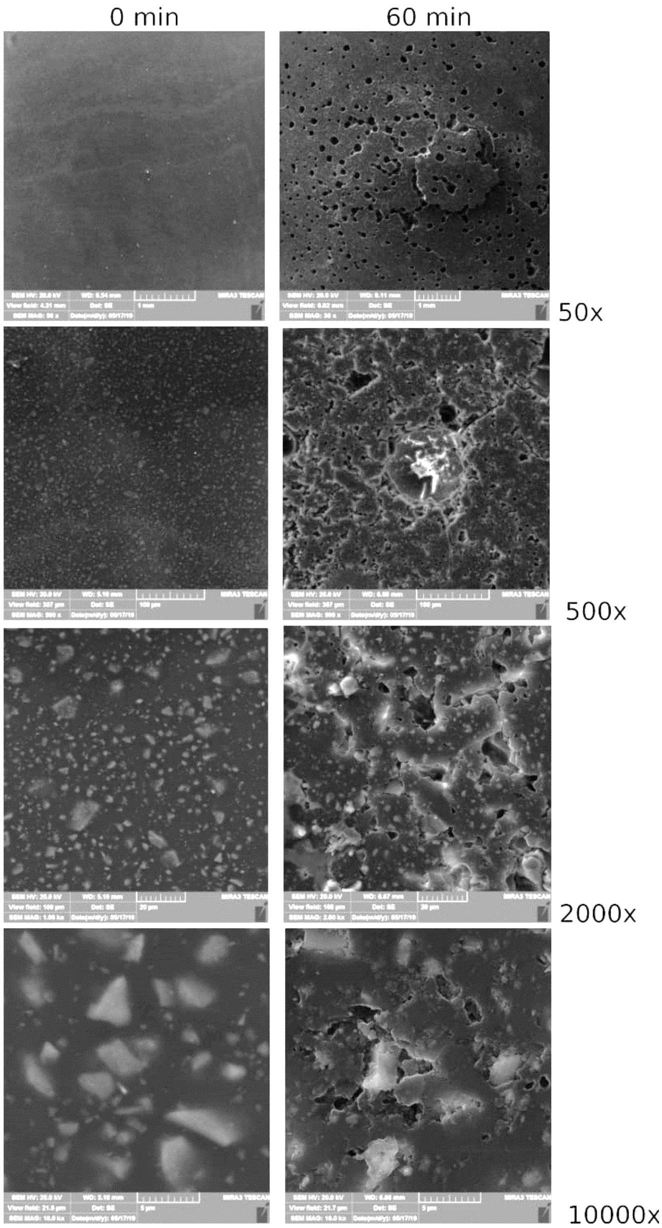


Figure 8. SEM micrographs of coating sample surfaces at different magnifications before (0 min) and at the end (60 min) of the exposure to cavitation.

Application of ultrasonic vibration method with a stationary sample according to ASTM G32 standard /14/ and computer image analysis /16/ will enable faster selection of materials for coating synthesis, evaluation of their efficiency in the protection of metallic and non-metallic surfaces, as well as their service life in similar operating conditions.

CONCLUSIONS

The research of basalt-based refractory coatings for the protection of metallic and non-metallic structures in civil engineering, mechanical engineering, and metallurgy, is a novelty, considering that these types of refractory materials have not been used in practice so far. Basalt-based filler is a cheap mineral raw material that Serbia has at its disposal, which is an advantage, and it is also an advantage that basalt and basalt processing technologies are environmentally friendly. Research has defined coating composition and procedures for their synthesis. Methods for characterization of refractory coatings using the ultrasonic vibration method with a stationary sample, scanning electron microscopy, and computer image analysis are defined, which enable rapid examination and evaluation of the possibility for applying the coating in given operating conditions. Future research should focus on the application of a basalt-based refractory filler with a smaller grain diameter (below 15 μm), as well as the application of organic additives that will enable the dispersion of the coating suspension. To expand the range of coating application, the possibility of adding different pigments to achieve the desired coating colour should be explored.

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