Marko Pavlović[1], Marina Dojčinović[1], Radica Prokić-Cvetković[2], Ljubiša Andrić[3]

CAVITATION RESISTANCE OF COMPOSITE POLYESTER RESIN / BASALT POWDER

OTPORNOST NA DEJSTVO KAVITACIJE KOMPOZITA POLIESTARSKA SMOLA/BAZALTNI PRAH

Originalni naučni rad / Original scientific paper
UDK /UDC: 678.674.018.9:666.19
Rad primljen / Paper received: 01.02.2019

Adresa autora / Author's address:
[1)] University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, email: rina@tmf.bg.ac.rs
[2)] University of Belgrade, Faculty of Mechanical Engineering, Belgrade, Serbia
[3)] Institute for Technology of Nuclear and Other Mineral Raw Materials, Belgrade, Serbia

Keywords
- composite
- unsaturated polyester resin
- basalt powder
- mechanical properties
- cavitation resistance

Abstract

The paper presents the results of research on cavitation resistance of the composite based on unsaturated polyester resin and basalt powder, as reinforcement. Basalt powder was obtained by grinding and micronising basaltic rocks from the Vrelo-Kopaonik deposit. Different amounts of basalt powder as reinforcement were applied (g): 0.15; 0.30; 045; 0,50. The mechanical properties (tensile strength, bending strength, hardness) and cavitation resistance properties were determined for the resulting composite. An ultrasonic vibration method (with stationary specimen) was applied according to ASTM G32 standard. Studies have shown that the mechanical properties and cavitation resistance of the composites increase with the addition of basalt powder as reinforcement.

Ključne reči
- kompozit
- nezasićena poliestarska smola
- bazaltni prah
- mehanička svojstva
- otpornost na dejstvo kavitacije

Izvod

U radu su prikazani rezultati istraživanja otpornosti na dejstvo kavitacije kompozita sa osnovom od nezasićene poliesterske smole i ojačivača u vidu bazaltnog praha. Bazaltni prah je dobijen mlevenjem i mikronizacijom bazaltnih stena iz ležišta Vrelo Kopaonik. Primenjene su različite količine bazaltnog praha kao ojačivača (g): 0,15; 0,30; 0,45; 0,50. Na dobijenom kompozitu ispitivana su mehanička svojstva (zatezna čvrstoća, čvrstoća na savijanje, tvrdoća) i svojstva otpornosti na dejstvo kavitacije. Primenjena je ultrazvučna vibraciona metoda (sa stacionarnim uzorkom) prema standardu ASTM G32. Ispitivanja su pokazala da se mehanička svojstva i otpornost na dejstvo kavitacije kompozita povećavaju sa dodatkom bazaltnog praha kao ojačivača.

INTRODUCTION

Basalt is a cheap and widespread raw material for making glass and glass ceramics, synthesis of new materials and products such as basalt wool, basalt fibers, basalt plastics, basalt armatures, composite materials, widely used for the manufacture of parts and equipment in the machinery industry, shipbuilding, construction /1-3/. Basaltic rocks from the Vrelo Kopaonik deposit belong to the group of pyroxene-olivine basalt. The basalt rock processing technology is environmentally clean and the products obtained by basalt technology are not carcinogenic, /4/.

Cavitation is a phenomenon that 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 a very short time (less than 1 μs), /5/. The implosion of the cavitation bubble causes the appearance of elastic, plastic deformation or the destruction of materials, called cavitation erosion. According to literature data, in conditions of cavitation stresses, the most common are metallic materials (steel and aluminium alloys), while ceramic materials are used less. There is 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 application in the design of equipment parts for mining and metallurgy, /6-8/.

The high influence of material resistance according to the cavitation effect is shown in the structure and properties of the material (above all the hardness and strength of the material), as well as in the hydrodynamic parameters of the cavitation process. The testing of material resistance to the effect of cavitation in practice is usually carried out in laboratory conditions using an ultrasonic vibratory cavitation test method (with stationary sample) according to ASTM G32 standard. The cavitation resistance of the material is determined in relation to the mass loss during the cavitation erosion testing.

The paper investigates the possibility of making polymeric composites with a reinforcement based on basalt powder of 35 μm grain size and quantity (g): 0.15; 0.30; 0.45; 0.50. The base of the composite is an unsaturated low density polyester resin. The basic properties that influence the selection of basalt as an reinforcement in the making of composites are: melting point 1300-1400 °C; density 2460-2960 kg/cm^3; high hardness 6.5-7 Mohs scale; basic amounts of glass 10-15%; compressive strength 80 MPa; porosity 3.78%; hygroscopicity 1-4%; moisture content 1,2%; high resistance to frost; wear resistance; high resistance to acids, alkaline and heat; ecological and hygienic quality. The basic properties that influence the choice of polyester resin as the basis for making composites are easy synthesis, low density and low cost.

Most literature data relate on the production of composite with a polymetric base and basalt micron particulate based reinforcement /3, 9/, the increase in the properties of the obtained composites and the expansion of their application in civil engineering and mechanical industry. Application of nano particles (nano alumina, nano clay, silicon-oxide) contributes to achieving better polymer reinforcement and higher quality composite, /10/. The nano-dimensional reinforcement enables installation of a larger quantity of filler in a polymeric basis without disturbing the mechanical properties of the base. Research on polymer composites/ basalt powder has the advantage that basalt is a cheap and pure raw material that can be used without a purification process. These composites can potentially be used in civil engineering and various fields in the industry.

EXPERIMENTS

For the study, the basalt powder was obtained by grinding and micronising basalt rocks from the Vrelo - Kopaonik deposit. Table 1 shows the composition of the used basalt powder of particle size below 35 μm.

Table 1. Chemical composition of basalt powder (%).

Sample	SiO_2	Al_2O_3	Fe_2O3	FeO	MgO	CaO	Na_2O	K_2O	TiO_2
Basalt	56.21	18.61	1.15	2.97	3.40	7.78	4.73	3.37	1.11

X-ray diffraction analysis of sintered refractory samples was done by X-ray diffractometer PHILIPS®, model PW-1710, Fig. 1. The microstructure of sintered samples was characterized by scanning electron microscopy method (SEM) using a JOEL JSM-6390LV microscope, Fig. 2.

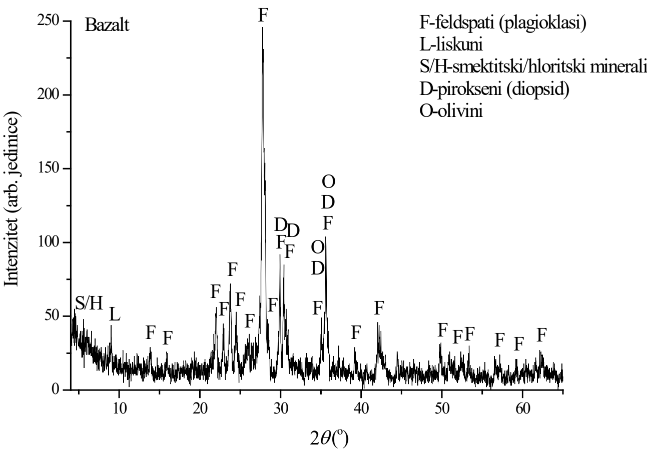


Figure 1. XRD of basalt sample

The basis of the composite was an unsaturated polyester resin with 40% styrene. The resin was measured 3 g on the analytical scale. For manufacturing the composite, quantities of basalt powder as reinforcement are measured: sample C1 0.15 g; sample C2 0.30 g; sample C3 0.45 g; and sample C4 0.50 g. The mixture of resin and basalt powder is placed on the mixer for 1 to 2 min. A magnet is placed in the vessel to prevent the mixture from adhering to the court walls. The mixture is then placed on an ultrasonic bath for 5 min to remove the bubbles. Subsequently, 2 % of the initiator for the metal-ethyl ketone peroxide (0.15 ml of initiator) is added to the mixture, and mixing is carried out in the ultrasonic bath for 15 s. The slurry mixture is poured into Teflon moulds. The poured mixture of the resin and reinforcement are left in the mould for 30-45 min at room temperature to cure (cross-linking). Following, the moulds are placed in a

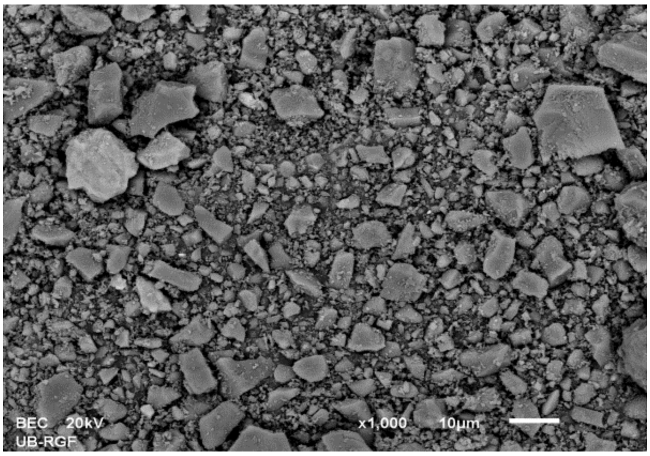


Figure 2. SEM micro photo of basalt sample.

Figure 3. Tube specimens of pure polyester resin (PR) for testing mechanical properties.

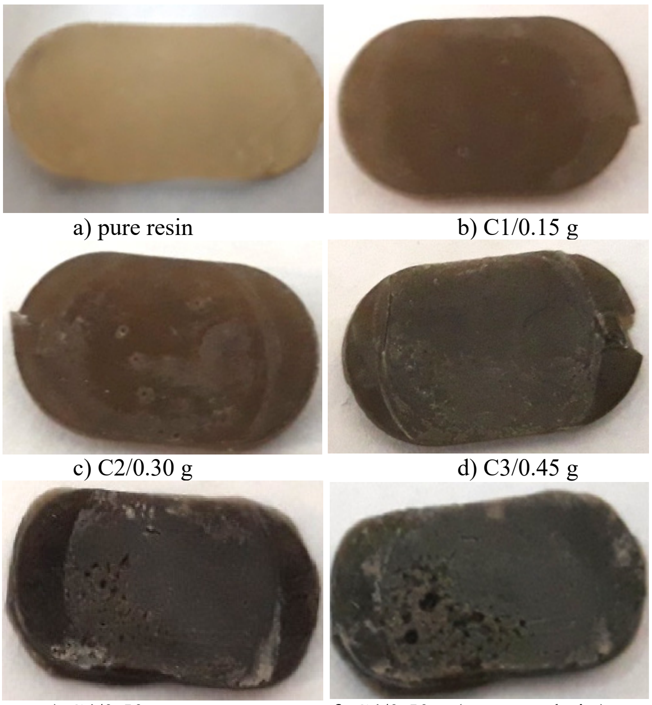
laboratory drier at 70 °C/2h, then moulded from the dryer and left for 48 hours at room temperature, after which the samples were removed from the mould. For testing the mechanical properties, pure resin tubes and composites were used, Figs. 3 and 4.

Figure 4. Tubes specimens of composite polyester resin/basalt powder for testing mechanical properties.

Tensile strength and bending strength tests were performed on the tensile test machine. The hardness of the samples was tested according to the Shor analysis on the Zorn Stendal DDR instrument. Cavitation resistance tests of composite samples and pure resin was done at the head of the tube. For cavitation resistance tests, an ultrasonic vibration method (with stationary samples) was used according to ASTM G32, /11/. During the test, the mechanical vibration concentrator is immersed in its water bath at 25 ± 1°C. The sample being tested is placed below the front surface of the vibration concentrator with a gap of 0.5 mm. The mechanical vibration frequency was 20 kHz, and amplitude 50 μm. A strong cavitation zone has formed below the front surface of the concentrator and the stationary test sample. The water in 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 strain during the test. Selected sample time (in min) was: 15; 30; 45; 60. After each test interval, the mass loss of the sample was measured by an analytical balance of 0.1 mg accuracy.

RESULTS AND DISCUSSION

Figure 5 shows the appearance of sample surfaces at the end of the cavitation test (60 min). Figure 6 shows the mass loss of sample during cavitation erosion test. It can be noted that in some composites there is grouping of pits on the surface, indicating the possibility of uneven distribution of the reinforcement and creation of potentially weaker sites, where damage to the sample surface and higher mass loss occurs. The smallest damage in the composite is 0.30 g of reinforcement (C2/0.30 g), Fig. 5c, and significantly greater damage and larger mass loss are in composite C4/0.50 g, Fig. 5e and Fig. 5f (connected pits).



a) pure resin b) C1/0.15 g

c) C2/0.30 g d) C3/0.45 g

e) C4/0.50 g f) C4/0.50 g (connected pits)

Figure 5. Surface photos of pure resin and composite samples during the cavitation erosion tests (60 min).

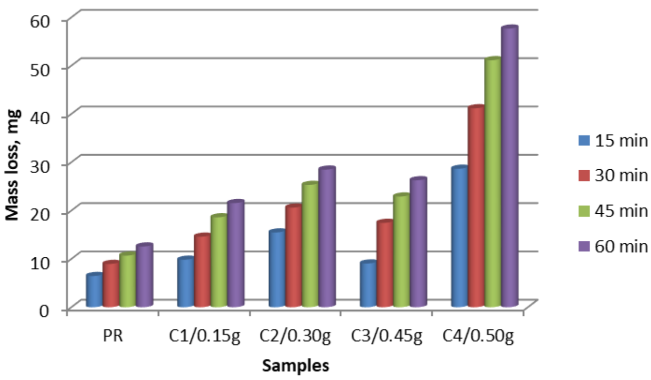


Figure 6. Mass loss of composite and pure resin samples during cavitation erosion tests.

Mechanical properties test results confirmed the assumption that when adding a larger amount of reinforcements (above 0.45 g) there are clusters in the composite structure and uneven distribution of reinforcement. Poor spots where deformation cracks initiate occur on composites C4/0.50 g. Tensile and bending strength test results are shown in Figs. 7 and 8, and the hardness test is shown in Fig. 9.

The addition of reinforcement up to 0.30 g contributes to the highest increase in R_m and σ, Figs. 7 and 8. Hardness test results show a dissipation of results probably due to the appearance of weak spots on the composite surface due to an uneven distribution of reinforcement in composite mass.

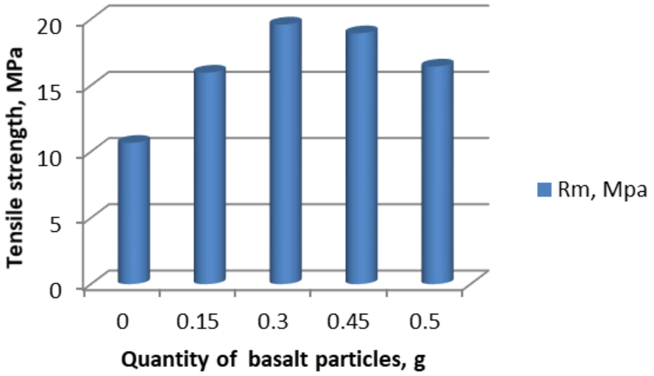


Figure 7. Influence of reinforcement particles on the tensile strength of composite samples.

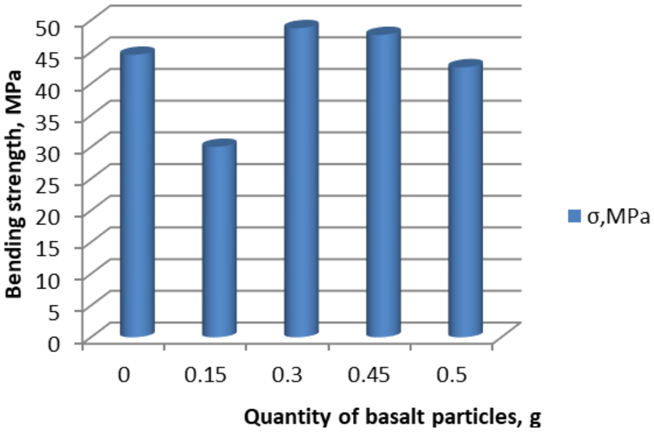


Figure 8. Influence of reinforcement particles on the bending strength of composite samples.

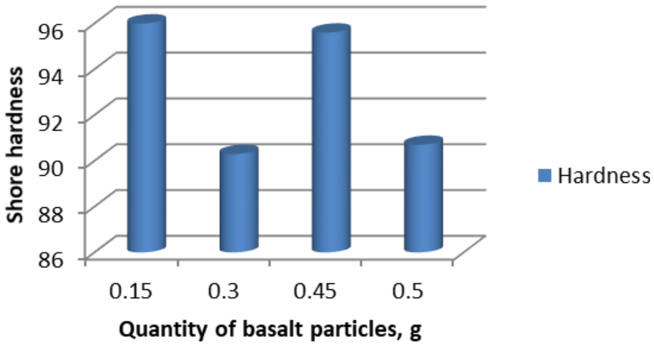


Figure 9. Influence of reinforcement particles on the Shore hardness of composite samples.

CONCLUSIONS

Research on the cavitation resistance of composite polyester resin/basalt powder shows a satisfactory cavitation resistance when adding basalt powder based reinforcement to 0.45 g. Composite samples show satisfactory mechanical properties and lower cavitation rate, as well as smaller surface erosion to 0.45 g of reinforcement. This indicates the possibility of applying them in the construction of parts in civil and mechanical engineering. Further research on the development of composites should be extended to the application of epoxy resins as the basis of the composite and the use of a basalt fiber-based reinforcement.

ACKNOWLEDGEMENTS

The research is financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia as part of projects TR 35002 and 34006 for which the authors are grateful.

REFERENCES

1. Barth, T.F.W., Theoretical Petrology, John Wiley & Sons Inc., New York, 1962, p. 387.
2. Fiore, V., Di Bella, G., Valenza, A. (2011), *Glass-basalt/epoxy hybrid composite for marine applications*, Mater. & Design 32 (4): 2091-2099. doi: 10.1016/j.matdes.2010.11.043
3. Todić, A., Nedeljković, B., Čikara, D., Ristović, I. (2011), *Particulate basalt–polymer composites characteristics investigation,* Mater. & Design 32(3): 1677-1683. doi: 10.1016/j.matdes.2010.09.023
4. Pavlović, M., et al., *Influence of the basalt structure and properties on development the cavitation damage*, Proc. 50th Int. Oct. Conf. on Mining & Metall. 2018, Borsko jezero, Serbia (Eds. Ana Kostov, Milenko Ljubojev), Bor: Mining and Metallurgy Institute, pp.155-158. ISBN 978-86-7827-050-5.
5. Dojčinović, M., Influence of the microstructure on cavitation erosion of steels, PhD Thesis, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, 2007.
6. Franc, J.P., Michel, J.M. (eds.), Fundamentals of Cavitation (series: Fluid Mechanics and Its Applications, Vol.76, Kluwer Acad. Publ., Dordrecht, 2004. ISBN 1-4020-2232-8.
7. Hammitt, F.G., Cavitation and Multiphase Flow Phenomena, McGraw-Hill, New York, 1980. ISBN 9780070259072
8. Dojčinović, M. et al. (2017), *Cavitation resistance of turbine runner blades at the hydropower plant 'Djerdap'*, Structural Integrity & Life 17(1):55-60.
9. Yılmaz, S., Bayrak, G., Sen, S., Sen, U. (2006), *Structural characterization of basalt-based glass-ceramic coatings*, Mater. & Design 27(10): 1092-1096. doi: 10.1016/j.matdes.2005.04.004
10. Kovačević, T., The influence of modified micro-particles obtained from nonmetallic fraction of waste printed circuit boards on mechanical and thermal properties of polyester resin synthesized from waste poly(ethylene terephthalate), PhD Thesis, University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia, 2018.
11. ASTM G32-10: Standard Test Method for Cavitation Erosion Using Vibratory Apparatus, ASTM Int., West Conshohocken, PA, 2010. doi: 10.1520/G0032-10