

# INTERACTIONS OF VARIOUS TYPES BETWEEN ROCK AND ALKALI-ACTIVATED BLAST FURNACE SLAG

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## **Abstract**

Alkali-activated binders (AAB) are very intensively studied materials nowadays. Because of possible usage as secondary raw materials, they can be environmentally efficient. Intensive research is focused especially on binder matrix, composition and its structure. For industrial usage, it is necessary to work with some aggregate for the preparation of mortars and concretes. Due to different structures of alkali-activated binders, the interaction with the aggregate will be different in comparison to an ordinary Portland cement binder. This paper deals with the study of interactions between several types of rocks used as aggregate and alkali-activated blast furnace slag. The research was focused especially on mechanical properties of prepared mortars.

**Key words:** alkali-activated binders, blast furnace slag, rock

## **1 INTRODUCTION**

Although AAB are well known for more than sixty years, the attention of researchers has intensified in the last two decades. It is mostly because the production of ordinary Portland cement is very environmentally inefficient. Many research works were done to study alkali activated binders, mortars, and concretes [1, 2, 7, 8]. The main focus of provided research works was put on chemistry and microstructure of various types of AAB [2]. Less number of papers is focused on the production of concretes and mortars. Interactions between binder matrix and aggregate were very intensively studied on ordinary Portland cement materials [3, 4, 5]. However, for alkali-activated binders this area is not well explored [6]. Because the interactions between alkali-activated materials and aggregate are not the same as for Portland cement, it is necessary to carry out a comprehensive study.

## **2 MATERIALS AND METHODS**

The alkali-activated materials were prepared in the same way as cement mortar for strength testing. Because there is no standard for testing such alkali-activated materials, the standard for cement testing was used [9]. Standard samples with dimensions of 160x40x40mm were prepared from an alkali-activated binder and aggregate made of various types of rock. The granulometry of aggregate was performed according to the standard for cement testing.

### **2.1 Alkali-activated blast furnace slag**

For the preparation of an alkali-activated binder, a finely milled blast furnace slag (BFS) with a specific surface area of 480m<sup>2</sup>/g was used. The chemical composition of BFS is presented in Table 1. The chemical composition is displayed without light elements as oxide or carbon. An activator was prepared from sodium silicate (water glass) with a modified silicate modulus of molar ratio  $M = 2.0$ . The modulus modification was done by adding a 50% sodium hydroxide solution. The chemical composition of the used water glass is given in Table 2. The amount of the added hydroxide solution was 11.9 ml to 100 ml of water glass.

**Tab. 1 Chemical composition of blast furnace slag**

Chemical element	[%]
Ca	30.05
Si	20.29
Fe	0.26
Al	6.11
Mg	1.83
S	0.65

**Tab. 2 Chemical composition of water glass (before modification)**

Oxide	[%]	M (SiO <sub>2</sub> / Na <sub>2</sub> O)
Na <sub>2</sub> O	7.53	3.42
SiO <sub>2</sub>	24.94	

## 2.2 Rock types and aggregate preparation

The rocks used for the preparation of an aggregate were chosen with regard to industrial usage in concrete preparation. Five types of rock were applied. The rock type and mineralogical composition are given in Table 3. As standard, quartz sand was used for the used rocks according to the standard for cement strength testing. This sand is sharply granulated to obtain fractions of 0.25 - 0.5, 0.5 - 1, and 1 - 2mm. The aggregate prepared from the rocks was crushed and sieved to the same size as standard sand.

**Tab. 3 Chemical composition of water glass (before modification)**

Basalt		Amphibolite		Marble		Travertine		Granite		
Mineral	%	Mineral	%	Mineral	%	Mineral	%	Mineral	%	
Augite	39.4	Biotite	3.1	Calcite	93.2	Calcite	98.2	Quartz	32.3	
Nepheline	14.0	Chlorite	7.6	Quartz	6.8	Quartz	1.8	Microcline	17.8	
Bytownite	16.4	Actinolite	34.1					Biotite	6.0	
Sanidine	14.5	Andesine	54.9					Chlorite	6.1	
Orsterite	9.0					Oligoclase				47.6
Hydroxyapatite	6.7									

## 2.3 Mechanical properties testing

Samples were prepared from the aggregate and binder according to the standard for cement strength testing. 450 g of the blast furnace slag and 450 g of each fraction of the aggregate was used. Compared to the standard, the difference consists in the usage of the liquid part of the mixture. The water amount was 100ml and the amount of the activator was 128 ml. These were chosen based on the previous work with alkali-activation of BFS [7]. The prepared samples with dimensions of 160 x 40 x 40 mm were cured under laboratory conditions and tested to flexural and compressive strength after 28 days.

## 2.4 Electron microscopy observation

After mechanical testing, the samples were observed on a scanning electron microscope (SEM), FEI Quanta 650 FEG (FEI, USA), equipped with energy-dispersive X-ray spectroscopy (EDX). The measurement of the samples was carried out under the following conditions: voltage 20 kV, current 8-10 nA, beam diameter 6

$\mu\text{m}$ , decreased vacuum in the chamber under the pressure of 50 Pa. The observation was done on the fracture face of sample after the strength tests. The observation was focused on grains of the aggregate and their surroundings.

### 3 RESULTS AND DISCUSSION

The mechanical testing and observations using a scanning electron microscope were done. From a mechanical point of view, it is obvious that the flexural strength has not the same trend as compressive strength. From Figures 1 and 2, it is apparent that the flexural strength of a standard sand sample is out of the trend in the compressive strength. The highest strength of samples corresponds with the strength of used rock. Only in the case of marble, the strength is very small – both flexural and compressive strengths. This can indicate a bad interaction between the binder and aggregate.

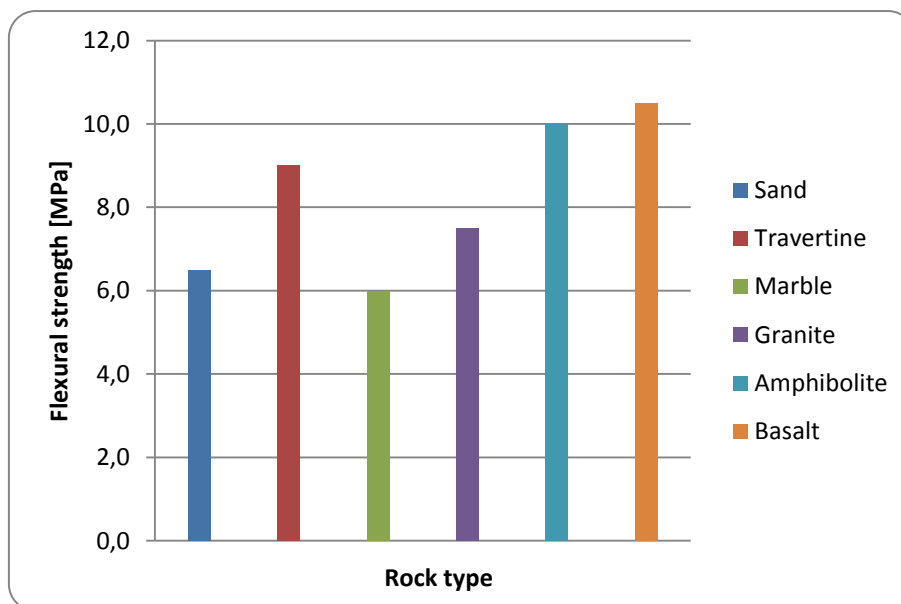


Fig. 1 Flexural strength of mortars with various types of aggregate

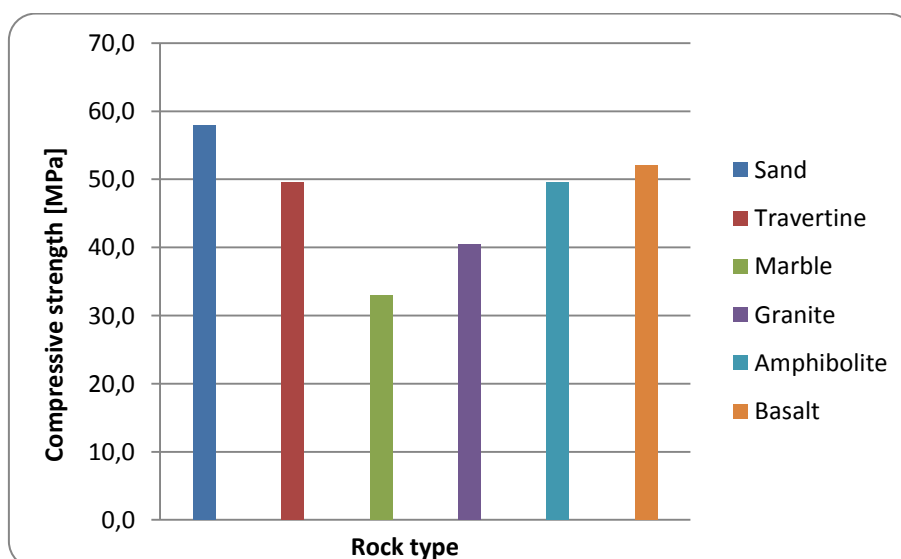
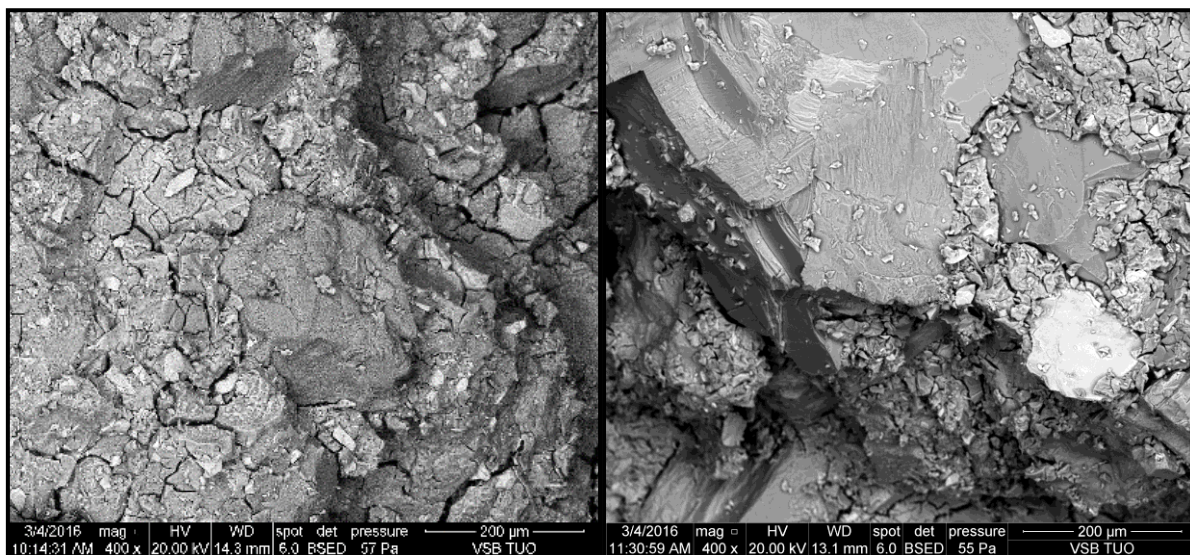
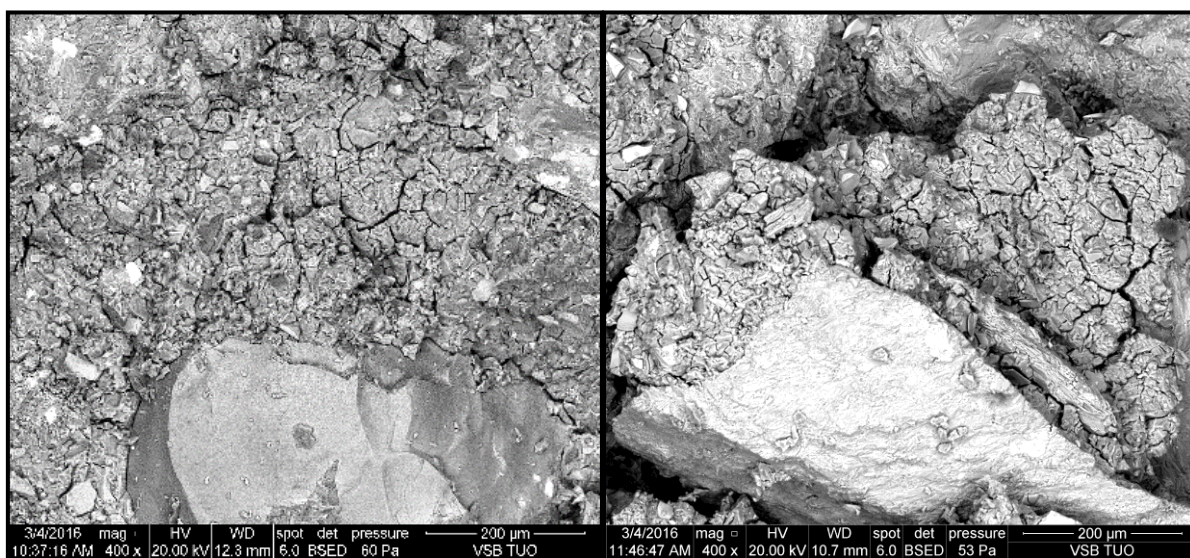


Fig. 2 Compressive strength of mortars with various types of aggregate

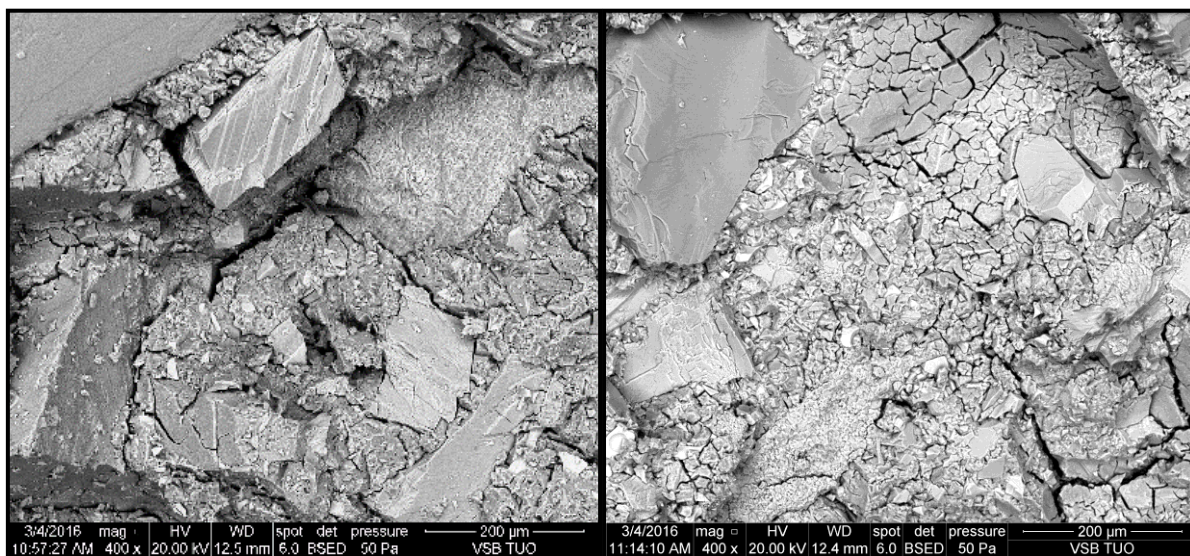
The observation on SEM is not as clear as the mechanical testing of samples. The samples with quartz sand and granite in Figure 3, basalt and amphibolite in Figure 4 are very similar. There are no significant differences in interfaces which correspond to the mechanical behaviour of samples.



**Fig. 3 AAB with quartz sand (left) and granite (right)**



**Fig. 4 AAB with basalt (left) and amphibolite (right)**



**Fig. 5 AAB with marble (left) and travertine (right)**

The behaviour of the samples with marble and travertine is interesting. However, the chemical composition of aggregate is nearly the same as the mineralogical composition; the mechanical properties are very different. It can be caused by the microstructure of rock. The marble consists of pure crystals of calcite which is obvious from the left in Figure 5. On the other hand, the travertine has a very fine structure which is poorly recognizable on SEM images (on the right in Figure 5). From the right in Figure 5, it is obvious that the calcite crystals of marble badly interact with the alkali-activated matrix opposed to the fine structured travertine.

#### 4 CONCLUSIONS

The provided experiment shows the influence of the used type of rock as an aggregate on the mechanical properties of alkali activated mortar. The rock types used in the experiment differed in chemical and mineralogical compositions. The shape of the aggregate has also a significant influence on the mechanical properties and interactions between the aggregate and mortar. It is obvious that the aggregate type has a significant influence on the resulting mechanical properties.

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#### REFERENCES

- [1] SHI C. B., KRIVENKO P., ROY D. *Alkali-activated cements and concretes*. New York: Taylor & Francis, 2006. ISBN 0-415-70004-3.
- [2] PACHECO-TORGAL F., CASTRO-GOMES J., JALALI S. Alkali-activated binders: A review: Part 1. Historical background, terminology, reaction mechanisms and hydration products. *Construction and Building Materials*. 2008, **22**(7), 1305-1314.
- [3] OLLIVIER J. P., MASO J. C., BOURDETTE B. Interfacial transition zone in concrete. *Advanced Cement Based Materials*. 1995, **2**(1), 30-38.
- [4] MITSUI K., LI Z., LANGE D. A., SHAH S. P. Relationship between microstructure and mechanical properties of paste-aggregate interface. *Materials Journal*. 1994, **91**(1), 30-39.
- [5] TRENDE U., BUYUKOTURK O. Size effect and influence of aggregate roughness in interface fracture of concrete composites. *Materials Journal*. 1998, **95**(4), 331-338.
- [6] SHI C., XIE P. Interface between cement paste and quartz sand in alkali-activated slag mortars. *Cement and Concrete Research*. 1998, **28**(6), 887-896.
- [7] MEC P., BOHÁČOVÁ J., KOŇAŘÍK J., ZÁVRSKÝ P. Alkali Activation of Blast Furnace Slag by Various Types of Activators. *Solid State Phenomena*. 2016, **244**, 94-101.
- [8] ŽELINKOVÁ M. Selected properties of geopolymers with different portions of ground fly-ash. *GeoScience Engineering*. 2015, **61**(2), 1-7.
- [9] ČSN EN 196-1. Methods of testing cement - Part 1: Determination of strength. Praha: Czech office for standards. Metrology and testings, 2016.