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STUDY ON PHYSICAL - MECHANICAL PROPERTIES OF ALKALI ACTIVATED MATERIALS BASED ON FLY ASH

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Resume

Alkali activated materials are relatively new materials, thanks to their good mechanical, physical, thermal properties and at the same time environmental friendliness, they could be widely adopted in different fields. The experiments, described in this article, are focused on the investigation of some basic mechanical-physical properties of alkali activated materials based on fly ash. For the following experiments were prepared two types of samples: in form of cubes and beams. On the cubes was tested compressive strength and on the beams – bending tensile strength and Young's modulus of the material. It was also investigated the influence of water glass modulus, temperature of heat treatment on the final strength of the samples.

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1. Introduction

The wide study of alkali activated materials was started in the first part of the last century. From that time were made a lot of experiments in order to find new alternative materials to concrete and other silicates with good properties and lower price [1 – 5].

Nowadays, there are not only the aspects of price and quality important but also of ecology. Utilization of production waste materials or decreasing of CO_2 emission are the next very important tasks which scientists have to solve. Cement production is the biggest emitter of CO_2 among all building materials. With each year consumption of cement grows and these days its production reaches 1.7 billion tons per year [6]. If we take into consideration that during production of 1 ton of clinker it is emitted 0.8 – 1.3 tons of CO_2 to the atmosphere, it becomes obvious, that production of cement plays not the last role in pollution of environment. For that reason in many countries is paid special attention to the study of clinker free cements, such as alkali activated materials [7, 8, 10 – 13].

The other advantage of these materials is they could be made on the base of waste materials (fly ash, slag) [3, 8, 9, 11, 13]. Each year on the planet it is produced hundred million tons of industrial wastes. Only a little amount of them finds further usage in different fields, the most part of wastes is stored, which requires huge areas, financial costs, and of course have a negative impact on the environment.

This article deals with an investigation of some basic mechanical-physical properties of alkali activated materials based on fly ash. The main objectives of the described in this article experiments are to test the influence of water glass modulus, temperature of heat treatment on the final strength of the samples, to determine the bending tensile strength and Young's modulus of the material. For the following experiments were prepared two types of samples: in form of cubes and beams. On the cubes was tested compressive strength and on the beams – bending tensile strength and Young's modulus of the material.

2. Experimental part

2.1. Work methodology

One of the aims of the following experiments was to find out compressive strength, bending tensile strength and Young's modulus of the alkali activated materials based on fly ash.

Compressive strength was measured on testing machine ZD 10/90 on the samples in form of cubes with dimensions 30 mm × 30 mm × 30 mm. The cubes were stressed in one direction by smoothly increasing strength till the appearing of cracks. Than the load was reduced, so that's why the full crush of samples didn't take place. The appeared cracks were approximately parallel to the compressive force. Compressive strength was calculated according to the following equation.

$$\sigma[MPa] = \frac{F}{S},$$

where
F – load applied [N]
S – area [mm^2]

In order to calculate bending tensile strength and Young's modulus were prepared 5 samples. Tests were conducted on the testing machine ZD 10/90. It was measured load (for calculation of all values) and displacement (for Young's modulus calculation). Tested samples had a form of beams with dimensions 300 mm × 40 mm × 20 mm.

The data for calculation of **bending tensile strength** and **Young's modulus** were measured by three-points bending on beams with cross-section approx. 40 × 20 mm (width × height) and support span 280 mm. Load was impacting in the center between supports (Fig. 1).

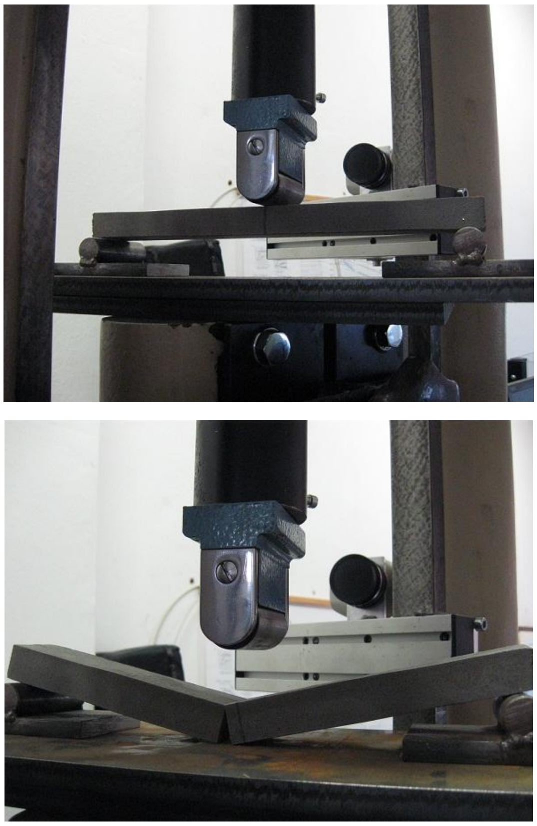

Fig. 1. Determination of bending tensile strength
(full colour version available online)

Where through very often the fracture came out from the middle of the sample, it was calculated nominal strength (from maximum bending moment in the middle of the sample) and also actual strength (from the actual moment in the place of fracture).

The nominal bending tensile strength was calculated according to the following equation.

$$\sigma_{nom}[MPa] = \frac{3Fl}{2bh^2},$$

where
F – load [N]
l – distance between supports [mm]
b – width of the sample [mm]
h – height of the sample [mm]

The actual bending tensile strength was calculated according to the equation:

$$\sigma_{actual} = \frac{3Fl_s}{bh^2}$$

where
F – load [N]
l_s – distance between the place of fracture and support (smaller) [mm]
b – width of the sample [mm]
h – height of the sample [mm]

The Young's modulus was calculated according to the next equations:

$$E = \frac{l^3 k}{48J}$$

where
l – distance between supports [mm]

$$k = \frac{F_{up} - F_d}{y_{up} - y_d}$$

where
F_{up} – upper load [N]
F_d – down load [N]
y_{up} – upper displacement [mm]
y_d – down displacement [mm]

$$J = \frac{bh^3}{12}$$

where
b – width of the sample [mm]
h – height of the sample [mm]

2.2. Samples preparation

As a basic material was used class F brown coal fly ash from Opatovice power station (Czech Republic). Its chemical composition and particle size distribution are shown in the Table 1 and Fig. 2.

As an alkali activator was used sodium hydroxide in form of solid flakes with a purity 98 % and water glass (sodium silicate) with a silicate modulus 3.35 - i.e. the molar ratio of silica to sodium oxide (content NaOH – 8 %, SiO_2 – 26.2 %, H_2O – 65.8 %) and density 1340 kg/m^3.

Table 1

Chemical composition of fly-ash (in %)

Si	Al	Na	K	Ca	Mg	Fe	Ti	O
25.3	15.72	0	2.16	0.88	0.58	3.61	1.01	50.74

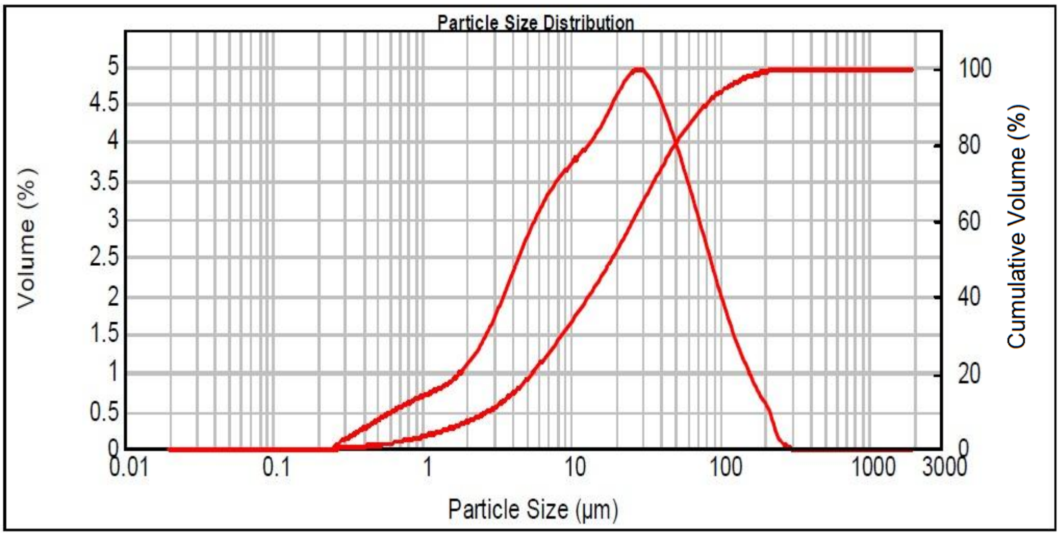

Fig. 2. Particle size distribution of fly-ash

For the experiments were prepared two types of samples. First type – in the form of cubes and second – in the form of beams. The method of mixture preparing was the same for all samples. Firstly, all components were well mixed, than mixture was put on high frequency vibration table and the last step was molding of the samples. In order to make samples were used silicon molds, which had a square form and were suitable for preparing of 16 samples with dimensions 30 mm × 30 mm × 30 mm. In order to make beams were used wooden molds with dimensions 300 mm × 40 mm × 20 mm. The next experiments were conducted in order to ascertain the influence of water glass modulus and heat treatment temperature on the strength of the samples, determinate the bending tensile strength and Young's modulus of the material.

- *Influence of water glass modulus on the final strength of the samples*

For this experiment were prepared 12 series of samples (for 16 samples in each set). Modulus of water glass (the molar ratio of silica to sodium oxide) was decreased by adding the corresponding amount of sodium hydroxide (Table 2).

Molded samples were put into the stove for 18 hours and temperature 65 °C. On the second day samples were unformed and put again to the stove on the same temperature and period of time.

- *Influence of heat treatment temperature on the strength of the samples*

For this experiment were prepared 4 series of samples (24 samples in each set). The composition of the samples was the same as the composition of set V6. All samples were 2 times in the stove, first day – 16 hours and second day – 24 hours. The difference was in temperature of heat treatment of the samples. Serie K1 was put to the stove at temperature 55 °C, serie K2 @ 60 °C, serie K3 @ 65 °C and serie K4 @ 80 °C.

- *Determination of bending tensile strength and Young's modulus*

In order to determinate bending tensile strength and Young's modulus it was prepared 5 beams with dimensions 300 × 40 × 20 mm. The composition of the mixture was the same as the composition of set V6. The samples were put two times for 18 hours into the stove at the temperature 65 °C.

Table 2

Composition of mixture (in %)

Name of samples	Fly ash	Alkali activator	Na_2SiO_3	NaOH	Ms
V1	68	32	31.07	0.93	2.60
V2	68	32	30.77	1.23	2.40
V3	68	32	30.48	1.52	2.26
V4	68	32	30.19	1.81	2.10
V5	68	32	29.90	2.10	2.00
V6	68	32	29.60	2.40	1.90
V7	68	32	29.40	2.60	1.80
V8	68	32	29.10	2.90	1.70
V9	68	32	28.80	3.20	1.60
V10	68	32	28.60	3.40	1.55
V11	68	32	28.30	3.70	1.49
V12	68	32	28.10	3.90	1.43

After heat treatment till testing the samples from all experiments were left in normal laboratory conditions.

2. Description of achieved results

The aim of the experiments was to ascertain the influence of water glass modulus and heat treatment temperature on the strength of the samples, determinate the bending tensile strength and Young's modulus of the material.

- *Influence of water glass modulus on the final strength of the samples*

The pieces were tested on compressive strength at once and in 28 days after final heat treatment. The results of the tests are shown in the Table 3 and Fig. 3.

It is obvious that decreasing of water glass modulus impacted on strength only in the early stages of curing. Depending on water glass modulus the compressive strength varied from 17 MPa till 29 MPa. In a month the strength of all samples was nearly the same. Meanwhile, the strength of samples V1 – V3 became two times higher than at the beginning, and the strength of samples which had the highest

Table 3

Influence of water glass modulus on the strength of the material

Name of samples	Average (MPa) 1 day	Standard deviation (MPa) 1 day	Average (MPa) 28 days	Standard deviation (MPa) 28 days
V1	17.09	2.10	35.44	2.06
V2	16.98	2.12	34.41	3.69
V3	17.18	0.70	32.48	4.19
V4	17.74	1.28	27.88	2.45
V5	19.09	2.68	28.22	2.46
V6	19.71	2.21	27.61	2.16
V7	21.58	2.45	27.67	1.71
V8	21.73	1.72	27.07	2.86
V9	26.50	2.96	28.46	2.74
V10	26.83	2.69	28.59	4.21
V11	28.73	2.27	29.98	1.93
V12	28.80	4.17	30.78	1.80

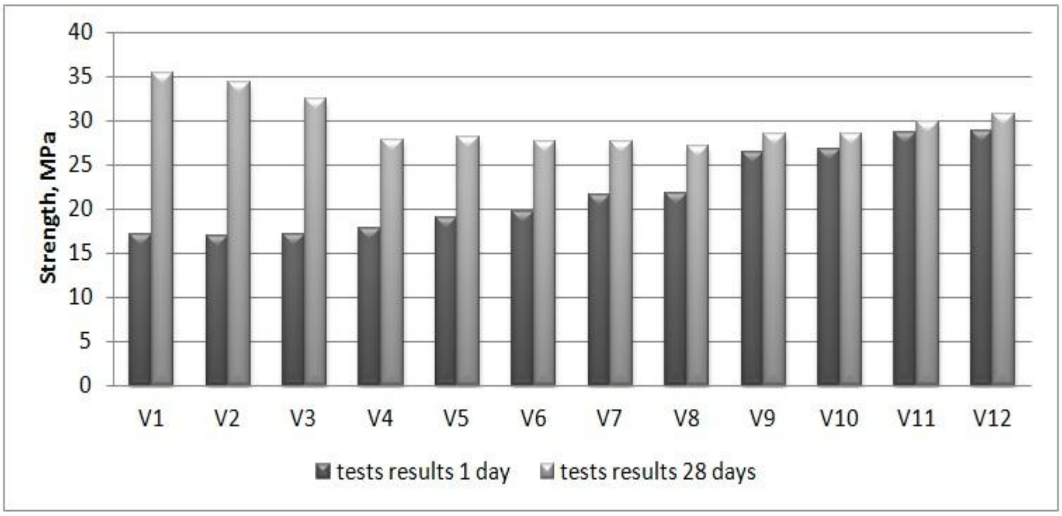

Fig. 3. Influence of water glass modulus on the strength of the material

strength at the early stages of curing (V9 – V12) almost didn't change.

- *Influence of heat treatment temperature on the strength of the samples*

The pieces were tested on compressive strength at once in 14 days and in 28 days after final heat treatment. The results of the tests are shown in the Table 4 and Fig. 4.

The results of the tests show that temperature of heat treatment had a considerable impact on the strength of the samples on the early stages of curing. The average strength varied from 12 MPa (K1) till 30.6 MPa (K4). In two weeks this difference reduced but still it was significant, from 21 MPa (samples K1) till 31.4 (samples K4). And only in a month the average strength of all sets was nearly the same.

- *Determination of bending tensile strength and Young's modulus*

Bending tensile strength was tested in 28 days after final heat treatment. The test results are in the Table 5.

The nominal strength varied from 4.61 to 9 MPa, and the average strength was 7.2 MPa, the actual strength was lower and varied from 4.32 to 8.14 MPa (average – 6.31 MPa).

It was also calculated Young's modulus, its average was 6895.68 MPa (Table 6).

3. Conclusions

In this paper were tested the basic mechanical-physical properties of alkali activated materials based on fly ash. The purpose of the experiments was to determine the influence

Table 4

The effect of heat treatment temperature on the strength of the samples

Name of samples	Average (MPa) 1 day	Standard deviation (MPa) 1 day	Average (MPa) 14 days	Standard deviation (MPa) 14 days	Average (MPa) 28 days	Standard deviation (MPa) 28 days
K1	12.20	0.72	20.64	1.82	30.35	0.75
K2	18.65	2.94	28.29	2.74	31.00	2.39
K3	30.16	2.94	31.05	2.55	31.49	2.48
K4	30.57	3.78	31.44	4.00	31.74	1.88

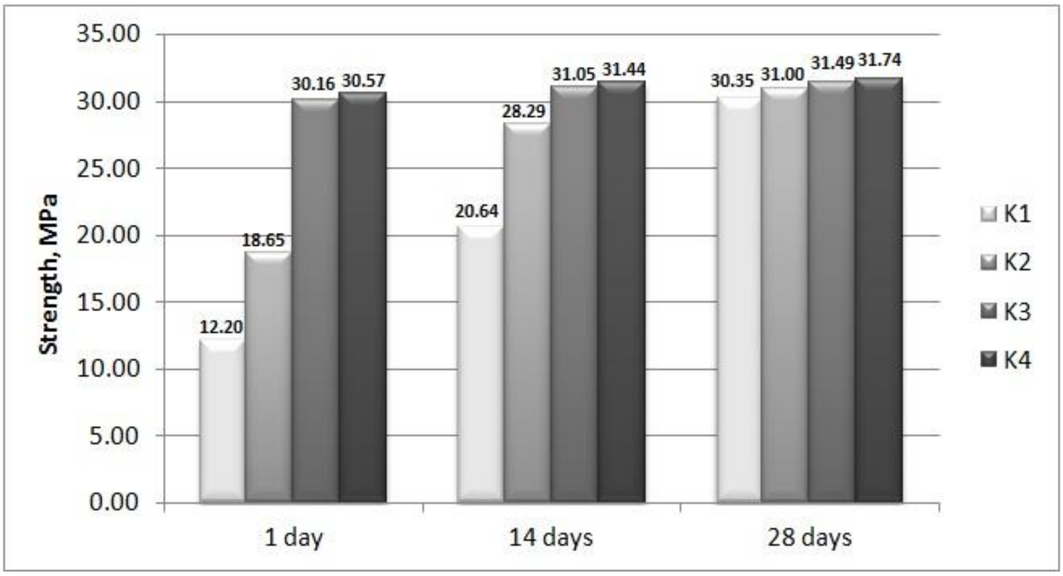

Fig. 4. The effect of heat treatment temperature on the strength of the samples

Table 5

Bending tensile strength test results

No. of sample	σ nominal (MPa)	σ actual (MPa)
1.	4.61	4.32
2.	5.77	5.26
3.	7.81	6.71
4.	8.86	7.13
5.	8.98	8.14
Average	7.20	6.31
Standard deviation	1.94	1.52
Koef. of variation	0.27	0.24
Kurtosis	-2.06	-1.30
Skewness	-0.58	-0.29

Table 6

Calculation of the Young's modulus

No. of sample	Young's modulus (MPa)
1.	7 439.27
2.	7 108.59
3.	6 328.77
4.	7 234.50
5.	6 313.29
Average	6 895.68
Standard deviation	514.26
Koef. of variation	0.075
Kurtosis	-2.87
Skewness	-0.38

of water glass modulus, temperature of heat treatment on the final strength of the samples, to find out the bending tensile strength and Young's modulus of the material.

The test results showed that the water glass modulus and temperature of heat treatment of the samples influenced on the strength of the material only in the early stages of curing. After one month of storing in normal conditions all samples had nearly the same compressive strength (30 – 33 MPa).

It was also determined the bending tensile strength of the material. Due to the fact that very often the fracture came out from the other side than from the middle of the beam, besides the nominal strength it was also calculated the actual strength of the material. The nominal strength was 7.2 MPa, the actual strength was a little bit lower – 6.31 MPa. The calculated value of Young's modulus was 6895.68 MPa.

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