Effect of Water Ratio in Fly-Ash Concrete on the Process of Alkali Activation

Rostislav Šulc

Department of Construction Technology
CTU in Prague, Faculty of Civil Engineering
e-mail: rostislav.sulc@fsv.cvut.cz

Abstract

Since 2003 research work of fly-ash alkali activation has been proceeding. This work is provided by the Department of Construction Technology, Faculty of Civil Engineering, CTU in Prague and the Department of Glass and Ceramics ICT Prague. A very important part in activation process of fly ash grains is the quantity of alkali activator and water. Water is used for preparation of activator solutions, its volume and its quantity is deciding for workability of the mixture. To achieve optimum results it was necessary to search quantity of activators and their concentration in activator solutions that allows required workability. Of course it is necessary to keep mechanical and physical properties of fly ash binder. Quantity of water in activator solutions may be various, but quantity of alkali activators is the same. This paper describes problems with different water ratio in fly ash concrete mixtures especially with reference to concentration of alkali activator solutions.

Key words: fly-ash, alkali activator, geopolymer, water ratio, fly-ash concrete

1 Introduction

POPbeton (fly-ash concrete) is new type of cement free concrete, where only fly-ash is used as binder. Whereas the term ash concrete signifies cement concrete with ash admixture as fine inert component supplementing the binder, the new type of concrete was named just POPbeton. POPbeton has ambitions to become new building material using some of further waste materials such as slag, metakaoline or fine glass waste. The area of POPbeton application can be extended for solidification of some dangerous waste materials, e.g. heavy metals.

The whole program is primarily focused on using brown coal fly-ash whose production is much higher than the production of black coal fly-ash in the Czech Republic. As the tests demonstrate brown coal fly-ash is less reactive and the final mixture has worse characteristics than the mixture with pure black coal fly-ash.

2 Material characteristics

Fly-ash is activated by the help of silica sodium water glass solution (event. silica-potassium) – water glass and strong alkali – sodium hydroxide or potassium hydroxide. In this case

Sodium water glass and sodium hydroxide were used to verify the effect of water quantity in the activation solution. The process of POPbeton production is more sophisticated from the point of view of the technological preparation. It was necessary to adjust the production process as you can see in the Figure 1.

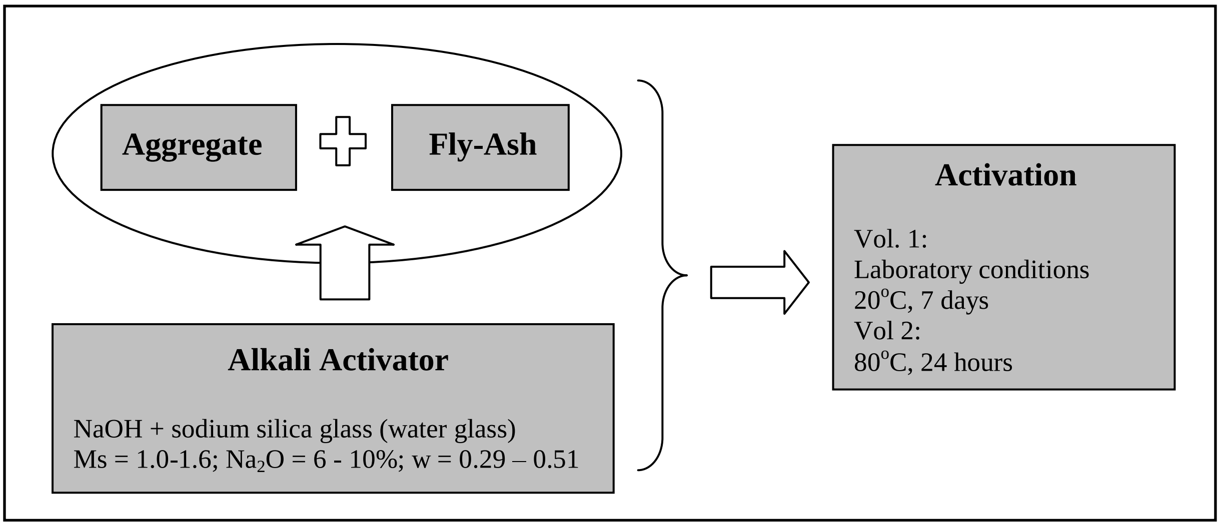

Figure 1: Scheme of POPbeton (fly ash concrete) preparation

For fly-ash activation it seems to be suitable to temper the prepared samples in the drying oven at the temperature of 80°C for 24 hours. The second way is activation under laboratory conditions (temperature at 20°C). The tempered samples have in practice immediately after the tempering completion final physical characteristics. In the process without tempering it is necessary to use activators and intensificators which will equally start the activation reaction. The process of physical and mechanical characteristics rising is slower and proceeds till the 90^{th} day of sample age. As test specimen cubes 100/100/100 mm were prepared, on which compressive strength and specific gravity were examined.

2.1 Fly-Ash characteristics

For the whole program fly-ash form the heating and power plant Opatovice was chosen. It is fly-ash coming from brown-coal burning. Brown-coal fly-ash is against the black-coal fly-ash less reactive as the pilot test showed [3]. Chemical composition of the fly-ash from Opatovice is according the Table 1. The element analysis was carried out by the appliance ARL 9400 – XRF spectrometer, at VŠCHT in Prague.

Table 1: Description of Fly Ash from Opatovice Brown Coal Power plant - in mass

SiO_2	Al_2O_3	Na_2O	Fe2O3	CaO	K_2O	MgO	TiO2	SO3	P2O5	suma
52.85%	31.84%	0.36%	7.34%	2.12%	1.69%	1.14%	1.51%	0.41%	0.21%	99.47%

2.2 Activators characteristics

The fly-ash is activated under highly alkalic environment which creates solution of sodium hydroxide (event. potassium). As suitable activator of the reaction aluminium hydroxide is added. Oxide calcium operates as calorifier of the reaction and so dramatically accelerates the reaction process. Water glass is the determinant factor for achievement of the activator solution minimal concentration and minimal water ratio of the mixture. Composition of the water glass is in the Table 2.

Table 2: Description of water glass (Na-silicate)

SiO_2	Na_2O	H_2O	suma
25.73%	8.64%	65.50%	99.87%

Composition of the mixture was as following:

- Fly-ash Opatovice
- NaOH
- Sodium water glass
- $Al(OH)_3$
- Burnt lime CL-90 G
- Aggregate 0-4 mm, locality Dobříň
- Aggregate 4-8 mm, locality Sýkořice
- Aggregate 8-16 mm, locality Sýkořice

3 Results

3.1 Effect of water quantity in alkali activator solution

Five series with different water quantity in the activator solution were prepared. The activator solution was being added into the mixture of fly-ash, aggregate and reaction regulators. The mixture was prepared in concrete mixer, stored in the forms and cultivated by vibration. The samples were got out from the forms after 7 days and put through measuring and weighing. Further the samples were put through destructive exam of compressive strength after 7, 14, 28 and 90 days.

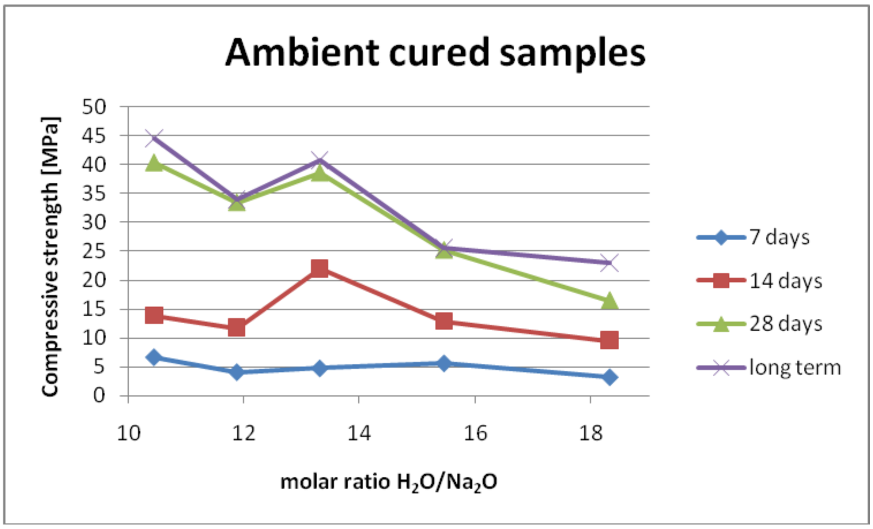

Figure 1: Compressive strength determinate by H_2O/Na_2O molar ratio – ambient cured samples

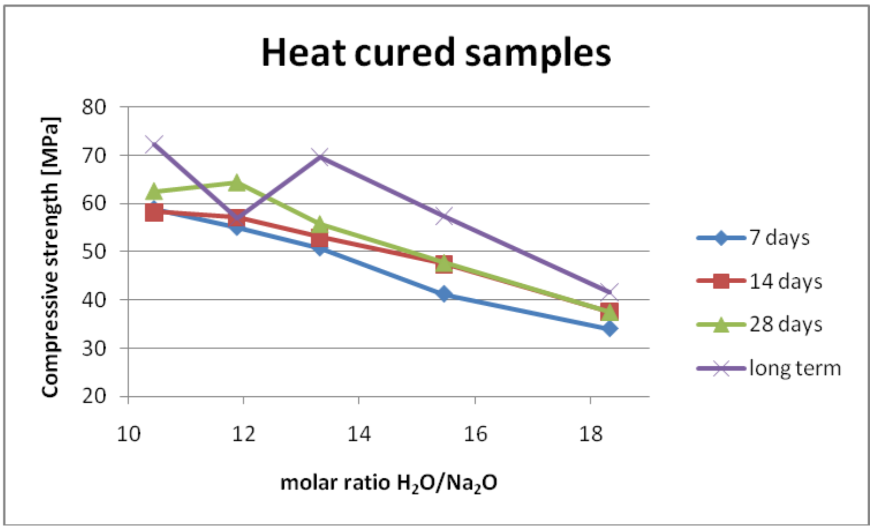

Figure 2: Compressive strength determinate by H_2O/Na_2O molar ratio – heat cured samples

The concentration of water glass was the determinant factor for minimal quantity of water in the activator solution. From the Table 2 is obvious that 65.5% of the water glass weight is the weight of water. Thus the water quantity was expressed in proportion as molar ratio H_2O and Na_2O under conservation of constant quantity of SiO_2, Al_2O_3 and Na_2O in all examined mixtures. Just these three oxides are fundamental in alumosilicate matrix from fly-ash.

In the Figure 3 and Figure 4 the water quantity is expressed depending on binder quantity – fly-ash. The water ratio (proportion of water quantity to fly-ash quantity) proceeded from 0.29 to 0.51.

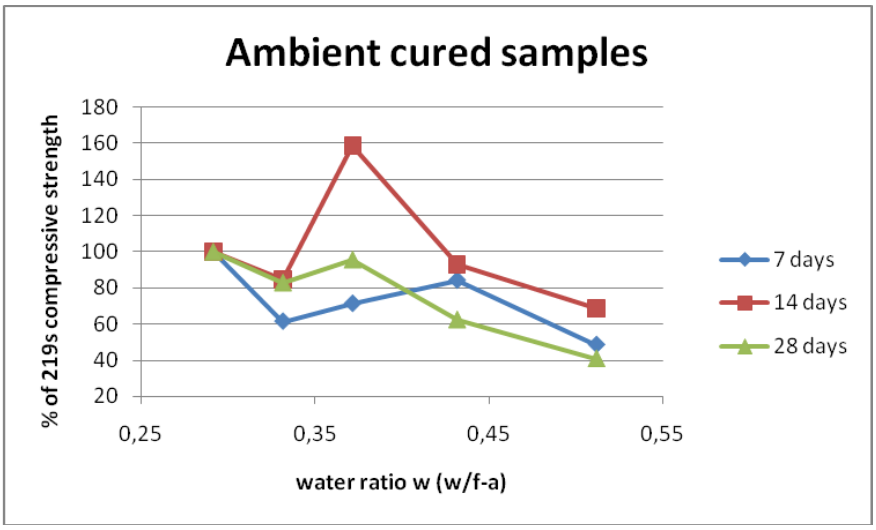

Figure 3: % of compressive strength determinate by water ratio – ambient cured samples

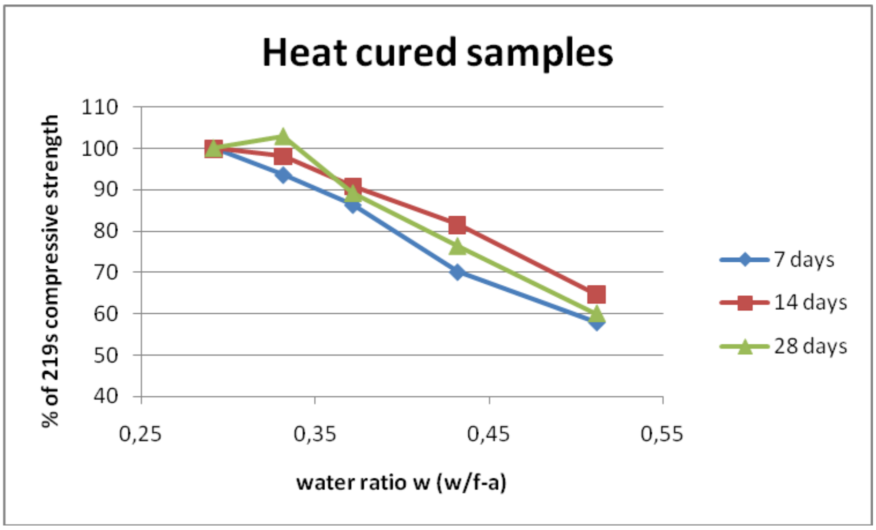

Figure 4: % of compressive strength determinate by water ratio – heat cured samples

3.2 Optimal water ratio

The samples were in the workability rate from hard workable mixture treated with vibration by w=0.29 which was showing „false" solidification already during the forms filing to floated mixture by w=0.51 without vibration treatment in order not to segregate the aggregate.

By the untempered samples gradual decline of strength namely from the water ratio value over w>0.37. The decline was strong above all by the samples 28 and 90 days old. With respect to the dates in the Figure 1 we can speak about final strength. This decline was rather strong and represented ca 60% decreases in the strength against the samples which were prepared with minimal water ratio. In the Figure 5 the trend was smoothed by the polynomial curve of 2nd grade with rather good value of reliability R^2=0.894. So it can be presumed that in this interval it is possible to make value corrections of other POPbeton mixtures according to the relation in the Figure 5.

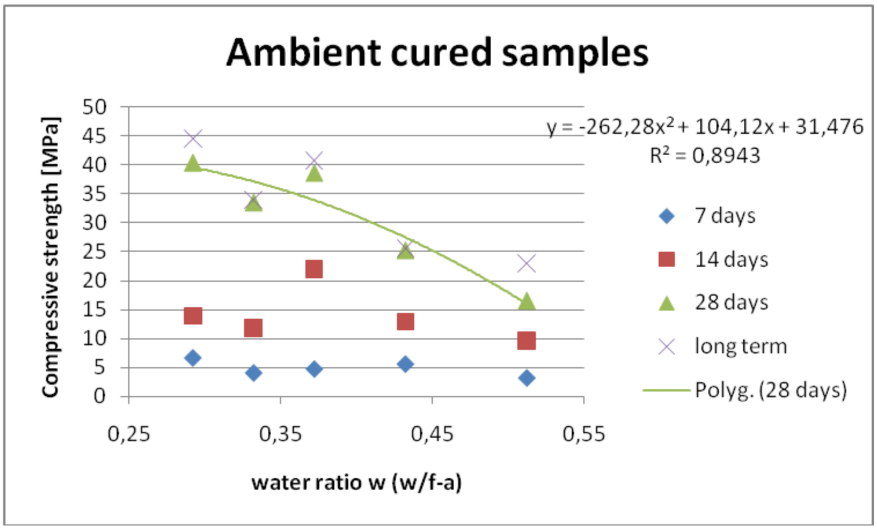

Figure 5: Trend of compressive strength – ambient cured samples

By the tempered samples the strength decrease was not so significant. It turned out that tempered samples have after 7 days 90% of their final strength. Alike the trend of decrease is same for all three examined time periods, as the Figure 4 shows. The decrease of strength in the measured interval of water ration was equal to ca 40% of sample strength with the lowest water ratio. The trend of polynomial curve of 2^{nd} grade shower out excellent conformity with for the value of reliability R^2=0.962. Again it can be presumed that relation stated in the Figure 6 sufficiently describes effect of water quantity in the mixture on the final compressive strength of POPbeton prepared by tempering.

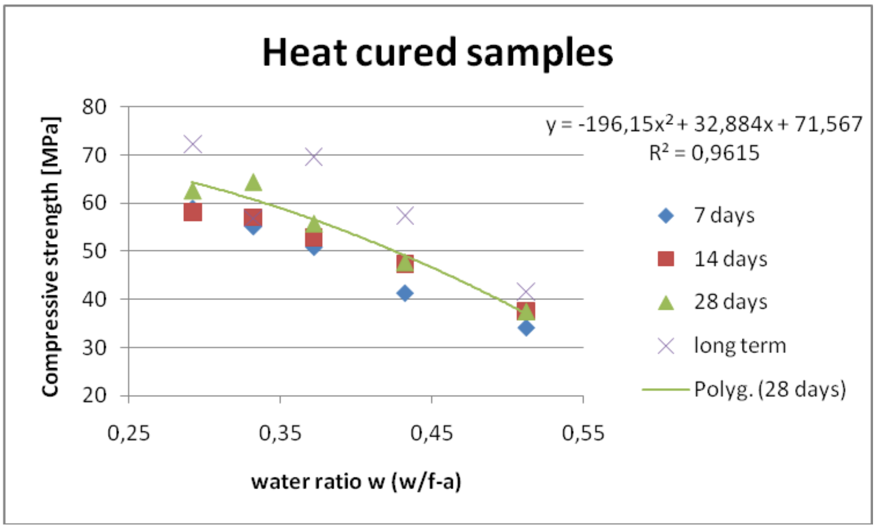

Figure 6: Trend of compressive strength – heat cured samples

4 Conclusion

It was proved how the water quantity in the mixture and the concentration of the activator solution change the final characteristics of POPbeton substance. In the relatively small range of water ration happens to drastically changes in the final values. Thus it can be expected that for keeping the declared POPbeton characteristics it is necessary to retain high standards for mixture processing, as it is by the cement mixtures as well.

Above stated estimations for final values of strength are partial base for corrections and comparison of POPbeton mixtures prepared from variously concentrated activator solutions.

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