Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

Development of Alkali-Activated Concrete Containing Recycled Wash Water

Vlastimil Bílek

ŽPSV a.s., Křižíkova 68, 660 90 Brno, Czech Republic, e-mail: <bilek@zpsv.cz>

ABSTRACT

Alkali-activated concretes are relatively well-known composites. They show good mechanical properties, good resistance to the attack of a variety of chemical media and some other suitable properties. But for practical use these concretes are unaccustomed. To be more beneficial in a practical usage scenario, they have to show some advantages – for example they may help in the consumption of some used materials from usual concrete production. One of these materials is recycled wash water, whose reuse in a concrete production is very limited. The paper shows some properties of alkali activated mortars with the addition of wash water. The mortars have a different composition of binder (slag or slag + fly ash) and a different composition of alkali activator.

INTRODUCTION

A relatively high volume of wash water arises during the production of Portland cement based concrete in concrete plants. This is the water left over after the washing of mixers and other equipment. The use of this water in concrete is limited - it shows a high basicity and it contains a lot of dry mass and especially remains of different admixtures. These remains can affect properties of new concrete and for this reason it is not possible to use it in a new concrete with a higher quality or in air-entrained concrete (see EN 1008). The main reason is not the dry mass of sludge water, but an undefined content of chemical admixtures.

One of the important properties of alkali activated materials is their very low sensitivity to superplasticizers, air-entraining admixtures and other chemical admixtures. This result is generally confirmed by many authors, for example Bakharev et al. (2000), Palacios et al. (2005) or Palacios et al. (2007).
The question sounds: Is it possible to use this sludge water in AAM as slag (and fly ash) alkali activated concrete thanks to their low sensitivity to chemical admixtures? This paper is focuses on replacing drinking water with sludge water and on a suitable composition of binder (content of slag and fly ash), a composition of alkali activator and

the influence of these characteristics on the development of properties of fresh mixtures and on the development of strengths.

USED MATERIALS

The following materials were used in the preparation of specimens:

Granulated blast furnace slag which is produced in plants in the North Moravia (Czech Republic) and ground in Stramberk cement plant to specific surface 420 m^2/kg. Composition of the slag is shown in table 1.

Table 1. Chemical composition of slag and fly ash [mass %]

	SiO_2	CaO	Al_2O_3	MgO	Fe_2O_3	SO_3	Na_2O	K_2O	TiO_2
slag	40	38	8	12	0,3	0,75	0,36	0,59	-
fly ash	49,7	3,62	24,9	1,15	14,7	1,26	0,62	1,91	1,39

Fly ash from power plant Chvaletice (Czech republic) was also used. This power plant burns brown coal. The composition of the fly ash is recorded in table 1.

Alkali activator is a blend of sodium water glass (with silicate modulus M_s = 1.8, content of dry mass is 56%, density 1.5 kg/m^3) and 50% solution of potassium hydroxide which was used for the correction of silicate modulus (see next paragraph).

Sludge water with the dry content of 60 g/kg (6 % of mass). The sludge water contains some remains of materials used in the production of concrete in concrete plant Uhersky Ostroh - portland cement, powder from sand, a very little amount of slag or powder from crushed aggregates (filler), polycarboxylate based superplasticizers and air-entraining admixture produced by Czech company Stachema. The precise analysis of the sludge water was not performed, because it is very difficult. The pH value of the sludge water was (12.2 ± 0.5).

MIXTURE PROPORTIONS AND TESTING PROCEDURE

Firstly, setting of alkali activated pastes was studied using Vicat apparatus. The procedure generally agreed with EN 196-3, The difference was that water / (slag + fly ash) ratio was kept at the value 0.38 (water in activator and dry mass of wash water was take into account). The dry mass of activator was kept at the value 12% of mass of (slag + fly ash).

For the study of a wash water effect on workability and strengths of alkali-activated mortars, three basic mortars compositions were chosen, see table 2 and 3. The ratios in the first line express the composition of alkali activator. The ratio 50/50 expresses that 50% of mass of activator represens Na_2O from water glass and K_2O from potassium hydroxide and 50% of mass is SiO_2 from water glass. In other words – the silicate modulus is 1.0. The ratios 60/40 and 70/30 mean 60 or 70% of (K_2O + Na_2O) and 40% or 30% of mass of SiO_2 respectively. The silicate moduluses are 0.66 and 0.43 respectively. The total content of activator Σ = masses (SiO_2 + Na_2O + K_2O) is expressed as a percentage considering to (slag + fly ash) mass and this was kept in the value 12% .

The water to slag ratio was kept at the value 0.60 considering water from water glass, hydroxide solution and in the case of wash water use, mass of water was considered without dry mass. The dry mass of sludge water is very small considering to binder and aggregates masses (i.e. 0.16 – 0.67 %) and it was not deducted from the solid part of mixture. This is better for practical reasons.

For all of the ratios four different mixtures were prepared where drinking water was replaced with sludge water 0%, 25%, 50% and 100% - the last case implies only sludge water was used – see table 2.

Similar sets of mortars were also prepared in which slag was replaced with fly ash. The proportions of these mixtures were modified using a specific density of fly ash; other mixture ratios were kept the same as in the case of slag mortars – see table 3.

Table 2. Alkali-activated mortars from slag with different compositions of alkali activator (different (K + N) / S ratio) [g]

(K+N)/S	50/50				60/40				70/30			
sludge w.	0	25	50	100	0	25	50	100	0	25	50	100
Slag	450	450	450	450	450	450	450	450	450	450	450	450
Fly ash	-	-	-	-	-	-	-	-	-	-	-	-
W. glass	92	92	92	92	73	73	73	73	55	55	55	55
50%KOH	27	27	27	27	49	49	49	49	69	69	69	69
Drink. w.	204	153	102	-	202	151	101	-	200	150	100	-
Sludge w.	-	53	106	212	-	52	105	209	-	52	104	207
Sand	1450				1450				1450			

Table 3. Alkali-activated mortars from slag and fly ash with different compositions of alkali activator (different (K + N) / S ratio) [g]

(K+N)/S	50/50				60/40				70/30			
sludge w.	0	25	50	100	0	25	50	100	0	25	50	100
Slag	225	225	225	225	225	225	225	225	225	225	225	225

Fly ash	225	225	225	225	225	225	225	225	225	225	225	225
W. glass	92	92	92	92	73	73	73	73	55	55	55	55
50%KOH	27	27	27	27	49	49	49	49	69	69	69	69
Drink. w.	204	153	102	-	202	151	101	-	200	150	100	-
Sludge w.	-	53	106	212	-	52	105	209	-	52	104	207
sand	1400				1400				1400			

All mortars were mixed in a laboratory mixer in the volume of 1 litre. Firstly, alkali activator, water and slag (or slag + fly ash) were dosed. The paste was mixed 45 s and after this sand was added during the mixing. The mixing went on another 4 minutes.

Workability was measured immediately after the mixing using minicone slump test. In this test a truncated cone is filled with mortar. The mortar cone is shaken 15 times in the jolting table and the cone flow was measured in two perpendicular directions; the result is the average value of these values.

Beams 40x40x160 mm were prepared from the mortar and they were tested at the ages of 1, 7 and 28 days. Only one beam was tested at each age and for this reason the strength values have only an indicative character.

DISCUSSION OF RESULTS

Setting of pastes with wash water. Four pastes were prepared from slag and four pastes were prepared where 50% of slag was replaced with fly ash. Drinking water was replaced with 0%, 25%, 50% and 100% of wash water. Results are presented in figure 1.

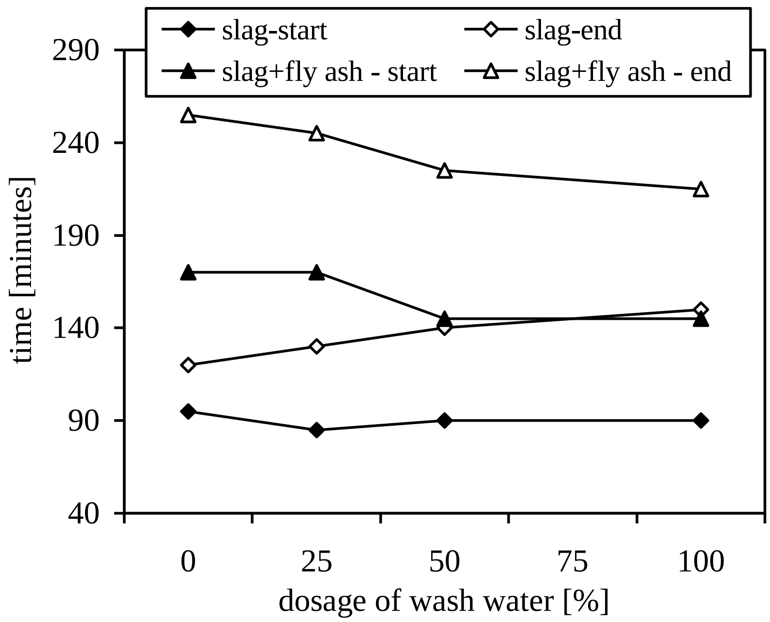

Figure 1. Start of setting and end of setting of pastes with wash water

Figure 1 shows that wash water doesn´t affect the start of setting of mixtures with slag only. In this case only the time of setting is prolonged as the portion of wash water in paste increases.

In the mixtures with slag and fly ash the start of setting is prolonged compred to only slag mixtures. Wash water addition accelerates the start of setting but it still occurs much later than in pastes with slag only.

Slag + wash water. After the replacement of drinking water with wash water the workability of mixtures (measured as minicone flow) stays nearly the same, see figure 2. Mixture 70/30 shows the best workability – this can be explained by a high amount of potassium ions K^+. But it is not true for other two mixtures.

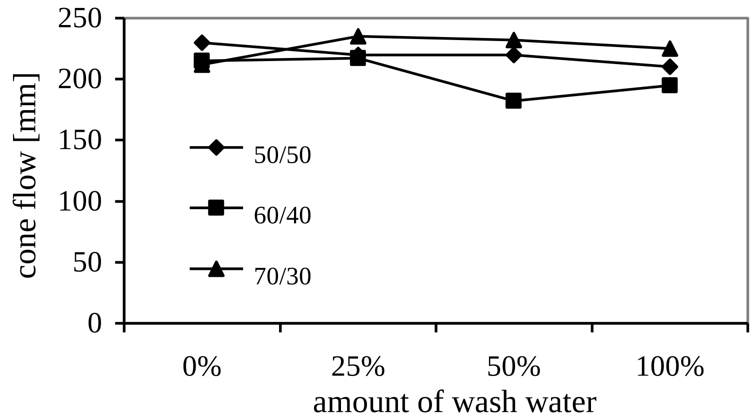

Figure 2. Workability of mortars made from slag with replacement of drinking water by wash water

The strengths results for different composition of alkali activator confirm formerly published results – the strengths are highest for ratio 50/50 or 60/40 – see figure 3. Probably, the high amount of alkali ions and also the presence of silicon ions enhance the strengths. An interesting result is represented by a low 1-day strength for ratio 50/50 and a high 1-day strength for ratio 60/40 and 70/30. The 7 days and 28-days strengths show opposite tendency.

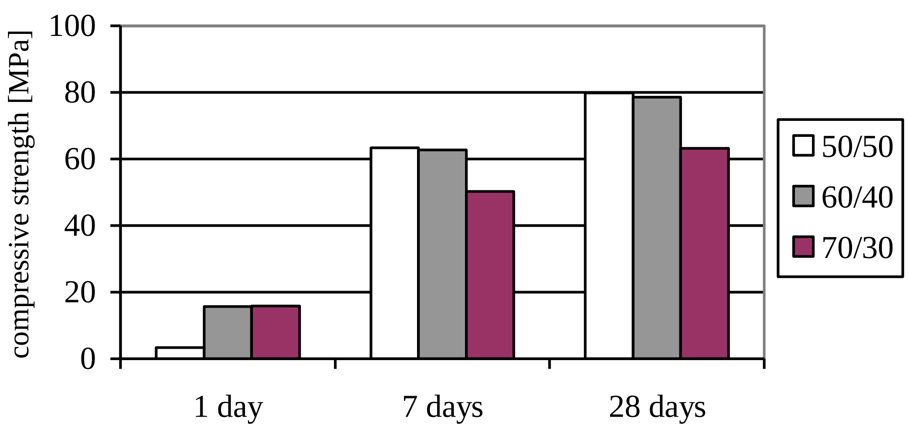

Figure 3. Development of compressive strengths for alkali-activated slag mortars with drinking water

The compressive strengths for combination of drinking water and wash water are shown in figure 4 which shows that content of wash water does´t have any important effect on compressive strengths. All values of the strengths are nearly the same. This is an important result.

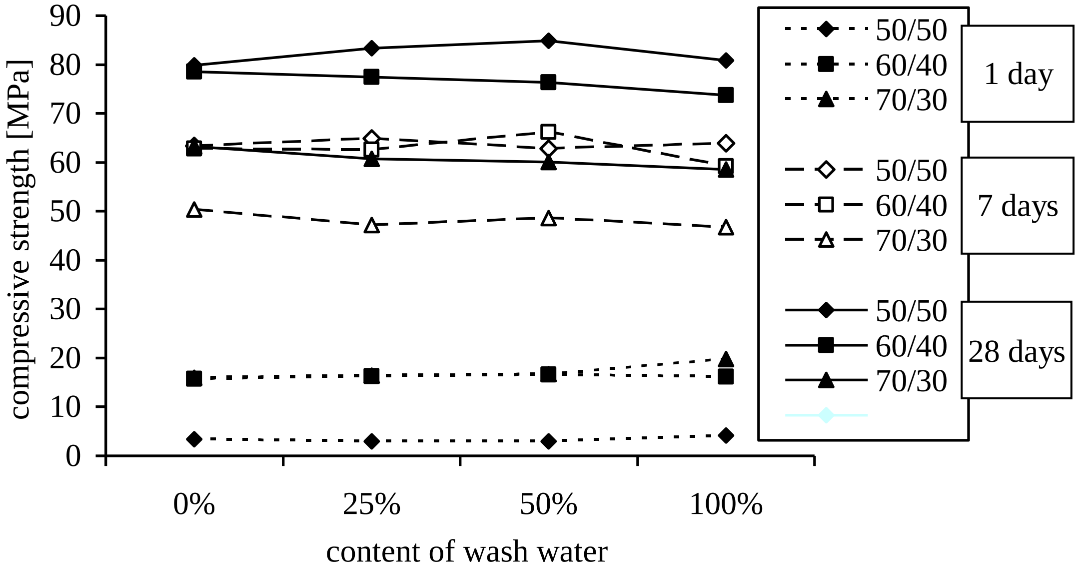

Figure 4. Compressive strength of mortars with replacement of drinking water with wash water

Slag + fly ash + wash water. Another set of experiments was performed with mortars where half of amount of the slag (50%) was substitued with fly ash (50%). The workability of the mixtures is shown in figure 5.

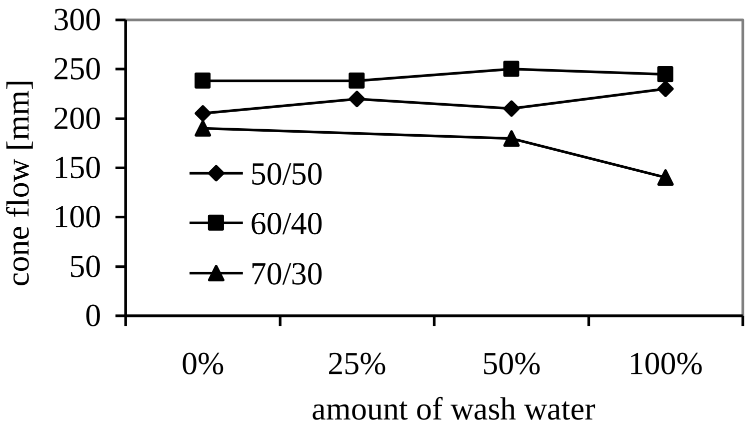

Figure 5. Workability of mortars made from slag and fly ash with replacement of drinking water with wash water

Generally, the figure shows a better workability for mixtures with fly ash addition. It was recorded also in the previous paper, Szklorzova, Bílek (2008). The reason is a

higher volume of fine material (fly ash has lower density), spherical shape of fly ash particles and probably also a lower activity of fly ash.
An increasing amount of wash water doesn´t have any influence on workability for ratios 50/50 and 60/40. For ratio 70/30 some decrease of workability was recorded. Maybe, this is a consequence of the activity of the dry mass in wash water in the presence of a high amount of alkali ions.

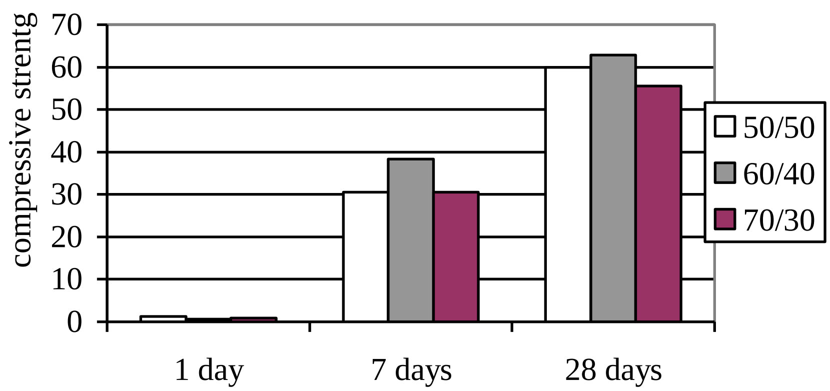

Figure 6. Development of compressive strengths for alkali-activated slag + fly ash mortars with drinking water

It is interesting that 1-day strengths are very low for all mixtures without wash water – see figure 6. This is an interesting result in comparison with some other results where slag was replaced with limestone. In that case the 1 day strength is higher for mixtures with limestone, Bílek (2007).

This could be explained as a consequence of a relatively higher amount of alkali activator with regard to slag. This low calcium fly ash is only poorly active and it is a bit similar to limestone, however one day strengths are much lower for the fly ash addition. It could be also a consequence of the positive role of limestone for the nucleation of new hydrates as in the case of portland cement with limestone Irassar et al. (2006). But during the time the strengths increase and at the age of 28 days they are relatively high.

Also, the values of strengths in the cases of wash water use – see figure 7 – are high, especially for mortars with ratio 70/30 which means for the highest content of alkali ions in activator. Probably, this composition is appropriate for the activation of mixtures with the replacement of slag with fly ash. In the other cases the strengths are not affected by wash water content.

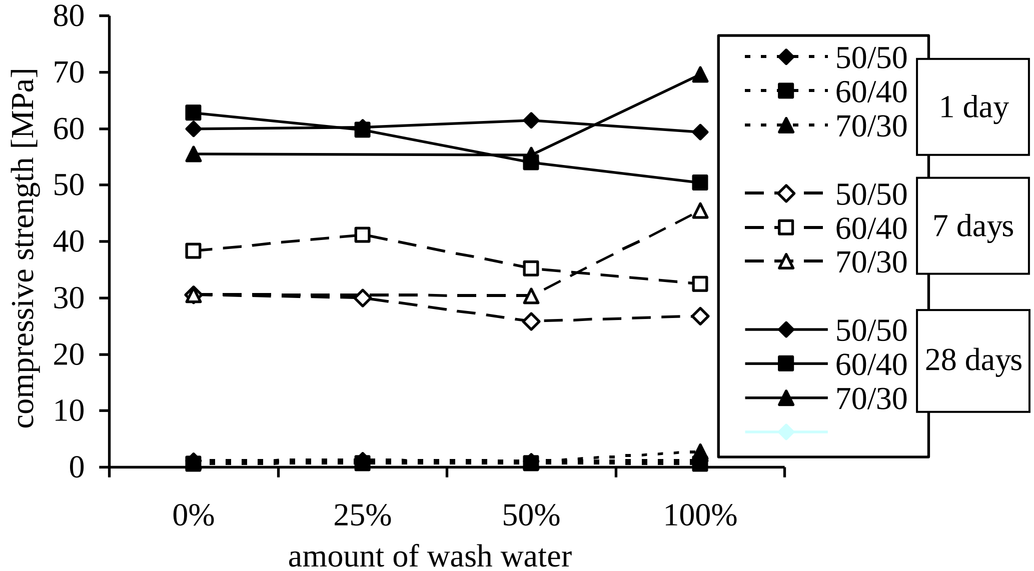

Figure 7. Compressive strength of mortars with replacement of drinking water by wash water

CONCLUSIONS

The influence of wash water used in the production of alkali activated mortars was studied in this paper. The results show that:

- wash water doesn´t affect setting in a way which would have an adverse impact on practice
- wash water nearly does´t affect workability of the alkali activated mixtures
- wash water nearly doesn´t affect strength of alkali activated mixtures

These results were obtained for the content of activator 12%. For a lower amount of activator some preliminary results show a positive effect of wash water, especially for early strengths. The research is continued.

Acknowledgement

This work was supported by Ministry of Education, Youth and Sport of the Czech Republic, Project No: 2B08024

REFERENCES

Bakharev, T., Sanjayan, Y.-B., Cheng, Y.-B. (2000). “Effect of admixtures on properties of alkali-activated slag concrete”, *Cement and Concrete Research 30, 1367-1374*

Bílek, V. (1986) Some possibilities of retardation of slag alkaline mixtures, student work, J. Brandstetr superviser, Brno University of Technology, Faculty of Civil Engineering, in Czech

Bílek, V. (2007) Alkali-activated slag concrete for the production of building elements, *Proceeding of International Conference Alkali-Activated materials – Research, Production and Utilization, ISBN 978-80-86742-18-2, Prague pp. 71 – 81*

Irrasar, E.F., Bonavetti, V.L., Menéndez, G., Donza, H., Carrasco, M.F.(2006) Durability of Ternary Blended Cements Containing Limestone Filler and GBFS, *Proc. of 7th Int. Conf. Durability of Concrete, V.M.Malhotra Ed., SP-234-21, ISBN 0-87031-207-3, pp.327-345*

Palacios, M., Puertas, F. (2005) “Effect of superplasticizers and shrinkage reducing admixtures on alkali-activated slag pastes and mortars”, *Cement and Concrete Research 35, 1358-1367*

Palacios, M., Banfill, P.F.G., Puertas, F. (2007) “Rheological behaviour of alkali activated slag pastes and mortars, *Proc. of Int. Conf. Alkali Activated Materials - Research, Production and Utilization, Praha, (Czech Republic), ISBN 978-80-86742-18-2, pp.493-508*

Shi, C., Krivenko, P.V., Roy, D.(2006) Alkali-Activated Cements and Concretes, Taylor & Francis, ISBN I 0: 0-415-70004-3

Szklorzova H., Bilek V.: „Influence of alkali ions in the activator on the performance of alkali activated mortars“, *Proc. of 3th Non-Traditional Cement and Concrete Symposium, Bilek and Kersner Eds., Brno, Czech Republic, 2008 ISBN 978-80-214-3642-8, pp. 777 – 784*