

Long-term strength properties of HVFA concretes

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Abstract. Fly ash from coal burning is used as active addition for concrete in Middle-Europe region for several decades. The intensity of its utilization increases still. In the role of supplementary cement addition it serves as binder, whereby it helps to reduce final price of concrete as well as improves both the rheological properties of fresh concrete and several characteristics of hardened concrete. Fly ash presents the co-product of energetic industry. Its production increases together with growth of energy consumption. These factors bring the opportunity and requirement of production of concretes with high volume of fly ash based addition. Thus, significant economic, environmental, technological and technical benefits can be achieved by using of high amount of fly ash for concrete production.

1. Introduction

Cement binder together with both aggregate and mixing water present elementary components needed for concrete production. Cement composes only 15 % by wt. of concrete. Even though, it presents most expensive part of concrete. Thus, significant decreasing of material costs can be achieved by relatively small saving of used cement. Cement production is very expensive process, because of high requirement on energy consumption. To produce the clinker is needed to burn several raw materials (limestone, clay, silicon sand, iron ore etc.) at high temperature, approximately at 1400 °C. Clinker products create during the burning process as well as huge amount of greenhouse gases, especially CO₂. This gas is generated both from fuel burning and thermic decomposition of initial raw materials. World-wide cement production was about 4000 million tons (3300 million tons of clinker capacity) in 2013 [1]. Cement industry shares of total CO₂ production with 5 % [2]. Mentioned facts give us relevant arguments to increase utilization of energetic by-products for building materials production.

1.1. Fly ash

One of these alternative materials is fly ash from coal burning. Fly ash is by-produced by both brown and black coal burning in power plant or heating plant. During the process of coal burning, almost all of organic components burn out. Fly ash as a product of burning contains nearly 100 % of mineral-only components, alumina-silicates especially. A part of molten fine-size mineral particles flows together with exhaust gas and during rapid cooling glassy-amorphous particles (fly ash) create. These particles have spherical shape, mostly. Consequently, the particles are filtered from exhaust gas by set of multiple filters and electrostatic separators [3, 4].

Fly ash produced in power plants and heating plants presents industrial waste and require to be stored or disposed. Storage of fly ash on damp is usually expensive. Moreover, fly ash storage can



cause the environmental loading. World-wide, it produces approximately 550 million tons of fly ash annually. Currently, over 30 % of fly ash produced in Europe (EU 15) is utilized as addition for both concrete and cements as well as for production of other building materials. The rest of that is deposited on damp.

Fly ash is ranked among type II additions, thus active additions according to EN 206-1 [5]. In term of reactive mechanism, fly ash is hydraulic active pozzolanic addition. It means that fly ash doesn't set and harden itself as well as in not latent hydraulic. It consists amorphous SiO_2 which reacts with Ca(OH)_2 formed by reaction of cement with water. Result of this pozzolanic reaction is C-S-H gel. Chemical composition is determining for pozzolanic properties of fly ash but its mineralogical composition as well as granulometric properties is much more important [6]. Commonly, both chemical and mineralogical composition of fly ash is quite non-homogenous. Even though, fly ash can be utilized for cement and concrete production very well. In the case of commercial usage of fly ash it has to satisfy requirements of standards. These requirements are divided into chemical, physical and others (durability, dangerous components content, radioactivity etc.) according to EN 450-1 [7].

1.2. High volume fly ash concrete

According to Malhotra definition, HVFA (High Volume Fly Ash) concrete is material in which the fly ash presents over than 50 % wt. of total binder amount [6]. This type of concrete is also able to satisfy the requirements on high-performance concrete. There, the common dosage of fly ash for concrete is around 15 to 25 % by wt. of cement binder, in Slovakia. In this point of view, concrete with fly ash content above 30 % can be classed as HVFA concrete.

2. Materials and methods

2.1. Materials

Fly ash addition is usually used in combination with OPC. It is well known that the combination of fly ash with another types of cement bring very good results in term of technological, technical, environmental and economic aspects. Especially, CEM III type cement together with added fly ash creates binder which possesses ternary behaviour. Ternary binder system is based on synergic effect of clinker, blast-furnace slug and fly ash [8].

Cement type CEM II/A-S 42.5 R according to EN 197-1 was used as a binder. This cement came from cement plant Holcim Turňa nad Bodvou, Slovakia. Mineral addition presented fly ash from brown coal burning from power plant Bukocel Hencovce, Slovakia. This fly ash was certified as a type II active addition for concrete according to EN 450-1. Chemical composition of used fly ash is shown in the table 1.

Table 1. Chemical composition of fly ash.

Component	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Alkalis	SO_3	LOI
Content [%]	52.56	22.45	9.02	6.74	1.80	1.31	0.98	2.86

Aggregate fractions 0/4, 4/8 and 8/16 according to EN 12620 were used as filler. Particular fractions came from the quarry Holcim Geča, Slovakia. Aggregate from Geča location is particular crushed gravel. Plasticizing admixture was used for both the improving the consistence of fresh concrete and decreasing of mixing water. Superplasticizer Berament[®] HT121 based on PCE modified by naphthalene was used. Mixing water according to EN 1008 was used.

2.2. Methods

Described experiment is aimed on evaluation of short-term mechanical properties of hardened concrete according to requirements of standard EN 206-1 (compressive strength after 28 days of hardening) as well as long-term mechanical properties (after 360 days of hardening). Several

experimental mixes were prepared. Particular mixes differed by fly ash content. The content of fly ash is presented by binder ratio (fa/c = fly ash/cement).

Recipes of particular mixes were designed according to previous experiences. Nine mixes were prepared which varied by binder ratio and/or water/total binder ratio (mixes marked FA0 to FA5). Table 2 contains characteristics of designed mixes. Part of cement was supplemented by fly ash with content started from 23 % wt. up to 50 % wt. Mix FA0 contains cement only. Mixes FA3 and FA4 were prepared with two different water/total binder ratios. Both pure water/binder ratio as well as water/binder ratio following the k-value concept is shown in the Table 2. Fly ash addition k-value in combination with CEM II/A-S type cement is set to 0.2. Consistence of all prepared fresh concretes was set to S3 class according to EN 206-1, thus 100-150 mm measured by Slump test.

Table 2. Characteristics of experimental mixes.

Mix mark	CSA* [%]	fa/c ratio	w/(c+fa) ratio	w/(c+k.fa) ratio
FA0-0	0	0.00	0.53	0.53
FA1-0	50	1.00	0.46	0.87
FA1-1	50	1.00	0.43	0.80
FA2-1	43	0.75	0.45	0.75
FA3-1	37	0.58	0.47	0.69
FA4-1	30	0.43	0.47	0.63
FA5-1	23	0.30	0.48	0.59
FA4-2	30	0.43	0.48	0.64
FA3-5	37	0.58	0.50	0.75

*CSA – proportion of cement supplementary addition (fly ash)

All mixes were prepared at laboratory ambient condition. Cube samples with dimension 150x150x150 mm were made after mixing and consistence measuring. Two cube samples for compressive strength test were made from every mix. Consequently, samples stayed in the cast for next 24 hours. Released samples were cured in water condition for up to 350 days. Compressive strength of particular samples was tested after 2, 7, 28, 56, 120 and 350 days.

3. Results

Six mixes with different binder (fly ash/cement) ratio were prepared (mixes FA1 to FA5 listed in the Table 2), including reference mix. Compressive strength and its in-time development of hardened concretes during first 28 days are shown on the Figure 1. The concrete with lowest fly ash content achieved highest strength (except non-fly ash content concrete). It is caused by higher clinker content compared to more-fly ash content concretes.

Process of cement hydration is faster than pozzolanic reaction of fly ash in concrete. Therefore, higher content of fly ash in concrete causes more gentle strength development. Concrete with non-fly ash content (0% fa mix on Figure 1) achieved highest compressive strength after 28 days of hardening and its strength development was faster, obviously.

Strength development of reference concrete decelerated after 56 days of hardening, significantly. On the contrary, strength development of fly ash-containing concretes was growing continuously, due to pozzolanic reactions of fly ash. Compressive strengths within 350 days setting and of hardening are shown on Figure 2. It is clear, that the compressive strengths of FA4 and FA5 concretes are higher than that of FA0 – reference concrete. FA4 and FA5 concretes achieved about 3.7 and 7 % higher compressive strength than FA0 concrete, respectively. In these cases, the synergic effect of ternary binder system has proved. Curves of compressive strength development shown on Figures 1 and 2, correspondent with fly ash content very well. Comparison of curves shows that compressive strength of reference concrete grows fast during first 28 days and then slows down. At the other side, compressive strength of fly ash-containing concretes grows slow at the start of hardening period but continues during next several months.

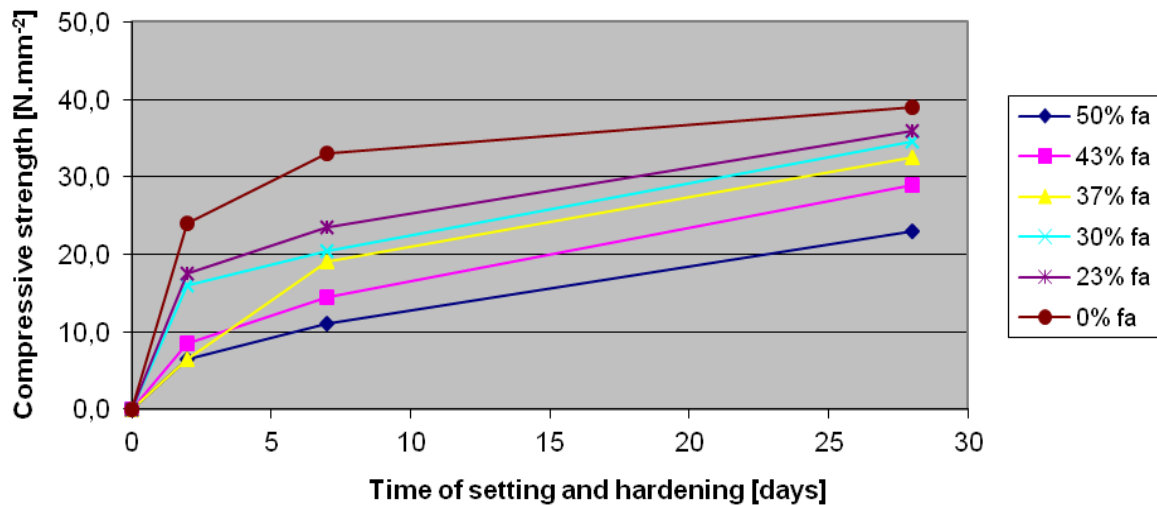


Figure 1. Development of compressive strength within first 28 days.

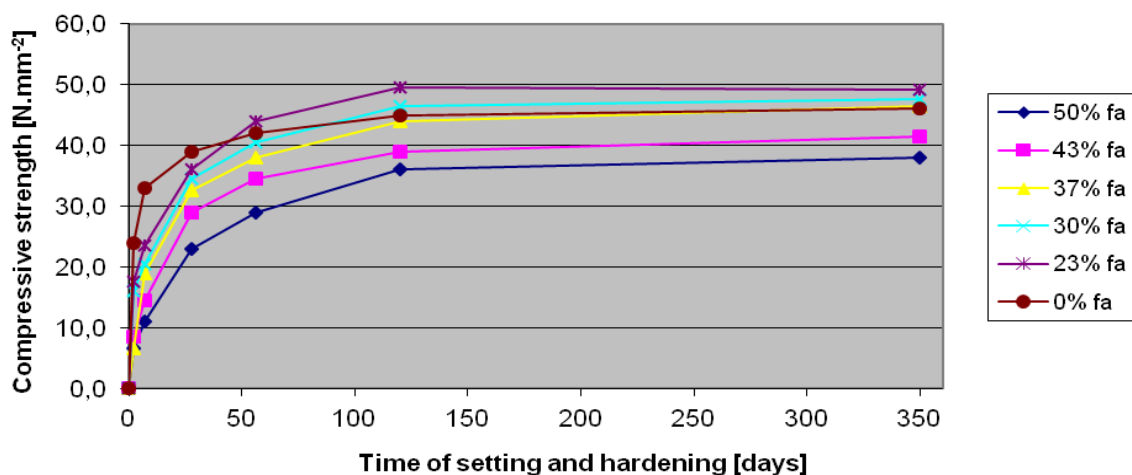


Figure 2. Development of compressive strength within 350 days.

Compressive strength of reference concrete after 350 days of hardening is only about 18 % higher than after 28 days. In the case of HVFA concrete is the increase from 37 to 65 % for FA5 down to FA1, respectively. In this point of view, FA1 mix concrete is optimal, in the case of requirement on higher long-time compressive strength.

Percentage increase of compressive strength within whole time of setting and hardening of concrete is shown on the Figure 3. Monitored time is divided into 6 periods. First period started from preparing of fresh. Columns on the Figure 3 describe the strength development behaviour of particular concretes. It is clear that reference concrete achieved more than 50 % of total compressive strength within first period 0 – 2 days. Its strength increase is no significant within period 121 – 350 days. On the other hand, strength increase of high-fly ash content concretes is more significant within period 8 - 28 days. This result confirms the pozzolanic behaviour of fly ash in HVFA concrete, too.

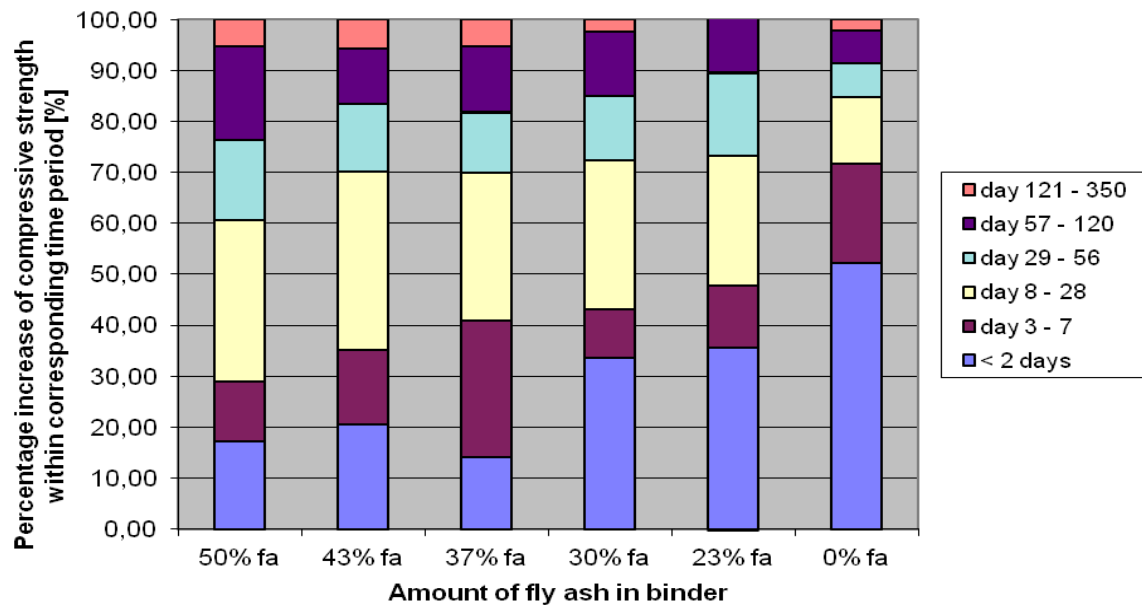


Figure 3. Compressive strength growth gradients of mixes.

It is well known that water/binder ratio influences on strength properties of hardened concrete. Moreover, binder ratio (fly ash/cement ratio) affects the concrete strength characteristics. Correlation between binder ratio and compressive strength of concrete after both 28 days and 350 day is shown on the Figure 4. Influence of the ratio on compressive strength after 28 days of hardening is more significant compared to influence on strength after 350 days. Reference concrete has got fly ash/cement ratio 0.00. Generally, increase of fly ash content in total binder causes decrease of compressive strength of hardened concrete. Following the trend growth from Figure 4, influence of binder ratio on compressive strength after 350 days is approximately 2 times lower than the influence after 28 days. On the basis of measured results it is apparent that the long-term compressive strength of HVFA concrete achieves high values.

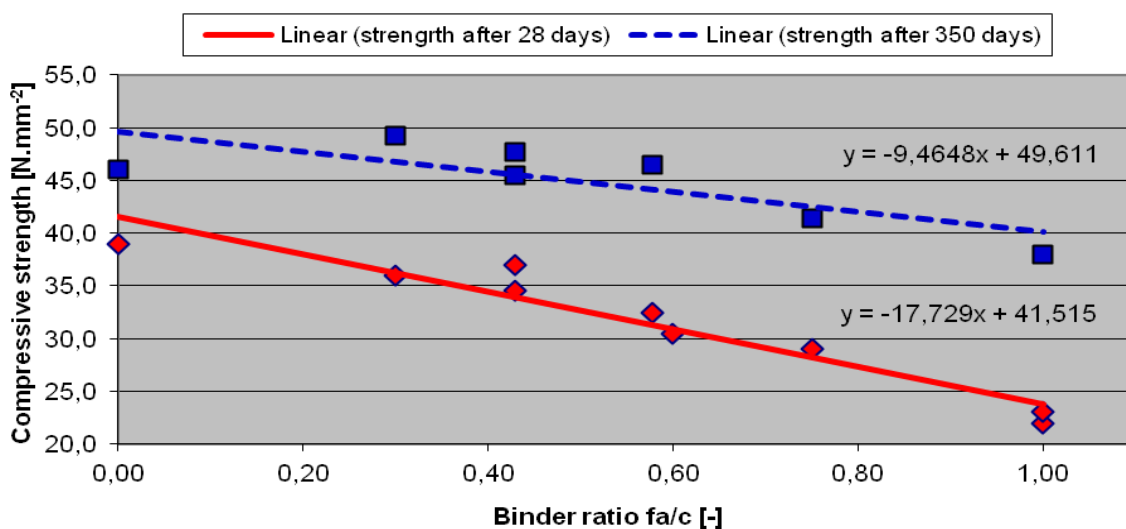


Figure 4. Correlation between compressive strength after both 28 and 350 days and binder ratio.

4. Conclusion

High volume fly ash concrete (HVFAC) presents interesting alternative for common only cement-based concrete. Besides improving of workability of fresh concrete by using of fly ash, it brings a lot of useful properties as a waterproof increasing, higher resistance of hardened concrete against aggressive environment etc. Despite of partial decreasing of strength grow rate it exists many cases when the high volume fly ash concrete is well useful. Long-term strength properties of HVFAC are often better comparing to common cement-based concrete. This behaviour is very useful for special massive structure due to low hydration heat development as well as for structure where gently hydration rate is required.

It is very important to keep low water/binder ratio, therefore high efficient plasticizing admixture should be used. Influence of added mixing water on compressive strength of hardened concrete should evaluate by use of k-value, according to EN 206-1. This value is specified as 0.2 for all cements expect the CEM I type cement. Thus, high amount of fly ash added to the concrete as a binder can cause that the type concrete wouldn't meet the requirements of present standards.

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