Jurnal
Teknologi

Full Paper

POSSIBILITIES OF DETERMINATION OF OPTIMAL DOSAGE OF POWER PLANT FLY ASH FOR CONCRETE

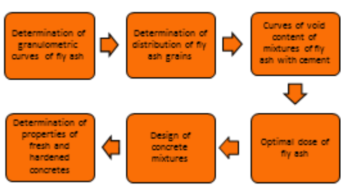
Rudolf Hela, Martin Tazky, Lenka Bodnarova*

Brno University of Technology, Faculty of Civil Engineering, Brno, Czech Republic

Article history
Received
21 June 2015
Received in revised form
17 September 2015
Accepted
19 December 2015

*Corresponding author
bodnarova.l@fce.vutbr.cz

Graphical abstract



Abstract

The paper describes possibilities of making use of high temperature combustion fly ash for production of concrete more effective. Efforts for maximal utilization of high temperature combustion fly ash are supported by high production of fly ash worldwide. Use of high temperature fly ash for concrete has to take into account considerably lower speed of hydration reactions compared to pure Portland cement. The paper states results of experimental determination of optimal dosage of fly ash as partial replacement of cement. Dosage of fly ash for production of concrete was optimized. Test results proved positive effect of dosage of fly ash with respect to granulometry of used cement and fly ash. Taking granulometry of fly ash and cement into consideration improves physico-mechanical properties of concrete compared to concrete with fly ash designed standardly without considering granulometry.

Keywords: Concrete, fly ash, granulometry of fly ash, optimal dosage of fly ash

1.0 INTRODUCTION

1.1 High Temperature Fly Ash

High temperature fly ash is characterized in the standard EN 206 as an addition of type II – addition with pozzolanic or latently hydraulic properties [1]. However, use of fly ash as addition is still researched and developed. It is necessary to verify maximal amount of fly ash for replacement of cement and find out how use of fly ash could be made more effective [2].

Use of high temperature fly ash for concrete has positive environmental and economic aspects; however, lower speed of hydration reactions compared to pure Portland cement has to be considered [3]. Initial strengths of fly ash are always lower compared to concrete with only Portland cement; this is frequent even after 28 days [4].

High temperature fly ash is an addition of type II, so-called active pozzolanic component. As regards pozzolanic properties of high temperature fly ash, reactive amorphous form of SiO_2 is particularly important [5]. From chemical point of view, pozzolanic property produced C-S-H gels at certain conditions, which are practically identical with hydration products of Portland cement. The essence of formation of these gels is chemical reaction of amorphous SiO_2 in water environment with ($Ca(OH)_2$), which is formed primarily as a by-product of hydration of allite (C_3S) and bellite (C_2S). For complete use of high temperature fly ash as pozzolanic addition into concrete, sufficient amount of $Ca(OH)_2$ is necessary. The rest of fly ash, which does not take part in pozzolanic reaction, has the function of micro-filler and therefore it can be characterized as an addition of type I [6]. The addition of fly ash can also achieve higher resistance to selected aggressive environments and higher resistance to high temperatures compared with concrete with ordinary Portland cement [4].

However, everyday practice of dosing fly ash as a partial replacement of cement is based mainly on results of tests and experience with given type of fly ash; it is usually between 15 % and 25 % by weight of cement. The amount, which can be used for partial replacement of cement, is then considered on the basis of the concept of the k-value, which is given in CSN EN 206 [1]. It is particularly this area, where dosing of fly ash can be optimized.

1.2 Optimization of Dosage of High Temperature Fly Ash

Method based on granulometry of fly ash and cement was proposed for experimental work focused on optimization of dosage. The conception is aimed at maximal density of dry mixture of cement with fly ash, possibly other additions [7]. Maximal density of fines in concrete mixture enhances properties of concrete (particularly hardened) in two ways:

The first positive impact is achieving minimal pore space of cement paste, which increases strength and durability properties of concrete. In this way, applied fly ash is considered as microfiller.

The second positive impact is based on forming of a very fine and dense network of C-S-H gels, which further fills the cement paste structure. This reduces porosity of the mastic cement microstructure as well as porosity of interfacial transition zones between aggregate and mastic cement. Non-hydrated part of fly ash still has the function of microfiller. However, it is necessary to mention positive influence of high temperature fly ash on rheology of fresh concrete. Optimized dose of fly ash brings improvement of physico-mechanical parameters of hardened concrete, which is also helped by lower dose of mixing water thanks to better workability of fresh concrete with fly ash [8].

Application and dosing of fly ash itself follows only mutual difference of granulometries of used fly ash and cement aiming at optimal ratio ensuring maximal density of the mixture of these components in dry state. As a routine, as much as 40% of fly ash can be dosed as a replacement of cement without worsening of strength and durability characteristics after longer interval of ageing. Positive effect of proposed method has been proved and it has considerable positive ecological and economic aspects.

2.0 EXPERIMENT

2.1 Methods of Work

To verify above mentioned optimization conclusions, several concrete mixtures of two strength classes were prepared: C40/50 and C50/60, hence on the border of high-strength concrete. Concrete of strength class C40/50 and C 50/60 were made. Reference concrete without fly ash was made for each strength class for the purpose of comparison.

Cement CEM I 42.5 R, CEMEX Czech Republic was used for the mixes.

Dosing was optimized for high temperature combustion anthracite fly ash from the power plant Detmarovice in the Czech Republic - Detmarovice power plant and for lignite fly ash produced by power plant Pocerady Czech Republic.

Samples for each strength class were prepared in accordance with standard methods of designing concrete with fly ash. Dosing for strength class C40/50 was 20% of fly ash by volume of cement in both cases; dosing for strength class C50/60 was always 17% of fly ash by volume of cement.

Before optimization, specific weight of cement and fly ash was determined by means of pycnometric method. Determined specific weight was used for calculation of percent proportion by volume to proportion by weight. Granulometry of cement and both samples of fly ash was analyzed by means of laser granulometer. For clearness, granulometric curves of both types of fly ash are given below (Figure 1).

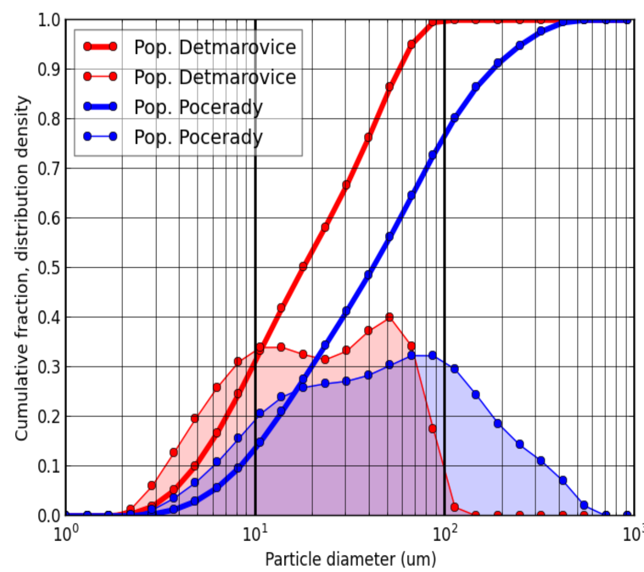
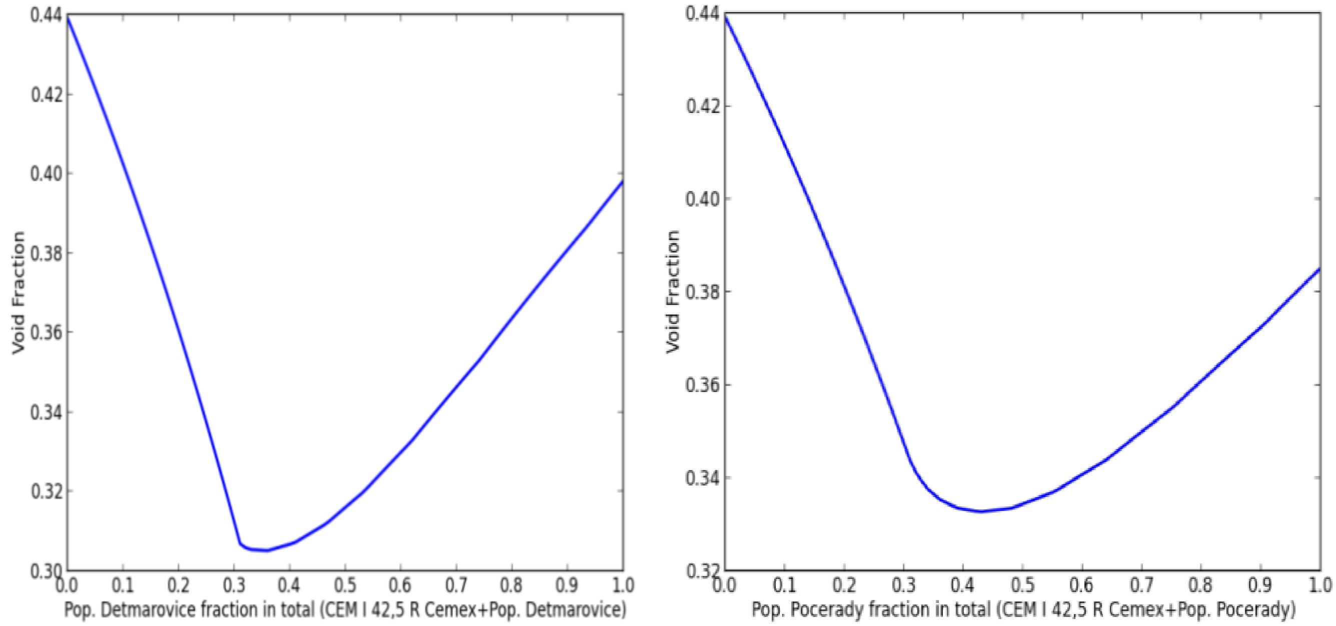


Figure 1 Granulometric curves and distribution of fly ash grains from samples Detmarovice and Pocerady

Optimal dose of fly ash for mix with cement was determined on the basis of the analysis of fly ash and cement. Optimization was carried out by a software application based on the work or T. Reschke [7]. Determined optimal dose of anthracite fly ash Detmarovice with given cement was 36% by volume of binders and for lignite fly ash it was 43% by volume of binder, which can be seen on attached diagrams (Figure 2 and 3), which are an output of the software tool used.

For plastifying, acrylic polymers based superplasticizer was used. The same percental dosage of plasticizer related to total volume of binders (hence content of cement and fly ash) was used for all produced concrete. To verify plastifying effect of fly ash, the same consistency of all prepared mixtures was set around 150 mm of slump in accordance with the standardized test stated in EN 12350 – 2 [9]. To achieve required consistency of all samples, dose of mixing water was adjusted. Consistency of fresh concrete mix was tested at the time up to 90 minutes from mixing – after 30 minutes.

Composition of concrete samples is given in Table 1.



A B

Figure 2 Curve of void content of mixture of fly ash Detmarovice with CEM I 42.5 R (A) and Curve of void content of mixture of fly ash Pocerady with CEM I 42.5 R (B)

Table 1 Composition of concrete

		REF C 40/50		**D-20 C 40/50**		**P-20 C40/50**		**D-OPT C40/50**		**P-OPT C40/50**	
		kg/m³	**note**	**kg/m³**	**note**	**kg/m³**	**note**	**kg/m³**	**note**	**kg/m³**	**note**
CEM I 42.5 R (CEMEX)		385	-	360	-	360	-	319	-	300	-
Fly ash	Detmarovice	-	-	90	20.0 % m_c	-	-	131	36.0 vol. %	-	-
	Pocerady	-	-	-	-	90	20.0 % m_c	-	-	150	43.0 vol. %
Sand 0-4 mm (Zabcice quarry)		910	49.3 % m_a	910	49.3 % m_a	910	49.3 % m_a	910	49.3 % m_a	910	49.3 % m_a
Crushed aggregate 8-16 mm (Olbramovice quarry)		480	26.0 % m_a	480	26.0 % m_a	480	26.0 % m_a	480	26.0 % m_a	480	26.0 % m_a
Crushed aggregates 11-22 mm (Lomnicka quarry)		455	24.7 % m_a	455	24.7 % m_a	455	24.7 % m_a	455	24.7 % m_a	455	24.7 % m_a
Plasticizer Mapei Dynamon SX 14		3.5	0.9 % m_c	4.0	1.1 % m_c	4.0	1.1 % m_c	4.0	1.4 % m_c	4.0	1.6 % m_c
Water		160	w = 0.42	180	w = 0.45	171	w = 0.43	167	w = 0.48	163	w = 0.47
Slump [mm]		140	S3	140	S3	140	S3	150	S3	130	S3

m_c = weight of cement m_a = weight of aggregates

		REF C 50/60		**D-17 C 50/60**		**P-17 C50/60**		**D-OPT C50/60**		**P-OPT C50/60**	
		kg/m³	**note**	**kg/m³**	**note**	**kg/m³**	**note**	**kg/m³**	**note**	**kg/m³**	**note**
CEM I 42.5 R (CEMEX)		445	-	430	-	430	-	370	-	347	-
Fly ash	Detmarovice	-	-	90	17.0 % m_c	-	-	150	36.0 obj.%	-	-
	Pocerady	-	-	-	-	90	17.0 % m_c	-	-	173	43.0 obj.%
Sand 0-4 mm (Zabcice quarry)		870	48.5 % m_a	870	48.5 % m_a	870	48.5 % m_a	870	48.5 % m_a	870	48.5 % m_a
Crushed aggregate 8-16 mm (Olbramovice quarry)		470	26.2 % m_a	470	26.2 % m_a	470	26.2 % m_a	470	26.2 % m_a	470	26.2 % m_a

	REF C 50/60		D-17 C 50/60		P-17 C50/60		D-OPT C50/60		P-OPT C50/60	
	kg/m³	note	kg/m³	note	kg/m³	note	kg/m³	note	kg/m³	note
Crushed aggregates 11-22 mm (Lomnicka quarry)	455	25.3 % m_a	455	25.3 % m_a	455	25.3 % m_a	455	25.3 % m_a	455	25.3 % m_a
Plasticizer Mapei Dynamon SX 14	4.0	0.9 % m_c	4.7	1.1 % m_c	4.7	1.1 % m_c	4.7	1.4 % m_c	4.7	1.6 % m_c
Water	160	w = 0.36	180	w = 0.39	180	w = 0.39	166	w = 0.40	167	w = 0.43
Slump [mm]	140	S3	140	S3	140	S3	140	S3	130	S3

m_c = weight of cement m_a = weight of aggregates

Verification of positive impact of optimization was observed on strength characteristics of hardened concrete. Compressive strength and static elasticity modulus of concrete were tested. Strength characteristics of hardened concrete were observed after 7, 28, 60, 90 and 360 days of standardized ageing [10]. Manufactured samples were labeled by initial letters of types of fly ash and number of weight proportion of fly ash by the weight of cement. Abbreviation OPT means Optimized dose of fly ash.

3.0 RESULTS AND DISCUSSION

3.1 Fresh Concrete

Practically all made tests of both fresh and hardened concrete proved positive influence of optimization of dosage of fly ash. As assumed, plastifying effect of both types of fly ash was apparent, which showed by reduction of mixing water dose necessary for required consistency. Development of consistency of fresh concrete in time is clear from the diagram (Figure 3). Because of the plastifying effect of fly ash, it was possible to reduce mixing water by ca 15 liter for 1 m³ of concrete for mixes with optimized fly ash dose compared to mix with usual dose of fly ash.

Concrete of both strength classes with original plasticizer showed loss of required consistency after 30 minutes (see Figure 3). For this reason, different plasticizer was tested for strength class C 50/60. This admixture was based on lignosulfonan and multi-carboxylate; labeling of mix-designs with this admixture in the diagram has a letter I. This admixture eliminated undesired loss of consistency in time. Loss of consistency in time depends greatly on compatibility of used plasticizer, cement and fly ash; influence of total volume of alkalies is evident.

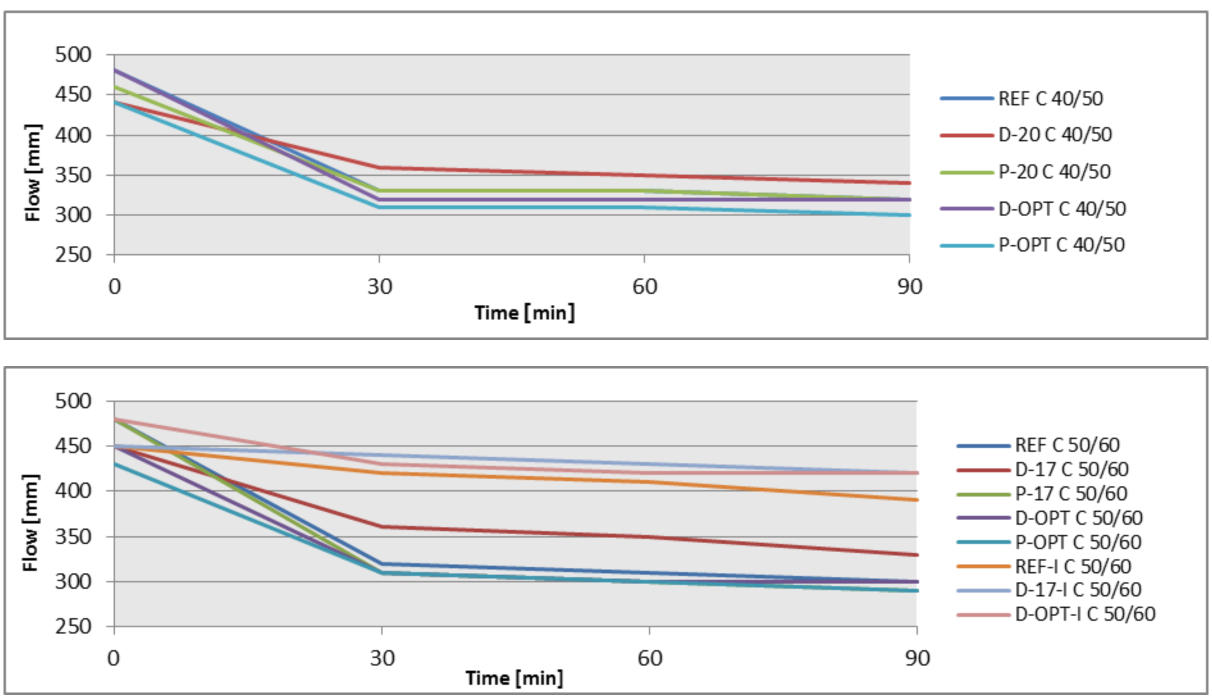


Figure 3 Dependence of consistency on the time elapsed from mixing

3.2 Hardened Concrete

To evaluate optimization of dosage of fly ash, physico-mechanical parameters of hardened concrete in longer period are crucial [11]. However, the tests of compressive strength imply that the values of samples with optimized dose of high temperature combustion fly ash achieve not only the same strengths as reference concrete or concrete with usual dose of fly ash, but in some cases the values of compressive strength are even higher. Diagrams in Figure 4 and Figure 5 show initial decrease of compressive strength of concrete designed in this way. However, it is necessary to take into account that these samples achieve comparable values of compressive strength as early as after 28 days compared to classic mix-design (see Figure 4, Figure 5 and Table 2). It was proved that optimal dose of fly ash showed no drop of strength even after 28 days, if the rule of maximal density of dry mix cement-fly ash is observed. The results also imply that optimized dose of anthracite fly ash shows better values for both strength classes, which is caused by more suitable chemical composition of anthracite fly ash, finer grains, which means larger specific surface and reactivity compared to optimized dose of lignite fly ash.

Results of static elasticity modulus of concrete show similar trend as compressive strength, however, none of the samples with fly ash exceeded the values of reference concrete [12]. Diagrams in Figure 6 and Figure 7 show percental decrease or increase of static elasticity modulus compared to reference concrete.

Table 2 Percentage increase or decrease compared with reference mixture [%]

Percentage increase or decrease compared with reference mixture [%]										
Days	**7**	**28**	**60**	**90**	**360**	**7**	**28**	**60**	**90**	**360**
Mix	**Compressive strength**					**Modulus of compression**				
D-20 C40/50	-20.3	-22.3	-9.7	-8.2	-4.6	-10.2	-5.0	-4.8	-4.6	-3.9
P-20 C40/50	-9.2	-11.4	0.0	2.9	3.5	-6.8	0.0	-1.6	-1.5	-1.3
D-OPT C40/50	-37.2	-26.2	-4.7	4.3	14.6	-18.6	-3.3	-3.2	-3.0	-2.6
P-OPT C40/50	-32.9	-27.1	-8.5	5.2	18.4	-11.9	-5.0	-4.8	-4.5	-3.9
D-17 C50/60	-2.8	-4.3	-4.4	-1.8	1.1	-24.5	-3.1	-9.4	-9.2	-5.0
P-17 C50/60	-10.4	-5.3	-2.5	5.6	7.0	-15.8	-4.8	-9.4	-7.6	-5.0
D-OPT C50/60	-13.6	-6.0	-1.9	3.3	3.6	-24.5	-4.8	-6.1	-4.4	-5.0
P-OPT C50/60	-30.4	-23.9	-16.2	-2.5	2.7	-29.4	-11.9	-11.1	-9.2	-7.5

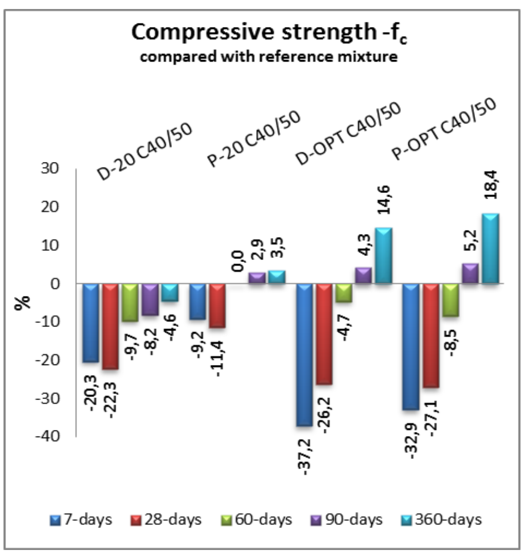


Figure 4 Compressive strengths of individual mixtures related to reference mixture for strength class C40/50

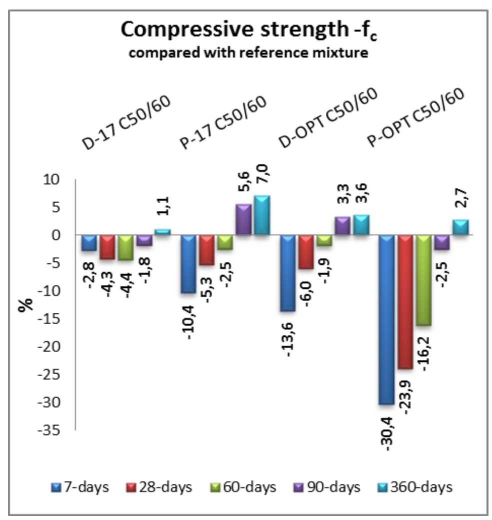


Figure 5 Compressive strengths of individual mixtures related to reference mixture for strength class C50/60

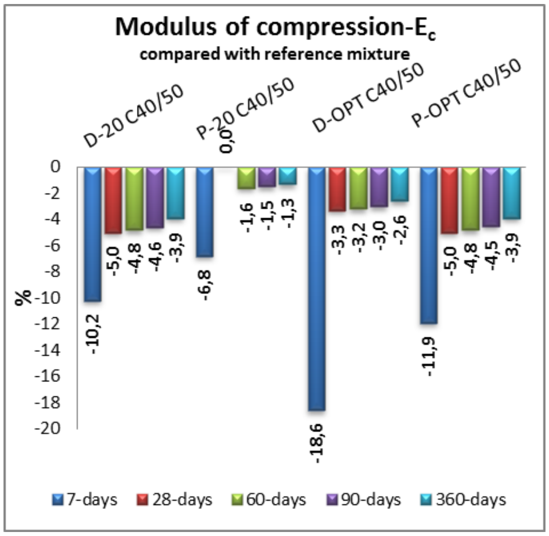


Figure 6 Static elasticity modulus of compression of individual mixtures related to reference mixture for strength class C40/50

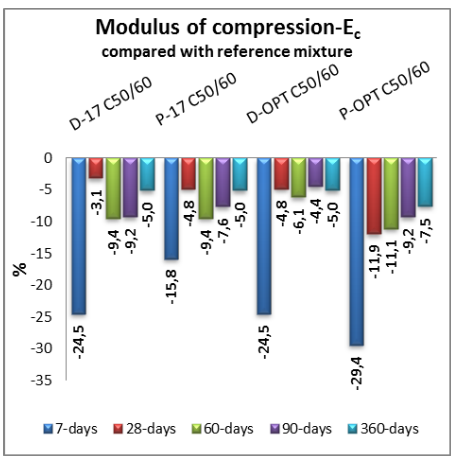


Figure 7 Static elasticity modulus of compression of individual mixtures related to reference mixture for strength class C50/60

4.0 CONCLUSIONS

The test results prove the possibility of optimization of fly ash dose related to given type of used cement. The aims of optimization are minimization of void content of the dry mix and fresh concrete and consequently reduce porosity in hardened cement paste. At the same time, dose of fly ash can be considerably increased with positive influence on workability of fresh concrete with no negative impact on compressive strength of concrete at the age of 28 days. The experiments proved that even relative high dose of fly ash (around 40% by volume of cement) are applicable for manufacture of high-performance concrete. The questions for further studies are more detailed examination of durability of these types of concrete and their resistance to various types of aggressive environment and making its use even more effective - for example by mixing with another type of additions. More effective use of fly ash has considerable environmental and economic potential.

Acknowledgement

This paper has been elaborated with the financial support of the project MPO TI4/582 “Possible industrial use of fly ash from low-temperature fluidized bed combustion for production of building materials”, and project GACR P104/12/1998 “Study of interactions of components of cementations composites exposed to high temperatures”, and has been worked out under the project No. LO1408 "AdMaS UP - Advanced Materials, Structures and Technologies", supported by Ministry of Education, Youth and Sports under the National Sustainability Programme I.

References

[1] EN 206-1 Concrete - Part 1: Specification, Performance, Production And Conformity.

[2] Fridrichová, M., Kulísek, K., Hoffmann, O., Dvořák, K., Magrla, R. 2014. Utilisation of Fluidised Fly Ash for Reduction of CO2 Emissions at Portland Cement Production. *Advanced Materials Research*. 1054: 168-172.

[3] Zach, J., Sedlmajer, M., Hroudová, J., Nevařil, A., edit by Bujnak, J., Vican, J. 2013. *Concrete and Concrete Structures 2013 - 6th International Conference*. Slovakia. 65: 296-301.

[4] Bodnárová, L., Jarolím, T., Válek, J., Brožovský, J., Hela, R. 2014. Selected Properties of Cementitous Composites with Portland Cements and Blended Portland Cements in Extreme Conditions. *Applied Mechanics and Materials.* 507: 443-448.

[5] Thomas, M. D. A., Shehata, M. H., Shashiprakash, S. G., Hopkins, D. S. A Cail, K. 1999. Use Of Ternary Cementitious Systems Containing Silica Fume And Fly Ash In Concrete. *Cement and Concrete Research*. 29: 1207-1214.

[6] Hela, R., Bodnárová, L., Maršálová, J. 2003. Fly Ashes Thermal Modification and their Utilization in Concrete. Fibre Concrete and High Performance Concrete, System-based Vision for Strategic and Creative Design. Roma. 1-3: 1649-1652.

[7] Reschke, R. 2001. Der Einfluss der Granulometrie der Feinstoffe auf die Gefügeentwicklung und die Festigkeit von Beton. Verlag Bau und Technik.

[8] Zobal, O., Holčapek, O., Reiterman, P. 2016. Frost Resistance of Concrete Screed with the Fly Ash Addition. *Key Engineering Materials.* 677: 80-85.

[9] EN 12350-2 Testing Fresh Concrete - Part 2: Slump-test.

[10] EN 12390-2 Testing Hardened Concrete - Part 2: Making and Curing Specimens for Strength Tests.

[11] EN 12390-3 Testing Hardened Concrete - Part 3: Compressive Strength of Test Specimens.

[12] ISO 1920-10 Testing of Concrete - Part 10: Determination of Static Modulus of Elasticity in Compression.