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UTILIZATION OF COAL FLY ASH INTO CEMENT CONCRETE ROADS

Представлено результати випробовувань щодо придатності часткової заміни цементу золою (0 – 15 %) в бетонованих дорогах. Проведено випробування бетонів із вмістом золи на стиск і на згин у віці 7, 28 і 90 діб, а також на морозостійкість і хімічну стійкість і отримані результати були порівнянні з відповідними результатами випробовувань контрольних зразків (C 30/37). На основі отриманих даних було встановлено, що ці бетони відповідають вимогам STN 73 6123 для побудовидорожнього покриття і альтернативне використання FA для бетонного дорожнього покриття є перевагою як у будівельній галузі, так і в галузі економіки і захисту довкілля.

Ключові слова: бетонне дорожнє покриття, зола, міцність на стиск, міцність на згин.

The summary of results of fly ash exploitability testing as a partial cement replacement (0 - 15 %) into the concrete road were presented in this paper. Compressive and tensile flexural strengths at ages of 7, 28, 90 days, frost and chemical resistance of fly ash concrete composites were measured and compared with reference specimen (C 30/37). Based on the results assements it can be stated that the requirements of STN 73 6123. Building of pavement were satisfied and the alternative utilization of FA in the concrete cover of pavements has significant benefits in building. in environmental as well as in economic area.

Key words: concrete road, coal fly ash, compressive strength, tensile flexural strength

Introduction. Technological developments in our society are still highly extensive nature and the forthcoming process of globalization significantly affects the state of the environment. There is also a slight increase in population, uncontrolled pumping of raw materials for production of materials and energy and urbanization of the environment. At the same time increases the amount of harmful emissions and waste. Mineral resources are considerably limited. As well as limited resources to feed a growing population (the problem of drinking water and food) are limited resources and materials needed for construction of buildings, infrastructure development and industry needed to further ensure the welfare of people. This is also true for conventional raw materials for production of construction materials and fuel. It follows that the need for change in approach to the design of concrete structures and concrete for road engineering [1]. Concrete is the most used building material in the world, but unfortunately it also leaves a major carbon dioxide. Portland cement, concrete's main binding agent, accounts for up 5% to 7% of the world's carbon dioxide emissions [2].

“Greening” - the word's significance perhaps is summarized best as anything that helps our world become physically better and healthier. In our industry, it includes cutting back carbon dioxide emissions by using less energy consumptive materials - that is, by maximizing use of waste products. Many articles have been written on how our industry can contribute. This can occur in a number of ways: (a) use activators, substitutes and replacements for Portland cement with waste products such as coal fly ash (CFA) [3], ground-granulated blast furnace slag cement, rice hull ash, silica fume, pozzolans of all types, and ground limestone; (b) reduce the “paste” fraction by minimizing amounts of these materials using well-graded aggregates; and (c) use water-reducing admixtures to lower w (water/cement ratio) and enhance concrete properties [4]. Although new technologies are being developed to help with this problem, there is a viable solution for the time being - fly ash. One of the most interesting by-products of the production processes, is fly ash, a fine grained residue of coal combustion in Thermal Production Stations of Electrical Energy, the usage of which has gained greater importance the moment the preservation of natural resources, the economizing of energy and the increase of environmental sensitivity and viable growth, has become an international issue. Internationally, fly ash has been used in many applications (ASCE, 1993; Linn and Symons, 1988) for several years, always aiming at the most beneficial end use and the protection of the environment (EC, 2000; European Committee for Standardization, 2000) [2]. Fly ash concrete was first used in the USA in 1929 for the Hoover Dam, where engineers found that it allowed for less total cement. Some of the reasons that fly ash is used in concrete paving have more to do with the physical characteristics of fly ash than the chemical and strength gain characteristics. Fly ash particles are smaller and almost totally spherical in shape, allowing them to fill voids, flow easily, and blend freely in mixtures. Additionally, when water is added to Portland cement, it creates two products: a durable binder that glues concrete aggregates together and free lime. Fly ash reacts with this free lime to create more of the desirable binder.

According to the American Concrete Institute, there was a 15-million ton reduction of carbon dioxide production in 2007, thanks to the incorporation of fly ash into concrete. The use of CFA concrete can not only lead to the sustainable development of the cement and concrete industries but would also provide a durable and economical alternative. To obtain the desired properties of strength and durability, maintenance of a low water-to-cement ratio is essential along with the use of a superplasticiser. The pore filling effect and pozzolanic properties of fly ash improve the properties of fresh and hardened concrete. This type of concrete is economical, environmentally-friendly and contributes to the reduced use of Portland cement, reduced CO_2 emissions, reduced heat of hydration allows the use of marginal aggregates susceptible to alkali-aggregate reaction and uses large volumes of abundantly available fly ash in the country that otherwise has to be disposed of in landfills at a considerable cost [5]. The use of fly ash in concrete can also address some specific durability issues such as sulphate attack and alkali silica reaction. However, a few additional precautions have to be taken to insure that the fly ash concrete will meet all the performance criteria.

CFA utilization as partial cement replacement in concrete cover was subject of our research. Physical (consistence, air content, concrete temperature, volume weight of fresh mixture), chemical (water activity, de- freezing substance resistance of concrete surface and frost resistance) and mechanical properties (tensile flexural and compressive strengths) of concrete based on fly ash as partial cement replacement were measured and presented.

Methods. Generally speaking, currently in the concrete industry, the percentage of fly ash as part of the total cementing materials in concrete normally ranges from 15 to 25%, although it can go up to 30-35% in some applications. The use of fly ash in concrete will improve some aspects of the performance of the concrete provided the concrete is properly designed. The main aspects of the concrete performance that will be improved by the use of fly ash are increased long-term strength and reduced permeability of the concrete resulting in potentially better durability.

The special kind of cement exploited for the Highway Engineering purposes (CEM 42,5 N) was used in mixtures preparation. The Slovakian fly ash from the brown (ENO Novaky) coal combustion (chemical properties of coal fly ash are presented in Table 1) was tested. Specific ratio of the fine aggregate to stone 40: 10: 50 (40% fraction 0/4; 10% fraction 4/8; 20% fraction 8/16; 30% fraction 16/32) was used in mixture. In accordance to the proposed prescription the specified amount of cement for 1 m^3 fresh concrete mixture 410 kg was replaced by the 5–15% ENO coal fly ash. Fluidifier (Muraplast FK 19), aeration addition (Centrament Air 202) as well as water were used for all composites [6, 7]. In accordance to STN EN 12350 (parts 3 and 7) four based testing of consistence assessment (slump test), air-volume (compressive method), volume weight (relative compaction - STN EN 12350 - 6:2001) and temperature assessment (STN EN 206-1: 2002) the test of fresh concrete was realized. After 7, 28 and 90 days (d) of hardening, the composites were tested on compressive strength (CS), tensile flexural strength (TFS) and on the frost resistance and determination of water activity and de-freezing substance resistance (STN 73 1326, STN 73 6123). Qualitative parameters of concrete hardening of pavement according to STN 73 1326 shows the Table 2. For the comparative study the reference composite (RC) concrete class (C 30 / 37) was prepared in accordance with requirements of Technical standards STN 73 6123 – Building of pavement.

Table 1

Chemical compositions of coal fly ash (CFA ENO)

Component wt. [%]	SiO_2	Al_2O_3	Fe_2O_3	TiO_2	CaO	MgO	K_2O	Na_2O	MnO
	37.50	15.60	7.67	1.30	22.94	2.77	1.21	0.63	0.11
Component wt. [%]	P_2O_5	SO_3 (S)		S_{pyrite}	S_{total}	Combustible substances (830 °C)	Residual organic carbon	Loss of drying	Loss of ignition
	0.18	7.29 (2.91)		< 0.01	2.91	2.14	0.28	0.16	2.59

Table 2

Qualitative parameters of concrete hardening of pavement according to STN 73 1326

Parameters	Group of pavement				
	L	I	II	III	IV
Characterized combined stress strength f_{cf} [N/mm^2]	4.5	4.5	4.5	4.0	3.5
The least amount of period of water activity and de-freezing substance		100 / 75		75 / 50	75 / 50
Prism compressive strength f_{cc} [N/mm^2]		32		28	25
The biggest coefficient of spatial arrangement of air voids [mm]			0.25		
Parameters	Group of pavement				
	L	I	II	III	IV
The least coefficient of frost resistance after 300 circles [%]		80		–	–
Cylindrical compressive strength [N/mm^2]		24		21	19

Results and Discussion.

Testing of fresh concrete mixture. The results of concrete mixture properties tested in accordance with Slovak technical standards proved that prepared fresh mixture of concrete of strength class C 30/37 on the base of CFA (0 – 15%) met the requirements of Technical standards. Its values as well as the specific requirements are presented in the Table 2, Figure 1.

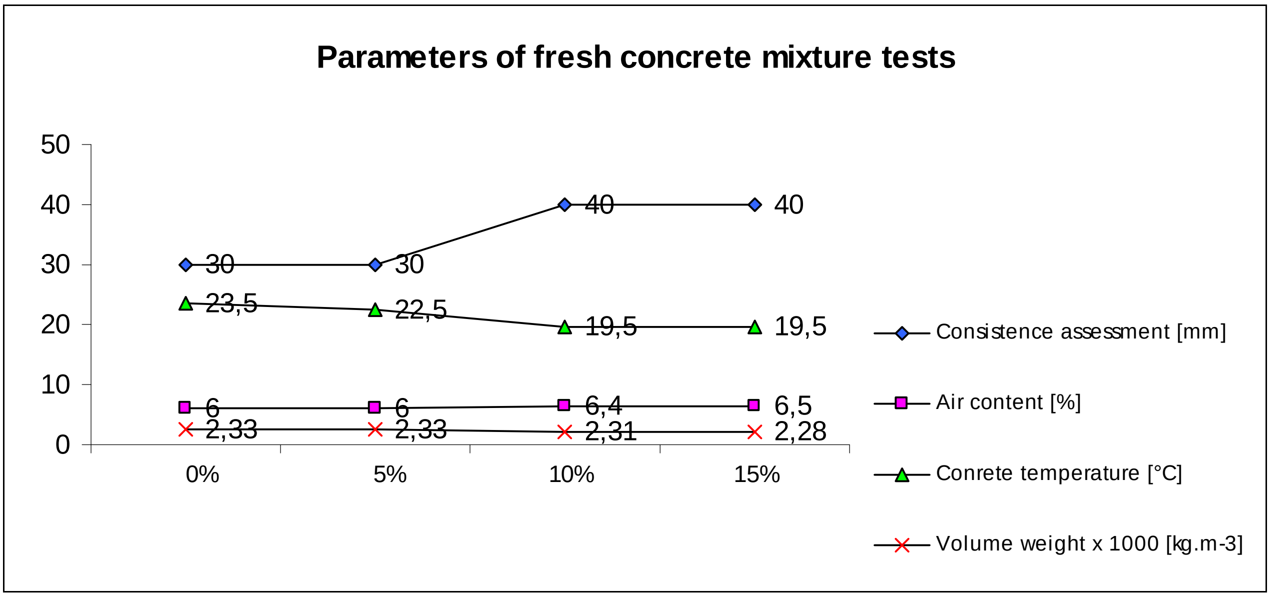

Figure 1. Graphic image of resultant values of fresh concrete mixture tests

Table 3

The requirements and results of fresh concrete mixture (C 30/37) test according to Slovak Technical standards (TS)

Type of test	Requirements according to TS	Measured value			
		0%	5%	10%	15%
Consistence [mm]	S1 (10 – 40 mm)	30	30	40	40
Air content [%]	maximal 7 – 8 %	6	6	6.4	6.5
Concrete temperature [^{o}C]	+5 °C to +25 °C	23.5	22.5	19.5	19.5
Volume weight [kg. m^{-3}]	compared with RC	2330	2330	2310	2280

Compressive and tensile flexural strengths CS and TFS development of composites based on various coal fly ash portions after 7, 28 and 90 days as the numerical formulation (average values of strength [N.mm^{-2}]) are showed in Table 3. Both strengths values of experimental composites with various portion of CFA are compared with values of RC and with requirements Technical standards (CS – 37. 0MPa / 28d, TFS – 4.5MPa / 28d). Based on these results it can be stated that the utilization of CFA with 5 % as well as 15 % of cement replacement is possible for the cement – concrete cover of pavement production, class of cement-concrete pavement group II.

Table 3

CS and TFS values of composites based on a partial cement replacement after 7, 28 and 90 days of hardening

Mixture	Hardening time [d]					
	7 d		28 d		90 d	
	CS [N.mm^{-2}]	TFS [N.mm^{-2}]	CS [N.mm^{-2}]	TFS [N.mm^{-2}]	CS [N.mm^{-2}]	TFS [N.mm^{-2}]
RC	44.2	5.8	48.4	6.9	57.2	8.2
5% CFA	40.0	6.1	44.2	6.6	53.7	8.1
10% CFA	35.7	5.1	42.4	6.2	52.6	7.1
15% CFA	31.0	4.9	37.2	5.6	41.1	6.8

Water activity, de- freezing substance resistance of concrete surface and frost resistance The results of water activity – with respect to all replacement (5 – 15% CFA) and de-freezing substance resistance of concrete surface based on certificate interpretation of the test performance showed that the composites met the requirements of Technical standard with results: slightly disturbed. The results of frost resistance tests showed that the requirements of Technical standard after 300 circles were fulfilled and in term of testing results of prepared composites on the base of 15% CEM 42.5 N replacement by CFA are suitable (frost resistance coefficient of 0.8) for the using in the area of Highway engineering – on the cement concrete roads production. In our previous works [8-10], tested composites based on 15 –20 % cement replacement by CFA by the same receipt (aggregate, cement, fly ash) after 100 circles of stresses were destroyed. As it determinates, the incorrect admixture caused the composites destruction on the coal fly ash base. Between used coal fly ash and choices chemical substance was not the required reaction process, whereby the composites were unsuitable for external utilization (cement concrete cover of pavement). In term of this fact, it could be stated, that the most important factor for increasing of frost resistance after 300 circles of concrete freezing and de - freezing (significant requirement of technical standard), suitable composition of chemical admixture is. In our research were tested three groups of admixtures from different Slovak producers, whose chemical composition is listed in the Table 4.

Table 4

Chemical composition of testing admixtures

Chemical composition	BETONRACIO [mg/kg]	STACHEMA [mg/kg]	MC-BAUCHEMIA [mg/kg]
Mg	<101	2140	<101
Si	<8,3	113	<5,1
P	<3,0	473,4	<3,0
S	93 160	47 280	99 680
Cl	188,9	294,4	195
K	222	324,2	224
Ca	5 799	2 476	5 130
Mn	<5,1	184,1	39,7
Fe	30,4	129,3	57,4
Co	15,5	8,1	14,7

All composites were made according to the same, a predefined recipe, with respect to the requirements of dosage recommended. The results of the strength measured on composites after 28 days of hardening showed (Figure 2) that the admixture from Stachema Company was the best. It is very interesting that only products of Stachema have significantly different chemical composition (Table 4 presents some of the chemical parameters). The other producers are in the assessment on the same level [11].

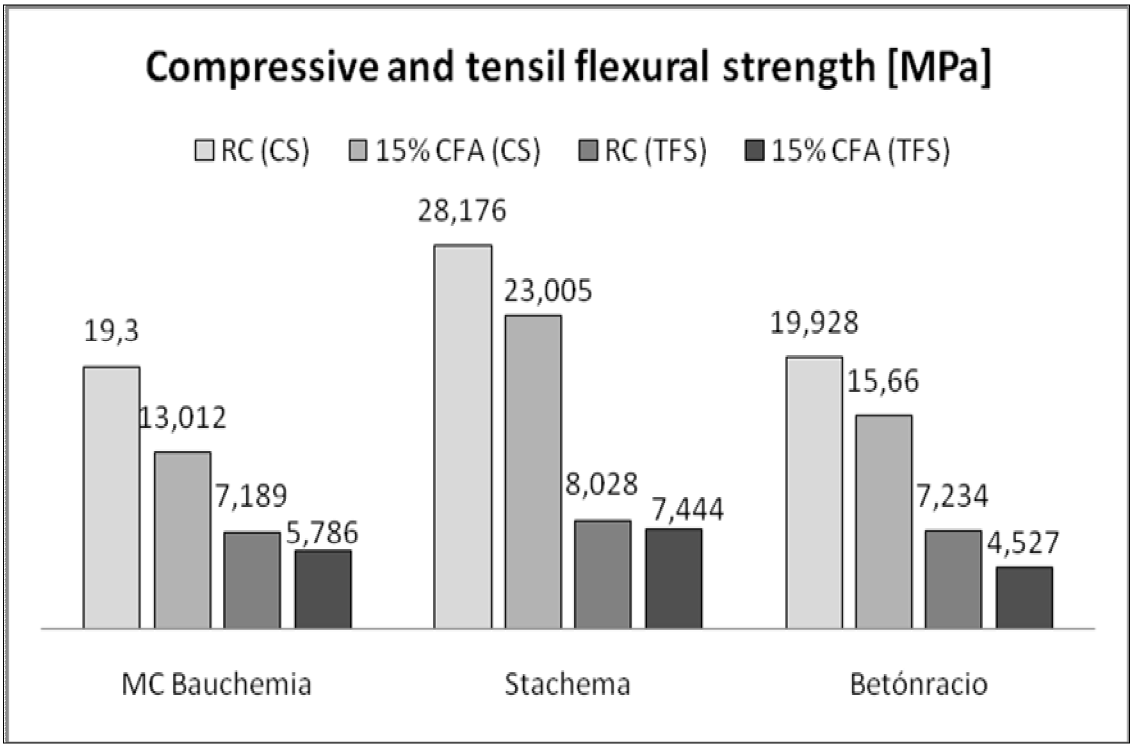

Figure 2. Results of CS and TFS of testing concrete based on the different admixtures after 28 days

Economical benefits The expected cost saving was calculated within the study of brown-coal fly ash utilization in concrete-cements in regard to application of raw materials in the road and highway constructions. Concrete mixture with 15% CFA compensation in road construction was selected for calculation. The road construction study of two-coat concrete-cement (CC) pavement of T1 tunnel [Two - layer concrete cover - 170/80 mm, Coated intermediate aggregate - 50 mm, Infiltration road spray 1,0 kg/m^2, Cement stabilization I - 180 mm, Aggregate 0-32, 0-63 (20+150 mm) - 270 mm] on Dx highway was used as a basis for this project. Costs were calculated without production and administrative expenses and without any profit as well. Respecting the specific technology these results came out (Table 5):

Table 5

Final calculation of CC two-layer cover of pavement

Description	Total price
CC two layer reinforced cover of pavement class I. thickness to 250mm – calculation according to the CENEKON 2009 database	553 555.88 €
CC two layer reinforced cover of pavement class I. thickness to 250mm – calculation based on our own recipe with 100 % Portland cement using	549 758.76 €
CC two layer reinforced cover of pavement class I. thickness to 250mm - calculation based on our own prescriptions (85 % Portland cement + 15% CFA)	532 294.80 €
Cost saving with 15% fly ash in CC I production	21 261.08 €

These unit prices were used for calculation of CC I pavement construction for two - layers tunnel with 698 m pipe length. The most effective alternative seems to be the number III. - with 15% fly ash compensation. It represents 21 260,08 € cost savings per one kilometer of concrete-cement pavement.

Conclusion. CFA/coal fly ash has considerable benefits when used in road construction, whether it is for embankment construction, for concrete in roads and bridges or for sub-base materials as in Fly Ash Bound Mixtures. Where PFA replaces natural aggregates, or acts as a cementitious binder, significant reductions in overall CO_2 emissions are possible to the benefit of the environment. In addition the existing stocks of material represent a large mineral reserve for future generations ensuring the sustainable construction of our road infrastructure. However, we are all responsible for the future of this planet and by maximizing the use of by-products materials, such as PFA, this will reduce natural aggregate depletion and leave resources for the future [12].

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