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# Energy Savings and Environmental Benefits of Fly Ash Utilization as Partial Cement Replacement in the Process of Pavement Building

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In this paper, the obtained results of fly ash exploitability testing as a partial cement replacement into the concrete cover of pavement are presented. In accordance with the proposed recipe the specified amount of cement in concrete mixture was replaced by 5-15% ENO fly ash. Fresh concrete mixture, compressive strength and combined stresses strength after 7, 28 and 90 days of hardening composites as well as frost and chemical resistance were tested and compared with reference composite (the concrete of class C 30/37) which satisfies the Technical standards requirements. Results showed that alternative utilization of FA have significant contribution in environmental as well as in economic area.

## 1. Introduction

Fly ash, generated during the combustion of coal for energy production, is an industrial by-product, which is recognized as an environmental pollutant. Because of the environmental problems presented by the fly ash, considerable research has been undertaken on the subject worldwide (Ahmaruzzaman, 2009).
The development of a new generation of cement-based concretes is related to the requirements for high technical solutions in civil engineering. Road concrete belonging to this group of special concretes is used in the construction of cement concrete road surfaces – concrete pavements. Road cement as an important component of concrete mixture must fulfils all EN standard requirements. The 21st century is the century of the global climatic changes and the key criterion for secondary market materials utilization has to be their environmental impact. From the long term and complex point of view it is necessary to consider investment projects carefully, which products have to serve for several decades. In the building engineering one of the cost effective opportunities is the construction of cement concrete road surfaces. Belgium, Germany, France and the USA mostly have the biggest share of these roads today (Gschwendt, 2001). Following world trends in highway constructions, even the Slovakia starts to apply the cement concrete road surfaces. They belong to the most progressive road constructions regarding their excellent properties of road concrete. The efforts of researcher in concrete constructions for transport infrastructures are focused on the road cement demand reduction. The use

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of coal fly ash (CFA), a secondary market material created through the generation of electricity from coal, offers more sustainable alternative by reducing the amount of consumed Portland cement, which has many benefits, improves concrete performance in both the fresh and hardened state and use is also cost effective (Pacheco et al., 2008, Reijnders, 2005). By requiring fly ash in concrete and other products, architects, engineers and regulators express a commitment to promote sustainable growth and exercise responsible building practices. Using fly ash is an exceptional way to “Build Green,” without compromising cost or quality in concrete production.
Our research is oriented to CFA utilization in the belite cement production as well in sphere of concrete preparation (Stevulova and Filkova, 2009). CFA utilization as partial cement replacement in concrete cover was subject of our research. Its influence on physical (consistence, air content, concrete temperature, volume weight of fresh mixture), chemical (water activity, de- freezing substance resistance of concrete surface and frost resistance), mechanical properties (combined stresses and compressive strengths) of concrete as well as economical and environmental benefits were spotted (Bacikova and Stevulova, 2007, 2009a, b).

## 2. Materials and methods

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 coal combustion (ENO Novaky) (chemical properties of CFA are presented in Table 1) with cooperation the building praxis (Central building laboratory of Slovak corporation) as a partial cement replacement in concrete was tested.

*Table 1: Chemical compositions of coal fly ash (CFA)*

| Component wt. [%] | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | $TiO_2$ | CaO | MgO | $K_2O$ | $Na_2O$ | MnO |
|---|---|---|---|---|---|---|---|---|---|
| CFA (ENO) | 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) | | $S_{pyrite}$ | $S_{total}$ $S_{(SO3)}$ + $S_{pyrite}$ | Combustible substances (830 °C) | Residual organic carbon | Loss of drying | Loss of ignition |
| CFA (ENO) | 0.18 | 7.29 (2.91) | | < 0.01 | 2.91 | 2.14 | 0.28 | 0.16 | 2.59 |

In accordance to the proposed prescription the specified amount of cement for 1m$^3$ fresh concrete mixture 410kg was replaced by the 5–15 % CFA. Natural gravel aggregate from stone – pit Soporna and Hanisberk in specific ratio of the fine to coarse aggregate 40 (0/4): 10 (4/8): 50 (16/32) was used in mixture. Fluidifier (Muraplast FK 19), aeration addition (Centrament Air 202) as well as water were used for all composites (Ondova et al., 2010). 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), combined stresses strength (CSS) and on the frost resistance and determination of water activity and de-freezing substance resistance (STN 73 1326, STN 73 6123). 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.

## 3. Results and Discussions

### 3.1 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, 5, 10 and 15 %) met the requirements of Technical standards. Its values are presented in the requirements in the Table 2.

*Table 2: 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 reference specimen | 2330 | 2330 | 2310 | 2280 |

### 3.2 Compressive and combined stresses strengths

CS and CSS 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, CSS – 4.5MPa / 28d). Figure 1 showed also the percentage increase of strength after every time period (100% is presented the maximal attained strength). 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 CSS 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$^{-2}$] | CSS [N.mm$^{-2}$] | CS [N.mm$^{-2}$] | CSS [N.mm$^{-2}$] | CS [N.mm$^{-2}$] | CSS [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 |

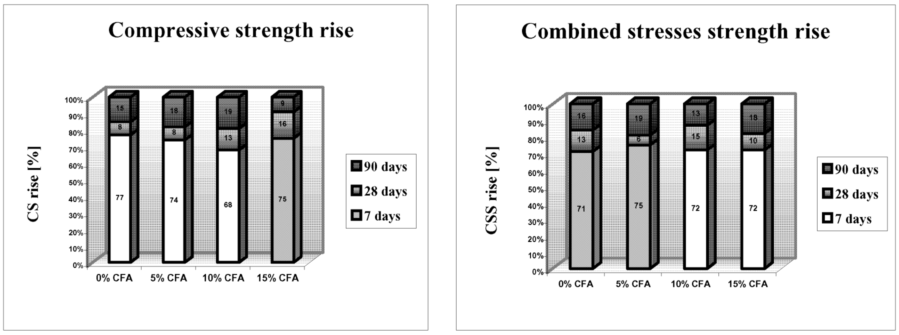


*Figure 1: Increase in compressive strength and combined stresses strengths values of composites based on CFA in comparison to RC with respect to time period of concrete hardening*

**3.3 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 (Table 4) 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 0.8) for the using in the area of Highway engineering – on the cement concrete Roads production. In our previous work (Bacikova and Stevulova, 2009a), tested composites based on 15 –20% CFA by the same receipt after 100 circles of stresses were destroyed. As determinates, the incorrect admixture caused the composites destruction on the CFA base. Between used coal fly ash and choices chemical substance was not the required reaction process, whereby the composites were unsuitable for external utilization. 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.

*Table 4: Qualitative parameters of concrete hardening of pavement according to STN 73 1326*

| Parameters | Group of pavement | | | | |
|---|---|---|---|---|---|
| | L | I | II | III | IV |
| Characterized CSS $f_{cf}$ [N/mm$^2$] | 4.5 | 4.5 | 4.5 | 4.0 | 3.5 |
| The least amount of circles of water activity and de-freezing substance | 100<br>75 | | | 75<br>50 | 75<br>50 |
| The least coefficient of frost resistance after 300 circles [%] | 80 | | | – | – |

### 3.4 Application of fly ash road concrete in building praxis

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 (Table 5) on Dx highway was used as a basis for this project. Its structure and dimension is full in compliance with requirements (TS 0803/2003 – design of concrete-cement carriageway at road communication).

*Table 5: Technical parameters of T1tunnel on Dx highway*

| | |
|---|---|
| Two - layer concrete cover | 170/80mm |
| Coated intermediate aggregate | 50mm |
| Infiltration road spray 1.0kg/m$^2$ | |
| Cement stabilization I | 180mm |
| Aggregate 0-32, 0-63 (20+150mm) | 270mm |

Costs were calculated without production and administrative expenses and without any profit as well. Current inputs of materials, transport costs, team and machine utilization was specified for Dx highway space. Respecting the specific technology these results came out in this calculation:

**Variant I. -** By 100% quantity of CEM I 42.5R Portland cement utilization for CC I production according to proposed recipe designed in catalogue items of CENEKON 2009 database the unit price **93.72 €/m$^2$** resulted.

**Variant II. -** The second alternative based on utilization of 100% quantity of CEM I 42.5R Portland cement for CC I production according to our own recipe the unit price **92.46 €/m$^2$** resulted.

**Variant III. -**The variant utilization of 85% quantity of CEM I 42.5R Portland cement for CC I production and utilization of 15% ENO fly ash according to our own recipe we obtained the unit price **86.76 €/m$^2$**.

These unit prices were used for calculation of CC I pavement construction for two - layers tunnel with 698 m pipe length. Results are illustrated in Table 6. 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.

*Table 6: 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 with 85 % Portland cement using and 15% ENO fly ash using | 532 294.80 € |
| Cost saving with 15% fly ash in CC I production | 21 261.08 € |

## 4. Conclusions

The development of new specifications and tests leads to reduction of amount material related problems when fly ash is used in concrete construction for transport infrastructure. Prospective opportunities of the coal fly ash utilization are in the road concrete production especially (whole road net measures almost 18000 kilometers in the Slovakia. Nowadays „boom“of road and highway construction evokes the necessity of further study of this subject. Reaching the required quality standards of strength properties with 30-35% fly ash compensation, it could be stated that harmful waste utilization is possible in different kind of industrial production. Together with more environmental (utilized CFA per 1km of track = 64 ton $CO_2$ emissions reduction) and economical benefits it contributes to the idea of sustainable development and decreasing degree of global pollution.

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