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Observation and Experience of Using Mechanically Activated Fly Ash in Concrete

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Abstract**—**Paper focuses on experimental testing of possibilities of mechanical activation of fly ash and observation of influence of specific surface and granulometry on final properties of fresh and hardened concrete. Mechanical grinding prepared various fineness of fly ash, which was classed by specific surface in accordance with Blain and their granulometry was determined by means of laser granulometer. Then, sets of testing specimens were made from mix designs of identical composition with 25% or Portland cement CEM I 42.5 R replaced with fly ash with various specific surface and granulometry. Mix design with only Portland cement was used as reference. Mix designs were tested on consistency of fresh concrete and compressive strength after 7, 28, 60 and 90 days.

Keywords**—**Concrete, fly ash, latent hydraulicity, mechanically activated fly ash.

I. Introduction

CURRENT trends in construction industry focus on two different ways: one of them seeks new construction materials with special properties and higher end-use properties, the other one explores ways of considerable decrease of manufacture cost and ecological load caused by production of construction materials. The second one has a unique chance of intensive use of substitutes for classic raw materials, of course on condition of keeping high final quality of construction material. As for production of concrete, the most natural way is reduced use of cement and use of active additions. The Czech Republic produces high amount of fly ash in power plants, therefore fly ash seems to be best option as replacement of cement. Since fly ash has been used as cement replacement for quite a long time, experience is rather extensive. Nowadays the research focuses on ways of increasing binding potential and activity of current fly ash with the aim of reduction of total amount of binding part in concrete [1], [2]. This paper focuses on experimental testing of possibilities of mechanical activation of fly ash and observation of influence of specific surface and granulometry on final properties of fresh and hardened concrete.

Classic fly ash is produced during high temperature combustion of black coal or lignite in power plants. It is a mineral residuum of combustion process caught from gaseous fumes in mechanical and electrostatic separators.

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Electrostatic separators use forces of electrostatic field at high electric potential. Direct current is supplied to negative electrodes in the area, where fumes flow out. Emitted electrons charge particles of fly ash and these are attracted by plate electrodes – collectors with positive charge. Effectiveness of this type of apparatus is up to 99%.

Mechanical separation can be realized on fabric filters. These filters are made from special fibers resistant to high temperature. Fabric is cleaned by compressed air blasting and fly ash falls into discharge hoppers. The advantage of such device is higher performance and separability compared to electrostatic separators. On the other hand, more electric energy is required for driving chimney fan to overcome aerodynamic resistance of filter.

Fly ash goes from separators into storage silos and it can be used as corrective component for production of blended cements [3]. Fly ash is also used in concrete as active or passive addition, depending on latent hydraulicity [4], [5]. Latent hydraulicity depends on the amount of SiO_2 in glassy phase, which can react with $Ca(OH)_2$ in cement. Residual combustible proportion has negative effects; it is so-called ignition loss, which should be less than 5 % by weight. These residua have negative effect also on super plasticizers or air entrainers [6].

Fly ash from lignite are more variable as regards chemical composition, granulometry and ignition loss, which is higher compared to black coal fly ash and it is a disadvantage for planned use in concrete.

Specific surface and granulometry of fly ash can be adjusted in economical and technologically simple way by means of two technologies: The first one lies in sorting fly ash at the primary stage on various types of separators. This way seems to be more advantageous; however, it requires additional cost for additional storage silos and adjustments of transportation ways for sorted fly ash. The second way is mechanical grinding of final mix of fly ash from all degrees of separation [7]. Additional cost is required here, too, in particular for transportation and grinding, however, final properties of fly ash can be constant and aimed at required properties of concrete.

II. Experimental Part

The experiment was focused on mechanical activation of fly ash. Mechanical grinding prepared various fineness of fly ash, which was classed by specific surface in accordance with Blain and their granulometry was determined by means of laser granulometer. Table I gives values for individual samples

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of fly ash and Fig. 1 gives granulometric curves from screen analysis.

TABLE I
MECHANICAL PROPERTIES OF FLY ASH

	Gringing time [min]	Bulk weight [kg/m^3]	Fineness of grinding [m^2/kg]
Fly ash input	0	917	216
FAGr20	20	766	270
FAGr40	40	709	345
FAGr45	45	685	405
FAGr60	60	682	460
FAGr75	75	690	520

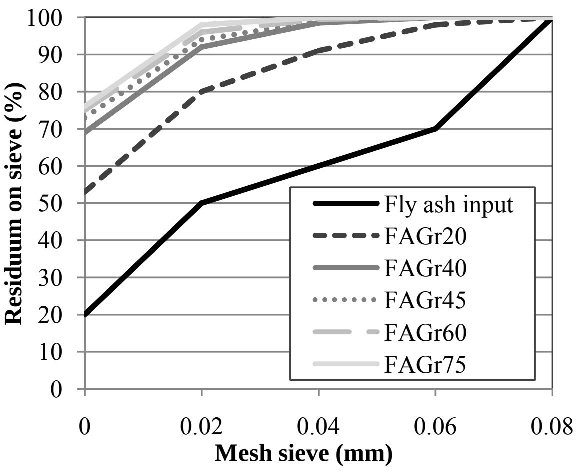

Fig. 1 Screen analysis of fly ash

Sets of testing specimens were made from mix designs of identical composition with 25% or Portland cement CEM I 42.5 R replaced with fly ash with various specific surface and granulometry. Mix design with only Portland cement was used as reference. Mix designs were tested on consistency of fresh concrete and compressive strength after 7, 28, 60 and 90 days.

A. Materials

1) Cement

Cement CEM 42.5 R made by Heidelberg cement Czech Republic in the amount of 263kg /1m^3 of concrete was used.

2) Aggregate

Two fractions of aggregate were used 0-4 (river sand) and 8-16mm (crushed) proportion 46:54. Proportion by weight was 812kg/m^3 for fraction 0-4 and 954kg/m^3 for fraction 8-16 mm.

3) Water

Water cement ratio was 0.5; it was calculated with respect to weight of binders, i.e. cement and fly ash.

4) Admixtures

To reach require consistency S3, acrylic plasticizer DYNAMON SX 14 by Mapei was used, dose 0.9% by weight of cement and fly ash.

5) Additions

Fly ash used was produced in power plant Pocerady Czech Republic at burning lignite. Fly ash was mechanically ground on ball grinder to reach various specific surfaces.

B. Laboratory Tests

Table II summarizes composition of mix-deigns. First, dry components were mixed, then 2/3 of mixing water were added, after partial homogenization the last third of the water together with plasticizer. The whole mixture was homogenized for the period of 3 minutes. After that, slump test was carried out. Fig. 4 shows values of consistency for mix-designs with individual samples of fly ash.

Each of the mix-designs was used for manufacture cubes 100 x 100 x 100mm.After one day, the cubes were taken out of steel forms and placed in water, where they stayed until the time of testing.

TABLE II
MIXTURE PROPORTIONS (KG/M^3)

Mixture	Cement	Fly ash	Water	0 – 4 mm River sand	8 – 16mm Crushed aggregate	Super plasticizer
Reference	350	0	175	812	954	3.15
With fly ash	288	88	175	812	954	3.15

Compressive strength was tested on three cubes of each mix-design after 7, 28, 60 and 90 days. Table III gives summary of compressive strength for individual mix-designs. Figs. 3 and 4 give development of strength in the period of 90 days; individual mix-designs are compared.

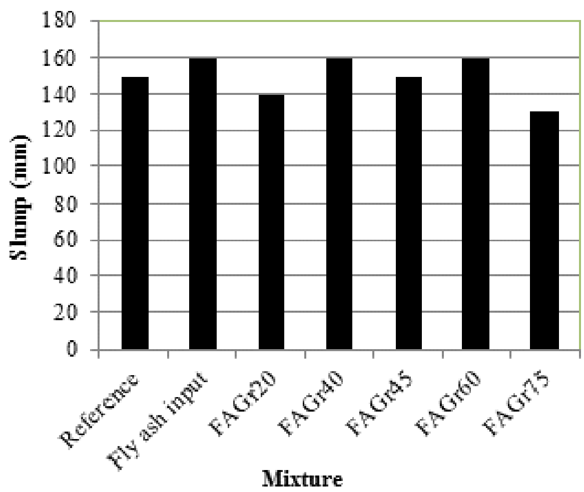

Fig. 2 Workability of fresh concrete – slump test

TABLE III
COMPRESSIVE STRENGTH (MPA)

Mixture	Reference	Fly ash input	FAGr20	FAGr 345	FAGr 405	FAGr 460	FAGr 520
7 Days	51.5	36.5	35.5	41.0	36.5	36.0	43.5
28 Days	57.5	47.5	50.5	52.0	53.5	52.5	55.0
60 Days	64.0	61.0	62.0	64.5	67.0	60.0	63.0
90 Days	61.5	61.0	62.0	68.0	65.0	65.0	67.0

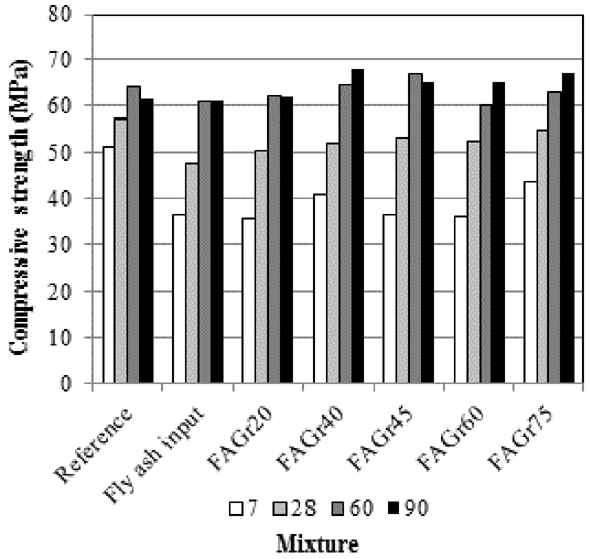

Fig. 3 Compressive strength – trend in 90 days

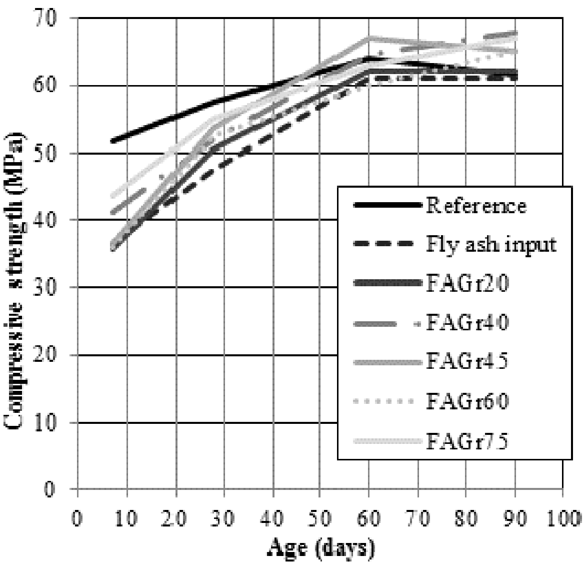

Fig. 4 Compressive strength – comparison

III. Conclusion

Mix-designs were designed for consistency S3 for reasons of application in ready mix concrete. This condition was satisfied with the exception of mix-design Fly ash – input and FAGr40.Consistency of these two mix-designs was S4.Water-cement ratio of all mix-designs was 0.5. It was found, that increase of specific surface decreases consistency. Increase of specific surface from 216m^2/kg (Fly ash input) to 520m^2/kg (FAGr75) decreased consistency by 50mm, which is no considerable problem as regards workability.

Mix-design with fly ash ground to 345m^2/kg reached the highest value of final compressive strength (68 MPa^2 after 90 days).This mix-design showed high values at all stages of testing. Mix-designs with fly ash with lower specific surface showed no change of compressive strength between 60 and 90 days. Even though increasing specific surface of addition brings higher strength of concrete in hardened state, still, the most suitable fineness of grinding seems to be the fineness, which does not exceed the fineness of ground cement.

From the economical point of view, activation of addition by grinding is advantageous. Grinding of 1 ton of fly ash from specific surface 216m^2/kg (Fly ash input) to specific surface 520m^2/kg (FAGr75) costs 14 EUR. Together with transportation and negligible price of fly ash, this is total price for addition, which can adequately replace cement, the price of which is around 90 EUR/ton.

From the ecological point of view, the replacement of cement with fly ash is also advantageous. Production of 1 ton of cement brings production of 0.85 ton of CO_2, which considerably increases carbon footprint of concrete. Carbon footprint of fly ash is already spend and calculated for production of electric energy.

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