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The Mechanical Activation of Fly Ash

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Abstract

One of the main options in looking for the new building materials is using of wastes from an industry as a replacement of the existing ingredient. This way is used in the concrete production too. Basic effort is to find a suitable replacement for economically and ecologically unfavorable cement by another component or components. As one of these components can be used fly ash – by-product of coal-fired electric power stations. The using of the fly ash as an additive into concrete is quite old, nevertheless this component offers a lot of new possibilities today too. Mechanical activation is one of them. As mechanical activation is known sorting or grinding of fly ash. Activation by sorting brings some disadvantages as is not using of all production and the high price for rebuilding the plants. Much more effective option provides grinding of the fly ash. This practice also comes to Czech Republic and submitted publication summarizes existing knowledge and presents result from first tests done on Czech fly ashes.

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1. Introduction

Fly ash is residue from coal-burning process in power plants. Benefits of fly ash are based on reactions of silica from fly ash with portlandite from cement reactions. Which create C-S-H structures similar to them formed during the cement hydration. Properties of fly ash for using in concrete depend on mining process of burned coal, burning process and process of separation. All these factors can influence chemical consumption, shape properties and fineness of fly ash. Lot of studies has showed that the main influence on properties of final cement-fly ash

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component has fly ash fineness. [1-21] This claim is not valid for alkali – silica reaction resistance of fly ash-cement composites, where main role play chemical consumption of fly ash. [1]

Generally speaking, utilization of fly ash in cement composite production brings economic benefits because it is usually a low-cost material and it can be used to replace higher cost materials. Additionally, in some cases, its use in cement composites represents technological advantages, such as pozzolanic activity. Finally, environmental aspects should be account when fly ash is used. [2]

For maximization of fly ash reactivity there were developed several methods. Basically is possible do divide these methods into four groups (i) chemical activation focused on modification of the chemical surface; (ii) mechanical activation – in some studies is this activation meant as a grinding process [2] but as a mechanical activation can be account sieving and air separation too; (iii) thermal activation, such as slow or rapid cooling, producing changes in the vitreous/crystalline ratio [2]; and (iv) combination of previous. This paper is focused on mechanical activation.

2. Mechanical activation

2.1. Sieving, air-separation, magnetic separation

Due to the separation process we can obtain several different fractions of fly ash. This method gives unmodified particles, which means – particles stay in spherical shape and fluidity of cement paste can be improved. On the other hand cenospheres and plerospheres are uncrushed and pozzolanic activity is not improved [3]. For the classified fine fly ash, the particles that are completely burned are more spherical in shape and have smoother surfaces as compared to the coarser fly ash particles [4].

Separation process can be taken directly in power plants, when fly ashes from each separator are stored separately. Separation process in power plants has several sections. Basically first section is gravity separation, for example Lljungström air preheater. Second one can be textile separators and the third one is electro filters. Each process gives fly ash with different fineness. Mostly are in process few electro filters divided into sections too. Fly ash obtain from electro filter has Blain specific surface area 200 – 300 m^2/kg.

Another separation process can be held by sieving, flotation or air classification. For sieving is mostly used sieves 200 and 325 mm, sometimes is sieve 90 mm used too [4]. As an air classifier can be used cyclone separator.

New possibility of separation process was described by Páya and et al. [2]. In this process original fly ash is suspended in water and mechanically and vigorously stirred, maintain stirring, a hand-electromagnet with a plastic shelter is introduced into the suspension and removed. Part of the fly ash adhered (magnetic fraction) to the plastic surface and, when the current is switched off, adhering fly ash is recovered. This process can be repeated several times and recovered samples are collected together. Non-magnetic particles are getting out from solution after drying. Due to this method we can obtain fractions with different chemical composition. For example test on mortars containing magnetic fractions showed good workability in spite of the lowest specific surface area. This unexpected result could be attributed to the adsorption reaction of water on the surface of particles, probably iron [2].

Problem of activation by separation is a quite large residue coarse fly ash which can be as high as 60-70 % of the whole mass. This reduces the cost efficiency of process [5].

2.2. Grinding

Grinding can be possible solution for coarse fly ash residue from separation processes [5]. For ground fly ash, process causes break up of large pleroshperes (i.e. decrease of porous particles) and decreases particle roughness. This reduction in water requirement together with the higher reactivity of finer fly ash increases the mortar strength. Grinding process of cenospheres increases the specific gravity and fineness, and consequently results in higher pozzolanic reactivity of the fly ash [1].

That can be used several kinds of grinding machines. Most often are ball mills [1, 2, 5, 6, 7, 8, 9, 10, 11, 12, 13]. But there can be used another kinds of mills such as hammer mill [3], attrition mill [14], jet mill [15] and vibro-energy mill [16, 17] for mechanical activation of fly ash.

Jet mill grinding can reduce risk of contaminating the product with milling media because the material itself is milling media [15].

The milling time has a big influence on fly ash fineness too. Efficiency of grinding process decreased during the time. For example Bouzoubaa et al. achieved that the first 2 hours of grinding in hammer mill was more effective in increasing the fineness. Milling time strongly depend on the kind of milling device.

Main effect of grinding is that coarse particles are by grinding crushed on smaller particles and as Fig. 1 shows, we can obtain small reactive particles and smaller less reactive particles which on the other hand can be good fillet between cement particles.

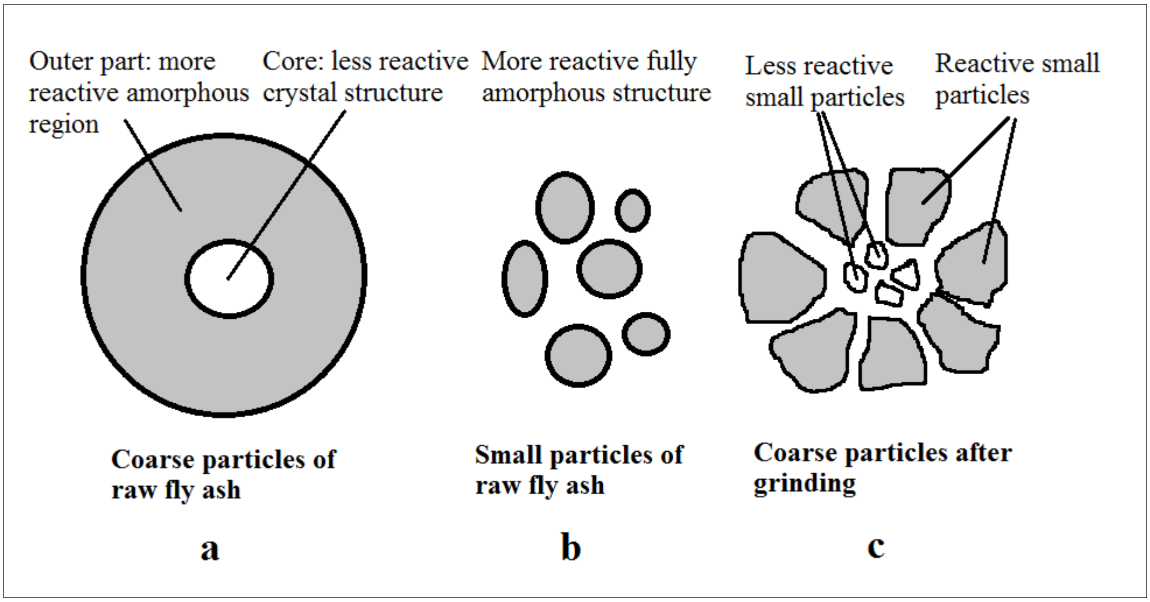

Fig. 1. Simplified simulation of the effectiveness of grinding from the view point of pozzolanic reactivity (a), (b) the coarse and fine portion of unprocessed (raw) fly ash particles; (c) pozzolanic reactivity of smaller particles formed after grinding). Picture adopted from Felekoglu et al. report [5].

2.2.1. Influence on workability

Basically fly ash admixture to cement results in a decrease in fluidity of pastes nevertheless additional grinding of fly ash improves the rheological properties of pastes [18].

Several studies described influence of fly ash fineness, particle shape or particle size distribution on the workability of fresh paste, mortars or concretes [3, 18, 19, 20].

Bouzoubaa with according to Cornelissen et al. presents that use of ground fly ash as a cementitious material for mortars and concretes results no negative effect on the workability.

Bouzoubaa et al. in his experiment used hammer mill and controlled water requirement of the fly ashes as a function of the grinding time. After 2 hours grinding the water requirement of the fly ashes decreased somewhat primarily due to the break of the large plerospheres. Increasing the grinding time from 2 to 4 did not affect water requirement. However further increasing the grinding time from 4 to 10 hours increased the water requirement because of the increase in the irregular-shaped particles [3].

Grzeszych et al. [18] claimed that grinding of fly ash brings about the rheological properties improvement. The effect is negligible for the lowest fly ash content, but becomes significant at higher values [5].

2.2.2. Influence on strength

Previous studies show that the grinding crushes the cenospheres and the large particles of fly ash resulting in higher specific gravity and fineness, and consequently higher pozzolanic reactivity of the fly ash. The amorphous silica of fly ash must be exposed to water molecules to react with $Ca(OH)_2$ from hydrated cement for pozzolanic reaction to take place. The degree to which individual fly ash particles are exposed depends to a great extend upon the surface of the individual grains relative to the surface of particles in which they are contained. And it is this reaction which can be accelerated due to the grinding [3, 5].

Kiattikomol et al. [11] observed 5 Class F fly ashes from different sources and found that the fineness of fly ash, not the chemical composition, was the major factor affecting compressive strength of cement mortars [1].

Aydin et al. [1] in his research concluded beneficial effect of grinding process. In a case of steam cured mortars, up to 60 % replacement of fly ash shows higher compressive strength than control mortar.

Felekoglu et al. [5] in his study presented low early ages compressive strength and explains it that the early strength enhancement of increase in the fineness of fly ash due to grinding was suppressed by the increase in water/binder ratio for a constant workability. At later ages this behavior weakens by ongoing pozzolanic reaction. Unreacted fly ash particles can still contribute ro the properties of cement mortar very well. This may be due “micro-aggregate” effect. There is always an optimum value of fineness which results in the highest compressive strength. In Felekoglu study, the optimum fineness of fly ash which has maximized compressive strength values was 480 m^2/kg.

Jaturapitakkul et al. [7] in his research compared ground fly ash as a replacement of condensed silica fume. By grinding in ball mill was the median particle size reduced from about 100 μm to 3.8 μm. Results shows, that addition of 5% -15% of condensed silica fume can be replaced by 15-35 % of ground fly ash to get same compressive strength at curing ages after 60 days.

2.2.3. Influence on durability

Ground fly ash has higher reactivity, but it is one another advantages. Smaller particles can fill space between cement particles and make higher durability and resistance to external influences.

Chindaprasirt et al. [21] in his report brings results from investigation of influence of the fly ash fineness on the chloride penetration of concrete. In study was used classified fly ash, and it was investigated that the Coulomb charge of concrete at the age of 28 days is significantly reduced with the incorporation of fly ash and the decrease is promoted with an increase in fly ash fineness. This assumption could also be applied to ground fly ash.

Aydin et al. [1] studied effect of grinding process on alkali-silica reaction resistance of fly ash incorporated cement pastes. Original fly ash Blain fineness was 290 m^2/kg and was increased to 907 m^2/kg. The samples were prepared by replacing 20, 40 and 60 % with both coarse and fine fly ashes. Results show lower ASR expansion for samples with higher dosage of fly ash (above 20%). But the effect of fineness on ASR expansion was not shown.

3. Experiment

3.1. Separation by sieving

Recently published results [22] are summarized here. In total, five ash samples were selected from different sources. In four cases, ashes from conventional high temperature combustion were used; the fifth ash sample comes from fluidized bed boiler combustion. Conventional ashes come from the power stations Dětmarovice, Tušimice, Počerady, and Ledvice. The fluidized fly ash also comes from the Ledvice power station.

First of all, granulometry was assessed in respect of the ash samples. Based on the particle size distribution, a limit was set according to which fly ash samples were divided into two fractions: below 90 μm fraction and above 90 μm fraction.

The chemical analysis, X-ray diffraction analysis, and pozzolanic activity were determined for such separated fractions.

Diversity in chemical composition shows higher loss by ignition in the fractions above 90 µm. These fractions have higher content of SiO_2 and lower content of Al_2O_3, Fe_2O_3 and CaO in compare with fraction below 90 µm. XRD analysis shows significantly higher representation of amorphous phase in fraction below 90 µm. This fact corresponds with significantly higher pozzolanic activity of fraction below 90 µm.

3.2. Ball mill grinding

Experiment [23] with grinding in ball mill was focused on observation optimal specific surface area of fly ash for using in concrete. Fly ash produced in Počerady power plant with specific surface area 216 m^2/kg was ground in laboratory ball mill for 20, 38, 45, 60 and 75 minutes and was obtained Blain specific surface area 270, 345, 405, 460 and 520 m^2/kg. The main observing parameter was compressive strength. Fly ash accompanied concretes achieved compressive strength of the reference concrete in the age of 60 days. The highest compressive strength in age of 90 days obtains concrete made with fly ash which has specific surface area 405 m^2/kg.

3.3. Attrition mill grinding

For experiment [24] was used fly ash produced in Dětmarovice power plant. Fly ash was taken from Ljungströem air preheater which can also serves as primary separator. This fly ash is used just for non-construction parts of roads. This fly ash was activated by attrition mill in FF Service a.s. laboratory. For grinding were used five different grinding disks (HR, JR, KR, TR, VR). Grinding was done repeatedly and in few combinations. Designation and number of repeating ("grinding system") is in Table 1. Particle size distribution was presented previously [24]. Ground fly ashes were used for preparation cement-fly ash pastes, where 25% of cement was replaced by fly ash. Water/binder ratio was 0.5. Samples 20×20×100 mm were made from pastes. In age of 28 days was samples used for compressive strength determination. On Figure 2. is showed comparison of compressive strength of reference cement paste and cement-fly ash pastes.

Table 1. Sample identification and grinding systems.

sample	grinding system
700	2 HR
701	1 JR
703	1 HR + 1 KR
704	1 HR + 1 TR

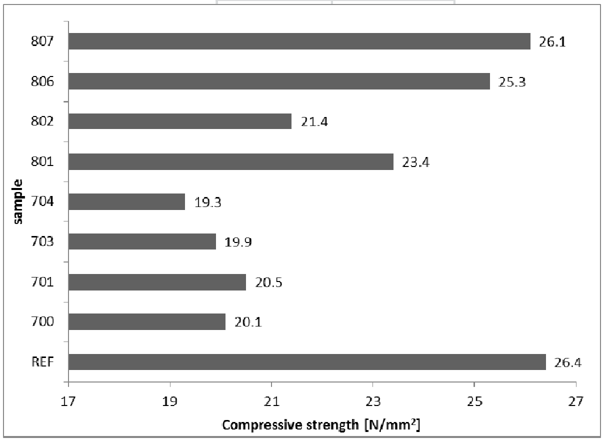

Fig. 2. Compressive strength of cement pastes (28 days).

According to Figure 2 can be told that considerable influence on fly ash properties has type of grinding disks than number of repeating cycles. Fly ash obtain from Ljungström air preheater can be used purely for non-construction application, however by activation it can get higher reactivity and can be used as partially replacement for cement.

4. Conclusion

In this paper are described several methods of mechanical activation of fly ash. Although sieving is much more cost effective in achieving small particle fly ash than grinding, the residue from the classification process still has to be disposed of. In some cases, coarse residue fraction of fly ash may be as high as 60-70%. Thanks to grinding we can eliminate this fact and activate residue after classification or whole mass of fly ash.

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