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Utilisation and Quality Management of Power Plant Fly Ash

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Abstract. Over the past decades, both the residential and industrial energy demand has increased due to the continuously growing consumption and production. As a large share of the electricity is still produced using fossil fuels, the utilisation of the by-products is a contemporary and pervasive issue. Fly ash is generated in large quantities in coal-fired power plants and has been proven to be an appropriate raw material for various industrial uses. Among others, it is applicable as an additive and lightweight aggregate in the cement and concrete industry, can be used for CO_2 sequestration, glass foam production, catalyst production, or as a base material for geopolymers, as well. Geopolymers are inorganic polymers produced via the reaction between solid alumina and silica containing or alkali silicate materials in alkali media. Due to their numerous advantageous properties and wide variety of utilisation possibilities, research on fly ash base geopolymers became widespread topic. The quality of fly ash is determined by technical requirements, and the degree of quality control requirements depends on the final use. In certain fields of applications, standards and regulations have already been created to ensure the consistent quality of the final products made from fly ash, e.g. in the cement and concrete industry. There are various methods for fly ash processing, however, the methods to achieve the necessary properties are not standardised.

Keywords: geopolymer, power plant fly ash, recycling, quality management

Introduction

As part of the continuous contemporary attempts for CO_2 emission reduction, many international organisations and countries emphasise not only the use of the best available technology in power plants, but the possibility of reduction and complete phase-out of coal in the upcoming years. After the decrease in coal consumption, a recurrent rise can be observed in the last few years due to the economic growth in Asian countries like China or India [1]. In the European Union, solid fuels take up 19% on average, as it is illustrated in Figure 1. However, the sources of energy production differ in the member states, with solid fuels being the main source of energy in Poland with 79%, Estonia with 73% and Greece with 61% share in the energy mix of each country [2].

In the coal-fired power plants, fly ash is separated from the flue gas using electrostatic precipitators, as a solid residue. The major components are SiO_2 and Al_2O_3, with other minor components being Fe_2O_3, TiO_2, CaO, MgO, K_2O, and Na_2O. Considering its morphology, fly ash is usually composed of mostly fine spherical particles, the median particle size ranging between 10 and 100 µm. Based on chemical composition, two types can be distinguished: class F ashes primarily consist of calcium alumino-silicate glass, quartz, tricalcium aluminate, and free lime (CaO), while class C fly ash is a high calcium fly ash, containing more than 20% CaO. However, the chemical composition and physical properties can vary significantly because of variations in the operation system of the power plant, the coal sources, and even due to the method and type of landfilling or storage [3, 4, 5].

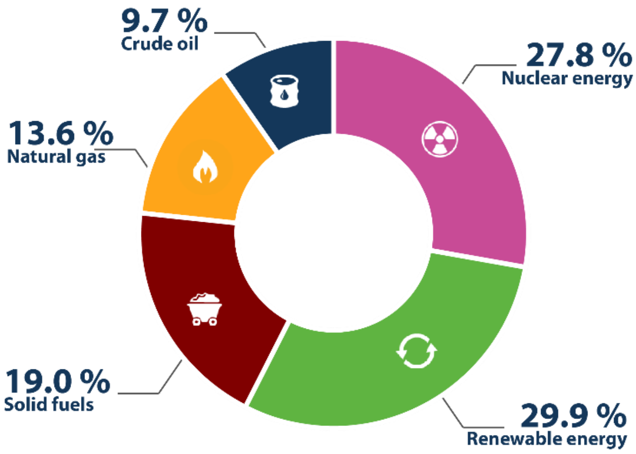

Figure 1. Energy production by source in the EU in 2017 [2]

In the article, the main utilisation methods are reviewed, along with some of the quality management methods and standards applied during the possible utilisations.

1. Fly ash utilisation

The generation of power plant fly is reported to be around 750 million tons per year worldwide. On a worldwide average, around 25% of the generated fly is utilised, for example for soil amendment, in the building industry, for the production of ceramics, catalysts, adsorbents etc., and concrete production takes up around 20% of this share [4]. In case of the European Union, India and the USA, the consumption of fly ash is higher than the worldwide average, with 90%, 60% and 50%, respectively [4]. With the use of fly ash with high fineness and low carbon, the water demand of concrete can be reduced, without changing the workability. The setting time of concrete can also be delayed with higher-calcium fly ashes, which results in longer curing time. If the necessary curing is provided, the long-term compressive strength of concrete can be improved, compared to Portland cement concrete [4, 6].

Another use of fly ash in the construction industry is the production of lightweight aggregate. Both class C and class F fly ash can be used as lightweight aggregate replacement, processed by milling, microwave radiation or sintering. Some of the advantages are the increased strength/weight ratio

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(because of the pozzolanic reaction of fly ash), improved thermal and sound insulation and fire resistance properties [7, 8].

Traditionally, fine-grained soils are not considered suitable for construction and are replaced with soil with better properties. However, using fly ash for the stabilisation of such soils provides not only a less expensive method, but the use of industrial by-product provides a more environmentally friendly solution. Some properties of fly ash stabilised soil that make the geotechnical application possible are:

- decrease in swelling shrinkage and plasticity potential,
- improved compressive and tensile strength,
- good performance on durability tests,
- decreased permeability,
- improved transfer properties [9, 10]

Fly ash can be used as an alternative source of feedstock for CO_2 sequestration, using the calcium oxide to be reacted with CO_2 to form stable carbonates. Its use is advantageous as it has low cost, high reactivity, and available near CO_2 emission sources. CO_2 can be captured with fly ash by adsorption and carbonation. In case of carbonation, temperature, pressure and H_2O are the key factors in the sequestration process. With optimised parameters, approximately 60 g CO_2/kg fly ash sequestration capacity can be achieved [11, 12].

Geopolymers are promising advanced materials with rapid worldwide development in the past years, that have the potential to substitute the traditional Portland cement and which can be used in various fields of industrial applications. Prepared via the reaction between solid alumina and silica containing or alkali silicate materials, such as metakaolin, fly ash, blast furnace slag or red mud, in alkali media, geopolymers have numerous advantages: good mechanical strength, acid and fire resistance, environmental sensitivity, low price and permeability in comparison with Portland cement [13, 14, 15].

Fly ash-based geopolymers prepared at room temperature have a practical significance for in-situ pouring for the cement and concrete industry, and results in energy reduction [15]. With the addition of lightweight aggregates, e.g. silica fume, pumice, expanded perlite etc., lightweight fly ash based geopolymer concrete can be produced, with reduced seismic risks, increased fire resistance and easier transportation [13, 16, 17]. Geopolymers have been proven to be adequate adsorbents for wastewater treatment. Fly-ash based geopolymers are suitable for the removal of anionic surfactant sodium dodecyl benzene sulfonate, copper ions and fecal coliforms as well [18, 19, 20]. Using fly ash based geopolymer as binder and expanded polystyrene, a composite insulating material (Figure 2) can be prepared. However, with increasing fly ash quantity, the resulting thermal conductivity increases, as well [21].

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Figure 2. A geopolimer-EPS composite specimen [21]

Other possible applications of fly ash include the production of fly ash foam glass as insulation material [22, 23], porous catalysts [4], hydraulic road binders [24] or proppant for oil and gas wells [25].

2. Quality management of fly ash utilisation

If some properties of fly ash are not appropriate (particle size distribution, specific surface area, reactive silica, high LOI or SO_3) for a given use, it can have negative effect on the final product. For this reason, many standards have been adopted to assure the performance of the products, containing the definitions and necessary properties of fly ash. For example, in case of the use in cement and concrete production, several standards have been created that define the chemical and physical requirements of fly ash to meet:

- EN 450-1 in Europe [26],
- ASTM C 618 in the USA [27],
- AZ/NZS 3582 in Australia and New Zealand [28],
- JIS 6201 in Japan [29],
- IS 3812-1 in India [30],
- GB/T 1596 in China [31],
- GOST 25818 in Russia [32],
- MSZ EN 450-1:2013 in Hungary [33].

For fly ash, some of the main properties that are determined in most standards are particle fineness, water demand, reactivity with lime or in mortars (activity index) setting time and the proportion of its main oxides (SiO_2, Al_2O_3 and Fe_2O_3) [1].

The possibility to use lower quality and deposited fly ash has become a widespread concept in the past years, which can be a challenging task due to the poor reactivity or the changes in the mineralogy and microstructure of the fly ash [34]. Considering that particle fineness and reactivity are important factors determining the applicability of fly ash, various methods have been tested to modify these properties, making the utilisation of fly ash more feasible. Increased proportion of coarse particle can

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decrease the reactivity of fly ash. Thus, to achieve the necessary particle size range determined in the given standard, screening, air classification or grinding of the base material can be used [5].

Screening is the simplest approach for fly-ash processing which can enhance reactivity by separating the coarse particles and foreign matters. The effect of screening can be observed in Figure 3. For dry screening, 45 and 63 μm sieves are the most commonly used, and still economical sieve sizes [5, 35]. Air classification provides particle separation size and density and may be performed for the removal of coarse particles or for the selective concentration of finer particle size. Via particle size control methods, the unburned carbon content of the fly ash can be decreased, too, the high quantity of which may also hinder fly ash utilisation. Other methods for unburned coal separation can be gravity and electrostatic separation, froth flotation and oil agglomeration [5, 35, 36, 37].

Figure 3. Images of raw (left), and sieved < 600 μm (centre) and < 63 μm (right) fly ash samples [36]

Grinding provides a method to reduce particle size and increase specific surface area, and it is a commonly used technique in the cement industry. During grinding, many operating and machine parameters (mill velocity, grinding media size, material, …) should be optimised to achieve the desired results in fly ash fineness. Most applications and researches focused on ball milling of fly ash, as during grinding, micro and even nano crystalline particles can be produced with a simple and comparatively inexpensive grinding technique [35, 38].

In case of geopolymer production, the mechanical activation of fly ash via grinding is also a crucial issue, as grinding in different types of mills can result in geopolymers with different mechanical and structural properties. Furthermore, the determination of optimal grinding time is also necessary for geopolymer production, as exceeding the optimum results in decreased compressive strength. The agglomeration of particles and/or decrease in surface area due to excessive grinding time has been observed, negatively affecting the mechanical properties [39, 40].

However, depending on the type of fly ash used, the processing may be two-fold, using the combination of initial separation and then grinding to get the highest amount and quality base material [38].

Summary

As part of the growing population and consumer demand, the utilisation of wastes and by-products can be a crucial issue in the near future. This issue has been realised by several industrial fields, and the use of industrial by-products, such as fly ash has become more and more widespread. Taking

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advantage of its beneficial properties, various construction materials and additives, catalysts, soil supplementary materials, and even environmentally friendly materials can be produced from fly ash. Because of the variable chemical and physical properties of fly ashes, many standards have been created to assure the quality of the final products, which properties can be achieved via different processes.

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