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THE USE OF FLY ASH: ENHANCING PERFORMANCE IN BUILDING MATERIALS

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Abstract: In this paper there is presented a review of the use of fly ash. Fly ash, a widespread environmental hazard, is harmful when discarded. However, recycling it brings many benefits. Adding fly ash to concrete not only strengthens structures but also lessens environmental impact. This process reduces the carbon footprint of concrete, making construction more eco-friendly. Embracing such practices is essential for sustainable building and a greener planet.

Keywords: fly ash, building materials, eco-friendly, environmental protection

1. INTRODUCTION

In recent years, the construction industry has been changing the way it builds, with a focus on eco-friendly practices. One noteworthy innovation gaining attention is the integration of fly ash as a substitute for cement in concrete production. Fly ash is a byproduct of coal combustion in power plants that is proving to be a valuable alternative that addresses waste management concerns and contributes to a more sustainable construction ecosystem. While fly ash offers various benefits, it is important to acknowledge the negative impact it has to the environment when it is deposited. In Figure 1 there are illustrated the various impacts on environment and life of fly ash.

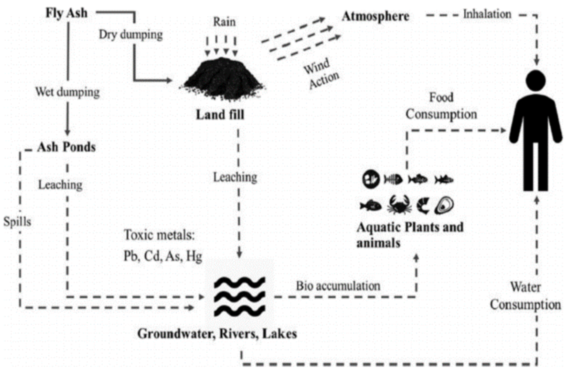

Figure 1. Various impacts of fly ash on the environment [1]

Nevertheless, the current volume of recycled fly ash remains lower that its production, with a reuse rate limited to a maximum of 30% [2].

Fly ash is a fine powder with particles like a spherical shape that is highly practical and useful, even though it is considered a waste product. It is generated from the combustion of coal in power plants. When coal burns at around 1600 ^{o}C, non-combustible minerals transform into a liquid state in the firebox, rapidly cooling and shaping into glassy structured spherical ash particles. Fig. 2 shows a typical layout of a coal-burning generating station.

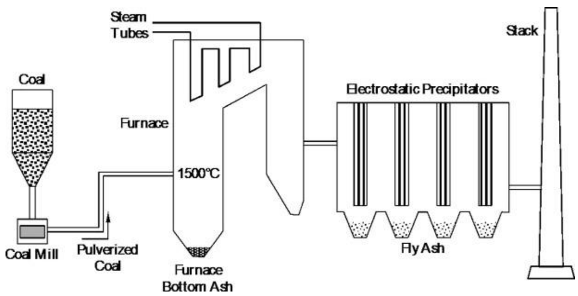

Figure 2. A diagram illustrating the structure of an electricity-generating station powered by coal [3]

The properties of these particles are influences by various factors. Multiple engineering applications make use of it and it is one of the most commonly used artificial pozzolans in the production of building materials [2], [4], [5].

2. PROPERTIES OF FLY ASH

2.1. Physical properties

Physical properties help in classifying the fly ash for engineering purposes.

Some of the influencing parameters of fresh mixed, unhardened and strength development of hardened concrete are the color, density, shape, size and particle size distribution of fly ash.

Color of fly ash is influenced by coal source, carbon content, iron content and burning conditions. The color varies from brown to gray [5].

Anthracite and bituminous coal and contain higher carbon residue resulting a dark brown color fly ash powder whereas lignite and sub-bituminous coal contains less carbon residue, revealing a gray color [1].

Fly ash powder contains spherical, rounded particles and a limited number of angular, irregularly shaped, bigger in size, with size range between 0.5-200 μm. Based on the type of deposition on the surface,

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particles can be rough or smooth. Images from Figure 3 reveal its spongy appearance in nature [1,6].

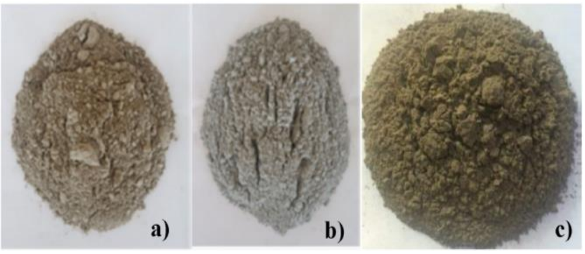

Figure 3. a) cement b) gray fly ash c) burned fly ash [6]

In Figure 4 are showed the SEM images for cement and fly ash, displaying the spherical shape of fly ash.

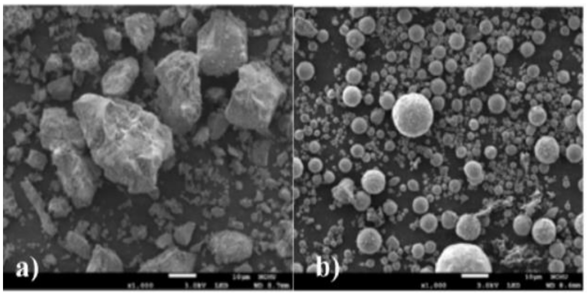

Figure 4. SEM image of a) cement b) fly ash [6]

2.2. Chemical properties

Fly ash can be classified as an amorphous ferro-aluminosilicate mineral.

The surface of fly ash particles contains amorphous iron oxides, aluminium oxides and manganese oxides, serving as a sink that adsorbs trace elements [7].

The chemical and mineralogical composition of fly ash is diverse depending on the coal nature, the type of burning and the type of emission control devices.

The place from which the coal originates influences the content of metal oxides.

The main constituents of coal fly ash powder are Si, Al, Fe, Ca, along with minor constituents such as Na, Mg, Ti, Zn, Cd, B, Ni, P, K, S, etc. [1].

According to ASTM standard, fly ash is classified into two classes: class F and class C, as illustrated in Figure 5.

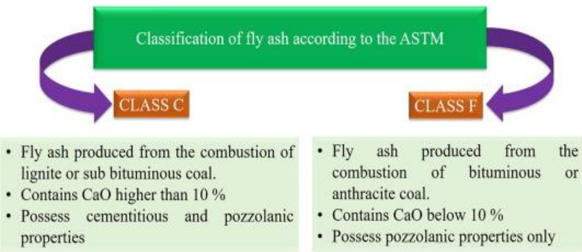

Figure 5. Fly ash classification according to ASTM illustrating the main differences [8]

Class C fly ash refers to coal fly ash powder which is derived from lignite and sub-bituminous coals with a percentage of calcium (Ca) greater than 15%.

Class F refers to coal fly ash powder which is derived from anthracite and bituminous coals with a percentage of calcium (Ca) lesser than 5%.

In application, class F has high fly ash content concrete mixes and is recommended for the structural and HP concretes. On the other hand, class C fly ash is suitable for residential construction.

The sum of the SiO_2, Al_2O_3, and Fe_2O_3 contents for class C fly ash must be between 50% and 70%, while for class F fly ash must be more than 70%. The content of calcium oxide (CaO) in class C fly ash should surpass 18% but for class F fly ash should be lower than 18% [6].

The fly ash with a high amount of calcium is usually produced from combusting of low-rank coals and has more cementitious properties than class F fly ash, for this reason the concrete produced by class C fly ash has a better early strength than normal concrete [6].

Based on formation time, fly ash is classified into 3 categories: primary, secondary and tertiary phases. The first phase undergoes no change. Secondary phases including the silicate and oxides are formed in the course of combustion of coal. Through the transport of fly ash comprising portlandite and gypsum, the tertiary phases are created [8].

3. UTILIZATION

Recycling coal fly ash is a good alternative to disposal and has important economic and environmental benefits [9].

Fly ash has found applications in fields of construction, fertilizers, landfills, geopolymers and metallurgy [10].

3.1. Concrete industry

The construction industry is focusing on developing building materials with better mechanical, durability, and environmental characteristics [11, 3].

As one of the most extensively used building materials globally, concrete is a key focus [12].

Fly ash, commonly used in cement as a substitute or additive, is part of efforts to create more environmentally friendly and high-performance construction materials [13].

Concrete consumption has a serious environmental impact. For every mass of Portland cement produced resulted an approximately equal carbon dioxide emission [14].

The use of good quality fly ash reduces the water demand of concrete compared to a Portland cement concrete of the same workability and increases ultimate strength [3].

Concrete production and consumption have a big impact on the environment, leading to an unsustainable industry. It is important for the concrete business to find ways to be more environmentally friendly. One way is by using waste materials [13].

Fly ash can improve the compressive strength, segregation of concrete and durability properties.

Fly ash class C has cementitious (high CaO content) and pozzolanic properties but fly ash class F has only pozzolanic properties. The fly ash pozzolanic properties render it beneficial for the replacement of cement [8].

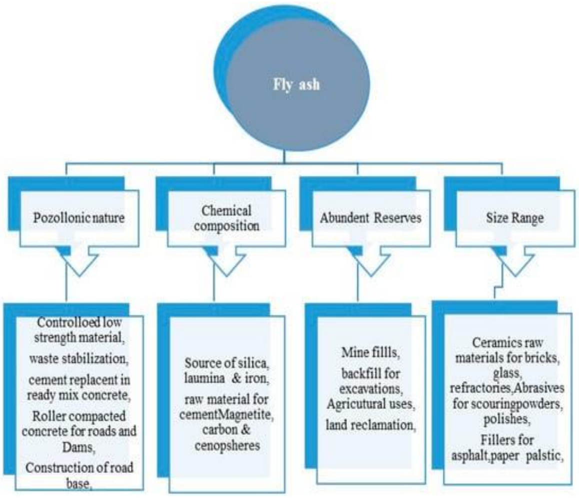

Fig. 4 Diverse fields where fly ash finds applications [10]

The reaction of the fly ash silica with calcium hydroxide released by CaO hydration result in Ca_2SiO_4 hydrate [8].

By adding fly ash in the binder, it results an improved workability, a reduced hydration heat and hence, the concrete cracking risk in the early stages [8].

Fly ash can improve the long-term concrete durability by reducing the ingress of aggressive agents, for example Cl^-. Also, the production costs can be reduced by the partial replacement of cement with fly ash [8].

Setting time of fly ash concrete is influenced by the characteristics and amount of fly ash used in concrete [3].

3.2. Mortar industry

Supplementary cementitious materials are an important part of the concrete industry, providing benefits such as better mechanical performance, increased durability, reduced energy consumption and lower greenhouse gas emissions [15].

Fly ash is used to cement mortar and concrete mixtures to enhance workability, reduce hydration heat, strengthen resistance to sulphate assaults, increase weather resistance and boosts later age strength. These advantages are attributed to the pozzolanic reaction between fly ash and Portland cement, leading to the creation of additional calcium silicate hydrate (C-S-H), decreased porosity and improved resistance to mass transport in concrete [5, 15].

Incorporating fly ash with Portland cement raises the volume of cementitious materials in comparison to typical concrete. Consequently, the paste volume increases, reducing interference among aggregate particles and enhancing the workability of the concrete [16].

3.3. Other applications

Fly ash utilization or recycling can be one of the solutions to the disposal issue, which can also save the environment.

Fly ash holds significant importance and presents numerous advantages, whether in its bulk form or as distinct natural nanostructured particles, as illustrated in Figure 4 [10].

3.3.1. Soil system

Fly ash proves valuable in revitalizing degraded soil when paired with organic amendments like compost. This combination minimizes heavy metal availability, eliminates pathogens, and enhances soil texture, nutrients and biological activity. Unlike traditional soil ameliorants such as dolomite and lime, fly ash offers favourable properties like high water retention and essential nutrients, promoting better soil health. Fly ash reduces CO_2 emissions compared to lime production, aligning with environmental concerns. Overall, incorporating fly ash into soil management offers a sustainable solution, enhancing soil quality, aeration, and nutrient content while minimizing environmental impact [8].

3.3.2. Ceramic industry

Fly ash, enriched with metal oxides such as Al_2O_3, SiO_2, Fe_2O_3, and CaO, proves to be a cost-effective resource for the ceramic industry. Its fine powdery structure allows direct incorporation into ceramic pastes without extensive pretreatment. Researchers have explored the production of stirred materials and glass-ceramics from fly ash, activating its war form at varying temperatures. Glass-ceramic materials based on ternary systems like Al_2O_3, Li_2O and Si_2O find industrial applications due to their advantageous negative and low thermal expansion coefficients. While traditionally expensive high-grade reagents have been used, recent developments utilize coal bottom ash and fly ash as precursors, achieving comparable thermal expansion coefficients at reduces costs [8].

3.3.3. Synthesis of zeolites

Zeolite synthesis using fly ash is gaining attention due to its similarity in composition to volcanic materials, which are natural zeolite precursors. The process involves alkaline hydrothermal crystallization, with three main steps: dissolution, condensation and crystallization. Despite challenges posed by inert quartz and mullite in ash, alkali hydrothermal reactions have been effective, particularly with $LiOH \cdot H_2O$ solution, which acts as a powerful activator. The concentration of alkaline solution influences the content of zeolite ABW type phases. Recent improvements include advanced treatments like alkaline fusion, hydrothermal treatment, and sometimes microwave-assisted synthesis. Notably, Na-X zeolite from coal fly ash is produced by fusing Li-ABW, is created through alkaline fusion followed by hydrothermal treatment in a $LiOH \cdot H_2O$ medium. These developments signify a promising direction for optimizing zeolite synthesis from fly ash, offering potential applications in various industries [8].

3.3.1. Water treatment

The increasing need for clean water, driven by groundwater and industrial pollution, has led to a focus on sustainable solutions. Recycling fly ash waste emerges as a cost-effective method for water treatment. Fly ash is affordable and effective in treating domestic wastewater, adsorbing organic compounds and toxic metals. The concern for public health regarding toxic heavy metals in wastewater is addressed through fly ash alkaline pH. Modified fly ash, transformed into zeolites, exhibits enhanced capabilities in removing pollutants. The innovative application of fly ash in membrane filters offers a promising solution for large-scale, efficient and environmentally friendly effluent treatment [8].

4. CONCLUSION

The utilization of fly ash in concrete production offers multiple benefits, making it a compelling alternative to traditional cement. Environmentally, the incorporation of fly ash minimizes cement consumption, reduction the overall carbon footprint of concrete production. Economically, this waste products proves valuable, promoting sustainability in the construction industry.

Fly ash enhances concrete workability, it contributes to water reduction, positively impacting workability without compromising performance.

Concrete properties, including strength, durability and microstructure, are positively influenced by fly ash. The refined pore structure leads to increased density, contributing to improved strength and durability over curing time. Fly ash also influences concrete strength, water permeability and carbonation.

Notably, fly ash reduces the risk of alkali-silica reaction, making it more resistant. Fly ash concrete performs effectively at higher temperature.

In conclusion, fly ash is a versatile and eco-friendly solution with diverse applications. It enhances concrete properties, reduces environmental impact in construction, and proves effective in water treatment. Fly ash also contributes to soil improvement and offers cost-effective options in ceramic industry. Zeolite synthesis from fly ash is a promising eco-friendly practice.

In essence, fly ash stands out as a valuable resource, promoting sustainability across various sectors.

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