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Utilization of Fly Ash in Construction

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Utilization of Fly Ash in Construction

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Abstract. In year 2016, Malaysia produce about 6.8 million tonnes of fly ash from six coal fired electric power station and this figure will increase due high demand of electric production. Fly ash is a waste product from the combustion of pulverized coal in electricity power plants and considered as a contributing factor for air, water and soil pollution that lead to human health problems and various geo-environmental issue. However, fly ash can be converted into valuable and useful product if properly utilized and many researches has been carried out in aim to increase the utilization of fly ash in various sectors especially in construction sector. In line with current economic conditions, all construction works required cost efficient with good quality of work. Therefore, fly ash is suitable to be used as an alternative raw material to enhance or replacing the existing construction material. In produce construction material many different industries and construction because it is oxide-rich material. The paper will be discussing the potential of managing waste of fly ash by utilizing it as construction materials.

1. Introduction

These days, concrete has become main building material with more than 10 billion tons produced annually in construction industry [1][2]. The important characters of concrete compare to other materials are excellent strength, easy to molded in any form, an engineered material that can meet almost any desired specification, adaptable, quite incombustible, afford- able, and easily obtained. Higher demand for construction materials has been rising to sustain the fast-growing global population. As a result, there is continual depletion of raw materials and natural sources and leading to increase the construction material cost. To this effect, engineers are faced with the challenge of resolving this potential sustainability problem [3].

The current global trends are focused on recovery of usable materials from waste as well as utilization of waste as raw materials whenever feasible in construction. Fly ash is a waste product from the combustion of pulverized coal in electricity power plants that faces an increasing production required large area for disposal. In year 2016, Malaysia produce about 6.8 million tonnes of fly ash [4]. The fly ash is deposited either in a dry landfill over a vast area of land which is not possible in urban areas or deposited in an ash pond which also has its shortcomings [5]. Dispose tonnes of waste in without any treatment would cause land pollution, water pollution, air pollution as well as destruction to flora and fauna. [6]. Fly ash has been successfully used in concrete industry since over 50 years but its application is still limited due to lack of understanding of the characteristics of fly ash itself and the properties of concrete containing fly ash [2][7].

2. Fly Ash Generation and Environmental Issue

Fly ash can be defined as a waste residue that is released from coal combustion process in electric power stations [8-15]. Fly ash is the unburned residue that is carried away from the burning zone in the boiler by the flue gases and then collected by either mechanical or electrostatic separators [4][16][17]. Malaysia started the development of coal-fired electric power station in year 1987 and currently there are six coal fired electric power station in Malaysia [18-20]. Those electric power station produce about 6.8 million tonnes of fly ash [4]. According to statistics, fly ash rate of production is clearly far outweighs consumption due to increased amounts of energy being generated by coal-fired power plants and widely available across the globe as shown in Table 1 [17][21].

Table 1. Fly ash production in different countries [22].

Country	Amount of Production (million tons/year)	Country	Amount of Production (million tons/year)
India	112	Malaysia	6.8
China	100	Canada	6
USA	75	France	3
Germany	40	Denmark	2
UK	15	Italy	2
Australia	10	Netherland	2

Fly ash contains silica, alumina, ferric oxide and other oxides material that might turn fly ash into hazardous material. These hazardous material is contributing factor in air, water and soil pollution that lead to human health problems and various geo-environmental issue [23-28]. These bad situations will interrupt the entire ecological cycles if not properly disposed [14][25][26], therefore good waste management practice needed to sustain a healthy environment [20]. Fly ash emissions from coal combustion units show a wide range of composition with present of elements below atomic number 92 and considered as major source of air pollution. The ultrafine particle of fly ash will behave like cumulative poisons after remain for long periods of time when reaches the respiratory region [13][28]. As a result, several physiological disorders and other related health problems such as respiratory problem, cancer, anaemia, hepatic disorder, gastroenteritis and dermatitis will arise [13][23]. Several studies on the present ground showed that wet disposal of this waste causes migration of metal into the soil [29]. The populations located near the fly ash dumping area facing surface water pollution and underground water pollution. However, the surface water pollution is more critical than the underground water pollution. The surface water pollution decreases the fish population and other aquatic organisms due to heavy metal material and organic matter content contained in the water. The surface water contamination also causes skin diseases, diarrhoea and death due to bathing and drinking of water from the contamination river [23].

2.1. Properties of Fly Ash

Physical and chemical characteristics of fly ash is important, as these characteristics influence its subsequent use and disposal [11][30]. Those characteristics of fly ash is depend on the type of coal used, the combustion condition and temperature at which the coal was fired, the collector setup, the air fuel ratio and other factors [11][17][25][31]. Few generalizations were made in particle size distribution, morphology, surface area, hydraulic conductivity or permeability and density of the fly ash [32]. Fly ash consists of predominantly fine particles ranging from grey to tan to reddish brown [33] with an average size of particles is 20μm and the bulk density ranging from 0.54g/cm^3 to 0.86 g/cm^3 [1][11][34][35]. 70% to 90% of the particle were solid glassy spheres, while the balance containing Quartz, Mullite, Hematite and Magnetite and a small portion of unburned Carbon as shown in Figure 1 [11][20][36].

American Society for Testing and Materials (C618 − 12a), classifies fly ash into two classes, Class C and Class F [30][32][37]. Typically fly ash contains significant amount of Silicon Dioxide (SiO_2), Aluminium Oxide (Al_2O_3) and Calcium Oxide (CaO) [38] and the class divides based on its chemical composition and source of origin [16]. Class F fly ash produced by burning anthracite or bituminous coal and only has pozzolanic properties while Class C fly ash produced by burning lignite or sub-bituminous coal and has both pozzolanic and cementitious properties [39]. The main difference between these two classes is the amount of calcium, silica, alumina, and iron content. Class F fly ash, contains less than 10% CaO and minimum SiO_2 +Al_2O^3 +Fe_2O_3 content of 70%, whereas Class C fly ash, contains more than 20% CaO and minimum SiO_2 +Al_2O_3 +Fe_2O_3 content of 50% [16].

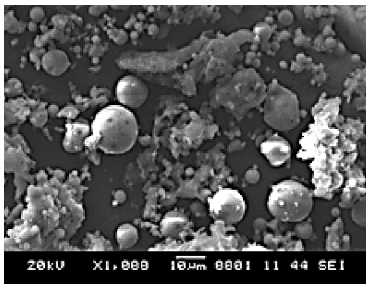

Figure 1. Morphology of Fly Ash [20].

3. Utilization of Fly Ash

In last 30 years, many researches has been carry out in aim to increase the utilization of fly ash in various sectors since it is not considered as hazardous waste [13][28]. Figure 2 shows many countries across the globe utilize this residue waste and turn it into useful product as an alternative to another industrial resource, process or application [21][31]. The utilization of fly ash can be categorized into three classes of application, low, medium and high technology application [17].

Fly ash suitable to be used as raw material in many different industries and construction because it is oxide-rich material [28]. Currently, the fly ash was successfully use in improving the construction material and excellent to be used in agriculture sector to enhance the soil properties too [13]. The fly ash also can be utilized in brick manufacturing, ceramics manufacturing, road construction, concrete production and other activities as shown in Figure 3. The most important areas of fly ash utilization is a concrete production [40], either in conventional concrete or geopolymer concrete. Many researches have been done to find use of fly ash in cement, concrete, and other cementitious composites.

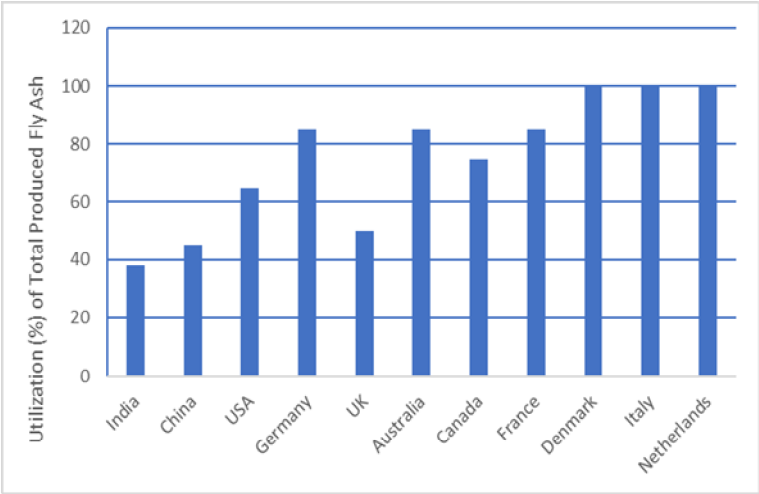

Figure 2. Utilization Percentage of Total Produced Fly Ash in different countries [22].

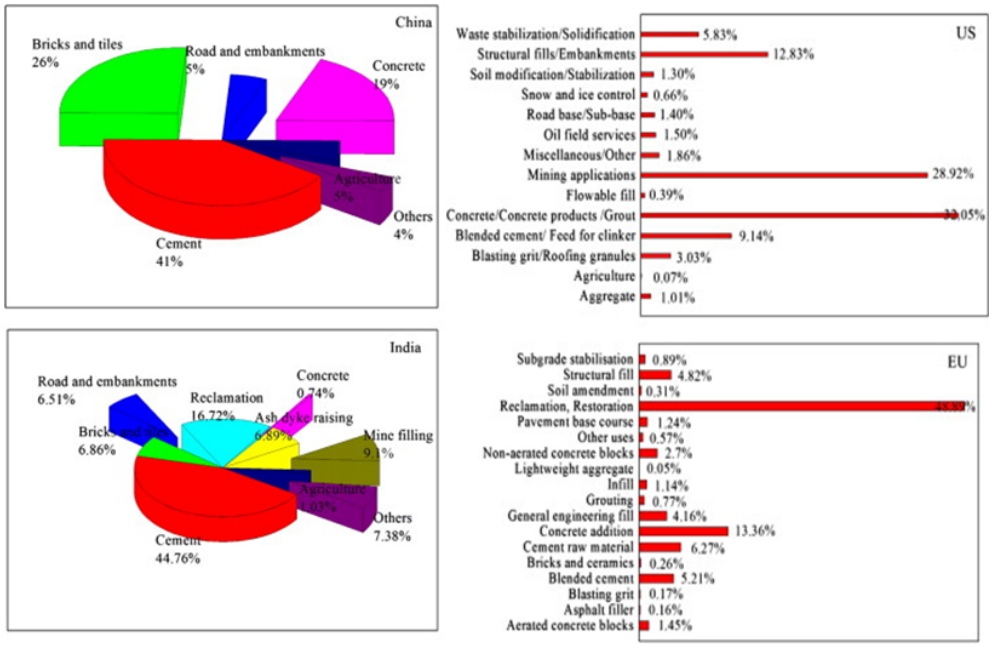

Figure 3. Fly Ash Utilization in China, India, US and EU [11].

3.1. Utilization of Fly Ash in Building Construction

The utilization of fly ash in the construction industry is not a new technology but it is a growing technology in improving the construction quality as well as the environment quality. Adding fly ash in concrete give benefits in term of economical, ecological and technical [2][41-43]. Currently, fly ash used by cement industries as a pozzolanic material for manufacturing of Portland Pozzolana Cement since the SiO_2 and Al_2SiO_3 content is very similar to Portland Cement [27]. In the presence of moisture and at room temperature, it reacts chemically with calcium hydroxide to derive compounds possessing cementitious properties [20][44]. Technically, the use of fly ash together with Portland cement contributes to the consumption of $Ca(OH)_2$ which is formed during the hydration of cement and leads to the formation of cementitious products [42][45]. The glassy phase of fly ash and calcium hydroxide generated leads to the formation of additional C±S±H gel and results in higher density and strength [43]. The compressive strength increased at later ages compared to the early ages [45]. This green technology enhances the durability and service life of concrete structures [17][46].

Fly ash can be used as a partially cement replacement by cement weight or as an admixture to the concrete mix [32]. The utilization fly ash as a component of blended cement can save a significant amount of energy and cost in cement manufacturing [17][36]. The cement replacement using fly ash can be up to 75% of cement weight, however there are strict standards governing its use such as the American Society for Testing Materials ASTM C 618 and European Standard EN 450-1[35]. The new cement alternative in the field of building and construction materials is geopolymer concrete with fly ash [47][48]. This concrete mixture produced a concrete with high compressive strength, low creep, good acid resistance and low shrinkage [20].

Normally fly ash was used in blended cement to product insitu concrete mix however fly ash also can be used in high strength precast and prestressed concrete. Having slow strength development at early age, the use of fly ash in high strength precast and prestressed concrete has been limited. Somehow, current studies have validated that superplasticized fly ash concrete with low water-to-cement ratio can be proportioned to meet the very early age strength as well as other requirements for precast or prestressed concrete products [17].

Significant research about an artificial lightweight aggregate has been carried out using fly ash to replace normal aggregates [49][50]. Fly ash can be used in manufacturing of light-weight aggregates

by using sintered (fired) and unfired (cold bonded) processing methods [51-53]. This aggregates are light due to the presence of air voids [24] and used in structural lightweight concrete to reduce the dead load of a concrete structure and leads to the economic savings in terms of structural design [17][36][38][54].

3.2. Utilization of Fly Ash in Road and Embankment Construction

Utilization fly ash in road and embankment construction has many advantages compared with the conventional method. Saves top soil which otherwise is conventionally used, avoids creation of low lying areas (by excavation of soil to be used for construction of embankments) [54]. Fly Ash may be used in road construction for filling purposes, stabilizing and constructing sub base or base [13][17] [20][28][55].

Embankment can be constructed using fly ash as fill material. However, the graters concern using fly ash as a fill is the potential of leachate and an associated contamination to the ground water. There are several techniques such as a site grading, compaction, and surface water control, that can be used to prevent leachate from happen [32]. The well-compacted fly ash shows good shear strength comparable to normal soils used in earth-fill operation. Fly ash also has good permeability and even moisture-density curve therefore, it's become desirable material use for embankment construction, backfilling and land development works[36].

Fly ash alone or in combination with lime, is used to stabilize the subgrade in order to reduce plasticity, enhance strength, and improve workability of weak soils [17]. Soil mixed with fly ash and lime will increases California Bearing Ratio (CBR), increased (84.6%) on addition of only fly ash to soil [13][55]. For construction of base and subbase courses for pavements, fly ash is used either with lime or portland cement, and aggregate [17]. Concrete containing large amounts of fly ash can be proportioned to meet strength and durability requirements for road paving work. The 50% fly ash Class C mixture provides an excellent alternative for paving even though this mixture gained strength more slowly at the beginning [56].

3.3. Utilization of Fly Ash in Masonry Work and Other Application

Fly ash can be utilized in manufacture of the fired, unfired, and steam cured bricks and become top 3 among the sector of utilization [11]. Fly ash bricks have a number of advantages over the conventional burnt clay bricks [24][27][35][57][58]. 40% to 70% fly ash can be used in brick production and the fly ash brick is technically acceptable, economically viable and environment friendly [13]. Blocks and paving stones can also be manufactured by adding appropriate amount of coarse aggregate to the mixture [17].

Fly ash pipes are more watertight and more resistant to weak acids and sulphates attack relative to ordinary cement concrete pipes. Fly ash also used in manufacture high-flexural strength ceramics. These include railroad ties, electric line insulators, fence posts and others suitable application [17].

4. Conclusion

Fly ash is waste residue that is released from coal combustion process in electric power station and it can cause air, water and soil pollution if not treated will properly method and procedure. Luckily, this waste residue can be turn into valuable material when properly utilized in various sectors. Generally, fly ash will to be utilized in construction industries to enhance the existing construction material because of its pozzolanic property. The utilization of fly ash gives benefits in term of economical, ecological and technical aspects. However, further study needs to be done on recovery of products from fly ashes with a wide range of characteristics.

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