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GREEN CONSTRUCTION MATERIAL – BANGLADESH PERSPECTIVE

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Abstract- *The use of fly ash in concrete construction have become of increasing importance because of not only its ability to improve the fresh and hardened properties of concrete but also its environmental credentials. This study aimed to explore the possibility of using fly ash in concrete construction produced from the only coal based power plant in Barapukuria, Bangladesh. Initial characterization tests of samples collected during summer 2010 and winter 2011 showed promising results and met international standard (ASTM and European standard, EN) criteria for using them in concrete construction. However, the particle size of the summer fly ash did not meet either of the standards criteria and the winter one was found coarser than fly ashes generally used in concrete construction in the Europe and USA. It is recommended that processing the fly ash by particle size classification will help to produce a valuable supplementary cementitious material and will contribute to the sustainable development of the country.*

Keywords: Barapukuria power plant, Fly ash, Concrete construction, Particle size, Classification

1. INTRODUCTION

Sustainability issue in construction sector came forward in last two decades due to concerns regarding using virgin materials as well as emission of greenhouse gases from production of raw materials (e.g. cement). Next to water, concrete is the most consumed material over the world. A statistics [1] stated that on an average 3 tons of concrete per capita per year was required. Cement is the prime product of concrete and requires energy to produce. At the same time cement industry contributes approximately 5% of global man made CO_2 production. On an average 9 kg of CO_2 is produced for every 10 kg cement production. Furthermore, 50% of this CO_2 produced from chemical process involved in making clinker, 40% from burning fossil fuel and the rest 10% account for electricity and transport purpose [1].

Being emission a key issue to attain sustainability in construction industry, supplementary cementitious materials (SCM) are gaining interest. Numerous researches have shown potential of using SCMs for instance fly ash from coal combustion, Ground Granulated Blast Furnace Slag (GBBS) from iron industry, Silica fume and Metakaolin [2]. These SCMs provide dual benefits in concrete construction. Those not only cut the emission in material production but also improve several properties of fresh and hardened concrete, for example, workability, water demand, permeability and finally durability.

Fly ash is a by-product produced from pulverized coal combustion in power generation and formed from the non-combustible minerals found in coal. In 2004 approximately 40% of the total produced fly ash (71 million tons) in the USA was used in different applications, of which 59% was utilized in the cement and concrete industry [4]. In the EU the use of produced fly ash in various applications was 47% of the 44 million tons generated in 2003. Here, proportion of fly ash used in cement and concrete construction was somewhat higher than the U.S. (71%) [5]. In 2006, two units of 125 MW coal based power plant has started generation in Barapukuria, Bangladesh. The power sector, as master plan of Bangladesh power ministry projects a high growth in coal based power generation in near future. However, due to lack in knowledge on fly ash properties there is no strategy plan for usage of the fly ash generated as by-product of the system.

This study evaluates basic characteristics of fly ashes produced from coal based power generation in Barapukuria, Bangladesh. It will also provide recommendations to make the fly ash useable in sustainable concrete construction in the country.

2. COAL BASED POWER GENERATION

As per U.S. Department of Energy (2006) more than one fourth of power generated worldwide is coal based. However, as of July 2011 Bangladesh is producing only 250 MW (3.66% of total production) power from the only coal based power plant in Barapukuria, Dinajpur [3]. A total of 303 million tonnes of high quality minable coal has been estimated in the Barapukuria-Phulbari basin in six horizons [6]. According to Barapukuria Coal Mining Company Limited (BCMCL) and Overseas

Development Administration (ODA), UK [6], the characteristics of coal are shown in Table 1.

Table 1: Characteristics of Barapukuria-Phulbari coal [7]

Rank	Bituminous (high volatile)
Proximate analysis	
Moisture	10%
Ash	9%
Fixed carbon	51%
Volatile matter	30%
Ultimate analysis	
C	77.35%
H	4.95%
N	2.30%
S	0.53%
Cl	0.01%
Calorific value	25.68 MJ/KG
Hardgrove Grindability Index (HGI)	43-72% (mean 53%)

The coal has high heating value, low sulfur and ash content which indicate that it is an ideal fuel for power generation, cement production and other industrial use. Currently 1 million ton of coal is being produced per annum from this mine of which 65% is being supplied to the 250 MW thermal power plants and other 35% is being used in brick field and other domestic industries. At present, on an average 65 thousand tons of fly ash is being produced from those thermal power plants (considering 10% ash content).

As mentioned earlier the government plans to boost the coal based power generation dramatically in near future, there would be real concern about the management of huge quantity of fly ash produced from these coal based power plant. Commercial use of fly ash in various construction works includes, as SCM in concrete construction, sub-base course in highway construction and grout applications. To apply the produced ashes in different applications the following steps are necessary:

a) Check whether the ash meets current international standard (s);
b) Adopt and apply necessary treatment facility to make it useable for various application; and
c) Formulation of national standard specification for fly ash use in different applications.

3. CHARACTERIZATION OF FLY ASH

For a pilot study two run-of-station fly ashes has been collected from the Barapukuria thermal power plant during different seasons of a year. Analysis and discussion of various characteristics will be provided in the following sections.

3.1 Chemical properties

Chemical analysis of the fly ashes were conducted using X-ray fluorescence (XRF) and shown in Table 2. The table also compares with results obtained by Wardell Armstrong [8]. It is confirmed that the fly ashes produced in Barapukuria is a low calcium fly ash (<10% by mass). The SiO_2 and Al_2O_3 content of fly ashes varied significantly over 6 month period and also distinguished from that reported by Wardell Armstrong [8]. However the sum of major oxides (SiO_2+Al_2O_3+Fe_2O_3) was found to be higher than 70% by mass in all cases as required by the European standard EN 450 [9].

Table 2: Oxide analysis of Barapukuria plant fly ash.

Oxides in percentage	Summer (Jul 2010)	Winter (Jan 2011)	Wardell Armstrong [8]
CaO	1.08	0.65	0.56
SiO_2	59.22	51.49	54.40
Al_2O_3	25.61	31.60	35.60
Fe_2O_3	2.90	2.80	2.90
MgO	0.27	0.28	0.18
MnO	0.03	0.03	0.11
TiO_2	2.23	3.13	3.20
K_2O	0.91	0.87	0.66
Na_2O	0.21	0.18	0.06
P_2O_5	0.61	0.56	0.46
Cl	-	-	-
SO_3	0.32	0.19	0.13

\- Not detected/supplied

No traces of chloride were found in any of fly ashes which seems promising in connection with durability of concrete produced from this fly ashes. SO_3 content was found far below the limiting value specified in the EN standard (<3% by mass). MgO and P_2O_5 were also meeting the criteria specified in European standard [9]. Overall both of the fly ashes reported here satisfied the requirements (for using in concrete construction) as specified in European standard EN 450 [9].

3.2 Physical properties

Physical properties of fly ashes are compiled in Table 3. Loss-on-ignition (LOI) and 45 µm sieve residue tests were carried out in accordance with the relevant standards EN 196-2 [15], EN 450-1 [9] and EN 451-2 [16] respectively. In terms of LOI both fly ashes were Category A (LOI < 5.0%). ASTM C618 limits LOI value to 6.0% for both class C and F fly ashes.

The 45 µm sieve residue of summer fly ash was found to be very high and did not satisfy the either criteria by EN 450 (< 40%) and ASTM C618 (< 34%). However, the winter fly ash confirmed to EN 450 category N (<40%) and satisfied the requirement of ASTM C618.

Table 3: Physical properties of Barapukuria plant fly ash.

Properties	Summer (Jul 2010)	Winter (Jan 2011)
[a]LOI, %	1.37	4.18
45 µm sieve residue, %	66.46	24.04
d10, µm	10.71	4.59
d50, µm	58.89	22.06
d90, µm	168.02	82.55
Blaine fineness, m^2/kg	211	270

[a] LOI determined at 975 °C

The particles size distribution of both fly ashes was carried out using laser detraction technology. The distribution is shown in Figure 1. The two fly ashes tested here showed distinctive behaviour. This also supports the tendency found from 45 µm sieve residue, and Blaine fineness test. The d_{50} of winter fly ash was found to be approximately 40% of summer. According to the suppliers' information both the fly ashes were collected from the flue gas outlet point. However, it was confirmed that, the fly ash collected during summer is not a general type produced in this plant. The identified significant change in particle size could cause due to reasons as follows:

a) presence of high percentage of inert material (other than carbon and does not burn in furnace)
b) change in coal properties (e.g. HGI);
c) change in feed coal size (also could be related to HGI); and
d) change in furnace residence time.

Blaine fineness of both the fly ashes were found to be lower in comparison with average UK fly ashes. This also indicated that the fly ashes are composed of low carbon and larger particle size materials. This also indicates the improved surface charecteristics of remaining carbon which should perform better in producing air-entrained concrete [10].

Scanning Electron Microscope (SEM) micrograph could explore, whether the particles were fused together or the individual particles formed are of this size.

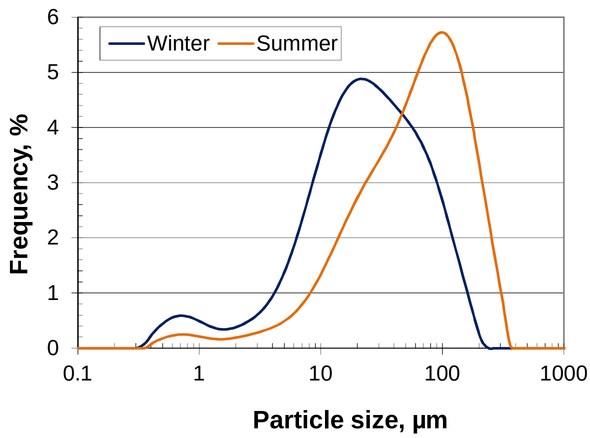

Fig.1: Particle size distribution of Barapukuria fly ash

Color of the fly ash could give indication of several properties such as:

a) level of unburned carbon present in fly ash; and
b) burining temperature of pulvarized coal.

Figure 2 shows comparison in color of the two fly ashes collected from Barapukuria power plant.

Fig.2: Appearance of Barapukuria fly ashes. Summer sample (top); and Winter sample (bottom)

The winter fly ash is whitish ash color whereas the summer one is light brown. These indicates presence of a lower level of unburned carbon in both the fly ashes. Also the brownish color of summer fly ash could be due to a relatively higher burning temperature and presence of more Fe_2O_3. The picture aslo supports both 45 µm sieve residue result and particle sized distribution of these two fly ashes. The average particle size of summer fly ash was double of the winter one.

3.3 Mortar fresh properties test

To explore the applicability of the fly ashes in cementitious system, preliminary work has been done on mortar flow. Two ordinary Portland cement (OPC) of 42.5 N grade from Bangladesh and the UK were used for this test. The mix proportion and flow test of mortar was followed as per EN 450–1[9] and EN 1015–3 [11]. Figure 3 shows comparison between the flow values obtained from two cements. While the flow of mortar samples with the winter fly ash was close to the control mortar (using OPC), the summer fly ash did not show promising workability in cementitious system. Excessive larger particle size is mainly responsible for that. Generally, low LOI and low retention on 45 µm sieve fly ash gives higher flow than the control mortar [10]. The regular spherical shape of these fly ashes incorporates this enhanced flow (so called ball-bearing effect). With increase in particle size the shape became irregular and flow went down.

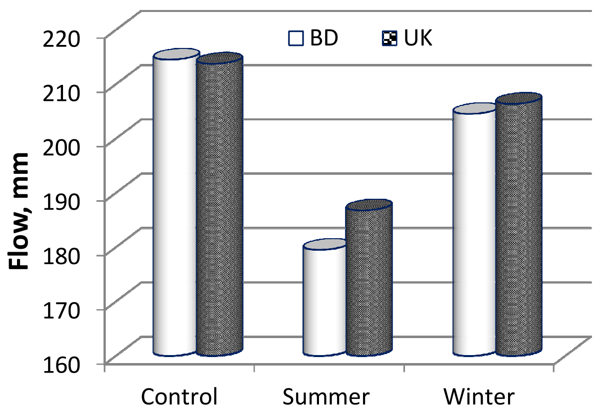

Fig.3: Comparison of mortar flow

Flow of mortar is an important property as it determines the water demand and later the ultimate strength of the concrete. Therefore, while these fly ashes meet other requirements specified in international standards it could be a valuable SCM to be used in concrete if the fineness of the material could be controlled in a regular basis.

4. FUTURE WORK AND RECOMMENDATION

These preliminary experimental work and analysis suggests that the burning of fly ashes were reasonably well as a lower level of unburned carbon was present in both sample. However, the summer fly ash was very coarse in size and unable to meet currently available standards, either of ASTM or EN. Recent study shows that the pozzolanic reactivity of fly ash in cementitious system depends on its glass/amorphous content and fineness [10]. Further work is necessary to explore the following area:

a) X-ray diffraction (XRD) analysis will reveal the glass/amorphous content in fly ashes;
b) SEM analysis is necessary to explore morphology of the particles;
c) activity index test with mortar prism will show reactivity of fly ash in cementitious system; and
d) finally, durability study is required to explore the long term performance of produced concrete from this fly ash.

It should be mentioned again that these fly ashes tested are run-of-station type. By controlling the burning condition it is possible to achieve a low LOI fly ash, however, controlling the fineness of the run-of-station fly ash is not an easily achievable job. In this respect, to make the effective use of this valuable by-product the following activities/investigations can be followed:

a) separation and collection of finer particles;
b) exploring various applications for using the coarse and high LOI part (e. g. highway sub-base, wastewater treatment)
c) grinding larger sized particles by mechanical means;
d) chemical activation; and

In United Kingdom many of the existing power plants installed various technologies to separate unburned carbon from the run-of-station fly ashes and also classify the fly ash in various sizes to use those in different applications. For instance in general <12% retention in 45 µm sieve fly ash portion is considered to be used in concrete construction. In highway construction different fineness grade fly ashes are currently being used for various purposes, for example, stabilizing the base course, as mineral filler in asphalt pavement and in grouts for pavement subsealing [14]. The two fly ashes reported in this study could be used for stabilization for base course of highways as coarse fly ashes showed better performance in that application. LOI of the collected fly ashes from Barapukuria power plant is well suited for using in concrete construction; however, it needs control of particle size by classification. The following section will provide information on currently available separation technologies.

5. FLY ASH CLASSIFICATION TECHNOLOGY

Cemex, UK classifies and processes fly ashes produced from several power plants in UK. Those production plants are equipped with air classification units capable of taking run of station material with typical fineness characteristics up to about 30% retained at 45 µm sieve and reducing this to around 9%. Some power generation units are equipped with STi carbon separator, reducing carbon from around 9-11% to below 5%. Other sites depend on high frequency LOI testing and rejecting material that exceeds EN450 limits. The LOI of the two ashes tested were below 5% as of run-of-station condition. Therefore, only air classification might be sufficient to separate finer particles for effective use of the finished product in concrete.

A typical air classifier is shown in Figure 4 [12]. These modern classification units can handle 1 to 200 ton fly ash per hour.

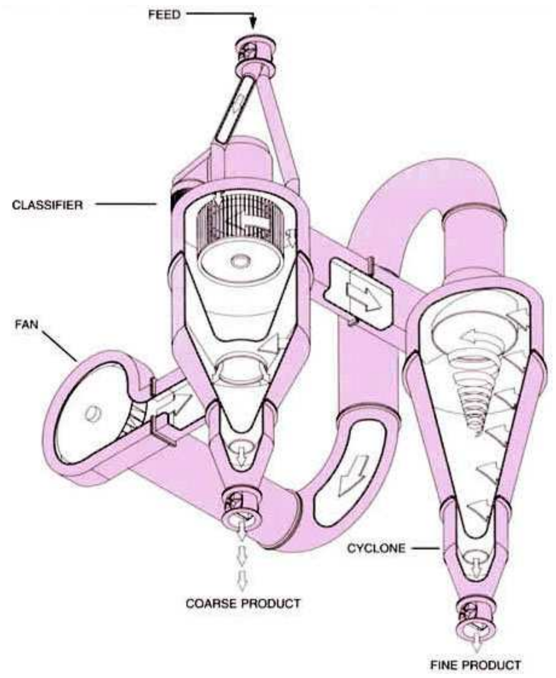

Fig.4: Typical fly ash air classification system [12]

It is also possible to set the cut point in between 5 to 500 µm. The air classification unit maintains a balance between the physical principles of centrifugal force, drag force and gravity to generate a high-precision method of classifying particles according to size or density. The materials are fed into the feed-spout and fall onto the rotating distributing plate hub. Centrifugal force flings them through ports onto the lower distributing plate. Coarse particles move outward and settle by gravity into the tailings cone to be discharged (or recycled through the mill).

Fine particles are carried into the separating zone where selector blades keep out oversized fines by centrifugal force. These are discharged with the coarse material and selected fines continue with the circulating air, through the blades and into the fines cone. Fine particles drop out as the air turns through vanes to return to the main fan.

6. CONCLUSION

This study aimed to explore the possibility of using fly ash produced from Barapukuria power plant in Bangladesh. Several preliminary test results suggest that these fly ashes satisfy the criteria specified by internationals standards and could be a valuable SCM for using in concrete. The only obstacle identified here was the particle size of the fly ashes. By introducing a fly ash classification system in the plant this could be easily overcome.

Further study is required for detailed characterization by SEM and XRD. Reactivity of fly ash in cementitious system and durability performance of produced concrete are also essential. However, before that a control on particle size needs to be established. Works are being carried out in the Department of Civil Engineering, Chittagong University of Engineering & Technology, Bangladesh [13] and Concrete Technology Unit, University of Dundee, UK [10].

7. ACKOWLEDGEMENT

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