Journal of Engineering Science 03(1), 2012 59-67

JES
an International Journal

PROSPECT OF BANGLADESHI FLY ASH IN CONCRETING WORKS

Md. Moinul Islam* and Md. Saiful Islam

Department of Civil Engineering, Chittagong University of Engineering &Technology, Chittagong-4349, Bangladesh

Received 01 September 2012; Accepted 18 October 2012

ABSTRACT

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.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. 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 the year 2006, two units of 125 MW coal based power plant has started generation in Barapukuria, Bangladesh. Around 65 thousand tons of fly ash is being produced from those thermal power plants. 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. Two different grades of concrete (M28 and M38), each with eight different cement replacement level 0, 10, 20, 30, 40, 50, 60 and 70% were used for the experimental program. Among all the concretes studied, the optimum amount of cement replacement is reported 30%, which provides around 12% higher compressive and 53% higher tensile strength as compared to OPC concrete.

Keywords: *Climate Cement, Compressive strength, Environmental pollution, Fly ash, Tensile strength.*

1. INTRODUCTION

Sustainable development can be defined as development which meets the needs of people living today without compromising the ability of future generations to meet their own needs. It requires a long-term vision of industrial progress, preserving the foundations upon which human quality of life depends: respect for basic human needs and local as well as global ecosystems. Concrete is the second most consumed material on Earth after water and is an essential product in the building sector. Portland cement is one of the ingredients in concrete. Cement is a fine grey powder and constitutes 7 to 15% by weight of concrete's total mass. The net cement production in the world is increased from about 1.4 billion tonnes in 1995 to almost 3 billion tonnes in the year 2010, expected to be around 5 billion tonnes in the year of 2040. Cement manufacture is an energy intensive process. Consuming energy from fossil fuels such as oil and coal creates carbon dioxide (CO_2), the most important Greenhouse Gas (GHG) causing climate change. On an average 0.72–0.98 tonne of CO_2 is produced for every tonne of cement production (IEA, 2006). Almost all industries know that in order to continue to meet the demands of a growing world population, they must become smarter in the way they use, reuse and recycle raw material, energy and waste in the economy. Using waste from other industries as raw material is a huge opportunity for the cement industry to reduce its environmental impact, because it allows companies to access materials for use in the kiln and the mill without extracting them directly from the ground. There are a number of mineral by-products produced by the mining and power generation industries that contain useful materials that can be extracted for use in cement production, or in making concrete. Being emission a key issue to attain sustainability in construction industry, supplementary cementitious materials (SCM) are gaining interest. Numerous researches has shown potential of using SCMs for instance pulverized fuel ash (fly ash) from coal combustion, GBBS from iron industry, Silica Fume and Metakaolin (Duran, 2011). These SCMs provide duel benefits in concrete construction. Those not only reduce the emission of CO_2 in material production but also improve several properties of fresh and hardened concrete, for example, workability, water demand, permeability and finally durability. It is generally agreed that with the proper selection of admixtures, mixture proportioning and curing, supplementary cementitious materials can noticeably improve the durability of concrete (Zichao, 2003). Recently these has been a growing trend for the use of SCMs in the production of composite cement

* Corresponding author: moinul91@yahoo.com

because of ecological, economical and diversified product quality reason. A sustainable industrial growth will influence the cement and concrete industry in many respects as the construction industry has environmental impact due to high consumption of energy and other resources. One important issue is the use of environmental-friendly concrete, which is termed as green concrete, to enable worldwide infrastructure growth without affecting the environment (Claus, 2005). Recently, many new materials and techniques have been developed to control corrosion by reduction of penetrable aggressive species. Partial replacement of Portland cement with supplementary cementitious materials has been used widely in aggressive environmental applications. It is generally recognized that the introduction of pozzolan in blended cements improves concrete protection against chloride-induced corrosion of steel reinforcement by reducing its permeability/diffusivity, particularly to chloride ion transportation and increasing the resistivity of the concrete (Thomas, 1999).

Fly ash is a pozzolanic material i.e. a siliceous or siliceous and aluminous material which in itself possesses little or no cementitious value but which will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties (ASTM C125-03). In the presence of moisture, alumino-silicates within the fly ash react with calcium ions to form calcium silicate hydrates (Malhotra, 1994). Through pozzolanic activity, fly ash chemically combines with water and calcium hydroxide, forming additional cementitious compounds which result in denser, higher strength concrete. The calcium hydroxide chemically combined with fly ash is not subject to leaching, thereby helping to maintain high density. The conversion of soluble calcium hydroxide to cementitious compounds decreases bleed channels, capillary channels and void spaces and thereby reduces permeability. Depending on the location of each power plant, the unused fly ash is disposed at the ponds, lagoons or landfills. When unused fly ash and bottom ash disposed from coal combustion power plants, it makes major negative environment effects such as air pollution and groundwater quality problem due to leaching of metals from the ashes, specially the unused fly ash which has very small particle size (Janos, 2002). According to the ASTM C618 -03, the fly ash is suitable for use in concrete when no more than 34 percent of the particle is retained on the No. 325 (45μm) sieve. Fineness of ground disposed fly ash plays very important role on compressive strength of concrete. However, the ground disposed fly ashes which have particle sizes retained on sieve No. 325 and less than 5% by weight can be used as good pozzolanic material (Cheerarot, 2004). It should be noted that since pozzolanic reaction can only proceed in the presence of water, fly ash concrete should be cured for long period. Thus, fly ash concrete used in under water structures such as dams will derive full benefits of attaining improved long term strength and water tightness. Sufficiently cured concrete containing good quality fly ash shows dense structure which offers high resistance to the infiltration of deleterious substances. The pozzolanic reactivity reduces the calcium hydroxide content, which results in reduction of passivity to the steel reinforcement but at the same time, the additional secondary cementitious material formed make the paste structure dense and thereby gives more resistance to the corrosion of reinforcement.

Fly ash is an inorganic, non-combustible by-product of coal - burning power plants. As coal is burnt at high temperatures, carbon is burnt off and most of the mineral impurities are carried away by the flue gas in the form of ash. The molten ash is cooled rapidly and solidifies as spherical, glassy particles (Malhotra, 2002). Fly ash particles range in diameter from <1 microns up to 150 microns. Fly ash is removed from the flue gas by means of a series of mechanical separators followed by electrostatic precipitators or bag filters. As per ASTM C618 specification Class F ashes are mainly produced from bituminous or anthracite coals and that Class C ashes are mainly produced from sub-bituminous or lignite coals, but the main criterion for classification are its chemical requirements: $SiO_2 + Al_2O_3 + Fe_2O_3 > 70\%$ for Class F and $SiO_2 + Al_2O_3 + Fe_2O_3 > 50\%$ for Class C. However, many sub-bituminous and lignite coal ashes meet the chemical requirements of Class F.

Today, there is a general trend to replace higher levels of Portland cement with fly ash in concrete and is due to considering two main aspects. The first aspect is economics as in most markets fly ash is less expensive than Portland cement. Therefore, as the replacement level of fly ash increases, the cost to produce concrete decreases. The second aspect and arguably the most important is the environment. Fly ash is deposited in landfills if not used in concrete. Also from an environmental perspective, the more fly ash being utilized in concrete, less the demand for Portland cement clinker i.e. the less requirement for Portland cement production and therefore the lower CO_2 emissions. If properly used, fly ash can significantly enhance the properties of concrete. Replacement of higher levels of Portland cement with fly ash in reducing the CO_2 emissions associated with the manufacturing of Portland cement is now a day's demand as for manufacture of every tonne of Portland cement, almost one tonne of CO_2 is released into the atmosphere and cement production accounts for approximately 7% of the total carbon dioxide emissions (Mehta, 1999). Therefore it is important for the cement and concrete industry to start utilizing more fly ash to meet these demands rather than increase the Portland cement production (Malhotra, 2002).

Replacing Portland cement with fly ash can reduce the exothermic reaction between cement and water (Bremner, 2004). Because of the slower pozzolanic reaction, partial replacement of Portland cement with fly ash results in a release of heat over a longer period of time. Therefore, the concrete temperature remains lower as the heat is dissipated during hydration (Joshi, 1997). It has been estimated that the contribution of fly ash to early age heat generation ranges from 15-30% of that of an equivalent mass of Portland cement (Berry, 1986). In a large concrete block made with same amount of cementitious material, cement concrete showed a temperature differential of 65°C between the interior and exterior surface whereas fly ash concrete showed only 35°C temperature differential at a placement temperature of 19°C under identical condition (Malhotra, 2002).
Compressive and tensile strength at a given age and the rate of strength gain of fly ash concrete are affected by the characteristics of the fly ash (properties, chemical composition, particle size, reactivity), the cement with which it is used, the proportions of each used in the concrete, the temperature and other curing conditions (Hobbs, 1983). Although concrete mixtures containing fly ash tend to gain strength at a slower rate than concrete without fly ash, the long-term strength is usually higher (Bremner, 2004). After the rate of strength gain of hydraulic cement slows, the continued pozzolanic activity of fly ash provides strength gain at later ages if the concrete is kept moist; therefore, concrete containing fly ash with lower strength at early ages may have equivalent or higher strength at later ages than concrete without fly ash as long as the concrete is moist cured or exposed to sufficient quantities of moisture during service. High calcium fly ashes (Class C) will show a more rapid strength gain at early ages than concrete made with a lower calcium fly ash (Class F) because Class C ashes often exhibit a higher rate of reaction at early ages than Class F ashes (Smith, 1982). However, Class F ashes will contribute to greater long-term strength gain of concrete than Class C ashes in spite of its slower rate of strength development at early age. Because of its fineness and pozzolanic activity, fly ash in concrete improves the quality of cement paste and the microstructure of the transition zone between the binder matrix and the aggregate. As a result of the continual process of pore refinement due to the inclusion of fly ash hydration products in concrete, a gain in strength development with curing is achieved (Joshi, 1997).

The beneficial use of coal burning power plant fly ash in concrete has increased the interest of researcher for the evaluation of the performance of such concrete. The relevant studies indicate that the percentage of cement replaced with fly ash and their relative proportion for making concrete is very important. Concrete mixes made by replacing cement with fly ash are reported to show better results for compressive, tensile as well as flexural strength, freezing and thawing resistance, shrinkage, permeability and abrasion resistance than conventional concrete mixes (Tarun, 1996). Fly ash has dual effects in concrete i.e. as a micro-aggregate and as a pozzolana. Fly ash improves the interfacial bond between the paste and the aggregates in concrete (Poon, 2000). According to Malhotra (2000), the concrete incorporating moderate and high volumes of fly ash showed superior resistance against strength deterioration, rebar corrosion and the penetration of chloride ions compared to the control concrete specimen.

1.1 Research Significance

Portland cement is the most important constituent of concrete. Unfortunately, cement manufacturing consumes large amount energy about $7.36*10^6$ kJ per tone of cement. The net cement production is expected to be increased to almost 5 billion tones in the year 2040. This would lead to the emission of about 5 billion tones to CO_2 in the atmosphere. In order to reduce the harmful green house effect, use of cement may be replaced with other environmentally friendly and efficient cementitious material such as fly ash (Reiner, 2006). It also ensures the proper utilization of fly ash, by-product of coal combustion in power plants, in an effective way which otherwise been dumped making environmental hazard. Limited studies (Wardell, 1991; GSB report, 1996) are reported to be carried out to investigate the performance of Barapukuria fly ash as partial replacement of cement in concrete production. In this study, an attempt has been made to observe the effect of fly ashes produced from coal based power generation in Barapukuria, Bangladesh with different levels of cement replacement on the strength characteristics of concrete.

2. EXPERIMENTAL PROGRAM

The experimental program was planed to quantify the compressive strength and tensile strength of concrete using fly ash as partial replacement of cement. Cement replacement at various percentage levels were used in this investigation to observe the effects of different fly ash levels in concrete in contributing strength at various ages of curing.

Table 1 : Chemical Composition of Ordinary Portland Cement and Fly Ash

Constituents	Composition	OPC (%)	FA (%)
Calcium Oxide	CaO	65.18	0.65
Silicon Di-Oxide	SiO_2	20.80	51.49
Aluminum Oxide	Al_2O_3	5.22	31.60
Ferric Oxide	Fe_2O_3	3.15	2.80
Magnesium Oxide	MgO	1.16	0.28
Sulfur Tri-Oxide	SO_3	2.19	0.19
Sodium Oxide	Na_2O	--	0.18
Loss on Ignition	--	1.70	4.2
Insoluble Residue	--	0.6	--

-- = not measured items.

Table 2: Grading and Physical Properties of Coarse and Fine Aggregate

Properties	Coarse Aggregate	Fine Aggregate
Grading of Aggregates		
Sieve Size (mm)	**Cumulative % Passing**	
25.0	100	100.0
12.5	100	100.0
9.5	45	100.0
4.75	0	100.0
2.36	0	94.0
1.18	0	78.5
0.6	0	55.5
0.3	0	13.0
0.15	0	2.5
Physical Properties of Aggregates		
Specific Gravity	2.67	2.59
Unit Weight	1635 kg/m^3	1540 kg/m^3
Fineness Modulus	6.45	2.57
Absorption Capacity	0.8 %	1.2 %

2.1 Materials Used

(a) Cement: ASTM Type I Portland Cement was used as binding material. Chemical compositions of OPC are given in **Table 1**,which was determined as per BS EN 196-2.

(b) Fly ash: A low calcium ASTM Class F fly ash was used in this investigation. Chemical analysis of the fly ash which was determined as per BS EN 196-2 is shown in **Table 1.**
(c) Aggregate: Locally available natural sand passing through 4.75 mm sieve and retained on 0.075 mm sieve was used as fine aggregate. The coarse aggregate was crushed stone with a maximum nominal size of 12.5 mm. The grading of the aggregates and its physical properties are given in **Table 2.**

2.2 Mix Design and Sample Preparation

Two different grades of concrete namely M28 and M38 were used in the program. Seven different mix proportions of cement fly ash (90:10, 80:20, 70:30, 60:40, 50:50, 40:60, 30:70) were used as cmentitious material. Cement fly ash mix ratio of 100:0 i.e. plain concrete specimens were also cast as reference concrete for comparing the properties of fly ash concrete. Thus the fly ash concrete means the concrete made by using cement and fly ash as cementitious material with sand, stone chips and water. Relevant information of different concrete mixes is given in **Table 3.**

Table 3 : Mix proportions and properties of fresh concrete

Mixture constituent & properties	Grade of Concrete	
	M28	**M38**
Cement (kg/m^3)	435	500
Water (kg/m^3)	218	218
Sand (kg/m^3)	545	520
Stone Chips (kg/m^3)	1150	1120
w/(c+fa)	0.50	0.44
Slump (mm)	68	60
Air content (%)	1.3	1.1

Around 300 no's of cubical specimens of 100 mm size were prepared according to the mix proportion as described for both compressive and tensile strength test. The small size of specimen i.e. 100 mm cube was taken in order to accommodate large number of specimens in the limited sized curing tanks. The specimens were demoulded after 24 hours of casting and cured in plain water at 27±2°C. The concrete test specimens were designated keeping concrete grade and replacement as variable. Thus M38FA40 concrete means grade of concrete is M38 and cement fly ash mix ratio is 60:40.

2.3 Experimental Procedures

The compressive strength and tensile strength of various water cured concrete specimens were tested at the ages of 3, 7, 28, 56, 90 and 180 days in accordance with the BS EN 12390-3:2009 for compressive strength and BS EN 12390-6:2000 for tensile strength. At each case, the reported strength is taken as the average of three tests results.

3. RESULTS AND DISCUSSIONS

3.1 Compressive Strength

The compressive strength of OPC and fly ash concrete of two different grades M28 and M38 has been graphically presented in **Figure 1** and **Figure 2**. Also for the ease of comparison, the relative compressive strengths are plotted in **Figure 3** and **Figure 4**. At early ages of curing, OPC concretes achieve relatively higher compressive strength as compared to fly ash concrete. Test result shows that the 7 days compressive strength for OPC concrete is 9%, 16%, 26%, 34%, 43%, 59% and 75% higher than M38FA10, M38FA20, M38FA30, M38FA40, M38FA50, M38FA60 and M38FA70 concrete respectively. Up to curing period of 56 days, compressive strength is seen to decrease with the increase in fly ash content when compared with no fly ash concrete. 90 days compressive strength test result of the specimens up to 50% replacement level are very similar to OPC concrete, within the range of ±12% variation. Compressive strength is slightly higher by 6%, 9%, 12%

8% and 1% for M38FA10, M38FA20, M38FA30, M38FA40 and M38FA50 concrete respectively; whereas the 90 days strength for M38FA60 and M38FA70 concrete is reported to be lower by 31% and 43% respectively when compared with no fly ash concrete. 180 days compressive strength data for M38FA10, M38FA20, M38FA30, M38FA40 and M38FA50 concrete are respectively 8%, 11%, 16%, 13% and 2% higher than no fly ash concrete. M38FA60 and M38FA70 concrete strength are lower than M38FA0 concrete by 25% and 39%. Cement normally gains its maximum strength within 28 days. During that period, lime produced form cement hydration remains within the hydration product. Generally, this lime reacts with fly ash and imparts more strength. For this reason, concrete made with fly ash will have lower strength than cement concrete up to 28 days and subsequently higher strength at the later ages of curing. Fly ash retards the hydration of C_3S in the early stages but accelerates it at later stages. Conversely in cement concrete, this lime would remain intact and with time it would be susceptible to the effects of weathering, loss of strength and durability. Yamato and Sugita (1983) found that the later age strength of fly ash concrete was higher than that of the control.

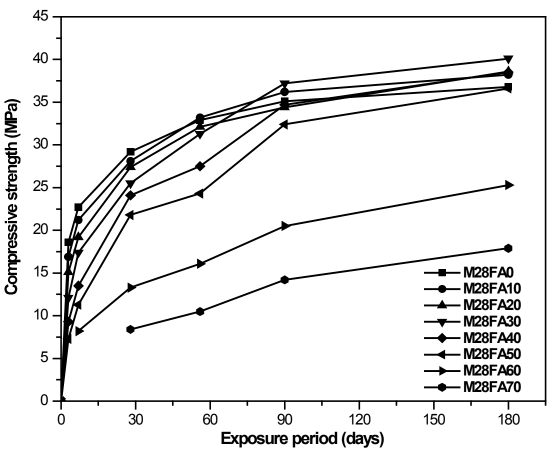

Figure 1: Compressive strength - Exposure time relation for M28 fly ash concretes

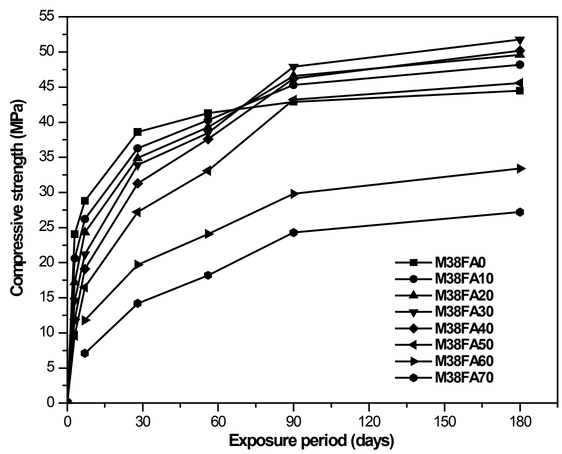

Figure 2: Compressive strength - Exposure time relation for M38 fly ash concretes

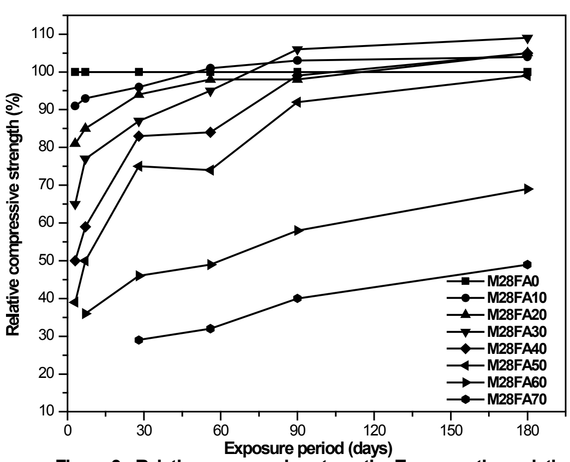

Figure 3: Relative compressive strength - Exposure time relation for M28 fly ash concretes

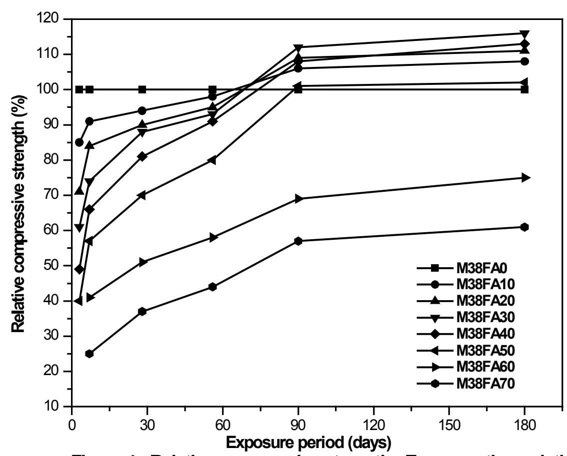

Figure 4: Relative compressive strength - Exposure time relation for M38 fly ash concretes

Rate of strength gaining for different types of concrete is observed to vary with the grade of concrete. Among all the concrete studied, 180 days compressive strength is increased by around 26%, 31%, 32%, 37%, 33% and 25% for concrete M28FA0, M28FA10, M28FA20, M28FA30, M28FA40 and M28FA50 respectively as compared to 28 days strength of M28 grade OPC concrete; whereas the same value is increased by around 15%, 25%, 28%, 34%, 30% and 18% for concrete M38FA0, M38FA10, M38FA20, M38FA30, M38FA40 and M38FA50 respectively compared to 28 days strength of no fly ash M38 grade concrete. At the end of 180 days curing period, the overall strength gaining for M38 grade concrete is around 3% lower as compared to M28 grade concrete. Thus it is seen that strength gaining is relatively faster for lower grade concrete as compared to higher grade concrete.

3.2 Tensile Strength

The tensile strength of concrete mixes made with and with out fly ash was determined at the ages of 3, 7, 28, 56, 90 and 180 days. **Figure 5** and **Figure 6** shows the variation of tensile strength with age for different fly ash concretes**.** Also for the ease of comparison, the relative tensile strength is plotted in **Figure 7** and **Figure 8**. The tensile strength of the specimens is seen to increase with age. At early ages of curing (3 days and 7 days) the tensile strength decreases with increase in fly ash content in concrete. However the rate of decrease diminishes with increasing age of curing. As compared to control specimen tensile strength values are 94%, 90%, 99% and 91% for M28FA10, M28FA20, M28FA30 and M28FA50 concrete respectively at the curing age of 28 days. After 90 days, maximum tensile strength of 4.4 MPa was achieved for M28FA40 concrete, with an increase of 28% higher strength than M28FA0 concrete. At similar age of curing, even the concrete M28FA10, M28FA20, M28FA30 and M28FA50 showed higher tensile strength of 6%, 22%, 28% and 20% respectively than OPC concrete.

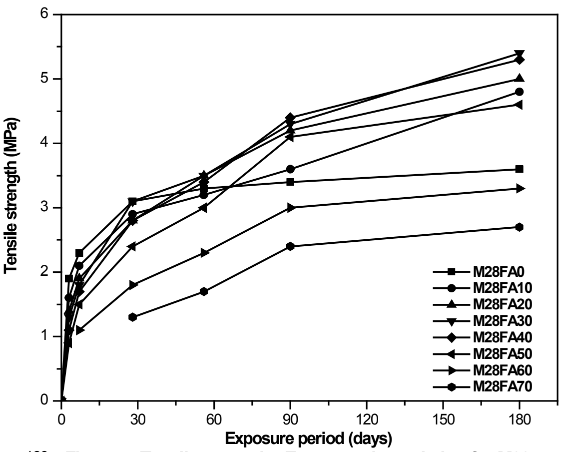

Figure 5: Tensile strength - Exposure time relation for M28 fly ash concretes

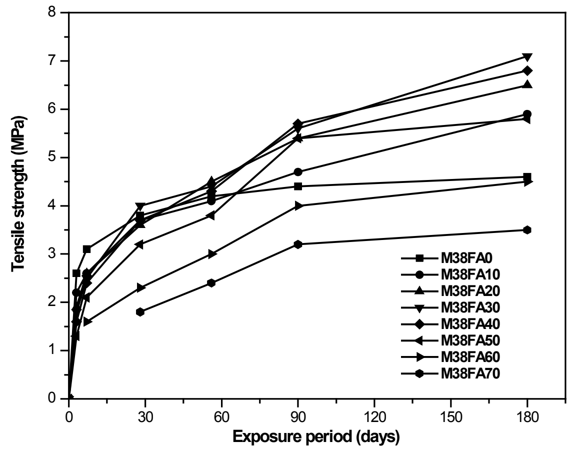

Figure 6: Tensile strength - Exposure time relation for M38 fly ash concretes

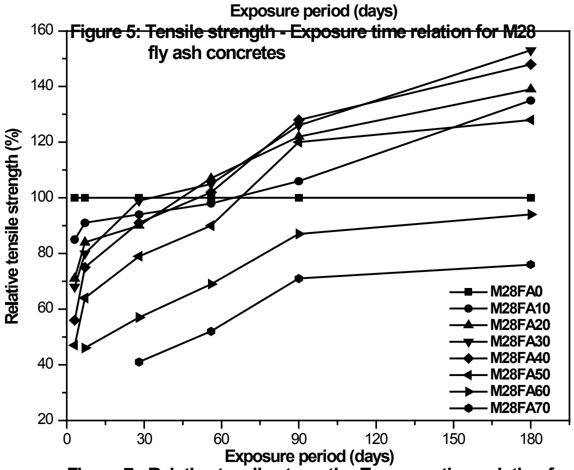

Figure 7: Relative tensile strength - Exposure time relation for M28 fly ash concretes

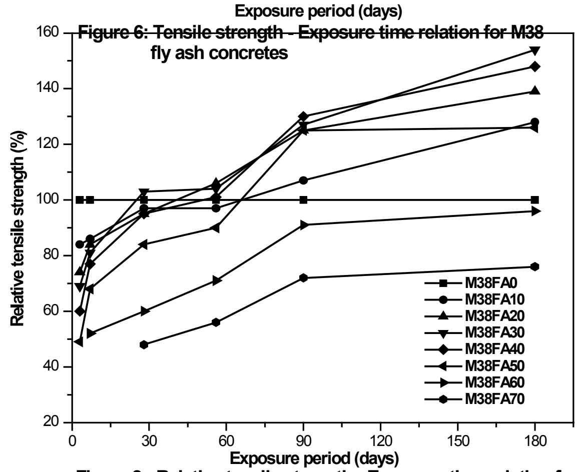

Figure 8: Relative tensile strength - Exposure time relation for M38 fly ash concretes

At an age of 180 days curing, a maximum tensile strength of 5.4 MPa was achieved for M28FA30 concrete which is 53% higher than the reference concrete. Even 10%, 20%, 40% and 50% fly ash replaced concrete showed higher strength. However, M28FA60 and M28FA70 concrete provided a decrease in strength of around 6% and 24%. It is due to the fact that fly ash being a pozzolanic material, the reactive silica of pozzolan and calcium hydroxide producing from the hydration of cement react together and produce calcium silicate hydrate which imparts strength for concrete. As it takes time to produce $Ca(OH)_2$ by hydration of cement, strength gaining rate slows down at initial ages of curing but increases at the later ages. Korac and Ukraincik (1983) found that the early-age strengths upto 50% fly ash concretes were lower than that for the controls and after long curing period, the strengths were found comparable.

Again, the rate of strength gaining for different types of concrete is observed to vary with the grade of concrete. Among all the concrete studied, 180 days tensile strength is observed to be increased by about 15%, 56%, 61%, 76%, 71%, 48% and 8% for concrete M28FA0, M28FA10, M28FA20, M28FA30, M28FA40, M28FA50 and

M28FA60 respectively as compared to 28 days strength M28 grade OPC concrete; whereas the same value is increased by around 21%, 54%, 68%, 85%, 78%, 52% and 16% for concrete M38FA0, M38FA10, M38FA20, M38FA30, M38FA40, M38FA50 and M38FA60 respectively compared to 28 days strength of M38 grade no fly ash concrete. At the end of 180 days curing period, the overall strength gaining for M38 grade concrete is around 7% higher as compared to M28 grade concrete. Thus it is seen that tensile strength gaining is relatively faster for higher grade concrete as compared to lower grade concrete.

4. CONCLUSIONS

Based on the results of the investigation conducted on different fly ash concrete made with various level of cement replacement as mentioned and cured for various curing period up to 180 days, the following conclusions can be drawn:

(1) At the early ages of curing, the rate of gain in strength of fly ash concrete specimens is observed to be lower than the corresponding OPC concrete.

(2) Fly ash concrete mix having various cement replacement level up to 40% exhibited satisfactory results for both compressive and tensile strength.

(3) The study reveals that optimum fly ash content is 30% of cement. Fly ash concrete with 30% cement replacement shows around 12% higher compressive strength as well as 53% higher tensile strength than OPC concrete after 180 days curing.

(4) Use of high volume fly ash in any construction work as a replacement of cement, provides lower impact on environment (less CO_2 emission) and judicious use of resources (energy conservation, use of by-product).

(5) Use of fly ash reduces the amount of cement content as well as generation of heat due to hydration of concrete mix. Thus, the construction work with fly ash concrete is economomical and environmentally safe.

ACKOWLEDGEMENT

Material supplied by Barapukuria power plant authority is credited. Laboratory facility provided by the Department of Civil Engineering, Chittagong Uniiversity of Engineering & Technology, Bangladesh is also gratefully acknowledged.

REFERENCES

ASTM C125-03. Standard Terminology Relating to Concrete and Concrete Aggregates, ASTM Internationals, United States, 2003.

ASTM C618-03. Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, ASTM Internationals, United States, 2003.

Berry, E.E., and Malhotra, V.M., Fly Ash in Concrete, Energy, Mines and Resources Canada, CANMET, Ottawa, Canada, 1986.

Bremner, T.W., and Thomas, M.D.A., Learning Module on Traditional and Non- Traditional Uses of Coal Combustion Products (CCP), http://www.unb.ca/ civil/Bremner & Thomas/ CIRCA/Webpages/ Circa_1_ Introduction.htm, 2004.

BS EN 196-2. Methods of testing cement-Part 2: Chemical analysis of cement. BSI, London, 2005.

Cheerarot, R. and Jaturapitakkul, C., A study of disposed fly ash from landfill to replace portland cement, Journal of Waste Management, Vol.24 (7), 701-709, 2004.

Claus Pade., Danish Technological Institute, Concrete Centre Featured at Technical Seminar Fly ash in Concrete, Poland, 9-11 March, 2005.

Durán-Herrera, A., Juárez, C. A., Valdez, P. and Bentz, D.P., Evaluation of sustainable high-volume fly ash concretes, Journal of Cement and Concrete Composites, Vol. 33(1), 39-45, 2011.

Hobbs, D.W., Influence of Fly Ash on the Workability and Early Strength of Concrete, Proceedings, 1st International Conference on the Use of Fly Ash, Silica Fume, Slag and other Mineral By-Products in Concrete, ACI SP–79, 289-306, Detroit, Michigan, 1983.

IEA (International Energy Agency), Energy Technology Perspectives: Scenarios & Strategies to 2050, IEA, Paris, 2006.

GSB Report Bakr et. al: Geology and Coal deposit of Barapukuria Basin, Dinajpur District, Bangladesh, 1996.

Janos, P., Wildnerova, M., Loucka, T., Leaching of metals from fly ashes in the presence of complexing agents, Journal of Waste Management, Vol.22, 783–789, 2002.

Joshi, R.C., and Lohtia, R.P., Fly Ash in Concrete – Production, Properties and Uses, Advances in Concrete Technology, Vol. 2, Gordon and Breach Science Publishers, Printed in India, 1997.

Korac, V., and Ukraincik, V., Studies into the Use of Fly Ash in Concrete for Water Dam Structures, Fly Ash, Silica Fume, Slag and Other Mineral By-Products in Concrete, ACI SP-79, 173-185, 1983.

Malhotra, M., et al., Long-Term Performance of Steel Reinforcing Bars in Portland Cement Concrete and Concrete Incorporating Moderate and High Volumes of ASTM Class F FlyAsh, ACI Materials Journal, Vol. 97(4), 409-419, 2000.

Malhotra, V.M. and Mehta, P.K., High – Performance, High – Volume Fly Ash Concrete, Supplementary Cementing Materials for Sustainable Development Inc., Ottawa, Canada, 2002.

Malhotra, V.M. and Ramezanianpour, A.A., Fly Ash in Concrete, Second Edition, Natural Resources Canada, Ottawa, Ontario, CANMET – Canadian Centre for Mineral and Energy Technology, 1994.

Mehta, P.K., Concrete Technology for Sustainable Development, Concrete International, V. 21(11), 47-53,1999.

Poon, C. S., Lam, L. & Wong, Y. L., A study on high strength concrete prepared with large volumes of low calcium fly ash, Cement and Concrete Research, Vol.30(3), 447-455, 2000.

Reiner, M., and Kevin, R., High-Volume Fly Ash Concrete: Analysis and Application, Practice Periodical on Structural Design and Construction, Vol. 11 (1), 58-64, 2006.

Smith, R.L., Raba, C.F., and Mearing, M.A., Utilization of Class C Fly Ash in Concrete, 6th International Fly Ash Utilization Symposium, Reno, Nev., March, 31, 1982.

Tarun, R. Naik., Shiw, S. Singh., and Mohammad, M. Hossain., Permeability of High Strength Concrete Containing Low Cement Factor, Journal of Energy Engineering, Vol.122 (1), 21-39, 1996.

Thomas MDA, Bamforth PB., Modeling Chloride diffusion in concrete: effect of fly ash and slag, Journal of Cement Concrete Research, Vol. 29(4), 487–95, 1999.

Wardell Armstrong; Techno – economic Feasibility study of Barapukuria Coal Project, Dinajpur, Bangladesh, 1991

Yamato, Takeshi., and Sugita, Hideaki., Shrinkage and Creep of Mass Concrete Containing Fly Ash, Fly Ash, Silica Fume, Slag and Other Mineral By- Products in Concrete, ACI SP 79, 87-102, 1983.

Zichao. Wu. and Naik, T.R., Chemically Activated Blended Cement, ACI materials Journal, Vol.100(5), 434-440, 2003.