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High volume fly ash-strength development in concrete: a review

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Abstract: Concrete has gained high popularity compared to its compatriots i.e. steel, timber etc all over the world and the sole reason for it being its high durability and strong resistance to abrasive actions of the environment. There has been a continuous rise in the production of concrete with the passing decades and as a result the cost of cement has gone very high consequently. Therefore, the need of using some additional ingredients to the concrete has become the necessity of the modern age to control the cost of overall production of concrete. Nowadays the use of mineral admixtures is on its peak and different aspects of their compatibility are under research which is bringing fruitful amount of economy to the cost control of concrete. As of today the use of Fly Ash, a by-product of coal industry, has gained very popularity in the field of material engineering due to its strong impact of the performance of concrete in the severe weathering and abrasive environments. In this paper, there will be a critical review of the strength evaluation (compressive strength) of high volume fly ash be presented along with critical analysis of various variables including the normal consistency, setting time, fineness, strength activity index etc will be critically presented in light of the on-going research today.

***Key words:** Fly ash, Concrete, Compressive Strength.*

Introduction:

The present energy demand in the world has demanded a greater usage of coal consumption and thereby an increase in the production of fly ash due to fact that it is a by-product of the coal industry. ACCA (2009) conducted a study in which it stated that more than 62 million tons of fly ash is being produced in the United States per year and the use of fly ash is only 39.3%. There is more than 98 million tons of fly ash produced per year in China whereas the recycling process contributes to only a consumption of 42%. It is dilemma that most of the fly ash is dumped into waste in landfills (Kim and Prezzi, 2008). It is also important to mention that a lot of research is undergoing to educate the intellectuals about the utility of this waste and to convert it into a fruitful substance. Due to the technical benefits of FA, the development and use of cements which are blended with the minerals is gradually increasing. Lai (2009) underwent through an investigation to determine the properties of blended cements, 35% type II OPC with 67% slag, and palm oil fuel ash (POFA), rice husk (RHA) and ash from timer and found that there resulted a better performance in terms of durability and strength.

(Bouzoubaa et al.2001) commented that the use of Fly ash and Rise Husk Ash is imparting higher performance to the resulting concrete and improves the properties of blended cement concrete thereby reducing the cost of production and eliminating various environmental pollutions.

The FAUP (Fly Ash Utilisation Programme) stated that the impressive utilization of fly ash has been seen in mass concrete, asphalt fillers, lightweight aggregate and as stabilizer to the road bases. The remaining amount of the fly ash waste is being dumped in a large area in land fills. The ACI Committee 232 has reported that there lies an ecological imbalance in the production of fly ash and its utilization whereas the production estimates are very high. (Zain et al., 2010; Tangchirapat et al., 2007) have reported that the use of palm oil fuel ash has been used as a good improver in the properties of cement paste and mortar. Fly Ash is the common pozzolanic material that has been used quite extensively in material testing experimental procedures due to fact that it contains a high amount of siliceous and aluminous components with high potential of using as a raw material for the production of blended cements and mortars (Bijen, 1983; Ravina, 1997). In the production of high performance concrete there are various other supplementary materials used which include ground granulated blast furnace slag, silica fume and fly ash. The sole reason for their utility is the presence of high amount of pozzolans in their chemical and physical structure. It is a well known fact the these pozzolanic materials are the by-products of industrial processes and their use in concrete enhances the environmental friendly concrete manufacture (Haque and Kayali, 1998)

It is observed from the study of literature that there is no strength reduction up to a certain limit due to incorporating fly ash in concrete. As a consequence, the basic aim of this review paper is to educate the readers about the ongoing research on the properties of fly ash in utility in concrete and the various physical and chemical aspects of fly ash to be kept in mind while using fly ash in concrete preparation.

Physical and chemical properties of fly ash:

Fly ash is a composite material. According to ACI 232 it has different sizes which vary from 1μm to 80 μm. Fly ash density varies from 1 Mg/m^3 3 Mg/m^3. The principle chemical component includes Silicon dioxide, Calcium oxide, Aluminum oxide and Iron oxide. ASTM C618 Classify Fly ash into two main classes, one is Class F fly ash in which the sum of percentage of these oxides (SiO_2, CaO, Al_2O_3 and

Fe_2O_3) is greater than 70 and the other is Class C fly ash in which the sum of percent of these oxides is in between 50 to 70. The Chemical and Physical properties of Fly ash is given in Table

Table 1 *Physical and Chemical Properties of Fly Ash*

Physical properties of Fly Ash		
Reference	Chindaprasirt and Ruzkan, 2008	Bouzoubaa et al 2001
Material specific gravity (gm/cm3)	2.43	2.12
Mean particle size (µm)	4.8	21.1
Fineness (Blaine)	5700 (cm^2/gm)	2210 (cm^2/gm)
Chemical Properties of Fly Ash		
Silicon dioxide	41.2	62.5
Aluminum oxide	21.59	20.8
Iron oxide	11.2	4.6
Calcium Oxide	14.3	5.7
Magnesium oxide	3.29	1.6
Sulfur trioxide	2.3	2.02
Sodium oxide	1.2	.2.4
Potassium oxide	2.6	1.7

Fineness effect of fly ash on strength of concrete:
In correspondence to the literature, particle size distribution of fly ash has been termed as one of the important factor in ensuring strength of concrete and mortar. ASTM C618 states that the fly ash is most suitable to be used in concrete when not more than 34% of the particles are retained on the sieve number 325. Wu and Li (2005) found that fly ash and the mean particle size of fly ash is a very significant factor in imparting strength to the concrete. The particle size smaller than 9 micro meter was incorporated in a research and it yielded a strength activity index of more than 100% in comparison to that of the control sample within a duration of 28 days. The mortar which was containing fly ash finer had gained greater extent of strength as compared to the one which was manufactured with the coarser fly ash.

ACI committee 232 reported that the strength and durability enhancing capability of fly ash is widely dependant on the characteristics of the ash. Slanicka (1991) and Paya et al. (1995) separated fly ash in terms of particle size distribution and observed that there was greater compressive strength of concrete specimen which were prepared with finer fly ash particles and the concrete specimen which were prepared with the coarser fly ash particles showed a poor strength performance when subjected to 28 days strength evaluation as per the ASTM procedures. Mehta (1985) had been associated with the investigation of concrete properties under the use of mineral and blended cement particles. In his experimental setup he investigated 11 fly ashes from various sources in the USA and determined that the content of calcium and particle size distribution is one of the vital factor in governing the strength performance of concrete under development rate. Whereas Erdogdu and Turker (1998) had stated that fly ashes do not have similar properties under different factions of size.

An increase in the specific surface area of the blended cement can increase the activity of grain in the blended cement which will increase the surface energy of the particles of cement. On the other hand, on increasing the contact surface between the fly ash and the grains of clinker enhanced the hydration between the silicon oxide and calcium hydroxide (Fu et al., 2002). The researchers investigated the fineness effects on the strength of the mortar samples made with the blended cements with a high amount of fly ash. It can be concluded from the table that the strengths of the mortars got increased at various ages with the increase in specific surface area (Kiattikomol et al. (2001) determined the fly ash compressive strength mortar with different particle sizes, the results are being illustrated in the tables. Chindaprasirt et al. (2005) had incorporated two different types of fly ash of Type F fly ash with a variable fineness. He concluded that the mortar which was containing the classified fineness of fly ash attained greater strength in terms of compressive strength whereas the original fly as mortar attained a comparatively lower amount of compressive strength. Dhir et al. (1998) concluded that the development of strength in concrete is a function of fineness of fly ash and the strength is highly reduced with a decrease in the fineness of fly ash. Tangpagasit et al (2005) suggested that the concrete specimen prepared with higher fineness of fly ash had shown a higher range of strength development. Therefore, they recommended that the use of fly ash with larger grain size is not suitable for incorporation in concreting.

Pozzolanic activity of fa:
A pozzolanic material is the one which contains siliceous or alumino-siliceous materials that itself does not possess cementitious properties however when these substance comes in contact with alkali and alkaline earth hydroxides, they start chemical reaction at ordinary temperatures to form compounds that bears cementitious properties. The crystalline minerals of fly ash do not possess any hydration properties under normal temperatures. The amorphous glass when reacts with calcium hydroxide and as a consequence get released from the hydration reaction of clinker to form calcium silicate hydrate etc. (Fu et al., 2002) commented that the activity of fly ash is highly dependant on the vitreous and crystalline minerals.

It is however a well known phenomenon that due to the addition of pozzolanic material in to concrete, the amount of calcium hydroxide gets reduced in the cement paste and the permeability of the cement matrix gets highly enhanced. Due to this action, the resulting concrete becomes highly resistant to the abrasive actions of environment in the form of sulfate attack and chloride ingress into the cement and concrete matrix which gradually deteriorate the matrix with the passage of time and the resulting concrete structure is highly unsafe for its intended purpose in terms of serviceability. (Chindaprasirt, et al., 2008;) commented that the pozzolanic materials like fly ash has a higher likelihood to be incorporated in concrete as a partial replacement of cement which yields a better economy in the cost of construction of concrete. It is also observed by researchers that the calcium hydroxide produced by the reaction of cement hydration components with pozzolan and as a result generates additional calcium silicate hydrate gel. Chindaprasirt et al. (2007) concluded that the carbon to silicate ratio in the calcium silicate hydrate will be lower for the cases where fly ash blended cements are used. Mortars prepared in fly ash thus possesses better performance in the cases of sulfate prone environment as compared to control sample. The main reason for this enhanced behavior of fly ash in resistance against sulfate attack and other chemical compounds that the incorporation of fly ash gives a higher impermeability to concrete matrix and the resulting concrete structure is safe against the perforation issues and penetration of these hazardous substances for the service use of concrete during the life span of the structure.

Strength activity index of fly ash:

The American Society of Testing and Materials Committee 311 define the strength activity index as the ratio between the compressive strength of mortar that contains substituting materials 21% by weight of binder and that the control mortar at the same ages. Kiattikomol et al. (2001) investigated the SAI (strength activity index) of fly ash with different particle sizes. For the small particle sizes, they obtained the SEI (strength activity index) value of 122%. Similar kind of results were analyzed by Jaturapitakkul et al, (1999) with a variant increase in the particle size of fly ash. It is indicative from the figure that the (SAI) gradually increases with increase in the fineness of fly ash (Karim et al.) (SAI) of coarser fly ash particles can be enhanced by grinding the fly ash sample to the extreme capacity and resources thereby enhancing its strength activity index. However, Qian et al. (2001) accomplished that with the addition of sodium sulfate can increase the strength of the cement paste very significantly when fly ash is present in the cement sample (blended cement). (Bouzoubaa et al. (1997) conducted a research on three samples of fly ashes and concluded that the optimum time of grinding for the fly ash samples approximately range from four hours to six hours. Tangpagasit et al. (2005) concluded that the strength activity index of blended cements containing fly ash greatly depend on the median particle size of fly ash and the age of curing of the cement specimen. Thereafter, the phenomenon of influence of fineness of fly ash on strength activity index of the cement and concrete specimen was understood by researchers.

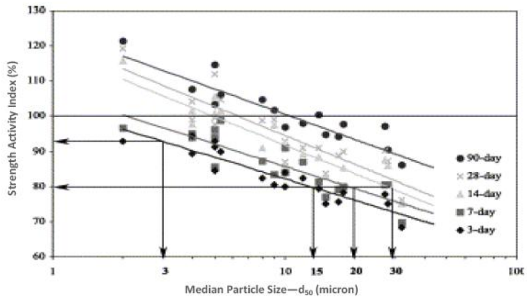

Figure 1: *Relationship between median particle size and strength activity index*

Additional use of fly ash:

As it is clear from the literature study that the use of fly ash in cement concrete enhances the performance of in respects of strength and resistance against chemical and environmental aspects that greatly deteriorate the cement and concrete matrix and inducing stresses in the concrete specimen which greatly influence the overall serviceability of the structure. It is commented by Toutanji et al. 2004 that all of the supplementing materials to cement and concrete have their own mechanism of action within the cement matrix and imparts different amounts and extent of performance levels to the resulting concrete specimen. Since fly ash exists in different classes, (Bijen, 1996) commented that all types of fly ash possesses an exclusive role in imparting performance levels to the resulting concrete specimen. Haque and Kavali (1998) used highly fine fly ash to produce a highly workable concrete mixture which possessed a greater compressive strength. Apart from the enhanced compressive strength of the concrete specimen, the water penetration into the concrete specimen was greatly reduced with the use of highly fine class F fly ash.s Bouzoubaa et al. (2001) conducted a study on the mechanical properties and durability characteristics of cement and concrete with the addition of fly ash and concluded that the high volume fly ash possessing coarser fly ash particles did not induce high strength to concrete specimen and consequently lesser durability characteristics. The properties of hardened concrete that were under investigation were compressive strength, flexural strength. The properties of freshly prepared concrete were slump test, air content testing, stability of air content in the concrete mixture and the initial and final setting time of cement paste. It was concluded from the research that the concrete samples prepared with the addition of blended cements shown greater performance levels in terms of mechanical properties and enhanced durability characteristics. Whereas, the concrete samples prepared in unground fly ash shown lesser levels of mechanical properties and lesser durability levels except that the phenomenon of deicing salt scaling was accurately elaborated under performance levels of durability testing when done in unground fly ash concrete samples. Ferreira et al (2003) detected from his experimental program of fly ash that the possible applications of fly ash in concrete can be in the areas of road pavement, embankments and sorbent miscellaneous conditions.

Consistency, setting time and flow of fa mixed paste:

Consistency of a cement paste is defined as the amount of water that will produce a paste of standard consistency when added to hydraulic cement. (Neville and Brooks, 2003) stated that the setting time refers to the change of hydraulic cement mortar from liquid to rigid state. Cheerarot and Jaturapitakkul (2004) commented that the normal consistency of cement pastes prepared with fly ash was 28% and that prepared in Ordinary Portland Cement was 26%. Felekoglu et al. (2009) deducted the statement from their research that increasing the fineness of fly ash particles may result in higher mixing water demand during the preparation of concrete batch due to an increase in the surface area of fly ash as a result of the grinding process. Therefore, optimum fly ash fineness is a function of mixing water for a constant workable batch of concrete. Another important parameter of the properties of fly ash particles that strongly influence the characteristics of the resulting concrete batch is the initial particle shape characteristics which in the long run determines and regulates the amount of water required for the preparation of mortars.

Compressive strength of concrete with fa:

For any type of concrete structures compressive strength is very important stricture which has a strong effect on the cost of structure**.** Cost of concrete can be decrease by using industrial by-product and agriculture by-product. According to ACI Committee 232 fineness, texture, Density and particle size distribution of fly ash effect fresh as well as hardened concrete strength. According to Oner et al., 2005 as compare to ordinary Portland cement denser calcium silicate hydrate (C-S-H) concrete is produce when not only fly ash but other pozzolan are added to concrete.

Strength of concrete is mainly affected by the amount of calcium percentage. Papadakis state that when aggregate are replaced with low-calcium fly ash higher strengths are achieved after 14 days. In another research he replaces cement with fly ash and obtains high strength after 90 days.

Chindaprasirt and Rukzon (2008) obtained a better performance of fly ash concrete as compared to the Ordinary Portland Cement concrete at the age of ninety days. In another study conducted by Bouzoubaa et al. (2001), a similar pattern of experimental data was observed. Haque and Kayali (1998) elaborated the effects of 15% replacement of cement with fly ash in concrete for 56 days time period. Memon et al. (2002) investigated the effects of mineral admixtures and chemical admixtures on the development of compressive strength, porosity and pore size distribution in concrete.

Neville (1995) proposed the compatibility of an empirical equation for the prediction of compressive strength development in the presence of fly ash.

Splitting tensile strength and flexural strength of fly ash concrete:

(Gambhir, 1993) stated that the determination of tensile strength of concrete specimen while subjected to flexural loading is an essential factor to estimate the load at which the members of concrete starts to crack. Bouzoubaa et al. (2001) investigated that the twenty-eight days flexural strength of concrete prepared in fly ash concrete specimen in comparison to the control samples prepared in Ordinary Portland Cement concrete. He concluded that the ratio of tensile strength to compressive strength of concrete members depends upon the general level of compressive strength that is applied primarily on the member during the test procedure; higher the compressive stress on the concrete member then this ratio will be lower and vice versa.

Conclusions and recommendations:

A large amount of fly ash is produced world-wide in factories and power plants and there is a strong lack of re-use of this important waste of the industries. So, if the consumption of fly ash in cement or concrete has become a worthwhile topic for research among the intellectuals. Due to the presence of large amount of silica in the matrix of fly ash, fly ash exhibits a strong pozzolanic property which has shown a greater performance in both, attaining high strengths and enhancing the durability characteristics of concrete.

For about 25% to 30% replacement of cement with fly ash can impart satisfactory results to the compressive strength of hydraulic cement concrete. However, there is no remarkable change in the compressive strengths of concrete samples prepared in fly ash in the early ages i.e. 7 days or less. When the fly ash obtained is having a higher level of grinding, it enhances the strength development and the corresponding properties of the hardened concrete samples. it is however important to note that the test results which are obtained from samples cured for a shorter period of time are quite different from those which are obtained from the samples which are cured for an extended period of curing and this phenomenon is clearly indicated from research that the strength gain of concrete is higher on later stages in the presence of fly ash rather than in an early age.

References:

[1] Basri HB, Mannan MA, Zain MFM (1999). Concrete using waste oil palm shells as aggregate. Cem. Conr. Res., 29: 619-622.

[2] Beycioglu A, Başyigit C, Kilinçarslan S, Şamandar A (2011). Effect of mineral admixtures on properties of lightweight pumice concrete. Int. J. Phys. Sci., 6(7): 1591-1603.

[3] Bijen J (1996). Benefits of slag and fly ash. Constr. Build. Mater., 10(5): 309-314.

[4] Bouzoubaa N, Zhang MH, Bilodeau A, Malhotra VM (1997). The effect of grinding on the physical properties of fly ashes and a

portland cement clinker. Cem. Concr. Res., 27(12): 1861-1874.

[5] Bouzoubaa N, Zhang MH, Malhotra VM (2001). Mechanical properties and durability of concrete made with high-volume fly ash blended cements using a coarse fly ash. Cem. Concr. Res., 31: 1393-1402.

[6] Chatveera B, Lertwattanaruk P (2009). Evaluation of sulfate resistance of cement mortars containing black rice husk ash. J. Environ. Manage., 90: 1435-1441.

[7] Cheerarot R, Jaturapitakkul C (2004). A study of disposed fly ash from landfill to replace portland cement. Waste Manage., 24(7): 701-709.

[8] Chindaprasirt P, Homwuttiwong S, Sirivivatnanon V (2004). Influence of fly ash fineness on strength, drying shrinkage and sulfate resistance of blended cement mortar. Cem. Concr. Res., 34:1087–1092.

[9] Chindaprasirt P, Jaturapitakkul C, Sinsiri T (2005). Effect of fly ash fineness on compressive strength and pore size of blended cement paste. Cem. Concr. Compos., 27(4): 425–428.

[10] Chindaprasirt P, Kanchanda P, Sathonsaowaphak A, Cao HT (2007). Sulfate resistance of blended cements containing fly ash and rice husk ash. Constr. Build. Mater., 21: 1356-1361.

[11] Chindaprasirt P, Rukzon S (2008). Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. Constr. Build. Mater., 22: 1601-1606.

[12] Chindaprasirt P, Rukzon S (2009). Pore structure changes of blended cement pastes containing fly ash, rice husk ash, and palm oil fuel ash caused by carbonation. J. Mater. Civil. Eng., 21(11): 666-671.

[13] Chindaprasirt P, Rukzon S, Sirivivatnanon V (2008). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash. Constr. Build. Mater., pp. 932-938

[14] Chusilp N, Jaturapitakkul C, Kiattikomol K (2009). Effects of LOI of ground bagasse ash on the compressive strength and sulfate resistance of mortars. Constr. Build. Mater., 23: 3523–3531.

[15] Deboucha S, Hashim R (2010). Effect of OPC and PFA cement on stabilized peat bricks. Int. J. Phys. Sci., 5(11): 1671-1677.

[16] Dhir RK, McCarthy MJ, Magee BJ (1998). Impact of BS EN 450 PFA on concrete construction in the UK. Constr. Build. Mater., 12(1): 59-74.

[17] Erdogdu K, Tucker P (1998). Effects of fly ash particle size on strength of Portland cement fly ash mortars. Cem. Concr. Res., 28:1217–22.

[18] Esen Y (2010). The effect of cure conditions and temperature changes on the compressive strength of normal and fly ash-added concretes. Int. J. Phys. Sci., 5(17): 2598-2604.

[19] Felekoglu B, Turkel S, Kalyoncu H (2009). Optimization of fineness to maximize the strength activity of high-calcium ground fly ash – Portland cement composites. Constr. Build. Mater., 23: 2053-2061.

[20] Ferreira C, Ribeiro A, Ottosen L (2003). Possible applications for municipal solid waste fly ash. J. Hazard. Mater., 96: 201-216.

[21] Fly Ash Utilization Program (FAUP) (2002). A technology project in mission mode of government of India; http://www.tifac.org.in/index.php.

[22] Fu X, Wanga Z, Tao W, Yang C, Hou W, Dong Y, Wu X (2002). Studies on blended cement with a large amount of fly ash. Cem. Concr. Res., 32: 1153-1159.

[23] Gambhir ML (1993). Concrete Technology, Tata McGraw-hill publishing company, New Delhi India, pp. 66-91.

[24] Ganesan EK, Rajagopal K, Thangavel K (2008). Rice husk ash blended cement: Assessment of optimal level of replacement for strength and permeability properties of concrete. Constr. Build. Mater., 22(8): 1675-1683.

[25] Ganesh Babu K, Rao GSN (1993). Efficiency of fly ash in concrete. Cem. Concr. Compos., 15: 223-229.

[26] Haque MN, Kayali O (1998). Properties of high-strength concrete using a fine fly ash. Cem. Concr. Res., 28 (10): 1445-1452.

[27] Isaia GC, Gastaldini ALG, Moraes R (2003). Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. Cem. Concr. Compos., 25: 69-76.

[28] Iyer R (2002). The surface chemistry of leaching coal fly ash. J. Hazard. Mater., 93: 321-329.

[29] Janos P, Wildnerova M, Loucka T (2002). Leaching of metals from fly ashes in the presence of complexing agents. Waste Manage., 22: 783-789.

[30] Kiattikomol K, Jaturapitakkul C, Songpiriyakij S, Chutubtim S (2001). A study of ground coarse fly ashes with different finenesses from various sources as pozzolanic materials. Cem. Concr. Compos., 23: 335-343.

[31] Kim B, Prezzi M (2008). Evaluation of the mechanical properties of class F fly ash. Waste Manage., 28: 649-659.

[32] Lai FC (2009). High volume quaternary blended cement for sustainable high performance concrete, 34th Conference on Our World in Concrete and Structure, pp. 16-18.

[33] Li G, Wu X (2005). Influence of fly ash and its mean particle size on certain engineering properties of cement composite mortars. Cem. Concr. Res. ,35: 1128–1134.

[34] Mahmud HB, Majuar E, Zain MFM, Hamid NBAA (2009). Mechanical properties and durability of high strength concrete containing rice husk ash. J. Adv. Concr. Tech., 79(1): 21-30.

[35] McCarthy MJ, Dhir RK (1999). Towards maximising the use of fly ash as a binder. Fuel, 78: 121-132.

[36] Mehta PK (1983). Pozzolanic and cementitous by-products as mineral admixtures for concrete—A critical review. In: Malhotra VM (eds) Proceeding of the 1st International conference on the use of fly ash, silica fume, slag and other minerals by-products in concrete: proceeding of Montebello conference, ACI SP-79, Detroit, pp. 1-48.

[37] Mehta PK (1985). Influence of fly ash characteristics on the strength of Portland – fly ash mixture. Cem. Conc. Res., 15: 669-674.

[38] Mehta PK (1999). Concrete technology for sustainable development. Concr. Int., 21(11): 47-52.

[39] Memon AH, Radin SS, Zain MFM, Trottier JF (2002). Effect of mineral and chemical admixtures on high-strength concrete in seawater. Cem. Concr. Res., 32: 373-377.

[40] Neville AM (1995). Properties of concrete. Longman. Essex.

[41] Neville AM, Brooks JJ (2003). Concrete technology. Perason education limited.

[42] Oner A, Akyuz S, Yildiz R (2005). An experimental study on strength development of concrete containing fly ash and optimum usage of fly ash in concrete. Cem. Concr. Res., 35: 1165-1171.

[43] Papadakis VG (1999). Effect of fly ash on Portland cement systems: Part I. Low-calcium fly ash. Cem. Concr. Res., 29: 1727-1736.

[44] Papadakis VG (2000). Effect of fly ash on Portland cement systems: Part II. High-calcium fly ash. Cem. Concr. Res., 30: 1647-1654.

[45] Papadakis VG, Tsimas S (2002). Supplementary cementing materials in concrete: Part I: efficiency and design. Cem. Concr. Res., 32(10): 1525-1532.

[46] Paya J, Monzo J, Borrachero MV, Mora EP, Lopez EG (1996a). Mechanical treatment of fly ashes part II: particles morphologies in ground fly ashes (GFA) and workability of GFA mortar–cement mortars. Cem. Concr. Res. 26(2): 225-235.

[47] Paya J, Monzo J, Borrachero MV, Peris-Mora E (1996b). Comparison among Magnetic and non-magnetic fly ash fraction: strength development of cement-fly ash mortars. Waste Manage., 16(1-3): 119-124.

[48] Paya J, Monzo J, Peris-Mora E, Borrachero MV, Tercero R, Pinillos C (1995). Early-strength development of Portland cement mortars containing air classified fly ash. Cem. Conc. Res., 25: 449-456.

[49] Karim et al. 4153

[50] Qian J, Caijun S, Zhi W (2001). Activation of blended cements containing fly ash. Cem. Concr. Res., 31(8): 1121-1127.

[51] Ravina D (1997). Properties of fresh concrete incorporating a high volume of fly ash as partial fine sand replacement. Mater. Struct., 30: 473-479.

[52] Rukzon S, Chindaprasirt P (2009). Strength and chloride resistance of blended Portland cement mortar containing palm oil fuel ash and fly ash. Int. J. Miner. Metall. Mater., 16(4): 475-481.

[53] Safiuddinii M, West JS, Soudki KA (2010). Hardened properties of self-consolidating high performance concrete including rice husk ash. Cem. Concr. Compos., 32: 708-717.

[54] Sarkar SL, Kumar A, Das DK, Banerjee G (1995). Utilization of fly ash in the development of cost effective cementitious product. In: The fifth canmet/ACI International conference on fly ash, silica fume, slag, and natural pozzolans in concrete, held in Milwaukee, USA, pp. 439-458.