IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 13, Issue 3 Ver. IV (May- Jun. 2016), PP 01-08
www.iosrjournals.org

Mechanical Properties of High Volume Fly Ash Concrete

F.N.Okoye[1], N.B.Singh[2]
[1.] *Department of Civil Engineering, Sharda University, Greater Noida, India*
[2] *Research and Technology Development Centre, Sharda University, Greater Noida, India*

Abstract: *High volume fly ash concrete reduces the demand for cement and gives mechanical strength appropriate for normal construction. In the present investigation Portland cement has been replaced up to 60% by Fly ash. Five concrete mixes were designed to determine the effect of fly ash on workability, compressive, tensile and flexural strengths of concrete. Portland cement was replaced with fly ash by 20%, 30%, 40% and 60% respectively, while 100% Portland cement was used as control. The mechanical properties were determined at 3, 14, 28, 56 and 90 days of hydration. Heat evolution profile has revealed that with the increase of fly ash, the rate of heat evolution is decreased. X-ray diffraction and SEM studies have shown the formation of different hydration products.*
Keywords: *Fly ash, Portland cement, Strength, High volume, Concrete*

I. Introduction

Concrete is one of the most important building materials (Rashad 2013) and nearly 12 billion tonnes of concrete are made which uses nearly 1.6 billion tonnes of Portland cement (PC) (Malhotra and Mehta 2005). Production of one tonne of PC emits about 1 tonne of CO_2 (Rashad and Zeedan 2011). In addition to CO_2, SO_3 and NO_x gases are also released which deplete ozone layer and causes acid rain (Scrivener and Kirkpatrick 2007, Park Sang and Kang Hwa 2008). Already measures are being taken by the cement industries to reduce green house gases by reducing raw materials and energy consumption. One of the major breakthroughs is the use of supplementary cementitious materials for making blended cements.

Due to industrial development and urbanization, billion tonnes of industrial wastes (mainly referred to solid wastes) are generated annually. The simplest and most efficient way is recycling the industrial wastes by substituting them for the virgin raw materials, supplementary cementitious materials (SCM) and set-controlling material (gypsum) for cement production, thereby reducing the environmental impact of cement industry and other related industries (Tongsheng et. al 2013). Fly ash (FA) produced by burning pulverized coal in power stations consists of finely divided ashes. Certain amount of hydraulic minerals (such as C_3S, C_2S, C_3A) and/or vitreous phases are formed in fly ash during their high temperature formation and/or subsequent cooling treatment, therefore fly ashes present hydraulic or pozzolanic activity and can be used as SCM. HVFA concrete with 50–60% fly ash content is used to achieve the sustainable development (Xiao-Young and Ki-Bong 2015).

In 1970s, HVFA cements were produced by partially replacing 50% PC with low calcium fly ash. However with the use of superplasticizers (SP), the high performance HVFA cement concretes with high workability, satisfactory mechanical properties, and superior durability have been achieved (Hoang-Anh et. al 2015, Bilodeau and Malhotra 2000, Obla et. al 2003). However HVFA cement in concrete suffers with an increases in the initial and final setting times of concrete together with decrease in early and even later ages of compressive strengths (Sujjavanich et. al 2005 and Poon et. al 2000). In order to solve these problems, a good understanding of the mechanism of action of fly ash HVFA cement in concrete is essential. Therefore, the purpose of this research study is to investigate the hydration of HVFA cement and its influence on mechanical properties of the concrete.

II. Experimental Program

2.1. Materials

Ordinary Portland cement (ASTM-150 type 1) and low calcium fly ash (Class F) were used in this investigation. Polycarboxylate type super plasticiser (Chryso-730) complying BS 5075 Part 3 was used. Chemical compositions of PC and FA are given in Table 1. Coarse aggregates of sizes 20 mm and 10 mm were used. Fine aggregate used was river sand.

The specific gravity of 20 mm and 10mm gravel used are 2.5 and 2.4, water absorption were 0.17% and 0.87% and fineness modulus were 2.7 and 2.8 respectively, while that of fine sand was 2.6 and fineness modulus 2.1.

Table1. Chemical composition of PC and FA

Constituents	Composition (%)	
	PC	Fly ash
Silicon dioxide (SiO_2)	19.01	50.7
Calcium Oxide (CaO)	66.89	2.38
Magnesium Oxide (MgO)	0.81	1.39
Phosphate (P_20_5)	0.08	-
Sodium Oxide (Na_2O)	0.09	0.84
Potassium Oxide (K_2O)	1.17	2.40
Manganese Oxide (MnO)	0.19	-
Aluminium Oxide (Al_2O_3)	4.68	28.80
Iron Oxide (Fe_2O_3)	3.20	8.80
Loss on ignition	2.48	3.79

2.2. Mix Proportion

In this investigation, a total of twenty concrete mixes were prepared including the control mix. Ten mixes were made for compressive strength, five for tensile and five for flexural strength measurements. Superplasticizer was used to achieve a desired slump of 40-90 mm with a W/B ratio of 0.3. In all the mixes, the amount of coarse aggregate was kept constant while cement was replaced with fly ash in the ratios of 20%, 30%, 40% and 60% respectively. Mix GCC was used as the control. A detailed mix design is given in Table 2.

Table2. Mix design

Mix NO	Quantity of ingredients Kg/m^3					
	Binder content(Kg/m^3)		Coarse Aggregate content(Kg/m^3)		Fine aggregate	Superplasticizer (wt% with reference to Binder)
	OPC	Fly ash	20mm	10mm	Sand	
GCC	540	0	670	430	711	1.0
GC1	432	108	670	430	653	1.2
GC2	378	162	670	430	639	1.3
GC3	324	216	670	430	623	1.3
GC4	216	320	670	430	610	1.5

GCC= Control, GC1= 20% FA, GC2= 30% FA, GC3= 40% FA,
GC4= 60% FA. W/B ratio = 0.3.

2.3. Slump Cone Test

The workability of the fresh concrete was determined by using slump cone test in compliance with BS EN 12350-2 : 2000 standard.

2.4. Compaction Factor

Compaction factor is another method of determining the workability of concrete. In this study, compaction factor apparatus was used to determine the workability of concrete as per BS 1881:Part 103: 1993 standard.

2.5. Compressive Strength

The compressive strength test was conducted with 100 mm x 100mm x 100mm mould using mix proportions given in Table 3. The specimens were demoulded after 24 hours of casting in wooden moulds and stored in water until the day of testing. The compressive strengths were determined at 3, 14, 28, 56 and 90 d with a compression testing machine of capacity 2000KN at a loading rate of 140KN/min.

2.6. Split Tensile Test

The test was performed with cylindrical mould of size 150mm diameter and 300mm height as per ASTM C 496-90 requirement for all the five concrete mix designs given in Table 3. After demoulding, the specimens were cured in a curing tank for 28 days in accordance with the requirement of BS 1881: Part 3: 1983. After curing, the specimens were wiped to remove water and placed on a compression testing machine with plywood strip packing top and bottom, arranged longitudinally along the plane of loading. The upper plate was carefully lowered to touch the plywood strip. The load was applied continuously without shock at the rate of 400N/s. The split tensile strength was calculated from Eq.(1) Neville (1973).

$$f_t = \frac{2P}{\pi LD} \quad (1)$$

where, f_t= Split tensile strength, P=Maximum load (N), L=Length of specimen and D= Diameter of the specimen

2.7. Flexural Strength

The test was conducted with beam mould of size 100mm x 100mm x 500mm in compliance with EN 12390-51997 requirement. After demoulding, the specimens were cured in a curing tank for 28 days in accordance with requirement of BS 1881: Part 3: 1983. After curing, the specimens were placed in a universal testing machine supported over a span of three times the depth of the beam on two supporting rollers as shown in Fig.1. Two other loading rollers were placed on top of the beam. The arrangement of the specimen on the machine was done in a way that the load was applied towards the surface as cast in the mould. Specimen axis was aligned with the axis of the loading device. The load was applied without shock at the rate of 200m/s.

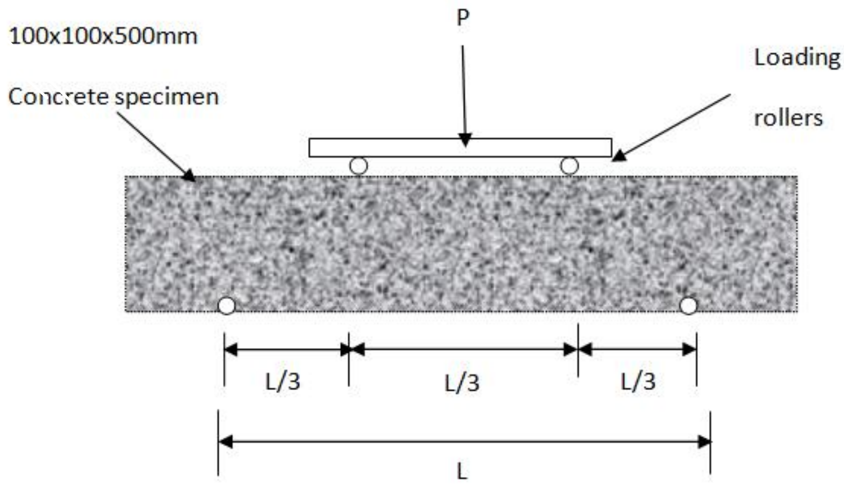


Fig.1. Loading Arrangement for 3-Point Flexural Test

The flexural strength is calculated from Eq.(2) BS 1881-118 (1983).

$$F_{cf} = \frac{PL}{BD^2} \quad (2)$$

where, F_{cf}= flexural strength, P= maximum load (KN), L= distance between the rollers (m), b= average width (m) and d=average depth (m).

2.8 Hydrated Samples

10g each of PC, 60%FAPC and 20%FA PC were weighed in different polythene bags. In each bag 5 mL distilled water was added and mixed thoroughly (w/s = 0.5). The cements were allowed to hydrate at room temperature. Isopropyl alcohol and ether were used to stop the hydration at different intervals of time. The hydrated samples were dried at 105^{o}C and stored in a desiccator.

2.9 X-Ray Diffraction Studies

X-ray diffraction studies of anhydrous PC, PC hydrated for 3 days and 60%FA PC hydrated for three days were recorded with a X-ray diffractometer using CuKα radiation.

2.10 SEM Studies

SEM pictures of 3 days hydrated samples were taken with Quanta FEG 250 ESEM instrument.

III. Results And Discussion

3.1. Heat of Hydration

Rapid heat evolution took place when cement was mixed with water. The variation of rate of heat evolution with time is given in Fig. 2. Soon after contact of cement with water, a rapid heat evolution occured (stage 1) and lasted in about fifteen to thirty minutes. The second stage is the induction period in which very little hydration occured and the concrete became flow able. During the induction period, dissolution of ions continues and nuclei of critical sizes are formed. With the formation of critical size nuclei, hydration of alite phase accelerated with time (stage 3) and reached to a maximum value within 15 h and after that deceleration of hydration started. Concrete temperature increased rapidly during this period. As time increased, the rate of heat generation gradually slowed down (stage 4 & 5) and the process became diffusion controlled. In the presence of Fly ash the rate of heat evolution decreased and the decrease was more in presence of 60 wt% FA. In the presence of fly ash, lowering of heat evolution occurred but the shape remained the same. Fig. 3 shows total heat evolved as a function of time and the curves followed the sequence

PC > PC+20% FA > PC+60%FA

This sequence is due to the fact that as the amount of fly ash increased, total amount of PC generating heat is decreased.

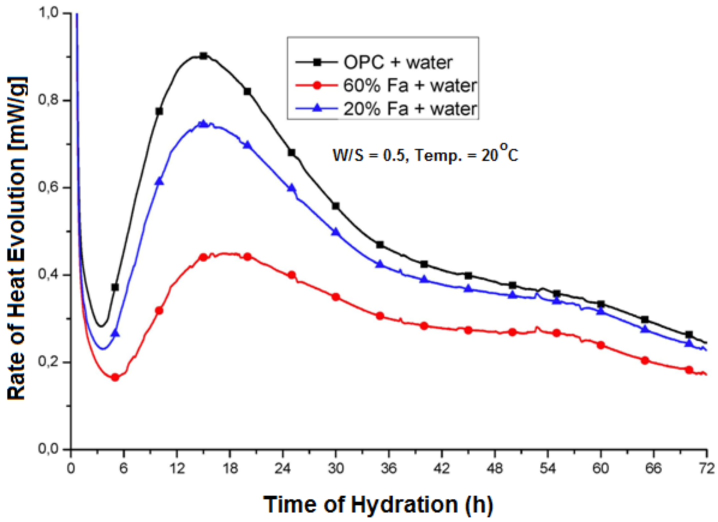


Fig. 2 Rate of heat evolution with time

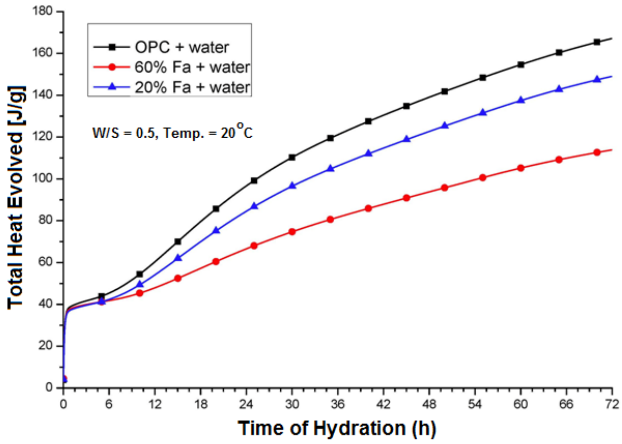


Fig.3 Total heat evolved with time

X-ray diffraction patterns of anhydrous PC and PC+60%FA hydrated for 3days are given in Fig.4. The curves show that PC when allowed to hydrate for three days, a large amount of CH and small amount of ettringite were formed, whereas the concentration of C_3S/C_2S phases were lower as a result of hydration reaction. When PC+60%FA was allowed to hydrate for 3 days, consumption of C_3S/C_2S phases decreased and the amount of CH generated during the hydration of PC alone was decreased. The decrease in CH intensity is due to pozzolanic reaction.

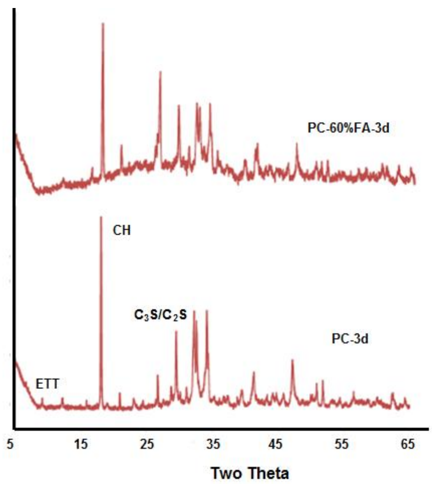
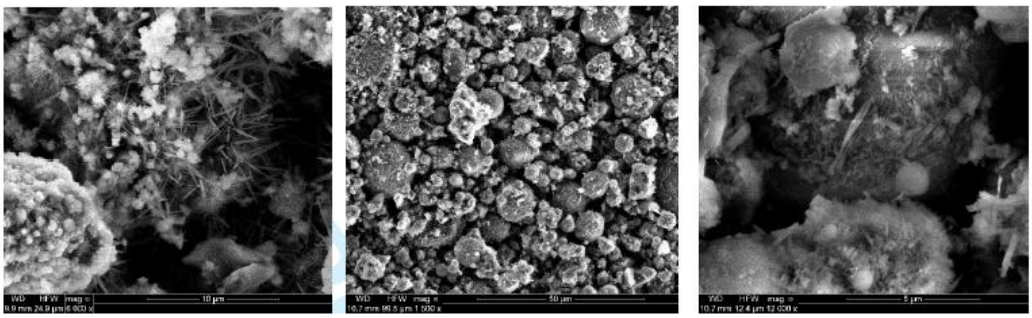


Fig.4 X-ray diffraction

SEM pictures of PC and PC+60%FA hydrated for 3 days are shown in Fig.5. Lot of fibrous hydration products are seen in both the cases but less in PC+60%FA. These may be due to ettringite and CH formation. PC+60%FA hydrated sample also shows lot of unreacted FA particles of spherical shape. From the figure it appears that hydration products are formed at the surface of FA.



a b1 b2

Fig.5 SEM micrograph of (a) PC hydrated for 3 d and (b1&b2)PC+60%FA hydrated for 3 d at two magnifications

Table 3 gives slump and compaction factor values of concretes. The slump loss increased with FA addition. In all the mixes, concrete with fly ash showed higher slump giving higher workability than the control mix at a constant w/c ratio of 0.3 and it was highest with 60%FA replacement. The results on compaction factor test showed similar pattern as that of slump or workability. The compaction factor for GCC and GC4 gave 1% and 4% higher values respectively than the standard value given by BS 1881, Part I03 (1993). The code specified that the compaction factor should be in the range of 0.85-0.95.

Table 3. Slump and compaction factor of concrete with different proportions of fly ash

Mix No	Slump (mm)	Compaction factor
GCC	38	0.96
GC1	40	0.872
GC2	40	0.88
GC3	42	0.90
GC4	48	0.99

The results of compressive strength of HVFA concrete with age are shown in Fig.6. The results showed that the compressive strength increased with time but there is no regular sequence with the increase of FA addition. The values of compressive strength for 60% FA addition were found lowest at all the ages but the values were in the range which can be used for normal construction work. Concrete with HVFA reduces high cement consumption and mitigate against green house emission.

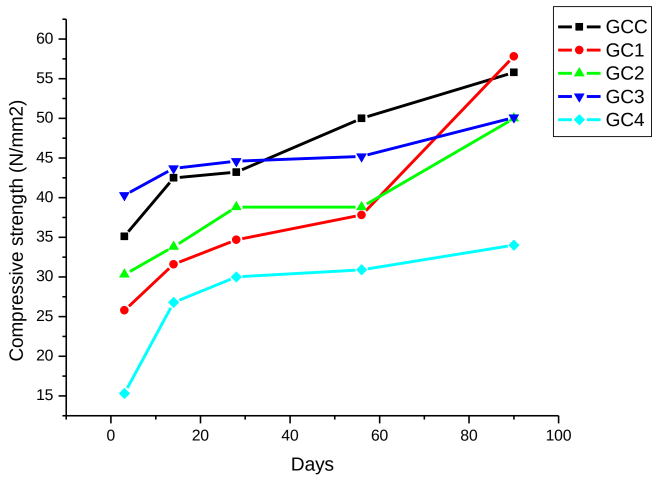


Fig.6 Compressive Strength of Concrete with Various Proportions of Fly Ash

The results of the flexural strength were obtained by casting five beams for each mix design using 100mmx100mmx500mm prism and cured for 28 days. The results are presented in Table 4. It is observed from the result that GC1 and GC2 with 20% and 30% cement replacement have higher flexural strengths than the control. Moreover, the flexural strength of GC3 with 40% replacement is higher than that of GC4 with 60% replacement. All the concrete with fly ash content with the exception of GC4 with 60% fly ash, satisfy the standard set by British Airport Authority (BAA) for Airport pavement quality concrete. The regulations limit the flexural strength to $4N/mm^2$ at 28 day (Calverley 1977). The concrete with 60% fly ash is not suitable for Airport pavement but can be used for low strength concrete for pedestrian walk ways.

Table.4 Flexural strength of concrete with different proportions of fly ash

Mix NO	Percentage replacement	Flexural strength (N/mm^2)
GCC	0	5.25
GC1	20	6.15
GC2	30	5.72
GC3	40	4.35
GC4	60	3.9

In splitting tensile strength, five cylinders were cast for each mix using 150mm diameter and 300mm height cylinder and the specimen cured for 28 days. The results are presented in Fig.7. From the figure it is observed that the tensile strength of concretes made with fly ash are lower than the tensile strength of the corresponding control at the same period of curing.

The values decreased with FA addition. The splitting tensile strengths of all the mix designs satisfied the standard specifications of bridge and road construction. The Department of Transport, Specification for Road and Bridge Works, H.M. Stationery Office, London, 1976, gave specification on the limit of tensile strength of concrete to be used in road construction to be 1.85N/mm2 splitting tensile strength at 7 days. Hence, all the mix designs are suitable for road construction, having satisfied the relevant specifications.

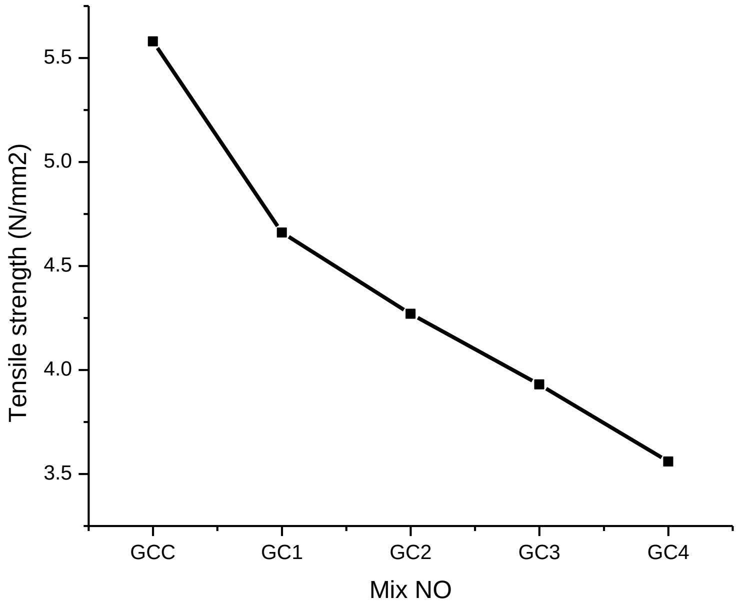


Fig.7 Tensile Strength of OPC Concrete with Different Proportions of Fly Ash

IV. Conclusions

The benefits derived from the use of HVFA concrete have made it possible for engineers and other stakeholders in construction industry to execute projects that are in harmony with nature. Fly ash plays a very important role in greening our environment when used in concrete, not only for its high compressive strength and durability performance but also in areas of sustainability. Following conclusions have been made:

1. The concrete containing different proportions of fly ash showed higher workability than the control. Higher the replacement of cement by FA, the higher was the workability.
2. HVFA cement reduced cement consumption in concrete and minimized the amount of energy required in cement production.
3. The compressive strength of concrete with fly ash decreased as the proportion of fly ash increased without any regular sequence. However the compressive strengths obtained were of the order that could be used for normal construction work.
4. The flexural strength decreased as the proportion of fly ash increased.
5. In general it can be inferred that high volume fly ash concrete can be used in normal construction work.

Acknowledgements

The authors wish to express their profound gratitude to Federal government of Nigeria through the TET FUND for their financial support, without which, it wouldn't have been possible to carry out this research work. We are also thankful to Prof. Godwin Onu, the Rector, Federal Polytechnic Oko, Nigeria for granting the first author study leave and for his moral support.

References

[1]. A. Bilodeau, and V.M. Malhotra, High-volume fly ash system: concrete solution for sustainable development. Mater J; 97(1), 2000, 41–8.
[2]. BS1881 - 118, Testing Concrete - Method for determination of flexural strength. British Standards Institute, London, U.K., 1983.
[3]. BS1881 - 103, Testing Concrete - Method for determination of compacting factor. British Standards. Institute, London, U.K, 1993.
[4]. M.A.A. Calverley, The design of British Airports Authority pavements. Int. Conf. On Concrete Pavement Design, Purdue University, West Lafayette, Indiana, USA, 1977, pp.97–106.
[5]. Department of Transport, Specification for Road and Bridge Works, H.M. Stationery Office, London, 1976.
[6]. V.M. Malhotra and P.K. Metha, High performance, high volume fly ash concrete, 2nd edu. Ottawa (ONT): Supplementary Cementing Materials for Sustainable Development; 2005. 124 pp (available from supplementary cementing materials for sustainable development inc.) Ottawa, Canada, KIY 2B3, 2005.
[7]. A.M. Neville, Properties of Concrete, 2nd Ed. Pitman Publishing, London, U.K, 1973.
[8]. H.A. Nguyen, T.P. Chang, J.Y. Shih, C.T. Chen and T.D. Nguyen, Influence of circulating fluidized bed combustion (CFBC) fly ash on properties of modified high volume low calcium fly ash (HVFA) cement paste, Construction and Building Materials, Vol 91, 2015, pp. 208–215, DOI:10.1016/j.conbuildmat.2015.05.075.
[9]. K.H. Obla, R.L. Hill and R.S. Martin, HVFA concrete—an industry perspective, Concr Int., Vol.25, Issue 8, 2003, pp.29–34, Order URL: http://worldcat.org/oclc/4163061.
[10]. P. Sang-Sook and K. Hwa-Young, Characterization of fly ash-pastes synthesized at different activator conditions. Korean J Chem Eng; 25(1): 2008, 78–83.
[11]. C.S. Poon, L. Lam and Y.L. Wong, A study on high strength concrete prepared with large volumes of low calcium fly ash, Cem Concr Res., Vol.30, Issue 3, 2000, pp.447–455, DOI:10.1016/S0008-8846(99)00271-9.
[12]. [A.M. Rashad, Metakaolin as cementitious material: History, scours, production and composition – A comprehensive overview, Construction and Building Materials, Vol.41, 2013, pp. 303–318, DOI:10.1016/j.conbuildmat.2013.03.038.
[13]. A.M. Rashad and S.R. Zeedan, The effect of activator concentration on the residualstrength of alkali-activated fly ash pastes subjected to thermal load, Constr Build Mater, Vol.25, 2011, pp.3098–3107, DOI:10.1016/j.conbuildmat.2010.12.044.
[14]. K.L. Scrivener and R.J. Kirkpatrick, Innovation in use and research on cementitious material. In: 12th International congress of chemistry of cement, Montreal, Canada, 2007.
[15]. S. Sujjavanich, V. Sida and P. Suwanvitaya, Chloride permeability and corrosion risk of high-volume fly ash concrete with mid-range water reducer. Mater J;102(3):2005, 177–82.
[16]. Z. Tongsheng, G. Peng, G. Pinhai, W. Jiangxiong and Y. Qijun, Effectiveness of novel and traditional methods to incorporate industrial wastes in cementitious materials—An overview, Resources, Conservation and Recycling;74:2013, 134– 43.
[17]. W. Xiao-Yong and P. Ki-Bong, Analysis of compressive strength development of concrete containing high volume fly ash, Construction and Building Materials, Vol.98,2015, pp.810–819, DOI:10.1016/j.conbuildmat.2015.08.099.