Size Effect Study on Fly Ash Concrete

C.Marthong

Lecturer, Civil Engineering Department, Shillong Polytechnic, Shillong
Shillong, Meghalaya, India, 793008

Abstract

An experimental study on geometrically similar fly concrete cylinder of different sizes subjected to compressive load was carried out. Strength was evaluated at age of 28 and 90 days. This study investigated the size effect phenomenon for concrete inclusion with 20% fly ash as partial replacement of cement. Results from the test showed the existence of a size effect of fly ash concrete and followed closely the size effect law proposed by Bažant. The size effect is more pronounce at the age of 28 days strength as compared to 90 days strength.

Keywords: Fly ash, strength, size effect, Bažant.

1. Introduction

Available theories of material behavior that predict size effects are receiving increasing attention in the technical literature nowadays. It has been demonstrated that the size of the specimen plays an important role. Thus, the use of test results from standard specimen should be judiciously done in practice giving due consideration to the existence of size effect. Concrete is a heterogeneous material, which is generally full of micro cracks. Upon loading, these micro cracks propagate and the accumulation of such micro cracks leads to a major crack and finally ends in failure. It is well established that the mathematical modeling of such behavior should be based on the principles of fracture mechanics. Material models based on fracture mechanics can predict a size effect, if geometrically similar specimens of different sizes are considered. In brief, the "size effect" can be stated that the nominal stress (σ_N) at failure decreases as the characteristic dimension (D) of the structure is increased. Many researchers tried to correlate the result of σ_N found by testing specimens with the size effect law proposed by Bažant [1984].

According to ASTM C-618 [1978], pozzolana is a siliceous or a siliceous aluminous material which contains little or no cementitious value, but in finely divided form and in the presence of moisture or water, chemically reacts with calcium of moisture at ordinary temperature to form compound possessing cementitious properties. Such material commonly includes fly ash, calcined diamotaceous earth, rice husk ash and pulverized burnt clay. Many researchers are being done on the possible use of locally available materials to partially replace cement in concrete as cement is widely noted to be most expensive constituents of concrete. The utilization of fly ash in concrete as partial replacement of cement is gaining immense importance today, mainly on account of the improvement in the long-term durability of concrete combined with ecological benefits. India has vast resource of fly ash generation all across the country. This material if segregated, collected and used properly can resolved the major problems of fly ash disposal and reducing the use of cement, which consumes lot of energy and natural resources. Different grades of ordinary Portland cement (OPC) are available depending on the respective country codal classification. Bureau of Indian Standard (BIS) normally classify three grades of OPC namely: 33, 43 and 53, which are commonly used in construction industry. The strength gain in fly ash concrete also depends on the grades of OPC [Marthong, 2002].

Extensive research has shown the use of substitute's material, which possessing pozzolanic properties (fly ash) that it can produce concrete of better resistance to sulphate attack and reduce permeability. Study conducted by Mehta [1983], [Meland, 1986], Naik and Ramme [1990], Mullick [2005], Shi Cong et al. [2008)] have shown that inclusion of fly ash as partial replacement of cement contributes to the long-term strength gain and improvement in durability. However, experiments on various form of fly ash concrete are being conducted without varying the size of tested specimens. Thus, the available results cannot be used directly for prototype implementation in actual field because of differs in the size of specimen. The optimum percentage of fly ash added in concrete depends on the type and sources of fly ash. However, researchers reported an optimum amount varies from 10-20% for which fly ash concrete has lesser effect on the strength at the later age. Therefore, in the present study 20% replacement by fly ash on cement was considered.

2. Size effect law

Classical theories assumed that the strength of geometrically similar structure is not size dependent. This assumption is based on plasticity analysis. Concrete structures, which are quasi-brittle in nature, however do not follow this trend. Therefore, the size effect implies the dependence of strength of structure on its size. The size dependency of concrete structures may be described by the size effect law proposed by Bažant [1984] covering various practical cases. The mathematical expression of this law is given as

$$\sigma_{N_U} = \frac{Bf_t^{/}}{\sqrt{1+\dfrac{D}{D_0}}} \qquad (1)$$

where, $f_t^{/}$ is the tensile strength of concrete, B and D_0 are two empirical constants depending on the shape of structures and obtained by linear regression analysis of the test results. D/D_0 is the relative structural size ratio. The strength is usually defined as nominal stress at peak load. There are various possible correlations of the size effect, but bi-logarithmic representation is the most accepted one. In bi-logarithmic plot, log σ_{N_U} is plotted against log D. Fig. 1 show a typical plot where strength theory based on yield or strength criteria predicts no size effect, represented by horizontal line. The size effect is stronger with the response lying closer to the linear elastic fracture mechanics (LEFM) and asymptote i.e. with a slope of -1/2.

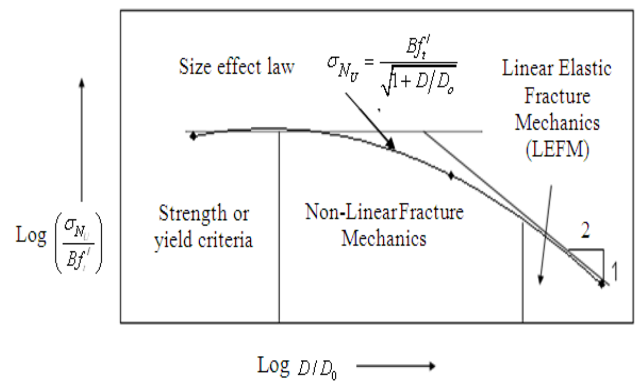

Fig. 1 Plot of size effect law [Bažant, 1984]

3. Review on size effect of concrete structural element

The experimental research on size effect of concrete structural elements may be traced long back in 1925 [Sabnis and Mirza, 1979]. Sener et al. [1999] tested two groups of RC beams with various sizes. The results revealed the existence of a significant size effect, which was approximately described by the size effect law proposed by Bažant. Krauthammer et al. [2003] investigated numerically and experimentally the size effect phenomenon of high strength concrete (HSC) for a cylindrical specimens that subject to axial load impact. Results from their tests and simulations showed the existence of a size effect in NSC cylinders under impact loading. Sener et al. [2004] tested a large number of geometrically similar columns with three different slenderness ratios. The size effects become stronger as the slenderness ratio increases. Elfahal et al. [2005] investigated numerically and experimentally the size effect phenomenon of normal strength concrete (NSC) for a cylindrical specimens that subject to axial load impact. Results from their tests and simulations showed the existence of a size effect in NSC cylinders under impact loading. Bindiganavile and Banthia [2006] studied size effect of plain concrete beam under impact loading. The result of the impact test fitted to Bažant's size effect law. Koc and Sener [2009] tested geometrically similar columns of different sizes with different types of notches for both normal and high strength concrete to study the size effect. Axial loads were applied to the specimens till failure. The bi-logarithmic plots in all the cases followed Bažant's size effect law. Choudhury [2010] tested eighteen beam-column connections specimens with nine controls and nine retrofitted of three different sizes for size effect study. The bi-logarithmic plots for both control as well as retrofitted specimens follow closely the size effect law. Marthong [2012] tested thirty six beam-column connections specimens with eighteen control and eighteen rehabilitated specimens of three sizes under two different cyclic loading frequencies for size effect study. The bi-logarithmic plots for both control as well as rehabilitated specimens follow closely the size effect law.

Literature survey shows researchers correlated the existence of size effect with the size effect law proposed by Bazant [1984]. Size effect study has been carried out on various concrete structural elements including plain and high strength concrete. The use of fly ash in concrete is gaining immense importance today, mainly on account of the improvement in the long-term durability of concrete combined with ecological benefits. The review of literature however, could not find any size effect study related to fly ash concrete. Thus, it was felt necessary to explore the possibility of existence of size effect when OPC was partially replaced by fly ash.

4. Experimental program

Experimental investigations are carried out on concrete cylinders. Four different sizes as shown in Fig. 2 were considered. Aggregate was scale down appropriately. The mix was designed for target cube strength of 30 MPa at 28 days with water-cement ratio of 0.38. OPC of 53 grades was partially replaced with 20% fly ash by weight [Marthong, 2002]. A simple method of mix proportioning using fly ash (i.e. fly ash as part replacement of cement by weight) has been adopted. The compressive strength was examined at 28 days and long term contribution up to 90 days. Therefore, six specimens were cast per size of sample for strength test. Specimen sizes and detail proportions are shown in Table 1.

Coarse aggregate from crushed basalt rock was use. Flakiness and Elongation Index were maintained well below 15%. River sand was used as fine aggregate. Material used have been tested as per relevant codal provision [IS 2386 (I, III), 1963].

53 grades OPC classified by BIS conforming to IS 12269 [1987] was used.

Fly ash (FA) used in this study was obtained from Obra Thermal Power Plants, India. This fly ash conforms to the requirement of IS 3812 (Part I) [2003] and also ASTM C-618 type F [1878]. Specific gravity of FA and OPC are found out to be 2.51 and 3.20 respectively.

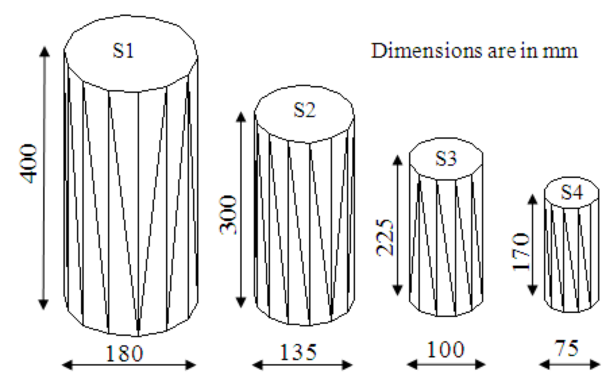

Fig. 2 Concrete specimen sizes

Table 1 Specimen sizes and detail proportions of OPC and FA

Symbols	Replacement Ratio	Mark	Sizes, mm (height x diameter i.e. H x D)	Nos
FA-0	100% OPC+0% FA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6
FA-20	80% OPC+20% FA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6

5. Role of fly ash on cementitious and concrete properties

The fineness of fly ash is required to be equal or finer than cement for its good cementing efficiency. Fineness of OPC in this investigation is found to be 6% residue on 90 micron sieve, while that of fly ash is 5%. This show that fly ash is of finer and hence can be expected to have appreciable influence on the strength development on concrete.

Normal consistency of cement with inclusion of fly ash increased as compared to pure cement. Hence more water is required for wetting the particles, as the total surface area of the particle is increases.

Setting time of cement with inclusion of fly ash increased as compared to pure cement paste. The delays in setting times is due to the reducing the C_3S ($3CaO.SiO_2$) content and C3A ($3CaO.Al_2O_3$) and thus increasing the C_2S ($2CaO.SiO_2$) contents.

Inclusion of fly ash increases the soundness of mixtures or decreases the Le-Chatelier's expansion because of decreasing in carbon and increasing in silica content.

Workability of concrete increased with the inclusion of fly ash in comparison to that of concrete with pure cement. The reason may be due to the increase of the paste volume that leads to the increase of plasticity and cohesion.

Table 2 presents the compressive strength for different combination at different ages of 28 and 90 days. It is seen that strength of concrete decreases with inclusion of fly ash in all sizes. However, the gain in strength by the smaller specimens at the age of 90 days is better as compared to the larger specimen size.

Table 2 Compressive strength

	28 Days Compressive strength (N/mm^2)		**90 Days Compressive strength (N/mm^2)**	
Mark	**FA-0%**	**FA-20%**	**FA-0%**	**FA-20%**
S1	32.687	25.44	36.238	28.56
S2	23.93	18.56	26.91	21.30
S3	16.43	13.30	19.45	15.89
S4	11.88	10.23	14.45	12.52

6. Analysis of results for exploring the presence of size effect

The strength is usually defined as nominal stress at peak load. Stress (σ_{N_U}) in all specimens were calculated and bi-logarithmic plots were drawn. Other parameter was also considered and the possible existence of size effects was investigated.

6.1 Bi-logarithmic plot

Using stress (σ_{N_U}) and characteristic dimension (D), bi-logarithmic plots were drawn. The size effect law as proposed by Bažant [1984] given in Eqn. 1 was used for the statistical regression of the data. B and D_0 are the two unknown constants which can be determined by statistical regression analysis. The value of tensile strength of concrete ($f_t^{/}$) was calculated as per IS 456 [2000] and was taken as 2.504 N/mm^2. To facilitate the evaluation of the constants in the size effect law, Eqn. 1 can be rearranged as follows:

$$\left(\frac{f_t^{/}}{\sigma_{N_U}}\right)^2 = \frac{1}{D_0 B^2}.D + \frac{1}{B^2} \qquad (2)$$

The above equation is of the form of $Y = AX+C$ where $Y = \left(f_t^{/} \big/ \sigma_{N_U} \right)^2, X = D$ and the constants C and A are given by $C = \frac{1}{B^2}$ and $A = \frac{1}{D_0 B^2}$, Hence value of B and D_0 are $B = \frac{1}{\sqrt{C}}$ and $D_0 = \frac{C}{A}$. The calculated value of all stresses and other parameters necessary to carry out regression analysis and to draw bi-logarithmic plot are presented in the Table 3. The typical regression analysis for concrete with 0% FA at 28 days is shown in Fig. 3 and values of B and D_0 were found to be 0.87 and 48.85 respectively. Using these values, the bi-logarithmic plot were drawn with log (D/D_0) in the X axis and log $(\sigma_{N_U} \big/ B f_t^{/})$ in the Y axis as shown in Fig. 4. Similarly, values of B and D_0 for other specimens were calculated and all bi-logarithmic plot are drawn accordingly (Fig. 5 to 7). It is observed from these plots that the trend of the curve follows a horizontal line at the initial part, indicating no size effect. The curve approaches a straight line with slope of about -1/2 towards the end (LEFM zone). In the intermediate zone there is a smooth curved transitional part. Thus, it can be concluded that all plot shows presence of size effect in accordance with Bažant's size effect law. However, size effect of fly ash concrete was observed to be more prominent for the specimens tested at 28 days as compared to that of 90 days.

Table 3 Parameters for bi-logarithmic plotting

Specimen		σ_{NU} N/mm^2	Dia. D (mm)	$\left(\frac{f_t'}{\sigma_{NU}}\right)^2$	Log (D/Do)	$Log\left(\frac{\sigma_{NU}}{Bf_t'}\right)$
0% FA at 28 days	S1	1.285	180	3.796	0.714	0.108
	S2	1.672	135	2.241	0.538	0.283
	S3	2.093	100	1.431	0.360	0.367
	S4	2.690	75	0.860	0.182	0.429
20% FA at 28 days	S1	1.000	180	6.267	0.671	-0.112
	S2	1.297	135	3.726	0.495	0.185
	S3	1.694	100	2.184	0.317	0.342
	S4	2.317	75	1.168	0.139	0.365
0% FA at 90 days	S1	1.425	180	3.088	0.649	0.153
	S2	1.881	135	1.772	0.473	0.353
	S3	2.478	100	1.021	0.296	0.431
	S4	3.272	75	0.585	0.016	0.515
20% FA at 90 days	S1	1.123	180	4.973	0.631	0.050
	S2	1.489	135	2.829	0.454	0.283
	S3	2.024	100	1.530	0.277	0.382
	S4	2.835	75	0.779	0.099	0.153

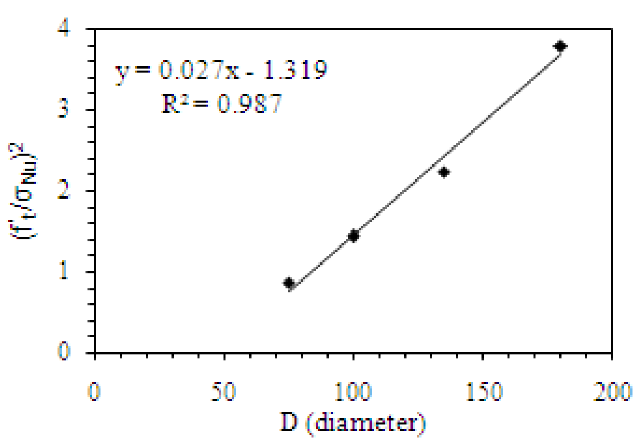

Fig. 3 Typical regression plot

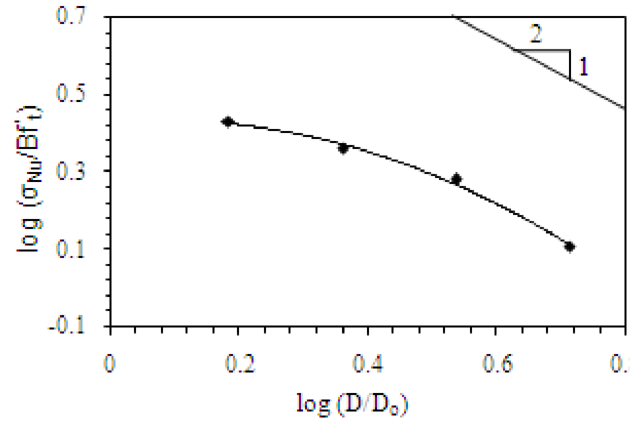

Fig. 4 Bi-logarithmic plot for 0% FA at 28 days

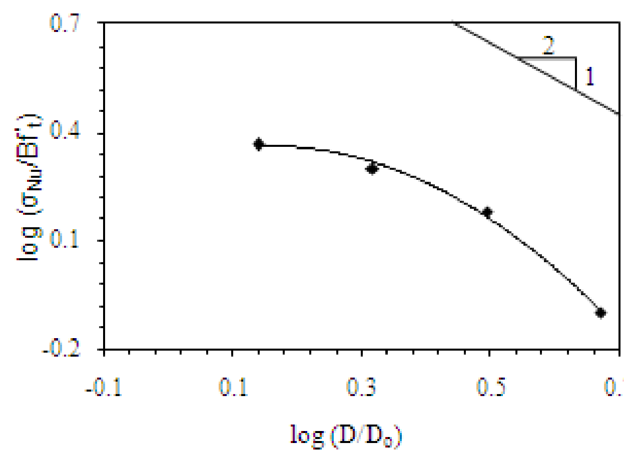

Fig. 5 Bi-logarithmic plot for 20% FA at 28 days

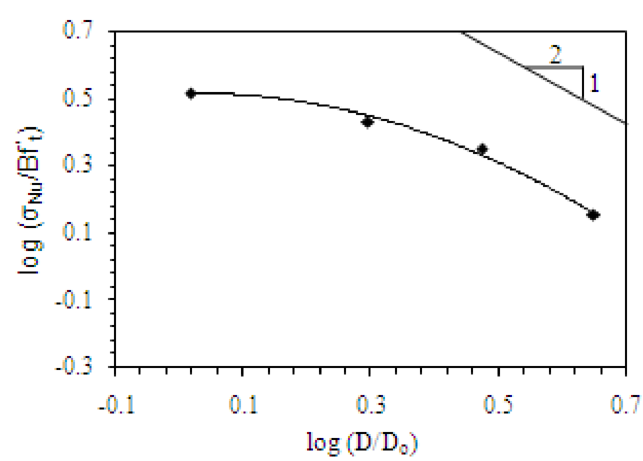

Fig. 6 Bi-logarithmic plot for 0% FA at 90 days

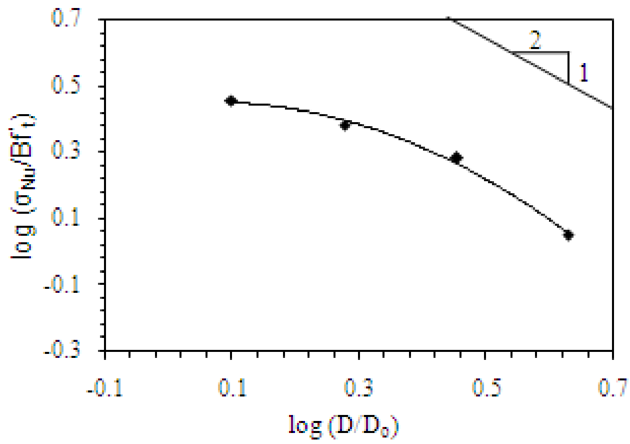

Fig. 7 Bi-logarithmic plot for 20% FA at 90 days

6.2 Size effect on gain in ultimate strength

The compressive strength of all specimens at age of 28 and 90 days are shown in Table 2. The contribution to long term gain in strength at 90 days over the 28 days was calculated. It is observed that cement replacement by fly ash has lesser effect on the strength at the later age. The variation of this gain is presented in Fig. 8. This clearly indicates that the gain in strength increases as the specimen size decreases supporting the size effect principle.

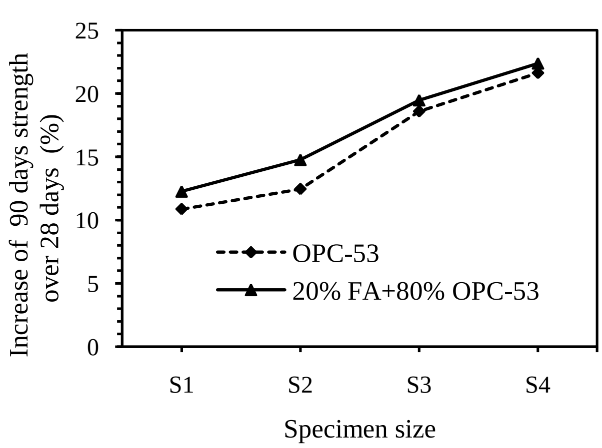

Fig. 8 Gain of strength at 90 days over 28 days

7. Conclusions

Analyzed results were used for drawing bi-logarithmic plot. For the purpose of statistical regression of data, the size effect law proposed by Bažant [1984] was used. Different plots were drawn for concrete strength with 0% and 20% replacement by fly ash. Strength test were performed at 28 and 90 days. In all the cases, it was found that these graphs followed the well established size effect law as proposed by Bažant [1984]. It was also noted that, the gain in long term strength for small specimen was the maximum and it decreased as the specimen size increased. This is an indication for existence of size effect. Further, size effect on fly ash concrete was observed to be more at the early age of 28 days as compared to the 90 days strength.

References

[1] ASTM. *Specification for pozzolanas.* ASTM C 618 1978, Philadelphi.

[2] Bažant, Z. P. (1984). *Size effect in blunt fracture: Concrete, rock, metal*. Journals Engineering Mechanics, ASCE, **110**(4): 518–535.

[3] Bindiganavile, V., and Banthia, N. (2006). *Size effects and the dynamic response of plain concrete.* Journal of Materials in Civil Engineering, ASCE, **18**(4), 485-491.

[4] Choudhury, A. M. (2010). *Study on size effect of RC beam-column connections with and without retrofitting under cyclic loading*. Doctoral Thesis, Department of Civil Engineering, Indian Institute of Technology, Guwahati, India.

[5] Elfahal, M. M., Krauthammer, T., Ohno, T., Beppu, M., and Mindess, S. (2005). *Size effect of normal strength concrete cylinder subjected to axial impact.* International Journal of Impact Engineering, Elsevier, **31**,461-481.

[6] IS 2386 (1963). *Methods of test for aggregates for concrete - Part 1: Particle size and shape*. Bureau of Indian Standard, New Delhi.

[7] IS 2386 (1963). *Methods of Test for aggregates for concrete - Part 3: Specific gravity, Density,*

Voids, Absorption and Bulking. Bureau of Indian Standard, New Delhi.

[8] IS 12269 (1987). *Specification for OPC-53 grade cement*. Bureau of Indian Standard, New Delhi.

[9] IS 3812(2003). *Pulverized fuel ash-Specification, Part I: For use as pozzolana in cement mortar and concrete (Second Revision)*. Bureau of Indian Standard, New Delhi.

[10] IS 456 (2000). *Plain and reinforced concrete - Code of Practice*. Bureau of Indian Standard, New Delhi.

[11] Krauthammer, T., Elfahal, M. M., Ohno, T., Beppu, M., and Mindess, S. (2003). *Size effect of high strength concrete cylinder subjected to axial impact.* International Journals of Impact Engineering, Elsevier, **28**, 1001-1016.

[12] Koc, V., and Sener, S. (2009). *Size effect in normal- and high-strength concrete with different notches under the axial load*. Journal of Materials in Civil Engineering, ASCE, **21**(9), 433-445.

[13] Marthong, C. (2002). *Effect of partial replacement of three grades of cement by fly ash on concrete properties*. M.Tech Thesis, Civil Engineering Department, Institute of Technology-BHU, Varanasi, India.

[14] Marthong, C.M. (2012). *Experimental study on rehabilitated RC beam-column connections under cyclic loading*. Doctoral Thesis, Department of Civil Engineering, Indian Institute of Technology, Guwahati, India.

[15] Mehta, P. K. (1983). *Pozzolanic cementitious by-products as mineral admixtures for concrete –A critical review.* ACI Journal, Vol. **79**, 1983, pp. 1.

[16] Meland, F (1986). *Use of fly ash in cement to reduce alkali-silica reaction. Fly ash, silica fume, slag and natural pozzolana in concrete.* Pro. 2nd Int. Conf: ACI pub. Sp-91, V.M.Malhotra, ed., American Concrete Institute (ACI), Detroit, Mich., 1986, pp. 591-608.

[17] Mullick, A. K (2005). *Use of fly ash in structural concrete: Part I-Why?,* The Indian Concrete Journal, Vol. **79** (5), pp. 13-22.

[18] Naik, T. R., and B. W. Ramme, B. W. (1990). *Effects of high lime. Fly ash content on water demand, time of set and compressive strength of concrete.* ACI Materials Journal, **87,** pp. 619-26.

[19] Shi Cong, Chi Sun Poon and Dixon Chan (2008). *Influence of fly ash as a cement addition on the hardened properties of recycled aggregate concrete*. Material and structures, **41,** pp. 1191 - 1201.

[20] Sabnis, G., M, Mirza, M., S (1979). *Size effects in model concrete* Journal of Structural Division, ASCE, **105**(ST6), 1007-1020.

[21] Sener, S., Barr BIG, and Abusiaf, H. F. (2004). *Size effect in axially loaded reinforced column.* Journal Structural Engineering, ASCE, **130**(4):662-670.

[22] Sener, S., Bažant, Z. P., and Becq-Giraudon, E. (1999). *Size effect on failure of bond splices of steel bars in concrete beams.* Journals of Structural Engineering, ASCE, **125**(6), 653-660.