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Comparative Size Effect Study of Concrete Made With Materials Possessing Pozzolanic Properties

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Abstract—The entire construction industry is in search of a suitable and effective the waste product that would considerably minimize the use of cements and ultimately reduces the construction cost. Fly ash (FA), Sawdust ash (SDA) and Rice husk ash (RHA) which has the pozzolanic properties is a way forward. Experiments of various forms of concrete made with materials possessing pozzolanic properties have been carried out without varying the specimen size. It has been demonstrated that the size of the specimen plays an important role. Therefore, the available results cannot be used directly for prototype implementation in actual field because of differs in the size of specimen. The present study investigated the size effect phenomenon for plain-concrete and concrete inclusion with materials possessing pozzolanic properties as partial replacement of cement. Geometrically similar concrete cylinders of different sizes were cast. Compressive strength was evaluated at the age of 28 and 90 days. Bažant size effect law was used to investigate the possible existence of size effect. Results from the test showed similar trend on the existence of size effect in both plain-concrete and concrete inclusion with materials possessing pozzolanic properties. This suggest that test results from standard specimen should be judiciously exercise in practice giving due consideration to the existence of size effect. Further, size effect was observed to be more for concrete inclusion with materials possessing pozzolanic properties as compare to concrete with pure cement and more pronounce at the age of 28 days as compared to 90 days strength.

Keywords— Fly ash, Sawdust ash, Rice husk ash concrete, Strength, Bazant Size effect law.

I. INTRODUCTION

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. Available theories of material behavior that predict size effects are receiving increasing attention in the technical literature nowadays. 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 Bazant [1].

Pozzolanic definition given in [2] is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form in the presence of moisture, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties.

Many researches 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. Experimental study to evaluate the behaviour of concrete for the possible used in the construction industry with the inclusion of various waste products such as fly ash [3, 4], Rice husk ash [5, 6], sawdust ash [7] are available in the technical literature. In most cases, experiments on various forms of concrete specimens with or without inclusion of material possessing pozzolanic properties have been carried out without varying the specimen size. Therefore, 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 material possessing pozzolanic properties added in concrete depends on their sources. However, researchers reported an optimum amount varies from 5-20% for which concrete has lesser effect on the strength at the later age. In the present study, 10% replacement on cement by RHA was considered [6]. The detail percentage replacement on cement by material possessing pozzolanic properties is furnished in Table 1.

II. SIZE EFFECT LAW

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 [1] covering various practical cases. The mathematical expression of this law is given as:

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

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.

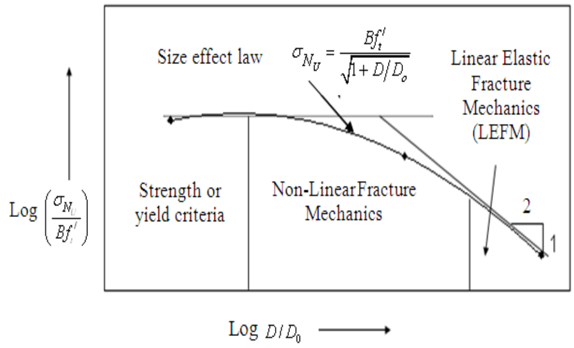

Fig. 1 Plot of size effect law [1984]

III. 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 [8]. Reference [9] 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. Reference [10] investigated the size effect phenomenon of high strength concrete (HSC) for a cylindrical specimens that subject to axial load impact. Results showed the existence of a size effect in NSC cylinders under impact loading. Reference [11] tested a large number of geometrically similar columns with three different slenderness ratios. The size effects become stronger as the slenderness ratio increases. Reference [12] investigated numerically and experimentally the size effect phenomenon of normal strength concrete (NSC) for a cylindrical specimens that subject to axial load impact. Results showed the existence of a size effect in NSC cylinders under impact loading. Reference [13] studied size effect of plain concrete beam under impact loading. The result of the impact test fitted to Bažant's size effect law. Reference [14] 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. Reference [15] tested beam-column joints retrofitted of three different sizes for size effect study. The bi-logarithmic plots follow closely the size effect law. Reference [16] tested beam-column rehabilitated connections of three sizes under two different cyclic loading frequencies. In both cases, the bi-logarithmic plots follow closely the size effect law. Twenty four geometrical similar concrete cylinder with four different sizes made of fly ash-concrete [17] and sawdust ash-concrete [18] were tested for size effect study. The bi-logarithmic plots shows the effect in size is more pronounce at the early age of concrete strength. Literature survey shows researchers correlated the existence of size effect with the size effect law proposed by Bazant [1]. Size effect study has been carried out on various concrete structural elements including plain, high strength, fly ash and sawdust ash concrete. The review of literature however, could not find any size effect study related to RHA concrete and its comparative study with other materials are addressed together. Thus, it was felt necessary to explore the possibility of existence of size effect when OPC was partially replaced by RHA.

IV. 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. The replacement of 53 grades OPC by weight with materials possessing pozzolanic properties are given in Table 1. 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. River sand was used as fine aggregate. Materials used have been tested as per relevant codal provision [19, 20]. Ordinary Portland cement (OPC) of 53 grades classified by BIS [21] was used. The rice husk collected from local mill in Meghalaya was used in this study [6].

Table 1: **Specimen sizes and detail proportions of OPC and RHA**

Symbols	Replacement Ratio	Mark	Sizes, mm [height(H) x diameter(D)]	Nos.
RHA-0 **[Present study]**	100% OPC+0% RHA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6
RHA-10 **[Present study]**	90% OPC+10% RHA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6
FA-0 and FA-20 **(Marthong, 2012e) [17]**	100% OPC+0% FA 80% OPC+20% FA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6
SDA-0 and SDA -10 **(Marthong, 2012f) [18]**	100% OPC+0% SDA 90% OPC+10% SDA	S1 S2 S3 S4	400x180 300x135 225x100 170x75	6 6 6 6

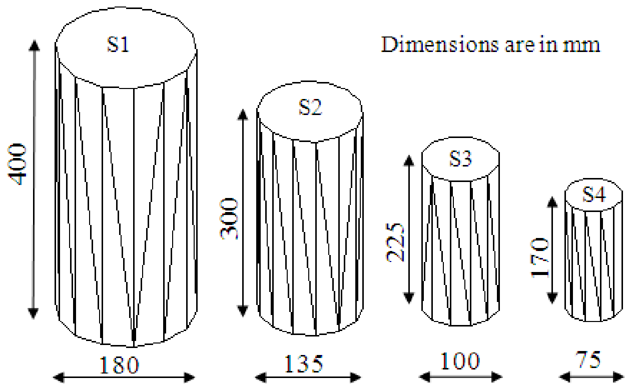

Fig. 2 Concrete specimen sizes

Table 2: **Compressive strength**

	28 Days Compressive strength (N/mm^2)		90 Days Compressive strength (N/mm^2)	
Mark	**RHA-0%**	**RHA-10%**	**RHA-0%**	**RHA-10%**
S1	31.36	24.31	35.21	27.44
S2	22.33	16.58	24.58	20.21
S3	14.10	12.12	18.43	14.89
S4	10.18	9.00	13.67	12.45

V. ROLE OF RHA ON CEMENTITIOUS AND CONCRETE PROPERTIES

The fineness of RHA 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 RHA is 5%. This show that RHA 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 RHA 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 RHA increased as compared to pure cement paste. This behavior may be due to the low rate of hydration in the paste containing RHA.

Workability of concrete increased with the inclusion of RHA in comparison to that of concrete with pure cement. Therefore, it can be inferred that to attain the required workability, mixes containing RHA will required higher water content than the corresponding conventional mixes.

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 RHA 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.

VI. 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 such as gain in ultimate strength 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 [1] 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 2.504 N/mm^2 [22]. 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 $Y = \left(f_t^/ / \sigma_{N_U} \right)^2, X = D$ 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 typical regression analysis for concrete with 0% RHA at 28 days is shown in Fig. 3 and values of *B* and D_0 were found to be 0.75 and 48.60 respectively. Using these values, the bi-logarithmic plot were drawn with log (D/D_0) in the *X* axis and log $(\sigma_{N_U} / Bf_t^/)$ in the *Y* axis as shown in Fig. 4a. Similarly, values of *B* and D_0 for other specimens were calculated and all bi-logarithmic plot are drawn accordingly (Fig. 5a and 6a). 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 RHA-concrete was observed to be more prominent for the specimens tested at 28 days as compared to that of 90 days. The bi-logarithmic plot for concrete inclusion with fly ash (Fig. 5b and 5c) and sawdust ash (Fig. 6b and 6c) are also present here for comparative study. Comparing these curves, it is observed that in all cases the plot follow a similar trends. This shows that, in all form of concrete there exist a significant size effect, which gives an attention that test results from standard specimen should be judiciously used in practice giving due consideration to the existence of size effect.

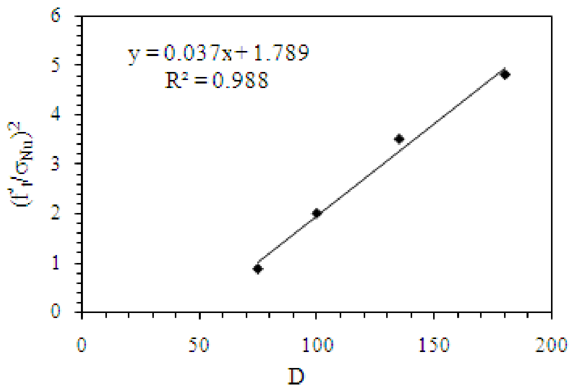

Fig. 3 **Typical regression plot**

6.2 Size effect on gain in ultimate strength

The compressive strength of all RHA-concrete 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 RHA has lesser effect on the strength at the later age. The variation of strength gain as shown in Fig. 7a follow a similar trend as that of concrete inclusion with fly ash and sawdust ash shown in Fig. 7b and 7c. This clearly indicates that the gain in strength increases as the specimen size decreases supporting the size effect principle in all form of concrete irrespective of materials.

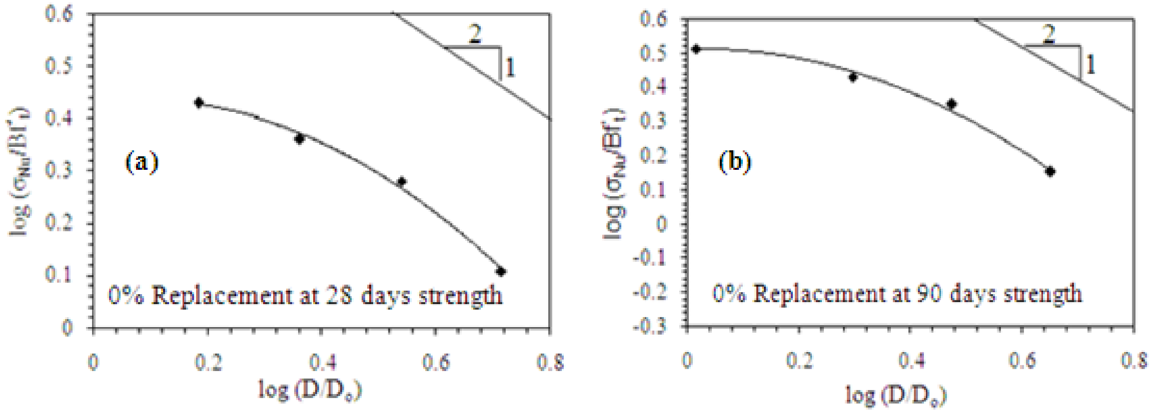

Fig. 4 Bi-logarithmic plot for pure concrete

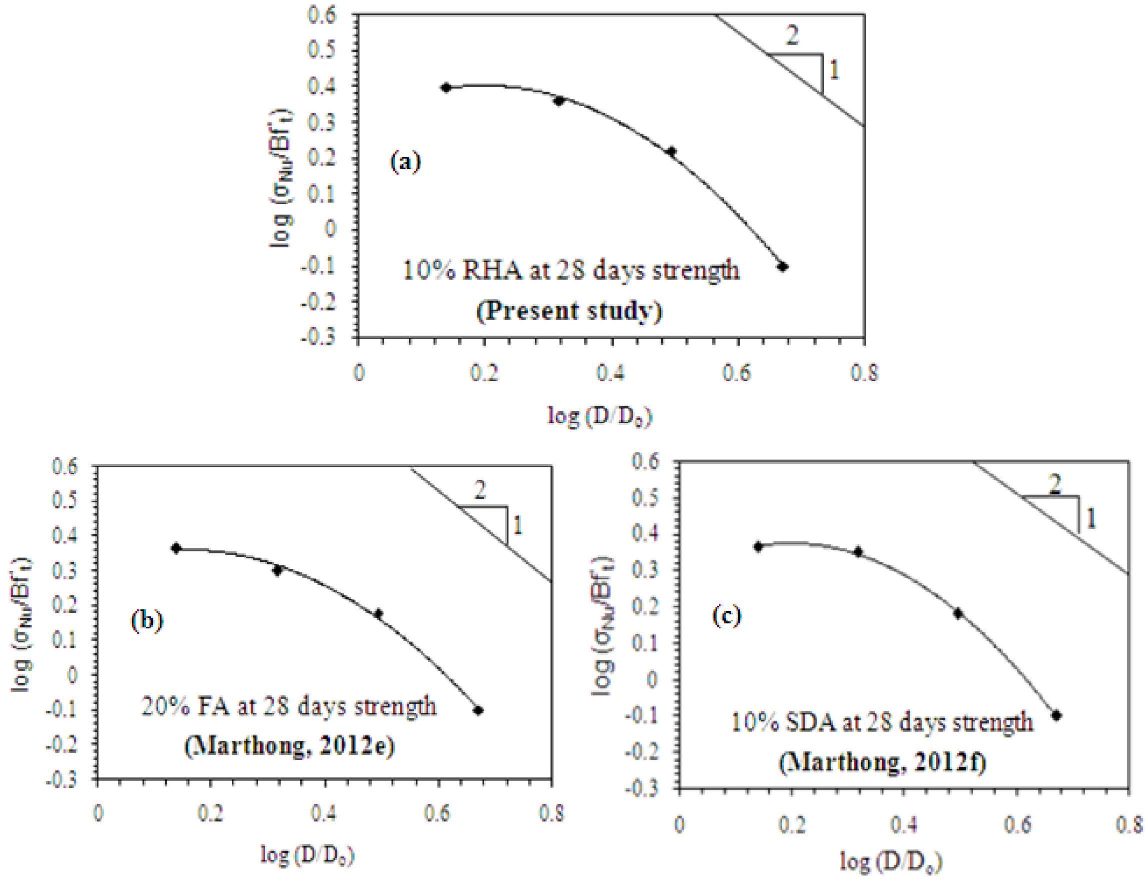

Fig. 5 Bi-logarithmic plot at 28 days strength

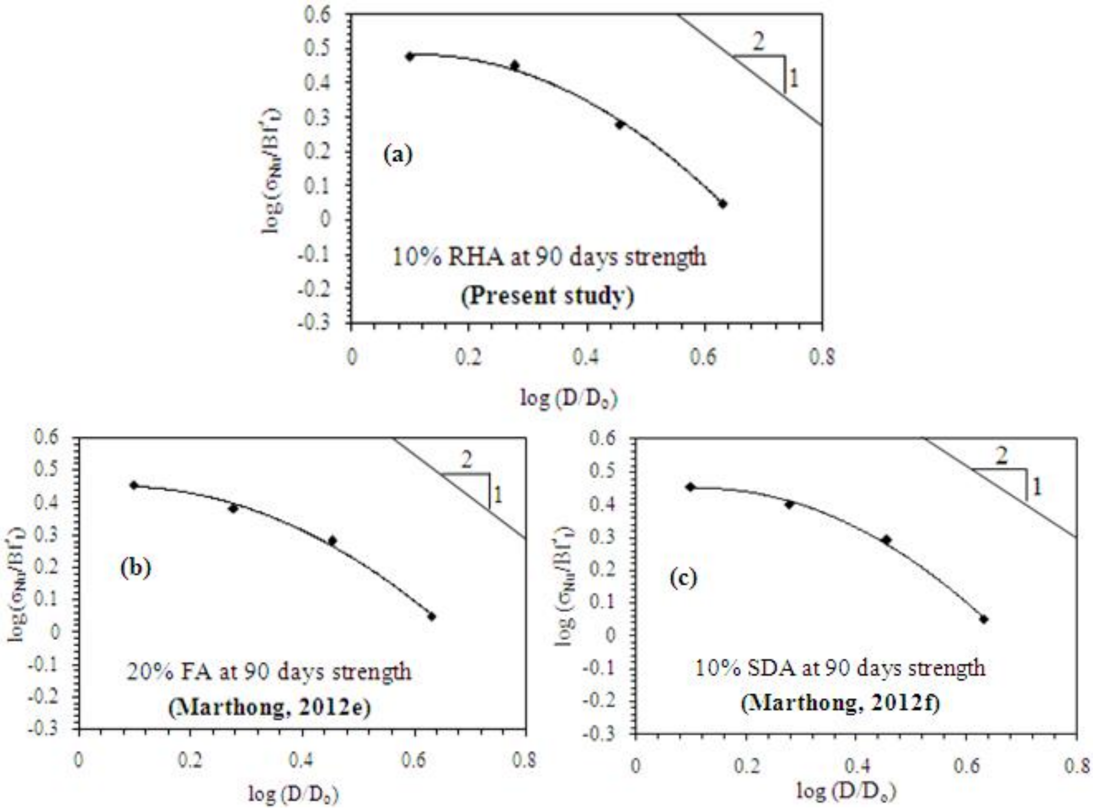

Fig. 6 Bi-logarithmic plot at 90 days strength

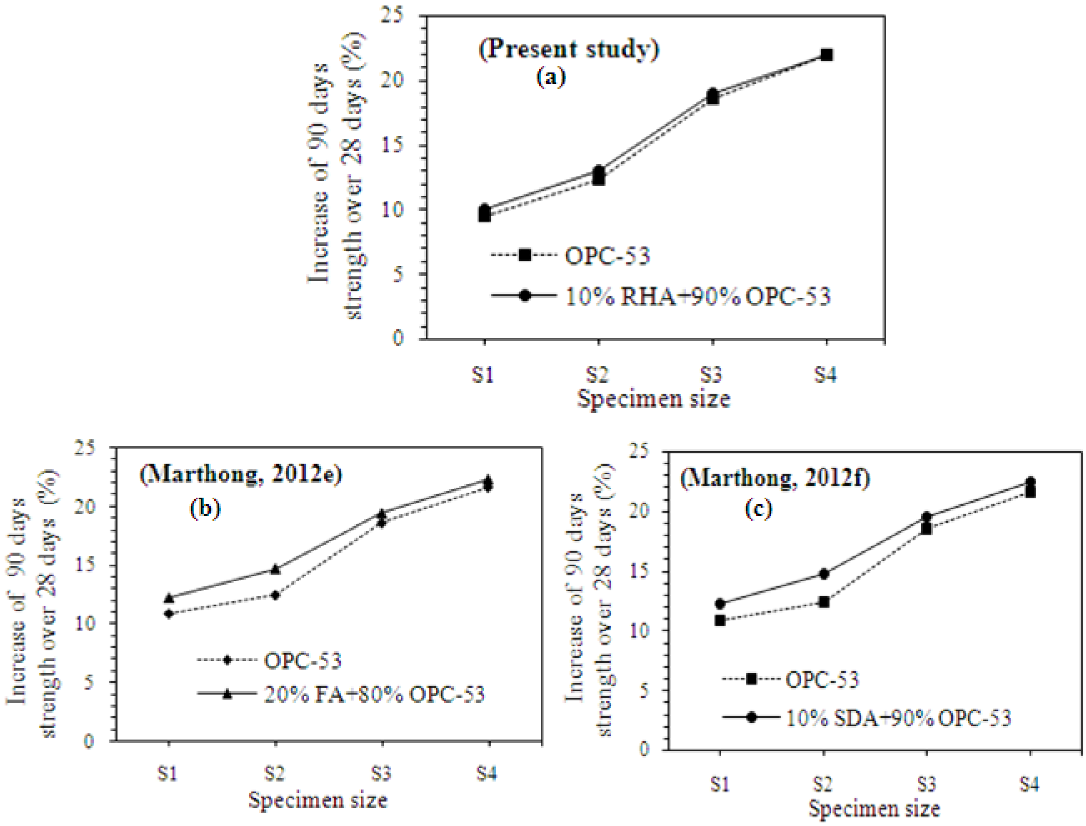

Fig. 7 Gain of strength at 90 days over 28 days

VII. 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 [1] was used. Different plots were drawn for concrete strength with 0% and 10%

replacement by RHA. Strength test were performed at 28 and 90 days. In all cases studied, it was found that these graphs followed the well established size effect law as proposed by Bažant [1]. 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. The size effect was observed to be more for rice husk ash-concrete as compare to concrete with pure cement. Further, the size effect of rice husk ash- concrete is more pronounce at the age of 28 days as compared to 90 days strength. Comparative study of all size effect curves shows similar trends. The study suggest that, test results from standard specimens should be judiciously done in practice giving due consideration to the existence of size effect.

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