

Compressive Strength and Durability of Bamboo Leaf Ash Concrete

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ABSTRACT

Substitution of Bamboo Leaf Ash (BLA) as a cement substitute is an upcoming research topic. The objective of this paper is to study the feasibility of calcined bamboo leaf ash as a partial substitute to cement and its effect on compressive strength, pozzolanic activity, sorptivity and porosity characteristics in hardened concrete. Cement was replaced with BLA with a percentage of 10% to 30% with a uniform increment of 5%. Fallen dry bamboo leaves burnt in open atmosphere were heated in a muffle furnace for 4 hours at 500°C to induce pozzolanic activity. The grade of concrete was taken in such a way that it will give a characteristic compressive strength of 20 MPa. The chemical composition of BLA was obtained by XRF analysis. The nature of BLA was assessed by XRD analysis and found to have an amorphous structure. The pozzolanic activity was ensured by ASTM lime test (ASTM C311 and ASTM C109). Other durability characteristics, like sorptivity and porosity, were performed as per ASTM guidelines (ASTM C1545 and ASTM C127) to assess the resistance of BLA concrete against sorption and the volume of voids. From the experiments conducted, it was understood that cement could be replaced with BLA till 15% with a little compromise in strength and durability characteristics and that this replacement was found to be an optimum one.

KEYWORDS: Bamboo leaf ash, XRD, XRF, Pozzolanic activity, Compressive strength, Sorptivity.

INTRODUCTION

General

Ordinary Portland cement is one of the most important binding materials in terms of quantity produced. Since it is manufactured at very high temperatures, it consumes a lot of energy. Along with huge amounts of energy consumption, it emits harmful gases, which pollute the atmosphere. Apart from energy consumption and emission of harmful gases, calcium hydroxide, a product obtained during the hydration of cement, is a nuisance for construction industry. This affects the durability of Portland cement pastes, mortars and concretes. Natural pozzolans are

vitreous cementitious materials, which by themselves possess little or no cementing value, but finely ground in the presence of moisture, they will chemically react with calcium hydroxide at ordinary temperatures to form hydrated phases possessing cementing properties. It is well known that hydrated phases formed during pozzolanic reaction commonly improve the performance of concrete. Also, the assessment of pozzolanic activity of cement replacement materials is becoming increasingly important because of the need for more sustainable cementing products. A sincere attempt has been made to study the possibility of using bamboo leaf ash as a partial substitute to cement, as it is amorphous in nature and has been found to have pozzolanic properties after calcination.

Bamboo is a naturally occurring composite material

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which grows abundantly in most of the tropical countries. It is considered a composite material, because it consists of cellulose fibers imbedded in a lignin matrix. Cellulose fibers are aligned along the length of the bamboo providing maximum tensile flexural strength and rigidity in that direction. Over 1200 bamboo species have been identified globally. Bamboo has a very long history with human kind. Bamboo chips were used to record history in ancient China. Bamboo is also one of the oldest building materials used by the human kind. It has been widely used for household products and extended to industrial applications due to advances in processing technology and increased market demand.

Previous Works

Yusoff et al. (1992) studied the chemical composition of one, two and three year old bamboo (*Gigantochloa scortechinii*). The carbohydrate content of bamboo plays an important role in its durability and service life. Durability of bamboo against mould, fungal and borers' attacks is strongly associated with its chemical composition. Furthermore, the ash content of bamboo is also made up of inorganic minerals, primarily silica, calcium and potassium. Manganese and magnesium are two other common minerals. Silica content is the highest in the epidermis, with very little in the nodes. Reactions of this ash (heated at moderately high temperatures) with calcium hydroxide are known to be pozzolanic in nature. The mechanism for this display of strength is the reaction of silicates with lime to form secondary cementitious phases (calcium silicate hydrates with a lower Ca/Si ratio) which display gradual strengthening properties usually after 7 days.

Dwivedi et al. (2006) reported the reaction between calcium hydroxide (CaOH) and bamboo leaf ash for 4 hours of reaction, using the differential scanning calorimetry (DSC) technique, while Singh et al. (2007) studied the hydration of bamboo leaf ash in blended Portland cement. Bamboo leaf ashes were obtained in a laboratory electric furnace at 600°C calcining

temperature for 2 hours of retention. Once calcined, the ashes were ground and sieved below 90 µm, fineness similar to that of Portland cement. The ash showed grey colour. These studies concluded that bamboo leaf ash is an effective pozzolanic material. When 20% weight of bamboo leaf ash was mixed with OPC, the compressive strength values of mortars at 28 days of hydration were found to be quite comparable to those of OPC.

Ernesto et al. (2007) discussed the characterization and studied the pozzolanic behavior between calcium hydroxide (CaOH) and bamboo leaf ash (BLA) obtained by calcining bamboo leaves. Based on the chemical composition, morphology and XRD pattern test on bamboo leaf ash, they concluded that this kind of ash is formed by silica with a completely amorphous nature and a high pozzolanic activity. Sabir et al. (1998) measured the uni-directional water absorption of mortar and concrete. They tested the sorptivity of various mortars, found out the variation in sorptivity with curing period and investigated the compressive strength. McCarter et al. (1996) studied the absorption of water and chloride ion penetration into concrete and found that sorptivity is to be minimized to bring down problems due to either chloride ion penetration or sulphate attack on concrete. Bai et al. (2002) found from their studies that addition of fly ash increases sorptivity, whereas addition of silica fume reduces sorptivity.

Bentz et al. (2001) discussed sorptivity-based service life prediction for concrete pavement. Service life models for concrete pavement and bridge deck degradation due to the sorption of deleterious species have been developed for the cases of sulfate attack and freeze/thaw. Their models demonstrated the approaches to the general problem of service life prediction, like the characterization of the material's appropriate mechanical and transport properties, adequate characterization of the exposure environment and development of a quantitative relationship between transport properties and the degradation state of the material.

Akaninyene et al. (2013) studied the effect of Periwinkle Shell Ash (PSA) and Bamboo Leaf Ash (BLA) on the mechanical properties of concrete for a standardized mix of 1:2:4. They have conducted experiments with varied percentages of PSA and for 10% of BLA. They concluded that concrete with 80% cement, 10% PSA and 10% BLA gives better strength than other mixes. Hence, in the present work it is proposed to study the effect of substitution of BLA in different percentages of replacement of cement on the

compressive strength and sorptivity characteristics.

Karthikeyan and Dhinakaran (2014) studied the effect of ultra-fine GGBFS on compressive strength and sorptivity of mortar and concrete. Experiments were conducted by varying the percentage of UFGGBFS from 3% to 7% with an increment of 2%. They found that replacement of cement with mortar and concrete with 5% UFGGBFS yielded better resistance against compressive load and sorption.



Bamboo leaf ash before Calcination

Bamboo leaf ash after Calcination

Figure (1): Colour change due to calcination of BLA

EXPERIMENTAL INVESTIGATIONS

Materials Used

Fallen dry bamboo leaves have been collected from a nearby place and converted into ash by burning them in a closed pit. The ash obtained from the bamboo leaves was then subjected to heating at a temperature of 500°C for a period of 4 hours in a muffle furnace. Once calcined, the ashes were ground and sieved below 90 µm, fineness similar to that of Portland cement. The ashes of the bamboo leaves obtained were kept in well sealed polythene to prevent moisture absorption. Initially, the ash appeared dark black in color, but on calcining, a color change to grey was noticed (see Figure 1). According to ASTM C618:2003 definition, for a material to be classified as a pozzolan, it should

contain SiO₂ with a percentage of at least 70%. The ASTM C618 specification is the most widely used one, because it covers the use of fly ash as a pozzolan or mineral admixture in concrete. The three classes of pozzolans are: Class N, Class F and Class C. Class N is raw or calcined natural pozzolan such as some diatomaceous earths, opaline cherts and shales, tuffs, volcanic ashes, pumicites, as well as calcined clays and shales. Class F is pozzolanic fly ash normally produced from burning anthracite or bituminous coal. Class C is pozzolanic and cementitious fly ash normally produced from burning lignite or bituminous coal. Based on this classification, the bamboo leaf ash used here can be classified as Class N pozzolan.

Thus, to determine the chemical composition and pozzolanic nature of bamboo leaf ash, X-Ray

Fluorescence (XRF) test has been carried out using an XRF-analyzer of S8 TIGER model. XRF tests samples for the determination of major and trace elements in solids. The mix proportion has been arrived at as per the guidelines of ACI 613-54. To determine suitable mix proportions, certain design stipulations are strictly used. In the present research work, concrete with a characteristic compressive strength of 20 MPa was used. Crushed annular aggregates of size 20 mm (down size) were used. The specific gravity of cement and bamboo leaf ash was found to be 3.15 and 2.0, respectively. Similarly, the specific gravity of both fine aggregate and coarse aggregate was found to be 2.65. To determine the specific gravity of coarse aggregate, wire basket method based on ASTM C 127 was used. Also, water absorption of coarse aggregate was found to be 0.5% and that of fine aggregate was 1%. Sand used for the present research work was river sand and moderate type of exposure was maintained. The target mean strength was obtained to be 25.8 MPa. The water to cement ratio was 0.50 and the final mix proportion ratio of 1:1.44:3.19 was used.

Specimen Details

Concrete cubes of size (150 mm × 150 mm × 150mm) were made and cured. The cube specimens of similar size were cast for control condition and also for various percentage replacements of cement with bamboo leaf ash (BLA); namely, 10%, 15%, 20%, 25% and 30%. The specimens were tested at the ages of 7 days and 28 days so as to observe a trend in change in compressive strength to study the effect of age of concrete.

Pozzolanic Activity Index

Pozzolanic activity of BLA has been studied by testing the strength activity index with Portland cement as per ASTM C 311. In the test mixture, 20% of the mass of the cement was replaced with BLA. The ratio of (cement to sand) and ((cement + BLA) to sand) was taken as 1:2.75 and a quantity of water was added as to give the required consistency. As ASTM C618 permits

testing of either 7- or 28- day compressive strength by casting three specimens with control mixture and other three with test mixture, specimens were tested at the age of 28 days. After the specimens were cast, they were kept at 23°C for one day. Then, the specimens were removed from the moulds and cured in saturated lime water as per ASTM C 109. Compressive strengths of all the six specimens were determined and strength activity index was determined from the ratio of compressive strength between test mixture and control mixture.

Porosity

Apparent porosity of control concrete and concrete with different percentages of BLA was tested at the age of 28 days using weight loss method. In this method, cube specimens were dried in a hot air oven with a temperature of 110° C for one day and the weight was measured as dry weight (W_d). The specimens were taken out, kept in boiled water for 2 hours and left in the warm water for another one day. Then, the specimens were weighed in water and air. They were designated as W_{sd} and W_a , respectively. The apparent porosity was calculated from the following formula: Apparent Porosity (AP) = $[(W_a - W_d)/(W_a - W_{sd})] * 100$.

Sorptivity

Permeability is an important parameter for water retaining structures. A more important parameter (which is directly related to durability) of structures above ground is sorptivity. It has also been shown that the sorptivity coefficient is essential to predict the service life of concrete as a structural material and to improve its performance. Resistance against capillary suction of concrete was measured through sorptivity test as per ASTM C1585 standard. Cylindrical specimens of 100 mm diameter and 50 mm height were prepared by cutting the top and bottom of the 100 mm x 200 mm cylindrical concrete and pre-conditioned by drying the sample for 7 days in a 50°C oven and then allowing it to cool in a sealed container for three days. The sides and top of the concrete sample were applied

with epoxy resin to prevent the entry of water during rest and the sample was further sealed with electrician's tape for added safety. The initial mass of the sample was noted and the sample was immersed to a depth of 5-10 mm in water from the bottom ensuring that only the bottom face was exposed to water (see Figure 2). Mass of the sample was noted at periodical intervals (i.e., 1 to 256 minutes) by removing the sample suitably. Difference in mass over a period of

immersion gives an idea of the amount of water absorbed by the concrete due to capillary suction. Graph was plotted by taking gain in mass (volume of water absorbed under capillary suction) per unit area of the cylinder in the ordinate and the square root of the elapsed time in the abscissa. Trend line (line of best fit) was drawn to get a slope equation and hence the sorption coefficient ($W=S t^{1/2}$).



Figure (2): Top view of the container with cylindrical specimens

RESULTS AND DISCUSSION

Characterization of Bamboo Leaf Ash

Chemical composition of bamboo leaf ash was obtained by XRF analysis of the sample. Table 1 shows the main elements (expressed as oxides) present in bamboo leaf ash. Silica (SiO_2) is the major component in ash, followed by CaO , SO_3 , K_2O , Al_2O_3 and Fe_2O_3 in concentrations of 6.0%, 3.31%, 3.05%, 1.99% and 1.92%, respectively. Oxides as MgO , P_2O_5 and Na_2O show contents below 1% and the rest of oxides (PbO ,

ZnO) are present in percentages under 0.1%. Thus, as per the ASTM definition and based on the values in Table 1, we can conclude that bamboo leaf ash has pozzolanic properties and can be classified as a Type N pozzolan. Bamboo leaf ash was studied by using XRD for its mineralogical composition and the results are given in Fig. 3. From the results of XRD, it was clearly understood that bamboo leaf ash has a completely amorphous nature and the broad band was localized between 10° and 20° . It was also observed that the presence of crystalline minerals was not detected in the

XRD results. Therefore, we can clearly substantiate the fact that bamboo leaf ash can be used as a feasible

substitute for cement as partial replacement along with satisfactory strength gain.

Table 1. Chemical composition of bamboo leaf ash

Formula	Concentration (%)	Formula	Concentration (%)
SiO ₂	80.27	TiO ₂	0.18
CaO	6.00	MnO	0.06
SO ₃	3.31	ZnO	0.02
K ₂ O	3.05	PbO	0.02
Al ₂ O ₃	1.99	Pd	94 ppm
Fe ₂ O ₃	1.92	Ru	93 ppm
MgO	1.73	SrO	86 ppm
P ₂ O ₅	0.91	CuO	82 ppm
Na ₂ O	0.26	ZrO ₂	44 ppm
Cl	0.23		

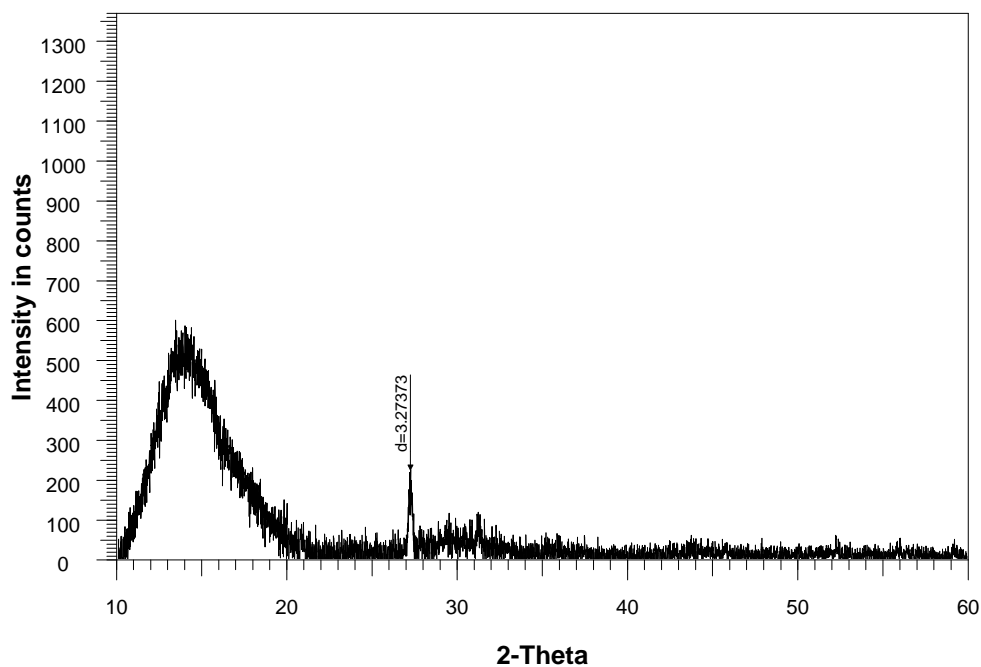


Figure (3): XRD pattern of bamboo leaf ash

Workability

Workability was found to be reduced while replacing cement partially with bamboo leaf ash. The same trend was observed for all the percentages of replacement of cement with bamboo leaf ash. This is due to that concrete containing bamboo leaf ash requires more water for a given consistency due to its absorptive character of cellular bamboo leaf ash particles and of high fineness (this increases its specific surface area). Therefore, in order to enhance the fluidity and consistency of the mix, a proper dosage of additional water required was added.

Evaluation of Pozzolanic Activity

To assess the pozzolanic activity of bamboo leaf ash in concrete, ASTM lime test was conducted. The details of results are tabulated in Table 2. It was inferred that strength activity index or pozzolanic activity index of specimens with bamboo leaf ash was above 80% of the control specimen at the age of 28 days and was fulfilling the requirements as pozzolan to be used in concrete as per ASTM standard. With the addition of BLA beyond 20%, strength activity index has shown a reverse trend, giving an idea of optimum percentage of pozzolanic admixture to be used.

Table 2. Strength activity index of bamboo leaf ash as per ASTM C311

Mix description	Compressive strength (N/mm ²)	Strength activity index
Control specimen	34.00	100.00
10 % BLA	28.39	83.50
15 % BLA	30.94	91.00
20 % BLA	29.23	85.97
25 % BLA	20.74	61.00
30 % BLA	16.15	47.50

Evaluation of Compressive Strength

The results of compressive strength for the various mixes are presented in Fig.4. For control concrete, the strength of 22.75 MPa was observed at 28 days. For 10%, 15% and 20% replacement with bamboo leaf ash, there was a reduction in the strength to 18.56, 20.38 and 19.1 MPa, respectively. This can be attributed to the higher water content in the mix in order to maintain similar workability. Increasing bamboo leaf ash to more than 20% leads to further reduction in the strength resulting in much lower values in the range of 10-13 MPa. It can be seen that the reduction in strength of the concrete mix with 10% bamboo leaf ash was around 18% with respect to that of control concrete mix. But, for further replacement with 15% and 20%, the percent reductions dropped down to 10% and 16%,

respectively. However, with increasing the amount of bamboo leaf ash being substituted to 25% and 30%, the percentage reduction in strength showed a drastically increasing trend.

Evaluation of Sorptivity and Voids

Figure 5 gives the details of the amount of penetration or absorption of water into the various samples with respect to increase in time. The readings taken at various time intervals were represented in seconds. The masses of the various samples were recorded at all the stipulated times. The change in weight of the sample with respect to its initial oven dried weight is calculated. The increase in weight observed represents the water absorption of the sample and the same was represented in terms of the volume of

water ingress through the surface; i.e., as flow (Q) in mm^3 . The penetration depth (mm) for each of the samples at every single time interval was determined by dividing the flow by the surface area exposed to absorption. The total mass gain due to water absorption in the control concrete cylindrical specimen after a period of 256 minutes was 42g. Distinctively, for the 10% replacement specimen also, the mass gain was observed to be 42g, similar to that of the control concrete specimen. But, for specimens with higher

replacement of cement with bamboo leaf ash (BLA), the mass increased in the range of 52 to 70 g for 20% and 30% samples, respectively. Thus, the durability characteristic of the specimens was estimated based on observations taken over a short period of time based on the sorptivity coefficient. From the results of sorptivity test, the water gain of the specimen with respect to increasing time was observed to follow an increasing trend. The sorption coefficient was obtained from the slope of the trend line.

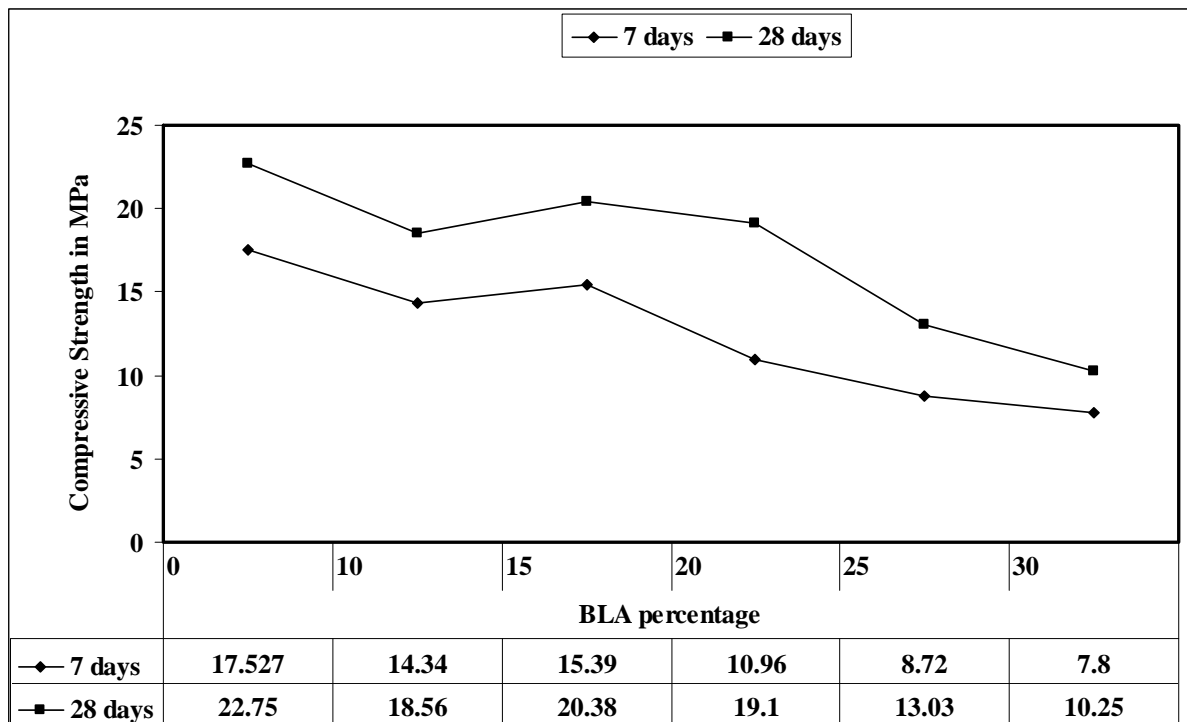


Figure (4): Compressive strength of BLA concrete

For the control concrete specimen, the sorption coefficient, as given by the slope of the trend line, was $s = 5.83 \text{ mm/s}^{1/2}$. From the results obtained, it was seen that with an increase in the amount of cement replacement, the sorption coefficient varies distinctively. For a small replacement with bamboo leaf ash (BLA), the sorption coefficient was within the acceptable values and even less than that of the control concrete. This was specifically observed in the 10% replacement specimen having its sorptivity coefficient

as $4.76 \text{ mm/s}^{1/2}$. This was a less value in comparison with that of the control concrete specimen and thus indicates a good durability nature of the new bamboo leaf ash blended cement mix. For concrete with 15% BLA, the value was found to be only $4.04 \text{ mm/s}^{1/2}$ and was very much less than that of the control concrete. In the 20% replacement sample, the sorptivity coefficient obtained was $6.28 \text{ mm/s}^{1/2}$. This value was higher than that of the 10% and the 15% replacement samples and may be attributed to the increase in the number of

pores in the specimen due to the higher amount of bamboo leaf ash contained in it. But, such a range of sorption coefficient value is acceptable and accounts for a reliable durability nature of the sample. With higher amounts of replacement of cement with bamboo

leaf ash; i.e., 25% and 30%, a completely higher variation in values was obtained with sorption coefficient values lying in the range from 6.8 mm/s^{1/2} to 12.2 mm/s^{1/2}, respectively.

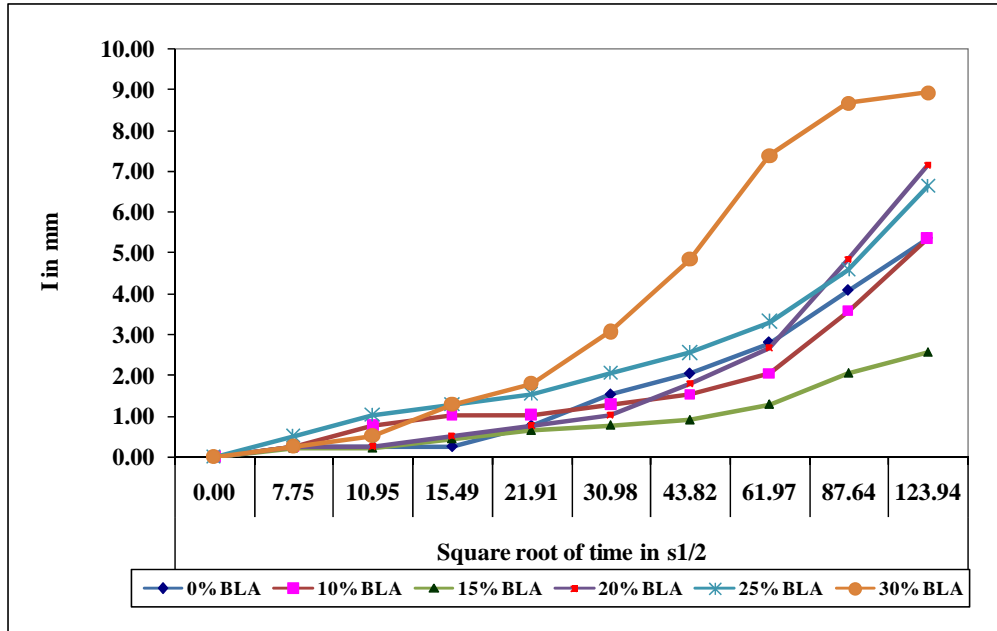


Figure (5): Sorptivity of BLA concrete

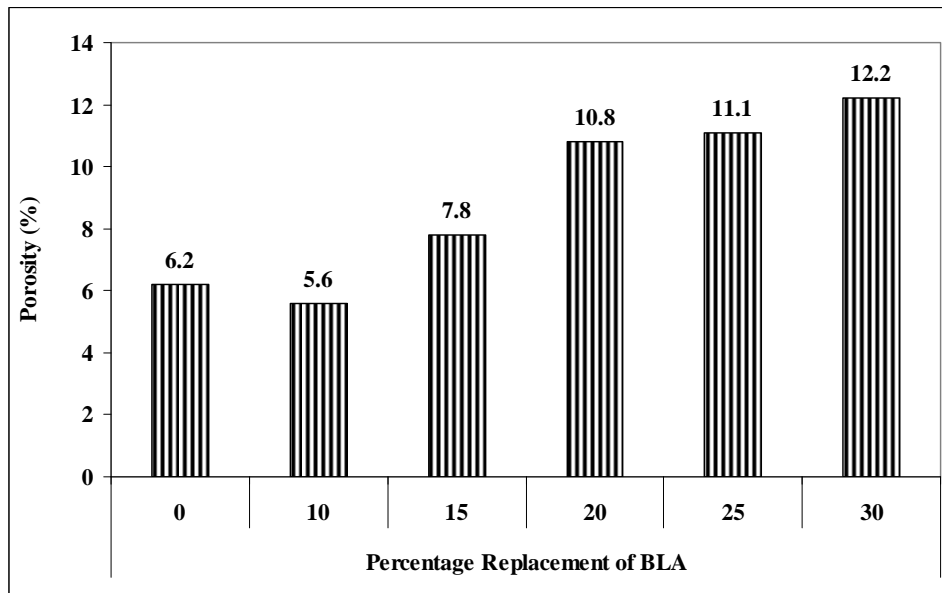


Figure (6): Porosity of bamboo leaf ash concrete

Figure 6 depicts the results of porosity measurement conducted for control and BLA admixed concrete. It was inferred from the results that porosity of concrete with 10% of BLA was less than that of the control concrete and the reason might be due to modification of microstructure (filling of voids). However, further addition of BLA to 15% increased the porosity to a little extent and showed a further ascending trend for 20, 25 and 30% BLA. This could be due to a number of reasons. One reason could be the slower rate of hydration of BLA. Another reason could be the low pozzolanic activity of BLA. It could also be due to aggregation of particles.

CONCLUSIONS

From the experimental investigation conducted on BLA concrete for its chemical composition, XRD analysis, pozzolanic activity index, compressive strength, sorption and porosity measurements, the following conclusions are drawn:

- XRF and XRD analysis of bamboo leaf ash has clearly proved its feasibility as a possible mineral admixture for cement due to its chemical composition and its amorphous nature.
- Pozzolanic activity index of 20% BLA was found to be more than 80% of that of the control mixture. It is concluded that BLA can be used as a pozzolan to replace cement in concrete.

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- The optimum replacement of OPC with BLA taken at the ages of 7 days and 28 days of concrete for the selected grade was found to be 15% and the corresponding reductions in compressive strength were found to be 12% at the age of 7 days and 10% at the age of 28 days. This reduction of 10% in strength is very acceptable.
- The values of sorption coefficient under capillary suction of BLA concrete were found to be less than that of the control concrete. Hence, the presence of 15% BLA in the mix improves the durability of concrete by filling the voids in the cement. Reduction in porosity of 1.6% for concrete with 15% BLA compared to control mixture may be acceptable from the durability point of view.
- With an optimum amount of BLA substitution, cost incurred for cement can be reduced to around 15% of the original value. Thus, an advantage of cement replacement is the substantial cost reduction.

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