International Journal of Information, Engineering & Technology

Volume 12, Issue 3, PP 39-48, ISSN: 2360-9194, August, 2023
DOI: 42721454381235
Double Blind Peer Reviewed International Research Journal
https://arcnjournals.org
arcnjournals@gmail.com
Journal Series: Global Academic Research Consortium (garc)

Influence of Mix Composition and Curing Age on the Mechanical Properties of Bamboo Leaf Ash Blended Cement Laterized Concrete

***Gambo Z[1]; Odeyemi S.O[2]; Bolarinwa M.O[2]**
[1]Department of Civil Engineering, Ramat Polytechnic, Maiduguri, Borno State, Nigeria
[2]Department of Civil Engineering, Kwara State University, Kwara State, Nigeria

Abstract: *This Research investigates the effect of mix composition and curing age on the mechanical properties of bamboo leaf ash (BLA) blended laterized concrete. The experiment was carried out by partially replacing Bamboo leaf ash (BLA) of 0% to 20% by weight of cement at 5% interval. The concrete was batched with a mix ratio of 1:2:4. The cubes produced were allowed to cure for 7 - 56 days. Compressive strength test was conducted on the samples at interval of 7 days. Slump test and setting time of the concrete cubes were conducted. The result obtained showed that compressive strength of the concrete increased with increase in length of curing age, but decreased as the percentage of BLA increases. However, the strength still within the allowable range of workability for concrete in line with the British standard. BLA replacement of 5% – 15% was found to be suitable considering the strength and safe use of the concrete. It was concluded that BLA replacement of 5%, 10% and 15% showed no significant loss in strength compare to the control sample and is suitable for use in concrete.*

Key words: *Concrete, Compressive Strength, Split Tensile Strength, Bamboo Leaf Ash (BLA), X-ray Florescence.*

1. INTRODUCTION

In the cement industry, continuous attempts are being made to reduce the cost of production of Portland cement and consumption of raw materials, energy expense, protect the environment and enhance quality of cement, ordinary Portland cement is one of the most important building materials in terms of quantity produced. Since it is produce at a high temperature (1500˚c) it consumes a lot of energy, emitting harmful gases one polluting the atmosphere (awwal et al, 2016), therefore an alternative to its use is a matter of urgency. One way of achieving this is to use certain law cost materials for partial replacement of Portland cement in concrete production (Kabiru *et al,* 2022). Hence alternative to conventional building materials have been focus at most researchers recently and their suitability as local materials for building construction purposes. This work focus on the use of bamboo leaf ash (BLA) as a partial replacement of the conventional concrete binder namely cement. Also the recent clement for green, sustainability building and eco-friendly construction material aims at reducing the production of harmful gasses that pollutes the environment and minimizing waste that litters the environment. Utilization of such agricultural waste like bamboo leaves serves as an effective method of minimizing waste generated, saving energy and ensuring sustainability in the built environment.

MATERIALS AND METHODS

The materials used for the research include the following:

Bamboo leaf ash (BLA)

Bamboo leaves used was sun-dry to expel water content later undergo burning to remove inorganic materials that might be present in it. Further, it was calcined at 650°C using muffle furnace for 2 hours retention time at the laboratory of the Department of Mechanical Engineering, Kwara State Polytechnic, Ilorin, Kwara State. The XRF analysis on the calcined BLA was carried out. After cooling, it was sieved using 0.15 mm sieve and shown in Plate 1a-c

(a) (b) (c)

Plate 1: Bamboo leaf ash material. (a) dry BL (b) burnt BLA (c) Calcined BLA.

Cement

The cement used for the production of the concrete samples is Ordinary Portland cement (OPC); type 1

Aggregate

Fine aggregate (natural river bed sand) that passes through sieve 4.75mm and coarse aggregate (crushed stone) of maximum size of 19mm was used and both conform to BS 882:1992.

The mix design for the Portland concrete grade 25 was performed in line with BS EN 206 (2014) and BS 8500 -2 (2012). A total of 5 mixes were made. Table **1** depicts the details of all the mix proportions. Water binder ratio (w/b) of 0.5 was kept constant for all the mixtures using 195kg/m3 of water. The cement was partially replaced by 5%, 10%, 15% and 20% BLA Mixing was done manually as stated by BS EN 1881-125 (2013) and was controlled with a device in order to guard against the escape of water and cementitious elements during mixing apportioning. The specific gravity for both BLA and cement was executed in line with ASTM C188 (2016) and particle size distribution for BLA was performed in line with ASTM D 7928 (2017). Chemical analysis for both BLA and cement was performed through the use of x-ray diffraction equipment which conformed to BS EN 196-2 (2013). Compacting factor, the slump was examined in line with stipulated procedures in BS 1881-103 (1993) and BS EN 12350-2 (2009), respectively.

Cubes of sizes 100mm*100mm*100. A total number of 18 cubes, were prepared and cured according to the methods stipulated in BS EN 12390-2 (2009) for 7, 28, and 56 days compressive strength and tensile strength, 28 days for the flexural strength test. Three samples were produced for each test. Compressive strength and split tensile strength test were performed in line with BS EN 12390-3 (2009), BS EN 12390-6 (2009), and BS EN 12390-5 (2009) test methods. Each sample was being subjected to loading at failure using an automated electronic testing machine which conforms to BS EN 12390

Table 1: Mix design and mix procedure

MIX	Cement (kg)	BLA (kg)	60% of Sand (kg)	40% of Laterite kg	100% of Granite (kg)
0%	5.20	0.00	7.8	5.18	25.9
5%	4.92	0.26	7.8	5.18	25.92
10%	4.428	0.492	7.8	5.18	25.92
15%	3.786	0.642	7.8	5.18	25.92
20%	3.039	0.752	7.8	5.18	25.92

RESULTS AND DISCUSSION

Preliminary Tests on BLA, OPC and Aggregate

The preliminary tests carried out include Oxide composition, Soundness, Consistency, setting time, specific gravity and particle size distribution. The results are presented in the Tables 2 to 5.

Table 2: Oxide Composition

Chemical Composition (%)	Cement	BLA
Silica (SiO_2)	20.600	69.112
Calcium oxide (C_2O)	62.927	10.814
Aluminium (AI_2O_2)	5.985	2.523
Iron (Fe_2O_2)	3.341	1.741
Phosphorus (P_2O_2)	0.639	1.525
Chloride (CI)	0.151	0.670
Sulphur (S)	2.622	0.406
Manganese (Mn)	0.129	0.245
Potassium (K_2O_2)	0.266	4.814
Loss of Ignition (LOL)	3.34	8.15

BLA consists of essential compounds which are known to have binding properties for better concrete work. The percentage composition of CaO was found to be 10.814 which means the ash was cementitious itself, though CaO for cement was found to be 62.927

which was higher than BLA. CaO is responsible for the formation of tri-calcium silicate and dicalcium silicate which both react with water to make up calcium silicate hydrate (C-S-H) which is the main agent in term of strength development for concrete. The percentage of SiO2 + Al2O3 + Fe2O3 was found to be 73.38% which was more than a minimum of 70% stipulated by ASTM C618 (2008) for pozzolana. Furthermore, loss of ignition (LOL) for BLA was higher than OPC but still within the range of 12% stipulated by ASTM C618 (2008).

Table 3 Physical properties of BLA blended cement paste.

-	BLA Replacement (%)				
Physical Property	**0%**	**5%**	**10%**	**15%**	**20%**
Soundness (mm)	1-1	1-4	1.5	1.7	2.0
Consistency (%)	37.5	46.0	51.4	55.8	65.6
Initial setting time (min)	104	130	190	242	270
Final setting time (min)	259	302	358	407	475

The soundness test was conducted in order to determine the presence of uncombined lime in cement. The test was performed based on BS EN- 196-3 (2005). From Table 3, it was evident that soundness increased as the percentage replacement of BLA increased, but there was no volume change in all the blended cement. This could be as a result of the particle size of the bamboo leaf ash. The BLA for all the percentage replacement conforms to BS EN- 196-3 (2005) of not exceeding 10mm. The percentage increment was 0.3%, 0.4%, 0.6% and 0.9%. Consistency was conducted based on IS 4031-4 (1988). The consistency value increases as the percentage replacement of BLA increased with cement. Which could be as a result of the particle size of the BLA. The penetration depth of 5mm was achieved at all replacement level which conforms to IS 4031-4 (1988) standards of the limit between 5-7mm penetration depth. The highest consistency value was attained at 20% BLA replacement. The percentage increment was 22.6%, 37%, 48.8%, and 74.9%, respectively. This study conforms to previous findings. Setting time was conducted according to BS EN - 196-3 (2005). From the result setting time increased as the percentage replacement for BLA increases with cement. The initial and final setting time of bamboo leaf ash was higher as compared to that of cement paste in all the mixes. This could be as a result of a high amount of potassium oxide (4.814%) found in BLA which hampers the heat of hydration. Thus, this slow process in term of the heat of hydration is an advantage during mass concrete production which in turn reduces thermal stress. The cement conforms to BS EN - 196-3 (2005), not exceeding 2 hours for initial and 10 hours for final setting time. BLA does not meet the initial setting time but met the final setting time for all the mixes of not exceeding 10hours.

Table 4: Specific Gravity

Test	Result	Code Specification	Code
Fine Aggregate	2.43	2.4 – 2.9	ASTM 33 (2003)
Coarse Aggregate	2.48	2.4 – 2.9	ASTM 33 (2003)

Table 4 shows that the coarse and fine aggregate also conforms to the limit stated by ASTM – 33 (2003)

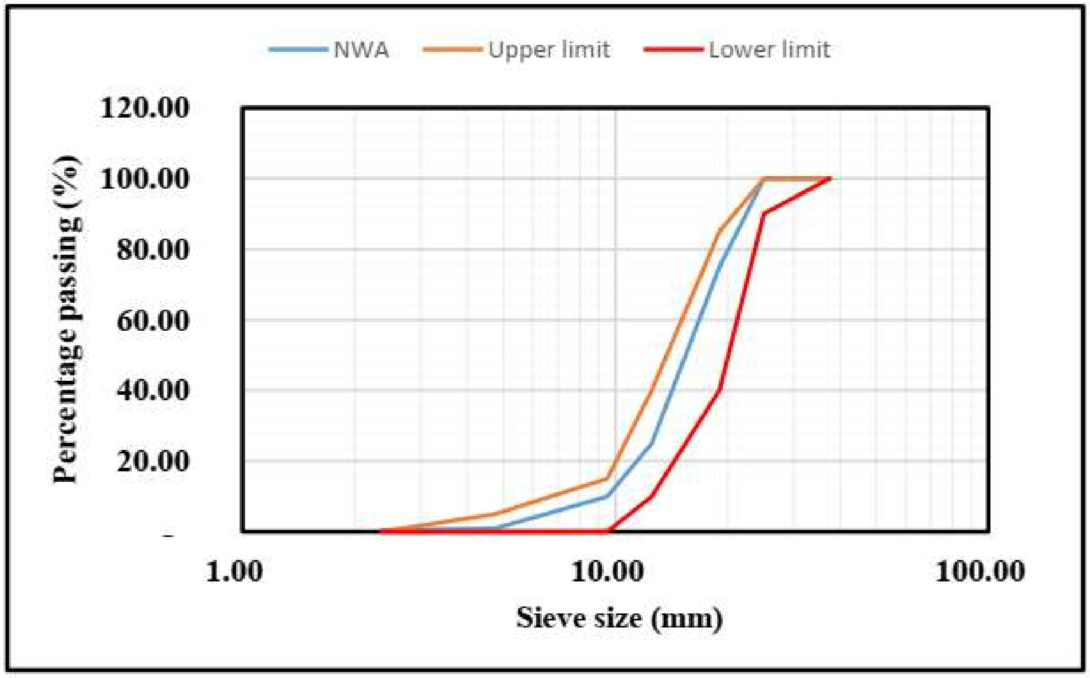

Fig 1 Particle size distribution of coarse aggregate according to ASTM-33 standards.

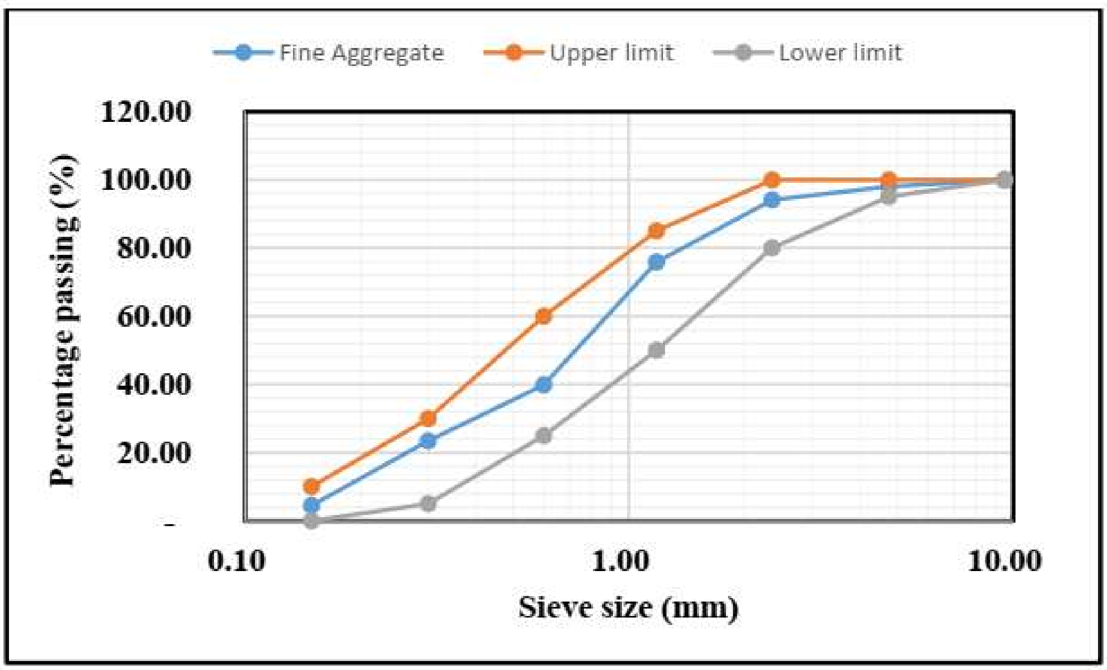

Fig. 2 Particle size distribution of fine aggregate according to ASTM-33 standards.

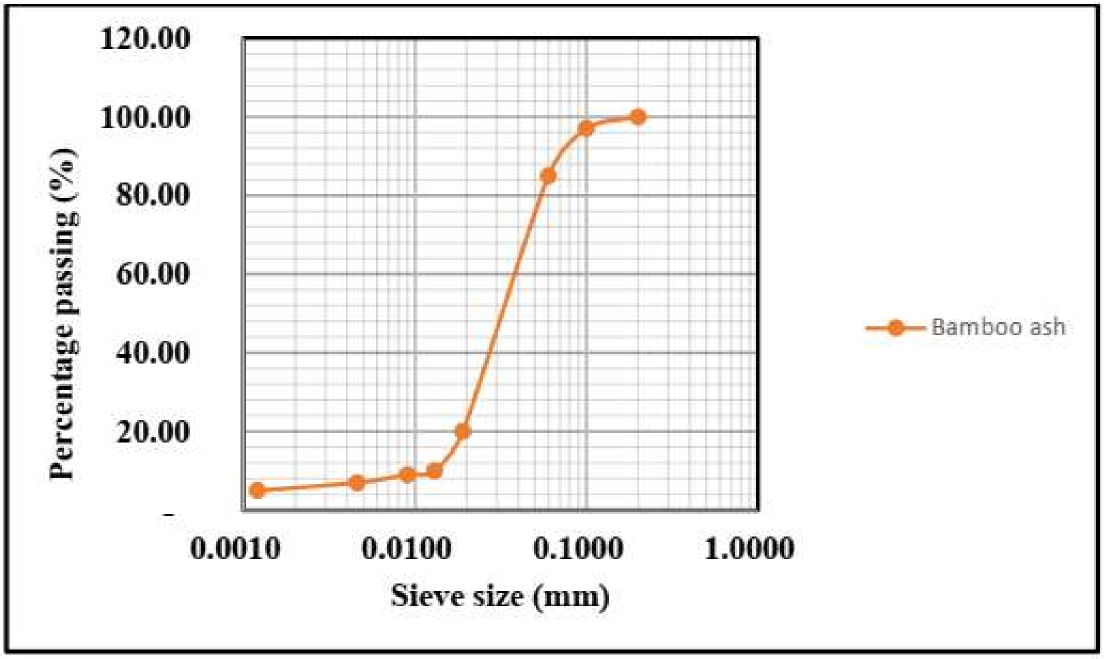

Fig. 3 Particle size distribution of BLA according to ASTM - D7928

The gradation results for coarse aggregate, fine aggregate, and bamboo leaf ash are illustrated in Figs. (**1-3**) accordingly. The gradation for coarse aggregate shows that 90% of coarse aggregate was between 9.5mm and 25mm. This means most of the aggregate passed the 25mm sieve. The envelope curve was also between the upper and lower limit curve as stipulated by ASTM - 33 (2003), so, therefore, it can be used for normal concrete weight concrete. The particle size of fine aggregate falls between 0.155 to 4.75mm within zone 2 which also satisfies the requirement that the fine aggregate should be less than 45% retained on any sieve by ASTM - 33 (2003). Fig. (**3**) depicts the particle size distribution of BLA. The figure illustrated that, about 20% of its particles falls within 0.001mm (1 μm) to 0.02mm (2 μm) and 80% falls within 0.02mm (2 μm) to 0.15mm (150 μm). This is in line with specifications of ASTM - D7928 (2017). Based on this fineness particle behaviour, the water demand and surface area of the bamboo leaf ash were enhanced. The maximum particle size for bamboo leaf ash adopted in this work was 0.150mm (150 μm). Fineness modulus of fine aggregate was found to be 2.55, which was within the limit 2.3-3.1 and conformed to ASTM - C33- (2003). Hence, the material can be used to produce good concrete. Silt content of 4.67% for fine aggregate was in line with the requirement of ASTM - C33 (2003) of not exceeding 5%.

Workability Test of Fresh Concrete

The result for slump and compacting factor test are been presented on table 2. The slump value increased from 60mm at 0% to 63mm at 5% replacement BLA. This could be as a result of a high amount of $Si0_2$ and CaO present in BLA which improved the workability. Thereafter, there was a drastic drop in the slump as the percentage replacement increased from 10%, 15%, and 20%. This reduction could be connected to the huge surface area of the ash and excessive content of carbon which remained unburned in BLA.

Olukotun et al. (2019) and Afolayan et al. (2019) obtained similar result with different cement replacement.

The compacting factor of cement was higher than BLA at all level of percentage replacements. As the percentage replacement of BLA increases, the CF reduced as well. The values obtained falls within the range of 0.70- 0.98 based on BS 1881- 103. The reduction could be as a result of large surface area and particle size of the BLA. Percentage reduction were 1.36%, 2.20%, 3.14% and 4.40% according

Table 5: Slump and Compacting Factor Test

Fresh Properties	BLA Content (%)				
	Control	5%	10%	15%	20%
Slump (mm)	60	63	58	56.5	55.5
Compacting Factor (CF)	0.955	0.942	0.934	0.925	0.913

Compressive Strength Test

The compressive strength of normal concrete and concrete blended with BLA at curing age of 7, 28 and 56 days is presented in Fig. (**4**). An early strength was observed at 7 days for percentage replacement from 5% to 10% replacement and a drop in strength at 15% and 20% replacements was noticed. These trends also apply to 28 and 56 days of compressive strength. The increase in strength could be as a result of the presence of high amount of amorphous silica (SiO_2 = 69.112%) present in the ash and high amount of CaO (10.814%) which was responsible for the formation of tri calcium silicate and di calcium silicate which both oxidises with water to form calcium silicate hydrate which was the determining factor for strength gain. Tricalcium silicate is mostly reactive at early ages which gave the ash more strength at 7 days for 5% and 10% replacement while di calcium silicate is most reactive at later ages but contributes very little to strength development unlike tricalcium silicate. The maximum strength was recorded at 10% BLA replacement at 7, 28 and 56 days curing age, respectively. The drop in strength could be that C-S-H is most effective at 10% BLA replacement. Any further increase beyond 10% BLA replacement would lead to strength reduction. Similar results were obtained by Sani *et al*, (2020) and Wilson *et al*, (2021) who used different material to replace cement in concrete.

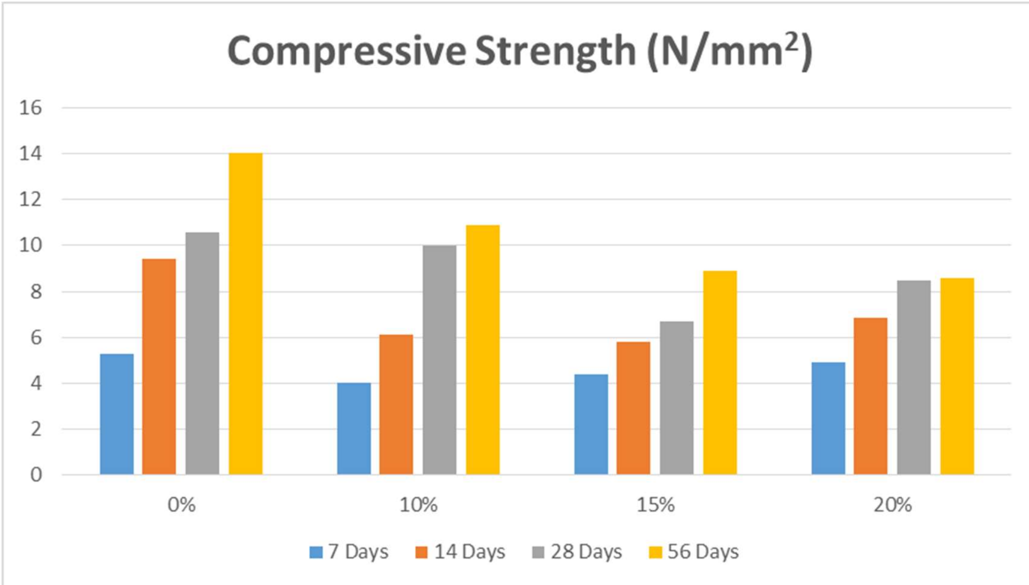

Figure 4: Compressive Strength

Splitting Tensile Strength

The STS of PCC concrete and concrete blended with BLA at curing age of 7, 28, and 56, days is illustrated in Fig. (**5**).The figure indicated that there was a gradual increment in STS as the percentage replacement of BLA increased up to 10%. The STS peaked at 10% percentage replacement and later dropped at 15% and 20% percentage replacement of BLA. Thus, there was strength gain at 15% and 20% BLA replacement as the curing age goes beyond 28 days, the strength obtained was even higher as compared with the control sample. This implies that BLA replacing cement up to even 20% can increase the serviceability requirement of concrete as compared with that of reference structure. The strength increment could be as a result of high content of amorphous silica and CaO present in BLA. This trend in terms of strength gained and a reduction was similar to that of compressive strength results. The drop in strength could be that, the amount of BLA fragments shown in the mix was greater than the prescribed to integrate with the released lime during the heat of hydration operation which in turn led to excess silica leaching out, thereby resulting in reduction in strength as it partially substituted a segment of the cementing elements. The maximum strength was attained at 10% BLA content. Similar results were obtained by Wilson *et al*, (2021) with different replacemet

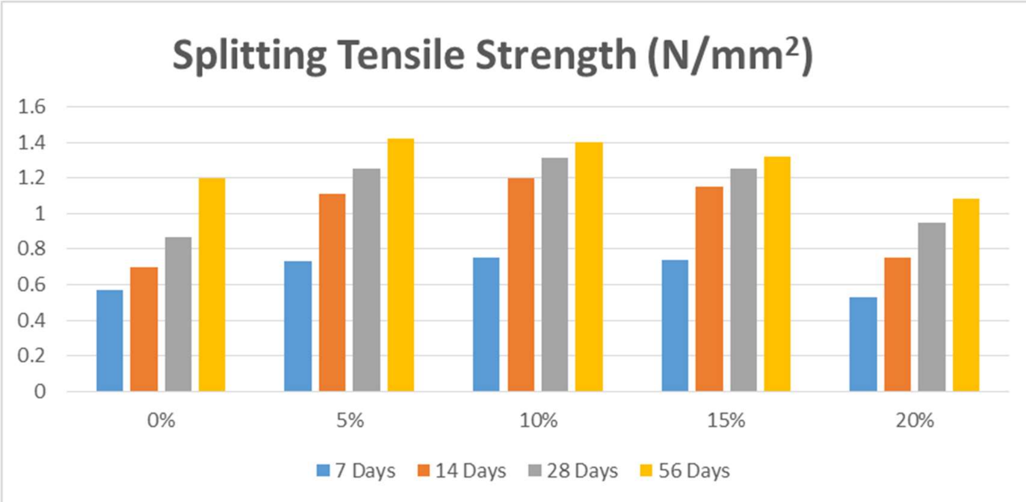

Figure 5: Splitting Tensile Strength

CONCLUSION

From the above experimental results, analysis, and discussions, the following conclusions were reached:

1) The chemical analysis performed on BLA indicated that it contained essential chemical compounds. In summary, BLA is a good pozzolanic material and can partially replace cement.

2) The consistency, setting time, and soundness of blended bamboo cement paste reduced as the percentage replacement of BLA contents increased. Slump values and compacting factor of BLA concrete reduced as well as BLA content increased.

3) The compressive and split tensile of BLA concrete increased. The optimum level of replacement was achieved at 10% BLA which yielded higher strength value in all the test conducted on hardened concrete.

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