

# EXPERIMENTAL INVESTIGATIONS ON SUSTAINABLE CONCRETE WITH BAMBOO WASTE

## Abstract

The practice of using sustainable materials has gained popularity worldwide. In the construction sector, cement contributes approximately 7% of global CO<sub>2</sub> emissions and many other greenhouse gases, resulting in global warming. So concrete containing sustainable supplementary cementitious materials (SCM) is used to reduce CO<sub>2</sub> emissions and attain long-term strength. The bio-waste material of bamboo, i.e., bamboo flakes and bamboo leaves, was procured and dried under the sun. The leaves and flakes were burned separately in a controlled manner in a burn barrel. The chemical tests on bamboo flake ash (BFA) and bamboo leaves ash (BLA) were used to characterize the ash's chemical characteristics. The findings revealed that the ashes comprise key elements such as SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub>. As per ASTM C618:2003, to be classified as pozzolanic material, the combination of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> must be greater than 70%. Hence, it satisfies the ASTM condition, as in BFA and BLA, the combination content of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> was 80.02% and 80.83%, respectively. Therefore, the ash possessed high pozzolanic activity. Cement was replaced by BFA at 5%, 10%, and 15% by weight of cement. Concrete made by partial replacement of cement with BLA and BFA was tested for compressive strength at 7, 14, and 28 days of curing. And the split tensile test was conducted based on the optimum value obtained from compressive strength. After 28 days, the optimal strength was found to be at 5% replacement. The durability test (water absorption) shows that sustainable concrete has greater durability as compared to conventional concrete. Though several SCMs have been used, the use of bamboo flakes (BFA) as an SCM has been considered new research.

**Keywords:** Sustainable, Bamboo, Bamboo Flakes Ash (BFA), Bamboo Leaves Ash (BLA), Pozzolanic, SCM

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## I. INTRODUCTION

This concrete is the major material used for construction worldwide because of its availability, bond strength, low cost, greater life span (durability), and, most importantly, its versatility [1]. It is composed of cement, fine and coarse sand, water, and various admixtures that increase strength and durability by reducing water content. The amount of cement produced around the world is about 41 billion metric tonnes [2]. The production of cement produces carbon dioxide (CO<sub>2</sub>) and other harmful gases [3].

According to a certain study, for every 1 kg of cement, (0.8-0.9) kg of carbon dioxide is released into the atmosphere [3]. The concrete produced may be having good quality but there is the presence of micro cracks, small voids, and capillary pores in the hardened concrete, in which the deteriorating agent like chloride (Cl) penetrates through the pores or voids and result in a deterioration of the structure [4]. In order to reduce energy and environmental impact on concrete partial replacement of cement with locally available waste material should be used [5]. As our world is moving towards sustainable development so the use of different types of waste cementitious material could be the best alternative to produce Sustainable concrete. Generally, there are two types of supplementary material i.e. hydraulic material, which when reacts with water forms a cementitious material, and pozzolanic material which reacts chemically with the calcium hydroxide Ca (OH)<sub>2</sub> produced during the hydration of cement. Researchers from all over the world have recently started to look at the usage of low-cost and low-energy alternatives to traditional building materials. Bamboo covers approximately 1.57 crore hectares in India, accounting for approximately 12.8% of the total forest available in India. Bamboo, one of the plants with the quickest growth rates, is one option for such a replacement that has a lot of economic potential. Bamboo generates different types of waste in the form of leaves, flakes, and many more.



**Figure1:** Bamboo

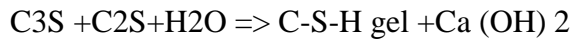


**Figure 2:** Bamboo Species Adapted from

**Dr. Kavitha S, 2018** In this project, we have used bamboo leaves and bamboo flakes as a supplementary cementitious material. By-products of bamboo like bamboo leaves and bamboo flakes are agricultural waste that is disposed of in landfills, eventually damaging the environment by polluting the air and occupying useable land. To give a good finish or proper shape the inner and outer surfaces of the bamboo were removed that waste is called Bamboo flakes. Bamboo flakes are an innovative material as no one has used them as cementitious material to date. The chemical composition of BLA and BFA satisfied the specification of ASTM C-618 (2001) and BS EN 197-1 as the addition of the percentage composition of SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, and Fe<sub>2</sub>O<sub>3</sub> is greater than 70% [3]. So BLA and BFA are pozzolanic in nature.

The hydration of cement produces Calcium Hydroxides as a by-product which is responsible for the deterioration of the concrete structure. The addition of pozzolanic material containing high amounts of amorphous silica in the concrete mix results in a reaction between  $\text{Ca}(\text{OH})_2$  and oxides of silica, producing the calcium silicate hydrate gel, which is the main constituent responsible for the bonding of concrete-making material [1].

The chemical reaction is as shown below:



The above reaction shows that the pozzolanic material reacts with the by-product formed i.e.  $\text{Ca}(\text{OH})_2$

As the replacement percentage of cement increases the amount of by-product formed from the hydration of cement decreases hence less amount of calcium hydroxide will be available to react with silicon dioxide hence unreacted silica will remain resulting in less C-S-H gel formation. This causes a decrease in strength and the strength will go on decreasing as the percentage replacement of pozzolanic material increases. It is applicable to most of the pozzolanic material.

Using this waste (BLA & BFA) as a cement substitute reduces not only the economic and environmental challenges associated with waste disposal but also the cement content, resulting in decreased  $\text{CO}_2$  emissions and energy required during cement manufacture. Therefore, the main aim of this study was to determine how BLA and BFA blended cement concrete affected the mechanical, workable, and durable characteristics of concrete.

### **Research Gap Identification**

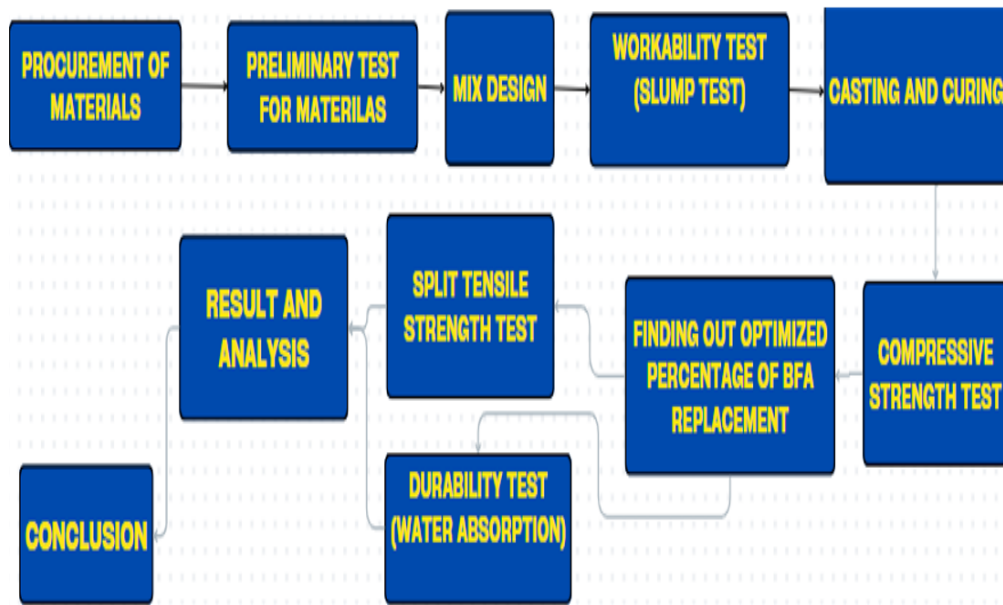
1. As per previous research conducted, the use of bamboo leaf ash to replace cement partially to obtain sustainable concrete.
2. We have introduced/used bamboo flake ash as a Pozzolanic material for cement replacement, which has been considered new research.

## **II. OBJECTIVE AND METHODOLOGY**

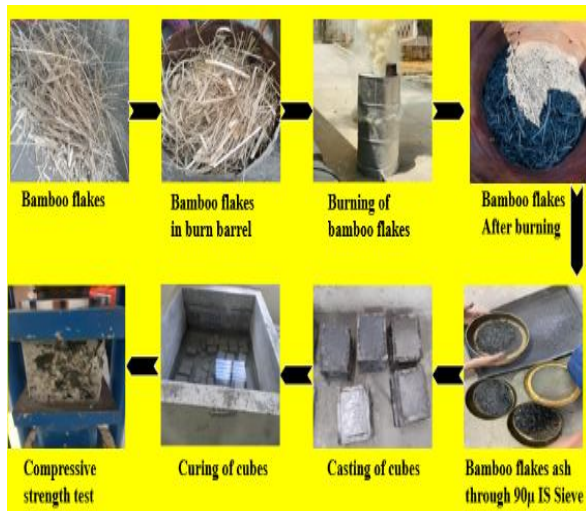
### **Objective**

1. To evaluate the optimized percentage replacement of cement with bamboo flake ash and bamboo leaves ash
2. To find the mechanical properties of concrete by partial replacements of cement and compare them with the properties of conventional concrete.
3. To assess and compare the durability property of sustainable concrete and conventional concrete.

### Methodology



**Figure 3:** Flowchart for Methodology



**Figure 4:** Process of Testing of Cubes Using BFA



**Figure 5:** Process of Testing of Cubes Using BLA

### III. MATERIAL PROPERTIES

- 1. Cement:** Ordinary Portland cement (Birla) of Grade 53 was used for this research. The physical properties of the Cement are shown in table-1.

**Table 1: Physical Properties of Cement**

Sl. No.	Properties	Test Method	Test result	Limitations As per IS 12269-2004
1	Normal Consistency in (%)	Vicat Apparatus (IS:4031 Part- 4)	28%	25 -35 %
2	Specific Gravity	Sp. Gr bottle (IS:4031Part- 4)	3.125	≤ 3.15
3	Initial Setting Time	Vicat Apparatus(IS: 4031 Part - 5)	55 min	>30
4	Final Setting time		490 min	<600
5	Fineness of cement	Sieve test on 90 $\mu$ Sieve (IS: 4031 Part-1)	1.2%	< 10%

**2. Bamboo Flakes Ash:** Bamboo flakes are defined as the extruded waste parts of bamboo culms while making bamboo products such as mats, trays, and many more. Mainly they are generated from the bamboo processing industry.

In this research, the Bamboo flakes were collected from the local street of KR market, Bengaluru which is shown in the figure below. The process of ash preparation, storage, sieving, and chemical testing was done. Apart from this, we collected 25kg of bamboo flakes which after burning came out as 1.5kg ashes.

The dry bamboo flakes are sundried and burned using a burn barrel in FCRC (Fire and Combustion Research Center) Lab, at Jain University.



**Figure 6:** Bamboo Flakes  
K.R Market Area Burning



**Figure 7:** Bamboo Flakes

**3. Bamboo Leaves Ash:** When bamboo reached the mature stage and becomes mature, its bottom leaves start falling. The bamboo leaves used in this research were collected from the Jain global campus. The fallen leaves are collected and sundried for 1-2 days. After that, the collected bamboo leaves were taken to Fire and Combustion Research Centre, Jain University. Then the leaves were put in the burn barrel for about 1 hour. The burned ash was cooled for some time and kept in an airtight zipper bag by sieving it through a 90 $\mu$ -IS sieve in order to preserve oxygen. Because the ashes lose their chemical composition as it comes in contact with moist air and reduces strength too.

While burning 28 kg of bamboo leaves and the ash produced from it was 5.535 Kg.

The leaves were burnt in the same lab as BFA as shown in Fig 6 and the same procedure was followed to prepare ash.

#### 4. Chemical Properties of OPC VS BFA VS BLA

**Table 2: Chemical Properties Of OPC, BFA & BLA**

System	SiO <sub>2</sub>	Al <sub>2</sub> O <sub>3</sub>	Fe <sub>2</sub> O <sub>3</sub>	CaO	MgO	K <sub>2</sub> O	N <sub>2</sub> O	SO <sub>3</sub>	IR	LOI
OPC	21.40	5.03	4.40	61.14	1.35	0.48	0.24	2.53	1.65	1.29
BFA	66.10	6.02	3.21	7.29	2.28	.	.	8.84	.	8.84
BLA	68.31	3.82	4.29	8.70	1.66	.	.	0.59	.	6.12

**5. Water:** Portable water available in the Concrete technology lab of the Jain Global campus was used for the experiment.

**6. Superplasticizer (Builplast-SP):** PEB (Polycarboxylate ether-based) superplasticizer was used in this research. The physical Properties of the superplasticizer are given in table-3.

**Table 3: Physical Properties of Superplasticizer**

Name	BUILDPLAST-SP
Color	Dark Brown
Standard	Conforming to IS:9103-1999
State	Liquid
SP.Gravity	1.15-1.17
PH value	7-8

- 7. Fine Aggregate:** In this experiment, M-sand was used, which was prepared by crushing stones of various shapes and sizes. The physical properties of M-sand are given in table-4.

**Table 4: Physical Properties of M-Sand**

Sl. No.	Physical Properties	Test Results	Code of Reference
1	Specific gravity	2.61	IS 2386 part 3-1963
2	Fineness modulus	3.025	IS383-1970
3	water absorption	8.6%	

- 8. Coarse Aggregate:** In this research, 20mm downsize coarse aggregate having a specific gravity of 2.7 and water absorption capacity of 0.8% was used in this research.

#### IV. MIX PROPORTION

Cement- 404.18kg  
Fine Aggregate-664kg  
Coarse Aggregate-1220kg  
Superplasticizer (BUILDPLAST-SP) - 3.238kg  
Water to cement ratio -0.4  
Mix Proportion By weight = **1:1.64:3.02**

The total amount of dry volume of concrete required to cast 1 cube was 8.2 kg as per calculation. By considering losses we have taken 8.5 kg of concrete cube of size 150mm\*150mm\*150mm. The quantity of each material required to cast cubes is given below:

**Table 5: Mix Proportions to Cast Cubes**

BFA/BLA %	Cement Kg	BFA/BFA kg	Fine Aggregate kg	Coarse Aggregate kg	Superplasticizer ml	Water Content ml
0%	1.5	0	2.465	4.533	12	600
5%	1.425	0.075	2.465	4.533	12	600
10%	1.35	0.15	2.465	4.533	12	600
15%	1.275	0.225	2.465	4.533	12	600

Also, we have cast a cylinder based on the optimum percentage of BFA. The quantity of BFA required to cast a cylinder of size 100mm\*200mm (diameter\*depth). The total quantity of material we used to cast the cylinder was 4kg. The quantity of each material required to cast the cylinder is given below:

**Table 6: Mix Proportion to Cast Cylinders**

BFA/BLA %	Cement Kg	BFA/BLA kg	Fine Aggregate kg	Coarse Aggregate kg	Superplasticizer ml	Water Content ml
0%	1.5	0	1.16	2.15	6	280
5%	1.425	0.075	1.16	2.15	6	280

## V. MIX PROCEDURE

First, all the concrete making material are dry mixed for 5 minutes, then about 70% of the mixing water is added and mixed for 3-4 minutes, 10-15% of water and 60-70% of superplasticizer is added and mixed again for about 2 minutes as superplasticizer.

After adding a superplasticizer don't mix the concrete for a long time as decreases the setting time and the chances of the early setting are high. The remaining water and superplasticizer are added and mixed for some time.

## VI. CURING

A total of 36 cubes are cast and curing was done for 7 days, 14 days & 28 days, and 3 cylinders are cast for 5% BFA replacement and cured for the same time as concrete cubes.

## VII. PROPERTIES OF CONCRETE

### 1. Fresh concrete property

- Workability (Slump Test):** From the experiment, we got a slump value of 105mm at 0.8% superplasticizer by weight of cement. The workability of a concrete mix to make a cube was found to be reduced when the cement was partially replaced with bamboo flakes ash and bamboo leaves ash. The same pattern was seen for all percentages of cement replacement with BFA & BLA. Due to the cellular nature of BFA/BLA particles and their high fineness (Which increases with their surface area), concrete containing BFA & BLA absorbs more water for a given consistency, requiring more water overall. As compared to BLA, the BFA is finer and absorbs more water during mixing.

As a result, a proper dosage of additional water was added to improve the fluidity and consistency of the mix.





**Figure 8:** Slump Test on Concrete

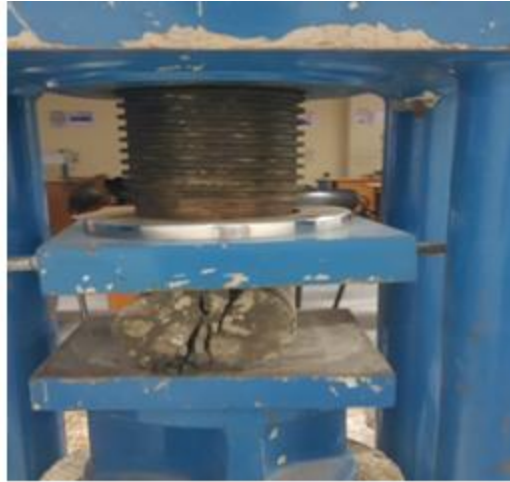
## 2. Mechanical Properties of Concrete

- **Compressive Strength Test:** The concrete cubes were formed using normal concrete with BFA and BLA substituting cement at 5%, 10%, and 15% respectively. The compressive strength test was performed on a specimen of cubical size 150mm in a 3000KN Universal Testing Machine. The compression testing figures are shown below.



**Figure 9:** Compressive Strength Test of Cube

- **Split Tensile Strength Test:** A split tensile strength test is carried out on conventional concrete with the optimal percentage of bamboo leaves ash (5%) and bamboo flakes ash (5%). The cylinder was placed in a curing tank for 7D, 14D, and 28D and tested after curing.



**Figure 10:** Split Tensile Strength Test

### 3. Durability Property of Concrete

- **Water Absorption Test:** After the concrete cube has been cured for 28 days, it is dried in an oven at 108 degrees Celsius for 24 hours. This ensures that all the moisture is completely removed from the concrete cube. The cube is then weighed to establish the dry weight.

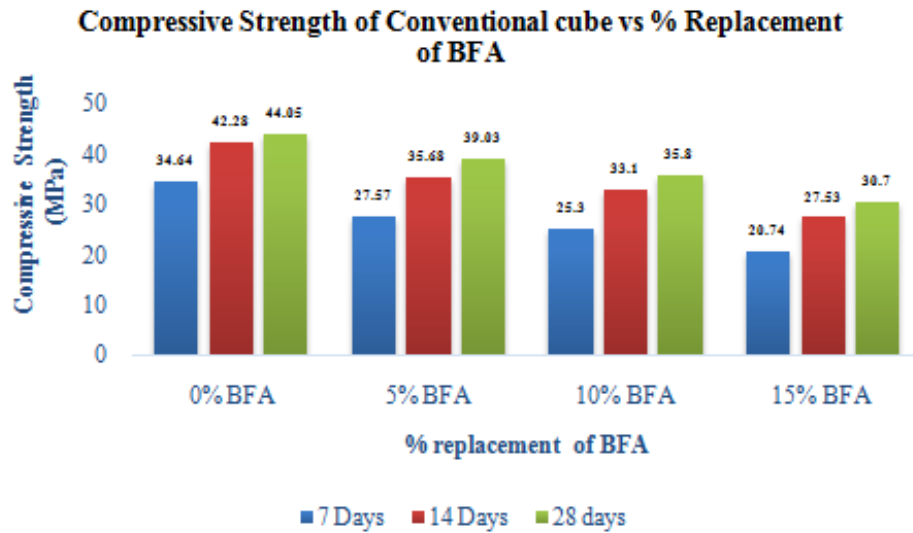


**Figure 11:** Water Absorption Test

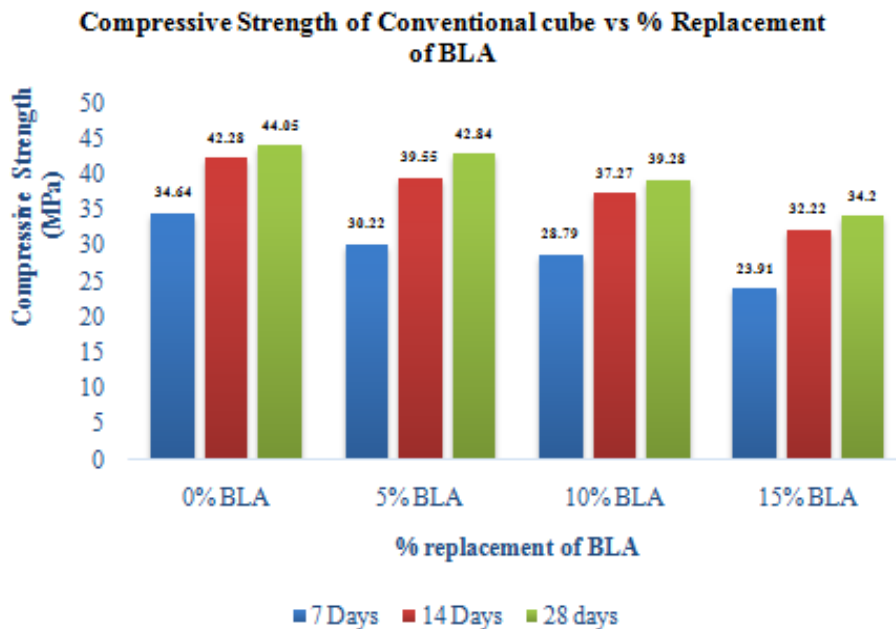
Then, the dried cube is immersed in water for 24 hours to allow water to penetrate into the concrete. After the immersion period, the cube is weighed again to determine the water weight absorbed. By comparing the dry weight and the weight after immersion, the concrete cube's water absorption has been calculated. This value reflects the ability of the concrete to resist the ingress of water.

## VIII. RESULT AND DISCUSSION

The average compressive strength for conventional concrete cubes and BFA/BLA-based concrete cubes is given below:



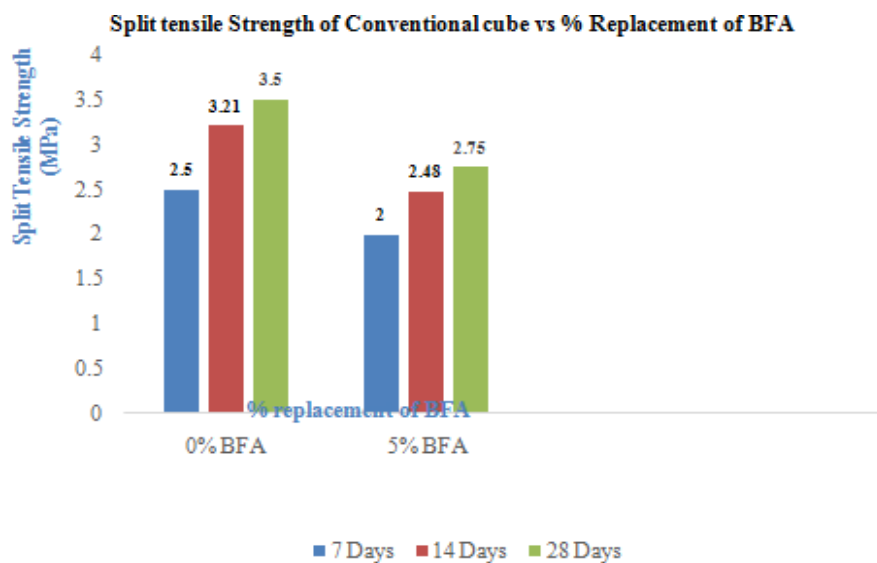
**Figure 12:** Comparison of Compressive Strength of Conventional Cubes and BFA-Based Cubes At 7D, 14D & 28D.



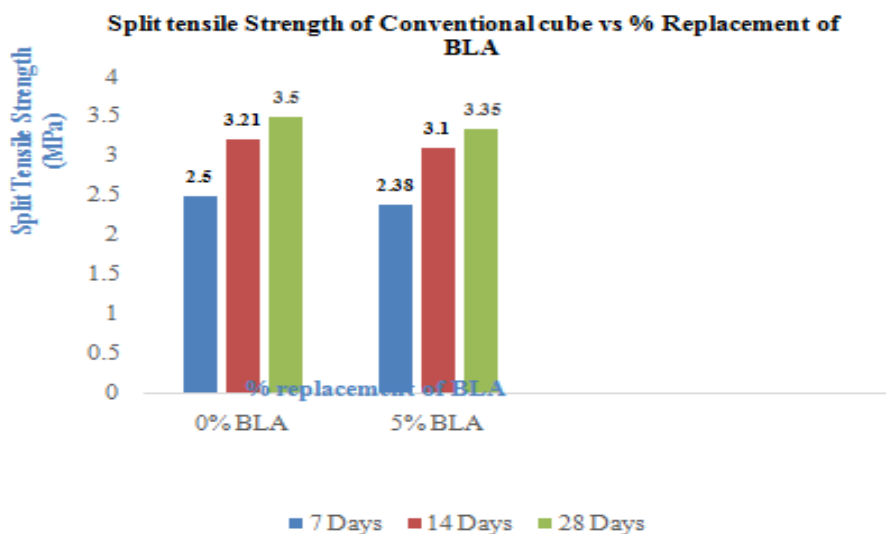
**Figure 13:** Comparison of Compressive Strength of Conventional Cubes and BLA-Based Cubes At 7D, 14D & 28D

The fig.12 & fig. 13 shows that the compressive strength of conventional concrete is more as compared to BLA and BFA based concrete cubes. The 5% replacement of BLA and BFA has shown the optimum strength and it goes on decreasing as the percentage replacement of ashes increases. The reason of this is due to the incomplete hydration of the concrete mix as the ashes are finer than cement. The BLA based concrete gives more strength as compared to BFA based concrete cubes. Therefore the concrete mix with higher replacement of SCM becomes less workable and have lower strength as compared to conventional concrete cubes.

The average split tensile strength for conventional concrete cylinders and BFA/BLA-based concrete cylinders is given below:



**Figure 14:** Comparison of Split Tensile of Conventional Cubes and BFA-Based Cubes at 7D, 14D & 28D.



**Figure 15:** Comparison of Split Tensile of Conventional Cubes and BLA-Based Cubes at 7D, 14D & 28D

The above graph shows that the split tensile strength of conventional cylinder is more as compared to BFA and BLA based cylinder. If we compare the BFA and BLA cylinders the split tensile strength of BLA based cylinder is more. The 5% replacement gives optimum strength for concrete cylinders.

The water absorption test comparison of conventional cubes, 5% BFA, and BLA-based cubes are shown below.

**Table 7: Water Absorption Test**

Mix	Dry weight (Kg) W1	Weight of Specimen after immersion in water (Kg) W2	% Water absorption
Conventional	7.753	8.141	5%
5% BFA	7.957	8.305	4.37%
5% BLA	7.777	8.056	3.587%

## IX. CONCLUSION

1. The workability of concrete mix decreases with an increase in the percentage replacement of BFA/BLA. So required amount of water is added to make a mix workable.
2. The 5% of BFA gives the optimum value of Compressive strength result as 27.57 MPa, 35.68 MPa, and 39.03 on the 7<sup>th</sup>, 14<sup>th</sup> and 28<sup>th</sup> day of curing and 5% BLA gives optimum strength as 30.22MPa,39.55MPa and 42.84 MPa respectively on the 7<sup>th</sup>, 14<sup>th</sup> and 28<sup>th</sup> day of curing.
3. The split tensile strength for the optimum percentage (5%) of BFA is 2 MPa, 2.48 MPa & 2.75 MPa and 5% BLA is 2.38MPa, 3.1MPa and 3.35 MPa respectively on the 7<sup>th</sup>, 14<sup>th</sup>, and 28<sup>th</sup> day of curing.
4. Superplasticizer helps to increase the workability of concrete as well as the early strength of concrete.
5. The water absorption of conventional is more than 5% BFA cubes and more than 5% BLA cubes. It shows that as compared to conventional and BFA-based concrete cubes BLA based cubes shows good durability property.

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