An experimental study on alternative cementitious materials: Bagasse ash as partial replacement for cement in structural lightweight concrete

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This paper reports the effect of bagasse ash and lightweight aggregates on the properties of structural lightweight concrete. In this study, bagasse ash is physically and chemically characterized and partially replaced in the ratio of 0%, 5%, 10%, 15% and 20% by weight of cement and natural lightweight coarse aggregate pumice is also physically characterized and replaced by 100% with natural coarse aggregate and Natural River sand as fine aggregate were used to produce structural lightweight concrete. As there were no mix design procedure for lightweight concrete as that of normal concrete as per Bureau of Indian Standards, trial batches were done to meet the structural lightweight concrete requirements as per American Concrete Institute (ACI). The fresh properties of structural lightweight concrete like slump test and hardened properties like compressive strength of cubes and cylinders and split tensile strength were carried out. The test results indicated that fresh and hardened properties of the structural lightweight concrete increases as the percentage of replacement of bagasse ash increases up to certain extent.

1. INTRODUCTION

To meet the sustainable development challenges facing the concrete industry, this paper reviews some environmentally friendly concrete technology including the improved cement manufacturing technology, the use of supplementary cementitious materials, recycling concrete and other materials, enhancement of service life of concrete structures. With the ever increasing demand and consumption of cement and in the backdrop of waste management, scientists and researchers all over the world are always in quest for developing alternate binders that are environment friendly and contribute towards sustainable management. Researchers all over the world today are focusing on ways of utilizing either industrial or agricultural waste, as a source of raw material for industry. Fly ash is considered as most prolific cementitious material compared to other industrial and agricultural by products because of its chemical composition, particle size and its availability. But other potential by-products of agricultural waste such as sugarcane bagasse ash needs to be investigated.

2. STRUCTURAL LIGHTWEIGHT CONCRETE

Structural lightweight concrete is defined as per ASTM C330 the concrete has minimum 28-days compressive strength of 17MPa and 28days equilibrium density or air dried density between 1400-1850 kg/m^3[1]. Structural lightweight concrete is primarily used to reduce the dead load of the structures, having a more efficient strength to weight ratio than normal weight concrete. In most cases, the marginally higher cost of lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost. They provide civil engineers the flexibility to enhance functionality and architectural designs with structures that are taller, have longer spans, lighter foundations, expressive roof designs, greater elasticity and thus more resistance to seismic movements. They have primarily been used in offshore oil platform's, bridge decks to allow for a wider deck for additional traffic lanes, piers and beams, slabs and wall elements in both steel and concrete frame buildings, parking structures, tilt up walls and topping slabs. They have also been successfully used in the pre-cast industry to manufacture bigger size elements without increasing overall weight. Lightweight concrete improves fire resistance, partly due to the fact that the lightweight aggregates have been subjected to heating process during manufacture. With lightweight concrete, the co-efficient of thermal expansion can be significantly reduced by around one third and thermal conductivity by over 25% with generally speaking, the lighter the weight of the concrete greater the insulating properties [2].

Designers recognize that structural lightweight concrete will not typically serve in an oven-dry environment. Therefore, structural design generally relies on equilibrium density (sometimes referred to as air-dry density); the condition in which some moisture is retained within the lightweight concrete. Equilibrium density is a standardized value intended to represent the approximate density of in place concrete when it is in service. Field acceptance is based on measured density of fresh concrete. Equilibrium density will be approximately 50 to 130 kg/m^3 less than the fresh density and a correlation should be agreed upon prior to delivery of concrete [3].

2.1 Constituents of structural lightweight concrete

Lightweight aggregates

By definition, structural lightweight concrete primarily contains aggregates that are either all lightweight aggregates or a combination of lightweight and normal weight aggregates.

Lightweight aggregates suitable for structural concrete may be natural aggregates such as pumice or scoria, or they may be processed aggregates such as expanded shales, clays, slates and slags, sintered fly ash aggregates and expanded polystyrene beads. Lightweight aggregates are more porous than normal weight aggregates hence Lightweight aggregates that are not pre-saturated will absorb water in the concrete mix. To control slump, the lightweight aggregates should be pre-wetted before being used in the mix. This absorbed water is not part of the mix water in the lightweight mix, and it does not directly affect slump, water cement ratio, or quality of the paste. There are three ways to pre-wet lightweight aggregate particles: through sprinkling, thermal quenching and vacuum saturation. If the aggregates in lightweight concrete are properly pre-wetted, then the concrete behave much like normal weight concrete [4].

Bagasse ash

Bagasse ash is an agricultural/industrial waste and it is by-product of sugarcane milling process in sugarcane factories [5]. The sugarcane is a major crop growing in Mysore and Mandya district. There are around eight sugar mill factories in and around Mysore and Mandya districts which extract

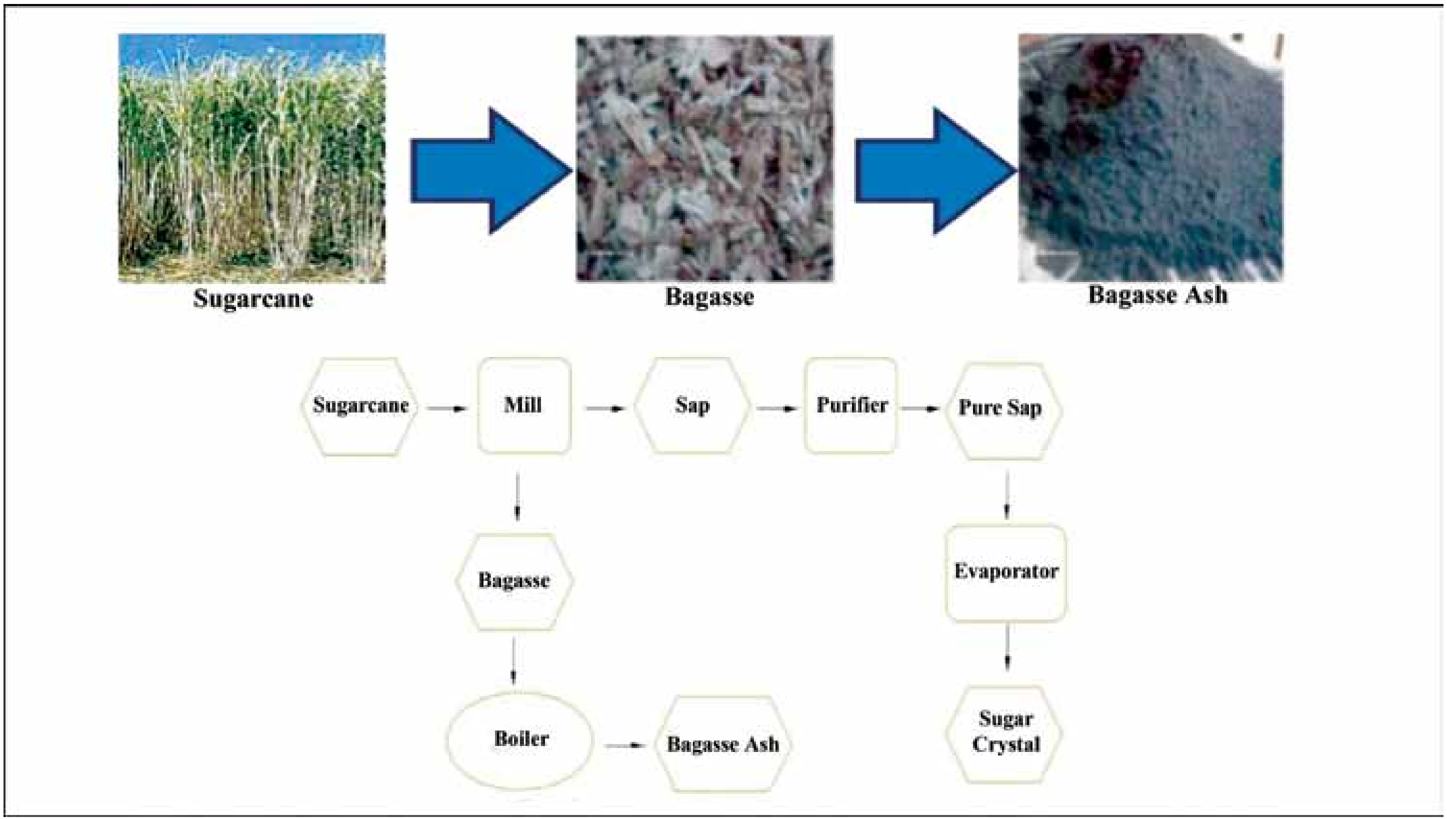

Figure 1. Flow diagram of bagasse ash

sugarcane juice from around 30 lakh metric tons sugarcane yearly to produce sugar. Sugarcane bagasse (SCB) which is a voluminous by-product in the sugar mills obtained when juice is extracted from the sugarcane. For each 1 ton of sugarcane crushed, a sugar factory produces nearly 300 kg of bagasse. Since bagasse is a by-product of the cane sugar industry, the quantity of production in each country is in line with the quantity of sugarcane produced. It is, however, generally used as a fuel to fire furnaces in the same sugar mill for power production that yields about 3-5% bagasse ash which becomes an industrial waste or agricultural waste and poses disposal problems, as shown in Figure 1. Due to uncontrolled burning conditions, bagasse ash generated will be black in colour which indicates high amount of carbon present which liberates carbon dioxide to the atmosphere which is a serious threat to human beings. The residual ash obtained from sugarcane factory to be used as an alternative cementitious material will also not show much predominant pozzolanic activity in concrete as it contains high amount of carbon and organic materials due to uncontrolled burning temperature at around 700°C. The fruitfulness of bagasse ash is, it contains high amounts of un-burnt matter, silicon, aluminum, iron and calcium oxides which are essential chemicals requirements to be used in concrete. For obtaining amorphous (non-crystalline) and reactive sugarcane bagasse ash (SCBA), they are burnt under controlled conditions and several trials were conducted to define optimum burning time and temperatures. At the optimum burning temperature the bagasse acts as a pozzolanic material which can be used as alternative cementitious materials in concrete. Hence, an attempt has been made to use bagasse ash as alternative cementitious material in the production structural lightweight concrete.

3. MATERIAL PROPERTIES

3.1 Cement

Ordinary Portland cement conforming to IS 12269:2013 was used. The properties are determined as per relevant Indian standards and the test results obtained are shown in Table 1.

Table 1. Physical properties of cement

Test	Result
Specific Gravity	3.05
Normal consistency (%)	30
Initial setting time (min)	140
Final setting time (min)	255
Specific surface area (cm^2/gm)	3135
Bulk Density kg/m^3 (i) Loose (ii) Compacted	 1161 1306

3.2 Bagasse ash

The field observation and qualitative studies of sugarcane bagasse ash revealed that it consists of a major amount of carbon and organic materials. This is due to the incomplete combustion of bagasse fiber in boiler system. Therefore, it becomes necessary to recondition the sample for use as pozzolanic material by re-ashing again at 250°C for 24 hrs in oven in the laboratory to exclude the high carbon content. It was then passed through 150 µ IS sieve and the resulting ash was chemically analyzed and physically characterized. The chemical & physical test results are shown in Tables 2 and 3.

Table 2. Chemical properties of bagasse ash

Chemical Composition	SiO_2%	Al_2O_3 %	Fe_2O_3%	CaO %	LOI %
Residual Bagasse Ash	65.37	0.22	5.98	1.50	21.04
Reburnt Bagasse Ash	68.67	0.22	5.98	1.50	14.00

Table 3. Physical properties of bagasse ash

Test	Result
Specific Gravity	2.15
Bulk Density kg/m^3 (i) Loose (ii) Compacted	 360 433
Specific Surface Area, cm^2/gm	2475

As per IS 3812 (part1):2013 specifications the combined chemical composition of $SiO_2 + Al_2O_3 + Fe_2O_3 = (68.67 + 0.22 + 5.98) = 74.87\%$ satisfies the pozzolanic nature of bagasse ash according to test specification the bagasse ash qualifies to be a class F pozzolana and the loss on Ignition value for the bagasse ash was found to be (LOI) 14 % which is slightly more than specified by the same standard satisfying the above requirements the bagasse ash has got pozzolanic properties and hence it can used as replacement material for cement to produce structural lightweight concrete.

3.3 Properties of pozzolanic material (as per IS 1727 : 1967)

The test shall be done as specified in IS 1727 Methods of Physical Tests for 'Hydraulic Cement' except that in place of cement, a mixture of pozzolana and cement in the proportion:0.8:N0.2 by weight, blended intimately shall be used: The results are shown in Table 4.

where $N = \dfrac{Specificgravityofpozzolana}{Specificgravityofcement}$

Table 4. Physical properties of pozzolana

Test	Result
Normal consistency (%)	41
Initial setting time (min)	165
Final setting time (min)	380

3.4 Fine aggregate

Natural river sand as fine aggregate was used. The properties are determined as per relevant Indian standards and the test results obtained are shown in Table 5.

Table 5. Physical properties of fine aggregate

Test	Result
Specific Gravity	2.67
Bulk Density (kg/m^3)	1497
Fineness modulus	3.5

3.5 Lightweight coarse aggregate

Pumice a natural lightweight aggregate was used as lightweight coarse aggregate. The properties are determined as per relevant Indian standards and the test results obtained are shown in Table 6.

Table 6. Physical properties of pumice lightweight aggregate

Test	Result
Specific Gravity	1.03
Bulk Density (kg/m^3) Loose	393.47
Compacted	457.65
Flakiness Index (%)	3.85
Elongation Index (%)	5.6
Water Absorption (%), 24 hrs	30

4. MIX PROPORTIONING

Mix design method applying to normal weight concrete is generally difficult to use with light weight aggregate concrete. The lack of accurate value of absorption, specific gravity and the free moisture content in the aggregate make it difficult to apply the water cement ratio accurately for mix proportioning [6].

Light weight concrete mix design is usually established by trial mixes. The proportions of fine to coarse aggregate and the cement and water requirement are estimated based on the previous experiences with particular aggregate. Various degree of water absorption by different light weight aggregates is one of the serious difficulties in the design of mix proportions. a reliable information of saturated, surface dry bulk specific gravity becomes difficult. Sometime the aggregate is saturated before mixing so that is does not get alternate on account of absorption by aggregate [6].

As per Indian standards there is no mix design procedure for the structural lightweight concrete, hence we have done the trail batches in order to achieve the boundary conditions as per ACI 213 R-03 which are shown in Table 7.

Table 7. Boundary conditions (requirements) of structural lightweight concrete as per ACI 213 R-03

Conditions	Limits
Equilibrium Density	1400-1840 kg/m^3
Concrete strength @ 28 days	17 MPa
Slump	25-125 mm
Difference in Fresh & Equilibrium Densities	50-130 kg/m^3

4.1 Trial mix proportions

Table 8 describes the trail batches of structural lightweight concrete and the boundary conditions were attained in Trial-3; hence further castings were done on the basis of Trail-3 which is considered as control mix of structural lightweight aggregate concrete.

Table 8. Trail mix proportion of structural lightweight concrete

Headings	Trail-1	Trail-2	Trail-3
Cement (kg/m^3)	427	427	480
Fine aggregate	676	889	865
Lightweight coarse aggregate (Pumice), (kg/m^3)	426	344	335
Aggregate ratio, (CA:FA)	0.62 : 0.38	0.50 : 0.50	0.50 : 0.50
W/C Ratio	0.45	0.45	0.4
Water (Litres/m^3)	192	192	192
Strength at 28 days (Mpa)	16.85	20.04	22.52
Density (kg/m^3)	1698	1723	1773
Slump, mm	55	45	30

4.2 Control mix proportion

Table 9 describes the mix proportions of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete as fixed from Table 8.

Table 9. Mix proportioning of structural lightweight concrete

Concrete type	% of Bagasse Ash	Cement kg/m^3	Bagasse ash kg/m^3	Fine Aggregate kg/m^3	Pumice kg/m^3	W/C Ratio	Water, kg/m^3
SLWC (0% BA)	0	480	0	865	335	0.4	192
SLWC-1 (5% BA)	5	456	24	865	335	0.4	192
SLWC-2 (10% BA)	10	432	48	865	335	0.4	192
SLWC-3 (15% BA)	15	408	72	865	335	0.4	192
SLWC-4 (20% BA)	20	384	96	865	335	0.4	192

SLWC – Conventional or OPC based Structural Lightweight Concrete; SLWC-1 – Structural Lightweight Concrete with 5% replacement of bagasse ash SLWC-2 – Structural Lightweight Concrete with 10% replacement of bagasse ash; SLWC-3 – Structural Lightweight Concrete with 15% replacement of bagasse ash; SLWC-4 – Structural Lightweight Concrete with 20% replacement of bagasse ash

4.3 Density of mixes

Table 10 shows the densities of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete as fixed from Table 8 and in order to meet the boundary conditions as per Table 7 the density of each cubes & cylinders are checked.

Table 10. Densities of the structural lightweight concrete

Concrete type	% of Bagasse Ash	Fresh density, kg/m^3		Equilibrium density kg/m^3	
		Cube	Cylinder	Cube	Cylinder
SLWC (0% BA)	0	1773	1756	1805	1797
SLWC-1 (5% BA)	5	1776	1762	1807	1804
SLWC-2 (10% BA)	10	1735	1722	1767	1750
SLWC-3 (15% BA)	15	1730	1713	1770	1755
SLWC-4 (20% BA)	20	1726	1708	1763	1750

5. TEST RESULTS AND DISCUSSIONS

5.1 Physical and chemical analysis of cement and bagasse ash

The physical properties of cement and bagasse ash as described in Table 3. The specific surface area of bagasse ash is found to be higher than that of OPC. The density and specific gravity are found to be less than those of OPC. The chemical compositions of cement and bagasse ash are compared as described in Table 2. The chemical analysis indicates that the bagasse ash has higher silica content than OPC. The bagasse ash has also considerable amount of Al_2O_3, Fe_2O_3 and CaO.

5.2 Slump Test

Table 11 shows the slump test results of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete.

Table 11. Slump values of structural lightweight concrete

Concrete type	Slump, mm
SLWC, (0% BA)	30
SLWC-1, (5% BA)	85
SLWC-2, (10% BA)	45
SLWC-3, (15% BA)	40
SLWC-4, (20% BA)	25

Figure 2 indicates that, increase in bagasse ash content up to 15%, there is an increase in slump value of structural lightweight concrete compared to conventional structural lightweight concrete, beyond that there is a reduction in slump value. It indicates that without any chemical admixtures we have obtained the required slump value as per ACI 211.2-98.

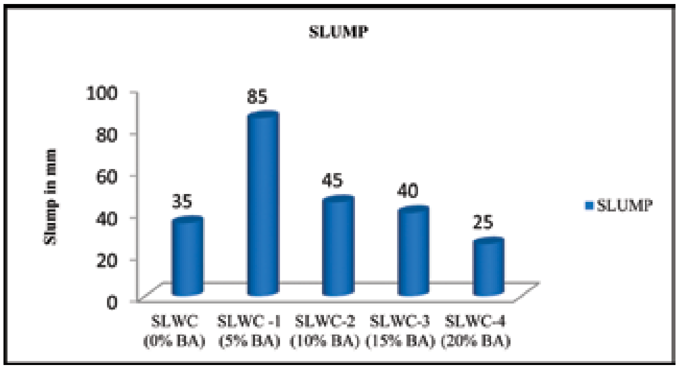

Figure 2. Variation of slump value with replacement of bagasse ash.

Further, decrease in slump values can be attributed to the higher percentage of loss on ignition (LOI) i.e., 14% as indicated above which is more than 7% as per IS 3812 (part-2): 2013 value may affect the degree of water absorption and in turn affects the workability.

5.2 Compressive Strength

Cube compressive strength

Table 12 shows the compressive strength of cube specimens of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete.

Table 12. Cube compressive strength values of structural lightweight concrete

Cube	7 Days (N/mm^2)	28 Days (N/mm^2)	56 Days (N/mm^2)	90 Days (N/mm^2)
SLWC **(0% BA)**	15.62	22.04	22.6	22.85
SLWC-1 **(5% BA)**	15.46	20.13	23.73	24.56
SLWC-2 **(10% BA)**	16.52	21.25	22.26	23.68
SLWC-3 (15% BA)	16.43	21.94	22.60	24.39
SLWC-4 **(20% BA)**	15.07	19.56	20.45	23.37

Figure 3 indicates that, increase in bagasse ash content up to 15%, there is equal in compressive strength value of structural lightweight concrete when compared to conventional structural lightweight concrete at 28 days of curing, beyond that there is a reduction in compressive strength.

For 56 and 90 days curing, it shows that increase in bagasse ash content up to 15%, there is equal and higher in compressive strength value of structural lightweight concrete when compared to conventional structural lightweight concrete, beyond that there is a reduction in compressive strength. This was due to the combined effect of relative fineness and the pozzolanic activity of bagasse ash. Decrease in compressive strength values with increase in the substitution ratio indicated that filler effect is predominant only up to 15% ash substitution.

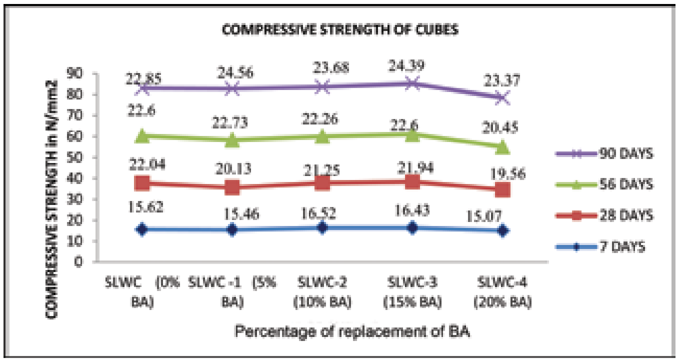

Figure 3. Cube compressive strength of structural lightweight concrete with increase in bagasse ash.

Cylinder compressive strength

Table 13 shows the compressive strength of cylindrical specimens of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete.

Table 13. Cylinder compressive strength values of structural lightweight concrete

Cylinder	7 Days (N/mm^2)	28 Days (N/mm^2)	56 Days (N/mm^2)	90 Days (N/mm^2)
SLWC **(0% BA)**	12.04	17.62	18.40	18.44
SLWC-1 **(5% BA)**	11.94	18.27	18.37	18.94
SLWC-2 **(10% BA)**	11.69	19.65	19.83	19.86
SLWC-3 (15% BA)	13.59	18.57	18.90	19.95
SLWC-4 **(20% BA)**	13.10	16.90	17.30	17.46

Figure 4 indicates that increase in bagasse ash content up to 15%, there is increase in compressive strength value of structural lightweight concrete when compared to conventional structural lightweight concrete at 28 days of curing, beyond that there is a reduction in compressive strength.

For 56 and 90 days curing, it indicates that increase in bagasse ash content up to 15%, there is increase in compressive strength value of structural lightweight concrete when compared to conventional structural lightweight concrete, beyond that there is a reduction in compressive strength.

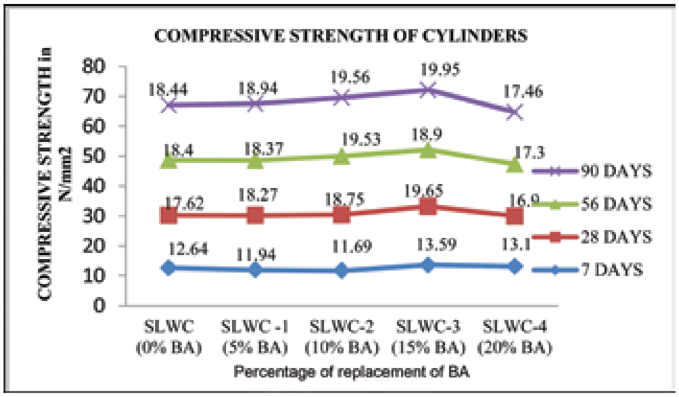

Figure 4. Cylinder compressive strength of structural lightweight concrete with increase in bagasse ash.

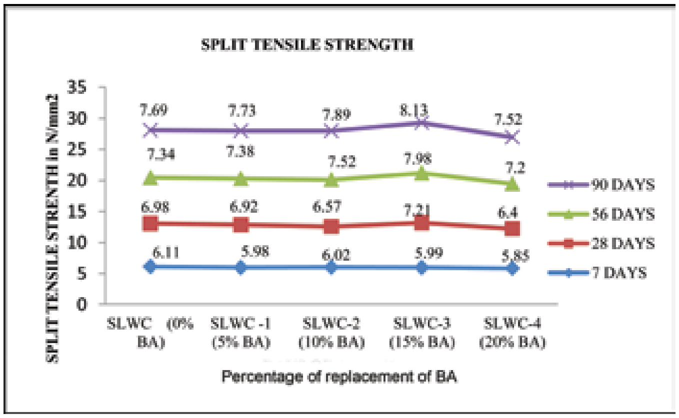

Figure 5. Variation in split tensile strength with increase in bagasse ash

This was also due to the combined effect of relative fineness and the pozzolanic activity of bagasse ash. Decrease in compressive strength values with increase in the substitution ratio indicated that filler effect is predominant only up to 15% ash substitution.

5.3 Split tensile strength

Table 14 shows the split tensile strength of cylindrical specimens of structural lightweight concrete after replacing the varying percentage of bagasse ash by weight of cement in control mix of structural lightweight aggregate concrete

From the Figure 5 it indicates that, increase in bagasse ash content up to 15% there is a greater split tensile strength value of structural lightweight concrete when compared to conventional lightweight concrete, beyond that there is a reduction in split tensile strength value.

6. CONCLUSIONS

From the present investigation, the following conclusion were drawn.

- The chemical composition test indicated that, the bagasse ash can be classified as Class F pozzolana which can be concluded as pozzolanic material to be used in structural lightweight concrete.
- Bagasse ash up to 15% is found to be better substitute for cement for achieving workability in structural lightweight concrete as per ACI 2112.2-98 without any addition of chemical admixtures.
- From the compressive strength results of cubes and cylinders, it is found that on 15% of bagasse ash replacement with cement will yield better strength as compared to OPC based lightweight concrete.
- From the split tensile strength results, it is found that on 15% of bagasse ash replacement with cement will yield better tensile strength as compared to OPC based lightweight concrete.
- It can be concluded that, bagasse ash is predominant up to 15% as substitute for cement to produce structural lightweight concrete which can be used for practical applications.

Table 14. Split tensile strength values of structural lightweight concrete

Concrete type	7 Days (N/mm^2)	28 Days (N/mm^2)	56 Days (N/mm^2)	90 Days (N/mm^2)
SLWC **(0% BA)**	6.11	6.98	7.34	7.69
SLWC-1 **(5% BA)**	5.98	6.92	7.38	7.73
SLWC-2 **(10% BA)**	6.02	6.57	7.52	7.89
SLWC-3 (15% BA)	5.99	7.21	7.98	8.13
SLWC-4 **(20% BA)**	5.85	6.40	7.20	7.52

Acknowledgement

During the preparation of this manuscript, we thank the efforts of Dr. K. Manjunath, ME (Geotech), PhD (IISC), Professor, Department of Studies in Civil Engineering, University BDT College of Engineering, Davangere.

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