

An Experimental Study on Hardened Strength Properties of G.P.C by Partial Replacement of Cement with Bagasse Ash at ambient curing

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ABSTRACT: The production of cement by the industry causes pollution to the environment. Geopolymers release very less carbon dioxide when compared to ordinary portland cement during its manufacture. It is an alternative construction material that has comparable mechanical properties to that of ordinary Portland cement concrete, consisting of an aluminosilicate and an alkali solution. Bagasse Ash is a burnt waste produced in sugar factories after extraction of sugar cane. Bagasse ash based geopolymer concrete was prepared and the specimens were cured by the ambient curing method. The fresh and hardened properties of GPC for M20 grade were studied for a 12 M concentration of NaOH solution for 10%, 20% and 30% replacement of BA. The BA based geopolymer concrete achieved a very good compressive strength and split tensile strength at 20% replacement of Bagasse ash by weight of cement. Thus, Bagasse ash based geopolymer concrete will be an adequate construction material for in-situ casting, as heat curing will be uneconomical.

KEYWORDS: Geopolymer Concrete (GPC), Alkaline Liquid, Bagasse Ash (BA), Ambient Temperature, Geopolymerisation.

I. INTRODUCTION

Every year the worldwide production of ordinary Portland cement (OPC) is approximately increasing more than 4000×10^6 Tonne (Statista 2014). According to the current growth rate, the levels of OPC production will only increase, in order to fulfill the adequate demand to build the infrastructure. The production of OPC is causing about 7% of the world's greenhouse emissions into the atmosphere (Hardjito et al. 2004). That is more than 1763.7 pounds of carbon dioxide per tonne is produced during the manufacture of OPC (Motorwala et al. 2008). In need of suggestion to decrease the high amount of carbon dioxide (CO₂) emissions and global warming, a new binder called as Alkali activated cement or geopolymers was discovered. Geopolymers release nearly 80%- 82% less carbon dioxide when compared to ordinary portland cement during its manufacture, creating it a more eco-friendly construction material (Sakulich 2011).

The term 'geopolymer' was introduced by Davidovits in the year 1978. Apart from ordinary Portland cements, geopolymers do not form calcium-silicate-hydrates (CSHs) for matrix formation and strength, but utilize the polycondensation of silica and alumina precursors to attain structural strength. Two main constituents of geopolymers are: source materials and alkaline liquids. The source materials on aluminosilicate must be rich in aluminium (Al), ferric oxide (Fe₂O₃) and silicon (Si). They could be by-product materials such as Bagasse Ash, Fly Ash, Silica Fume, Slag, Rice-Husk Ash, Red Mud, etc. Bagasse ash is produced in large quantities worldwide; hence its disposal is a challenging task. Bagasse ash has high silica content hence it can be used as a binding material. Therefore, a Bagasse

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ash based geopolymer concrete was investigated in this study. The hardening in low calcium based geopolymer concrete takes place by a process called Geopolymerisation. During this study the curing of geopolymer concrete was investigated at ambient temperatures. The methodology of the study includes Mix design and procurement of materials, physical tests on collected materials. The hardened strength properties of geopolymer concrete were achieved by conducting compressive strength test and split tensile strength test.

The study has following objectives

- To find the suitability of Sugar Cane Bagasse Ash (SCBA) as partial replacement material in concrete mix for M20 grade concrete.
- To obtain a better understanding of the compressive strength and tensile strength properties of geopolymer concrete at ambient curing.
- To identify the factors influencing mechanical properties of geopolymer concrete.
- To study the cost effectiveness of GPC and conventional concrete per cubic meter for M20 grade.

II. EXPERIMENTAL PROGRAM

1. MATERIALS

i. Cement

The most common cement used is ordinary Portland cement. Birla super 53 grade cement conforming to the requirements of IS: 102629-2009 was used. Tests conducted on the cement were specific gravity & fineness modulus.



Fig.1 (a) Bagasse ash (b) M-sand (c) & (d) Coarse Aggregate

ii. Bagasse Ash (BA)

Sugarcane Bagasse Ash procured from Pandavapura Sahakara Sakhare Karkhane Ltd. (PSSK Ltd.) is used in the present study as a partial replacement of cement.

iii. Aggregates (CA and FA)

The locally available aggregates were procured, where coarse aggregate was of size 20mm retained (15%), 12.5 mm retained (20%) and 6.3 mm retained (35%) by weight of aggregates. Due to high temperature the aggregate were absorbing large amount of water from the mix. Hence saturated surface dry aggregates were used in the concrete mix. The fine aggregate obtained was M-sand of size passing 4.75 mm and retained on 150 μ IS sieve (30% by total weight of Aggregates) in order to prevent dust.

iv. Alkali Activator

In the alkaline activator substances of Silica are dissolved in strong alkaline conditions with high P^H. During the dissolution of the silica and aluminum the alkaline solution is active and plays a main role in the condensation process (Lindgard et al. 2012). Sodium hydroxide, potassium hydroxide, sodium silicate and potassium silicate are the common activators used for geopolymers. Sodium hydroxide was the main activator used in this study, where sodium silicate was added to increase the silica content in the medium. From previous investigations it is found that sodium hydroxide in conjunction with sodium silicate, proved to be an effective alkaline activator, resulting promising mechanical properties as it improves the reaction between the binder and alkali solution. Sodium hydroxide causes a higher rate of dissolution compared to that of potassium hydroxide (Memon et al. 2013).

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Vol. 6, Issue 6, June 2017

- a. Sodium Hydroxide Solution (NaOH Solution):** Caustic soda is the other name to Sodium hydroxide, which is manufactured by the electrolysis of sodium chloride brine in a membrane or diaphragm electrolytic cell (Occidental Chemical Corporation 2000). Sodium hydroxide (NaOH) procured was in the form of flakes.
- b. Sodium Silicate Solution (Na₂SiO₃ Solution):** Alkali silicates Solutions are also termed as “water glass”. Sodium silicate was procured from a small scale chemical industry in liquid form.
- v. Super Plasticizer**
The super plasticizer named 'Conplast SP430(G)' was used in order to improve the workability of Geopolymer concrete. These Super plasticizers are of high range water reducing Naphthalene based. Conplast SP430(G) used complies with IS:9103:1999, BS:5075 Part 3 and ASTM-C-494.

2. INDIVIDUAL TESTS ON MATERIALS

The raw materials physical and chemical properties were tested and are tabulated as following

- i. Bagasse Ash
- ii. Cement.
- iii. Coarse aggregates.
- iv. Fine aggregates.

3. CHEMICAL PROPERTIES OF BAGASSE ASH

Table 1 Chemical Properties of Bagasse Ash

Sl. No.	1	2	3	4	5	6	7	8	9
Chemical Composition	SiO ₂	Fe ₂ O ₃	Al ₂ O ₃	K ₂ O	CaO	SO ₃	Mn	Zn	Cu
Percentage by weight	62.43	6.98	4.38	3.53	2.51	1.48	0.50	0.30	0.10

[Pandavapura Sahakara Sakhare Karkhane Ltd. (PSSK Ltd.), Mandya]

4. PHYSICAL PROPERTIES

Table 2 Physical Properties of Bagasse Ash

SL.NO	Physical Test	Result	Codal provision	Code referred
1.	Specific Gravity of BA	2.484		
2.	Fineness of BA by sieve analysis	4.20	Which is less than 10	IS: 4031-(Part-1)1996
3.	Specific gravity of cement	3.07	3 - 4	IS: 4031-(Part 6)
4.	Fineness of Cement	2.30	Which is less than 10	IS: 4031-(Part-1)1996
5.	Avg. Specific gravity of M-sand	2.76		IS:2386(part-3)-1963 (Reaffirmed -2002)
6.	Fineness modulus of M-sand	2.32	2.0 to 3.5 (2.0-2.6= Fine Sand)	IS:383-1970
7.	Specific gravity of coarse aggregates	2.603	2.5 - 3.0 For road construction,	IS: 2386 part 3-1963 (Reaffirmed 1997)
8.	Percentage of Water absorbed by coarse aggregate	0.015	Shall not be more than 0.6 per unit weight.	IS: 2386 part 3-1963 (reaffirmed 1997)
9.	Fineness modulus of Coarse Aggregate	3.58	3.5 to 6.5-For all in or combined aggregates.	IS: 2386 part 3-1963 (Reaffirmed 1997)

5. RELATED WORK

In this study concrete of M20 grade is considered. The method of mix design, material calculations, mixing technique and curing are done different than conventional concrete. As there is no particular standard code for geopolymer concrete, all the materials required for construction of GPC are proportioned according to B.V RANGAN and DAVIDOVITS method of mix design for geopolymer concrete. The coarse aggregates collected were in saturated surface dry condition. Alkaline liquids (NaOH & Na₂SiO₃) were prepared 24 hours prior to casting day. Super plasticizer is added and the mix is completed. After the casting, moulding and demoulding, the specimens are kept for

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Vol. 6, Issue 6, June 2017

ambient curing. Later the specimens were tested after 3, 7 and 28 days for compressive strength and split tensile strength for different percentage of BA.

i. Preparation of Alkaline Liquid

In this study alkaline liquid is prepared by mixing the Sodium Silicate solution and Sodium Hydroxide solution. Sodium Silicate solution is readily available in standard solution form. Sodium hydroxide is available in the form of flakes, pellets etc, whose solution was prepared for a 12Molar mass of solid which depends on required concentration of NaOH solution.

WKT, for 1 Molar of NaOH, the molecular weight is 40g.

Therefore, for 12 Molar of NaOH we need = $12 \times 40 = 480$ g of NaOH pellets.

When the 480 gram of NaOH pellets is dissolved in 1000 ml of water we obtain a Sodium Hydroxide solution of 12M with large amount of heat liberation. Hence the solution is prepared in a water bath with constant stirring. After the preparation of NaOH solution, sodium silicate solution is added to the sodium hydroxide solution slowly and by constant mixing. The alkaline liquid is prepared 24 hours before casting.

ii. Mixing and Curing of GPC

Mixing of GPC cannot be done by hand mix method as in case of conventional concrete. It requires a concrete pan mixer. The concrete mix is done in two stages one dry mix and wet mix. In the dry mix first all the dry materials (CA, FA, cement & BA) are added and dry mixing is done for not less than 2 minutes.

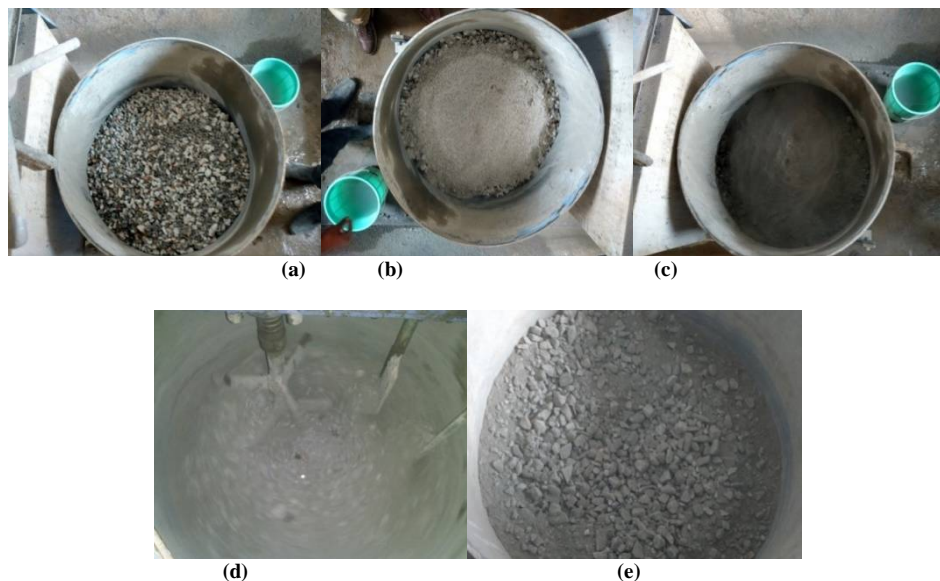


Fig.3 Addition of (a) Coarse Aggregate (b) M-sand (c) Bagasse ash (d) & (e) Dry mix

Once the uniform color and mixture is obtained, alkaline liquid should be added, that was prepared 24 hours prior and then super plasticizer must be added. The addition must be done continuously. Initially 20% of water is added; the mix turns to be workable for a minute and becomes stiff. Again some 15- 20% of water by weight of cement is added and the wet mix is continued for 3 – 4 minutes till uniform mix is obtained. After the mix is done the moulds are filled with concrete and compacted. Compaction is done using vibrating table and the specimen is demoulded after 24 hours.

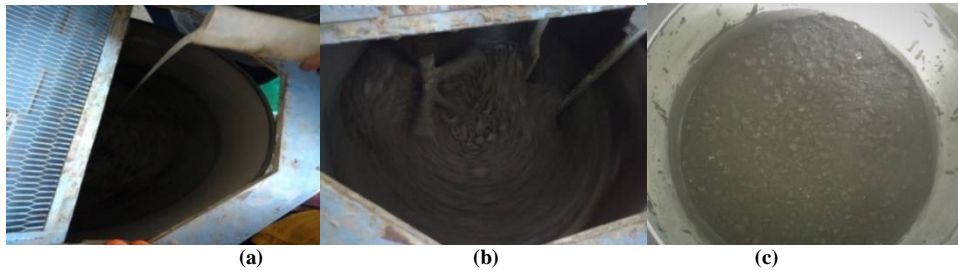


Fig.3 (a) Addition of Alkaline liquid, (b) & (c) Wet mixing



Fig.4 (d) Compacting (e) Moulding (f) Ambient curing

Later the specimens were kept open to atmospheric temperature (which was 35° C) for 3, 7 and 28 days. The curing temperature will also influence the strength of GPC. In the GPC, chemical reaction and polymerization process starts during curing process.

III. MIX DESIGN AND CALCULATIONS OF PROPORTIONS

Table 3 showing Considerations

Bagasse ash based type	low calcium
Ratio of [Na ₂ SiO ₃ /NaOH] solution	2.5 by mass
Molarity of NaOH solution	12M
Alkaline liquid to binder ratio	0.3
Aggregates	77% (75 to 80% of mass of concrete)
Super plasticizer	2.0% of Bagasse Ash

PROCEDURE FOR MIX DESIGN OF G.P.C

The mix design is carried out for 1 m³

I. Wet Density:

Wet density of geo polymer concrete = 2400 kg/m³.

II. Mass of Combined Aggregate:

Mass of combined aggregate = 77% of mass of concrete = $(77 \times 2400) / 100 = 1848 \text{ kg/m}^3$

III. Mass of Alkaline To Binders:

Mass of binders to alkaline liquid = $(2400 - 1848) = 552 \text{ kg/m}^3$

IV. Mass of Bagasse Ash:

Given data Alkaline liquid to binders ratio by mass = 0.3

Mass of fly ash = $[552 / (1 + 0.3)] = 424.6154 \text{ kg/m}^3$

V. Mass of Alkaline Liquid:

Mass of alkaline liquid = $552 - 424.6154 = 127.3846 \text{ kg/m}^3$

VI. Mass of Sodium Hydroxide Solution

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 6, June 2017

Ratio of Na₂SiO₃ solution to NaOH solution by mass = 2.0
Mass of sodium hydroxide solution = [157.72/ (1 + 2.0)] = **42.4615 kg/m³**

VII. Mass of sodium hydroxide Solution:

1 molar = 40gm of NaOH pellets in 1000 ml of water (Molecular Weight)
For, 12 molar=12×40 gm
Mass of pellets = 480 gm of NaOH pellets in 1000 ml of water.
Total sodium hydroxide solution = [12×40 + 1000]= 1480 kg/m³
Percentage of sodium hydroxide solids in NaOH solution,
= [(480/ (1000+480))×100]= 32.432%
Sodium hydroxide solid = 0.324 × 42.4615= **13.7713 kg**
Volume of Water required = [42.4615 -13.7713] = **28.6902 litres**

VIII. Mass Of Sodium Silicate Solution and Water content Required:

Mass of sodium silicate solution = [127.3846 - 42.4615] = **84.9231 kg/m³**
Water content in sodium silicate solution = 55.9% = 0.559×84.9231 =47.472 kg
Solids = 84.9231-47.472 = 37.4511kg

IX. Mass of Course Aggregates and Fine Aggregates

Total mass of aggregate (Course aggregates + fine aggregates) = 1848 kg/m³

15% of 20mm=	277.2 kg/m³
20% of 12mm=	369.6 kg/m³
35% of 6mm =	646.8 kg/m³
30% of fine sand =	554.4 kg/m³

X. Super Plasticizer

Super plasticizer = 2.0% of mass of fly ash = 424.6154×0.020 = **8.4923 kg/m³**

XI. Table 4: Mix proportion for Geopolymer concrete

FOR 1m ³	
MATERIALS	MASS Kg/m ³
Coarse Aggregate	15% of 20 mm 277.200
	20% of 12 mm 369.600
	35% of 6 mm 646.800
Fine Aggregate	30% 554.400
Cementitious material	424.615
Na ₂ SiO ₃	84.923
NaOH	42.462
Super plasticizer	8.492
Extra water	42.46

IV. RESULTS AND DISCUSSIONS

In the present study the experimental work was carried on fresh and hardened strength properties. A total of 54 numbers of specimens were prepared to study the compressive strength and split tensile strength of geopolymer concrete at ambient curing. The percentages of bagasse ash replaced with cement are 10%, 20% & 30% by the weight of cement.

- i. Compression Strength Test - Cubical specimens of size (150×150×150) mm.
- ii. Split Tensile Strength Test - Cylindrical specimens of size, Diameter=150mm and Height=300mm.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Website: www.ijirset.com

Vol. 6, Issue 6, June 2017

1. WORKABILITY OF GEOPOLYMER CONCRETE

The workability of Geopolymer concrete for a Na_2SiO_3 to NaOH ratio of 2.0 and M20 grade concrete is measured using slump cone method and the values are as follows

Table 5: Slump for different percentage of BA based Geopolymer concrete

Concrete Type	Slump in mm
Conventional Concrete	110
10% BA based GPC	15
20% BA based GPC	80
30% BA based GPC	80

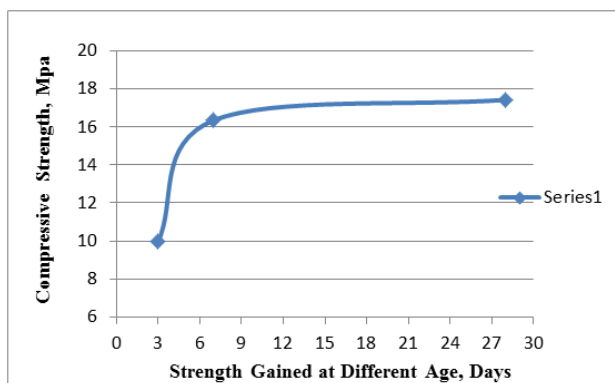
It is found that the geopolymer concrete has very good workability at 20% and 30% replacement of BA.

2. Test Results on Compression Test

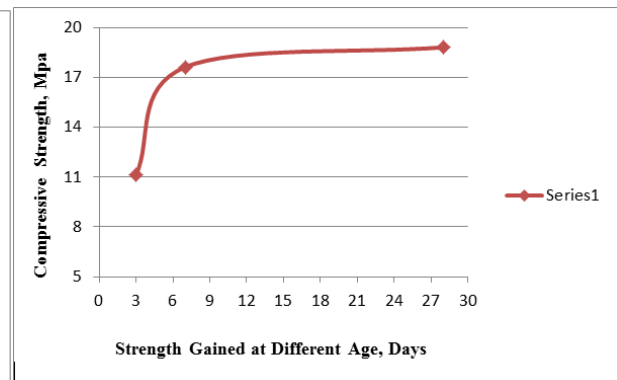
27 cubes were casted for compression strength test for M20 grade concrete at 3, 7 and 28 days, for 10%, 20% & 30% replacement of cement by its weight with BA respectively. An optimum dosage of BA replacement was determined. Table 6 give Compressive strength of GPC for different percentage Bagasse Ash.

Table 6: Compressive strength of GPC for different percentage Bagasse Ash

Compression Strength Test Results						
% of BA	3 DAYS		7 DAYS		28 DAYS	
	Avg. load, kN	Avg. stress, MPa	Avg. load, kN	Avg. stress, MPa	Avg. load, kN	Avg. stress, MPa
10%	224.03	9.96	367.88	16.35	392.10	17.43
20%	250.65	11.14	396.75	17.63	424.43	18.82
30%	167.18	7.43	286.88	12.75	312.53	13.89

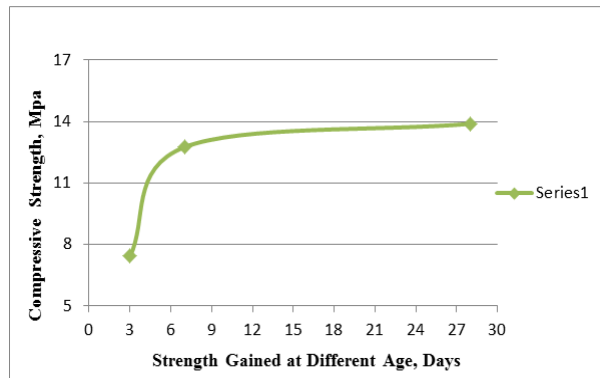


Graph 1: Compressive Strength for 10 % of BA

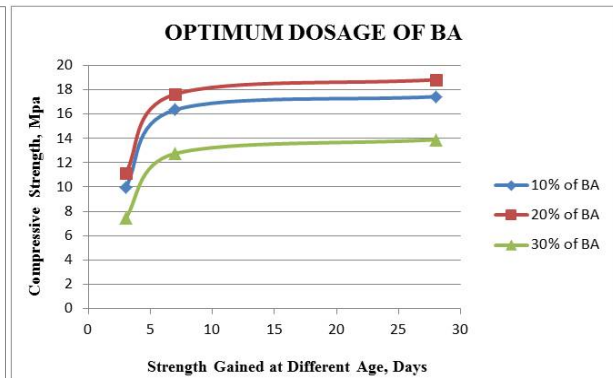


Graph 2: Compressive Strength for 20 % of BA

Observations: The graphs of age verses compressive strength were plotted for Geopolymer concrete bagasse ash replacement for M20 grade. In Graph 1 for 10% replacement of BA, it was observed that the strength of GPC was increased by 39.08% from 3rd day to 7th day and 6.19% from 7th day to 28th day. Whereas in Graph 2 for 20% replacement, it was seen that the strength was increased by 36.81% from 3rd day to 7th day and 6.32% from 7th day to 28th day.



Graph 3: Compressive Strength for 30 % of BA



Graph 4: Optimum Dosage of BA

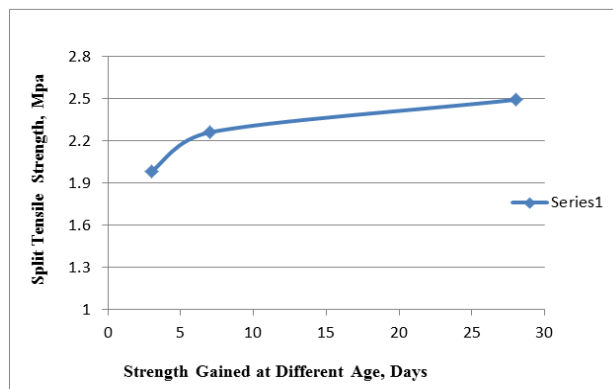
Observations: A graph of age verses compressive strength is plotted for Geopolymer concrete with bagasse ash replacement for M20 grade. From Graph 3 for 30% replacement, it was observed that the strength was increased by 41.72% from 3rd day to 7th day and 8.94% from 7th day to 28th day. The above Graph 4 shows the optimum dosage of BA replacement with cement. It was observed that the strength was 7.38% and 35.49% high for 20% replacement of BA than 10% and 30% replacement of BA respectively. Hence 20% of BA replacement is considered as optimum dosage.

3. TEST RESULTS ON SPLIT TENSILE STRENGTH TEST

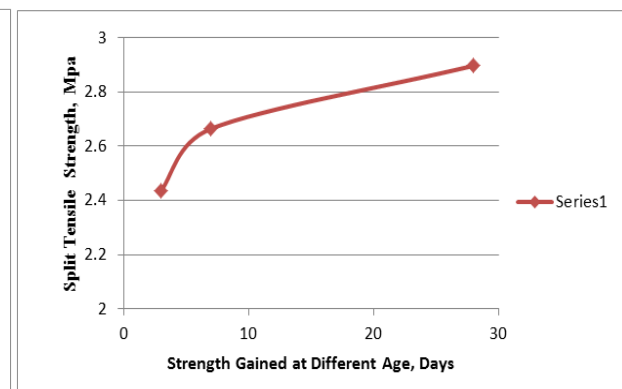
27 cylinders were casted for Split Tensile Strength Test of GPC for M20 grade concrete at 3, 7 and 28 days to 10%, 20% & 30% replacement of cement by its weight with BA. An optimum dosage of BA that can be replaced was determined. Table 7 give Compressive strength of GPC for different percentage Bagasse Ash.

Table 7: Split tensile strength of GPC for different percentage Bagasse Ash

Split Tensile Strength Test Results						
% of BA	3 DAYS		7 DAYS		28 DAYS	
	Avg. load, kN	Avg. stress, Mpa	Avg. load, kN	Avg. stress, Mpa	Avg. load, kN	Avg. stress, Mpa
10	141.45	1.990	109.83	2.261	176.2	2.493
20	172.33	2.439	188.4	2.66	204.78	2.897
30	148.47	2.100	163.28	2.311	171.77	2.430



Graph 5: Split Tensile Strength for 10 % of BA



Graph 6: Split Tensile Strength for 20 % of BA

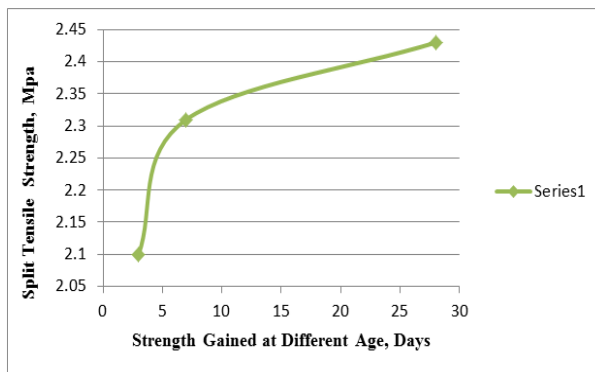
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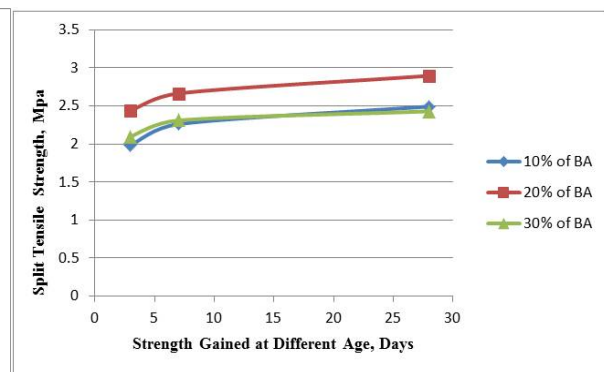
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Vol. 6, Issue 6, June 2017

Observations:The graphs of age versus Split Tensile Strength were plotted for Geopolymer concrete bagasse ash replacement for M20 grade. In Graph 5 for 10% replacement of BA, it was observed that the strength of GPC was increased by 11.99% from 3rd day to 7th day and 9.31% from 7th day to 28th day. While in Graph 6 for 20% replacement, it was seen that strength was increased by 8.48% from 3rd day to 7th day and 8.01% from 7th day to 28th day.



Graph 7: Split tensile Strength for 30% of BA



Graph 8: Optimum Dosage of GPC

Observations: The graphs of age versus compressive strength is plotted for Geopolymer concrete with bagasse ash replacement for M20 grade. From Graph 7 for 30% replacement, it was observed that the strength was increased by 9.13% from 3rd day to 7th day and 4.89% % from 7th day to 28th day. The above Graph 8 shows the optimum dosage of BA replacement with cement. It was observed that the split tensile strength was 13.94% and 16.12% high for 20% replacement of BA than 10% and 30% replacement of BA respectively. Hence 20% of BA replacement is considered as optimum dosage.

V. CONCLUSION

Following are the conclusions drawn from the study:

- The compressive strength of geopolymer concrete with 20% of bagasse ash increases by 7.38% than the GPC with 10% of bagasse ash and decreases to 26.19% for GPC with 30% of bagasse ash. The strength of GPC is decreased by 12.85%, 5.9% and 30.5% for 10%, 20% and 30% respectively when compared to conventional concrete.
- The split tensile strength of GPC with 20% of bagasse ash increases by 13.94% than the GPC with 10% of bagasse ash and decreases to 26.47% for GPC with 30% of bagasse ash. Tensile strength of GPC is decreased by 16.9 %, 3.43% and 29% for 10%, 20% and 30% respectively when related to conventional concrete
- Since the use of cement is reduced by partially replacing with BA, amount of energy interacted is less. These concretes can be called as ecofriendly concrete as the GPC uses BA as binding material.
- The GPC is best suited for pavement and bridges construction in high temperature regions (Ambient curing).
- Bagasse ash based geopolymer concrete can be used in construction of fire resisting structures.
- The rate of Geopolymer concrete per cubic meter is found to be 1.7 times more than that of conventional concrete, but this will be economical when considered in large scale as ambient curing is done at uncontrolled temperature.
- There is an increase in hardened properties of GPC for 20% replacement of BA with cement, which indicates that the concrete has gained strength at ambient temperature which can be improved in future study. But the strength attained by the concrete at later age (28 days) is less than conventional concrete. This might be due to the uncontrolled temperature of atmosphere during curing period that will not be constant.

International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 6, Issue 6, June 2017

VI.SCOPE FOR FUTURE STUDY

- Study may be done to enhance the hardened properties of bagasse ash based GPC by varying the molarity of NaOH and for different grade of concrete at ambient temperature.
- The study on bagasse ash based Geopolymer concrete blending completely with cement for different percentage of Bagasse ash.
- The study on fresh and hardened properties of bagasse ash based geopolymer concrete with carbon Nano fibers with different aspect ratios.
- A comparative study on bagasse ash based GPC at ambient curing and oven curing.

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BIOGRAPHY



Mr. Mohammed Abdul Khader Khan was born in Mysore, India on 07th June 1993. He graduated with Bachelor of Engineering., in CivilEngineering under VTU-Belgaum, from MIT-Mysore in the year 2015,and is currently pursuingMaster of Technology in Structural Engineering at NCET, Bengaluru, Karnataka.



Mr. Gururaj M H was born on 31st July 1986. He did his M-Tech in Structural Engineering from Basaveshwar Engineering College Bagalkot (2012) and purusing his Ph.D from VTU Belagavi. He has 5years of Research experiece and 2 years industrial experiece and is presently working as Assistant professor in MIT Mysore, Karnataka.



Dr. B.G Naresh kumarwas born on 21st May 1959. He did his ME in Structural Engineering from University of Roorkee (1986) and obtained his Ph.D from University of Roorkee (1997). He has more than 31 years of teaching experiece and is presently working as Professor and Principal in MIT Mysore, Karnataka.