Study on Strength and Durability Characteristics of Concrete with Ternary Blend

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Abstract. In the present scenario to fulfill the demands of sustainable construction, concrete made with multi-blended cement system of Ordinary Portland Cement (OPC) and different mineral admixtures is the wise choice for the construction industry. In this research work, M20 grade mix of concrete (with water - binder ratio as 0.48) is adopted with glass powder (GP) and SugarCane Bagasse Ash (SCBA) as partial replacement of cement. GP is an inert material, they occupy the landfill space for considerable amount of time unless there is a potential for recycling. Such glass wastes in the crushed form have a good potential in the infrastructure industry. Replacement of cement by GP from 30% to 0% by weight of cement in step of 5% and by SCBA from 0% to 30% in step of 5% respectively was adopted. In total, seven different combinations of mixes were studied at two different ages of concrete namely 7 and 28 days. Compressive strength of cubes for various percentage of replacement were investigated and compared with conventional concrete to find out the maximum mix ratio. Flexural strength of concrete for the maximum mix ratio was found out and durability parameters viz., water absorption and sorptivity were studied. From the experimental study, 20% SCBA and 10% GP combination was found to be the maximum mix ratio.

1. Introduction

1.1. General

Now a day the world is witnessing the construction of very challenging and difficult structures, concrete being the most important and widely used structural material is called upon to possess very high strength. The main ingredient in the conventional concrete is the Ordinary Portland Cement (OPC). The amount of cement production emits approximately equal amount of carbon dioxide into the atmosphere. Cement production is consuming significant amount of natural resources. To overcome the above ill effects, the advent of newer material and construction techniques and in this drive, admixture has taken newer things with various ingredients has become a necessity. The addition of pozzolanic materials with OPC a century old practice is an alternative in the construction industry.
1.2. Sugarcane bagasse ash (SCBA)
Bagasse is the fibrous residue of sugarcane after crushing and extraction of juice. Sugarcane Bagasse Ash is a by-product of sugar factories found after burning sugarcane bagasse which itself is found after the extraction of all economical sugar from sugarcane [12]. Mostly, bagasse produced is burnt for energy needed for sugar processing. The disposal of this material is already causing environmental problems around the sugar factories [2]. The use of bagasse ash as partial replacement of cement at 10%, 20% and 30% and there was an increase in strength at 10% and low permeability was investigated [13]. 5 to 30% Ground Bagasse Ash (GBA) in partial replacement of cement in concrete and found that there is an increase in early and later compressive strength at 20% and decrease in water permeability [7] [11]. The use of SCBA as sand replacement material to improves quality and reduce the cost of construction material [8]. The main composition of bagasse ash is siliceous oxide that react with free lime from cement during hydration process.

1.3. Glass powder (GP)
Glass is one of the most versatile substances on Earth, used in many applications and in a wide variety of forms. When manufactured, glass is a mixture of silica, soda, and lime, the amount of waste glass produced has gradually increased over the recent years due to an ever growing use of glass products. Most waste glass is being dumped into landfill sites. The landfilling of waste glass is undesirable because waste glass is non biodegradable which makes the environment harmful. There is huge potential for using waste glass in the concrete construction sector. When waste glasses are reused in making concrete products, the production cost of concrete will go down. This move will serve two purposes; first, it will be environment friendly; second, it will utilize waste in place of precious and relatively costlier natural resources [10]. Waste glass when ground to a very fine powder shows some pozzolanic properties as it contains high SiO$_2$ and therefore to some extent it replaces the cement and contributes for strength development. The use of finely ground glass powder as partial replacement of cement or aggregate up to 20%. Compressive strength was decreased when cement was partially replaced with glass powder when compared with glass aggregate [9]. The use of ground waste glass powder as partial replacement of cement at 0%, 10% and 20% was studied [1]. Due to high alkali content, Alkali Silica Reaction (ASR) expansion was drastically reduced during the pozzolanic reaction. Partial replacement of cement by glass powder at 10%, 20% and 30% was investigated. There was an increase in strength at 20% when the size of glass powder was less than 90 microns [4].

2. Materials
2.1. Cement
OPC 53 grade cement conforming to IS 10262 – 2009 was used in this work. The specific gravity was 3.15.

2.2. Fine aggregate (FA)
The locally available river sand with specific gravity 2.60 was used as fine aggregate in this investigation. The sand is free from clay, silt, and organic impurities. Fine aggregate were found to be less than 4.75 mm size which confirms to IS: 383-1970 (Zone: II).

2.3. Coarse aggregate (CA)
Crushed granite metal obtained from a local source with specific gravity 2.60 was used as a coarse aggregate that passed through 20 mm sieve and retained in 12 mm sieve.
2.4. Water
The quantity of water in the mix plays vital role on the strength of the concrete. Hardening occurs because of the chemical reaction, called hydration, between the cementitious materials and water. Water available in the campus conforming to the requirements of water for concreting and curing as per IS: 456-2009.

2.5. Sugar Cane Bagasse Ash (SCBA)
SCBA ash was collected from Dhanalakshmi sugar factory, Perambalur, Tamil Nadu, India. The value of Specific gravity was 2.17. The particle size of SCBA was found to be 0.840 microns.

![Figure 1. Particle size distribution of SCBA by intensity](image_url)

2.6. Glass Powder (GP)
Glass powder was prepared from waste glasses. The value of Specific gravity was 2.42. The particle size of GP was found to be 1.168 microns.
Table 1. Chemical composition of SCBA and GP

| Components                | SCBA | GP  |
|---------------------------|------|-----|
| Silica (SiO$_2$)          | 79%  | 70% |
| Alumina (Al$_2$O$_3$)     | 9.52%| 1.50%|
| Lime (CaO)                | 2.60%| 11.24%|
| Iron Oxide (Fe$_2$O$_3$)  | 3.86%| 2.65%|
| Magnesia (MgO)            | 2.50%| 2.50%|
| Sodium Oxide (Na$_2$O)    | 0.31%| 12.20%|
| Chromium Oxide (Cr$_2$O$_3$)| 1.00%| 1.00%|
| Sulphur Trioxide (SO$_3$) | 0.4% | 0.4% |
| Loss in Ignition          | 0.32 | 0.32 |

3. Methodology and Mix proportions

M20 Grade of concrete is used. The percentage of binder (cement) was kept constant at 70% by weight of the mix. Replacement of cement by SCBA was from 0% to 30% in step of 5% and GP with range of replacement from 30% to 0% in step of 5% respectively. In total, seven different combinations of mixes were studied at two different ages of concrete namely 7 and 28 days. The mix ratio which had maximum value in compression at 7 and 28 days age was selected from different mix ratios. Beams were cast for conventional and mix ratio having maximum compression value. Then the beams were tested for the flexural behaviour. Durability parameters viz., Water absorption and Sorptivity were studied for all different mix ratios. The specimens of size 150 mm × 150 mm × 150 mm were cast by partially replacing the binder (cement) with GP and SCBA for compressive strength estimation. The same mix was followed for casting the beam of size 100 mm × 150 mm × 1000 mm. For durability test, 100 mm diameter and 50 mm height cylinder specimens were cast for sorptivity test and water absorption test.
Table 2. Mix design and Proportions

| M20 Mix proportion |       |
|---------------------|-------|
| Cement (Kg/m³)      | 399.2 |
| Fine aggregate (Kg/m³) | 672.8 |
| Coarse aggregate (Kg/m³) | 1097.2 |
| Water (Litres/m³)   | 191.6 |
| Water cement ratio  | 0.48  |
| Mix Ratio           | 1:1.68:2.75 |

Table 3. Mix Proportion Percentages

| Mix designation | Cement | SCBA | GP | Fine Aggregate (FA) | Coarse Aggregate (CA) |
|-----------------|--------|------|----|---------------------|-----------------------|
| S               | 100%   | 0%   | 0% | 100%                | 100%                  |
| S1              | 70%    | 0%   | 30%| 100%                | 100%                  |
| S2              | 70%    | 5%   | 25%| 100%                | 100%                  |
| S3              | 70%    | 10%  | 20%| 100%                | 100%                  |
| S4              | 70%    | 15%  | 15%| 100%                | 100%                  |
| S5              | 70%    | 20%  | 10%| 100%                | 100%                  |
| S6              | 70%    | 25%  | 5% | 100%                | 100%                  |
| S7              | 70%    | 30%  | 0% | 100%                | 100%                  |

4. Experimental Investigations

4.1. Compressive strength

In this experimental work, totally 48 number of cubes with the standard size of cube 150 mm × 150 mm × 150 mm were cast, 6 cubes were conventional and other 42 cubes were made with partial replacement of binder by GP from 30% to 0% in step of 5% and SCBA with range of replacement from 0% to 30% in step of 5% respectively. The test was conducted in compression testing machine (CTM) of 3000 kN capacity for different ages of concrete viz., 7 and 28 days as per the specifications given in IS 516: 1959 under normal room temperature.
4.2. Flexural Strength

All the beams are of same dimensions, 100 mm x 150 mm x 1000 mm. The beams were designed as singly reinforced beam with 2 nos. of 8 mm diameter bar in tension zone and 2 nos. of 8 mm diameter bar at compression zone. For shear reinforcement 6 mm diameter bars were used at 100 mm spacing. The specimens were tested using two point loading by 100 T loading frame. The deflection and flexural strength of beam was calculated by placing LVDT at the mid span and quarter of span of the beam. In this two point loading method, the load was divided into two parts as, \( P = P/2 + P/2 \). Here ‘\( P \)’ is the total load given on the beam through the loading frame and was divided into two separate loads by placing two I-sectioned rollers below the beam and the load was transferred to beam. The load at first crack was noted when the cracking was developed in the concrete and the maximum load was indicated by LVDT.
4.3. Durability tests
Total number of 32 specimens of size 50 mm height and 100 mm diameter were cast to study the durability properties such as water absorption in accordance with ASTM C 642 and sorptivity in accordance with ASTM C 1585.

4.3.1. Water absorption. Water absorption specimens were dried in the oven at a temperature of 100 to 110 °C for not less than 24 hours. Then the specimens were removed from the oven, allowed it to cool in dry air (preferably in desiccators) to a temperature of 20 to 25 °C and the oven dry mass was determined and the value was designated as A. Then the specimens were immersed in water at approximately 21 °C for not less than 48 hours. Saturated mass after immersion was determined and designated as B. The specimens were immersed in the tub water and allowed it to boil for 5 hours. Then the specimens were allowed to cool by natural loss of heat for not less than 14 hours to a final temperature of 20 to 25 °C. Surface moisture was removed with a towel and the mass of the specimen was determined. The soaked, boiled, surface-dried mass was designated as C. Finally immersed apparent mass was determined and the values were designated as D.

4.3.2. Sorptivity test. This method is intended to determine the susceptibility of an unsaturated concrete to the penetration of water. Test specimen was placed in the hot air oven at a temperature of 50 °C for 3 days. After the 3 days oven curing, specimen was kept in a room temperature for 15 days. The specimen’s side and top surfaces were sealed with sealing material by keeping bottom side of the specimen open. Bottom surface was exposed to water. Then the mass of the specimen was noted at different intervals of time. Mass of dried specimen was noted and the procedure as per ASTM C1585 was followed.

5. Results and Discussion
5.1 Compressive strength
The seven different combination mixes were tested and the results were shown in Table 4.

| S. No. | Designation | Mix ratio     | 7 DAYS (MPa) | 28 DAYS (MPa) |
|--------|-------------|---------------|--------------|---------------|
| 1.     | S           | Conventional  | 14.24        | 22.28         |
| 2.     | S1          | 0% SCBA + 30% GP | 12.25        | 21.69         |
| 3.     | S2          | 5% SCBA + 25% GP | 15.92        | 23.65         |
| 4.     | S3          | 10% SCBA + 20% GP | 16.39        | 26.72         |
| 5.     | S4          | 15% SCBA + 15% GP | 17.08        | 28.81         |
| 6.     | S5          | 20% SCBA + 10% GP | 18.63        | 29.18         |
| 7.     | S6          | 25% SCBA + 5% GP  | 16.87        | 27.21         |
| 8.     | S7          | 30% SCBA + 0% GP  | 15.81        | 26.12         |

From the experimental investigations, conventional mix had compressive strength of 22.28 MPa. The compressive strength increased from S2 mix (5% SCBA + 25% GP) and maximum compressive strength was obtained with S5 mix (20% SCBA + 10% GP). The compressive strength of S5 mix was 30.96% more than that of S (conventional mix). This increase was attributed to the pozzolanic property of Supplementary Cementitious Materials (SCM) added viz., SCBA and GP.
5.2. Flexural strength
The beam prepared with the mix ratio S5 (20% SCBA and 10% GP) produced slightly higher flexural strength compared with that of conventional concrete. The flexural strength values are shown in Table 5.

| Description                      | Conventional mix | S5 mix (20% SCBA 10% GP) |
|----------------------------------|-------------------|--------------------------|
| Peak load (kN)                   | 46.9              | 49.60                    |
| First crack load (kN)            | 23.3              | 24.00                    |
| Maximum deflection in mm         | 9.28              | 9.14                     |
| Deflection under loads in mm     | 6.56              | 4.26                     |
| Flexural strength (MPa)          | 14.59             | 15.43                    |

From the flexure test, the peak load carrying capacity of S5 mix (20% SCBA 10% GP) had increase in strength of 5.75% in comparison with that of conventional mix and the load at first crack was also higher than that of the conventional mix by 3%. The load-deflection curve for the conventional beam and the beam made with S5 mix are shown in the Figure 6.
5.3. Water absorption and sorptivity

From water absorption and sorptivity results, S5 mix (20% SCBA+ 10% GP) showed 6.97% and 4.08% decrease in the amount of water absorbed respectively compared with that of S mix (conventional mix). The decrease in water absorption of S5 mix (20%SCBA+10% GP) is due to the filling up of micro pores in the concrete matrix by GP and SCBA leading to the dense compact and impervious concrete.

Figure 6. Load Vs Deflection curve

Figure 7. Water absorption values
6. Conclusions
From the experimental results, the maximum mix ratio percentage was found to be S5 mix (20% SCBA + 10% GP). In this research, out of the total weight requirement of the binder (Cement), 30% by weight of total binder was fulfilled with SCM viz., combination of SCBA as 0% to 30% in step of 5% and GP as 30% to 0% in step of 5%. The remaining 70% of the total requirement of binder was Cement i.e., cement percentage as binder was kept constant at 70% for all mix ratio. Totally seven different combinations of mix ratios were studied for a curing period of 7 days and 28 days.

- In the mix ratio S5 (20% SCBA+10% GP) the compressive strength was increased compared with other mix ratios (including conventional concrete) i.e., 18.63 MPa and 29.18 MPa for 7 days and 28 days respectively. There was 30.96% increase in compressive strength compared with that of conventional.
- The peak load for the conventional beam was 46.9 kN and for S5 (20% SCBA+10% GP) mix ratio was 49.6 kN. S5 mix showed increase in strength of 5.75% in comparison with that of conventional mix and the load at first crack was also higher than that of the conventional mix by 3%.
- The fineness of GP and SCBA helped to fill up the micro pores in the concrete matrix which in turn produced a compact dense and impervious mass. This helped in achieving better resistance to compression and flexure.
- From the water absorption and Sorptivity test results, S5 mix ratio (20% SCBA+10% GP) showed decreased in water absorption by 6.97% and 4.08% respectively compared with that of S mix (conventional mix ratio).
• Overall the compressive strength and flexural strength were increased compared with conventional without adding any chemicals or superplasticizer.
• Due to the pozzolanic properties of both SCBA and GP, there was an increase in strength in some mechanical properties like compressive strength and flexure etc. and some durability properties viz., water absorption and sorptivity. Therefore these waste materials can successfully enhance the durability and strength which further contribute to sustainability in construction.

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References
[1] Ana Mafalda Matos and Joana Sousa-Coutinho 2012 Durability of mortar using waste glass powder as cement replacement. Constr. Build. Mater. 36 205-15.
[2] Aukkadet Rerkpiboon, Weerachart Tangchirapat and Chai Jaturapitakkul 2015 Strength, chloride resistance and expansion of concretes containing ground bagasse Ash. Constr. Build. Mater. 101 983-9.
[3] Cordeiro G C, Toledo Filho R D, Tavares L M and Fairbairn E M R 2012 Experimental characterization of binary and ternary blended-cement concretes containing ultrafine residual rice husk and sugar cane bagasse ashes. Constr. Build. Mater. 29 641-6.
[4] Dhanaraj Mohan Patil and Keshav Sangle K 2013 Experimental investigation of waste glass powder as partial replacement of cement in concrete. Int. J. Adv. Technol. Civ. Eng. 2(1) 112-7.
[5] Dhinakaran G, Revanth Kumar K, Vijayarakhavan S and Avinash M 2017, Strength and durability characteristics of ternary blend and lightweight HPC. Constr. Build. Mater. 134 727-36.
[6] Ettu L O, Ezeh J C, Anya U C, Nwachukwu K C and Njoku K O 2013 Strength of ternary blended cement concrete containing Afikpo rice husk ash and saw dust ash. Int. J. Eng. Sci. Invention 2(4) 38-42.
[7] Ganesan K, Rajagopal K and Thangavel K 2007 Evaluation of bagasse ash as supplementary cementitious material. Cem. Concr. Compos. 29 515-24.
[8] Juliana Moretti P, Almir Sales, Fernando Almeida, Mariana Rezende A M and Pedro Gromboni P 2016 Joint use of construction waste (CW) and sugarcane bagasse ash sand (SBAS) in concrete. Constr. Build. Mater. 113 317-23.
[9] Kaveh Afshinnia and Prasada Rao Rangaraju 2016 Impact of combined use of ground glass powder and crushed glass aggregate on selected properties of Portland cement concrete. Constr. Build. Mater. 117 263-72.
[10] Mahsa Kamali and Ali Ghahremaninezhad 2015 Effect of glass powders on the mechanical and durability properties of cementitious materials. Constr. Build. Mater. 98 407-16.
[11] Noorul Amin 2016 Use of bagasse ash in Concrete and its impact on the strength and chloride resistivity. J. Mater. Civ. Eng. ASCE 23(5) 717-20.
[12] Nuntachai Chusilp, Chai Jaturapitakkul and Kraiwood Kiattikomol 2009 Utilization of bagasse ash as a pozzolanic material in concrete. *Constr. Build. Mater.* **23** 3352-8.

[13] Sumrerng Rukzon and Prinya Chindaprasirt 2012 Utilization of bagasse ash in high strength concrete. *Mater. Des.* **34** 45-50.

[14] Obilade I O 2014 Strength of ternary blended cement concrete containing rice husk ash and saw dust ash. *The Int. J. Eng. Sci.* **3**(8) 22-7.

[15] Vijaya Bhaskar Reddy S and Srinivasa Rao P 2016 Experimental studies on compressive strength of ternary blended concretes at different levels of micro silica and GGBS. *Mater. Today: Proc.* **3** 3752-60.

[16] ASTM C 1585 2004 Standard test method for Measurement of Rate of Absorption of water by Hydraulic cement concretes.

[17] ASTM C 642 2006 Standard test method for Density, Absorption and Voids in Hardened Concrete.

[18] IS 10262 2009 Indian Standard for Concrete Mix Proportioning – Guidelines, *Bureau of Indian Standards*, New Delhi, India.

[19] IS 456 2000 Indian Standard Plain and Reinforced Concrete - Code of Practice, *Bureau of Indian Standards*, New Delhi, India.

[20] IS 516 1959 Indian Standard Methods of Tests for Strength of Concrete, *Bureau of Indian Standards*, New Delhi, India.