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Experimental study on geopolymer concrete with partial replacement of bethamcherla waste stone powder

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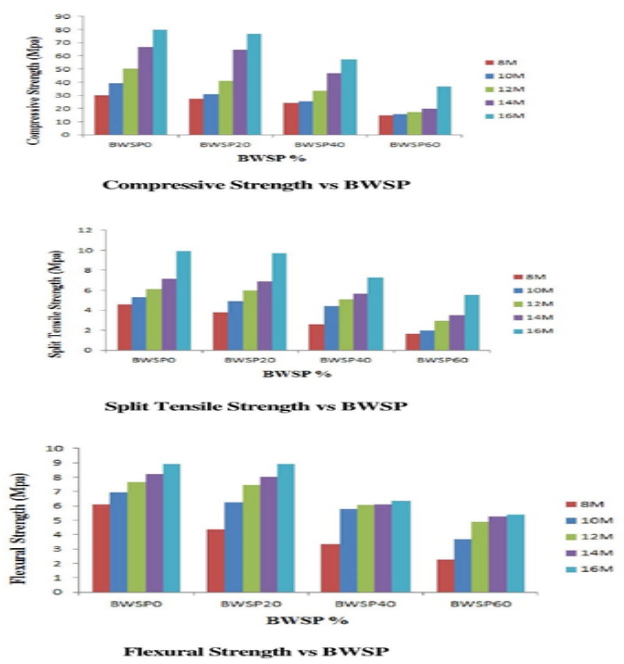
Graphical abstract



Abstract

The process of making portland cement uses up a lot of resources and has a harmful environment effect since it produces a lot of greenhouse emissions. The by-product of the stone cutting and polishing industries is Bethamcharla waste Stone Powder (BWSP). Each industry produces an average of 513900 tonnes of waste each year, which is then simply deposited on the plains of Bethamcharla. The potential approach to using stone waste powder for civil construction projects is presented in this research. The state of Tamil Nadu has enormous industrial polishing potential. There are around 2000 stone polishing machines in this town as a result of the large amount of stone powder produced during the manufacturing of completed goods and the same powder being dumped in and around the companies. In order to convince civil engineers to employ this new industrial waste material in Geopolymer Concrete (GPC), this research will examine the effects of substituting BWSP for Ground Granulated Blast-furnace Slag (GGBFS). Experimental investigations were conducted toward issues relating to strength. In the amounts of 20, 40 & 60 % by weight of GGBFS, the BWSP was employed as a substitute. Initial total mixes are prepared during the experimental inquiry with varying molarities of 8, 10, 12, 14, and 16 as well as changes to the mix proportions. According to the trials, the 16 molarity and 1:1.32:3.1 (GGBFS: FA: CA) mix with alkaline solution delivered preferable outcomes, allowing for the fullest possible use of BWSP in the mix. The current study provides information on the behaviour of BWSP in Geopolymer Concrete. As determined by the study, the minimum strength of concrete (M25) cannot be affected while using 60% BWSP with 16 molarity for construction.

Keywords: Bethamcherla waste stone powder, geopolymer concrete, GGBFS, strength

1. Introduction

Alternative building materials were made possible by the concepts of energy conservation and environmental protection. Construction companies all throughout the world have historically used ordinary portland cement concrete. It is well understood that the calcination process used to produce cement releases an equal amount of carbon dioxide gas, which has been linked to a number of problems such as global warming and the greenhouse effect. (P Subashree *et al* 2018)

With the use of waste silica fume, fly ash, rice husk ash, ground-granulated blast furnace slag, and other materials, an entirely new binding substance called geopolymer is formed. (M. Alshaaer *et al* 2012). In this study, the bethamcharla waste stone which can be found in India's mines area of the tamilnadu, is the source of the bethamcharla waste stone powder. The bethamcharla waste stone is taken out of the mines and transferred to a polishing facility, where it is polished on a machine before being utilised for flooring and small ornamental projects. Slurry is produced during the polishing step, and when it is exposed to the air, it dries and turns into powder, which is waste produced by the bethamcherla waste stone polishing industry. In light of this, it is suggested that geopolymer concrete make the most use possible of this waste material. In this study, bethamcharla waste stone powder and GGBFS are employed as the building blocks for making geopolymer concrete. E. Rabiaa *et al* (2020) investigated on the production of GPC employing nano materials and steel fibres came to the conclusion that adding either 4% or 6% nanometakaolin to GPC significantly improved its mechanical properties. Vemundla Ramesh and Dr. Koniki Srikanth (2020) evaluated the mechanical characteristics and mix design of GPC and came to the conclusion that a ratio of 2.5 of Na_2SiO_3 to NaOH produces good outcomes. Sherin Khadeeja Rahman and Riyadh Al Ameri (2021) created a brand-new self-compacting GPC in an ambient environment and discovered that a mix with no cement and no superplastisizer produced 40Mpa. Numanuddin M. investigated on the use of industrial waste as product waste in GPC, Azad *et al*. (2021) concluded that alkali-activated geopolymer binders outperform manufacturing waste in terms of durability. According to the aforementioned literature review, the majority of research has been done to assess the qualities of geopolymer concrete, but greater attention has been paid to flyash and GGBFS-based GPC in terms of strength properties. As a result, the current experimental effort was designed to assess the strength characteristics of GPC using powdered Bethamcherla stone waste.

2. Materials

2.1. Ground granulated blast furnace slag (GGBFS)

As the main binder, GGBFS adhering to IS 12089-1987 requirements is utilised to produce geopolymer concrete (GPC). From 0 to 60 percent with an increment of 20 by weight, this principal binder is substituted by bethamcharla waste stone powder. The test results are shown in Table 1. GGBFS has a 2.61 specific gravity.

Table 1. Properties of GGBFS

Sl. No	Property	Value In %
1.	Silicon-di-Oxide (SiO_2)	30.05
2.	Aluminium tri oxide (Al_2O_3)	20.14
3.	Ferric Oxide (Fe_2O_3)	0.72
4.	Calcium Oxide (CaO)	35.90
5.	Magnesium Oxide (MgO)	6.87
6.	Manganese oxide(MnO)	0.07
7.	Titanium oxide(Tio_2)	0.08
8.	Potassium oxide (K_2O)	0.53
9.	Phosphorus pentoxide (P_2O_5)	0.17
10.	Sulfur trioxide ($SO_{3)}$	0.20
11.	Loss on Ignition	1.52
12.	Blaine fineness	4560 cm^2/g

Table 2. Properties of BWSP

Sl. No	Property	Value In %
1.	Silicon-di-Oxide (SiO_2)	23.23
2.	Aluminium tri oxide (Al_2O_3)	3.56
3.	Ferric Oxide (Fe_2O_3)	1.82
4.	Calcium Oxide (CaO)	40.78
5.	Magnesium Oxide (MgO)	1.21
6.	Manganese oxide(MnO)	0.03
7.	Titanium oxide(Tio_2)	0.20
8.	Potassium oxide (K_2O)	0.68
9.	Phosphorus pentoxide (P_2O_5)	0.17
10.	Sulfur trioxide ($SO_{3)}$	0.29
11.	Loss on Ignition (LOI)	0.322
12.	Blaine fineness	5840 cm^2/g

2.2. Bethamcherla waste stone powder (BWSP)

When all of the moisture from the sludge has evaporated in the parasol, the powder is collected. If lumps are discovered, they are ground up and the material is then sieved through a 90µ sieve to remove any unwanted organic matter. The material that passes through the 90µ sieve is then collected and used in the current investigation. According to ASTM D3682-01 codal requirements, the chemical make-up and physical characteristics of BWSP are listed in Table 2. BWSP has a 2.80 specific gravity.

2.3. Aggregates

2.3.1. Fine aggregate

As a fine aggregate, river sand that complies with IS 383:2016's Zone II grading standards and has a fineness modulus of 2.38 and specific gravity of 2.54 was determined (Figure 1).

Figure 1. Bethamcherla Waste Stone Powder

2.3.2. Coarse aggregate

The coarse aggregate utilised was pit-run gravel with a standard size of 20 mm and a specific gravity of 2.74 that was acceptable to IS: 383:2016. The fineness modulus of 7.15 was determined. The tap water with pH 6.9 is used for mixing as well as curing purposes.

2.4. Alkaline solution

The sodium silicate solution contains 14.7 percent Na_2O, 29.4 percent SiO_2 and 55.9 percent water by mass. Commercial sodium hydroxide pellets are also utilised. After conducting a number of tests in accordance with workability and strength, the alkaline solution to binder ratio was set at 0.45 and the sodium silicate to sodium hydroxide ratio was adopted at 2.0. A high range water-reducing naphthalene-based super plasticizer was added to the mixture to improve workability at a level of 6 kg/m^3 of the binder content.

2.5. Mix proportion

Due to the lack of standardized mix design processes to determine the target mean strength of GPC, it has not yet been advised to use internationally standard codal requirements for mix design of GPC. Using the design suggested by Lyoyd and Rangan and assuming a GPC density of 2400 kg/m^3, the necessary materials were determined. 75% of the entire volume was anticipated to be occupied by coarse and fine particles combined. The calculated ratio of alkaline liquid to binder was 0.45. The key binding component for the production of GPC was thought to be GGBFS. BWSP is used in place of GGBFS, the binding material, in percentages of 0, 20, 40 and 60%. Table 3 provides the suggested GPC's mix proportions of 1:1.32:3.1 (GGBFS: FA: CA).

Table 3. Comparison of GPC mix proportions (kg/m^3)

S. No	Description of Item	8M	10M	12M	14M	16M
1	GGBFS	415	415	415	415	415
2	Coarse Aggregate	1287	1287	1287	1287	1287
3	Fine Aggregate	548	548	548	548	548
4	NaOH Pellets	16	20	23	26	28
5	Sodium Silicate	126	126	126	126	126
6	Water	15	15	17	18	23
7	Plasticizer	6	6	6	6	6

3. Experimental work

The proposed experimental work that GGBFS is replaced with BWSP in the proportion 0, 20, 40 & 60% by weight Cubes, cylinders and prisms of geopolymer concrete were cast and tested in a laboratory for grades 8M, 10M, 12M, 14M, and 16M. The necessary ingredients for the mixes were weighed, and dry mixing was done for three to four minutes to ensure that the components were consistent. Then, alkaline liquid a mixture of sodium hydroxide and sodium silicate solutions and super plasticizer were added to the dry mix. It takes 6 kg/m^3 of super plasticizer to make the material workable. For 6 to 8 minutes, the dry mix components and alkaline solution are well combined. To guarantee that the materials were mixed uniformly, precautions were taken. The concrete was correctly compacted after mixing and being poured into steel moulds. The literature research makes it abundantly evident that curing temperature has a significant impact on the compressive strength of GPC, which is why ambient temperature curing is used. After being cast, the cubes are exposed to ambient temperature, and after being demolded, the specimens are maintained there until the testing date. The numerous tests conducted on GPC samples to determine their performance are thoroughly described. Strength tests are conducted on the specimens such as compressive strength, split tensile strength and flexural strength. The experiential work is conducted with a total of 540 specimens, which are cast and put through laboratory testing, to determine the strength properties. Among 540 specimens, 180 are cubes, 180 are cylinders and 180 are prisms.

3.1. Compressive strength test

According to IS 516:1959, the compressive strength of GPC was evaluated. In order to determine the cube compressive strength, 180 specimens were tested in a compression testing machine (CTM) at a constant loading rate of 140 kg/cm^2/min till failure. Test results for the specimens' average strengths are recorded and documented. Figure 2 displays the compressive strength vs. BWSP percentage for 8M, 10M, 12M, 14M, and 16M. For geopolymer concrete, the increase in compressive strength occurs quickly, and when the BWSP percent rises over the course of 28 days, the strength decreases. Even when GGBFS is replaced with BWSP, compressive strengths in geopolymer concrete increase as molarity rises from 8 to 16. 16M demonstrated the highest compression strength of all the molarities. GPC concrete with 16M demonstrated the best performance in terms of developing strength among all molarities. Frequently for concrete, the concrete's strength after 28 days is referred to and taken into consideration while designing structural parts. In this view, the 28-day strength for different blends has also received increased attention.

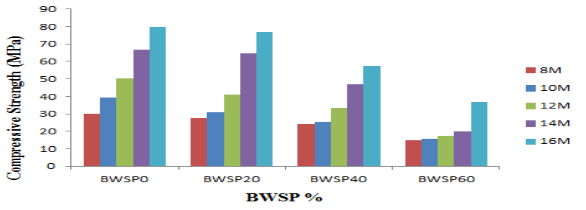


Figure 2. Compressive Strength vs BWSP

3.2. Split tensile strength test

The Split tensile strength vs BWSP percentage for 8M, 10M, 12M, 14M, and 16Mare presented in Figure 3. The split tensile strengths of geopolymer concrete are increasing as molarity increases from 8 to 16. This is true even when GGBFS is replaced with BWSP, and the rate of strength gain is roughly equal for all mixes, with the exception of BWSP20, where the decrement is significantly less when compared to BWSP0 mix. 16M displayed the highest split tensile strength of any molarity. When compared to compressive strength percent decrement, all BWSP mixes exhibit reduced strength degradation in split tensile strength. Therefore, it may be said that BWSP mixes perform better in terms of split tensile strength.

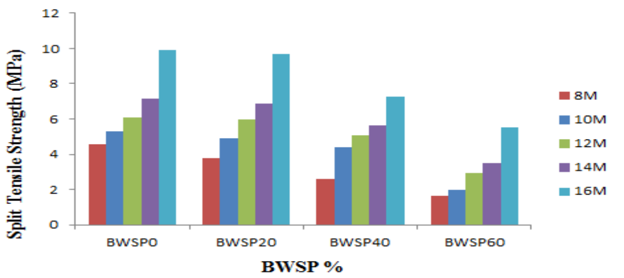


Figure 3. Split Tensile Strength vs BWSP

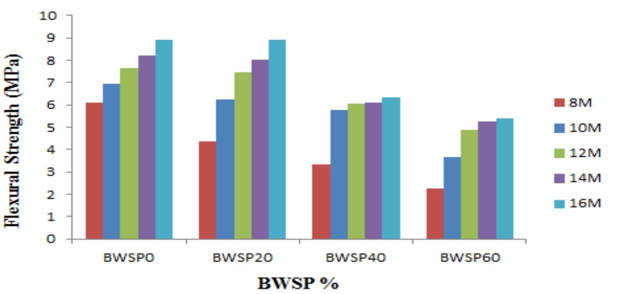


Figure 4. Flexural Strength vs BWSP

3.3. Flexural strength test

The Flexural strength vs BWSP percentage of 8M,10M,12M,14, and 16M arepresented in Figure 4. It is evident from Figure 4 that as molarity rises from 8 to 16, flexural strengths also rise. The molarity with the highest flexural strength overall is 16M. Additionally, the strength gaining process is more rapid for BWSP0 and BWSP20 mixes than it is for BWSP40 and BWSP60 mixes. When compared to compression and split tensile strength, all BWSP mixtures exhibit less strength degradation in flexure. Thus, it can be said that for BWSP mixes in flexure, the strength loss is minimal. It has been shown after thorough investigation that geopolymer concrete manufactured with a 16 molarity is superior to other molarities in compression, split tension and flexural strength. As a result, future strength studies will exclusively concentrate on Geopolymer concrete made with this molarity.

4. Conclusion

i. The key finding of the current study is that using BWSP with a 16-molarity is feasible for the GPC up to a 60 percent substitution of GGBFS without compromising the required strength (25 MPa) of concrete.

ii. For BWSP20 to 60 percent mixtures with 16 Molarity, the 28-day compressive strengths range from 76.89 to 36.74 MPa. When compared to BWSP0 mix, the compressive strength reduction for BWSP20 to 60 percent ranged from 3.50 percent to 53.9 percent (with 16 Molarity).

iii. The split tensile strength declines as the BWSP content in the mixes rises. For combinations of BWSP0 to BWSP60, the 28 days range from 9.90 to 5.50. For BWSP20 to BWSP60 mixtures, there is a 2.32 to 44.44 percent decrease in split tensile strength.

iv. The 28-day flexural strengths range from 8.92 to 5.42 MPa for BWSP mixes of 0% to 60%, and the percentage decline from BWSP0 mix to BWSP20, 40, and 60% is respectively 0.11, 29.04, and 39.24 percent.

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