Strength and stability characteristics of GGBS and red mud based geopolymer concrete incorporated with hybrid fibres

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Ordinary Portland Cement (OPC) production produces substantial CO_2 emission. Geopolymer Concrete (GPC) will be of considerable cure to Global Warming related with construction industry since GPC replaces OPC completely or about 80% with industrial waste products. In this study GPC was made up of Ground Granulated Blast furnace Slag (GGBS) and Red Mud (RM) incorporating hybrid fibres in various ratios. Results show that, among all the mixes, one mix showed the best mechanical properties owing to the incorporation of hybrid fibres and reduction of Red Mud.

1. INTRODUCTION

With the recent innovations in concrete technology, Concrete has become one of the most widely used construction material today due to its versatility and cost effectiveness. Ordinary Portland cement (OPC) is conventionally used as the primary binder to produce concrete. Production of Portland cement is currently exceeding 2.6 billion tons per year worldwide and growing at 5 percent annually. Five to eight percent of all human-generated atmospheric carbon dioxide worldwide comes from the concrete industry. Demand for concrete as a construction material is on the increase so as the production of cement. Concrete usage around the globe is second only to water. The production of cement is increasing about 3% annually. Producing one ton of cement requires about 2 tons of raw materials (shale and limestone) and releases 0.87 tons of CO_2 and about 3 kg of Nitrogen Oxide (NO). The global release of CO_2 from all sources is estimated at 23 billion tons a year and the Portland cement production accounts for about 7% of total CO_2 emissions. Among the greenhouse gases, carbon dioxide contributes about 65% of global warming. Hence several efforts are in progress to address the global warming issue. These include the utilisation of supplementary materials such as fly ash, granulated blast furnace slag, silica fume and rice-husk ash, and also the development of alternative binders to Portland cement. In view of sustainable development in the construction industry, geopolymer technology shows considerable promise as an alternative binder to Portland cement.

2. REVIEW OF LITERATURES

Researchers have been working under this topic for decades to create sustainable material for construction with a view to reduce environmental pollution and simultaneously to safeguard dwindling natural resources. Few of the outcomes are as follows,

Geopolymerisation was done in the mixture of Red mud, Fly Ash, Micro silica and water. Best results are expected in the ratio 10:80:10 adding 120 litres of water. Ultimate load carrying capacity and stiffness of beam reduces when 30% of red mud is added in the mix which concludes that red mud can be added up to 30% [1]. The possibility of use of red mud as a good initial material for geopolymer preparation was indicated. The compressive strength results are within the range of 10.2 MPa to 17.2 MPa. SEM analysis confirms the homogeneity of samples. The detection of amorphous phase is quite hard [2]. It was observed that weight losses in specimens gradually increase in all mixes with increase in temperature up to 500°C. Also residual Compressive strength coefficient of specimens exposed to 200°C is slightly higher than cubes tested at room temperature while with further increase there is loss in compressive strength gradually which concludes that higher temperature curing is not required in all cases of GPC [3]. A new type of geopolymer composite was synthesised from two industrial wastes, red mud (RM) and rice husk ash (RHA). The studied geopolymer have compressive strengths of up to 20.5 MPa, which is comparable to most Portland cements. A few barriers, such as long curing duration make it practically difficult [4]. Portland cement was completely replaced with GGBS. It is observed that compressive strength increased with the increase in the molarity of sodium hydroxide (9M) and while comparing hot air oven curing and curing by direct sun light, oven cured specimen gives higher compressive strength [5].

3. EXPERIMENTAL EXAMINATION

3.1 Raw materials

3.1.1 Red mud

Red mud or red sludge is a solid waste product of the Bayer process, the principal industrial means of refining bauxite [6]. For the study, Red Mud is obtained from a company near Mettur Dam in Salem, Tamil Nadu. The solid mass obtained is dried up in the sun light until it becomes moisture free. It is then powdered thoroughly and sieved through 90µ sieve. The specific gravity is 1.67.

3.1.2 Ground granulated blast furnace slag (GGBS)

Ground-granulated blast-furnace slag is obtained by quenching molten iron slag from a blast furnace in water or steam, to produce a glassy, granular product that is then dried and ground into a fine powder [7]. GGBS used for this study is obtained from a company in Bengaluru which is processed from slag obtained from a company at Bellary and Bhadravathi. The specific gravity is 2.19

3.1.3 Copper slag

Copper slag is a by-product material obtained during the manufacturing of copper. The slag is a black glassy and granular in nature and has a particle size range like sand [8]. Copper Slag used for this study is obtained from a company in Thoothukudi. It is well-dried in the sun light until it becomes moisture free. It is then sieved in a 4.75 mm sieve. The fineness modulus of the copper slag is 7.14. The Uniformity coefficient is 2.37 and the Coefficient of curvature is 1.053. The specific gravity is 4.01

3.1.4 River sand

It is obtained from a local quarry near Nagercoil and sieved in a 4.75 mm sieve. The fineness modulus of the river sand is 6.34. The uniformity coefficient is 2.37 and the coefficient of curvature is 1.053. The specific gravity is 2.54.

3.1.5 Coarse aggregate

In this study, coarse aggregates of size 20 mm and 10 mm are to be used. The impact value of coarse aggregate of size 20 mm is 13.20% and for 10 mm it is 17.720%.

3.1.6 Alkaline solution

The most common alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. Here, Sodium hydroxide and Sodium Silicate are used as alkaline solution since Al-Si minerals are more soluble in sodium based compounds [9].

Sodium silicate is the common name for a compound sodium meta-silicate, Na_2SiO_3, also known as water glass or liquid glass. In this study, Sodium silicate solution of composition SiO_2-29.4%, Na_2O -14.73% and H_2O -55.9% by mass is used. Generally sodium hydroxide is available in solid state by means of flakes or pellets. Here, sodium hydroxide solution (made from pellet form) of 10M concentration is used.

3.1.7 Fibres

Fibers are usually used in concrete to control cracking due to plastic shrinkage and drying shrinkage. They turn brittle fracture mechanism to ductile fracture mechanism. In this study, following fibres are used

- Metallic type - Steel fibre (Corrugated type) of aspect ratio 50

- Non-metallic type - Polypropylene fibre (fibrillated type), 6 mm size
- Natural Type - Banana fibre of aspect ratio 50.

Polypropylene fibers improve mix cohesion; pumpability over long distances; freeze-thaw resistance and resistance to explosive spalling in case of a severe fire [10] while, Steel fibers improves structural strength; ductility; impact and abrasion resistance; freeze-thaw resistance and also reduces steel reinforcement requirements and crack widths [9]. Banana Fibres encompass merits like low density, good Sound abatement capability, low abrasively and high biodegradability. Pretreatment of Banana fibres are done by immersing it in 6 % NaOH for 2 hours to overcome the bio-degradability of natural fibres. They are then washed thoroughly by running water. It is then filtered and dried at 80°C for 24 hours [11].

3.1.8 Superplasticisers

A sulphonated naphthalene-formaldehyde based superplasticiser is used here.

3.1.9 Water

Ordinary tap water which is free from impurities is used for mixing if required to attain suitable workability that is measured in terms of slump in the range of 80-100 mm.

3.2 Mix design

Right now, there is no Indian Standard method for mix design of geopolymer concrete. Consequently the mixing proportions are prepared by Trial mix method. In this investigation, mix design procedure developed by Lloyd and Rangan was adopted [12]. The density of Geopolymer concrete is assumed as 2400 Kg/m^3. Mass of combined aggregate is selected in the range of 70-80%. Alkaline Liquid to binder ratio adopted is between 0.30 and 0.45. Sodium silicate to Sodium hydroxide ratio ranges from 2 to 3. Molarity of NaOH is fixed as 10M. Mix details are shown in Table 1.

3.3 Methodology

In this research, four different mixes are prepared by varying the proportions of the ingredients. The mixes are designated as Mix A, Mix B, Mix C and Mix D along with the control mix as Mix R. Mix A-71% of combined aggregate (percentage of RM-30 and GGBS-70) [1] and addition of steel fibre and polypropylene fibre. Mix B-73% of combined aggregate (percentage of RM-27 and GGBS-73) and addition of steel fibre and banana fibre. Mix C-75% of combined aggregate (percentage of RM-24 and GGBS-76) and addition of banana fibre and polypropylene fibre and Mix D-77% of combined aggregate (percentage of RM-21 and GGBS-79) and addition of steel fibre, banana fibre and polypropylene fibre in the geopolymer concrete as

Table 1. Mix proportion

MIX	A			B			C			D		
Mass of combined aggregate (%)	71			73			75			77		
Alkaline liquid to binder ratio	0.31			0.33			0.35			0.37		
Na_2SiO_3 to NaOH ratio	2.1			2.3			2.5			2.7		
GGBS (Kg/m^3)	371.910			355.670			337.770			322.340		
Red mud (Kg/m^3)	159.390			131.540			106.660			80.580		
River sand (Kg/m^3)	255.600			262.800			270.000			277.200		
Copper slag (Kg/m^3)	255.600			262.800			270.000			277.200		
Coarse aggregate-20mm(Kg/m^3)	596.400			613.200			630.000			646.800		
Coarse aggregate-10 mm(Kg/m^3)	596.400			613.200			630.000			646.800		
Sodium hydroxide(Kg/m^3)	53.130			48.720			44.440			40.290		
Sodium silicate(Kg/m^3)	113.540			112.060			111.100			108.790		
Superplasticizer (Kg/m^3)	26.565			24.360			22.220			20.150		
Fibres (%) (S-Steel, P-Polypropylene, B-Banana)	S	P	B	S	P	B	S	P	B	S	P	B
	1	1	-	1	-	1	-	1	1	1	0.5	0.5

Figure 1. Mixing process

shown in Figures 1 and 2. Admixture of about 2% of fibre and 5% of superplasticiser (sulphonated naphthalene-formaldehyde based) by weight of cementitious material is added to assist workability. Control Mix is made for M_{30} grade.

Curing is done by subjecting the specimens to hot air inside a chamber at a temperature of 40-50°C for 24 hours. They are then demoulded and kept in room temperature till required age is reached. After prescribed age, the mechanical properties are determined.

For compressive strength test and flexural strength test, the specimens were cast and tested as per IS 516:1959. It

Figure 2. Fibre addition while mixing

Figure 3. Water absorption test

is carried out on cube specimens of size 150 x 150 x 150 mm and on prism specimens of size 100 x 100 x 500 mm. Center point loading system is used here. The specimen is placed in the machine such a way that the load is applied at the uppermost surface.

3.3.1 Durability tests

3.3.1.1 Saturated water absorption test

Saturated water absorption (SWA) tests were carried out on 150 mm cube specimen at the age of 28 days curing as per ASTM C 642 as in Figure 3. The drying was carried out in a hot air oven at a temperature of 105°C. The dried specimens were cooled at room temperature and immersed in water for 28 days. The specimens were taken out after specified instance, and weighed.

Figure 4. Acid attack

3.3.1.2 Acid attack test

The acid attack testing procedure was conducted by immersing concrete cube specimens of 150 mm size after the specified initial curing in a tub containing 5% H_2SO_4 for 28 days as shown in Figure 4. The degree of attack was evaluated by measuring the expansion of concrete cubes, compressive strength, and weight losses of the specimens.

The weight loss is calculated as,

% of weight lost = $(W_b - W_a) \times 100/W_b$

where
W_b = weight of specimen before attack
W_a = weight of specimen after attack

3.3.1.3 Sulphate attack test

The sulphate attack testing procedure was conducted by immersing concrete cube specimens of 150 mm size after the specified initial curing in a tub containing 5% Sodium Sulphate for 28 days as shown in Figure 5. The sulphate solution was replaced whenever the pH value exceeded 9.5. The changes were noted as in previous case.

Figure 5. Sulphate attack

3.3.1.4 Alkalinity measurement test

The broken pieces of tested specimen were again broken into small pieces using hammer and ball mill and then powdered. The powdered samples (say 20 gm) was put into 100ml distilled water. The aqueous solution was allowed to stand for 72 hours and more and agitated often, to enable more of free lime of hydrated cement paste to get dissolved in water. The pH of the aqueous solution is measured by pH meter after 72 hours.

3.3.1.5 Carbonation test

The carbonation depth test was carried out according to RILEM CPC – 18 recommendations. 1% phenolphthalein solution is mixed in 70% ethyl alcohol and the same is sprayed onto the fresh concrete surface which has been cleaned for dust and loose particles. Phenolphthalein is a colourless acid indicator which turns red or pink when the pH is above a value of 9.5, that is, when the concrete is alkaline. If no coloration occurs, carbonation has taken place and depth of the carbonated surface layer can be measured. However this method is not proved to be accurate in case of geopolymer concrete. Figure 6 shows the specimen under carbonation test.

Figure 6. Carbonation depth

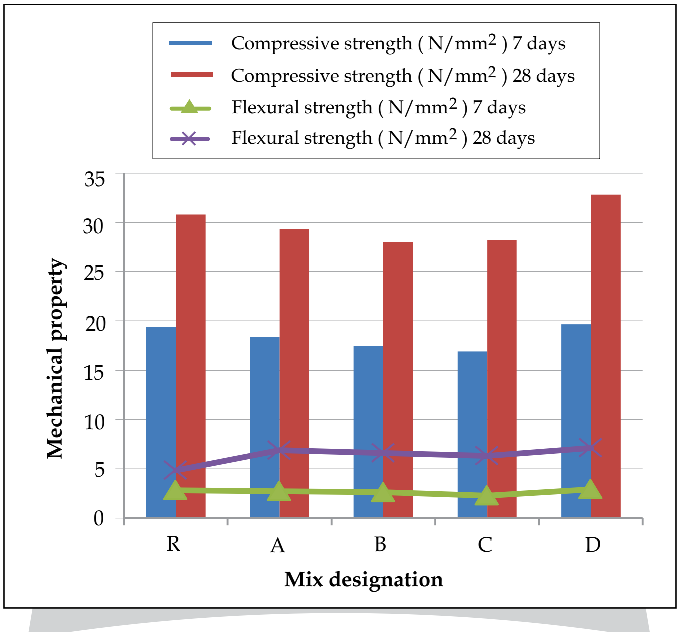

Figure 7. Mechanical properties

4. RESULTS AND DISCUSSIONS

4.1 Mechanical properties

Figure 7 shows the 7 days and 28 days compressive strength and flexural strength are tested as per the specifications.

4.2 Saturated water absorption

After Specified Period of 28 days, there were no specific changes in weight or compressive strength both in Control mix and Mix D which shows GPC is dense in nature and thus can prevent ingression of environmental effluents through its pores.

4.3 Acid attack

Table 2 shows the test results of specimen under Acid attack.

4.4 Sulphate attack

Table 3 shows the test results of specimen under Sulphate attack

4.5 Alkalinity

For Mix R,

Alkalinity measure (pH value measured using pH meter) after 72 hours was 12.20.

Table 2. Acid attack test result

Mix designation	Average weight loss		Average compressive strength (loss/gain)	
	Kg	%	N/mm^2	%
R	No	significant	25.46	14 (loss)
D	changes	were seen	40.34	23 (gain)

Table 3. Sulphate attack test result

Mix designation	Average weight loss		Average compressive strength (loss/gain)	
	Kg	%	N/mm^2	%
R	No	significant	26.40	12 (loss)
D	changes	were seen	38.38	17 (gain)

For Mix D,

Alkalinity measure (pH value measured using pH meter) after 72 hours was 13.10.

4.6 Carbonation depth

For Mix R,

The maximum penetration of pink colour (carbonation depth) was about 8.60 mm.

For Mix D,

The maximum penetration of pink colour (carbonation depth) was about 10.40 mm.

5. CONCLUSION

Based on the investigation carried out on the GGBS and Red Mud based Geopolymer Concrete, the following conclusions were drawn,

1. Geopolymer concrete is more ecological and has the prospective to swap ordinary Portland cement concrete from top to bottom in many applications such as precast elements.

2. It helps to prevent global warming and it utilises the waste materials effectively thereby reducing the risk of waste disposal and safeguards the dwindling natural resources.

3. Mix A performs better than Mix B and Mix C on account of the increased binder content.

4. Among all the mixes, Mix D shows best mechanical properties owing to the incorporation of hybrid fibres (steel fibre + Polypropylene fibre + Banana fibre) and reduction of Red Mud.

5. It can be seen that, there is about 30% increase in flexural strength of fibre incorporated GPC when compared to OPC concrete.

6. Specimens attained their properties at a curing temperature of 40-50^{o}C. Hence sunlight curing is sufficient for the cited mix proportion which further overcomes a disadvantage of GPC and makes it adaptable to on-site constructions.

7. GPC exhibited strength gain of 23% when contacted with 5% Sulphuric Acid and 17% strength gain with 5% Sodium Sulphate while OPCC suffered losses in both cases.

8. Usage of copper slag reduces the risk of damages caused by alkali-silica reaction and provides higher resistance to environmental impacts.

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