Mechanical Properties of Geopolymer Concrete with Alternative Materials

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Abstract

Concrete is considered the world's best versatile, durable and reliable construction material which is next only to water. It is the most consumed material requiring large quantity of cement, fine aggregates, course aggregates and water. Constituents of concrete can be replaced partially or fully with alternate materials to make geopolymer concrete. The present study focuses on sustainable geopolymer technology of making concrete using industrial wastes ie, Class F fly ash, GGBS, Metakaolin and Bagasse ash, M-sand, Pond ash, Recycled aggregates and Recycled water and their effects on mechanical properties. The combination of these materials has yielded interesting and encouragable results.

Key words: Geopolymer, fly ash, GGBS, Bagasse ash, Sustainability.

Introduction

Concrete, a composite material is the second most consumed in the world after water and is a versatile material that can be molded into almost any shape [1]. Manufacture of cement involve high energy consumption and emits greater amount of CO_2 during production [2]. Extraction of natural sand (sand) from river beds results in loss of vegetation on river banks and lowering of ground water table [3]. Ecological imbalance, increased cost of transportation and construction are caused by use of cement, sand and coarse aggregates. Extensive use of traditional materials of cement concrete (CC) results in their faster depletion and cause several disadvantages and affects the environment. It is important to address the problems effectively by finding alternate materials to reduce or completely replace traditional materials to save the environment [4]. Some of the alternative materials that can be used as replacement of cement, fine aggregate and coarse aggregate are fly ash, ground granulated blast furnace slag (GGBS), bagasse ash, rice husk ash, coconut shell, M-sand, foundry sand, pond ash, blast furnace slag, recycled aggregates and recycled water etc. In this study geopolymer concrete is prepared by replacing the ingredients ie, binder, fine aggregate, coarse aggregate and water with alternative materials.

Geopolymer acts as a binder to bind the aggregates in geopolymer concrete (GPC). It is formed when silica and alumina present in base material are activated by combination of sodium silicate and sodium hydroxide solution at high alkanility. Geopolymer concrete has better sulphate resistance, acid resistance and undergoes less creep [5]. Bagasse ash (BA) is the by-product of sugar refining industry and is a pazzolonic material with 85-90 % of silica and alumina [6]. Slag sand (SS) is a by-product produced in the process of iron making in blast furnace which is mildly alkaline and doesn't pose risk of corrosion to steel in concrete and also reduces cost of concrete [7]. Recycled aggregates (RA) are produced from crushing the concrete waste of demolished buildings to a required size.

A study has revealed that, compressive strength of geopolymer concrete increases with increase in concentration of sodium hydroxide in terms of molarity, sodium silicate to sodium hydroxide ratio, curing temperature and curing time. [8, 9]. Optimum compressive strength was achieved for sodium silicate to sodium hydroxide ratio of 2.5 and molarity of 12M. Increase in molarity decreases workability of geopolymer concrete [10, 11, 12]. Also, workability increases with increase in fly ash content and alkaline-binder ratio in geopolymer concrete [13]. Improved workability was noticed when M-sand was used in geopolymer concrete [14, 15]. Compressive and split tensile strengths decrease with increase in fly ash content [10, 16]. Increased replacement of bagasse ash in concrete resulted in decreased workability and compressive strength [17]. The properties of geopolymer concrete improved when sand is replaced with M-sand up to the level of 60 % [18]. Increased replacement of sand by pond ash decreased the compressive strength but increased flexural strength at the optimum replacement of 20 - 30 % [19, 20]. Maximum compressive strength was achieved at 25 to 50 % replacement of sand with slag sand [21]. With increased replacement of coarse aggregate by recycled aggregate, decrease in compressive, split tensile and flexural strengths was observed [22]. The properties of geopolyers with specific combinations of flyash, baggase ash and GGBS are not much reported in the literature. The present research is an approach to find possible alternative materials for making geopolymer concrete as an alternative to cement concrete. Alkaline solution of 12 M with sodium silicate to sodium hydroxide ratio 1.25:1 and fly ash to GGBS ratio of 80:20 are considered for making geopolymer concrete based on the referred literature [8, 9]. Objective of the study is to characterize the materials, check their suitability for making geopolymer concrete and to study the workability and mechanical properties of geopolymer concrete using alternative materials.

Materials and Methods

Flyash and pond ash (PA), GGBS, slag sand (SS) and bagasse ash (BA) were procured from RTPS, Shaktinagar, Raichur, Jindal Steel works, Bellary and Mandya respectively in Karnataka, India. Commercially available sodium hydroxide, sodium silicate and metakaolin (MK) were used. Natural sand (NS) was procured from Kaveri river bed. Coarse aggregate and M-sand (MS) were procured from Ramnagar. All the materials were characterised for physical properties.

Physical properties of flyash, GGBS, bagasse ash, metakaolin and aggregates are given in **Tables 1** and **2** respectively. Mix combinations of binders, fine aggregates and coarse aggregates and particle size distribution curves for natural sand, M-sand, slag sand, pond ash are shown in **Table 3** and **Figure 1** respectively.

Table 1. Physical properties of Fly ash, GGBS, Bagasse Ash and Metakaolin

Ingredient / Property	**Fly ash**	**GGBS**	**Bagasse ash**	**Metakaolin**
Specific Gravity	2.3	2.9	2.0	2.6
Residue on 45µ in percentage	0.5	0.5	2.0	0

Table 2. Physical properties of aggregates

Ingradient/ Property	**Natural Sand**	**M-sand**	**Pond ash**	**Slag sand**	**Coarse aggregate**	**Recycled aggregate**
Specific Gravity	2.59	2.5	2.33	2.53	2.62	2.3
Water absorption (%)	0.9	1.8	2	1.2	0.5	3
Grading Zone	III	II	I	II	-	-

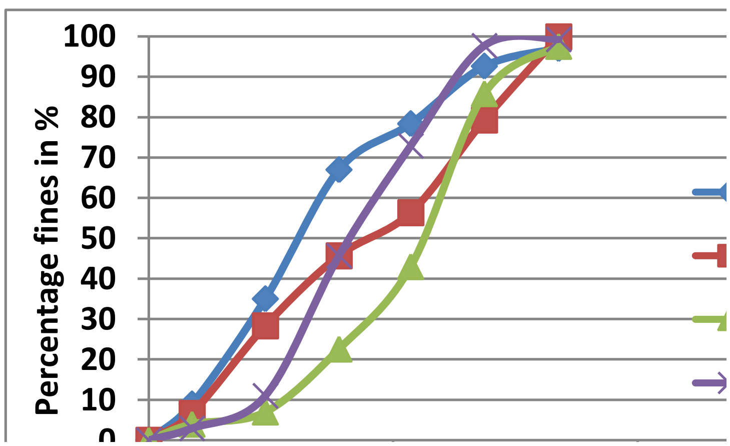

Figure 1. Particle size distribution curves for sand, M-sand, Pond ash and Slag sand

Cement concrete and geopolymer concrete samples with alternative fine aggregates were prepared for binder, fine aggregate and course aggregate in 1:1:2 proportions with fluid-binder ratio of 0.45. The binder was a combination of flyash and GGBS with 80:20 ratio. Alkaline solution of 12 M with sodium silicate to sodium hydroxide ratio of 1.25:1 was considered. Workability of concrete samples in fresh state using slump-cone test and mechanical properties were analysed by replacing fly ash content in the binder with 5% bagasse ash and 5% metakaolin.

Geopolymer concrete was used to cast cubes of size 150x150x150mm and beams of size 100x100x500mm to determine compressive strength and flexural strength respectively as per IS Codes. L-shaped specimens were cast by inserting a wooden block of size 90x60mm in cross section and 150mm in height in 150x150x150mm cube mold. They were tested for shear strength by a method proposed by Baruah and Talukdar [23]. Cylinders of size 150x300 mm were cast to determine split tensile strength. The course aggregate was replaced with recycled aggregate. Modulus of Elasticity was also determined.

Table 3. Mix Combinations of binders, fine aggregates and coarse aggregates

Sample ID	Binder	Fine aggregate	Coarse aggregate	Fluid/ Binder ratio	Slump (mm)
CC	Cement	Sand	Natural	0.45	90
GPC-NS	80%Flyash+ 20%GGBS	Sand	Natural	0.45	110
GPC-SS	80%Flyash+ 20%GGBS	Slag sand	Natural	0.45	85
GPC-MS	80%Flyash+ 20%GGBS	M-sand	Natural	0.45	0
GPC-PA	80%Flyash+ 20%GGBS	Pond Ash	Natural	0.45	0
GPC-BA	75%Flyash+ 20%GGBS + 5%Bagasse ash	Sand	Natural	0.45	20
GPC-MK	75%Flyash+20%GGBS+ 5%Metakaolin	Sand	Natural	0.45	40
GPC-RA	80%Flyash+ 20%GGBS	Sand	Recycled	0.45	0

Results and discussion

Table 4 and **Figure 2** give the compressive strength of cement concrete and geopolymer concrete with alternative binders. The reduction in strength of geopolymer concrete was observed when 80 % fly ash was replaced with 75 % fly ash and 5 % bagasse or 5 % metakaolin. The reduction in strength is 1.7 % and 3.5 % respectively. With respect cement concrete the compressive strength of geopolymer concrete was found 28 % lesser. As per earlier studies, similar results were achieved when cement was replaced with 5 % alternative binders such as bagasse ash and metakaolin in cement concrete [17, 24].

Table 4. Compressive strength of cement concrete and geopolymer concretes with alternative binders.

Sample ID	28 days Compressive strength (in MPa)	Remarks
CC	32.1	Not Applicable
GPC	23.1	28 % less than CC
GPC-BA	22.7	29 % less than CC and 1.7% less than GPC
GPC-MK	22.3	31 % less than CC and 3.5% less than GPC

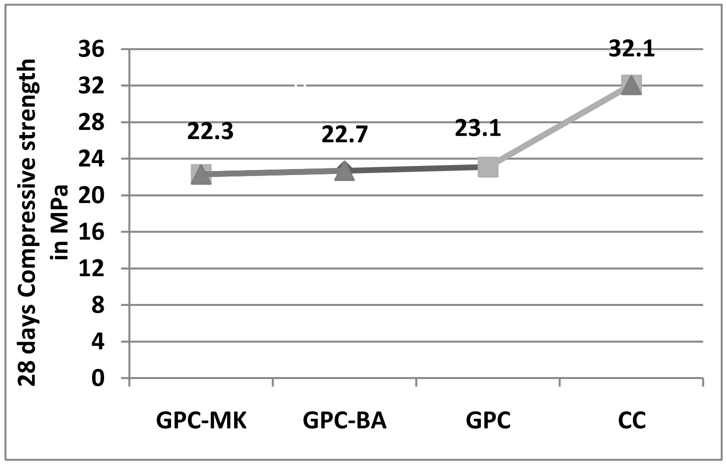

Figure 2. Compressive strength of CC and GPC with different binders

Table 5 shows the density and compressive strength of geopolymer concrete with alternative fine aggregates. There was not much variation observed in case of densitty cement concrete and geopolymer concrete with different aggregates. The compressive strength of cement concrete after 3 days and 7 days was more compared to geopolymer concrete with alternative fine aggregates. This low early strength of geopolymer concrete is due to slower polymerization during initial stages. There is a gradual increase in compressive strength of geopolymer concrete for fine aggregates ie., from pond ash to natural sand to slag sand and M-sand.

Table 5. Density and compressive strength of CC and GPC with alternative fine aggregates

Sample ID	**Density after 28 days in Kg/m^3**	**Compressive strength in MPa**		
		3 days	**7 days**	**28 days**
CC	23.25	14.67	22.6	32.10
GPC-NS	22.67	2.31	3.3	23.11
GPC-MS	22.64	2.48	4.09	25.33
GPC-SS	22.81	2.52	3.82	24.70
GPC-PA	22.38	2.50	3.7	21.04

Table 6 shows the compressive strength of cement concrete and geopolymer concrete with coarse aggregates and recycled aggregates. There was 26 % reduction in strength when recycled aggregate was used with cement concrete as compared to cement concrete with natural aggregate. Reduction in strength was 29 % for geopolymer concrete compared to cement concrete both recycled aggregate. This is due to higher water absorption by recycled aggregates in concrete [25, 26].

Table 6. Compressive strength of CC and GPC with recycled coarse aggregates

Sample ID	28 days Compressive strength in MPa	Remarks
CC	32.0	Not applicable
CC-RA	23.5	26 % less than CC
GPC-RA	16.6	48 % less than CC 29 % less than CC-RA

Split tensile strength for cement concrete is around 10 % of compressive strength and same was observed for geopolymer concrete with various fine aggregates. **Table 7** gives Split tensile strength of cement concrete and geopolymer concrete with alternative fine aggregates. Split tensile strength of geopolymer concrete was found maximum and minimum for M-sand and pond ash respectively.

Table 7. Split tensile strength of CC and GPC with alternative fine aggregates

Sample ID	Split tensile strength in MPa	Remarks
CC	3.49	Not applicable
GPC-NS	2.45	30% less than CC
GPC-MS	2.82	19% less than CC & 15% more than GPC-NS
GPC-SS	2.58	26% less than CC & 5% more than GPC-NS
GPC-PA	2.17	38% less than CC & 11% less than GPC-NS

Table 8 shows flexural strength of cement concrete and geopolymer concrete with alternative fine aggregates. According to IS 456:2000, flexural strength should be $0.7\sqrt{f_{ck}}$ which is equal to 3.5 MPa for M 25 grade concrete. The flexural strength obtained for concrete with various combinations was more than 3.5 MPa. Geopolymer concrete with M-sand and pond ash showed highest and lowest flexural strength respectively.

Table 8. Flexural strength of CC and GPC with alternative fine aggregates

Sample ID	Flexural strength in MPa	Remarks
CC	4.44	NA
GPC-NS	4.06	8.5% less than CC
GPC-MS	4.22	5% less than CC & 4% more than GPC-NS
GPC-SS	4.14	6.8% less than CC & 2% more than GPC-NS
GPC-PA	3.77	15% less than CC & 7% less than GPC-NS

Table 9 shows shear strength of cement concrete and geopolymer concrete with alternative aggregates. Geopolymer concrete has good shear strength and the strength values obtained are similar to earlier study [23]. Geopolymer concrete with M-sand has higher shear strength compared to geopolymer concrete with slag sand and pond ash.

Table 9. Shear strength of CC and GPC with alternative fine aggregates

Sample ID	Shear strength in MPa	Remarks
CC	9.5	
GPC-NS	7.81	17.8% less than CC
GPC-MS	8.67	8.7% less than CC & 11% more than GPC-NS
GPC-SS	7.25	23% less than CC & 7% less than GPC-NS
GPC-PA	6.85	27.8% less than CC & 12.3% less than GPC-NS

Variation of stress with strain is shown in Figure 5. It was observed that the variation of stress with respect to strain is not linear and found similar to cement concrete. Among Geopolymer concrete with various fine aggregates, geopolymer concrete with M-sand has maximum modulus of elasticity than with natural sand, slag sand and pond ash.

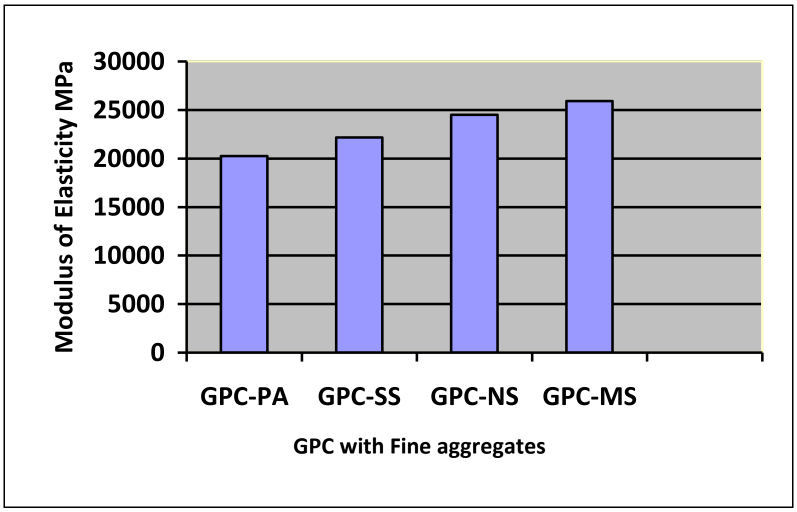

Figure 5. Modulus of Elasticity of GPC with various aggregates

Conclusions

Following conclusions are drawn by the study on cement concrete and geopolymer concrete with alternative materials.

- Slump value for geopolymer concrete with natural sand is more than cement concrete.
- Workability of geopolymer concrete decreases when alternative binders such as bagasse ash and metakolin are used even in small percentages. The workability of geopolymer concrete is better with natural sand and slag sand among the various fine aggregates.
- Compressive, split tensile, flexural and shear strengths of geopolymer concrete with M-sand and slag sand are higher than the geopolymer concrete with natural sand and pond ash.

- Compressive strength of geopolymer concrete with recycled aggregates is very low compared to geopolymer concrete with natural aggregates.

- Air cured geopolymer concrete with various fine aggregates and alternative binders at lower replacement levels can be used as structural concrete and total sustainability can be achieved.

Acknowledgement

The authors would like to thank the authorities of R V College of Engineering, Bengaluru for their support and encouragement.

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