EXPERIMENTAL STUDY ON PERFORMANCE OF RECYCLING WASTE MATERIALS IN GEOPOLYMER CONCRETE

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ABSTRACT: Concrete usage is second to water in this present day world. Ordinary Portland Cement (OPC) is conventionally used as the primary binder to produce concrete due to its availability of the raw materials over the world and ease of mould ability. The application of concrete in the realms of infrastructure, habitation, and transportation has greatly promoted the development of civilization, economic progress, stability and quality of life. The environmental issues associated with the production of OPC are well known. The amount of the carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced.

On the other hand, the abundant availability of fly ash worldwide creates opportunity to utilize this by-product of burning coal, as a partial substitute for OPC to manufacture cement concrete products. This investigation aimed at producing geopolymer concrete that can be cured in the ambient or room temperature only. For accepting this geopolymer concrete in structural applications, various acceptability tests like setting behaviour at green state of concrete and mechanical strength at hardened state of the material. Also a procedure for designing the geopolymer ingredients for a desired strength is a must, so that the field engineers can readily use this material are to be evaluated. The objectives of different phases of work are presented here to 1. Evaluate the physical and mechanical properties of Geopolymer paste and Mortars with different percentages of Fly ash and GGBS. 2. Obtain the optimum dosage of Fly ash and GGBS Geopolymer Concrete by determining the hardened and mechanical properties of Geopolymer Concrete with different curing conditions (Outdoor and Oven Curing 60ºC for 24hours)

GEOPOLYMER CONCRETE

The concrete in which locally available industrial by-product materials or geological origin materials are used as a binder instead of cement is known as Geopolymer Concrete (GPC). GPC is economical and eco-friendly as it utilises the abundantly available wastes and has very less greenhouse foot print (Duxson et al., 2007). In fly ash based geopolymer the silica and alumina present in the source material are induced by alkaline activators to form a gel known as sodium aluminosilicate hydrate gel, which binds aggregates with any unreacted materials to form GPC. In fly ash based GPCs, polymerisation needs temperature, therefore the specimens are cured at 40-70°C for a period of 24 to 48 hours (Hardjito et al., 2004).

CONSTITUENTS OF GEOPOLYMER CONCRETE

In recent years, the use of geopolymer binders in substitution of cement binders in conventional concrete is gaining attention of researchers and industries. While producing one ton of cement, one ton of CO_2 is released to the atmosphere. Thus replacement of cement by geopolymer material in construction industry reduces pollution by two ways - Reduction in CO_2 emission into atmosphere by reducing the

consumption of cement; and utilization of fly ash, which is a by-product from

thermal power plants. The main constituents of GPC are source materials (Metakaolin, Fly ash, GGBS etc.) and alkaline activators (Sodium Hydroxide and Sodium Silicate). The choice of the materials mainly depends on factors such as cost, availability and type of their application etc. The activation of source materials can be done through the alkaline medium (sodium hydroxide or potassium hydroxide and; sodium silicate or potassium silicate).

APPLICATIONS OF GEOPOLYMER CONCRETE

The use of GPC is most advisable in precast applications due to its need for higher temperature curing conditions. In 2004, fly ash based GPC was used in the construction of railway sleepers, sewer mines, structural elements and retrofitting due to its excellent bonding with conventional concrete (Vasconcelos et al., 2011). Geopolymer concrete is also suitable for the underwater structures where early strength and rapid strength is required. Geopolymer composites were used to strengthen concrete structures such as reinforced beams. GPC can also be used for repair and rehabilitation of distressed structures. In Australia, GPC has been used to

construct box culverts, bridge decks, railway sleepers, wall panels, retaining walls and water tanks (Alderd et al., 2011). The first GPC building is "Global Change Institute Building" at University of Queensland in Australia. It is reported that geopolymer foam concrete can be used for thermal insulation (Zhang et al., 2015).

LITERATURE REVIEW ON GEOPOLYMER CONCRETE

Purdon (2018), was probably the first researcher to investigate the alkaline activated slags. Subsequent to this, many researchers performed studies on alkali activated slag to show that it is a promising and an alternative binder to Ordinary Portland Cement (OPC).

Rattanasak et al. (2018), carried the experimental investigation on setting times and strength of the high calcium fly ash based geopolymer pastes. Calcium chloride and Sucrose were taken as admixtures by weight of the fly ash as 1% and 2% and concluded that the calcium chloride decreases the initial setting time whereas sucrose delays the final setting time. The dosage of 1% gives the better results compared to 2% as per this study.

Kumar et al. (2019), studied the behaviour of fly ash based geopolymer for different parameters such as fly ash to alkaline solution ratio, concentration of sodium hydroxide and sodium silicate and geopolymer solids to water ratio, to find which combination of those parameters yields the maximum compressive strength. It has been found that the optimum contents of parameters are fly ash: alkaline solution

as 60:40, concentration of sodium hydroxide as 12M, concentration of sodium silicate as 2M, geopolymer solids to water ratio as 2.15 and sodium silicate to sodium hydroxide ratio as 2.5.

Morsy et al. (2019), studied the behaviour of fly ash based geopolymers by varying the ratio of sodium silicate to sodium hydroxide (0.5, 1, 1.5, 2 and 2.5) cured in oven at 80^0C for 24 hours. The maximum compressive strength was obtained at sodium silicate to sodium hydroxide ratio of 1, due to its homogenous and less porous matrix. This strength was found to be increasing with increase in age.

Debabrata Dutta and Somnath Gosh (2019), studied the effect of composition of alkaline activator with fly ash and fly ash + GGBS combinations. The influence of the percentage of Na2O content (6% and 8%), silicate modulus (0.5, 1 and 1.5) and the curing temperatures (55°C, 65°C, 75°C and 85°C) on the strength of geopolymer mortars. It has been observed that %Na2O content should be lower in the presence of the GGBS whereas for the fly ash based samples, %Na2O should be more to achieve the better strength.

Gunneswara Rao et al. (2019), studied the normal consistency and setting times of fly ash based geopolymer pastes by varying the concentration of sodium hydroxide (8M-16M), sodium silicate to sodium hydroxide ratio (1.5, 2.0, 2.5 and 3) and temperature (30°C, 60°C and 90°C). It has been concluded that there was an increase in setting time with increase in the concentration of the sodium hydroxide (8M-12M) for alkaline liquid ratio 1.5 and 2. With further increase in the concentration of the sodium hydroxide, setting time decreased. It was also observed that the temperature plays a vital role in decreasing the setting times. There was a reasonable decrease in setting time till 60°C, thereafter the setting time decreased significantly.

Rao et al. (2020) studied the behaviour of fly ash and GGBS based geopolymer pastes and mortars for different molarities of sodium hydroxide (8M, 12M and 16M) and two different curing regimes (outdoor and oven curing at 60°C for 24 hours). It has been found that addition of GGBS reduced setting time and also eliminated the need for oven curing and required strength can be achieved under outdoor curing itself.

EXPERIMENTAL PROGRAM

This present study deals with study of final setting time, normal consistency for geopolymer paste and compressive strength of fly ash and GGBS based geopolymer mortar. The calcined source material class F fly ash (commonly used) is partially replaced with GGBS and the mix is activated with alkaline solution. Molarity (concentration) of sodium hydroxide varies as 8, 12 and 16.

Fly ash and GGBS

Materials used in this research are GGBS obtained from Andhra Cements, Vishakhapatnam, India and fly ash from Ramagundam Thermal Power Plant, India with a specific gravity of

Alkaline Activator Solution

The alkaline solution is the combination of sodium hydroxide and sodium silicate solutions. Sodium hydroxide is used in the present study because it is less expensive than potassium hydroxide and widely available. Sodium hydroxide of 98% purity is available in pellets form is used in the investigation. These sodium hydroxide pellets were dissolved in potable water and prepared the solution of required molarity. Sodium hydroxide solution of required molarity and sodium silicate in liquid form are mixed and stored at room temperature for 24 hours before its use.

Geopolymer Paste

The source materials i.e. fly ash and GGBS with different proportions by weight are mixed in dry condition in a pan mixer. The mixture is activated by adding alkaline solution and mixed for 3minutes to ensure homogeneity by uniform colour. A series of geopolymer pastes are prepared by varying the proportions of calcined source material (fly ash and GGBS) as well as different concentrations of alkaline activator (molarities of sodium hydroxide).

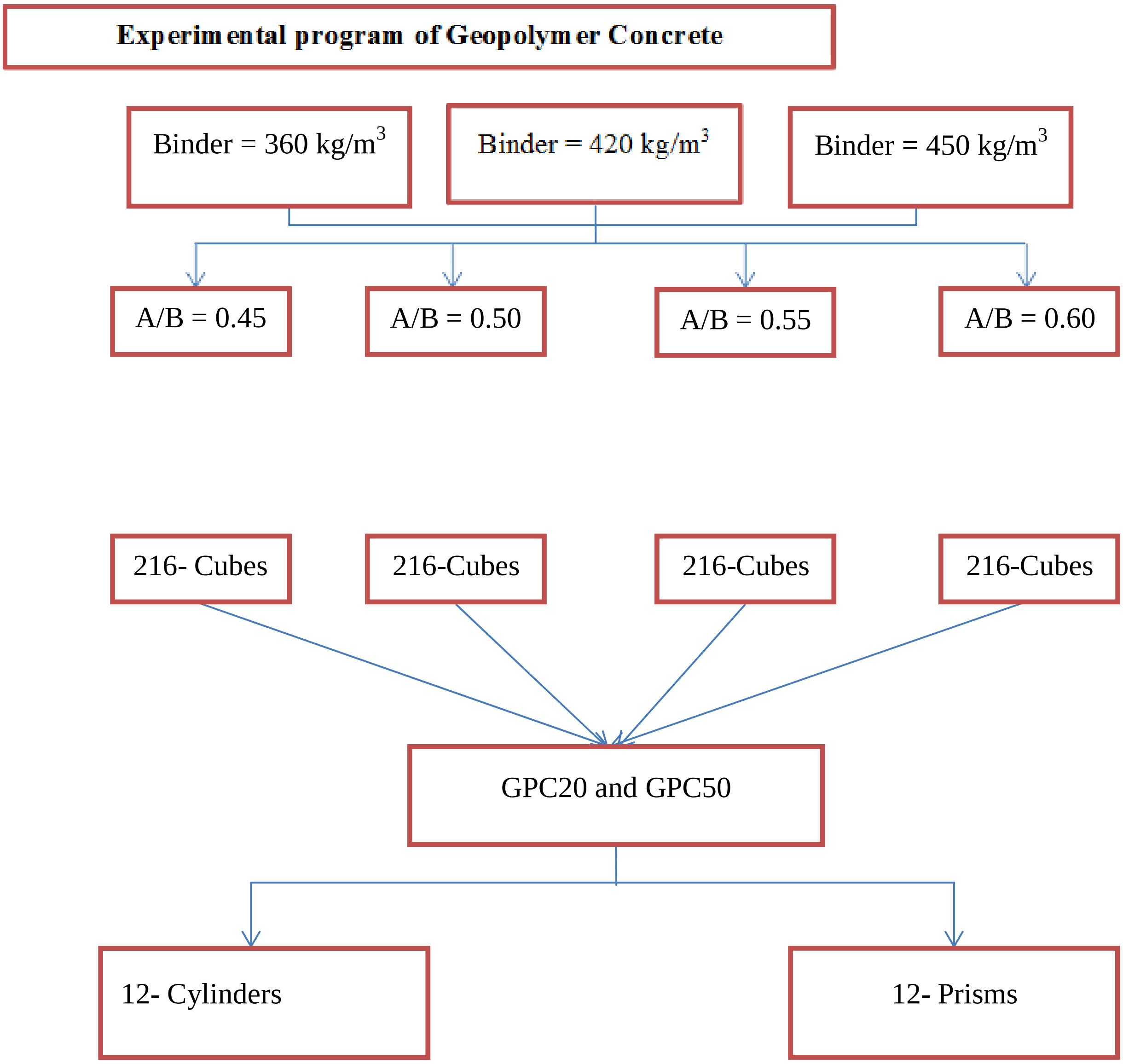

Figure Schematic Diagram of experimental program

MIX PROPORTIONS

Trail mix proportions were arrived by considering the guidelines of Indian Standard mix designs and from design procedures found in literature of GPC. Binder content, alkaline/binder ratio, fly ash/GGBS ratio, type of curing, age of curing were considered as parameters of research study. Three binder contents (360,420,450 kg/m^3) with four alkaline to binder ratios (0.45, 0.50, 0.55 and 0.60) were considered along with 70-30, 60-40, 50-50 as different combinations of fly ash and GGBS. The final mix proportions are presented in Table 4.8. Outdoor temperature curing is effective if the fly ash is partially replaced by GGBS (Nath et al., 2014). As Outdoor curing is the only possible curing method for in-situ construction it is necessitated to achieve same strength acquired by oven curing. Hence, the present study investigates on elimination of oven curing and attainment of required target strength by outdoor curing itself with replacement of fly ash by GGBS. Several trails are carried out considering the basic criterion to develop mixes of average cube strength around 20MPa, 30MPa, 40MPa, 50MPa at 28 days under outdoor curing and at the lower concentration of alkaline solution. Also it has been ensured that all these mixes have medium workability at fresh state. A comparison is also made with oven curing to relate the compressive strengths of outdoor curing.

Casting and Curing of GPC

The individual dry materials are weighed and mixed in a rotating drum pan mixer of 100 kg capacity. The alkaline liquid and required superplasticizer is added after uniformly mixing the dry materials. Proper homogenous mixing would be ensured by continuous mixing for 5 to 7 minutes and fresh property tests are conducted to ensure workability of GPC. The fresh concrete was transferred into concrete moulds (150mm x 150mm x 150mm) followed by table vibration for a period of 45 seconds and allowed to set for 24 hours. The specimens cast were de-moulded after 24 hours and cured at appropriate curing regime. For outdoor curing, specimens are left out in open air (temperature- 35±5ºC and relative humidity- 65%) up to specified age of testing (7 and 28 days). Temperature and humidity control are not necessary for outdoor cured specimens. In case of oven curing, the de-moulded specimens were kept in oven at a temperature of 60ºC for 24hours and taken out of oven and are kept at room temperature for specified age of testing (7 and 28 days).

MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE

Compressive Strength

Compressive strength of different mixes considered in this part of the investigation are presented in Table 4.18. Compressive strength reported in this table is the average value of three tested specimens.

Table 4.18: Compressive strength of geopolymer concrete

Grade of Concrete	**Compressive Strength (MPa)**			
	Outdoor Curing		**Oven Curing**	
	7 days	**28 days**	**7 days**	**28 days**
GPC20	27.35	31.11	29.2	33.94
GPC30	29.18	38.27	36.98	44.05
GPC40	44.56	50.69	47.78	59.26

GPC50	49.83	57.36	53.39	60.11

Effect of curing on Compressive Strength

The effect of outdoor curing (outdoor curing) and oven curing on compressive strength are investigated in this study. The compressive strength of geopolymer cured at oven temperature is greater than that cured at outdoor temperature. The strength gain is more because the polymerization process is accelerated at higher temperature than outdoor temperature. For many practical applications, it is very important to cure the concrete at outdoor temperature only. GPC specimens cured at outdoor temperature attained a maximum strength of about 57MPa for GPC50. The GPC20 GPC30 and GPC40 cured at outdoor temperature attained a strength of about 31, 38, 50MPa when Sodium Hydroxide molarity is taken as 8M. This indicates that outdoor curing of fly ash and GGBS based geopolymer concrete can be produced satisfactory even with low molarity of NaOH. Hence, oven curing can be eliminated for GPC made with replacement fly ash with GGBS, where oven curing is difficult. Table 4.18 shows the compressive strength value of the obtained from the experimental work for 7 and 28 days respectively. When different percentages of GGBS were taken in the mix with variation of alkaline content, the compressive strength was found to increase starting from 7 days and continued till 28 days. At 28 days, the mixture of having 50% GGBS content in the total binder achieved more strength than the geopolymer concrete with GGBS content of 30%.The improvement of strength of fly ash and GGBS based GPC is due to the increase of calcium content present in GGBS. This increase in compressive strength due to the presence of soluble calcium is known to significantly accelerate the hardening process (Lloyd et al., 2009).

Effect of Age on Strength of Concrete

The strength of concrete, commonly refers as the 28 days of the concrete, concrete gain strength even after 28 days. The 7 days strength and 28 days strength relation for GPC is very important. The work is done to estimate the strength of geopolymer concrete at 7 and 28 days strength. The strength of geopolymer concrete depends mainly on curing regime, type of binder content and molarity of alkaline activator. The gain of strength is faster at early age compared to that later age. This was observed in both types of curing, the gain of strength for oven cured GPC is higher compared to that of outdoor cuing. The compressive strength of the oven cured specimen for 7 days curing is more than the strength of outdoor cured sample. The early rate of strength gain within 7 days is high and later on the gaining in strength was not seen much as in conventional concrete. This aspect can be observed from the ratio of 28 day compressive strength to 7 day compressive strength. This ratio ranged from 1.04 to 1.35

for outdoor cured samples. The ratio of 28 day compressive strength to 7 day compressive strength of oven cured sample showed a range of 1.06 -1.32. This clearly indicates that compressive strength attainment beyond 7 days is very slow compared to conventional concrete as for conventional concrete this ratio is 1.50.

Split Tensile Strength

The outdoor and oven cured specimens at the age of 28 days are presented in Table The 28-day test results of splitting tensile strengths are in the range of 1.92- 3.25 MPa for outdoor and oven curing for grades GPC20-GPC50 respectively. This shows that outdoor curing at room temperature itself is sufficient for GPC specimens to gain its split tensile strength. This appears due to the strong bond of the geopolymer gel to the aggregate particle. At the age of 28 days, split tensile strength of GPC specimen cured under outdoor gained sufficient strength with the inclusion of GGBS to the fly ash and with the increase in GGBS there is tensile strength also. For geopolymer concrete, consistent increment in strength might be credited to the persistent formation of aluminosilicate hydrate and calcium silicate hydrate geopolymeric gels, contributed by both fly ash and GGBS (Nath et al., 2014).

Table : Split Tensile Strength for Geopolymer Concrete

Grade of Concrete	Split Tensile Strength	
	Outdoor Curing	Oven Curing
GPC20	1.92	2.74
GPC30	2.21	2.85
GPC40	2.45	3.00
GPC50	2.76	3.25

Flexural Strength

The flexural strength of geopolymer concrete at the age of 28 days is shown in Table.
It can be observed that strength of oven cured concrete specimens shows higher strength than the outdoor cured specimens due to the fast polymerization process. Flexural strength of outdoor cured geopolymer concrete 2.3MPa for GPC20 where as for the oven cured specimens it was about 2.56MPa and for GPC30, GPC40 and GPC50 there is an increase in the flexure strength. With increase in the GGBS content there is an increase in the flexural strength of the concrete. The GGBS content plays an important role in the mix for the formation of C-A-S-H gel. This gel formation is responsible for the strength contribution.

Table: Flexural Strength for Geopolymer Concrete

Grade of Concrete	Flexural Strength (MPa)	
	Outdoor Curing	Oven Curing
GPC20	2.28	2.56
GPC30	2.56	2.74
GPC40	2.8	2.93
GPC50	3.53	4.11

CONCLUSIONS

1. Through vigorous experimental studies on fly ash & GGBS base geopolymer concrete, it is

clearly evident that the replacement of fly ash with GGBS enhances the compressive strength of concrete irrespective of type of curing and for outdoor curing, the benefit is more.

2. The workability of geopolymer concrete decreases with increase in the GGBS content. The slump values are higher at high fly ash content and at high Alkaline- Binder ratio.
3. The compressive strength values are maximum at Alkaline-Binder ratio 0.5 for all the three binder contents (i.e. 360,420 and 450 kg/m^3). It is true for all the replacement of fly ash with GGBS.
4. The higher compressive strength in geopolymer concrete was achieved at 50 percent replacement of fly ash with GGBS and for binder content 360 kg/m^3, at outdoor curing the increase in strength is 24.7% than 40 percent replacement and 64.2% than 30 replacement respectively. Similar trend is also observed in binder content of 420 kg/m^3 and 450 kg/m^3.
5. The proposed mix design methodology holds good for both outdoor and oven curing conditions and helps in designing the geopolymer concrete in the range of compressive strength 20 MPa to 60 MPa.
6. The proposed methodology was validated with intermediate mixes and the results i.e. workability and compressive strength are reliable with developed methodology.
7. Compressive strength of geopolymer mortar increases with increase in percentage of replacement of fly ash with GGBS.
8. Method of curing plays an important role in polymerization process.
9. Addition of GGBS in geopolymer concrete significantly reduces the setting time and helps in attaining strength without the need for any heat curing.

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