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Effects of Addition of Cement in Flyash based Geopolymer Concrete

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ABSTRACT: Due to urbanization, cities and towns grow. As a result of urbanization, construction of huge buildings as well as massive concrete structures are built. For the construction of these concrete structures, Ordinary Portland Cement is one of the major ingredient. From cement industries, huge amount of CO_2 in emitted into the atmosphere.CO_2 is one of the major greenhouse gas which causes Global warming. Large amount of Fly ash is being produced as a by-product from coal burning power plants. Fly ash causes health issues to the public like asthma and require large area for the disposal. Production of Geopolymer concrete is one of the alternative way to reduce these problems altogether. In this study flyash is used as a major constituent for the production of geopolymer concrete. Sodium silicate and Sodium Hydroxides are used as alkaline solutions for the production of geopolymer concrete. An attempt has been made to study the effect of adding cement in geopolymer concrete replacing flyash with Ordinary Portland Cement at 10%, 20%, 30%, 40% and 50% replacement levels to determine the optimal replacement level. The results are compared with the control mix of geopolymer concrete. For this research, activators to fly ash ratio is taken as 0.35 and ratio of NaOH to Na_2SiO_3 is taken as 2.5.Molarity of Sodium hydroxide is fixed as 12M. The results show that, the addition of cement results in an increase in the compressive and impact strength. Replacement of 20% of flyash with Ordinary Portland Cement resulted in a maximum compressive strength of 49.7 N/mm^2. Addition of 20% of Ordinary Portland Cement was found to give maximum impact strength.

Keywords: Compressive strength, Fly ash, Geopolymer concrete, Impact resistance, Ordinary Portland Cement**.**

I. INTRODUCTION

In this century, cement is one of the major binding materials all over the world. The major ingredient to produce cement is lime stone ($CaCO_3$). Due to continuous production of Ordinary Portland Cement (OPC), the lime stone resources are depleting. As a result, the availability of raw material for the production of cement will also get reduced [1]. Greenhouse gases are the major cause for global warming. Main greenhouse gases are Carbon dioxide (CO_2), Methane, nitrous oxide (N_2O), Chlorofluorocarbon (CFCs), Hydroflourocarbons (including HCFCs & HFCs), Perflurocarbons and Sulphur hexafluoride. These gases are generated by the activities of human [2]. Increase in the CO_2 content increases the atmospheric temperature which results in global warming. CO_2 is the main contributor to climate change, especially through the burning of fuels from the cement manufacturing plants. Normally global average rate of CO_2 in atmosphere is 0.04% (i.e., 400ppm) [3]. But there is a rapid increase in the CO_2 content is reported in the year 2019 due to the human activities and the CO_2 content increased to 414.7ppm. According to the International Energy agency, India emitted 2299 million tonnes of CO_2 in the year 2018. Reduction of cement usage is one of the major solutions to reduce the CO_2 emission as well as to save the resources of raw materials.

Electricity is produced in different ways (i.e., hydroelectric power plants, burning of coal, through wind energy, from tidal waves etc.). Electricity produced from coal is one of the major sources of power generation in India. Approximately 60% of electricity is produced from thermal power plants. The main by-products from the combustion of coal are fly ash, bottom ash, boiler slag, flue gas, desulphurization products etc. Fly ash is the main by-product which is around 64% [1]. Fly ash is one of the major solid wastes in India; which requires large area to dump. Approximately 750 million ton of fly ash is produced each year from coal burning power plants. Fly ash is utilized in different ways such as making of bricks or blocks, cellular concrete products, light weight aggregates, manufacturing of cement and asbestos, road constructions and embankment, backfill etc. Still the utilization of fly ash has to be increased to balance the large production of fly ash.

Geopolymer concrete is an eco-friendly concrete having almost similar properties of OPC concrete. Geopolymer concrete consists of fly ash or slag, alkaline activators and aggregates. Fly ash or Ground granular blast furnace slag (GGBFS) is the major ingredient to make the geopolymer concrete. Maximum 70% of OPC can be replaced by slag but in the case of fly ash based geopolymer concrete OPC can be completely replaced. When the slag percentage beyond 70%, compressive strength reduces. But in the case of fly ash based geopolymer concrete, increasing the fly ash content increases the workability and reduces the permeability of the concrete. Also fly ash being a waste material is cheap when compared to OPC. Moreover geopolymer concrete has several advantages like high compressive strength, high tensile strength, low creep, low drying shrinkage, resistance to aggressive environment, high durability and fire resistance [4]. Curing temperature and curing time are key parameters which affect the strength of geopolymer concrete. It is reported in literature that when temperature is increased beyond 120°C, compressive strength decreases. Addition of water into geopolymer concrete will increase the workability but higher water content will reduce the compressive strength and make the concrete porous after temperature curing [5]. There are several studies going on about the mechanical properties of geopolymer concrete. However only a few literature is available on the energy absorption of the geolpolymer concrete. This present work aims to study the effect of replacement of fly ash with cement in different proportions on the workability, compressive strength and impact strength of fly ash based geopolymer concrete.

II. EXPERIMENTAL PROGRAMME

A. Materials

Geopolymer concrete combines an alkaline liquid with a geological source material containing silicon and aluminium to form a binder that does not use any portland cement. The chemical reaction that takes place is a polymerization process and this material is called as geopolymer.

In this study, the fly ash obtained from Mettur thermal power plant was used for the formation of geopolymer binder. During the geopolymerization process, aluminosilicate combines with the chemicals to form geopolymer. Mettur thermal power plant is located near Salem, India. The specific gravity of Mettur fly ash is 2.31. The chemical composition of fly ash is compared with that of the OPC and the details are given in Table 1. Manufactured sand (M-sand) with fineness modulus of 2.6 was used in this research work. Coarse aggregate having nominal size of 12mm was used in this study.

A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) were used as the activator solution [6]. Sodium hydroxide solution of desired concentration was prepared by mixing 97-98% pure NaOH pellets with distilled water [1]. The concentration of sodium hydroxide solution was kept constant (12M) for all mixtures. The specifications of sodium silicate are given in Table 2.

Table 1: The chemical composition of fly ash and OPC.

Constituent	Mettur fly ash (%)	OPC (%)
SiO_2	59.93	21.28
Al_2O_3	19.66	4.33
Fe_2O_3	2.82	1.85
CaO	3.33	64.30
Na_2O	0.34	0.17
K_2O	0.22	0.71
MgO	1.12	1.81
Loss of ignition	1.56	1.50

Table 2: Specifications of Sodium silicate (Na_2SiO_3).

Parameters	Specifications
Density (kg/m^3)	1450-1550
Total solid content by mass (%)	45-52
Specific gravity (g/cm^3)	1.45-1.55
pH	10-13
Colour	Colourless

B. Test Parameter

Replacement level of fly ash with cement is the parameter considered for this research. The replacement levels considered were 10%, 20%, 30%, 40% and 50% by weight of fly ash. Solution resting time was kept as 30 minutes. Alkaline solution was prepared 30 minutes before the preparation of the concrete mix. Curing time and curing temperature were fixed as 24hrs. and 90ºC respectively [7, 8]. Ratio of solution to fly ash and ratio of alkaline solutions were fixed as 0.35 and 2.5 respectively [9]. Mix proportion adopted for this research was 1:1.5:3.3 (i.e., fly ash: fine aggregate: coarse aggregate) [10, 11]. Mix proportion details are given in Table 3.

Table 3: Mix proportion details.

Mixes	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Fly ash (kg/m^3)	Cement (kg/m^3)	Alkaline activators (kg/m^3)	Water (kg/m^3)
mix-1	1320	600	400	0	140	0
mix-2	1320	600	360	40	125	16
mix-3	1320	600	320	80	112	32
mix-4	1320	600	280	120	98	48
mix-5	1320	600	240	160	84	64
mix-6	1320	600	200	200	70	80

Mix1 is the reference mix with no cement content. In mix-2, 10% of the fly ash is replaced with cement and in mix-6, 50% of the fly ash is replaced with cement.

C. Mixing, Casting and Curing

Making of geopolymer concrete consist of four steps. The steps are preparation of alkaline activator solution, mixing of dry aggregates, mixing of liquid components and finally mixing all components in a mechanical mixer. NaOH solution having the molarity of 12M solution can be prepared by mixing NaOH pellets in distilled water with proper proportion [12]. For NaOH solution with a concentration of 12M, 480g of NaOH pellets were dissolved in one litre of the solution [1]. The prepared NaOH solution with the concentration of 12M was added with the Na_2SiO_3 and mixed thoroughly. Thirty minutes after the preparation of alkaline activator solution, the solution was added to the mixture of coarse aggregate, fine aggregate and binders and mixed in a machine [13, 14]. After adding the solution into dry mix, extra water required was also added with water binder ratio 0.4 to the mix. Activators to fly ash ratio was kept as 0.35 and ratio between the activators was kept as 2.5 for all mixes.

After the mixing, the geopolymer concrete mixture was poured into the mould for compression and impact tests. The specimens were then vibrated using the vibrating table for 2 minutes to release any residual bubbles in the poured concrete. The moulds were then kept in controlled room temperature of 25 to 27°C leaving the top surface exposed to air [1]. The samples were demoulded after 24 hrs after casting and then cured in the hot air oven for 18 hrs and kept at ambient temperature until testing. The size of specimens for the compression test is 150 × 150 × 150 mm. The size of specimens for the impact test is 150mm diameter and 64mm height. The cured specimens are shown in Fig. 1.

Fig. 1. Specimens after casting.

D. Testing Method

The compressive strength of the specimens were found in a compression testing machine of capacity 2000 kN. The compression testing machine used is shown in Fig. 2.

Fig. 2. Compression test setup.

Specimens were placed in the machine and aligned centrally on the base plate of the machine. Load was applied gradually and continuously applied at a rate of 14N/mm^2/minute till the specimen fails. The values of the compressive strength are given in Table 4.

Impact strength: The impact strength of the specimens were found using the drop weight impact test as per the guidelines given by ACI committee 544 [15]. Fig. 3 shows the test setup of the drop weight impact test. Standard manually operated compaction hammer of a weight 4.45kg with a height of fall of 457mm was used to determine the impact strength. Test specimen was placed and positioned inside the brackets. Hardened steel ball of diameter 63.5 mm was kept over the specimen. Hammer was dropped repeatedly and recorded the number of blows required for the first crack and at the failure of the specimen [16].

Fig. 3. Impact test setup.

Table 5 shows the energy at first crack and at the failure of the specimens. Impact energy was calculated by using the following formula [17],

E=Nmgh

where,

E=Impact energy (N-m)

N = No. of blows

m = Mass of the dropped hammer (4.45kg)

g= Acceleration due to gravity (9.8m/s^2)

h=Height of the drop (475mm)

Table 4: Compressive strength of geopolymer concrete.

S. No.	Cement content (%)	Ambient curing	Percentage increase in strength	Heat curing	Percentage increase in strength
1.	0	29.42	—	35.86	—
2.	10	32.67	11.05	41.56	15.87
3.	20	38.53	30.96	49.69	38.54
4.	30	34.56	17.47	44.35	23.7
5.	40	26.67	-9.35	34.58	-3.6
6.	50	18.13	-38.4	24.76	-30.97

Table 5: Impact energy of specimens.

S. No.	Cement content (%)	Ambient curing		Percentage increase in energy at failure	Heat curing		Percentage increase in energy at failure
		First crack	Failure		First crack	Failure	
1.	0	1355	1574	—	3388	3627	—
2.	10	1734	1953	24.07	5421	5560	53.29
3.	20	2391	2591	64.61	7593	7812	115.38
4.	30	1632	1689	7.31	4756	4962	36.81
5.	40	1408	1445	-8.19	3678	3723	2.64
6.	50	410	470	-70.14	1071	1122	-69.06

III. RESULTS AND DISCUSSION

A. Workability

Fig. 4 shows that the workability of geopolymer concrete with respect to the percentage replacement of flyash with OPC. From the figure, it can be seen that, workability decreases when the percentage replacement of flyash with cement increases. Workability of geopolymer concrete decreases mainly due to utilization of a portion of water for the cement hydration process which increases the cohesion of the geopolymer concrete mix and also due to the rapid reaction of OPC with the alkaline activators [1, 18]. Hence to avoid the reduction in the workability, extra water that is needed for the hydration of water may be added.

B. Compressive strength

The effects of adding OPC in geopolymer concrete on the compressive strength is shown in figure 5. From figure 5, it can be seen that, the compressive strength of geopolymer concrete increases up to 20% replacement of flyash with OPC for both the cases of heat and ambient curing. Beyond 20% replacement, the compressive strength decreases. The maximum strength at optimal replacement level was found to be 38.53 N/mm^2 and 49.69 N/mm^2 respectively for ambient and heat cured specimens. The maximum increase in the strength of heat cured specimen was found to be 38.54% more than that of the reference specimens.

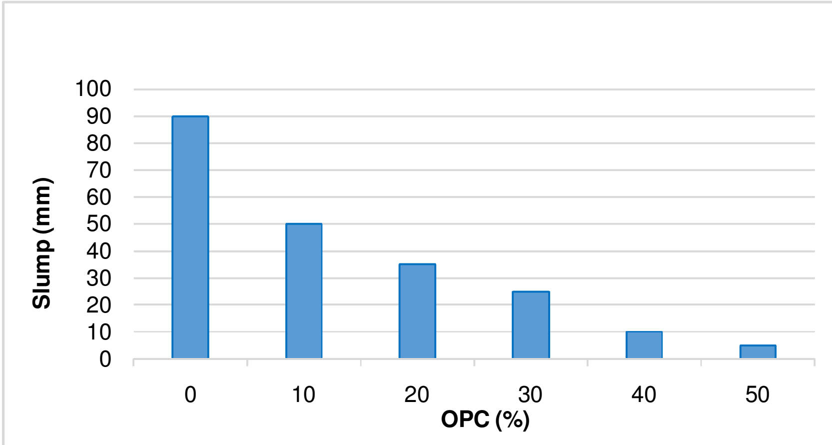

Fig. 4. Effects of OPC content on slump of geopolymer concrete.

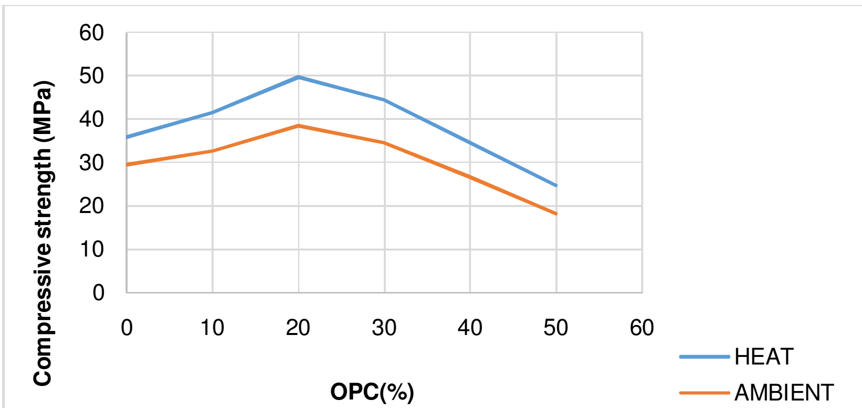

Fig. 5. Variations of compressive strength of geopolymer concrete with respect to replacement levels.

The decrease in strength beyond the optimal level of replacement is mainly due to its poor workability of mix. As the water available in the concrete is utilized by the cement for hydration, the workability decreases [1]. This results is improper compaction and hence there is a reduction in the strength.

C. Impact energy resistance

The effects of adding OPC on the impact energy of geopolymer concrete is shown in figure 6.From figure 6, it can be seen that, impact energy of the geoplymer concrete increases up to 20% replacement of flyash with OPC for both the cases of heat and ambient curing. Beyond 20% replacement, the impact energy absorption decreases.

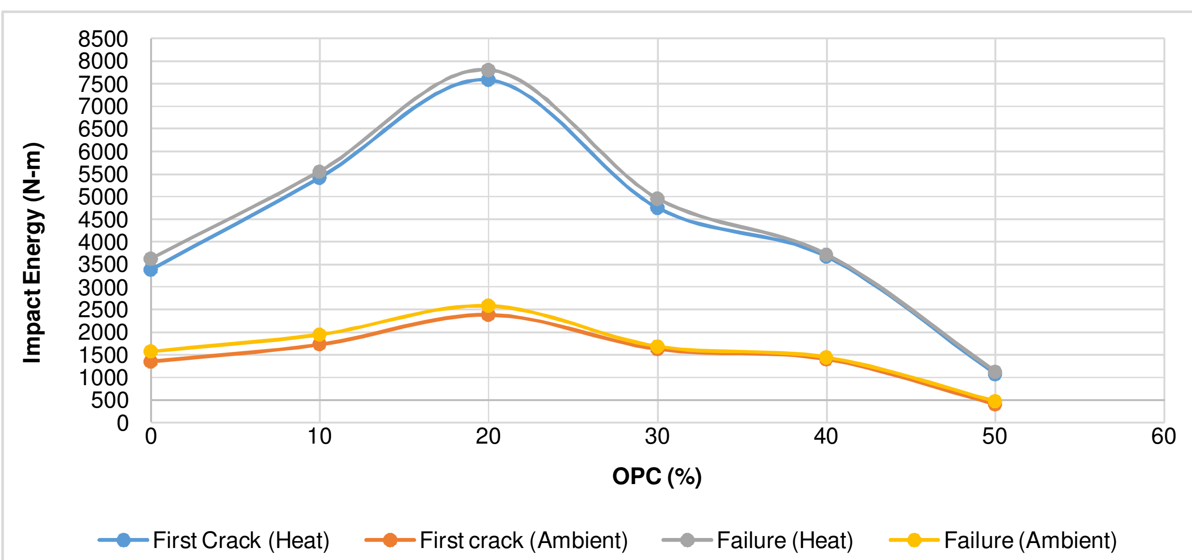

Fig. 6. Effects of OPC content on the impact energy of geopolymer concrete.

The maximum impact energy absorption at optimal replacement level was found to be 2.3 times that of the reference specimen. The maximum increase in energy at failure of heat cured specimen was found to be 115.38% more than that of the reference specimen. The decrease in impact energy resistance beyond the optimal level of replacement is attributed to the poor workability of the mixes [1, 16].

Since there is no significant difference between the energy observed at first crack and energy absorbed at failure, failure may be a brittle one.

IV. CONCLUSIONS

The following conclusions are derived based on this experimental work.

– Compressive strength of geopolymer concrete was found to be maximum at 20 % replacement level. The maximum value of compressive strength was found to be 49.7N/mm^2 which is 38.54% more than that of the control specimen.

– The strength of the heat cured specimens were found to be higher than those of the ambient cured specimens. The increase in the strength of heat cured specimens were found to be 22 to 36% higher for various mixes.

– The impact strength of specimens with 20% OPC was 2.3 times more than that of the control mix.

– At higher percentages of OPC, the geopolymer mix became stiff and the workability decreased.

V. FUTURE SCOPE

The results of the study will help to enhance the mechanical properties of geopolymer concrete with the addition of a 20% ordinary portland cement even under ambient curing. This type of geopolymer concrete with a small quantity of OPC which does not require heat curing can be called as semi geopolymer concrete and has lot of scope for further research.

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Conflict of Interest. There is no such conflict of interest.

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