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INVESTIGATION ABOUT THE EFFECT OF LATERITE AS FINE AGGREGATE ON THE STRENGTH OF GEOPOLYMER CONCRETE

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ABSTRACT

Recent developments in the field of concrete have led to a renewed interest in engineering properties of the concrete. Various aspects need to be considered in producing a high quality concrete. The consumption of Ordinary Portland Cement (OPC) causes pollution to the environment due to the emission of CO_2. An alternative material had been introduced to replace OPC in the concrete i.e Fly Ash based Geopolymer concrete. Fly ash is a by-product from the coal industry, which is widely available in the world. Moreover, the use of fly ash is more environmental friendly and save cost compared to OPC. Recently the demand for natural sand in construction industry also increased. To overcome this problem, an alternative materials namely laterite soil was introduced as sand replacement. Laterites are soil types rich in iron and aluminium and are easily available in Kerala. In this work an attempt is made to bring the idea of green concrete laterite as fine aggregate and fly ash as the binder. Compressive strength, split tensile, flexural strength were tested.

I. INTRODUCTION

The production of each ton of cement releases approximately an equal amount of carbon dioxide into the atmosphere. The emission of carbon dioxide is one of the major problems that cause global warming. Cement industry is partially responsible for this problem. The increased use of cement can be reduced by employing alternative materials such as Geopolymer which have sufficient compressive strength and durability. To develop such materials, marginal materials like fly ash, lateritic soil etc. can be used. Thus the disposal problems of fly ash which is an industrial waste can also be reduced. Huge volumes of fly ash are generated around the world; most of the fly ash is not effectively used, and a large part of it is disposed in landfills. As the need for power increases, the volume of fly ash would increase. Laterite is locally available, cost effective, energy efficient and environment friendly building material in Kerala.

The term geopolymer was coined by Joseph Davidovits in 1978. Geopolymers are a class of inorganic polymer formed by the reaction between an alkaline solution and an alumino silicate source and are synthesized by the activation of source materials which are rich in silica and alumina by alkaline media. Synthesis of geopolymer consists of three basic steps. The first is the dissolution of aluminosilicate in a strong alkali solution. This is followed by reorientation of free ion clusters. The last step is polycondensation. When in contact with a high pH alkaline solution, aluminosilicate reactive materials are rapidly dissolved into solution resulting in the release of aluminate and silicate ions, most likely in the monomeric form, which afterwards condensate to form a rigid network. Amorphous geopolymers are obtained by carrying out the polycondensation reaction at temperatures from 20 to 90 °C, while crystalline materials are formed in the autoclave at higher temperatures, up to 200 °C. Geopolymer possess three-dimensional silicoaluminate structures consisting of linked SiO_4 and AlO_4 tetrahedra by sharing all the oxygen atoms.

Laterite is one such marginal material abundantly available in many parts of the world, particularly in tropics and sub tropics. In India, there are large deposits of laterite in the peninsular region, which have not been fully utilised so far.

In this work, fly ash based geopolymer is used as the binder to produce concrete. Sodium silicate and sodium hydroxide is used as alkaline liquid and superplasticizer is added to improve workability. The effectiveness of laterite sand as partial replacement of fine aggregate in geopolymer concrete is analyzed in this study. Specimens were casted at varying total aggregate content, molarities and partial replacement i.e 25%, 50%,75%,100% of fine aggregate with laterite aggregate.

II. LITERATURE REVIEW

Many researchers prepared geopolymer blocks with different proportions and studied their properties.Geopolymer cements have been proposed as more ecologically friendly alternatives (Duxson et.al [1]) since their production does not involve limestone calcinations. Their defining characteristics are that they cure and set under ambient conditions to a material with an X-ray amorphous three-dimensional network of aluminate and silicate units with charge-balancing alkali cations (MacKenzie et.al [2]). Duxson et al. [4] studied the role of inorganic polymer technology in the development of „green concrete‟. They concluded that geopolymer materials are alkali-activated aluminosilicates, with a much smaller CO_2 footprint than traditional Portland cements, and display very good strength and chemical resistance properties as well as a variety of other potentially valuable characteristics. It is widely known that the widespread uptake of geopolymer technology is hindered by a number of factors, in particular issues to do with a lack of long-term (20+ years) durability data in this relatively young research field. There are also difficulties in compliance with some regulatory standards in Europe and North America, specifically those defining minimum clinker content levels or chemical compositions in cements. Work on resolving these issues is ongoing, with accelerated durability testing showing highly promising results with regard to salt scaling and freeze–thaw cycling. Geopolymer concrete compliance with performance-based standards is comparable to that of most other high-strength concretes.

III. EXPERIMENTAL PROGRAM

3.1. Materials

3.1.1. Fly Ash

Fly ash is an inorganic noncombustible finely divided residue collected or precipitated from the chimneys of coal fired boiler plants Fly ash is subdivided into two classes F and C, which reflect the composition of the inorganic fractions. Class F fly ashes are produced from bituminous and sub bituminous coals and contain alumino silicate glasses as active components. This fly ash is pozzolanic in nature and contains less than 10% lime (CaO). Class C fly ashes are derived from the lignite coals and contain calcium alumino silicate glasses with the high levels of calcium oxide, comprised in the glassy fraction. Class C fly ash generally contains more than 20% lime (CaO). Fly ash used in the study was sourced from Mettur Thermal Power Station in Tamilnadu.

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The chemical composition of fly ash as per the manufacturer is summarized in Table 1. Fly ash falls under class F as per ASTM C 618[38]

Fig.1. Fly Ash

Table 1. Properties of Fly Ash

Characteristics	Value
Fineness	360
Specific Gravity	2.14
Particle retained on 45 microns, max	32

3.1.2. Silca Ash

Laterite is the product of intensive and long lasting tropical rock weathering which is intensified by high rain falls and elevated temperature. Laterite consists mainly of the minerals kaolinite, goethite, hematite and gibbsite which form in the course of weathering. Moreover, many laterite deposits contain quartz as relatively stable relic mineral from the parent rock. The iron oxides goethite and hematite cause the red brown colour of the laterite.

Fig.2. Laterite Fine Aggregate

Table 2. Properties of Silica Ash

Characteristics	Value
Grading Zone	1
Specific gravity	2.37

3.1.3. Alkaline Liquid

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

Sodium Hydroxide was procured from The Travancore-Cochin Chemicals Ltd. Industrial grade Sodium Hydroxide(98% purity) was used for making geopolymer concrete. NaOH solution of molarity 8,10 and 12 were used. The Sodium Hydroxide (NaOH) solids were dissolved in water to make the solution. The mass of NaOH solids in a solution varies depending on the concentration of the solution (expressed in terms of molar,M). For instance, NaOH solution with a concentration of 8 M can be made by dissolving 320 grams (8 x 40) of NaOH solids (in flake or pellets) in one litre of distilled water. Specific Gravity of Sodium Hydroxide was 1.37.

Sodium silicate solution was procured from local market. The chemical composition of various compounds in the solution was Na_2O 18.69% by mass, SiO_2 41.31% by mass and remaining water. Specific Gravity of Sodium Silicate was 1.59.

According to Prof. J. Davidovits the alkaline liquid should be made prior to one day before mixing because at the time of mixing of Na_2SiO_3 with NaOH solution it generates a huge amount of heat and the polymerization takes place by reacting with one another, which will act as a binder in the geopolymer concrete.

3.1.4. Fine Aggregate

Fine aggregate used in this study is M sand. Fine aggregates are the aggregates whose size is less than 4.75mm. Sand is generally considered to have a lower size limit of about 0.07mm, also free from clay, minerals and salt. The specific gravity of fine aggregate was found out using pycnometer and sieve analysis was carried out to find out the grading zone of aggregate.

Table 3. Properties of Fine Aggregate

Properties	Value Obtained
Specific Gravity	2.65
Fineness Modulus	3.28
Grading Zone	Zone I

3.1.4.Laterite Fine Aggregate

The fine aggregate used was laterite soil. Hard laterite was collected from a quarry at Chingavanam in Kottayam district and 4.75mm down size materials were separated and the same was used for the present study. The test results conducted on fine aggregate is given in Table 4.

Table 4. Properties of Laterite Fine Aggregate

Sl.No	Properties	Magnitude and Unit
1	Specific Gravity	2.371
2	Grading Zone	Zone 1
3	Fineness Modulus	3.39

3.1.5. Coarse Aggregate

Locally available coarse aggregate with maximum size of 20 mm were used in this project.

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Table 5. Properties of Coarse Aggregate

Properties	Value Obtained
Specific Gravity	2.79
Bulk Density	1.32 g/cc
Water absorption	0.151%

3.1.7. Superplasticizer

To improve the workability of the fresh geopolymer concrete, a naphthalene sulphonate based superplasticizer was used. Commercial water reducing super plasticizer with a name Conplast-SP-430, manufactured by FOSROC, India was used in the present study.

3.2. Laboratory Work

Review of literature shows that the compressive strength of geopolymer mixture depends on the quantity of fly ash and percentage of total aggregate used for casting the specimen. The percentage content of total aggregate is an important factor. Both the lower content and excess content of fly ash leads to reduced strength. Hence the optimum content of fly ash is suggested to be found out on trial basis considering the reported values as guide lines. Water content increases the workability but reduces the compressive strength considerably. The water content is commonly expressed in ratio of weight as water to Na_2O ratio, water to geopolymer solids ratio, water to fly ash ratio etc.

3.2.1. Mixing

Different mixes were prepared by varying Total aggregate i.e 60%,65%,70%,75% and constant Fluid/Binder ratio 0.25 but varying the molarity of NaOH as 8M,10M and 12M; varying Na_2SiO_3/NaOH ratio as 2.5. For each total aggregate content , fine aggregate is replaced by laterite fine aggregate in 25%,50%,75% and 100% replacement. And the optimum mix were cured at 60^{o}C, 80^{o}C, 100^{o}C. Cubes of size 150mm x 150mm x 150mm were used for testing compressive strength on 3rd and 7th days. Water absorption test were also carried out.

For mixing, a drum mixer was used. The aggregates were prepared in saturated surface dry condition. The sodium silicate and sodium hydroxide solution was mixed together at least one day before casting. The materials were dry mixed for about 3 minutes and after that the alkaline liquid mixed with superplasticizer was added and mixed for about 4 minutes. Small amount of water was also added to increase workability.

Cubes with 15 cm × 15 cm × 15 cm, cylinders with 10 cm × 30 cm and beams with 50 cm × 10 cm × 10 cm sizes were casted. Cylinders and beams were casted for optimum mixes. Compaction of the specimens was done on table vibrator.

3.2.2. Curing

The specimens, thus, prepared were kept at room temperature for 1 hour, before they were temperature cured. The specimen, along with their moulds were then subjected to temperature curing in an electric oven at 80°C for 24 hrs.Specimens were taken out of the moulds at the end of the curing period and were kept in room temperature under laboratory conditions until they were tested..

3.3. Mix Proportion

The mix proportion of the concrete mix was designed based on the literature surveys conducted and the mix proportion was fixed on the basis of the trial mixes prepared.

Table 6. Constant parameters considered for the mixture proportion

Sl.No	Parameter	Value
1	Curing Temperature	80^0C - 60^0C
2	Curing period	24 h
3	Volume of total aggregate per 1m³ concrete	70%
4	Ratio of Sodium silicate to NaOH solution	2.5
5	Super Plasticizer in % by mass of fly ash	1%

Table 7. Variables considered for the mixture proportion

Sl.No	Parameters	For Geopolymer concrete block
1	Aggregate Content	60% to 75%
2	NaOH molarity	8, 10 and 12
3	Ratio of alkali solution to fly ash	0.55

3.4. Compressive Strength

150 mm × 150 mm × 150 mm cubes were casted for carrying out compression strength test. 3 day and 7 day strength of the specimens were measured.

3.4.1. Variation of compressive strength with different molarities of NaOH

As molarity of sodium hydroxide increases compressive strength also increases. By considering the economical factor we take 10M as the optimum mix which give enough strength for small scale construction purpose. This behaviour is mainly due to the fact that concentration of NaOH solution used for geopolymer synthesis has a positive influence on dissolution, hydrolysis and condensation reactions. So, it could be observed that there is an optimum value for the ratio of sodium silicate to sodium hydroxide. The variation is shown in the graph.

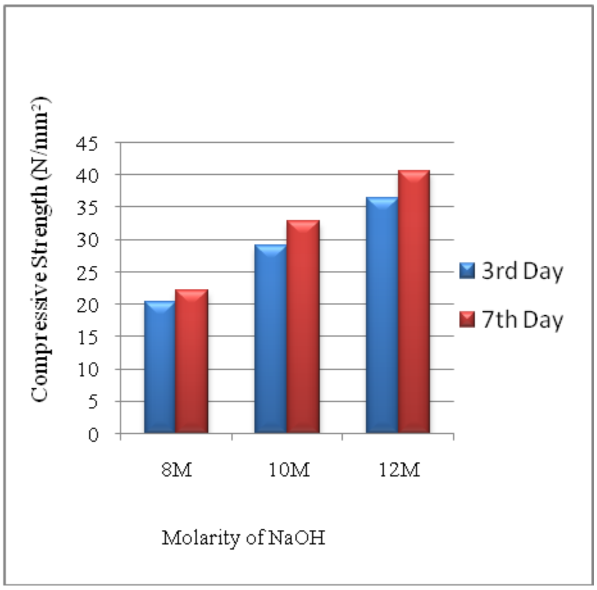

Fig.3. Variation of Compressive Strength with Different Molarities of NaOH

3.4.2. Variation of 7th day Compressive Strength with total aggregate content

It is observed that at 60% total aggregate content gives higher strength than other mixes. As binder content increases strength increases. 60% of total aggregate has 29 percentage increase in strength than 65% of total aggregate, this due to the increase in binder content..

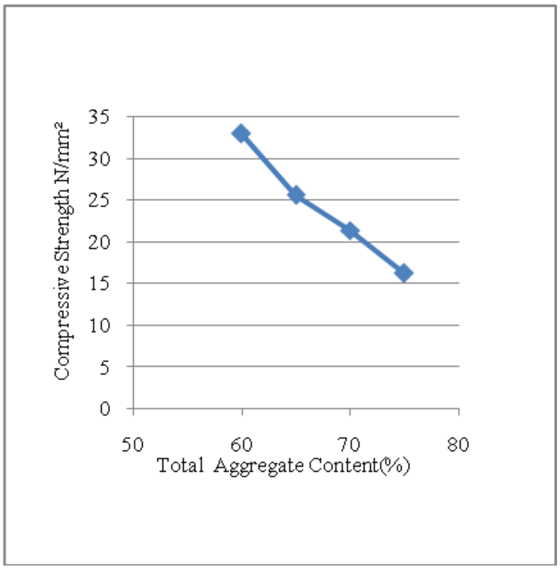

Fig.4. Variation of 7th day Compressive Strength with Total Aggregate Content

3.4.3. Variation of 7th day Compressive Strength with Percentage Replacement for Different Total aggregate Content

The variation of compressive strength for different percentage of replacement of fine aggregate and its concluded that for 60% total aggregate gives higher strength and in which 50% replacement of fine aggregate is taken as optimum, since it has enough strength to be used in small scale construction purpose.

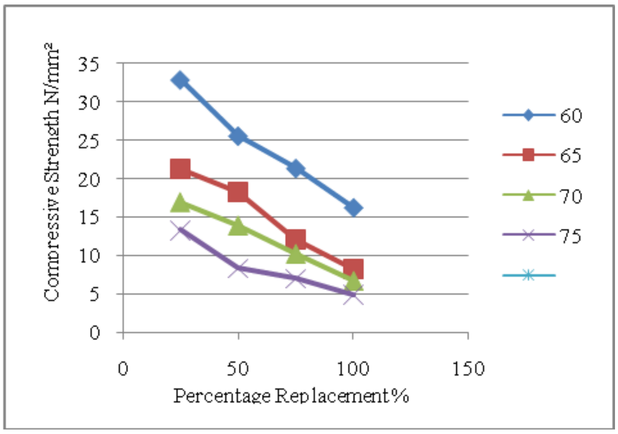

Fig.5. Variation of 7th day Compressive Strength with Percentage Replacement for Different Total aggregate Content

3.5. Split Tensile Strength Test

Tensile strength is the capacity of a material or structure to withstand tension. It is measured on geopolymer concrete cylinders of standard dimensions using a Universal Testing machine. The test is conducted after 7 days from date of casting. The diameter of the cylinder for the specimens was 150mm and the height was 300m. The graph shows the corresponding variations.

As binder content increases the flexural strength increases but there is no much variation in strength. There is 29% increase in split tensile strength for 12M than 10M geopolymer concrete.

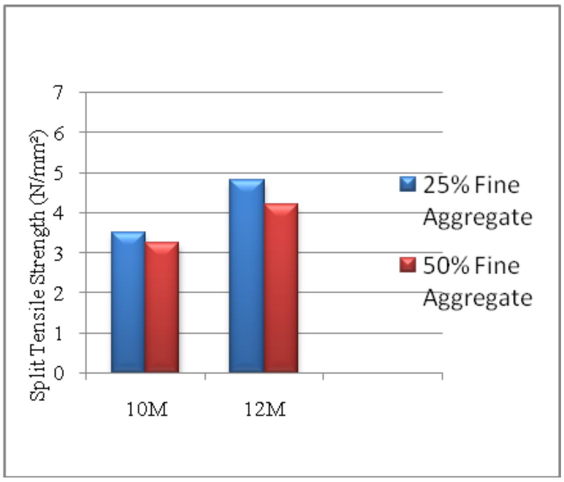

Fig.6. Variation of 7th day Split Tensile Strength with Molarities for 25% and 50% Laterite Fine Aggregate Content

3.6. Flexural Strength Test

Flexural strength of concrete is considered as an index of tensile strength of concrete. Tensile stresses are likely to develop in concrete due to drying shrinkage, rusting of steel reinforcement, temperature gradients and many other reasons. Beam tests are conducted to determine flexural strength of geopolymer concrete. Beams of size 100mm x 100mm x 500mm were casted and tested on universal testing machine after 7 days from date of casting. Graph shows the corresponding variations of compressive strength at varying percentages of laterite fine and molarity.

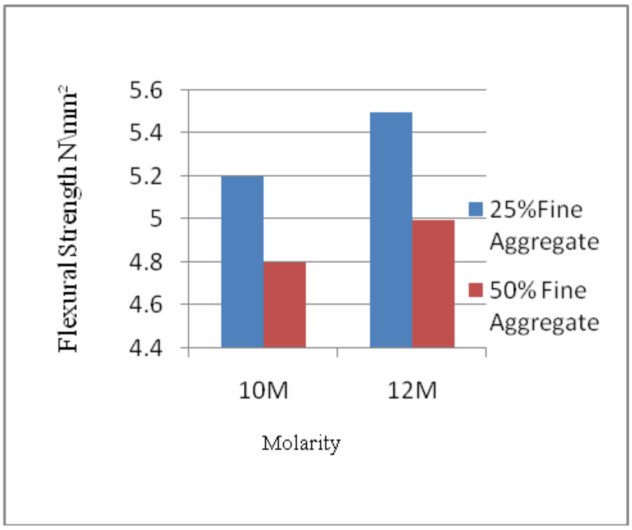

Fig.7. Variation of 7th day Flexural Strength with Molarities for 25% and 50% Laterite Fine Aggregate Content It is observed that there is no much variation in the flexural strength and split tensile strength for 10M and 12M geopolymer concrete. There is 4.16% increase in strength for 12M than 10 M geopolymer concrete.

3.7. Water Absorption

One of the most important properties of a good quality concrete is low permeability, especially one resistant to freezing and thawing. A concrete with low permeability resists ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate. Absorption for concrete pavers, the test procedure involves drying a specimen to a constant weight, weighing it, immersing it in water for specified amount of time and weighing it again. The increase in weight as a percentage of the original weight is expressed as its absorption (in percent). The average absorption of the test samples shall not be greater than 5% with no individual unit greater than 7%.Table 8 and 9 shows the water absorption percentage for optimum total aggregate content under different molarities.

Table 8. Percentage of water absorption for 60% total Aggregate with 10M

Percentage Replacement (%)	Saturated Surface Dry Weight (kg)	Oven Dried Weight (kg)	Water Absorption (%)
0%	8.183	7.983	2.51
25%	8.148	7.824	4.14
50%	8.102	7.770	4.27
75%	8.016	7.523	6.55
100%	7.986	7.492	6.59

Table 9. Percentage of Water Absorption for 60% total Aggregate with 12M

Percentage Replacement (%)	Saturated Surface Dry Weight (kg)	Oven Dried Weight (kg)	Water Absorption (%)
0%	8.398	8.196	2.46
25%	8.378	8.121	3.10
50%	8.235	7.985	3.13
75%	7.987	7.586	5.28
100%	7.625	7.021	8.602

3.8. Curing Temperature

The loss of strength beyond the curing temperature of 100 °C is due to the loss of moisture from the specimen. Even if sealed properly, at temperatures above 100 °C, the specimen may dry out and lead to a reduced strength. Similar observations were reported by investigators earlier. It could be observed that, upto a curing period of 24 h, the strength gain of geopolymer is proportional to the period of curing and no appreciable strength gain could be obtained beyond 24 h. This could be due to the reason that most of the polymerization would have been completed within 24 h.

Table 10. Specimen cured at different Temperature.

Specimen	**Curing Temperature**	**7^{th} day Strength(N/mm²)**
50% Fine Laterite (10M)	60^0C	25.22
50% Fine Laterite (10M)	80^0C	32.22
50% Fine Laterite (10M)	100^0C	29.33

IV. CONCLUSION

Lateritic soils are widely available in Kerala and can be used to manufacture building material with good civil engineering properties like compressive strength and water absorption. Laterized concrete with fly ash shows better compressive strength properties.

•Concrete with laterite fines replacing the natural sand can satisfactorily perform as a normal concrete when the laterite fines content does not exceed 50%.

•Higher the molarity of sodium hydroxide solution, higher will be the compressive strength.10M is taken as optimum considering the economical factor.

Compressive strength increases with increase in the temperature of curing upto 100^0C.

•Laterized geopolymer concrete is Eco-Friendly . And helps in the reduction of use of river sand as fine aggregate.

•And Mix proportions for M 20are Similar to Normal concrete Mix proportions.

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