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Durability and Strength Properties of Geopolymer Mortar Reinforced with Natural Fibre

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Abstract-The study in this paper is to eliminate the amount of cement from concrete or mortar by complete replacement of cement with geopolymer. Geopolymer is a binding material produced from the reaction of low calcium fly ash with alkaline activator solution. The activator solutions are combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). Systematic trials were carried to optimize the ratio of sodium silicate to sodium hydroxide in activator solution. This paper investigates the strength property of plain geopolymer mortar and geopolymer mortar reinforced with natural fibre for different percentages 0.1% to 0.5% by the weight of fly ash. The mortar cubes were tested at the curing ages of 3, 7 and 28days. The results of indicated that 0.4% was the optimum fibre content in fibre reinforced geopolymer mortar. Water absorption test was performed for durability study on fibre reinforced geopolymer mortar after 28 days curing period. It is also observed that compressive strength of GPM increases on addition of natural fibre (shel) from 0.1% to 0.4% and achieved maximum compressive strength 42.10N/mm2 (28 days) at 0.4%.

Keywords-Geopolymer, Class-F, Natural Fibre, Alkaline Activator, Water Absorption

1. INTRODUCTION

The increased emphasis on sustainable development and environmental protection has lead to examination of alternatives to conventional building materials. The process of Portland cement manufacturing requires large amount of energy and produces a large volume of carbon dioxide (CO_2) to the atmosphere. The low-calcium fly ash is used with sand in place of cement along with alkaline liquid to produce geo-polymer mortar. In 1978, J. Davidovits suggested that an alkaline liquid could be used to react with low-calcium fly ash that contains Si and Al to produce geo-cement. This geo-cement is formed by polymerization process. To make alkaline liquids sodium silicate and sodium hydroxide or potassium hydroxide and potassium silicate may be used.

J. Davidovits later in 1994, introduced the term ‘Geo-polymer’ to represent these geo-cement. In geo-polymer mortar or concrete the strength is depends on various factors such as types of source material, fineness of sand, chemical composition of fly ash, types of activator solution, ratio of solution to binder, Na2SiO3 to NaOH, curing temperature, types of curing and concentration of NaOH solution. Geopolymer concrete gains popularity globally towards the sustainable development. Low-calcium fly ash and alkaline liquid is used to produce binder which binds the aggregate. It is a new technology that minimizes CO2 production into the environment. The main constituents in low-calcium fly ash those would be activated are Si and Al. The low-calcium fly ash mixed with alkaline liquid and the binder is produced by polymerization. Sand obtained from the crusher plant, stone dust, natural sand and river sand is generally used as a fine aggregate in mortar, which is becoming insufficient and costly due to the transportation charges from their sources. Due to depletion of these sources many environmental problems are created.

2. LITERATURE REVIEW

Major **Davidovits Joseph (2002)** in this paper attempt is made to study environmentally driven geopolymer applications based on the implementation of (K,Ca)-Poly(sialate-siloxo) / (K,Ca)-Poly(sialate-disiloxo) cements. Geopolymeric cement generates six times less CO_2 during manufacture than Portland cement. Immobilization technologies with geopolymeric materials have three goals**.** First one is to seal the hazardous materials into an impermeable monolith. This prevents the direct contact of potential leachates, like ground water and percolating rain. Geopolymeric cements do not rely on lime and are not dissolved by acidic solutions. Portland based cements (plain and slag mixtureed) are destroyed in acidic environment.

Hardjito Djwantoro *et.al.* (2004) in this paper efforts were made to develop environmentally friendly construction materials. To reduce greenhouse gas emissions, fly ash based geopolymer concrete was developed. In geopolymer concrete, low-calcium fly ash was chemically activated by a high-alkaline solution to form a paste that binds the loose coarse and fine aggregates together. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods. Higher curing temperature resulted in larger compressive strength, even though an increase in the curing temperature beyond 60°C did not increase the compressive strength substantially. To evaluate the resistance of geopolymer concrete to sulphate attack, specimens were soaked in a 5% sodium sulphate (Na_2SO_4)

solution for different periods of time. The author concluded that higher concentration (in terms of molar) of sodium hydroxide solution results in a higher compressive strength. Higher the ratio of sodium silicate-to-sodium hydroxide liquid ratio by mass, higher is the compressive strength.

Wallah Edward Steenie (2009) in this paper attempt is made to study the drying shrinkage of heat-cured fly ash-based geopolymer concrete. As a relatively new material, extensive studies are still needed to explore this type of concrete as a construction material. One area that needs to be studied is its shrinkage behaviour, which is an important long-term property of concrete. Shrinkage is the decrease in volume of concrete with time. Unlike creep, shrinkage is independent of the external factors to the concrete. There are some types of shrinkage in the concrete which should be distinguished - plastic shrinkage, chemical shrinkage, thermal shrinkage and drying shrinkage. The aggregates play a significant role in affecting the shrinkage of concrete. This is related to the restraining effect of the aggregate on shrinkage. The higher aggregate content results in smaller shrinkage and also concrete with aggregates of higher modulus or rougher surfaces is more resistance to the shrinkage process. The author concluded that the heat-cured fly ash-based geopolymer concrete undergoes very low drying shrinkage.

Lloyd N A and Rangan B V *et.al.* (2010) tests are conducted to identify the effects of salient factors that influence the properties of the geopolymer concrete and to propose a simple method for the design of geopolymer concrete mixtures. Studies have been carried out on fly ash-based geopolymer concrete. The compressive strength and the workability of geopolymer concrete are influenced by the proportions and properties of the constituent materials that make the geopolymer paste. Heat-curing of low-calcium fly ash-based geopolymer concrete is generally recommended. Heat-curing substantially assists the chemical reaction that occurs in the geopolymer paste. Both curing time and curing temperature influence the compressive strength of geopolymer. The results of the tests conducted on large-scale reinforced geopolymer concrete member's show that geopolymer concrete is well-suited to manufacture precast concrete products that can be used in infrastructure developments and geopolymer concrete has excellent properties.

Al Bakri Mustafa Mohd *et.al.* (2011) made attempt to develop environment friendly concrete by replacing OPC with fly ash. The consumption of Ordinary Portland Cement (OPC) caused pollution to the environment due to the emission of CO2. The compressive strength increases with the increasing of fly ash fineness and thus the reduction in porosity can be obtained**.** Setting time of geopolymer depend on many factors such as composition of alkaline solution and ratio of alkaline liquid to fly ash by mass. However, the curing temperature is the most important factor for geopolymer. As the curing temperature increases, the setting time of concrete is decreases. During curing process, the geopolymer concrete experience polymerization process. Due to increase in temperature, polymerization become more rapid and the concrete can gain 70% of its strength within 3 to 4 hr of curing. The author concluded that fly ash-based geopolymer is better than normal concrete in many aspects such as compressive strength, exposure to aggressive environment, workability and exposure to high temperature.

Sanni H Shankar, Khadiranaikar R B (2012) investigated the variation of alkaline solution on mechanical properties of geopolymer concrete. The grades preferred for the investigations were M30, M40, M50 and M60; the mixes were designed for 8 molar. The alkaline solution used was the combination of sodium silicate and sodium hydroxide solution with the varying ratio of 2, 2.5, 3 and 3.5.

The test specimens were 150x150x150 mm cubes and 100x200 mm cylinders heat-cured at 60°C in an oven. The results revealed that the workable flow of geopolymer concrete was in the range of 85 to 145mm and was dependent on the ratio by mass of sodium hydroxide and sodium silicate solution. The freshly prepared geopolymer mixes were cohesive and their workability increased with the increase in the ratio of alkaline solution. It was concluded that the strength of geopolymer concrete can be improved by decreasing the water/binding and aggregate/binding ratios. Compressive strength and split tensile strength obtained were in the range of 20.64-60 N/mm^2 and 3-4.9 N/mm^2.

Yellaiah P. *et.al.* (2014) investigated the influence of various parameters on the consistency and setting times of low-calcium fly ash based geopolymer cement under varied heat curing temperature were investigated. The consistency of geopolymer cement does not show any variation when mixed with different combinations of alkaline activator solution; whereas the setting times were observed to be dependent on concentration of NaOH solution, ratio of alkaline liquid and variation in temperature. The test results revealed that the normal consistency of geopolymer paste is found to be at 28% of alkaline activator solution for all the selected mixtures. Wherein, increase in concentration of NaOH solution increases setting times; increase in alkaline liquid ratio decreases setting times up to certain limits viz; increase in alkaline liquid ratio from 1.5 to 2.0 decreases setting times; further increase in alkaline liquid ratio from 2.0 to 2.5 increases setting times.

Gull Iftekar, Sofi Yasir (2015) intended to study the properties of fly ash based Geopolymer concrete. M20 grade GPC can be formed by adopting nominal mix of 1:1.5:3 (fly ash: fine aggregates: coarse aggregates) by varying alkaline liquid to fly ash ratio from 0.3 to 0.45. The compressive strength, tensile strength and flexural strength tests were conducted on geopolymer concrete and parameters that affect it are analyzed and proved experimentally. The durability properties like permeability and acid attack are also studied. From the test results, it was concluded that geopolymer concrete possesses good compressive strength and offers good durability characteristics. With the increase of alkaline liquid to fly ash ratio strength decreases and alkaline liquid to fly ash ratio less than 0.3 is very stiff.

3. MATERIALS USED

3.1Fly ash

Fly ash considered one of the most important source materials to produce geopolymer cements. Low calcium based fly ash was used in this work which generally known as ASTM Class F. The ignition of hard, aged anthracite and bituminous coal generally produce Class F low-calcium fly ash. This low-calcium fly ash is pozzolanic in nature, and also contains CaO (lime) less than 7%. Having pozzolanic characteristics, the Si and Al of Class F low-calcium fly ash requires a binding agent, such as OPC, burnt lime or slaked lime unite to react and to form binding compounds. Adding an alkaline activator such as Na2SiO3 (water glass) to Class F fly ash can produce a geo-cement.

3.1.1. *Properties of fly ash*

- Specific gravity : 2.08
- Fineness Blaine's specific surface area : 462.8m^2/kg
- Soundness by autoclave : 0.27%
- Drying shrinkage : 0.057%

3.2 Fine aggregate

Fine aggregate generally includes the particles that all passes through 4.75mm sieve and retain on 0.075mm sieve. River sand or fine aggregate was used in this work. The grading of sand used conforms to Zone II of IS: 383-2016. According to its grading, IS specifications classify the fine aggregate into four types as fine aggregate of grading Zone-I to grading Zone-IV. The fine aggregates become progressively finer from grading Zone-I to grading Zone-IV. The sieve analysis helps to find out the zone of sand, size of aggregate and to find out particle size distribution of sand used.

3.1.2. *Properties of fine aggregate*

- Specific gravity : 2.62
- Water absorption : 1.62%
- Fineness modulus : 2.57

3.3 Natural Fibre

Natural Fibres are fibres that are produced by plants, animals and geological processes. In this study, we used Shel which is an example of Bast fibres. Shel is generally obtained from a multipurpose tree called Bhimal (Biul or Beuhal). Common occurrence of Bhimal is in North India upto an altitude of 2000m. Bhimal (Grewia Optiva scientific name) is a moderate sized tree which can grow up to 45 feet and 4.5 feet in girth. Besides fruits, fuel wood and fodder the tree also yield very useful jute like fibre called Shel. The shel fibre is extracted either by biological or chemical retting processes. Biological retting process is most widely practicable. In biological process, branches or stems are cut in the month of March and kept for cold water retting in bundles which lasts for 40-50 days. After that following beating, the stem is dried for few days. Finally, the bark of stem is extracted golden coloured fibres are separated from the bark. The fibres are sun dried and stored in dry place. The fibres obtained are 1-3m in length and 17-25microns is size. In this study, the shel fibre is cutted into smaller pieces of length 18mm. The shel fibre is used in varied proportions from 0.1% to 0.5% by the weight of binder.

3.4 Alkaline activator solution

Generally, the combination of NaOH or KOH and Na_2SO_3 or K_2SO_3 is used to make alkaline solution for polymerization. In this study, sodium hydroxide and sodium silicate are mixed together to from alkaline activator. NaOH pellets are dissolved in tap water to form 14M concentration solution. When the alkaline solution contains soluble silicate reactions occur at a high rate with low calcium fly ash, as compared to the use of alkaline hydroxides only. Na_2SO_3 solution added to the NaOH solution to prepare alkaline solution in SS/SH ratio 2.0. The alkaline solution is then produced by mixing both the chemical solutions together completely. There after an unspecified amount of heat is released due to the mixing Na_2SO_3 with NaOH solution. Therefore it is prepared 24 hours prior to use.

4. EXPERIMENTAL WORK

4.1 Compressive strength test

Compressive strength test is the most important test for all types concretes and mortars. Low-calcium fly ash based geopolymer mortar specimens were prepared as per IS: 4031 (part-I) – 1988 standard for ordinary cement mortar by replacing water with activator solution and cement with class-F fly ash. For activator solution, the concentration of sodium hydroxide (NaOH) solution is kept 14M and the ratio of Na_2SiO_3 to NaOH (i.e. SS/SH ratio) is kept 2.0. When NaOH solution was cooled then it was mixed with sodium silicate (Na_2SiO_3) in desired concentration (i.e. SS/SH ratio 2.0) at least 24 hours prior to use. All the specimens prepared for testing strength of geopolymer mortar were casted in standard moulds of size 70.6mm x 70.6mm x 70.6mm (IS: 10080). Specimens prepared then placed in hot air oven for curing at a specified temperature of 90^0C and allowed to cure for next 24 hours. The prepared moulds then de-moulded after 24 hours and allowed to ambient curing at room temperature until testing. The specimens prepared were tested at 3, 7 and 28 days for compressive strength under CTM

Table no.1 Compressive Strength of Geopolymer Mortar Reinforced with Shel

Fibre content	**Compressive strength (N/mm^2)**		
	3 days	**7 days**	**28 days**
0.1%	27.69	30.89	36.11
0.2%	29.30	32.50	38.12
0.3%	31.50	34.31	39.73
0.4%	33.50	36.72	42.10
0.5%	31.90	34.61	40.02

4.2 Water absorption test

A set of two Cubes specimen of 70.6mm x 70.6mm x 70.6mm size were casted for each percentage of natural fibre from 0.1% to 0.5% and placed for 28 days in room temperature. After that cube were kept in oven at a temperature of 105°C to a constant mass for 24 hours. The cubes weight was recorded as W1. Cooled the cubes to the room temperature and immersed in water for 24 hours till the saturation weight as W2. The percentage of gain in weight of cube is water absorption shown in table 2.

Table no.2 water absorption of geopolymer mortar reinforced with shel

Fibre content	**W1**	**W2**	**Water absorption %**
0.0%	650	688	5.85
0.1%	642	682	6.23
0.2%	646	689	6.65
0.3%	636	681	7.07
0.4%	632	680	7.59
0.5%	616	665	7.95

5. RESULT AND DISCUSSION

5.1 Compressive strength

A total of fifty four cubes 3 nos. in each set for different percentage of natural fibre (0.1%, 0.2%, 0.3%, 0.4% and 0.5%) are prepared to study their effect on compressive strength of GPM reinforced with natural fibre under curing temperature of 90^{0}C. The figures show that compressive strength of GPM increases significantly on the addition of natural fibre (shel) in different percentage. It is indicated by graph below clearly that the compressive strength at 3, 7 and 28 days increase in the similar manner with respect to change in percentage of natural fibre. It is also observed that compressive strength of GPM increases on addition of natural fibre (shel) from 0.1% to 0.4% and achieved maximum compressive strength 42.10N/mm^2 (28 days) at 0.4%.

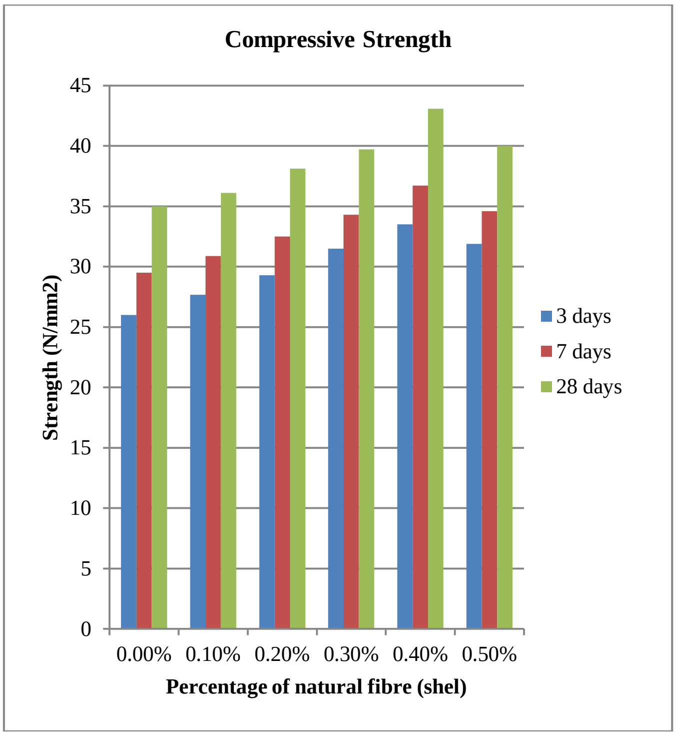

Figure 1 comparative Graphs for Compressive Strength at 3 Days, 7 Days and 28 Days

5.2 Water absorption

A total of 12 cubes 2 nos. in each set for different percentage of natural fibre 0.0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5% are prepared for water absorption test on GPM reinforced with natural fibre. After 28 days ambient curing specimens prepared are tested and percentage of water absorption is as shown graph below. Water absorption percentage of fibre reinforced GPM increases as the percentage of natural fibre (0.1 to 0.5%) increases.

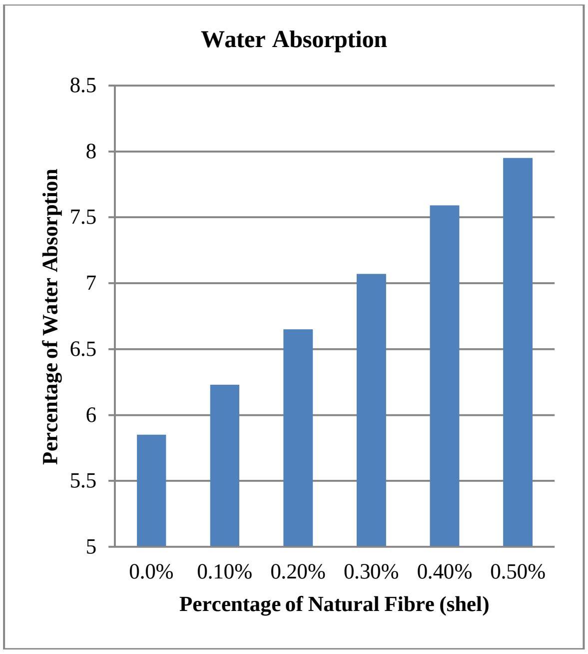

Figure 2 Graph for water absorption at 28 days

6. CONCLUSION

Based on the limited experimental study, the following conclusions are drawn:

- Compressive strength is found optimum at SS/SH ratio of 2.0 with 14M concentration of NaOH solution.
- At lower curing temperature higher setting time is observed and difficult to de-mould. Hence increase in curing temperature to 90^0C decreases setting time and provide an ease in de-moulding.
- The compressive strength of GPM reinforced with natural fibre (shel) increases with increase in fibre content from 0.1% to 0.4% and then further increase in fibre content from 0.4% to 0.5% decreases the compressive strength of GPM.
- Maximum compressive strength of fibre reinforced geopolymer mortar was found 42.10N/mm^2 at 0.4%.
- Water absorption percentage of fibre reinforced GPM increases as the percentage of natural fibre (0.1 to 0.5%) increases.

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