AN EXPERIMENTAL STUDY ON GEO-POLYMER CONCRETE USING SAW DUST AS PARTIAL REPLACEMENT FOR FINE AGGREGATE

S. Karthick Kumar[1], R. Guru Packiyam[2], P. Jai Singh[3], G.Kesavan[4], Dr. B. G. Vishnuram[5]

[1,2,3]U.G. Students, Department of Civil Engineering, P.S.R. Engineering College, Sivakasi – 626 140, Virudhunagar District, Tamilnadu, India.

[4]P.G. Student, Department of Civil Engineering, P.S.R. Engineering college, Sivakasi – 626 140, Virudhunagar District, Tamilnadu, India.

[5]Professor, Department of Civil Engineering, P.S.R. Engineering College, Sivakasi – 626 140, Virudhunagar District, Tamilnadu, India.

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Abstract - *In this experimental study strength characteristics of geo-polymer concrete with saw dust as partial replacement for fine aggregate. The replacement levels adapted in this study were 10%, 15%, 20% respectively. Geo-polymer mixes with aqueous solution with molarity values 10,12,14,16 were adapted. Geo-polymer was cast using materials such as fly ash, fine aggregate (with replacement level 10% -20%) and coarse aggregate of size 20mm and aqueous solution of $NaSiO_3$in pellet form in molarity basis as above. The test specimen cube of size 150mmx150mmx150mm were cast and cured at room temperature measured as 27^0C – 30^0C. The specimens were tested at the edge of 7 days, 14 days, 28 days in the compressive testing machine of 2000 k-N inn concrete laboratory. The test results are presented and compared for the specimen with different molarity ratio. It is found that the geo-polymer mix of 12 Molarity was shown maximum value of compressive strength and split tensile strength. It was also found from the graph drawn that geo-polymer mix with 15% replacement level has shown an increased gain of strength over the period of time when compared to the other*.

Key Words: ***fly ash, GGBS, saw dust, sodium hydroxide, sodium silicate, compressive strength, split tensile strength***.

1. INTRODUCTION

Concrete is a composite material consists of fine and coarse aggregate bonded together with a fluid cement (cement paste) that hardens (cures) over time. When the cement has chemically reacts with the water (hydrated), it hardens and binds the whole mix together. The initial hardening reaction usually occurs within a few hours. It takes some weeks for concrete to reach full hardness and strength.

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Concrete is a brittle material that has a high compressive strength, but a comparatively low tensile strength. Thus steel reinforcement of concrete is required to allow it to handle tensile stresses in concrete. Concrete is the second most widely used substance after water and over six million tons of concrete are produced every year.

Concrete is widely used for different applications such as new construction, repair, rehabilitation and retrofitting. Concrete building components in different sizes and shapes include wall panels, doorsills, beams, pillars and more. Post tensioned slabs are a preferred method for industrial, commercial and residential floor slab construction. It makes sense to classify the uses of concrete on the basis of where and how it is produced, together with its method of application, since these have different requirements and properties.

The Steel Reinforced concrete is the concrete made with the hydraulic cement, containing fine, coarse aggregate and discontinuous fiber or concrete incorporating relatively short, discrete and discontinuous fibers.

1.1 GEOPOLYMER CONCRETE

Geo-polymer concrete is a type of inorganic polymer composite, which has recently emerged as a prospective binding material based on novel utilization of engineering materials. It has the potential to form a substantial element an environmentally sustainable construction industry by replacing/supplementing the conventional concretes. GPC can be designed as high strength concrete with good resistance to chloride penetration, acid attack, sulphate attack, etc. The geo-polymeric concretes are commonly formed by alkali activation of industrial alumina silicate waste materials such as fly-ash (FA) and ground granulated blast furnace slag (GGBS), and have very small footprints of greenhouse gases when compared to traditional concretes. Because of possible realization of even superior chemical and mechanical properties compared to ordinary Portland cement (OPC) based concrete mixes, and higher cost effectiveness.

1.2 PREPARATION OFALKALINE SOLUTION

The NaOH solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solution can vary in different Molar. The mass of NaOH solids in a solution varies depending on the concentration of the solution. For instance, NaOH solution with a concentration of 16 Molar consists of 16x40 = 640 grams of NaOH solids per litre of water, were 40 is the molecular weight of NaOH. Note that the mass of water is the major component in both the alkaline solutions. The mass of NaOH solids was measured as 444 grams per kg of NaOH solution with a concentration of 16 Molar. Similarly, the mass of NaOH solids per kg of the solution for other concentrations was measured as 10 Molar: 314 grams, 12 Molar: 361 grams, and 14 Molar: 404 grams.

2. OBJECTIVES

1. To understand properties of geo-polymer concrete in order to use it as alternative for Ordinary Portland Cement
2. To establish the economical, technological and environmental benefits of geo-polymer binders over Ordinary Portland Cement
3. To draw conclusion on whether geo-polymer technology can provide an appropriate alternative of OPC

3. LITREATURE STUDY

1. **S. Saravanan et al, “Investigation on Compressive Strength Development of Geo-polymer Concrete Using Manufactured Sand” Science Direct Journal of Material proceeding Volume 18, 2019**

The almost issue related to excess consumption of cement is the emission of CO_2 and other greenhouse gases ultimately leading to environmental degradation. Global warming being the need of hour and which in turn has made the world’s industrialists to make efforts underway to enhance eco-friendly construction materials, conserving the rapid exhaust of natural non-renewable. A study reveals, the annual emission rate of carbonate burns in cement industries contributes around five to eight percent of the world greenhouse gas emissions and also it has become the second largest consumable next to water. Assessing the current scenario, polymer based concrete; geo-polymer concrete is a latest innovation in the construction sector and an environment friendly construction material obtained as a result of polymerization chain reaction of inorganic molecules. Also, demand for river sand has gone in great hike and ultimately become costlier and scarce in availability on account of various acts and legislations confronting illegal dredging of the same. Environmental and economy aspects are better obtained, if locally available sources can be used, which aids in minimizing the cost. In such a case the manufactured sand is an economic alternative to river sand in concrete. The ultimate objective of this thesis paper is to assess the properties of fly-ash based geo-polymer concrete by using manufactured sand as fine aggregate.

2. **Pratyush Kumar et al, "Study of Mechanical and Microstructural properties of geo-polymer concrete with GGBS and Metakaolin" Material Processiding Volume 5 2018**

Geo-polymers are a new type of artificial polymer which is developed when an alumina-silicate source is triggered or activated by the application of alkaline hydroxide and silicate solution. They have shown good mechanical properties and good resistance to chemicals, lesser shrinkage, no damage to environment and shows formidable durability. Ground granulated blast furnace slag (GGBS) is a good alumina-silicate source as it contains high amounts of alumina and silica which are necessary for the geo-polymerization reaction to take place. In this paper, three variations in terms of weight percentages of GGBS and meta-kaolin clay have been taken with 80%-20%, 50%-50% and 20%-80% respectively. A 10 M solution of sodium hydroxide with sodium silicate was used as alkaline activator solution. For practical purposes ambient curing of the geo-polymer samples has been adopted. The degree of reaction was evaluated for all the percentage variations of the geo-polymer concrete at 7 days of curing. The mechanical properties of geo-polymer concrete have been studied by compressive test, split tensile test and four point loading test. To understand the structural integrity of the casting of the geo-polymer specimens, ultrasonic pulse velocity test was performed. The study of micro-structures of geo-polymer concrete was carried out by Fourier transforms infrared spectroscopy technique.

4. MATERIALS STUDY

4.1 FINE AGGREGATE

Manufactured Sand (M – Sand) is a substitute of River sand for concrete construction. It is produced from hard granite stone by crushing. It is of cubical shape with grounded edges, washed and graded to as a construction material. It confirming to zone II of IS 383-1970.Sand is used in the work which has the particle was less than 4.75mm

4.1.1TEST FOR FINE AGGREGATE

SI.NO	PROPERTIES	M-SAND
1	Specific Gravity	2.70
2	Fineness modulus	2.9
3	Bulk density	1550.80

Table 1: Fine Aggregate test results

4.2 COARSE AGGREGATE

Aggregate which passes through 10 mm IS sieve and retained on 4.75 mm IS sieve are known as coarse aggregate. Aggregates should be properly screened and if necessary washed before use. Coarse aggregates containing flat, elongated or flaky pieces should be rejected. In this project 10mm, and 20mm aggregate are used. The grading of coarse aggregates should be as per specifications of IS 383-1970.

4.2.1 TEST FOR COARSE AGGREGATE

SL.NO	Properties	Coarse aggregate
1	Specific gravity	2.65
2	Bulk density	1570.62
3	Impact test	2.3

Table: 2: Coarse Aggregate test results

4.3 FLY ASH

Any country's economic and industrial growth depends on the availability of power. In INDIA also, coal is a major source of fuel power generation. About 60% power is produced using coal is fuel. Indian coal is having low calorific value (3000-3500 K. Cal) and very high ash content (30-45%) resulting in huge quantity of ash generated in the coal based thermal power stations. During 2005-06 about 112 million ton of ash has been generated in 125 such power stations. With the present growth in power sector, it is expected that ash generation will reach to 175 million ton per annum by 2012.

4.3.1 COMPOSITION OF FLYASH

Chemical Properties % by mass	Fly-ash MTPP
$SiO_2 + Al_2O_3 + Fe_2O_3$	90.5% Max
SiO_2	58% Max
CaO	3.6% Min
SO_3	1.8% Min
Na_2O	2% Max
LOI	2% Min
MgO	1.91% Min

Table3: composition of Flyash

5. ALKALINE LIQUIDS

Generally alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate at the room temperature. When the solution mixed together the both solution start to react i.e. (polymerisation takes place) it liberates large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent. The activators required to complete the polymerization process are typically sodium silicate (SiO_2/Na_2O) and sodium hydroxide (NaOH) solutions. The higher the NaOH content the higher the resultant compressive strength. Potassium based hydroxide solutions are able to be used instead of the NaOH solutions but are generally ignored due to the higher associated costs.

6. GEOPOLYMER MIX DESIGN

Density of GPC = 2400 kg/m^3 (assumed)

FA+CA = 77% (assumed)

Total aggregate = 77/100x2400 =1848 kg/m^3

Fine aggregate (30% of TA) = 555kg/m^3

Coarse aggregate (70% of TA) = 1293kg/m^3

Now we can say that 2400-TA = fly ash + alkaline liquids

i.e., 2400-1848 = 552 = fly ash + alkaline liquids

Assume, $\frac{\text{sodium silicate}}{\text{sodium hydroxide}} = 2.5$(from literature)

$\frac{\text{alkaline liquid}}{\text{flyash}} = 0.4$ (from literature)

Alkaline liquid = 0.4 fly ash (from above equation)

Fly ash + alkaline liquids = 552kg/m^3

=>1.4 fly ash = 552 kg/m^3

=>fly ash = 552/1.4 = 394.3 kg/m^3

Total alkaline liquid = 0.4 x 394.3 = 158kg/m^3

i.e. Na_2SiO_3 + NaOH = 158kg/m^3

Since Na_2SiO_3 = 2.5 NaOH, we can write the above equation as

2.5 NaOH + NaOH = 158kg/m^3

From which NaOH = 45.14kg/m^3

Now, W.K.T Na_2SiO_3 + NaOH =158 kg/m^3

Na_2SiO_3 = 158-45.14 = 112.85kg/m^3

6.1 VOLUME OF MATERIALS REQUIRED FOR 1m^3 OF GPC

Fine aggregate = 555 kg/m^3

Coarse aggregate = 1293 kg/m^3

Fly ash = 394.3 kg/m^3

Sodium hydroxide = 45.14 kg/m^3

Sodium silicate = 112.86 kg/m^3

Water content = 39.43 kg/m^3

Super plasticizer = 11.829 kg/m^3

6.2 PREPARATION OF ALKALINE SOLUTION

Apparatus required = 500 ml measuring PVC or glass beaker, glass stirrer, plastic tray with enough depth for water bath. The beaker is kept at the middle of the water bath and you have to hold the beaker with your hands.

Molarity used = 10 M

Size of cubes = 0.15 x 0.15 x 0.15 m

Volume of cubes = 3.374 x 10^{-3} m^3

Quantity of fine aggregate required =555 x 3.374 x 10^3 = 1.873 kg

Quantity of coarse aggregate required =1293 x 3.374 x 10^{-3} = 4.365 kg

$NaOH + Na_2SiO_3$ = (45.14+112.83) x 3.374 x 10^{-3} = 0.5332 kg/m^3

$\frac{Na2SiO3}{NaOH} = 2.5 \Rightarrow Na_2SiO_3 = 2.5\ NaOH$----------(1)

NaOH + 2.5 NaOH = 0.5332

NaOH = $\frac{0.5332}{3.5}$ = 0.152 kg

From (1), Na_2SiO_3 = 2.5 x 0.152 = 0.380 kg/m^3

First, take 100 grams of NaOH in a glass beaker and add water to it until the measurement in the glass jar shows 250 ml. this process should be done in a water bath. while adding water, mix it thoroughly using a glass rod. After mixing thoroughly, allow the beaker in the water bath for 10 to 15 minutes until it gets cool. Then, weight the content. Let us say the weight is 275 gms of NaOH solution. Therefore, to get 2170 gms of NaOH solution, we have to take (100/275) x 2170 = 789.1gms of NaOH pellets. Since tremendous heat will be generated for such quantity and also the beaker size is limited, this 789.1 gms is divided into 5 parts i.e., 157 gms. For 400 gms of NaOH, 1000 ml of water is needed. So, for 157 gms, 392.5 ml (393 ml approximately) of water is added (i.e., take 157 gms of pellets in a beaker, add water and mix it simultaneously until the reading reaches 393 in the beaker). This procedure is repeated for 5 times. After the solution is weighed, add 2.5 times sodium silicate to this solution in another plastic tray. Keep this tray 95% covered and keep it in a dark place. Use this solution after 24 hours. The next day, take fly ash, GGBS, fine aggregate, coarse aggregate thoroughly dry mix for required quantity. Then add this alkaline solution to it. Add 3% of super plasticizer to get enough workability. Add extra water 155 of fly ash + GGBS. Mix thoroughly and pour in into moulds.

Size of the cube = 0.15 x 0.15 x 0.15 m

Volume of the cube = 3.375 x 10^{-3} m^3

Quantity of fly ash = (90/100) x 394.3 = 354.87 kg/m^3

Quantity of fly ash for required volume = 354.87 x 3.375 x 10^{-3} = 1.198 kg/m^3

Quantity of GGBS = (10/100) x 394.3 = 39.43

Quantity of GGBS for required volume =39.43 x 3.375 x 10^{-3} = 0.133 kg/m^3

Quantity of extra water required = 15% of fly ash + GGBS

= (15/100) x (1.198+0.133) = 0.199 lit

Quantity of super plasticizer required = 3% of fly ash + GGBS

= (3/100) x (1.198 x 0.133) x 1000

= 39.9 ml.

7. MIX PROPORTION

7.1 MIX PROPORTION FOR CUBE

MATERIAL	1 Cube (kg)	9 Cube (kg)	15% Wastage(kg)
FA	1.873	16.857	19.386
CA	4.363	39.267	18.063(20mm) 27.094(10mm)
NaOH	0.152	1.368	1.573
Na_2SiO_3	0.380	3.420	3.933 lit
Flyash	1.198	10.782	12.399
GGBS	0.133	1.972	1.377
Extra water	0.199	1.791	2.059 lit

Table 4: Cubic mix proportion

7.2 MIX PROPORTION FOR CYLINDER

MATERIAL	1 Cylinder (kg)	3 cylinder (kg)	10% Wastage(kg)
FA	2.942	8.826	9.709
CA	6.852	20.559	9.046(20mm) 13.569(10mm)
NaOH	0.239	0.717	0.789
Na_2SiO_3	0.598	1.794	1.970 lit
Fly ash	1.881	5.643	6.207
GGBS	0.209	0.627	0.689
Extra water	0.314	0.942	1.032 lit

Table 5: cylindrical mix proportion

7.3 MIX CALCULATION FOR REPLACEMENT OF FINE AGGREGATE BY SAW DUST (CUBE)

MATERIALS	10% REPLACEMENT	15% REPLACEMENT	20% REPLACEMENT
FA	3.539kg (90%)	3.343 kg (85%)	3.146kg (80%)
CA	3.664 kg (20mm) 5.497 kg (10mm)	3.664 kg (20mm) 5.497 kg (10mm)	3.664 kg (20mm) 5.497 kg (10mm)
SAW DUST	393gms	590gms	790gms
Na_2SiO_3	610 ml	610 ml	610 ml
Fly ash	2.515 kg	2.515 kg	2.515 kg
GGBS	280gms	280gms	280gms
EXTRA WATER	0.597 ml	0.597 ml	0.597 ml
SP	13 ml	13 ml	13 ml

Table 6: Mix proportion for replaced geo-polymer concrete (cube)

7.4 MIX CALCULATION FOR REPLACEMENT OF FINE AGGREGATE BY SAW DUST (CYLINDER)

MATERIALS	10%	15%	20%
FA	7.943kg (90%)	7.943kg (85%)	7.943kg (80%)
SAW DUST	882.4gms	950gms	1200gms
CA	4.634kg(20mm) 7.490kg(10mm)	4.634kg(20mm) 7.490kg(10mm)	4.634kg(20mm) 7.490kg(10mm)
Na_2SiO_3	674ml	674ml	674ml
Fly ash	2.710kg	2.710 kg	2.710kg
GGBS	280gms	280gms	280gms
SP	15ml	15ml	15ml

Table 7: Mix proportion for replaced geo-polymer concrete (cylinder)

Fig: Casting and compression testing of specimen

8. TEST RESULTS

COMPRESSIVE STRENGTH

DAYS	10 Molarity (GP1) MPa	12 Molarity(GP2) MPa	14 Molarity (GP3) MPa	16 Molarity (GP4) MPa
7th day	31.3	34.2	30	28.6
14th day	39.2	41.66	36.44	32
28th day	43	48.9	42.9	40

Table 8: compressive strength results

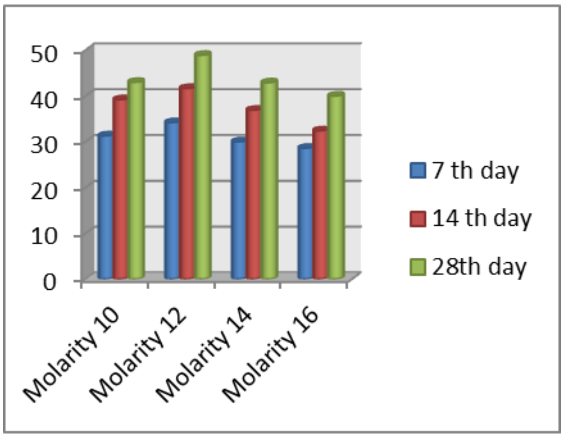

Chart 1: Variation of compressive strength

8.2 SPLIT TENSILE STRENGTH

DAYS	10 Molarity(GP1) MPa	12 Molarity(GP2) MPa	14 Molarity(GP3) MPa	16 Molarity(GP4) MPa
7th day	2.10	2.8	2.22	2
14th day	2.55	3	2.6	2.4
28th day	3	3.3	3.15	3

Table 9: split tensile strength results

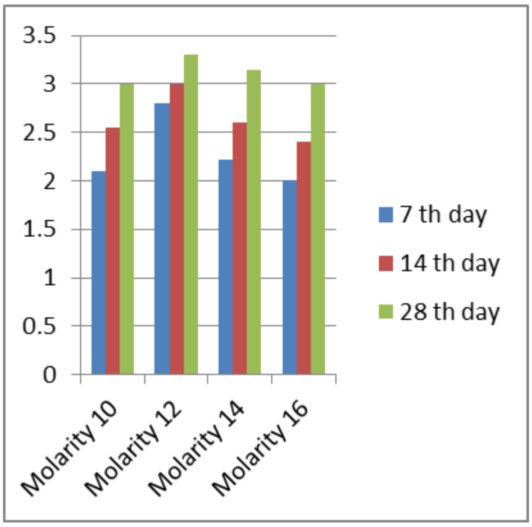

Chart 2: Variation of split tensile strength

Fig: Split Tensile Strength Test of Specimen

8.3 COMPRESSIVE STRENGTH ON REPLACED GEOPOLYMER CONCRETE

DAYS	12 Molarity(RGP 2)		
% of SD	10%	15%	20%
7th day	34.4	35.5	34
14th day	42	43.4	40.8
28th day	49	49.9	45

Table 10: compression strength of replaced geo-polymer concrete

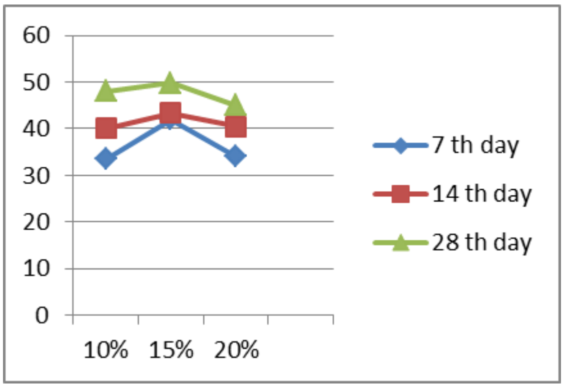

Chart 3: Variation of compression strength of replaced geo-polymer concrete

8.4 Split tensile strength of replaced geo-polymer concrete

DAYS	12 Molarity(RGP2)		
% of SD	10%	15%	20%
7th day	2.8	3	2.9
14th day	3	3.3	3
28th day	3.2	3.3	3.1

Table 11: Split tensile of replaced geo-polymer concrete

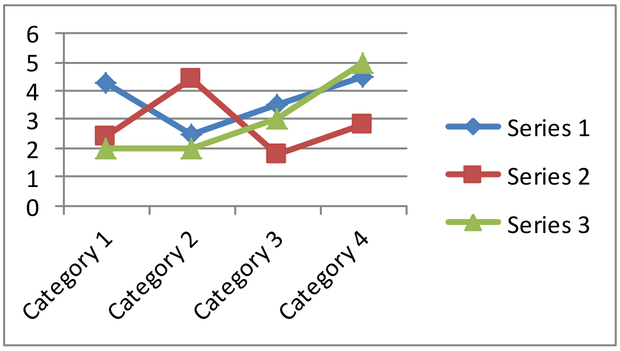

Chart 4: variation of split tensile strength on replaced geopolymer concrete

9. SUMMARY AND CONCLUSION

The researches conducted worldwide had established that it could replace ordinary cement concrete because of its advantages in many aspects particularly reduction of global warming. In this study geo-polymer mixes with different molarity of aqueous solution and different replacement level for fine aggregate by saw dust were adapted. The test results based on experiments conducted on compressive strength and tensile strength and other basic tests are discussed and presented in the project report.

From this experimental study it was found from the test results that the geo-polymer concrete RGP2 (12 M) has shown 8% increase in both compressive and split tensile strength when compared to the normal geo-polymer concrete.

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