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Experimental Investigation on Mechanical Properties of Geopolymer Concrete When River Sand Is Replaced with M-Sand

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ABSTRACT

In the modern era, global warming becomes a critical environmental issue. Each passing year, the amount of greenhouse gas emission to the atmosphere is in an increasing trend. Carbon dioxide (CO2) remains the ace greenhouse gas which cause significant influence on global warming. CO2 contributes about 82% of the total greenhouse gas emission. Cement industries are one of the major emitters of CO2. India is the world's second-largest cement producer next to China to reduce the utilization of cement in concrete. In the prospects and perspectives of waste reutilization and eco-sustainable concrete production, the feasibility of total replacement of cement with fly ash and replacement of natural river sand with M-Sand in geo-polymer concrete was investigated in this research.

Usage of this type of concrete can reduce the usage of cement and also the CO2 emission. The molarity of sodium hydroxide 14M and partial replacement of river sand with M-Sand with various percentages of 25%, 50%, 75% and 100%. A comparative study was conducted on the performance of mechanical properties of heat (600C & 800C) and ambient cured (7, 14, 28 days) geopolymer concrete. It was observed that higher compressive strength (7-, 14- and 28-days ambient curing) was attained for the eco-friendly concrete up to 50% replacement of river sand with M-Sand.

Keywords: Fly ash, M-Sand (manufactured sand), River sand, 14M.

1. INTRODUCTION

Concrete is construed as a globally preferred building material and it plays an inevitable role in the construction arena. Though concrete comprises of several ingredients, cement is considered as a key ingredient in the concrete which gives binding property. In recent years, the cement production has grown very rapidly all over the world due to the huge requirement of cement for multi-various construction purposes. Worldwide the Portland cement production increases 9% annually. India stands second in the world cement production and produces 6.9% of world's cement output. One tonne of cement production emits equal amount of CO2 to the atmosphere. Carbon dioxide is a primary greenhouse gas which contributes to global warming. Cement industries are the third largest source of CO2 emissions and they account for 8% of the total greenhouse gas emissions to the atmosphere. Greenhouse gas emission causes a serious threat to the environment (Asokan 2005; Bednarik et al. 2000). In World, nearly 12 billion tonnes of concrete are produced for construction every year. Owing to the huge requirement of concrete this quantity may increase in the forthcoming years. Over-exploitation of natural resources and unused waste industrial by-products generation causes serious jeopardy to the environment. So, an alternate technology should be used in construction which reduces the usage of cement in concrete. Geopolymer concrete is an appropriate technology to utilize the industrial by-products and also the usage of cement can be completely eliminated.

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2. LITERATURE SURVEY

During early 1940‟s due to frequent damages in Europe due to high number of fires, there was search begun to find better fire-resistant material. In this attempt alkali activated alumino-silicate materials was one of the discovery made by the scientists. In 1950‟s Glukhovsky first discovered alkali activated alumino-silicate material, however, not until the French scientist Joseph Davidovits introduce the term "geopolymer" in 1979 for his binder, this new binding material does not come into the limelight. Davidovits in 1988, for the first time, suggested the potential use of inorganic alumino-silicate binders in the construction industry.

Davidovits (1994) theorized that an alkaline liquid had the potential to react with the aluminium (Al) and silicon (Si) located in a source material of geological origin or in by-product materials such as fly ash and blast furnace slag to create binders. This reaction of alkaline liquid with aluminium and silicon is termed as polymerization process. These alumino-silicate polymers with an amorphous microstructure, which are formed in alkaline environment, are termed as geopolymers. The activation mechanism of alumino-silicate materials was proposed by Glukhovsky in 1959. This mechanism was broadly divided into three steps: (a) destruction–coagulation, (b) coagulation–condensation, and (c) condensation–crystallization.

In 1979, Davidovits proposed geopolymer chemistry concept, and the properties of this new binder material. The term poly (sialate) was also suggested by him, wherein sialate is an abbreviation form for silicon-oxo- aluminate (Davidovits 2008). The chemical structure of polysialates which exists in three different features based on silicon and aluminium proportions is shown in Figure 2.1. The poly (sialate) network consists of Si+4 and Al+3 ions in IV-fold coordination, sharing oxygen ions and ranges from amorphous to semi-crystalline (Davidovits 1989, Sakulich 2011). Poly (sialate) has an empirical formula of: Mn (-(SiO2)z –AlO2)n, wH2O, where „M‟ is the alkali element that is used; „n‟ is the degree of polymerization, „z‟ value lies in between 1and 3 depending on the chemistry of the reaction, and „w‟ depends on the extent of hydration reaction completed.

Hardjito and Rangan (2005), concluded that the water expels from the geopolymer matrix during the curing and further drying process. Later, water gets evaporated and leaves behind discontinuous nano-pores in the matrix. In this way the water in a geopolymer mixture, plays no role in the chemical reaction. It only serves the purpose of ensuring the workability to the mixture during handling.

3. OBJECTIVES AND METHODOLOGY

3.1 OBJECTIVES

The present work aims at evaluation of the response of ambient and heat cured geopolymer concrete in terms of its mechanical properties. The main objectives of the present project work are as follows.

- To study the compressive strength development of ambient and oven cured geopolymer concrete by replacing 25, 50, 75 and 100% river sand by M-Sand (M-SAND).
- To compare the mechanical properties of the fly ash based geopolymer concrete (GPC) cured under oven and in ambient conditions.

Fly ash samples are collected from NTPC Ramagundam, Telangana. River sand and manufactured sand were used as fine aggregate. Coarse aggregate was obtained from locally available sources. Combination of sodium hydroxide and sodium silicate solution was used as alkaline activator. In the experimental investigation, the evaluation mechanical properties include compressive strength, in direct flexural strength and split tensile strength of GPC.

3.2 METHODOLOGY

- Collect the M-Sand and sieved from IS Sieve 4.75mm to 75microns. The passed from IS Sieve 4.75mm and retained on 75microns dust was collected.
- Trail mix methodology of GPC mix design was adopted from Professor B. Vijaya Rangan [10].
- The fly-ash (class F), Locally available river sand (ZONE - II) and coarse aggregates (NMAS 20) was used for this investigation.
- The GPC, was cured with oven (600C & 800C) and ambient cured 7,14, 28days.
- The mix design for GPC mentioned below:

The test specimens of 150mmx150mmx150mm cubes are used. Conventional method is adopted instead of Hobart pa mixer however conventional method is not applicable in larger applications but here the mixture proportion is different for different cubes. The main objectives of the preliminary laboratory work were:

- To familiarize with the making of fly ash-based geopolymer concrete,
- To understand the effect of the sequence of adding the alkaline activator to the solid's constituents,
- To observe the behaviour of the fresh fly ash-based geopolymer concrete,
- To understand the basic mixture proportioning of fly ash-based geopolymer concrete.

Mixture Proportions

The main objective is to find compressive strength for GPC. Standard shape of 150mmx150mmx150mm cube taken and the density of geo-polymer concrete is assumed as 2500 Kg/m3. The rest of the calculations are done by considering the density of concrete.

- The total volume occupied by coarse aggregate is adopted as 70-80%.
- The alkaline liquid to fly ash ratio is 0.3 to 0.5
- Ratio of sodium silicate solution-to-sodium hydroxide solution, by mass, of 0.4 to 2.5. This ratio is fixed at 2.5 for all mixtures.
- Molarity of sodium hydroxide (NaOH) solution taken as 14M.
- Super plasticizer 0 – 5% of total cementitious material.

Trail Mix design Calculations for conventional

GPC Approximate calculations:

Weight of cube ⋡ (volume of cube x concrete density)

Volume of cube = 150 x 150 x 150(mm3) =0.003375m3

Weight of cube =0.003375m3 *2500kg/m3

= 8.4375kg = 8437.5 gm ≈ 8438 gm

For 1 cube Adopted :

Aggregates = 6100 (4000+2100) gm

Cementitious material = fly ash = 1450 gm

1) 14 M assumed(per 1 Lit water) NAOH molecular weight =40

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Molarity (M) = (weight / molecular weight) *(1000/volume of water) (Weight /40) * (1000/1000) = 14

Weight of NAOH = 14*40 =560 gm

2) Distilled water - 10% of Cementitious material 1450(0.1) = 145 ml

3) Super plasticiser – (0%) to (5%) weight of Cementitious material Adopted - 2%

(2/100*1450) = 29 gm ≈ 29ml

4) Alkaline liquids = fly-ash (0.3 to 0.5)

Adopted -0.480

1450*0.480 =696 ≈700 gm ≈ 700ml

5) Na2Sio3 to NAOH ratio - 2.5 (adopted) Na2Sio3 (liquid) = 500 ml = 500 gm NAOH (solid-liquid) = 200 ml = 200 gm

6) Approximately = Aggregates + Cementitious material + alkaline liquid + water + super plasticizer

6100 + 1450 + 700 + 145 + 29

8424 gm

7) After evaporation max 50% whole weight of liquid Adopted 40% loss

700+145+29 = 874ml 874*0.04 =349.6 ≈ 350ml

Final weight = 8424 - 350 =8074 gm

Finally, 8074gms ≯ 8438 gm ……….ok

Trail Mix design Calculations for fine aggregate replacing with M-Sand

The fly-ash, coarse aggregates, alkali solution, super plasticizer was kept constant for all mixes and the river sand replaced with M-Sand with 25%, 50%, 75% and 100%. For 14M NaOH : 200ml water + 112gms pellets

Replacement of M-SAND	Fly ash (gm)	Coarse aggregate (gm)	Fine aggregate (gm)	M-Sand (gm)	Alkali liquid		Super plasticizer (ml)
					NaOH (ml)	Na_2SiO_3 (ml)	
0%	1450	4000	2100	0	200	500	29
25%			1575	525			
50%			1050	1050			
75%			525	1575			
100%			0	2100			

Fig. 1: Mix Proportions for GPC with river sand replacing with M-Sand.

4. EXPERIMENTAL INVESTIGATIONS

The experimental part of the Project consists of a preliminary study for fundamental and primarily thorough a detrimental study. The former preliminary study consists of studying the strength development of Trail mix Geopolymer concrete containing M-Sand as a partially replaced material for conventional river sand. The replacement levels of river sand with M-SAND consisted of 0% (control) to 100%. The later detrimental one consists of studying the feasibility of using M-Sand based GPC with total replacement of conventional river sand. The workability, strength and Structure as the three-dimensional characteristics of concrete are considered.

4.1 MATERIALS

The constituent materials were planned for use both in the preliminary and primary investigation for the development of M-Sand geo polymer concrete are given below:

- Fly-ash (class F)
- Fine aggregate
- Coarse aggregate
- M-Sand
- Water
- Alkali solution

In the present study, one of the source materials used in making geopolymer concrete was Class F fly ash. It was collected from locally available source NTPC Ramagundam, Telangana, India.

Fig. 2: Fly ash.

The river sand is sieved using 4.75 mm sieve and the particles passing through 4.75mm sieve and retained on 75-micron sieve is defined as fine aggregate.

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Fig. 3: River sand.

The crushed rock particles having size below 4.75mm is defined as fine aggregate. It is further classified into coarse, medium and fine. The size of grains from 4.75mm to 2mm is known as coarse, 2mm to 0.425mm as medium and 0.425 mm to 0.075 mm defined as fine.

Fig. 4: M-Sand.

Aggregates are the major ingredients of concrete. It constitutes the total volume, provide a rigid skeleton structure for concrete, and act as economical space fillers. Aggregates contribute to both the weight and stiffness of concrete. Generally coarse aggregate are derived from rock. Their properties depend on the mineralogical composition of rock, the environmental exposure to which the rock has been subjected and the method of crushing employed to get different sizes. The physical, chemical and thermal properties of aggregates substantially influence the performance of concrete. The dimension between 20mm to 4.75mm termed as coarse aggregate.

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Fig. 5: Coarse aggregate.

Water is an important ingredient to make concrete. The purpose of adding water to concrete is, to distribute the cement evenly, react with cement chemically to produce calcium silicate hydrate gel and provide workable one. Small amount of water is needed to hydrate cement. Additional water is required to lubricate the mix. Excess water leads to bleeding stage ultimately creation of pores. Quantity of water is controlled by the w/c ratio. The water used must be free from oil, acid and alkali, salts and organic material. It should be potable.

Locally available M-Sand was the primary material used in this experimental work. The river sand, M-Sand and crushed stone granite coarse aggregate (college labortary) were used. Physical properties of fly ash, river sand, M-Sand , coarse aggregates were determined and were shown in Table 4.1.

Material	Property	Test result	code
Fly-ash	Specific gravity	2.19	IS: 12269-1987
	Fineness modulus	2%	
Fine Aggregate (sand)	Specific gravity	2.56	IS: 2386 (Part-I) - 1963
	Fineness modulus	2.71	
	Water absorption	1.1%	
Fine Aggregate (M-Sand)	Specific gravity	2.6	
	Fineness modulus	3.36	
	Water absorption	1%	
Coarse Aggregate	Specific gravity	2.72	IS 383 – 1987
	Maximum size	20mm	
	Fineness modulus	5.1	
	Water absorption	1.8%	

Fig. 6: Physical Properties of Materials.

S.No	Oxide	Mass (%)
1	SiO_2	91.04
2	Fe_2O_3	1.7
3	Al_2O_3	0.67
4	CaO	2.8
5	MgO	0.72
6	Na_2O	1.27
7	K_2O	1.13
8	TiO_2	0.21
9	LOI	0.46

Fig. 7: Chemical Composition of Fly Ash by XRF (mass %) SHYAM PRAKASH KOGANT.

S. No.	Oxide	Mass (%)	S. No.	Oxide	Mass (%)
1	SiO_2	58.132	16	Co	0.007
2	Al_2O_3	32.546	17	Ni	0.009
3	Fe_2O_3	4.044	18	Cu	0.012
4	CaO	1.41	19	Zn	0.013
5	Na_2O	0.17	20	Ga	0.006
6	K_2O	0.96	21	Ge	0.001
7	TiO_2	1.156	22	Rb	0.007
8	MgO	0.714	23	Sr	0.023
9	P_2O_5	0.474	24	Y	0.006
10	SO_3	0.125	25	Nb	0.004
11	Zr	0.046	26	Ba	0.035
12	Cr	0.015	27	Nd	0.021
13	Cl	0.021	28	Tl	0.001
14	Ti	1.156	29	Pb	0.008
15	Mn	0.029	30	Th	0.006

Fig. 8: Chemical composition of fly ash by XRF (mass %) Venkateswara Rao.

In the preparation of activator solution, sodium hydroxide (pellets 97-98% purity) and sodium silicate (liquid form) with specific gravity of 1.53 g/cc was used. The chemical constituents of sodium silicate solution were: Na2O -10.61%, SiO2 - 27.69% and H2O - 61.7% by mass respectively. Sodium hydroxide pellets and Sodium silicate were procured from Universal Chemical Corporation, Ramkrishna Bldg Tilak Road Abids, Hyderabad, Telangana, India. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets in tap water. In preparing NaOH solution with the required concentration, the guidelines given by Hardjito and Rangan (2005), were adopted. Process of preparing NaOH solution of particular molarity was detailed by Hardjito et al. (2005). The mass of NaOH solids in a solution depends on the concentration of the solution expressed in terms of molar,

M. For instance, NaOH solution with a concentration of 14 M consisted of 14 x 40 = 560 grams of NaOH solids per litre of the solution, where 40 is the molecular weight of NaOH.

Fig. 9: NaOH Pellets**.**

Fig. 10**:** Liquid form of Sodium hydroxide adding to Sodium silicate.

To improve the workability of the fresh geopolymer concrete, Fosroc conplast SP430 superplasticizer rebuild used.

4.2 PREPARATION OF GPC

Mixing and Casting

There were 5 mixture proportions which comprised RS100M-SAND 0, RS75M-SAND 25, RS50M-SAND 50, RS25M-SAND 75 & RS0M-SAND 100. The coarse aggregates, fly-ash, fine aggregates and M-Sand (based on the mix) mixed together uniformly about 2minutes and then freshly prepared sodium hydroxide which has molarity of 14M added to sodium silicate solution further this solution mixed with the dry material about 2minutes. Finally super plasticiser added to improve the workability. This entire mixture mixed about 3minutes for proper bonding all material. After the mixing was done, slump cone test was performed to knowing the workability of GPC. Later the cubes were casted by giving proper compaction in three layers with more than 35 blows. The specimens were allowed to dry up for 24hrs.

It was found that the fresh fly ash-based geopolymer concrete was dark in colour (due to the dark colour of the fly ash), and it was cohesive. The workability of the fresh concrete was measured by means of the conventional slump test.

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Fig. 11: Mixing of all Materials (Dry Mix).

Fig. 12: Adding Alkali Solution to the Dry Mix.

Curing

Previous works researches revealed that Geopolymer concrete gains high strength if the cube placed in hot oven or steam chambers. In this project the curing of cubes under ambient curing(7, 14, 28 days) and oven curing(600c & 800c) for 24hours was done. Curing under sun light but this is not feasible in some cases where the temperature is very low.

Fig. 13: Ambient Curing of Cubes

4.3 TESTING OF GPC

Physical Properties of Cube

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Shape and Size Test

The shape of cube should be purely square with sharp edges. Standard cube size consists length x breadth x height as 15cm x 15cm x 15cm.

Colour Test

A good concrete cube should possess uniform colour throughout its body.

Structure of Bricks

To know the structure of concrete cube, pick one cube from each mix and break it. Observe the inner portion of cube clearly. If there are any flaws, cracks or holes present on that broken face then that isn't bonded well.

Compressive Strength Test (IS 516-1989)

Compressive strength of concrete is the most important characteristic and it is an indexing property as concrete is designed to carry compressive loads. This test is conducted to determine the variation of strength of the specimens with varying ratios of coarse aggregate and reduction in fine aggregate content. Compressive strength test machine (CTM) with 2000KN capacity is used to conduct the test on cubes. After placing the cube between the plates in the CTM, load is applied until the crack is observed on the specimen. The load at the point of cracking is considered as failure load and it is noted. The compressive strength is calculated by

Compressive Strength ( ) = Failure load / Cross sectional area of specimen The testing of the specimen is shown in Figure 4.17.

Fig. 13: Testing of Cube Specimen.

Indirect Strength

The Sameh Yehia 2018[13] mentioned the indirect strengths from cube compressive strengths. The formula was;

indirect tensile strength = 1/10 of compressive strength (early state) indirect tensile strength = 1/5 of compressive strength (lately state) direct tensile strength = 0.85 of indirect tensile strength

shear strength = 10 to 12% of compressive strength flexural strength = 14% to 22% of compressive strength

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5. RESULTS AND DISCUSSION

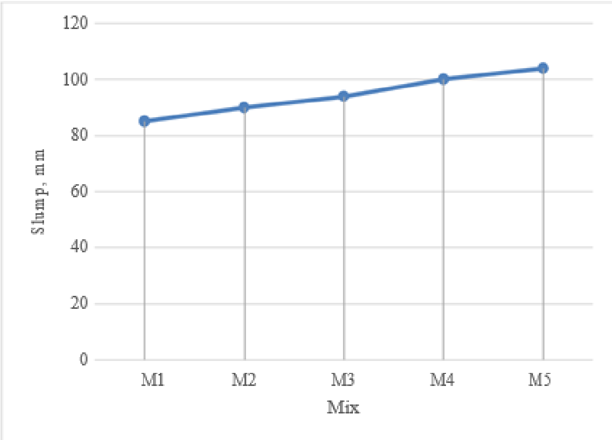

Fig. 14: Slump Test Results Graph.

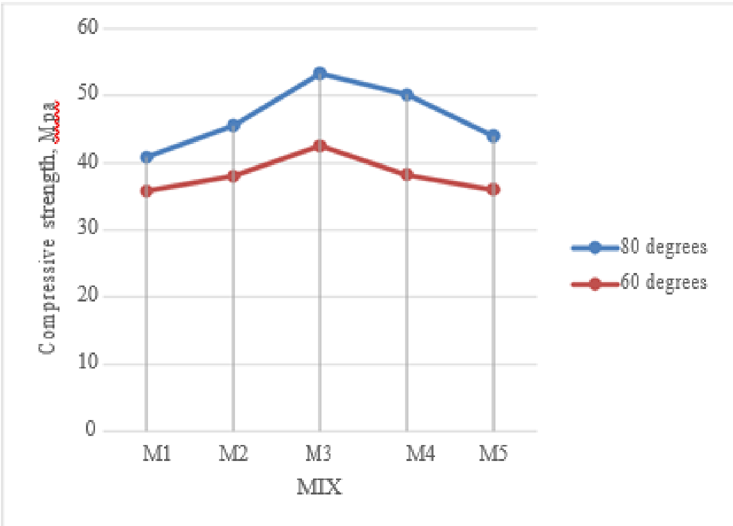

Fig. 15: Compressive Strength Test Results Graph (Oven Curing).

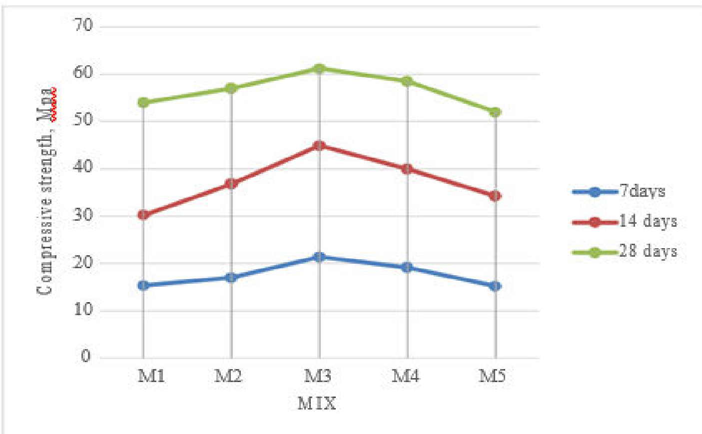

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Fig. 16: Compressive Strength Test Results (Oven Curing).

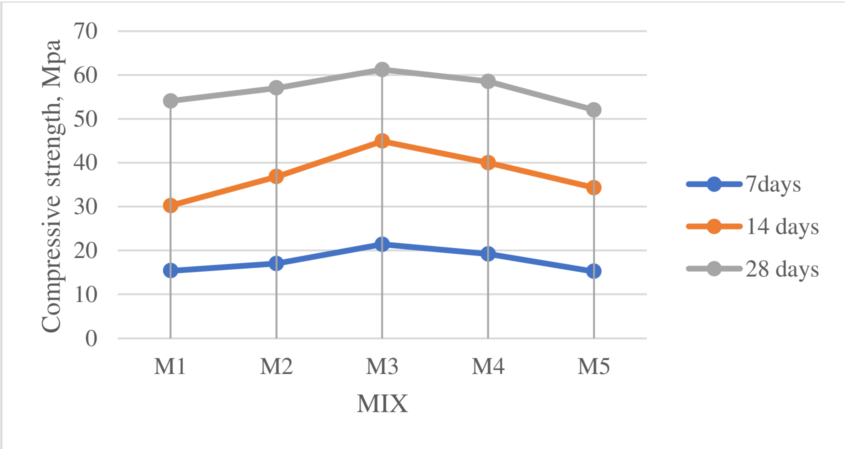

Fig. 17: Compressive strength test results graph (Ambient curing)

6. CONCLUSIONS

The aim of the present investigation is to evaluate the mechanical properties of oven and ambient cured geopolymer concrete as well as to examine their replacement of river sand with M-Sand ($RS_{100}MS_0$, $RS_{75}MS_{25}$, $RS_{50}MS_{50}$, $RS_{25}MS_{75}$ & RS_0MS_{100}). Totally 5 mixes of geopolymer concrete namely were considered. The conclusions were;

1. The grading zone is same for M-Sand and river sand but, M-SAND is coarser than sand. Sand particles are rounded and globular whereas M-Sand particles are angular, flaky and irregular in shape.
2. With the increase in M-Sand (M-SAND) content, the compressive strength of the geopolymer concrete is found to be increasing. It is evident from the results of compressive strength of geopolymer concrete at 7, 14, 28 days cured under ambient conditions and 80^0c, 60^0c at oven curing for 24 hours.
3. Compressive strengths of geopolymer concrete with 50% replacement of river sand with M-Sand at the age of 28 days respectively under ambient conditions are better than corresponding compressive strengths of fly ash based geopolymer concrete under oven curing.
4. For 28days ambient curing of geopolymer concrete, the percentage increase of compressive strength value for 25%, 50%, 75% and 100% replacement of river sand with M-Sand was 5.45%, 13.23%, 8.23% and 3.8% respectively.
5. The optimum dosage of M-Sand replacement in river sand in the geopolymer concrete was 50%.

SCOPE FOR FUTURE STUDIES

Based on the knowledge and experience gained during the experimental studies the following can be identified for further research.

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- Ambient cured geopolymer concrete composites by partial replacing of fly ash with other cementitious materials (GGBS, Marble dust, SCBA, MSWA etc.) investigated.
- Ambient cured geopolymer concrete with various molarities of NaOH can be investigated based on compressive strength.
- Influence of elevated temperatures on the ambient cured geopolymer concretes with partial replacing of fly ash with OPC can be investigated.
- Shrinkage and creep characteristics of ambient cured geopolymer concretes can be investigated.
- Durability tests on geo-polymer concrete can be investigated.
- Continuing similar research for using all types of M-Sand and waste from quarries of different rocks and origin.
- Studying the applications of M-Sand concrete for structural concrete for performance in flexure, shear, flexure and shear, torsion and for their combination.

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