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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 (CO_2) 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 CO_2. India is the world's second-largest cement producer next to China to reduce the utilisation 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 CO_2 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 (60^0C & 80^0C) 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 ecofriendly concrete up to 50% replacement of river sand with M-Sand.

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

I.INTRODUCTION

1.1 GENERAL

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 CO_2 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. Overexploitation 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.

Power generation in India predominantly depends on coal-based power plants. In thermal power plants, during the production of power, high heat is generated through the burning of coal; due to this process, enormous quantity of fly ash and bottom ash is produced as waste by-products. Yearly 131 million tonnes of fly ash are produced and only 60% of total production is used for other purposes. Remaining is unutilized. Similarly, ample quantity of bottom ash is also formed during the coal combustion. Fly ash is obtained in fine powdery form and bottom ash as coarser ash particles. Improper disposal of fly ash and bottom ash in open spaces causes environmental pollution.

Over exploitation of river sand for construction activities results in natural resources depletion. In order to maintain the sustainable development, it is necessary to find alternative material for the conventional concrete ingredients (Raijiwala & Pat 2010; Rangan 2008). Pozzolanic property of fly ash and grain size of bottom ash and M-Sand gives a greater scope to use these by-products as an alternative material for cement and river sand in concrete.

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1.2 AN OVERVIEW OF GEOPOLYMER CONCRETE

Geopolymer concrete is predominantly made by utilizing industrial by-products such as fly ash or ground granulated blast furnace slag (GGBS). Enormous quantity of fly ash is produced as a by-product from thermal power plants, proper utilization of fly ash is essential to reduce waste dumping and pollution. Due to abundant quantity, fly ash is the most preferred pozzolanic material to produce geopolymer concrete. Geopolymer concrete consist of two major constituents" viz., source material and alkaline activating solution. The source material should be rich in silicon and alumina. The alkaline activator is sodium or potassium-based liquids that are soluble alkali metals. The most common alkaline activator is sodium hydroxide (NaOH) and sodium silicate ($NaSiO_2$) (Juenger & Winnefled 2011; Rangan 2008). Schematic representation of polymerization of geopolymer concrete is shown in Figure 1.1.

Figure 1 Reaction mechanism of Geopolymerization

1.3 SOURCE MATERIALS FOR GEOPOLYMER CONCRETE

Fly Ash

In the recent decades, one of the main sectors which have high increase in the production of waste, specifically ash, are the hydro-electric power plants producing electricity to provide the requirements of the continuously increasing population. Coal ash is the material remaining the after the burning of coal at a temperature of 1500oC in suspended state and it together produces fly ash and bottom ash as by products. Bottom ash is collected in the boiler and whereas fly ash is collected in the chimney. From the year
2000, the coal ash has been shifted to "waste material" from the group of "hazardous industrial waste". It has become an accessible commodity.

Scenario of Fly Ash in India

The ash content present in Indian coal is upto 30 – 40% and its imported coals has 10 – 15% of ash content. It was found that, among the total ash generated only 80% of fly ash and 20% of bottom ash has been used and remaining has been dumped in open yard as landfills. The generation of fly ash increased year by year due to the electrical power requirement of the society. The awareness of utilizing Fly ash in construction industry is high when compared to bottom ash. In huge parts of coal ash, only the fly ash has been accepted as a basic material for production of geoplymers while the usage of bottom ash is less because of its maximum carbon content (Djwantoro Hardjito 2010; Si Hwan Kim et al. 2012; Singh & Siddique 2013).

Problems of soil mining

Sand mining from river bed is hazardous to the natural environment. By the over exploitation and use of the material and the deep pits dig in the river bed for sand mining either legally or illegally affects the ground water level and erode the banks and nearby land. In most of the rivers in the east coast of Tamil Nadu, backwater problem exists. The sand mining in rivers has made this more vulnerable by sea water intrusion. Indian Government has imposed ban on mining sand from riverbeds. Dwindling sand resources poses the environmental problem and hence government restrictions on sand quarrying resulted in scarcity of sand and significant increase in its cost. Frequently, the communities residing near the river sides are also make agitations against the sand mining.

Alternative to river sand

Concrete is a major building material which is used in construction throughout the world. It is extremely versatile and for its feasibility it is used for all types of structures. Due to rapid growth of construction activities, the consumption of concrete is increasing every year in all countries. Even bitumen roads are converted into concrete roads and new roads are laid with concrete only. This results in excessive extraction of natural aggregates. The use of these materials is being constrained by urbanization, zoning regulations, increased cost and environmental concern. Thus, it is becoming inevitable to use alternative materials for aggregates particularly fine aggregate in concrete. The use of alternative materials not only results in conservation of natural resources but also helps in maintaining good environmental conditions. Offshore sand, near shore marine sand, dune sand, M-Sand , manufactured sand (M-sand), M-Sand , ceramic waste, glass waste, bottom ash and other artificial aggregates produced from industrial waste are some of the referred other alternative sources in recent investigations. Among these, the M-Sand not being used for any applications other than road surfacing was identified as a potential source in the last decade for replacement of conventional river sand in concrete.

M – Sand

Nowadays, natural or river sands have become too scarce especially along the east coast of our Country. Further crushing process of aggregates leave sand-size material. These factors have encouraged the utilisation of 'Manufactured Sand' or M-Sand. Processing of crushed rock or aggregates to get optimum fines content is being done in the manufacture of M-Sand. Manufactured sand (M-Sand) is a substitute of river sand for concrete construction. Manufactured sand is produced from hard granite stone by crushing. The crushed sand is of cubical shape with grounded edges, washed and graded to as a construction material. The size of manufactured sand (M-Sand) is less than 4.75mm.

Environment is affected much due to the excavation of natural sand from river beds. The water head along river bed gets reduced by digging of sand. Also, the percolation of rain water in ground becomes less by this resulting in lower ground water level. Further, erosion of nearby land takes place due to lifting of sand to a greater extent. Flora & Fauna in surrounding areas get destroyed. Cost of natural sand becomes high as there is limited supply of it. As such, use of artificial sand namely M-Sand becomes essential

II.LITERATURE SURVEY

2.1 HISTORY OF GEOPOLYMERS

During early 1940‟s due to frequent damages in Europe due to high amount 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.

2.2 TERMINOLOGY AND CHEMISTRY

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 byproduct 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 aluminosilicate 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 aluminum 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.

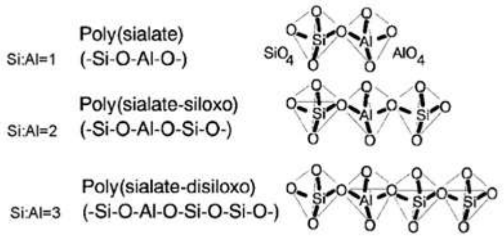

Figure 2.Structure of poly (sialate) in three different features (Davidovits 1979)

As mentioned earlier the geopolymerization, which is similar to hydration process in case of OPC, involves alumino-silicate oxides (Si2O5 and Al2O3) reacts with polysilicates, results in three dimensional polymeric bonds (Si-O-Al-O) under highly alkaline conditions. Sodium or potassium silicates which are available either in crystalline or noncrystalline forms are more commonly used as poly-silicates. (Davidovits 1991, Wallah and Rangan 2006). Significant contribution was made by the scientists Fernandez – Jimenez et al. (2009), Van Deventer et al. (2009) in developing different theories to explain the mechanism of geopolymerization and they have proposed a reaction mechanism for geopolymerization. They have presented a conceptual model which describes various sequential stages of geopolymerization as shown in Figure 2.2.

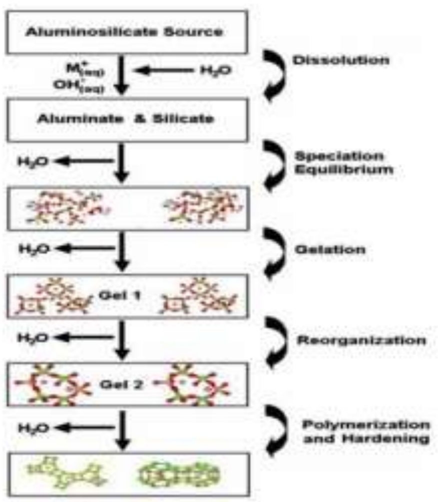

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Figure 3. Sequential stages in the process of geopolymerization (FernandezJimenez et al. 2009)

OBJECTIVE 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.

1.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).

2.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

1. 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.
2. Trail mix methodology of GPC mix design was adopted from Professor B. Vijaya Rangan [10].
3. The fly-ash (class F), Locally available river sand (ZONE - II) and coarse aggregates (NMAS 20) was used for this investigation.
4. The GPC, was cured with oven (60^0C & 80^0C) and ambient cured 7,14, 28days.
5. 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 solids 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.

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

Table 3.1 Mix Proportions for GPC with river sand replacing with M-Sand

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			

IV.EXPERIMENTAL INVESTIGATIONS

4.1 GENERAL

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 Geo-polymer 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.

4.3 PREPARATION OF GPC

Mixing and Casting

There were 5 mixture proportions which comprised RS_{100}M-SAND $_0$, RS_{75}M-SAND $_{25}$, RS_{50}M-SAND $_{50}$, RS_{25}M-SAND $_{75}$ & RS_0M-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

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the fresh concrete was measured by means of the conventional slump test.

Figure 4Slump cone test

Figure 5. Casting of cubes

Figure 6 GPC cubes

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(60^0c & 80^0c) for 24hours was done. Curing under sun light but this is not feasible in some cases where the temperature is very low.

4.4 TESTING OF GPC

Physical properties of Cube

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.

Figure 7. 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

V.RESULTS AND DISCUSSIONS

This chapter presents the results obtained from the tests (discussed in Chapter 4) conducted on geo-polymer concrete specimens and their composites. First of all, the results of mechanical properties of GPC (100% fly ash) and GPC with river sand replacing with M-Sand ($RS_{100}MS_0$, $RS_{75}MS_{25}$, $RS_{50}MS_{50}$, $RS_{25}MS_{75}$ & RS_0MS_{100}) specimens on mechanical properties and physical properties was presented.

5.1 Physical properties of Geo-polymer concrete

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Table 5.1 Physical properties of GPC cubes

Mix No.	RS – MS (%)	Shape and size test	Colour test	Structure test
M1	$RS_{100}MS_0$	For all cubes are cube shaped with sharp edges and size of 15 cm x 15 cm x 15 cm	All the cubes having the uniform colour for entire structure	There are no flaws, cracks or holes present on that broken face then that is a good quality
M2	$RS_{75}MS_{25}$			
M3	$RS_{50}MS_{50}$			
M4	$RS_{25}MS_{75}$			
M5	RS_0MS_{100}			

5.2 Fresh properties of Geo-polymer concrete

The Slump cone test results of the Geo-polymer concrete for the replacement of river sand with M-Sand by 0, 25, 50, 75 and 100 % are shown in table 5.2 and graphically represented in Fig 5.1.

Table 5.2 Slump cone test results

Mix No.	RS – MS (%)	Slump value (mm)
M1	$RS_{100}MS_0$	85
M2	$RS_{75}MS_{25}$	90
M3	$RS_{50}MS_{50}$	94
M4	$RS_{25}MS_{75}$	100
M5	RS_0MS_{100}	104

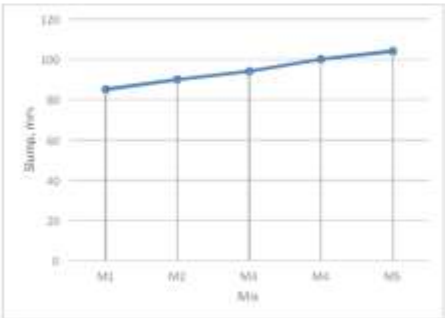

Figure 5.1 Slump test results graph

It is observed that there is increase in the workability of the Geopolymer concrete when the river sand is replaced with M-Sand . Based on the observations, all of the slump values are in the low to medium workability range.

5.3 Harden properties of Geopolymer concrete

Oven curing

The compressive strength by oven curing under 60^0c and 80^0c results of the Geopolymer concrete for the replacement of river sand with M-Sand by 0, 25, 50, 75 and 100 % are shown in table 5.3 and graphically represented in Fig 5.2.

Table 5.3 Compressive strength test results (Oven curing)

Mix No.	RS – MS (%)	Average Compressive strength (Mpa)	
		80^0c	60^0c
M1	$RS_{100}MS_0$	40.8	35.8
M2	$RS_{75}MS_{25}$	45.5	38
M3	$RS_{50}MS_{50}$	53.3	42.5
M4	$RS_{25}MS_{75}$	50.1	38.2
M5	RS_0MS_{100}	44	36

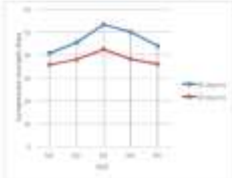

Figure 5.2 Compressive strength test results graph (Oven curing)

It is observed that there is increase in the compressive strength of the geopolymer concrete when the river sand was replaced with M-Sand . Based on the observations, all of the compressive strength values are higher for M-Sand replacement. The highest compressive strength gains for 80^0c as compare to the 60^0c. The optimum dosage of MSand replacement in river sand was 50%.

Ambient curing

The compressive strength by ambient curing under 7, 14 and 28 days results of the Geopolymer concrete for the replacement of river sand with M-Sand by 0, 25, 50, 75 and 100 % are shown in table 5.4 and graphically represented in Fig 5.3.

Table 5.4 Compressive strength test results (Ambient curing)

Mix No.	RS – MS (%)	Average Compressive strength (Mpa)		
		7days	14 days	28 days
M1	$RS_{100}MS_0$	15.39	30.23	54.05
M2	$RS_{75}MS_{25}$	17	36.8	57
M3	$RS_{50}MS_{50}$	21.4	44.9	61.2
M4	$RS_{25}MS_{75}$	19.2	40	58.5
M5	RS_0MS_{100}	15.23	34.3	52

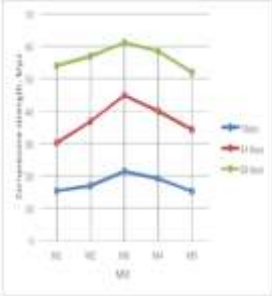

Figure 5.3 Compressive strength test results graph (Ambient curing)

It is observed that there is increase in the compressive strength of the geopolymer concrete when the river sand was replaced with M-Sand . Based on the observations, all of the compressive strength values are higher for M-Sand replacement. The optimum dosage of M-Sand replacement in river sand was 50%.

5.3.3 Comparison of curing based strength

It is observed that there is increase in the compressive strength of the geopolymer concrete when the river sand was replaced with M-Sand . Based on the comparison of oven and ambient curing, the compressive strength higher for 28days ambient curing as compare to the oven curing.

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.

Table 5.5 Compressive strength test results comparison

Mix No.	RS – MS (%)	Average Compressive strength (Mpa)		
		80^0c	60^0c	28 days
M1	$RS_{100}MS_{0}$	40.8	35.8	54.05
M2	$RS_{75}MS_{25}$	45.5	38	57
M3	$RS_{50}MS_{50}$	53.3	42.5	61.2
M4	$RS_{25}MS_{75}$	50.1	38.2	58.5
M5	$RS_{0}MS_{100}$	44	36	52

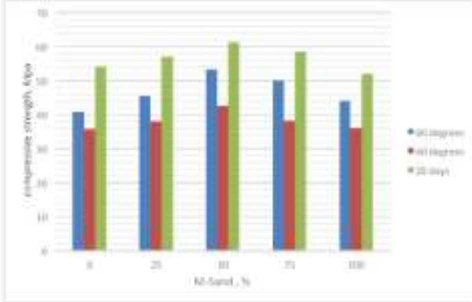

Figure 5.4 Compressive strength test results comparison graph

5.4 Indirect strength of Geopolymer concrete

Table 5.6 Indirect strength from compressive strength

Mix No.	RS – MS (%)	Strength (Mpa)				
		28 days ambient cured cube compressive strength	Indirect Tensile strength	Direct tensile strength	Shear strength	Flexural strength
M1	$RS_{100}MS_{0}$	54.05	5.405	4.324	6.48	5.146
M2	$RS_{75}MS_{25}$	57	5.7	4.56	6.84	5.28
M3	$RS_{50}MS_{50}$	61.2	6.12	4.896	7.344	5.47
M4	$RS_{25}MS_{75}$	58.5	5.85	4.68	7.02	5.354
M5	$RS_{0}MS_{100}$	52	5.2	4.16	6.24	5.047

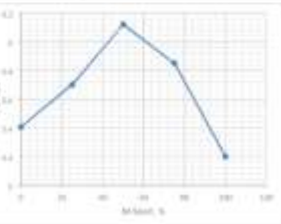

Figure 5.5 Indirect tensile strength test result graph

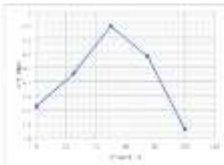

Figure 5.6 Direct tensile strength test results graph

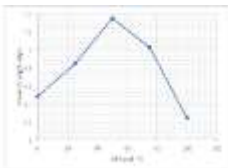

Figure 5.7 Shear strength test results graph

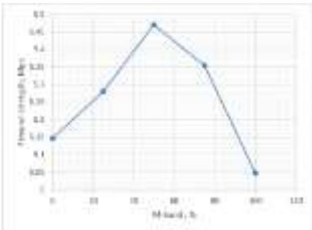

Figure 5.8 Flexural strength test results graph

VI.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.

- 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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