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Study on Mechanical Properties of Fly Ash and Metakaolin Based Geopolymer Concrete Using M-Sand as Replacement for Fine Aggregate

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Abstract: ***Geo polymer concrete is the developing concrete technology to minimize the emission of CO_2. Conventional concrete with the cement leads to hydration process which tends to emit CO_2. But in Geo polymer concrete, polymerization process takes place instead of hydration which reduces CO_2. Substitute of cement Class-F fly ash (90%) and Metakaolin (10%) are used. The Geo polymer concrete is activated by activator solution (Sodium Silicate and Sodium Hydroxide) to perform the setting process. M30 grade of concrete is adopted for this work. Due to the scarcity of the natural sand various materials like quarry dust, siliceous stone powder, copper slag is used. But M-sand attains more strength than others, easily available and economically cheaper in price. So, we adopt the manufactured sand as the replacement of river sand in the ratio of 0%, 25%, 50%, 75% and 100% in Geopolymer concrete. In conventional concrete two mixes are adopted one with M-sand and another with River sand as fine aggregate.***

The following strength tests are performed to test the Conventional concrete and Geo polymer concrete — Compressive Strength Test, Flexural Strength Test and Split-Tensile Strength Test. The curing process are done by ambient curing for 24 hrs at 80^o C and sunlight curing for 7 & 28 days. From the observation, the results obtained from the work for the M-sand replaced mixes are recorded, validated and compared with a conventional concrete.

Keywords: Geo polymer, Polymerization, Activator solution, Class-F fly ash, Metakaolin, M- sand.

I. INTRODUCTION

Geo polymer concrete is an environmentally friendly concrete and an alternate for Ordinary Portland cement (OPC). This helps in minimizing the emission of high amount of CO_2. Geo polymer is named by Daidovits in 1978. It is made from wastage of materials like Fly ash (Rich in Silica and Alumina), Metakaolin, GGBS (Ground Granulated Blast-furnace Slag), etc. In Geo polymer concrete, it takes place polymerization process is activated by the activator solution. To provide the alkalinity Sodium hydroxide and Sodium Silicates are used.

The application of Geo polymer concrete is same as cement concrete. However, it isn't popular and not used in wide areas. World first building is constructed using the Geo polymer concrete by the Queensland Global Change institute (GCI) at Australia.

The chemical ingredients used that may be dangerous and so it requires some safety measures. In concrete, the volume occupied by the sand is 37%. Natural sand is excavated from the river banks and it contains high percentage of organic materials, chlorides, sulphates, silt and clay, consequently it affects the durability, strength of the structure. Excavating excess of river sand is hazardous to environment.

Due to the scarcity of river sand to fulfill the requirement of fine aggregate, some alternative materials must be found. The easiest and economical of getting substitute for natural sand is known as Manufactured sand, which is made from the crushed stones of desired grade, size and free from impurities. We had an idea to replace the natural sand by manufactured sand of various ratios in Geo polymer concrete.

The research signifies the technology of making Geo polymer concrete using Fly ash (Class -F), Metakaolin as a binding material and M-sand is partially replaced in the ratio of 0%, 25%, 50%, 75%, 100%. In conventional concrete, M-sand and River sand are used as fine aggregate in two mixes. The curing process is done by both the oven curing and the sunlight curing for the Geo polymer Concrete. The laboratory tests for assessing the strength properties are performed and the results are validated.

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II. MATERIALS USED

A. *Cement*

Ordinary Portland cement of 43 Grade conforming to IS: 12269-1987 and the specific gravity of cement was found to be 3.15.

Table 1 Properties of Cement

Sl. No.	Property	Value
1.	Specific Gravity	3.1
2.	Fineness Modulus	4%
3.	Normal Consistency	32%
4.	Initial Setting Time	30 mins
5.	Final Setting Time	590 mins

B. *FLY Ash*

Class- F fly ash is rich in carbon and low in calcium. To produce the cementitious compounds, the glassy silica and alumina of Fly ash (Class- F) requires a bonding agent. Alternatively, adding the activator solutions such as Sodium Silicate and Sodium Hydroxide to a Class F fly ash can form a Geo polymer. Fly ash is collected from Thermal power plant at Mettur in Salem district, Tamil nadu, India conforming to IS: 3812 -1981. Specific gravity of fly ash (Class- F) 2.00 to 2.05. Fly ash (Class F) contains [10] SiO_2 – 38.8, Al_2O_3- 14.70, Fe_2O_3- 19.48, CaO- 18.10, MgO- 3.30, SO_3- 1.50. The specific gravity of used Fly ash (Class F – Mettur) is 2.5

C. *Metakaolin*

Metakaolin is the anhydrous calcined form of the clay mineral (kaolinite). It is calcinated by the professionals, under the controlled conditions for creating an amorphous aluminosilicate. The material contains [10] SiO_2 – 31, Al_2O_3- 53.5, Fe_2O_3- 6.58, CaO- 1.1, MgO- 0.12. The specific gravity of used Metakaolin is 2.6

D. *Fine Aggregate*

River sand is used as conventional fine aggregate, Due to the high demand and Environmental restrictions river sand is banned to excavate from the river banks. We need to move on towards an alternate for river sand is manufactured sand. Materials were collected from local availability in Puducherry, India. In M-sand particle sizes are lesser than 4.75mm. Fine aggregate properties conforming to IS: 383-1970 was used.

Table 2 Properties of River Sand

Sl. No.	Properties	Value
1.	Grading of Sand	Zone II as per IS 383
2.	Specific Gravity	2.78
3.	Water Absorption (%)	0.65
4.	Fineness Modulus	3.9

Table 3 Properties of M- Sand

Sl. No.	Properties	Values
1.	Specific Gravity	2.5
2.	Water Absorption (%)	1
3.	Fineness Modulus	3.2

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E. Coarse Aggregate

The Size of aggregate is 20mm and angular in nature. The Coarse aggregate are collected from local availability in Puducherry. Coarse aggregate properties conforming to IS: 383-1970 was used.

Table 4 Properties of Coarse Aggregate

Sl. No.	Properties	Values
1.	Specific Gravity	2.9
2.	Water Absorption (%)	0.5
3.	Fineness Modulus	7.84

F. Activator Solution

In Alkaline activators, the combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions are used for the activation of fly ash-based concrete. The strength of concrete is increased with the increase of concentration in fly ash-based Geo polymer concrete. Increase in concentration of sodium hydroxide solution concerning Molarity (M) makes the concrete to brittle. So, the concentration of NaOH was maintained at 14 M while the concentration of sodium silicate solution contains Na_2O of 16.37%, SiO_2 of 34.35% and H_2O of 49.72% is used as the activator solution.

G. Water

The water cement ratio adopted for conventional concrete is 0.45. Workability of concrete is measured by slump cone test during concreting.

H. Degree Of Curing

By referring the journals, during ambient curing the highest strength attained in 80^o C for 24 hrs curing period.

I. Mix Design

The mix design has gone according to IS: 10262-2009. The proportions adopted for M30 Grade concrete is 1: 2.4: 1.3 with the w/c ratio of 0.45 and cement content of 456 kg. A total of 7 mix designs are adopted. First two mix done as conventional concrete. First mix done is by using cement and River Sand than second mix is done by cement and M-sand. Rest of five mix designs are adopted as Geo polymer concrete of different M-sand ratios i.e. 0%, 25%, 50%,75%,100%. And the molarity of alkaline solution is 14 M were used.

III. EXPERIMENTAL INVESTIGATION

The0 workability of conventional and Geo polymer concrete is determined by using slump cone test. The slump value attained for conventional concrete is 90 mm. And for Geo polymer concrete for different ratios is 60-75 mm. The Moulds such as 9 cubes (150 mm x 150 mm x150 mm), 3 prisms (150 mm x 150 mm x 700 mm) and 3 cylinders (150 mm diameter and 300 mm height) are cleaned to remove the impurities in the mould and oil is applied inside the mould to avoid the sticking of concrete. The mould was filled with three layers, and each layer is tamped by the rod (16 mm diameter). Then specimens are allowed to cured for 24 hrs. And then 4 cubes were cured in ambient curing for 24 hrs at 80^0 C for Geo polymer concrete. And 6 cubes, 3prisms, 3 cylinders were cure for 7 and 28 days in sunlight curing for Geo polymer concrete. And for the conventional concrete 3 cubes, 3 prisms, 3 cylinders were cure for 7 and 28 days in water curing. The casting and curing of specimens are shown in the table. Compressive strength, split tensile strength and flexural strength of M30 grade concrete is determined by conducting the tests according to IS:526- 1959. The results were tabulated below.

A. Compressive Strength Test

All cubes were tested to find the compressive strength of both conventional and Geo polymer concrete by using Compression Testing Machine (CTM). For the Conventional concrete (Water curing) and Geo polymer concrete (Sunlight curing & Oven curing), the compressive strength of cube was tested at 7 days and 28 days in accordance with IS : 516 -1959. And for the Geopolymer concrete with oven curing is tested after 24 hrs at the temperature of 80^o C. The values obtained during the testing of specimen is recorded and shown in the below table.

Compressive Strength, $f_{ck} = P/A$

Where, P = Load in N.

A = Area of cube Specimen in mm^2.

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Table 5 Compressive Strength Test

MIX	MIX PROPORTION (90% FA + 10% MK + AS) OVEN CURING	COMPRESSIVE STRENGTH (80^{o} C FOR 24 hrs) (N/mm^2)
GPC-1	0% M.S+ 100% R.S	37.88
GPC-2	25% M.S+ 75% R.S	38.50
GPC-3	50% M.S+ 50% R.S	40.23
GPC-4	75% M.S+ 25% R.S	42.58
GPC-5	100% M.S+ 0% R.S	45.12

Table 6 Compressive Strength Test

SL.NO.	MIX PROPORTION	COMPRESSIVE STRENGTH (N/mm^2)	
		7 DAYS	28 DAYS
	WATER CURING		
CC-1	Conventional Concrete with R.S	21.11	37.7
CC-2	Conventional Concrete with M.S	23.20	39.20
	(90% FA + 10% MK + AS) SUNLIGHT CURING		
GPC-1	0% M.S+ 100% R.S	23.85	36.26
GPC-2	25% M.S+ 75% R.S	23.89	36.66
GPC-3	50% M.S+ 50% R.S	24.78	37.98
GPC-4	75% M.S+ 25% R.S	25.90	38.82
GPC-5	100% M.S+ 0% R.S	27.20	40.30

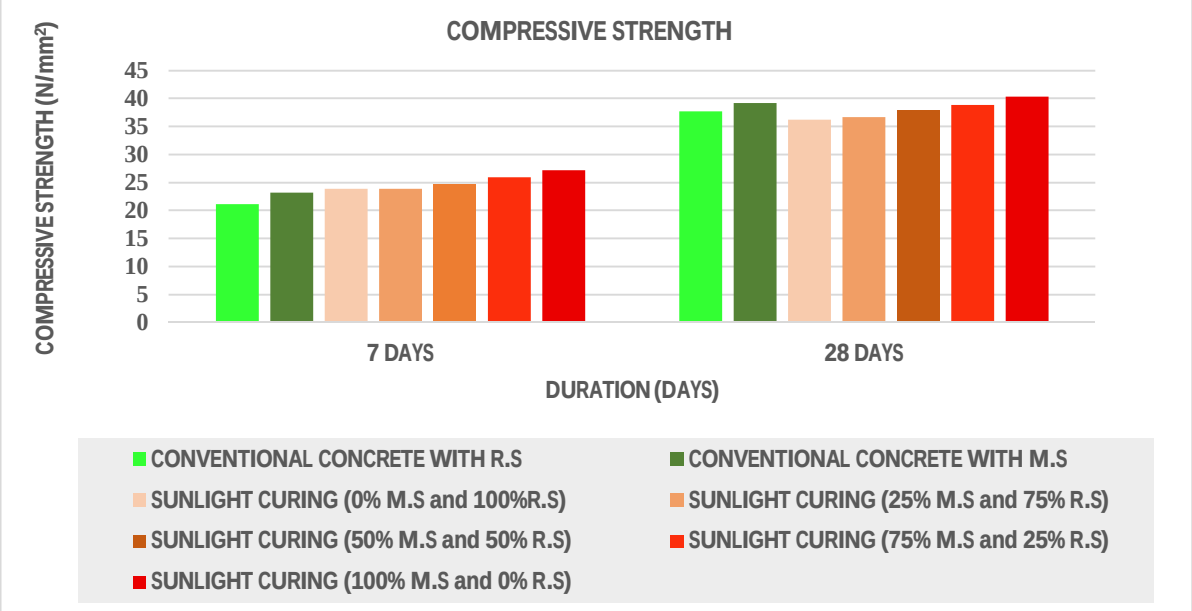


Fig. 1 Compressive Strength Test for 7 & 28 Days

From the graph Fig. 1, shows the comparison of compressive strength between both conventional concrete and with Geopolymer concrete using sunlight curing at the age of 7 and 28 days. The compressive strength of Geopolymer concrete is gradually increased with increasing the percentage of M-sand. The highest strength attained at 100% replacement of River sand by M-sand using sunlight curing.

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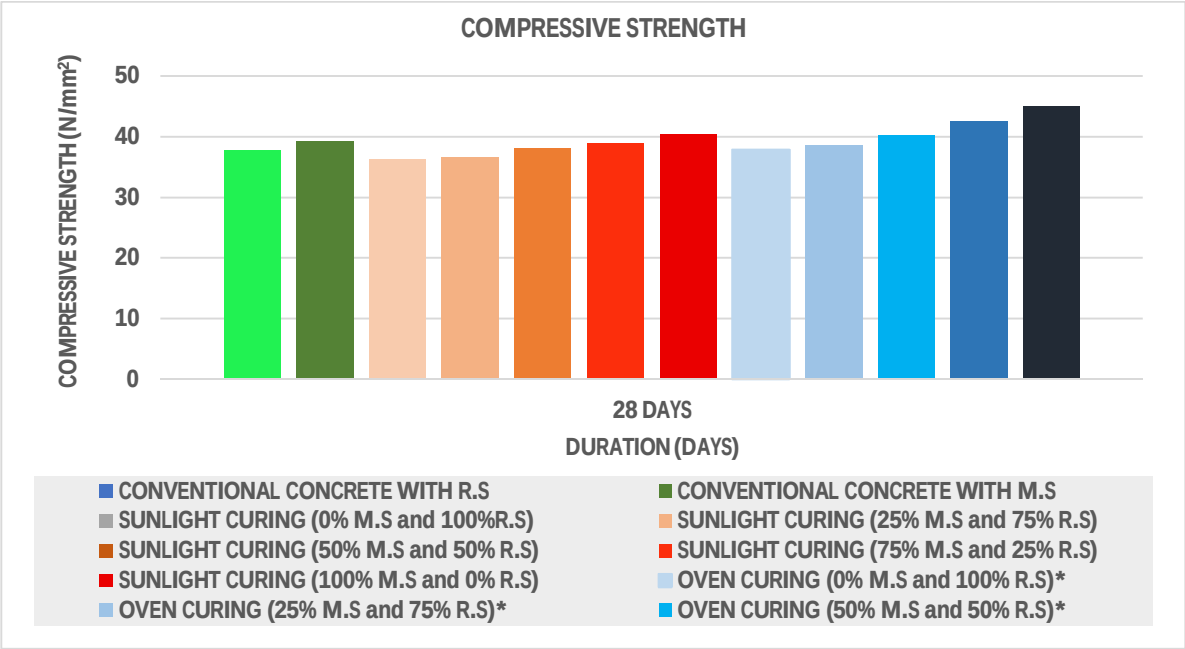


Fig. 2 Compressive Strength Test

* - Oven Drying at 80° C for 24 Hrs.

From the graph Fig. 2 shows the compressive strength of conventional concrete of 28 days curing is compacted with the geopolymer concrete of sunlight curing at the age of 28 days and of oven curing at 80° C for 24 hrs. The compressive strength of conventional concrete with M-sand is slightly higher than the conventional concrete with River sand. When comparing conventional concrete with Geopolymer concrete of various mix proportions using oven and sunlight curing, the highest compressive strength attained in 100% replacement of River sand by M-sand using oven curing. The compressive strength of geopolymer concrete using sunlight curing is slightly lower than oven curing but higher than the compressive strength of conventional concrete.

B. Flexural Strength

The flexural strength test is conducted to find the values of flexural strength. The test is conducted for M30 Grade concrete after 28 days of casting in accordance with IS : 516- 1959.

Flexural strength, $f_r = PL/bd^2$

Where, P = maximum load applied to the specimen in kN

L = length of the span on which the specimen was supported in mm

b = measured width of the specimen in mm

d = measured depth of the specimen at the point of failure in mm.

Table 7 Split Tensile Strength Test

SL.NO.	MIX PROPORTION	FLEXURAL STRENGTH (N/mm^2) (28 Days)
	WATER CURING	
CC-1	Conventional Concrete with R.S	4.04
CC-2	Conventional concrete with M.S	4.20
	(90% FA + 10% MK+ AS) SUNLIGHT CURING	
GPC-1	0% M.S+ 100% R.S	4.22
GPC-2	25% M.S+ 75% R.S	4.30
GPC-3	50% M.S+ 50% R.S	4.41
GPC-4	75% M.S+ 25% R.S	4.50
GPC-5	100% M.S+ 0% R.S	4.72

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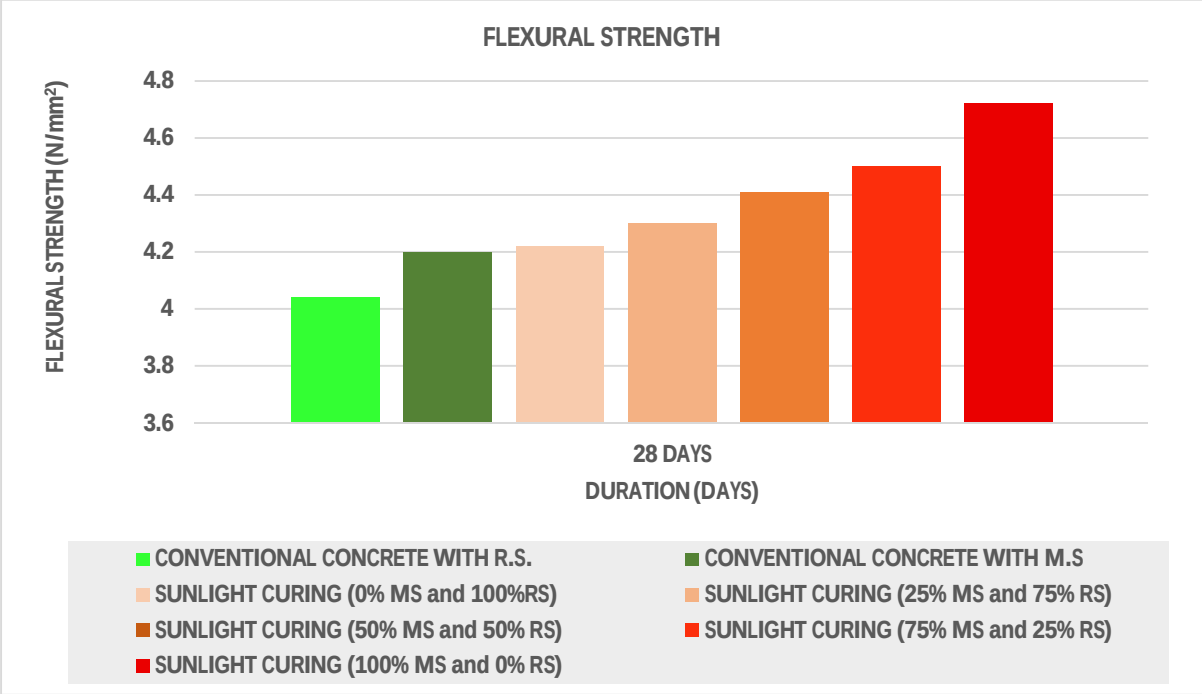


Fig. 3 Flexural Strength Test

From the above graph Fig. 3, the Flexural strength of both conventional and geopolymer concrete using sunlight curing of 28 days curing period. The maximum flexural strength obtained with 100% replacement of River sand by M-sand which is greater than the conventional concrete at the age of 28 days.

C. Split tensile test

The test was carried out to obtain the split tensile strength of M30 Grade concrete. The split tensile test is conducted after 28 days of casting in accordance with IS: 5816-1999and the values recorded are given in the below table.

Split tensile strength, $f_t = 2P / \Pi D L$

Where, P = Compressive load on the cylinder (kN)

L = Length of cylinder (kN)

D = Diameter of cylinder (kN)

Table 8 Split Tensile Strength Test

SL.NO.	MIX PROPORTION	SPLIT TENSILE STRENGTH (N/mm^2) (28 Days)
	WATER CURING	
CC-1	Conventional Concrete with R.S	2.30
CC-2	Conventional Concrete with M.S	2.5
	(90% FA + 10% MK + AS) SUNLIGHT CURING	
GPC-1	0% M.S+ 100% R.S	2.52
GPC-2	25% M.S+ 75% R.S	2.65
GPC-3	50% M.S+ 50% R.S	2.83
GPC-4	75% M.S+ 25% R.S	2.94
GPC-5	100%M.S+ 0% R.S	3.12

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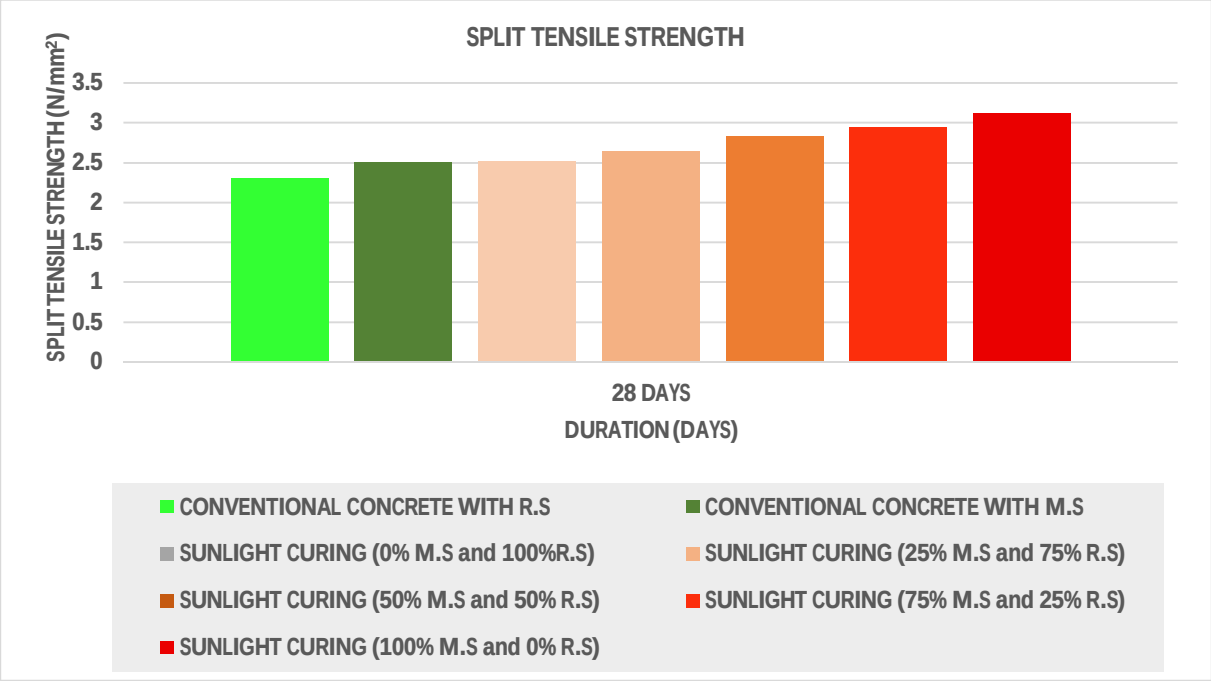


Fig. 4 Split Tensile Strength Test

From the graph Fig. 4, it can be seen that the split tensile strengths of the mixes increased with increase in the percentage of M-sand. The graph Fig. 4, shows the split tensile strength of both conventional concrete with geopolymer concrete with various mix proportions using sunlight curing at the age of 28 days. The Maximum strength obtained at the 100% replacement of River sand by M-sand. The split tensile strength of Geopolymer concrete at 0% M.S and 100% River sand in sunlight curing is slightly equal to the strength of conventional concrete with M-sand.

IV. CONCLUSION

In this project we studied about the Mechanical properties of Geopolymer concrete using M-sand in different proportions for the conventional River Sand. From the experimental investigation the following conclusion are drawn.

A. It is observed that the Compressive strength, Flexural strength and Split tensile strength is gradually increased with increasing the percentage of M-sand in Geopolymer concrete.

B. From the above experimental results, it is proved that in Geopolymer concrete M-sand can be used as a partial or complete replacement of fine aggregate.

1) The result shows the Compressive Strength, Flexural Strength and Split Tensile Strength for Conventional concrete with River sand at the age of 28 days is 37.7 N/mm^2, 4.04 N/mm^2 and 2.30 N/mm^2.

2) The result shows the Compressive Strength, Flexural Strength and Split Tensile Strength for Conventional concrete with M-sand at the age of 28 days is 39.20 N/mm^2, 4.20 N/mm^2 and 2.50 N/mm^2.

3) By using Oven Curing the Compressive Strength for Geopolymer concrete with M-sand of 0%, 25%, 50%, 75% and 100% at the age of 28 days is 37.88 N/mm^2, 38.50 N/mm^2, 40.23 N/mm^2, 42.58 N/mm^2, 45.12 N/mm^2

4) By using Sunlight Curing the Compressive Strength for Geopolymer concrete with M-sand of 0%, 25%, 50%, 75% and 100% at the age of 28 days is 36.26 N/mm^2, 36.66 N/mm^2, 37.98 N/mm^2, 38.82 N/mm^2 and 40.30 N/mm^2.

5) The result shows the Split Tensile Strength at the age of 28 days using sunlight curing for Geopolymer concrete with M-sand of 0%, 25%, 50%, 75% and 100% is 2.52 N/mm^2, 2.65 N/mm^2, 2.83 N/mm^2, 2.94 N/mm^2 and 3.12 N/mm^2.

6) The result shows the Flexural Strength at the age of 28 days using sunlight curing for Geopolymer concrete with M-sand of 0%, 25%, 50%, 75% and 100% is 4.22 N/mm^2, 4.30 N/mm^2, 4.41 N/mm^2, 4.50 N/mm^2 and 4.72 N/mm^2.

C. The Maximum strength attained in the compressive strength is 45.12 N/mm^2 in oven Curing and 40.30 N/mm^2 in Sunlight curing at the age of 28 days for the mix proportion of 100% M-sand in Geopolymer concrete.

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D. The Maximum strength attained in the Flexural strength is 4.72 N/mm^2 and Split tensile strength is 3.12 in sunlight curing at the age of 28 days for the mix proportion of 100% M-sand in Geopolymer concrete.

E. The optimum percentage replacement of M-sand in Geopolymer concrete is found to be 100% and this mix seems to be better in all aspects than the conventional concrete.

F. Adding to that, the Oven Curing of cubes produced better strength than those of Sunlight Curing and the Conventional Concrete with water curing.

1) Future Works

a) This Project has experimented only the Mechanical Properties of the Geo polymer concrete. So, we can go for the durability tests of the same.

b) The replacement of the Fly ash in this Project is 90%. Further this can be extended up to 100% of Fly ash in GPC.

c) The Molarity of the Activator Solution in this Project is 14M, so this can be extended by using different molarities.

d) The curing temperature adopted in this Project is 80° C for 24 hours duration. In future this can be studied by varying the curing temperature and also the duration of curing.

2) Abbreviations

a) CC - Conventional Concrete

b) GPC- Geopolymer Concrete

c) M.S - Manufactured Sand

d) R.S - River Sand

e) FA - Fly ash

f) MK - Metakaolin

g) AS - Activator Solution

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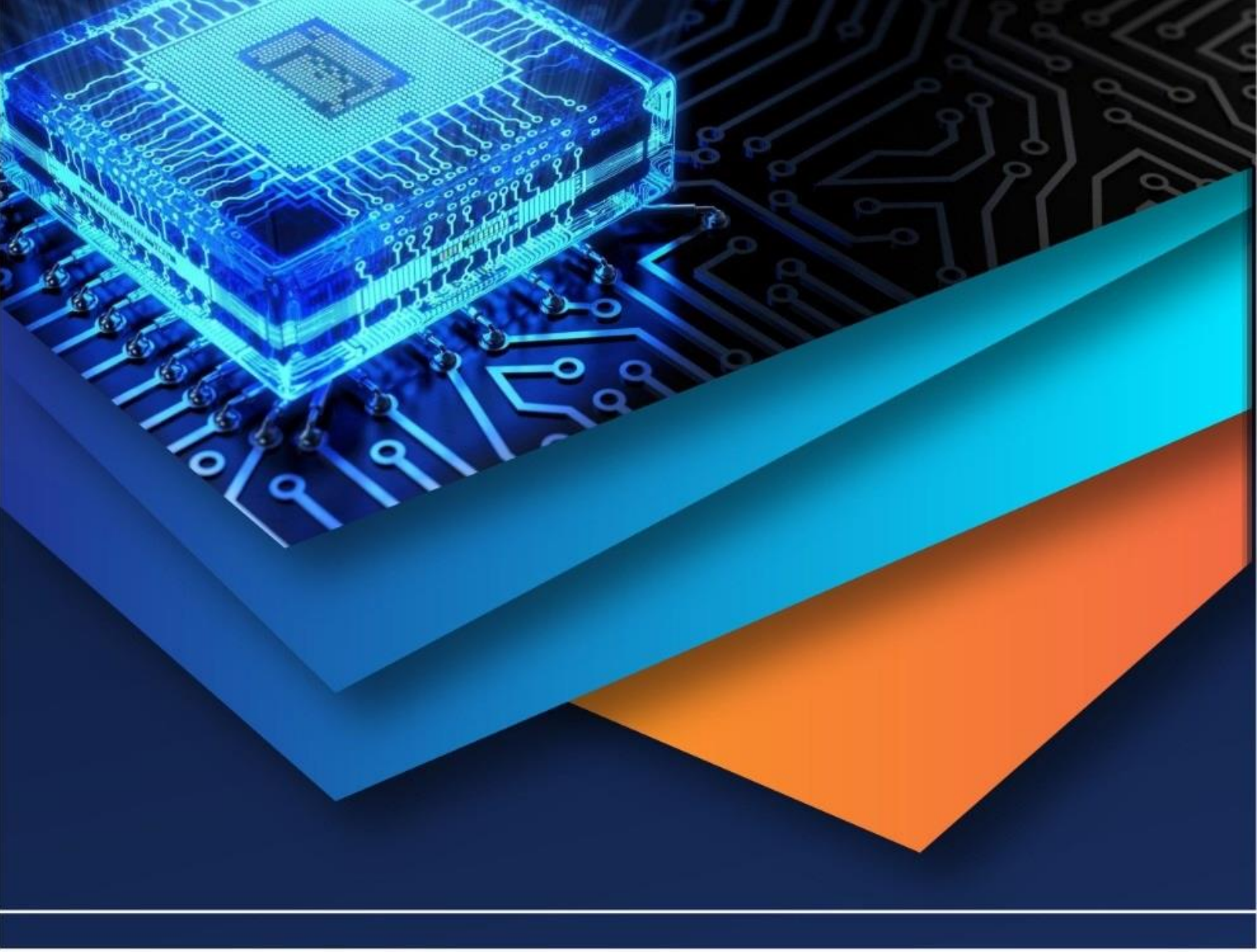
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