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Properties of Geopolymer concrete with two fly ashes of different sources with their varying chemical composition

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Abstract – *Civil engineers wants to modify the properties of the conventional concrete for there more satisfactory performance, so Geopolymer concrete is an innovative and environmental friendly construction material and an alternative soultion over portland cement concrete. Concrete is a widely used material,which requires large amout of OPC (Ordinary Portland Cement) and OPC produces large amount of carbon di oxide,which pollutes the atmosphere. Hence it is very important to find out the alternate solution over it. And Geopolymer concrete is an excellent alternative over OPC because Geopolymer concrete can be produced with mixing any amout of OPC. Overall in GPC we can use the less/limited amount of OPC and now a days it is very much required to use environmental friendly construction material.*

Key Words: Geopolymer concrete, Ready Mix Concrete, Fly Ash, Strength, Ordinary Portland Cement, heat curing, ambient curing, molarity.

1. INTRODUCTION

The name Geopolymer was given by French professor Mr. Davidovits in the year 1978. It is very necessary to reduce the waste generation from the industries and factories, and hence Geopolymer cement concrete is formed by utilizing the maximum amount of wastes generated from the different sources and waste materials like fly ash, ground granulated blast furnace slag. Fly ash is the waste product generated from the thermal power plants and similarly ground granulated blast furnace slag is the waste material which is generated from the steel plant. Hence by using these waste materials in Geopolymer cement concrete reduces the pollution from the environment and also reduces the emission of carbon to the atmosphere. Geopolymer concrete is inorganic polymer composition which are formed by reaction of alkali activation of aluminosilicate waste materials which are fly Ash and GGBS. Very important part of the project is that Geopolymer do not forms calcium silicates hydrates to attain the structural strength. In this project fly ash plays an important role, and in this two fly ashes are used which are taken from the different sources with their different chemical compositions form Tamilnadu, one fly ash is taken from Mettur thermal power plant and another fly ash is taken from Tuticorin thermal power plant Tamilnadu.

1.1 Main ingredients of Geopolymer concrete

- Fly Ash- A byproduct of thermal power plant.
- GGBS- Ground Granulated Blast Furnace Slag, it is a byproduct of steel plant.
- Fine aggregate and coarse aggregates are required to form the concrete mix.
- Catalytic Solution- Alkaline activator solution.

1.2 Materials Required

- Fly Ash – In this, Class F dry fly ash conforming to IS 3812-2003 obtained from Mettur and Tuticorin thermal power stations of Tamilnadu is used. In Geopolymer concrete, fly ash plays a very important role. Fly Ash which is going to be used should have low calcium content so that the rate of polymerization (Polymerization is a process of reacting monomer molecule to form polymer chains) should be fast.

  In this project work, two types of Fly ashes are taken with their different chemical compositions, described below in table,

Table-1:

Oxides	Mettur fly ash	Tuticorin Fly ash	Requirements as per IS 3812-2003
SiO_2	59.93%	63.24%	SiO2>35% total- >70%
Al_2O_3	19.66%	17.35%	SiO2>35% total- >70%
Fe_2O_3	2.82%	2.63%	SiO2>35% total- >70%
CaO	3.33%	2.05%	-
Na_2O	0.34%	0.24%	<1.5%
K_2O	0.22%	0.32%	<1.5%
MgO	1.12%	0.96%	<5%
LOI	1.56%	0.95%	<12%

- Fine Aggregates – Practically, sand is considered as fine aggregate and locally available river sand which is also termed as natural sand (Fine aggregate) having a fineness modulus of 2.75, specific gravity of 2.81 and conforming to grading zone-III as per Indian Standards IS: 383 - 1970 was used. And the bulk density of the fine aggregate (Sand) is 1693 kg/m^3.
- Coarse aggregate- Another major part of the Geopolymer concrete is covered by coarse aggregates. And in this locally available aggregates are being used but still aggregates should not be elongated/flaky. In this project crushed granite is used as a coarse aggregates and the maximum size of the coarse aggregate used as 19mm, in which the fineness modulus of 6.64 and a specific gravity of 2.73 is used.
- Sodium Hydroxide (NaOH) – Sodium Hydroxide is an Alkali and it is a highly reactive chemical. In this NaOH is being purchased from local chemical retailer shop.
- Sodium Silicate – In this project sodium silicate is used in the form of solution, which is manufactured at Madurai, at Salfa Industries which is again used for the preparation of alkaline activator. And the chemical composition of the sodium silicate solution by the manufacturer is as follows: 14.7% of Na2O, 29.4% of SiO2 and 55.9% of water by mass. It is used for making the soap solution, and it was purchased from local soap chemical retailer shop. Sodium hydroxide plays an important role for the preparation of alkaline activator. Sodium hydroxide when solids, it takes the shape/ or mould itself in the form of flakes. And in this project sodium hydroxide is used is 97% pure and manufactured at Mumbai, at Merck Specialties Private Limited.
- Super Plasticizer – This is used to achieve workability in the fresh Geopolymer concrete, and this is used in the form of liquid in brown color. Sulphonated naphthalene polymer based super plasticizer is used in this and Conplast SP 430 was used in all the mixtures. Conplast SP 430 is available in the form of a brown liquid that is instantly dispersible in water and is manufactured by Fosroc Chemicals (India) private limited, Bangalore. In this project Naphthalene based super plasticizer is used which is dark in color and easily available at local building material supplier.
- Water- Distilled water was used for the workability purpose and also for the preparation of sodium hydroxide solution.

Details of mix proportion of Geopolymer concrete;

Table-2:

Fly ash kg/m3	Fine aggregate kg/m3	Coarse aggregate kg/m3	NaOH solution kg/m3	Na2SiO3 solution kg/m3	Extra water kg/m3	SP kg/m3
394.3	554.4	1293.4	45.10	112.60	39.43	11.83

1.5 Importance of Geopolymer concrete

- It helps in the harmful waste reduction from the atmosphere.
- Geopolymer concrete is an alternative solution over conventional one because Conventional concrete generates tremendous amount of dust in the atmosphere.
- Helps in disposal of waste by utilizing fly ash and ground granulated blast furnace slag.
- Reduction in the use of cement which produces huge amount of carbon di oxide.
- It is an environmental (eco) friendly material.
- Sustainable development for better world.
- In this, conventional concrete is being replaced by Geopolymer cement concrete.
- GPCC have high strength and long life.
- GPCC have resistance to chloride penetration.
- GPCC also have resistance to chemical attack and it is capable to adjust according to the atmospheric/weather changes.

1.3 Properties of Geopolymer cement Concrete

- It has low heat of hydration as compared to conventional concrete.
- It provides excellent fire resisting property as compared to OPC based concrete.
- This concrete shows good resistance against acid attack from the atmosphere.
- This concrete makes good quality structural members.
- This concrete has less drying shrinkage.
- This material is now a day's widely used in pre casted members/units in construction field. Because this is actually an environmental friendly material for construction.
- It provides high early strength.
- There will be no chances of Alkali aggregate reaction.
- GPCC shows excellent performance over all its life time/ durability.

1.4 Applications

Geopolymer cement concrete is widely used today as a pre casted construction works (In which the connecting units of the building like beams, walls, columns etc are pre-casted), also used for the pavement construction, retaining walls, water tanks, pre casted bridge decks and pre casted pipes. Like this Geopolymer cement concrete having lots of applications in pre casted/ fabricated works.

2. TEST'S, DISCUSSION AND RESULTS:

2.1 Slump Cone Test:

Workability of freshly prepared Geopolymer concrete mixes was measured in terms of its slump using the conventional slump cone apparatus. All the mixtures which are made for the Geopolymer concrete were generally cohesive and shiny in appearance due to the presence of sodium silicate. Even though the measured slump values are more than 150mm, all the mixtures were generally stiff and the workability was poor. By testing, it has being observed that **Geopolymer concrete prepared by using fly ash from Tuticorin thermal power station has better workability than the Geopolymer concrete prepared from Mettur fly ash**. Workability of Geopolymer concrete decreases as the concentration of NaOH in the alkaline activator solution increases irrespective of the source of fly ash. This may be due to the reason that increasing the concentration of NaOH the total solid content in the mixture thereby reducing the water content

Graph:

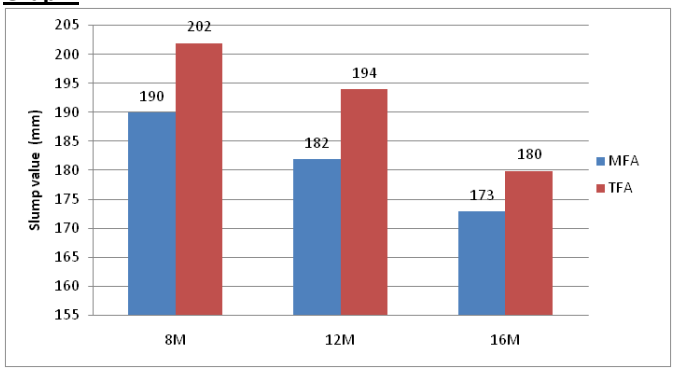

Chart-1: Effect of concentration of NaOH on workability

2.2 Compressive strength test:

For the evaluation of compressive strength, all the cube specimens were subjected to compressive load in a digital compression testing machine (UTM) with a loading capacity of 2000 KN. Specimens were placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom. The load was applied without shock and increased continuously at a rate of approximately 14 N/mm^2/min until the specimen breaks down. And the maximum load is recorded.

In this part, compressive strength is calculated by using different sources of fly ashes from Tamilnadu by using same concentration of NaOH. One fly ash is taken from Mettur thermal power plant and another fly ash is taken from Tuticorin thermal power plant. The effect of source of fly ash on the compressive strength of Geopolymer concrete is discussed in terms of **compressive strength index.**

The compressive strength index is the ratio between the compressive strength of Geopolymer concrete prepared by using Mettur fly ash and the compressive strength of Geopolymer concrete prepared from Tuticorin fly ash for the same concentration of NaOH.

Before subjected to the test, weight of each specimen was recorded and density of each specimen was calculated by dividing the weight of the specimen by its volume. Specimens were placed in the machine in such a manner that the load shall be applied to opposite sides of the cubes as cast, that is, not to the top and bottom of cube. Test must be conducted until the specimen breaks or crack appears on the surface of the specimen.

Observations:

Compressive strength of- GPCC with MFA

Table-3:

S.N	Geopolymer cubes of Mettur fly ash	7 Days		28 Days	
		Avg. Ultimate load in KN	Avg. Compressive strength in MPa	Avg. Ultimate load in KN	Avg. Compressive strength in MPa
1	Cube I	124.70	5.54	400.70	17.81
	Cube II	362.37	16.11	434.10	19.29
2	Cube III	177.73	7.9	498.97	22.18
	Cube IV	481.87	21.42	640.93	28.49
3	Cube V	195.13	8.67	576.60	25.63
	Cube VI	489.20	21.74	654.87	29.11

Compressive strength of- GPCC with TFA

Table-4:

S.N	Geopolymer cubes of Tuticorin fly ash	7 Days		28 Days	
		Avg. Ultimate load in KN	Avg. Compressive strength in MPa	Avg. Ultimate load in KN	Avg. Compressive strength in MPa
1	Cube I	85.17	3.79	393.37	17.48
	Cube II	322.27	14.32	463.63	20.61
2	Cube III	99.57	4.43	399.77	17.48
	Cube IV	500.83	22.26	585.57	26.03
3	Cube V	125.13	5.56	443.47	19.71
	Cube VI	560.77	24.92	695.83	30.93

Compressive strength index- Ambient curing:

It has observed that the compressive strength of Geopolymer concrete prepared by using Mettur fly ash is higher than that of Geopolymer concrete prepared from Tuticorin fly ash in ambient curing at room temperature.

Graph:

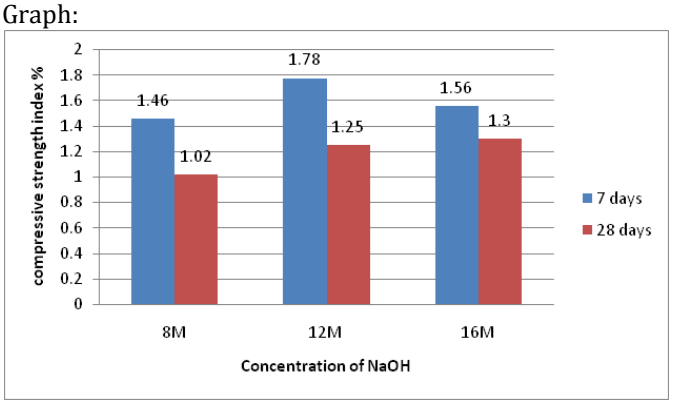

Chart-2: Compressive strength index- Ambient curing

Compressive strength index in heat curing:

In heat curing, compressive strength indicates for most of the cases is less than one which indicates that the compressive strength of Geopolymer concrete prepared by using **Tuticorin fly ash is greater than that of Geopolymer concrete prepared by using Mettur fly ash** in heat curing

Graph**:**

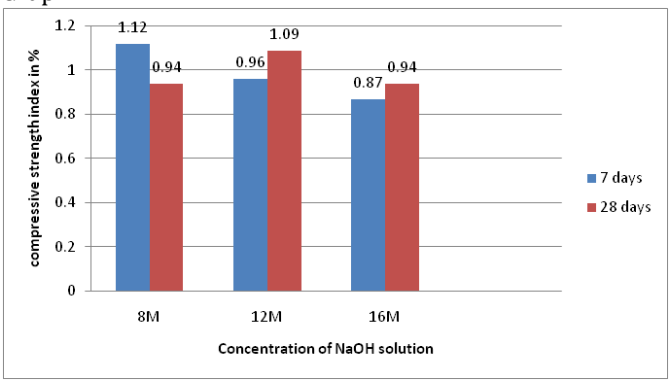

Chart-3: Compressive strength index- Heat curing

Gain in Compressive strength:

After performing the compressive strength test in all the cubes made up of Mettur fly ash and Tuticorin fly ash we have got the several test results, which is shown in a chart given below and chart no 5, chart no 6 showing the comparative results between GPCC made with MFA and TFA and it is observed that **TFA based GPCC gives higher compressive strength as compared to MFA based GPCC**.

Gain in compressive strength in Geopolymer concrete, due to heat curing in both Mettur fly ash and Tuticorin fly ash at the same concentration of NaOH solution in show below in graph.

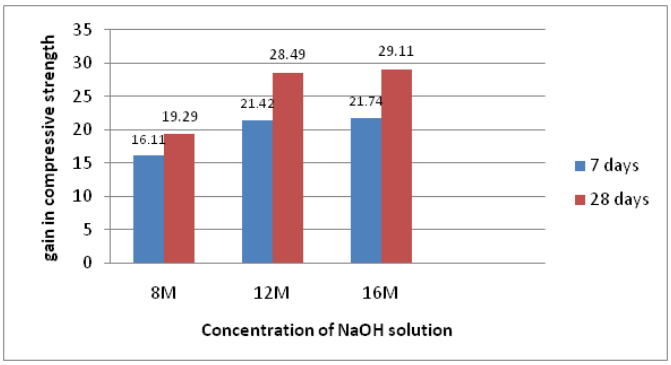

Chart-4: Effect of Heat curing- Mettur fly ash.

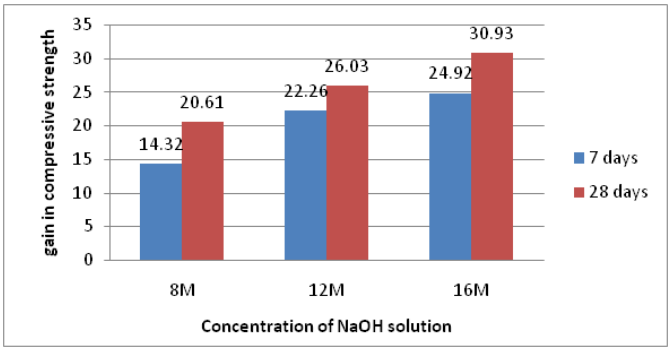

Chart-5: Effect of heat curing- Tuticorin fly ash.

2.3 Flexural strength test:

Flexural strength of Geopolymer concrete was determined using prism specimens by subjecting them to two point bending in Universal Testing Machine (UTM) having a capacity of 1000 KN. The load was applied without shock and increased continuously at a rate of 1800 N/min until the specimen failed. The maximum load applied to the specimen was recorded and the flexural strength of the specimen was calculated. The effect of various factors such as the source of fly ash, the concentration of NaOH solution and the curing temperature on the flexural strength of Geopolymer concrete has been investigated and presented test results of flexural strength are presented in Table below,

Table-5:

S.N	Geopolymer cubes of Mettur fly ash	28 Days	
		Avg. Ultimate load in KN	Avg. Flexural strength in MPa
1	Beam I	10.00	4.00
	Beam II	11.70	4.67
2	Beam III	12.50	5.00
	Beam IV	13.50	5.40
3	Beam V	15.00	6.00
	Beam VI	19.20	7.67

Table-6:

S.N	Geopolymer cubes of Tuticorin fly ash	28 Days	
		Avg. Ultimate load in KN	Avg. Flexural strength in MPa
1	Beam I	7.7	3.07
	Beam II	9.7	3.87
2	Beam III	11.00	4.40
	Beam IV	12.20	4.87
3	Beam V	14.00	5.60
	Beam VI	17.00	6.80

The effect of source of fly ash on the flexural strength of Geopolymer concrete is discussed in terms of **flexural strength index.** Flexural strength index is the ratio between the flexural strength of Geopolymer concrete prepared by using Mettur fly ash and the flexural strength of Geopolymer concrete prepared by using Tuticorin fly ash for the same concentration of NaOH.

Flexural strength index Graph:

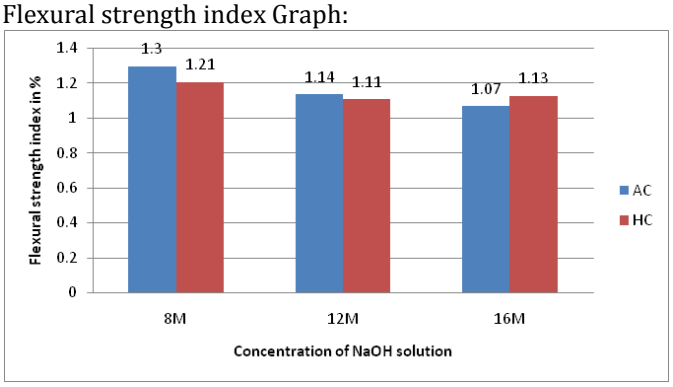

Chart-6: Flexural strength index in %

According to our test results it has being observed that the **flexural strength of Geopolymer concrete prepared by using Tuticorin fly ash is greater** than that of Geopolymer concrete prepared by using Mettur fly ash in heat curing. Comparison between Geopolymer concrete made by Mettur fly ash and Tuticorin fly ash at the same concentration of NaOH is shown below in graph, at heat curing. It shows the gain in flexural strength.

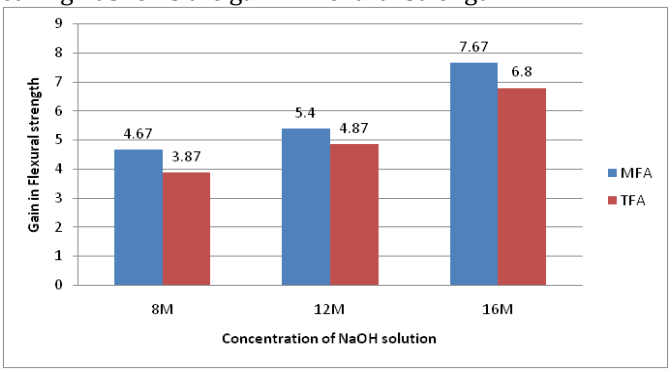

Chart-7: Gain in Flexural strength due to heat curing.

2.4 Split tensile strength test:

Split tensile strength was evaluated as per the test procedure given in Indian Standards IS.5816. In order to evaluate the splitting tensile strength of Geopolymer concrete, all the cylinder specimens were subjected to split tensile strength test in a 2000 kN digital compression testing machine.

The load was applied without shock and increased continuously at a nominal rate within the range of 1.2 N/(mm2/min) to 2.4 N/(mm2/min) until the specimen failed or cracks forms on the surface of the cylinder . The maximum load applied to the specimen was recorded.

After the tests performed on the Geopolymer concrete cubes following results are obtained, in this Geopolymer concrete is made up of Mettur fly ash and in this average ultimate load in KN and average split tensile strength in MPa is obtained which are mentioned in the table below.

Table-7:

S.N	Geopolymer cubes of Mettur fly ash	7 Days		28 Days	
		Avg. Ultimate load in KN	Avg. Split tensile strength in MPa	Avg. Ultimate load in KN	Avg. Split tensile strength in MPa
1	Cube I	14.33	0.20	68.43	0.97
	Cube II	63.60	0.90	88.10	1.25
2	Cube III	18.93	0.27	82.47	1.17
	Cube IV	76.70	1.09	94.13	1.33
3	Cube V	24.63	0.35	97.20	1.38
	Cube VI	102.73	1.45	107.57	1.52

Table-8:

S.N	Geopolymer cubes of Tuticorin fly ash	7 Days		28 Days	
		Avg. Ultimate load in KN	Avg. Split tensile strength in MPa	Avg. Ultimate load in KN	Avg. Split tensile strength in MPa
1	Cube I	8.30	0.12	57.23	0.81
	Cube II	52.77	0.75	65.97	0.93
2	Cube III	14.80	0.21	65.67	0.93
	Cube IV	72.53	1.03	101.67	1.44
3	Cube V	24.00	0.34	83.47	1.18
	Cube VI	100.10	1.42	172.20	2.44

Now In this part, Split tensile strength is calculated by using different sources of fly ashes from Tamilnadu by using same concentration of NaOH. The effect of different sources of fly ash on the split tensile strength of Geopolymer

concrete is discussed in terms of **split tensile strength index.**

Graph:

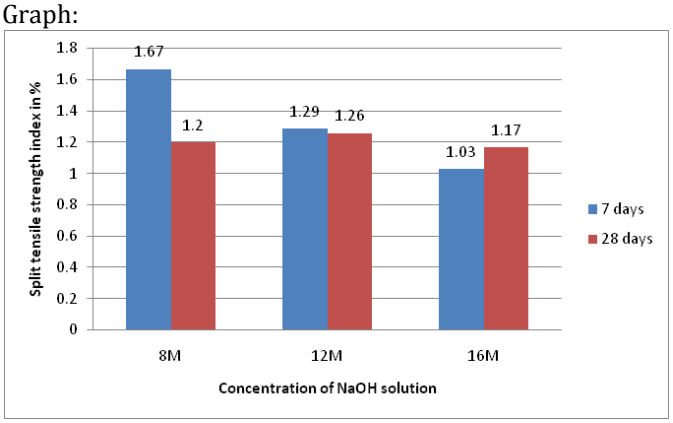

Chart-8: Split tensile strength index- ambient curing

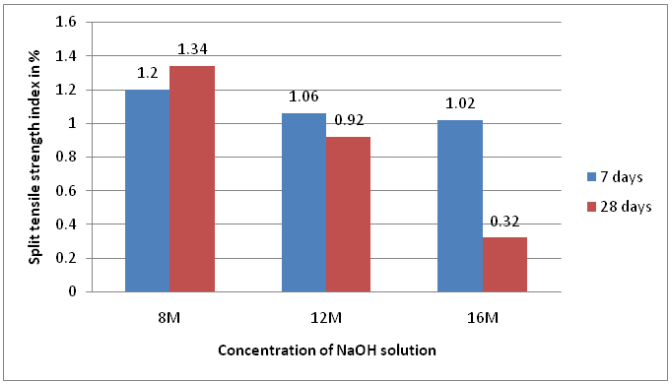

Chart-9: Split tensile strength index- heat curing

Now, gain in the split tensile strength of Geopolymer concrete made up of Mettur fly ash and Tuticorin fly ash is shown in the form of graph below, at the same concentration of NaOH with heat curing,

It has been observed that from the test results, **split tensile strength of Geopolymer concrete increases** as the concentration of NaOH solution increases for all the cases.

Graph:

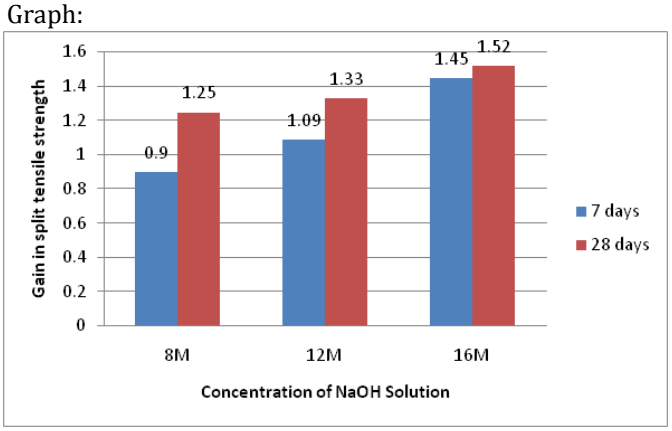

Chart-10: Effects on heat curing- Mettur fly ash

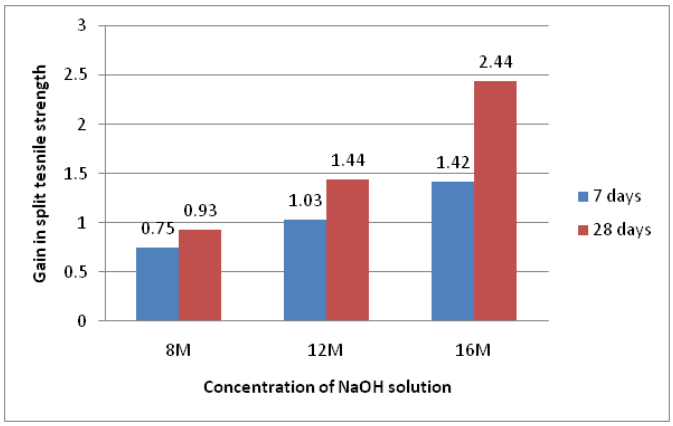

Chart-11: Effects on heat curing- Tuticorin fly ash

From the above data (graph) it has been observed that Geopolymer cement concrete prepared from the Tuticorin fly ash gains more split tensile strength at 28 days as compared to the Geopolymer cement concrete made up of Mettur fly ash at 28 days and at the same concentration of NaOH solution.

3. CONCLUSIONS

- Geopolymer concrete prepared by using fly ash obtained from Tuticorin thermal power station has better workability than the Geopolymer concrete prepared from Mettur based fly ash.
- Workability of Geopolymer concrete decreases as the concentration of sodium hydroxide in the alkaline activator solution increases.
- The average density values of Geopolymer concrete ranges from 2316 m3 to 2405 kg/m3 which was found approximately closer to that of ordinary Portland cement concrete.
- Compressive strength of Mettur fly ash Geopolymer concrete is higher than that of Tuticorin fly ash based Geopolymer concrete in ambient curing at room temperature.
- Compressive strength of Geopolymer concrete increases as the concentration of NaOH solution increases. This is applicable for all the curing temperatures, age of concrete and sources of fly ash.
- Heat curing resulted in an enhancement of compressive strength and split tensile strength at early ages only. The effect of heat curing on the increase in compressive strength and split tensile strength is not much significant after 7 days.
- Rate of increase in compressive strength and split tensile strength with respect to the age of concrete is more significant in case of ambient curing at room temperature in comparison with heat curing at 60oC
- Split tensile strength and flexural strength is higher in case of Mettur fly ash based Geopolymer concrete

for the same concentration of NaOH solution and at identical curing temperature.

- At last it is concluded that Geopolymer concrete based with Tuticorin fly ash gives better strength and performance as compared to the Geopolymer concrete based with Mettur fly ash.

4. DRAWBACKS OF GEOPOLYMER CONCRETE

- Geopolymer concrete takes more time to set/ gain strength, as compared to the conventional concrete.
- Cubes made with Geopolymer concrete takes minimum 3 days to set without leaving any nail impression over the cubes.
- This is considered as a drawback of Geopolymer concrete, this is observed on both the concrete cubes made of Mettur and Tuticorin fly ashes.
- To work with Geopolymer concrete, actually its delays the project because it takes lots of time to set which is practically not convenient.
- To make Geopolymer concrete extra ingredients are required like alkaline activator, NaOH solution etc which are not required for conventional concrete.
- To make Geopolymer concrete extra care is required for the preparation of concrete mix, and skilled labors are required.

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