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EXPERIMENTAL INVESTIGATION OF CONCRETE BY USING ALKALI ACTIVATED ALUMINO SILICATES

[1]J. Janet Kamalini, [2]Dr. R. Ilangovan
[1]Research Scholar,Department of Civil Engineering, [2]Professor,Department of civil Engineering
[1]Veerammal Engineering College,[2]University College of Engineering,Panruti

ABSTRACT—Concrete is the one of the world's most durable, reliable, and versatile construction material. Concrete is the most used construction material, which required large quantity of Portland cement. Production of Ordinary Portland cement is second to the automobile manufacturing which is the major generator of carbon di oxide, which pollutes the atmosphere. In addition to that, large amount of energy was also consumed during the production of cement. Hence, it is very essential to find an alternative material to the existing most expensive, most resource consuming Portland cement. Geopolymer concrete utilizes a material such as fly ash as a binding material in place of cement. Fly ash, a byproduct of coal obtained from the thermal power plant is available in plenty worldwide. Fly ash, rich in silica and alumina react with alkaline solution and produce Alumino silicate gel that act as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Since geopolymer concrete is the emerging field, an attempt has been made to find out the behavior of geopolymer concrete along with the use of quarry dust as fine aggregate. In this project complete replacement of cement by ASTM Class F fly ash and complete replacement of sand by quarry dust were used in M20 concrete mix. The parameter considered in our project is the molarity of alkaline activator. The grade chosen for the experiment is M20. The mixes were designed for molarity of 10M, 12M, and 16M. The alkaline solution used is the combination of sodium hydroxide and sodium silicate solution with the ratio of 2.50. Concrete specimens were prepared and cured under ambient temperature. The experimental program involves casting of geopolymer concrete specimens and testing the same at different ages of compressive strength.

1.INTRODUCTION

1.1 GENERAL

Concrete is the world's most versatile, durable and reliable construction material. Next to water, concrete is the most used material, which required large quantities of Portland cement. Ordinary Portland cement production is the second only to the automobile as the major generator of carbon di oxide, which polluted the atmosphere. In addition to that large amount energy was also consumed for the cement production.

Cement is conventionally used as the primary binder to produce concrete. The environmental problems associated with the production of cement are well known. The amount of the carbon dioxide released during the manufacture of cement due to the calcinations of limestone and combustion of fossil fuel is in the order of one ton for every ton of cement produced. Hence, it is imminent to find an alternative material to the existing most expensive most resource consuming Portland cement. OPC is extensively used in India due to its low cost and easy availability. Concrete can be cast in almost any desired shape, and once hardened, can become a structural (load bearing) element. On the other hand it also affects environment, also there are many negative influence of OPC. For example emissions of airborne pollution in the form of gases, noise, dust and vibration when operating machinery and during blasting in quarries, devouring of large quantities of fuel during manufacture and release of CO_2 from the raw materials during manufacture. Due to all such reasons it is needed to be replaced by non-producing CO_2 materials such as fly ash and various supplementary materials.

Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules. Another major problem of the environment is to dispose off the fly ash, a hazardous waste material, which is produced by thermal power plant by combustion of coal in power generation processes. Around 120 million tonnes of fly ash get assembled every year at the thermal power stations in India. It becomes a serious problem due to inadequacy of land disposal.

The geopolymer concrete aims at utilizing the maximum amount of fly ash and reduce CO_2 emission in atmosphere by avoiding use of cement to making concrete. Fly ash is rich in silica and alumina reacted with alkaline solution produced aluminosilicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement. The amorphous to crystalline reaction products resulting from the synthesis of alkali alumino silicates and high alkaline solutions is generically known as "geo-polymer".

Since there is demand for natural sand, the fine aggregate shall be replaced by quarry dust. Quarry dust is having high content of silica, which may increase the compressive strength of geopolymer concrete by the complete replacement of quarry dust.

1.2 GEO POLYMER

The name geopolymer was formed by a French Professor Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The geo polymers depend on thermally activated natural materials like Meta kaolinite or industrial byproducts like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These Silicon and Aluminium is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder.

Professor B. VijayaRangan (2008), Curtin University, Australia, stated that, "The polymerization process involves a substantially fast chemical reaction under alkaline conditions on silicon-aluminum minerals that results in a three-dimensional polymeric chain and ring structure.

The most common alkaline liquid used in geo polymerization is a combination of sodium hydroxide or potassium hydroxide and sodium silicates or potassium silicate. The reaction of Fly Ash with an aqueous solution containing Sodium Hydroxide and Sodium Silicate in their mass ratio, results in a material with three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds.

Geopolymer, a member of the family of inorganic polymers, based on alumino silicates, has recently emerged as an attractive and novel engineering binder material alternative to Portland cement. The chemical composition of the geopolymer material is similar to zeolitic materials, but the microstructure is amorphous. Any material that contains mostly silicon (si) and aluminium (Al) in amorphous form is a possible source material for the manufacture of geopolymer.

Geopolymer is the most recently developed construction material for large scale utilization of fly ash without any cement. Geo-polymer concrete possesses excellent strength and appearance similar to conventional concrete. Research on geopolymer reveals that geopolymer exhibit excellent mechanical property, fire resistance and acid resistance.

1.3 NECESSITY OF GEOPOLYMER CONCRETE

Construction is one of the fast growing fields worldwide. As per the present world statistics, every year around 260,00,00,000 Tons of Cement is required. This quantity will be increased by 25% within a span of another 10 years. Since the Lime stone is the main source material for the ordinary Portland cement an acute shortage of limestone may come after 25 to 50 years. More over while producing one ton of cement, approximately one ton of carbon di oxide will be emitted to the atmosphere, which is a major threat for the environment. In addition to the above huge quantity of energy is also required for the production of cement. Hence it is most essential to find an alternative binder.

The Cement production generated carbon di oxide, which pollutes the atmosphere. The Thermal Industry produces a waste called fly ash which is simply dumped on the earth, occupies larges areas. The waste water from the Chemical Industries is discharged into the ground which contaminates ground water.

Natural sand is a prime material used for the preparation of concrete and also plays an important role in Mix Design. Now a day's river erosion and other environmental issues have led to the scarcity of river sand. The reduction in the sources of natural sand and the requirement for reduction in the cost of concrete production has resulted in the increased need to find new alternative materials to replace river sand so that excess river erosion is prevented and high strength concrete is obtained at lower cost. Partial or full replacement of natural sand by the other alternative materials like quarry dust. Quarry dust is a kind of waste material that is generated from the stone crushing industry. Quarry dust can be used as a fully replacement for fine aggregate in geopolymer concrete.

By producing Geopolymer Concrete all the above mentioned issues shall be solved by rearranging them.Waste Fly Ash from Thermal Industry + Waste Quarry Dust from the stone crushing industry + Waste water from Chemical Refineries = Geo polymer concrete. Since Geopolymer concrete doesn't use any cement, the production of cement shall be reduced and hence the pollution of atmosphere by the emission of carbon di oxide shall also be minimized.

1.4 ECONOMIC BENEFITS OF GEOPOLYMER CONCRETE

Low-calcium fly ash based geopolymer concrete offers several economic benefits over Portland cement concrete .The price of a ton of fly ash is only a small fraction of the price of a ton of Portland cement, Therefore, after allowing for the price of the alkaline liquids required to geopolymer concrete , the price of fly –ash-based geopolymer concrete is estimated to be about 10 to 30% less than that of Portland cement concrete. A ton of low-calcium fly ash can be utilized to manufacture approximately 2.5 m^3 of high quality, fly-ash-based geopolymer concrete and hence can earn monetary benefits through carbon-credit trade.

1.5 APPLICATION OF GEOPOLYMER CONCRETE

In the short term, there is large potential for geopolymer concrete applications for bridges, such as precast structural elements and decks as well as structural retrofits using geopolymer-fiber composites. Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials (e.g., high-alkali activating solutions) and the need for a controlled high-temperature curing environment required for many current geopolymer. Other potential near-term applications are precast pavers & slabs for paving, bricks and precast pipes.

Civil construction applications- stabilized fills, pavement materials and soil stabilization.

Building materials- bricks, blocks, tiles, pavers and light weight acoustic panels, pipes, precast concrete products and ready mix products

Mining- paste backfill, tailings dams, liners , capping media , shotcrete and acid resistant concrete

Environment/ waste management- impermeablebarriers, hazardous, radioactive and contaminated materials in a very impervious, high strength material

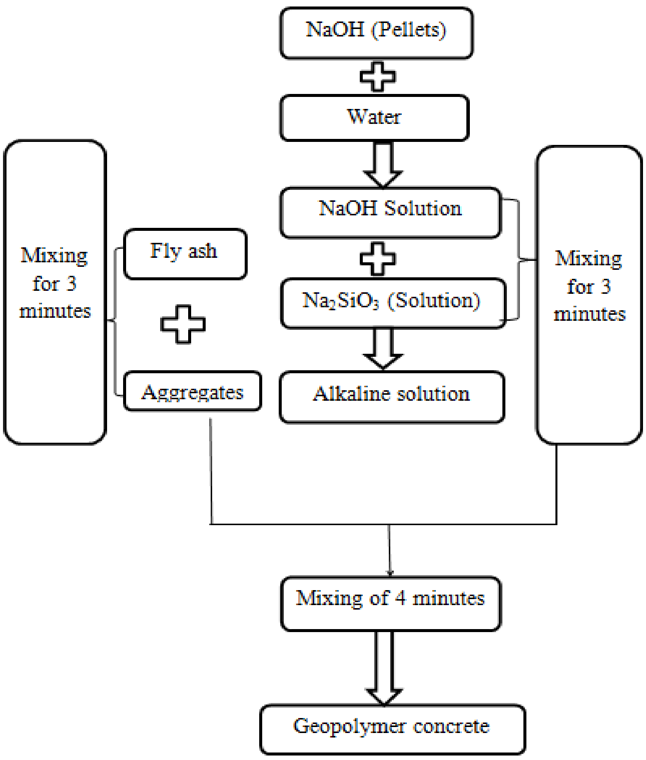
Special application-rapid set binders, high strength binders, light weight products, super flat floors, low shrinkage and acid resistant storage facilities.

II.METHODOLOGY

2.1. GENERAL

The flow diagram of the methodology indicates the step by step procedure for the complete project. The various stages are area selection, data collection, review of literature, experimental investigation and result analysis.

2.2. FLOW DIAGRAM OF THE METHODOLOGY



III.MATERIALS USED

3.1 GENERAL:

This chapter presents the detail of development of the process of making low calcium (ASTM CLASS F) fly ash based geopolymer concrete.

3.2 MATERIALS:

3.2.1 FLY ASH:

Fly ash is defined as the finely divided residue that results from the combustion of ground or powdered coal and that is transported by flue gasses from the combustion zone to the particle removal system.

Class F: Fly ash normally produced from burning anthracite or bituminous coal falls in this category. This class of fly ash exhibits pozzolanic property but rarely, if any, self hardening property. It is pozzolanic in nature (contains less than 15% lime (CaO)).Class F fly ash is available in the largest quantities. Class F is generally low in lime, usually under 15 percent. The chemical composition of the aluminosilicate precursors was determined using XRF. The chemical composition of the fly ash were determined by X- ray fluorescence (XRF) analysis . Hence we can define the fly ash as low calcium class F fly ash.

3.2.2.QUARRY DUST

A fine aggregate produced by crushing of stone or natural gravel to be used as an alternate of natural sand is called as Quarry Dust. The utilization of Quarry rock dust which can be called as manufactured sand has been accepted as building material in the industrially advanced countries of the west for the past three decades. As a result of sustained research and developmental works under-taken with respect to increasing application of this industrial waste, the level of utilization of quarry rock dust in the industrialized nations like Australia, France, Germany and UK has been reached more than 60% of its total production .The use of manufactured sand in India has not been much, when compared to some advanced countries.

Common river sand is expensive due to excessive cost of transportation from natural sources. Also large-scale depletion of these sources creates environmental problems. River sand is most commonly used fine aggregate in the production of concrete poses the problem of acute shortage in many areas. Whose continued use has started posing serious problems with respect to its availability, cost and environmental impact.

In such a situation the Quarry rock dust can be an economic alternative to the river sand. Quarry Rock Dust can be defined as residue, tailing or other non-voluble waste material after the extraction and processing of rocks to form fine particles less than 4.75mm. Usually, Quarry Rock Dust is used in large scale in the highways as a surface finishing material and also used for manufacturing of hollow blocks and lightweight concrete prefabricated Elements.

The use of Quarry dust in concrete is desirable because of benefits such as useful disposal of a byproduct, reduction of river sand consumption, and increased strength. Quarry dust has been proposed as an alternative to river sand that gives additional benefit to concrete. Quarry dust is know to increase the strength of concrete over concrete. The angular shaped quarry dust has a good inter locking that gives better binding strength and saves cement. quarry dust is totally inert material and its physical properties are similar to natural sand. quarry dust can be used as a partial or fully replacement for fine aggregate.

When examining the above qualities of fly ash and quarry it becomes apparent that if both are used together, the loss in early strength due to the gain in strength due to one may be alleviated by the gain in strength due to the other, and the loss of workability due to the one may be partially negated by the improvement in workability caused by the inclusion of the other.

In the present experimental work quarry dust was used as fine aggregate The chemical composition of the quarry dust determined by X-ray fluroscences (XRF) analysis.The chemical composition of the quarry dust in the experimental work is compared with sand.

3.2.3 ALKALINE SOLUTION

A combination of sodium silicate solution and sodium hydroxide solution was chosen as the alkaline liquid. Sodium based solution were chosen because they were cheaper than potassium based solution. The sodium hydroxide solids were commercial grades in pellets form with 97% purity.

The sodium hydroxide solution (NaOH) was prepared by dissolving the sodium hydroxide pellets in water. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. for instance NaOH solution with the concentration of 10M, 12M, and 16M consisted of 10x40=400 ,12x40=480,16x40=640 grams respectively of NaOH solids (in pellets form) per liter of the solution was taken, where 40 is the molecular weight of NaOH. Note that the mass of NaOH solids was only a fraction of the mass of the NaOH solution and water is the major component.

Sodium silicate solution (vitrosol D-A53) was used. The chemical composition range of the sodium silicate solution was Na_2O = 15.48%,SiO_2= 34.13% and water 49.61% by mass.

3.2.4 AGGREGATES

Aggregates are the important constituents of concrete. They give body to concrete reduce shrinkage and effect economy. The aggregates occupy 70 to 80 percentage of volume concrete. Without the study of the aggregates in depth and range, the study of the concrete is incomplete. Normal weight natural aggregates were chosen for our concrete.

The size of the aggregate bigger than 4.75mm is considered as coarse aggregate and aggregate whose size is 4.75mm and less is considered as fine aggregate. The aggregates texture was granular .specific gravity of the aggregates varies from 2.6 to 2.8.

Water absorption of aggregates is 0.96%. bulk density of aggregate is 2280 kg/m^3. Satisfactory concrete can be made with various aggregate grading with certain limits. One of the most important factors for producing workable concrete is good gradation of aggregates.

3.2.5. CEMENT

Cement used for this present experimental work was OPC 53 grade with following physical characteristics of specific gravity of 3.15 and fineness modulus of 3%.

3.2.6. WATER

Water is an important component of concrete. Tap water having PH value 7 was recommended in this experiment.

IV MIX DESIGN

4.1 MIXTURE PROPORTION:

Based on the limited past research on geo-polymer pastes the following ranges were selected for the constituents of the mixtures.

- Low calcium (ASTM Class F) dry fly ash as given in section 3.2.1
- Alkaline liquid as given in section 3.2.3
- Ratio of sodium hydroxide solution to sodium silicate solution, by mass of 2.5. This ratio was fixed at 2.5 for most of the mixtures because the sodium silicate solution is considerably cheaper than the sodium hydroxide solution.
- The molarity of sodium hydroxide (NaOH) solution can be in the range of 8M to 16M. It was fixed as 10M, 12M, and 16M.
- Coarse and fine aggregates, as given in section 3.2.4, of approximately 75% to 80% of the entire mixture by mass were used. This value is similar to that used in OPC concrete.
- Extra water, when added, in mass.

The following procedures were followed for preparing Geopolymer concrete.

1. Sodium hydroxide pellets were dissolved in water to get 10M, 12M and 16M
2. Sodium silicate solution was added with sodium hydroxide solution
3. Sodium hydroxide solution and sodium silicate solution were mixed together at least one day prior before adding the liquid to the dry materials.
4. All dry materials such as fly ash and aggregates were mixed in a pan for about three minutes.
5. Then the alkaline liquid was mixed with the dry mix.
6. The wet mixing was done for four minutes.

4.2 MIX DESIGN

The mix design for OPC and geopolymer concrete were carried out as per IS10262-2009. The mix proportion of concrete is 1 : 1.37: 2.91. The mix design calculation is shown in table 4.1.

Table 4.1 M20 Mix design as per IS 10262 2009

M20 CONCRETE MIX DESIGN as per IS 10262-2009					
S. NO	**GRADE DESIGN A-TION**	**M20**	**GC-20**		
			GC-10M	**GC – 12M**	**GC – 16M**
1	Type of cement	OPC 53 grade	-	-	-
2	Type of fly ash	-	Class F	Class F	Class F
3	Maximum nominal aggregate size	20mm	20mm	20mm	20mm
4	Maximum cement content	35.5 kg	-	-	-
5	Fly ash	-	33.3 kg	33.3 kg	33.3 kg
6	Maximum water cement ratio	0.45	-	-	-
7	Maximum alkaline to fly ash ratio	-	0.35	0.35	0.35
8	Workability (slump)	25mm	65 mm	50mm	35mm
9	Exposure condition	Normal	Normal	Normal	Normal
10	Degree of supervision	Good	Good	Good	Good
11	Type of aggregate	Crushed angular agg	Crushed angular agg	Crushed angular agg	Crushed angular agg

Table4.2 Test data for materials

M20 CONCRETE MIX DESIGN as per IS 10262-2009			
S.	**GRADE**	**M20**	**GC-20**

NO	DESIGN A-TION		GC-10M	GC – 12M	GC – 16M
1	Cement used	OPC 53 grade	-	-	-
2	Fly ash used	-	Class F	Class F	Class F
3	Specific gravity of cement	3.15	-	-	-
4	Specific gravity of flyash	-	2.806	2.806	2.806
5	Specific gravity of water	1.00	1.00	1.00	1.00
6	Specific gravity of 20mm coarse aggregate	2.755	2.755	2.755	2.755
7	Specific gravity of sand	2.601	-	-	-
8	Specific gravity of quarry dust	-	2.55	2.55	2.55
9	Water absorption of aggregate	0.96 %	0.96 %	0.96 %	0.96 %
10	Water absorption of sand	1.21 %	-	-	-
11	Water absorption of quarry dust	-	2.10 %	2.10 %	2.10 %

Table 4.3 Target strength for mix proportioning

M20 CONCRETE MIX DESIGN as per IS 10262-2009

S. NO	GRADE DESIGN A-TION	M20	GC-20		
			GC-10M	GC – 12M	GC – 16M
1	Target mean strength	26.6 N/mm^2	26.6 N/mm^2	26.6 N/mm^2	26.6 N/mm^2
2	Characteristic strength @ 28 days	20 N/mm^2	20 N/mm^2	20 N/mm^2	20 N/mm^2

Table 4.4 Selection of water cement ratio

M20 CONCRETE MIX DESIGN as per IS 10262-2009

S. NO	GRADE DESIGN A-TION	M20	GC-20		
			GC-10M	GC – 12M	GC – 16M
1	Maximum water cement ratio	0.5	-	-	-
2	Adopted water to cement ratio	0.45	-	-	-
3	Adopted alkaline to Fly ash Ratio	-	0.35	0.35	0.35

Table 4.5 Selection of water content

M20 CONCRETE MIX DESIGN as per IS 10262-2009

S. NO	GRADE DESIGN A-TION	M20	GC-20		
			GC-10M	GC – 12M	GC – 16M
1	Water content	15.97 L	14.96 L	14.96 L	14.96 L
2	Content of slump	25 mm slum	65 mm slum	50 mm slump	35 mm slum

		p	p		p

Table 4.6 Calculation of cement content

S.NO	GRADE DESIGNATION	M20	GC
1	Water cement ratio	0.45	-
2	Cement content	35.5kg	-
3	Alkaline to fly ash ratio	-	0.35
4	Fly ash content	-	99.9 kg

Table 4.7 Proportion of volume of coarse aggregate and fine aggregate content

S.NO	GRADE DESIGNATION	M20	GC
1	Adopted volume of coarse aggregate	68%	68%
2	Adopted volume of Fine aggregate	32%	32%

Table 4.8 Total quantity of materials

S.NO	GRADE DESIGNATION	M20	GC
1	Mass of cement in kg	35.5	-
2	Mass of water in kg	15.97	44.88
3	Mass of fine aggregate in kg	48.63	136.62
4	Mass of CA aggregatein kg	103.29	290.52
5	Water cement ratio	0.45	0.45

V RESULTS AND DISCUSSIONS

5.1 INTRODUCTION

The results of our experiment are presented and discussed in this chapter. The compressive strength data plotted in figure corresponding to the mean compressive strength of concrete specimens. The effect of various salient parameters on the compressive strength of geopolymer concrete is discussed. The parameters considered are as follows:

1. Ratio of alkaline solution to fly ash
2. Concentration of sodium hydroxide (NaOH) solution in Molar.
3. Ratio of sodium hydroxide Solution to sodium silicate solution by mass.
4. Curing type.
5. Replacing fine aggregate with quarry dust.

5.2 EFFECT OF SALIENT PARAMETERS

5.2.1 Ratio of Alkaline solution to fly ash

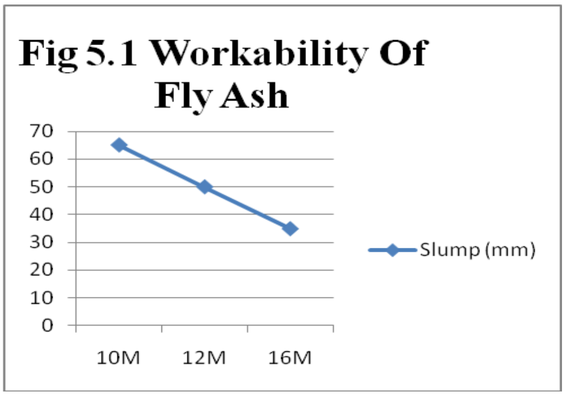
The ratio of Alkaline solution to fly ash by mass was fixed as 0.35 . The mass of water includes the alkaline solution. From the studies based on geopolymer concrete, the ratio of alkaline solutions werefixed as 2.5.

5.2.2 Concentration of sodium hydroxide (NaOH) solution

The effect of concentration of NaOH on the compressive strength of concrete was studied.The test specimen were left at ambient conditions for 7 days,14days,28 days.

5.2.3 Ratio of sodium hydroxide to sodium silicate solution

The ratio of NaOH solution to Na_2SiO_3 solution by mass of 2.5 were selected as the basic mixtures to study the effect of other parameters, for two reasons. Firstly, the cost of liquid is economical when the ratio is 2.5. Secondly, the test results were remarkably consistent when this ratio is 2.5.



5.2.4 Curing type

The test specimens were cured at room temperature for various curing periods of

7,14,28 days. Longer curing time improved the polymerization process resulting in higher compressive strength. The rate of increase in strength was slow upto 7 days of curing time. The results indicate that longer curing time increases the compressive strength of geo polymer concrete.

5.3 ADDITION OF EXTRA WATER

In fresh state, the geopolymer concrete has stiff consistency. Although adequate compaction is achieved, an improvement in the workability was considered as desirable. The addition of extra water improves the workability of fresh concrete. Figure 5.1 shows the variation of measured slump of fresh concrete with the ratio of water to fly ash, by mass. The slump test was chosen to measure the workability of fresh state concrete, as it is a simple test used extensively in practice. It can be seen from figure 5.1 that the slump value decreased as the molarity in the mixture increased.

5.4 DENSITY

The density of geo polymer concrete primarily depends on the unit mass of aggregates used in the mixture.. The density of geopolymer concrete made with different molarities (10M, 12M and 16M) is almost similar to conventional concrete.

5.5 COMPRESSIVE STRENGTH FOR DIFFERENT MOLARITIES

The compressive strength obtained for the three sets of molarities are compared. The purpose of these mixtures was to investigate the variation on the compressive strength of concrete for molarities of 10M, 12M and 16M. Figure 5.2 shows the compressive strength of alkaline activated fly ash and quarry dust based geo polymer concrete. The compressive strength of geo polymer made with fly ash quarry dust for 10M, 12M and 16M shows better strength. Among the three molarities, 16M shows higher compressive strength when compared to 10M and 12M.

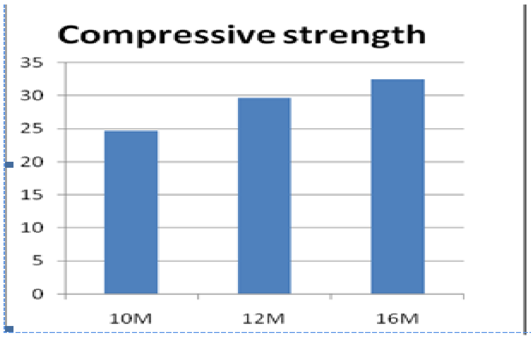


Fig 5.2 Compressive strength for geopolymer concrete at 28 days curing

VI.CONCLUSION

Geopolymer concrete is a concrete made from industrial by products , In order to make the construction process easier and reduce the cost of the construction. The average density of geo polymer concrete is similar to that of OPC concrete. Longer curing time produces higher compressive strength of geo polymer concrete. The use of fly ash and quarry dust in geo polymer concrete showed better results when compared to conventional concrete. The environmental pollution can also be minimized by controlling the emission of carbon di oxide during the manufacturing process of cement**.** Therefore, this concrete provides additional economic benefits when used in infrastructure applications.

In this project complete replacement of cement by ASTM Class F fly ash and complete replacement of sand by quarry dust were used in M20 concrete mix .The mixes were designed for molarity of 10M, 12M, and 16M. the alkaline solution used is the combination of sodium hydroxide and sodium silicate solution with the ratio of 2.50. Concrete specimens were prepared and cured under ambient temperature for 10M,12M & 16M. The experimental program involves casting of geopolymer concrete specimens and testing the same at different ages of compressive strength. The ratio of Alkaline solution to fly ash by mass was fixed as 0.35 Complete details of results are given in appendix 1. Longer curing time improved the polymerisation process resulting in higher compressive strength.

Based on the experimental work done on this project, the following conclusions are drawn:

1. 16M concentration of sodium hydroxide solution results in higher compressive strength of geo polymer concrete than 10M and 12M.
2. Sodium hydroxide to sodium silicate ratio 2.5 results in better compressive strength of geo polymer concrete.
3. Longer curing time produces higher compressive strength of geopolymer concrete.
4. The slump value of the fresh geopolymer concrete increases with the decrease of molarity.
5. The average density of geopolymer concrete is similar to that of OPC concrete.
6. The use of fly ash & quarry dust in geo polymer concrete showed better results when compared to conventional concrete.

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