MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE BY USING MILL REJECTED COAL AGGREGATE AS PARTIAL REPLACEMENT OF COARSE AGGERGATE

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Abstract - *The demand of cement (OPC) is increasing day by day for satisfying the need of development of infrastructure facilities. The production of OPC releases more quantity of carbon dioxide to the atmosphere, it is harmful to the human health and also pollute environment. Therefore, it is essential to find alternatives to make the concrete environment friendly. The one and only concrete that will produce zero percentage of carbon dioxide is geopolymer concrete and it is introduced in 1979 by davidovits to reduce the use of OPC in concrete.*

The objective of this project is to study the strength properties of class F fly ash (FA-50%) and ground granulated blast furnace slag (GGBS-50%) based geopolymer concrete (GPC) using mill rejected coal aggregate (Coal Washery Rejects) as coarse aggregate replacement at different levels (0%, 10%, 20%, 30% and 40%). In the present investigation it is proposed to study the mechanical properties viz. compressive strength, splitting tensile strength and flexural strength after 7, 28 and 90 days of curing at ambient room temperature.

The study indicated that mill rejected coal aggregate can effectively be used as coarse aggregate replacement (up to30%) without substantial change in strength.

Key Words: fly ash, ground granulated blast furnace slag, geopolymer concrete, mill rejected coal.

1.1 INTRODUCTION

In now a day's usage of concrete occupies second place around the world other than the water. Ordinary Portland concrete primarily consists of cement, aggregates (coarse & fine) and water. In this, cement is used as a primary binder to produce the ordinary Portland concrete. Due to increasing of developments in infrastructure, the usage of conventional concrete will be more and as well as the demand of cement would be increases in the future. Approximately it is estimated that the consumption of cement is more than 2.2 billion tons per year (Malhotra, 1999).

On the other hand, the usage of Portland cement may create some environmental issues such as global warming, green house effect etc. Because these problems may generate due to increasing of carbon dioxide (Co_2) present in the environment, from the past results nearly one tone of portland cement releases equal quantity of carbon dioxide (Co_2). In order to avoid these environmental issues associated with Portland cement there is need to use some alternatives such as fly ash, ground granulated blast furnace slag (GGBS), rise husk ash etc., as binders to make the eco friendly concrete. The aggregates (coarse and fine) are the most important ingredient of concrete occupying almost 70-80% of its total volume and directly affect the properties of concrete. So, there is need to use some alternatives such as coal ash, furnace slag, fiberglass waste materials, rubber waste, waste plastics, work sludge pellets etc.

In this respect, Davidovits [1988] proposed an alternative binder for the concrete technology and it shows a good results. These binders are produced by an alkaline liquid reacts with the silica (Si) and aluminium (Al) present in the source materials. The technology proposed by the Davidovits is commonly called as Geo-polymers or Geo-polymer technology.

1.2 Origin of Term 'Geopolymer'

The term ''Geopolymer'' was first introduced to the world by Davidovits of France resulting in a new field of research and technology. Geopolymer also known as 'inorganic polymer' has emerged as a 'green' binder with wide potentials for manufacturing sustainable materials for environmental, refractory and construction applications.

- **Geopolymer concrete (gpc):**

Ingredients required for creation of geopolymer binders are:

- Geopolymer source materials such as fly ash, ggbs, metakaolin, and rice husk ash, etc
- Aggregate system consisting of fine and coarse aggregate
- Alkaline Activator Solution

- **Applications of Geopolymers**

- Used in industrial floor repairs.
- Airfield repairs (in war zones).
- Fireproof composite panels.
- External repair and structural retrofit for aging infrastructure.
- For storage of toxic and radioactive wastes.
- Potential utilizations in Art and Decoration.

1.3 Properties of Geo-Polymer Concrete

Geopolymer are inorganic binders, which are identified by the following basic properties,

- Compressive strength depends on curing time and curing temperature. As the curing time and temperature increases, the compressive strength increases.
- Resistance to corrosion, since no limestone is used as a material, Geopolymer cement has excellent properties within both acid and salt environments. It is especially suitable for tough environmental conditions.
- Geopolymer specimens are possessing better durability and thermal stability characteristics.

1.4 Salient Features of Geo-Polymer Concrete

- Reduced CO_2 emissions of geopolymer cements make a good alternative to ordinary Portland cement.
- The mechanical behavior and durability property of Geo-polymer concrete is higher than nominal concrete mix.
- Geo-polymer Concrete is Eco-Friendly.
- Water absorption property is lesser than the nominal concrete.

1.5. Need for the Study

- To find an alternative for the ordinary Portland cement.
- To reduce CO_2 emission and produce eco-friendly concrete.
- To develop a cost efficient product.
- To provide high strength concrete than ordinary Portland concrete.

1.6. Objectives:

- To make a concrete without using cement (i.e. Geopolymer concrete).
- To study the different strength properties of geo-polymer concrete with percentage replacement of MRCA.
- To develop a mixture proportioning process to manufacture fly ash (ASTM Class F) and GGBS based geopolymer concrete incorporating MRCA as coarse aggregate with different replacement levels from 0% to 40% at ambient room temperature curing.
- To identify and study the effect of prominent parameters that affects the properties of fly ash and GGBS based geopolymer concrete incorporating MRCA as coarse aggregate with different replacement levels from 0% to 40% at ambient room temperature curing.

2. REVIEW OF LITERATURE

2.1 General

In this chapter study of geo-polymer concrete and the application of geopolymer concrete are discussed using following research articles and are presented.

2.2 Geo-Polymers

In 1978, Davidovits etal., proposed that an alkaline liquid could be used to react with the silicon (Si) and the aluminium (Al) in a source material of geological origin or in by- product materials such as fly ash and GGBS to produce binders.

2.3 Literatures on Geopolymer:

Rangan (2008) has reported on the fly ash-based geopolymer concrete. He study the effects of salient factors that influence the short and long term properties of the geopolymer concrete in the fresh and hardened states. He describes the applications and economic merits of geopolymer concrete in the construction industry. He finally concluded that the low-calcium fly ash-based geopolymer concrete has excellent compressive strength and is suitable for structural applications. The salient factors that influence the short and long term properties of the fresh concrete and the hardened concrete have been identified [1].

Lloyd and Rangan (2010) have reported on the geopolymer concrete with fly ash. They extensive studies conducted on the mechanical properties of fly ash-based geopolymer concrete. He observed the silent features that affect the properties of the geopolymer concrete with fly ash. The report describes the brief details of fly ash-based geopolymer concrete and a simple method to design geopolymer concrete mixtures has been described and illustrated by an example [2].

Djwantoro Hardjito (2005) has made an investigation on the Studies on Fly Ash-Based Geopolymer Concrete. This report describes the details of development of the process of making fly ash-based geopolymer concrete. He identifies the salient parameters affecting the properties of fresh and hardened geopolymer concrete. In this present investigation fly ash is used as the basic material and combination of sodium hydroxide and sodium silicate solution is used as binder material. He studies the elastic properties of geopolymer concrete, i.e., the modulus of elasticity, the Poisson's ratio, and the indirect tensile strength, are similar to those of ordinary Portland cement concrete [3].

Palomo et al. (1990) reported the study of fly ash-based geopolymers. They utilized blends of sodium hydroxide to sodium silicate and potassium hydroxide with potassium silicate as alkaline liquids. It was found that the type of alkaline liquids is a significant factor affecting the compressive strength of the concrete, and the combination of sodium silicate and sodium hydroxide gave the best compressive strength [4].

Cheng and Chiu (2003) reported the investigation of making fire-resistant Geopolymer using granulated blast furnace slag combined with metakolinite. The combination of potassium hydroxide (KOH) and sodium silicate (Na_2so_3) was used as alkaline liquids [5].

Ganapati Naidu et al. (2012) have studied the strength properties of geopolymer concrete using low calcium fly ash (ASTM Class F) replacing with slag in 5 different percentages of 0, 9, 16.66, 23.07 and 28.57. He observed that the compressive strength of geopolymer concrete increases with replacement of fly ash with GGBS. Fly ash was replaced by ground granulated blast furnace slag up to 28.57%, beyond that fast setting was observed. He observed 90% of compressive strength was achieved within 14 days [6].

Sekhar et al. (2014) have studied the Strength Studies on Fly Ash and GGBS Blended Geopolymer Concrete. In this present investigation, the effect of fly ash (class F) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete (GPC) at different replacement levels (FA50-GGBS50; FA25-GGBS75; FA0-GGBS100) are to be found. Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution has been used as an alkaline activator. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength after 7, 14 and 28 days and split tensile strength after 28 days of ambient room temperature curing. From the results, it is concluded that the increased level of GGBS increased the compressive strength of GPC at all curing periods and split tensile strength after 28 days of curing. Results revealed that fly ash and GGBS blended GPC mixes have attained enhanced mechanical properties at all curing periods [7].

Khadar et al. (2014) have study the strength properties of class F fly ash (FA) based geopolymer concrete (GPC) using slag as sand replacement at different levels (0%, 50% and 100%). Sodium silicate (Na2SiO3) and sodium hydroxide (NaOH) solution has been used as an alkaline activator. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength after 7, 14 and 28 days and split tensile strength after 28 days of ambient room temperature curing. From the results, it is concluded that the increased replacement level of slag increased the mechanical properties of FA based GPC mixes. Results recommended using fly ash based GPC mixes using slag as a sand replacement [8].

Pavan (2012) reported that the effect of fly ash (class F) and ground granulated blast furnace slag (GGBS) on the mechanical properties of geopolymer concrete at different replacement levels (FA100-GGBS0; FA50-GGBS50; FA0-GGBS100). Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution has been used as an alkaline activator. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength after 7, 14 and 28 days and split tensile strength after 28 days of ambient room temperature curing. From the results, it is concluded that the increased level of GGBS increased the compressive strength of GPC at all curing periods and split tensile strength after 28 days of curing. Results revealed that fly ash and GGBS blended GPC mixes have attained enhanced mechanical properties at all curing periods. Also in this study, the mechanical properties of GPC (FA0-GGBS100) were compared to M 45 grade of conventional concrete (CC) [9].

Priyanka et al. (2014) reported that the effect of molarity (8M, 10M and 12M) on strength properties of fly ash (class F) and ground granulated blast furnace slag (GGBS) blended geopolymer concrete (GPC) at the

50% replacement level (FA50-GGBS50). Sodium silicate (Na_2SiO_3) and sodium hydroxide (NaOH) solution has been used as an alkaline activator. In the present investigation, it is proposed to study the mechanical properties viz. compressive strength after 7, 14 and 28 days and split tensile strength after 28 days of ambient room temperature curing.

From the results, it is concluded that the increased molarity of NaOH solution increased the compressive strength of GPC at all curing periods and split tensile strength after 28 days of curing. Results revealed that fly ash and GGBS blended GPC mixes have attained enhanced mechanical properties at all curing period [10].

3. MATERIALS

3.1 General

In this chapter various materials and method of conducting the test were discussed in detail and was presented.

3.2 Materials Used

- Fly ash
- Ground granulated blast furnace slag (GGBS)
- Chemicals
  - -Sodium hydroxide
  - -Sodium silicate
- Aggregates
  - - Fine aggregate
  - - Coarse aggregate
  - - Mill rejected coal aggregate

3.2.1 Fly Ash

Fly ash is one of the most abundant materials on the Earth. It is also a crucial ingredient in the creation of geopolymer concrete due to its role in the geopolymerization process. A pozzolan is a material that exhibits cementitious properties when combined with calcium hydroxide. Fly ash is the main by product created from the combustion of coal in coal-fired power plants. There are two "classes" of fly ash, Class F and Class C. Each class of fly ash has its own unique properties. The physical and chemical composition of fly ash are shown in the Table 1

Table 1.Physical and Chemical Composition of Fly Ash

Particulars	Class "F" fly ash
Chemical composition	
% Silica(SiO_2)	63.4
% Alumina(Al_2O_3)	30.5
% Iron Oxide(Fe_2O_3)	3.0
% Lime(CaO)	1.0
% Magnesia(MgO)	1.0
% Titanium Oxide (TiO_2)	0.62
% Sulphur Trioxide (SO_3)	0.1
Loss on Ignition	0.24
Physical properties	
Specific gravity	2.24
Fineness (m^2/Kg)	360

3.2.2 Ground Granulated Blast Furnace Slag

Ground granulated blast furnace slag comprises mainly of calcium oxide, silicon di-oxide, aluminium oxide, magnesium oxide. It has the same main chemical constituents as ordinary Portland cement but in different proportions. The addition of G.G.B.S in Geo-Polymer Concrete increases the strength of the concrete and also curing of Geo-Polymer concrete at room temperature is possible. The physical and chemical composition of GGBS are shown in the Table 2.

Table 2. Physical and Chemical Composition of GGBS

Particulars	GGBS
Chemical composition	
% Silica(SiO_2)	31.41
% Alumina(Al_2O_3)	17.24
% Iron Oxide(Fe_2O_3)	0.62
% Lime(CaO)	34.48
% Magnesia(MgO)	6.79
% Titanium Oxide (TiO_2)	-
% Sulphur Trioxide (SO_3)	1.85
Loss on Ignition	2.3
Physical properties	
Specific gravity	2.68
Fineness (m^2/Kg)	400

3.2.3 Alkaline Liquid

A combination of alkaline silicate solution and alkaline hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than Potassium-based solutions.

3.2.4 Chemicals

In this project chemicals are the very important constituents. Sodium Silicate and Sodium Hydroxide liquid are obtained commercially from local suppliers in Chennai.

3.2.4.1 Sodium Hydroxide

The sodium hydroxide solids were of a laboratory grade in pellets form with 99% purity, obtained from local suppliers in Chennai. The sodium hydroxide (NaOH) solution was prepared by dissolving the pellets (a small, rounded, compressed mass of a substance of sodium hydroxide) in water. The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, sodium hydroxide solution with a concentration of 8M consisted of 8x40 = 320 grams of sodium hydroxide solids (in pellet form) per liter of the solution, where 40 is the molecular weight of sodium hydroxide.

3.2.4.2 Sodium Silicate

Sodium silicate solution (water glass) obtained from local suppliers in Chennai was used. The chemical composition of the sodium silicate solution was Na_2O=8%, SiO_2=28%, and water 64% by mass. The mixture of sodium silicate solution and sodium hydroxide solution forms the alkaline liquid.

3.2.5 Aggregates

The aggregates are the main components of the concrete which greatly varies the strength, density and other properties of the concrete. Different types of aggregates used are discussed below.

3.2.5.1 Fine Aggregate

The fine aggregate used in the project was locally supplied from the river Swarnamukhi, near chandragiri in chittoor district and confirmed to grading zone II as per IS: 383:1970. It was first sieved through 4.75mm sieve to remove any particles greater than 4.75mm. Properties of the fine aggregate are tabulated below in Table 3.

Table 3. Properties of fine aggregates

S.No	Characteristics	Values
1.	Type	Uncrushed (natural)
2.	Specific gravity	2.54
3.	Bulk Density	1668 kg/m^3
4.	Fineness modulus	2.76
5.	Grading zone	Zone II

3.2.5.2 Coarse Aggregate

Locally available coarse aggregate having the maximum size of (10 - 20mm) were used in this project. The aggregates were tested as per Indian Standard Specifications IS: 383-1970. Properties of the coarse aggregate are tabulated in Table 4.

Table 4. Properties of Coarse aggregates

S.No	Characteristics	Values
1.	Type	Crushed
2.	Specific gravity	2.6
3.	Bulk Density	1765 kg/m^3
4.	Fineness modulus	6.45
5.	Maximum size	20mm

4. MIX PROPORTION AND EXPERIMENTAL INVESTIGATION

4.1 Introduction

In this experiment mix design of Geo-polymer concrete and the experimental investigations are carried out on the test specimen to study the strength related properties of geo-polymer concrete was discussed in detail.The experimental test for strength properties of concrete are compressive strength, split tensile strength, Flexural strength test of concrete. Based on the test procedure given in IS 516-1959 code tests were conducted on specimens.

4.2 Mix Proportion for Geo-Polymer Concrete

Most of the reported works on geo-polymer material to date were related to the properties of geo-polymer paste or mortar, measured by using small size specimens. In addition, the complete details of the mixture compositions of the geo-polymer paste were not reported.Palomo et al (1999) studied the geo-polymerization of low-calcium ASTM Class F fly ash (molar Si/Al=1.81) using four different solutions with the solution-to-fly ash ratio by mass of 0.25 to 0.40. The molar SiO2/K2O or SiO2/Na2O of the solutions was in the range of 0.63 to 1.23.The mix proportion of geopolymer concrete is presented in Table 5.

4.3 Preparation of Alkaline Activator Solution

The mixture of sodium silicate solution and sodium hydroxide solution forms the alkaline liquid.A combination of alkaline silicate solution and alkaline hydroxide solution was chosen as the alkaline liquid. Sodium-based solutions were chosen because they were cheaper than potassium-based solutions. The Alkali activator solution has to be prepared 24 hours advance before use. The Sodium hydroxide is available in small flakes and Sodium Silicate in crystal forms depending on the required solution of different morality has to be prepared.

Table 5. GPC Mix Proportions

Materials		Mass (kg/m³)				
		100% CA	10% MRCA + 90% HBG	20% MRCA + 80% HBG	30% MRCA + 70% HBG	40% MRCA + 60% HBG
Coarse Aggregate	20 mm	774	77.4 + 696.6	154.8 + 619.2	232.2 + 541.8	309.6 + 464.4
	10 mm	516	51.6 + 464.4	103.2 + 412.8	154.8 + 361.2	206.4 + 309.6
Fine aggregate		549	549	549	549	549
Fly ash (Class F)		204.5	204.5	204.5	204.5	204.5
GGBS		204.5	204.5	204.5	204.5	204.5
Sodium silicate solution		102	102	102	102	102
Sodium hydroxide solution		41 (8M)	41 (8M)	41 (8M)	41 (8M)	41 (8M)
Extra water		55	55	55	55	55
Alkaline solution/ (FA+GGBS) (by weight)		0.35	0.35	0.35	0.35	0.35
Water/ geopolymer solids (by weight)		0.29	0.29	0.29	0.29	0.29

5. RESULTS & DISCUSSIONS

The various strength tests that are to be done listed as below.

- Compressive strength
- Split tensile strength
- Flexural strength

Test Specimens

The tests were carried out as per IS: 516-1959 and IS 5816 : 1999.The test specimens for compressive strength test were made of cubes having a size of 150mm x 150mm x 150mm cast iron steel moulds were used. For each mix proportion three numbers of cubes were cast and tested at the age of 7 days, 28 days and 90 days. The test specimens for split tensile strength test were made of cylinders having a size of 100mm diameter and 300mm high cast iron moulds were used. For each mix proportion three numbers of cylinders were cast and tested at 7 days, 28 days and 90 days. The test specimens for Flexural strength test were made of prism having a size of 500mm x 100mm x 100mm cast iron steel moulds were used. For each mix proportion three numbers of prisms were cast and tested at the age of 7 days, 28 days and 90 days.

5.1 Compressive Strength Test

Compressive strength was tested for the mixes with the various MRCA replacement levels of 0%, 10%, 20%, 30% and 40%. The samples were tested after curing periods of 7, 28 and 90 days. Table 6 and Fig 1 shows the compressive strength of GPC mixes (100%CA: 0%MRCA, 90%CA:10%MRCA, 80%CA:20%MRCA, 70%CA:30%MRCA and 60%CA:40%MRCA) at different curing periods.

Table 6. Compressive strength of GPC

Compressive strength, f'_c (MPa)	7 Days	28 Days	90Days
100:0	28.04	38.25	45.89
90:10	30.23	40.53	46.89
80:20	33.12	43.66	50.03
70:30	35.65	46.21	52.36
60:40	26.51	36.24	44.38

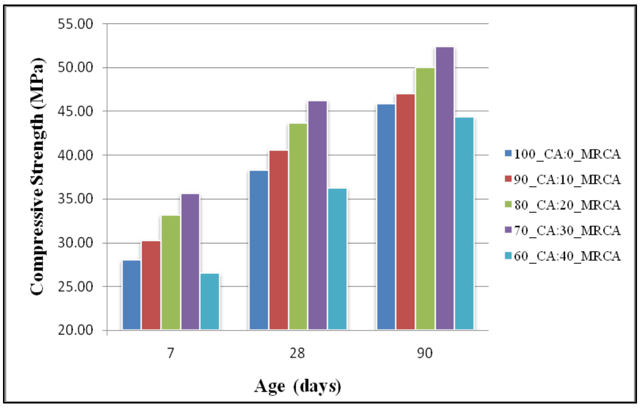

Fig: 1 Variation of Compressive Strength for various trail mixes

5.2 Split Tensile Strength Test

Split tensile strength was tested for the mixes with the various MRCA replacement levels of 0%, 10%, 20%, 30% and 40%. The samples were tested after curing periods of 7, 28 and 90 days. Table 7and Fig 2 shows the split tensile strength of GPC mixes (100%CA: 0%MRCA,90%CA:10%MRCA,80%CA:20%MRCA,70%CA:30%MRCA and 60%CA:40%MRCA) at different curing periods.

Table 7. Split tensile strength of GPC

Split tensile strength, f_{ct}	7 Days	28 Days	90Days
100:0[a]	2.48	3.26	3.79
90:10	2.66	3.42	3.86
80:20	2.88	3.64	4.06
70:30	3.12	3.91	4.38
60:40	2.35	3.12	3.69

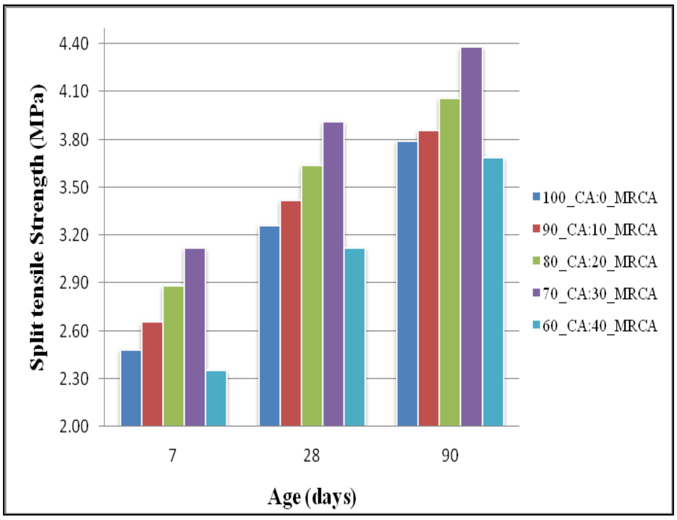

Fig: 2 Variation of Split Tensile Test for various trail mixes

5.3 Flexural Strength Test

Flexural strength was tested for the mixes with the various MRCA replacement levels of 0%, 10%, 20%, 30% and 40%. The samples were tested after curing periods of 7, 28 and 90 days. Table 8 and Fig 3 shows the flexural strength of GPC mixes (100%CA: 0%MRCA,90%CA:10%MRCA,80%CA:20%MRCA,70%CA:30%MRCA and 60%CA:40%MRCA) at different curing periods.

Table 8. Flexural strength of GPC

Flexural strength, f'_c (MPa)	7 Days	28 Days	90Days
100:0[a]	3.28	3.83	4.20
90:10	3.41	3.95	4.25
80:20	3.57	4.10	4.39
70:30	3.71	4.31	4.52
60:40	3.19	3.73	4.13

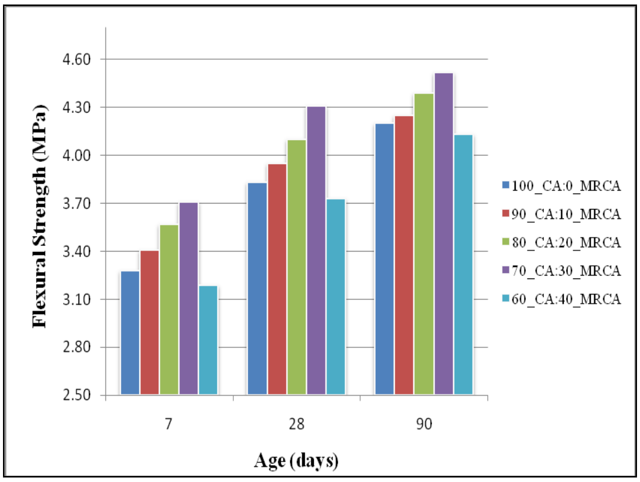

Fig: 3 Variation of Flexural Strength Test for various trail mixes

6 CONCLUSIONS AND FUTURE WORK

The primary aim of this research was to develop GPC with the various replacement levels of mill rejected coal aggregates in coarse aggregate and study the mechanical properties of GPC mixes at ambient room temperature.

6.1 Conclusions

Based on the investigation, the following conclusions have been drawn.

- There was a significant increase in compressive strength, split tensile strength, flexural strength with the increase in percentage of MRCA from 0% to 30% in all curing periods. The optimum percentage of MRCA obtained is 30% of its volume of coarse aggregate.
- The maximum compressive strength of geopolymer concrete for 7days, 28days and 90 days curing period is 35.65 MPa, 46.21 MPa and 52.36 MPa respectively by partial replacement of coarse aggregate by 30% replacement of mill rejected coal aggregate.
- The maximum Split Tensile Strength of geopolymer concrete for 7days, 28days, 90 days curing period is 3.12 MPa, 3.91 MPa and 4.38 MPa respectively by partial replacement of coarse aggregate by 30% replacement of mill rejected coal aggregate.
- The maximum flexural strength of geopolymer concrete for 7days, 28days and 90 days curing period is 3.71MPa, 4.31 MPa and 4.52 MPa by partial replacement of coarse aggregate by 30% replacement of mill rejected coal aggregate.

- When the percentage of mill rejected coal aggregate was increased to 40% a drastic fall in compressive strength, split tensile strength and flexural strength have been evidenced.
- The significant improvement in mechanical properties up to 30% MRCA replacement is mainly due to the blended of MRCA and HBG which fills the voids and increases the compressive strength of the concrete which in turn increases the other mechanical properties.

6.2 Future work

The following suggestions are recommended for future study

1. Further research is recommended to study the modulus of elasticity and bond strength between concrete and steel reinforcement.
2. Further research is recommended to study the other durability properties viz. water absorption, sorptivity, acid attack and chloride penetration of GPC mixes.
3. Keeping in view of the availability of natural resources and environmental aspects, it is recommended to replace some percentage of fine aggregate with quarry dust and granite slurry and coarse aggregate with demolished aggregates etc., in FA and GGBS based GPC mixes and study all GPC hardened and durability properties.
4. Development of cost effective FA and GGBS based GPC mixes.

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