

# A Study on the Variation of Strength Properties of concrete With Replacement of cement using Nano-Silica (NS) and Fly Ash (FA)

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**ABSTRACT:** This paper studies the recent investigations and development of combined application of Pozzolanic additions - Nano-Silica (NS) and Fly Ash (FA) on the strength properties of concrete for sub sequential growth of concrete industry. This investigation not only saves the natural resources but also controls the environmental pollution by usage of wastes. The limited work is done on partial replacement of Fly Ash and Nano-Silica in cement paste, mortar and concrete. In the present study the cement is partially substituted by 20% and 30% of Fly Ash and Nano-Silica 2.0%, 4.0% and 6.0% by weight. The experimental investigation results of concrete are tabulated using the combination of various proportions of Fly Ash and Nano-Silica are collate with that of Controlled Concrete. The mechanical strength development and durability properties of concrete are greatly influenced because of this combined application of Nano-Silica and Fly Ash compared to the Controlled Concrete properties.

**Keywords:** Nano-Silica (NS), Fly Ash (FA), Controlled Concrete, packing of Colloidal particles, Compressive Strength, Flexural Strength, Split Tensile Strength, Partial replacement.

## I INTRODUCTION

### 1.1 General

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 the some environmental issues such as global warming, greenhouse effect etc. Because these problems

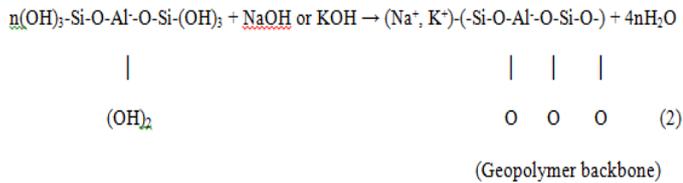
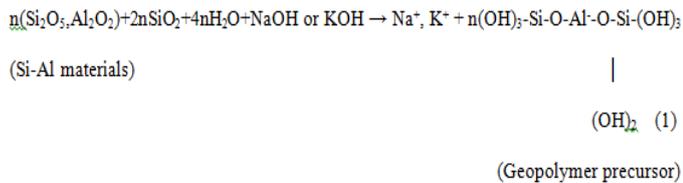
may generate due to increasing of carbon dioxide (CO<sub>2</sub>) present in the environment, from the past results nearly one tone of portland cement releases equal quantity of carbon dioxide (CO<sub>2</sub>). In order to avoid these environmental issues associated with Portland cement, there is need to use some alternatives such as fly ash, ground granulated blast furnace slag (GGBS), rise husk ash etc are as the 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 Geopolymers or Geo-polymer technology.

### 1.2 Geo-polymers

There are two major constituents present in the geopolymers, namely the alkaline liquids and source materials. The alkaline liquid used in geopolymerisation process is a mixture of sodium hydroxide (NaOH) and sodium silicate (Na<sub>2</sub>SiO<sub>3</sub>) or potassium hydroxide (KOH) and potassium silicate (K<sub>2</sub>SiO<sub>3</sub>). The source materials used for geopolymers are based on percentage of silica (Si) and aluminium (Al) present in the material. Fly ash, silica fume, ground granulated blast furnace slag (GGBS), rise husk ash etc are could be used as source materials. The selection of source materials is mainly based on requirement, cost, users demand etc.

The schematic structure of geopolymer material can be shown in Equations (1) and (2) (Davidovits, 1994; van Jaarsveld et al., 1997):



On the other hand, the usage of ground granulated blast furnace slag may create the some environmental benefits such as it produces less quantity of carbon dioxide as compare to the ordinary portland cement. It also gives better workability (i.e., easy to mixing, transporting, placing and compacting etc).

The sodium hydroxide (NaOH) solution was prepared by dissolving either the flakes or the pellets in required quantity of water. The mass of sodium hydroxide solids in a solution varied depending on the concentration of the solution expressed in terms of molarity (M). For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where, 40 is the molecular weight of sodium hydroxide (NaOH) pellets or flakes.

## 1.2.1 Constituents of Geopolymer

### 1.2.1.1 Source materials

In the present investigation the following materials are used as source materials.

- a) Fly ash
- b) Ground Granulated Blast furnace Slag

#### a) Fly ash

Fly ash (ASTM Class F) is used in the manufacturing of geopolymer concrete and which is obtained from the by-product of coal-burning power stations. The production of fly ash will be increases day by day in our country, so it is best opportunity to employ this by-product in the geopolymer concrete. Approximately it is estimated that the production of fly ash is more than 780 million tons per year especially in the countries like China and India (Malhotra, 2002). So, the abundant availability of fly ash may create the good opportunity to employ in the manufacturing of geopolymer concrete.

#### b) Ground Granulated Blast furnace Slag (GGBS)

Ground granulated blast furnace slag is also one of the source materials used in the manufacturing of geopolymer concrete and which is obtained by the blast furnace used to make iron. GGBS is used in the ordinary Portland concrete either in the form of mineral admixture or in the form of constituent of blended cement. Ordinary Portland cement is typically replaced by 35 to 65% of the GGBS. It improves strength and durability properties of the concrete and also increases the service life of concrete structures.

## 1.2.2 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.
- LTGS Brick, railways sleepers, electric power poles, marine structures, waste containments etc..

## 1.2.3 Advantages of Geopolymers

Geopolymer concrete is more resistant to corrosion and fire, has compressive and tensile strengths, gains its full strength quickly (cures fully faster), low creep, no shrinkage, good acid resistance, low permeability, resistant to sulphate attack and durable finishes.

## 1.3 Aim of the Project

The behavior of geopolymers were studied the many of researches using various types of source materials like fly ash, GGBS, rice husk ash etc. The present study dealt with the development and the mechanical properties of geopolymer concrete incorporating MRCA as coarse aggregate with different replacement levels from 0% to 50% at ambient room temperature curing. The results of those studies will be described in future chapters.

## II LITERATURE SURVEY

This Chapter presents the Historical background of the geopolymer concrete, Terminology and Chemistry of the geopolymers. The study of literature survey corresponding to the geopolymer concrete technology has done in this chapter. The research work carried out on geopolymer concrete using various industrial by-products and wastes materials. This chapter gives a comprehensive review of the work carried out by various researchers in the field of reusing the industrial by-products and wastes materials in concrete as full or partial replacement of aggregates.

### 2.1 Historical Background

The phenomenal durability of ancient concretes and mortars compared to those being used in modern time prompted research into the nature of these ancient compounds. Results from various studies, summarized by Davidovits, proved that there is in fact a very distinct difference between ancient mortars and the Portland cement-based building materials in use today. The ancient products seem to be not only physically more durable, but also more resistant to acid attack and freeze-thaw-cycles. Initially it was thought that this difference is the consequence of calcium silicate hydrates (of the C-S-H-gel type) which constitute the main part of Portland cement. Later, however, it was discovered that these ancient concretes also contain amounts of C-S-H gel and consequently researchers turned their attention to the large amounts of zeolitic phases also found in the ancient products. It was later concluded that the long term durability of ancient mortars is the result of high levels of zeolitic and amorphous compounds in their compositional make-up.

The use of pozzolanic materials in the manufacture of concrete has a long, successful history. In fact, their use pre-dates the invention of modern day Portland cement by almost 200 years. Today, most concrete producers worldwide recognize the value of pozzolanic enhancements to their products and, where they are available; they are becoming a basic concrete ingredient. Mineral admixtures such as ground granulated blast furnace slag (GGBS), fly ash and silica fume are commonly used in concrete because they improve durability reduce porosity and improve the interface with the aggregate. Economics (lower cement requirement), energy, and environmental considerations have had a role in the mineral admixture usage as well as better engineering and performance properties. The lower cement requirement also leads to a reduction for CO<sub>2</sub> generated by the production of cement. The engineering benefits from the use of mineral admixtures in concrete result partly from their particle size

distribution characteristics, and partly from the pozzolanic and cementitious reactivity. Experimental programs conducted with the purpose of proving this theory partly resulted in the rediscovery of a new family of mineral binders named "Geopolymers" because of similarities with organic condensation polymers as far as their hydrothermal synthesis conditions were concerned.

### 2.2 Terminology and Chemistry

Davidovits, created and applied the term Geopolymer. For the chemical designation of geopolymers based on silico-aluminates, "Poly (sialate)" was suggested. Sialate is an abbreviation for silicon-oxo-aluminate.

Polysialates are chain and ring polymers with Si<sup>4+</sup> and Al<sup>3+</sup> in IV-fold coordination with, oxygen and range from amorphous to semi-crystalline. Also positive ions such as Na<sup>2+</sup>, Ca<sup>2+</sup>, K<sup>2+</sup> and other metallic cations must be present in framework cavities to balance the negative charge of Al<sup>3+</sup>. The structural link of the Sialate was shown in Fig 1 The amorphous to semi-crystalline three dimensional silico-aluminate structures were christened Geopolymers of the following types:

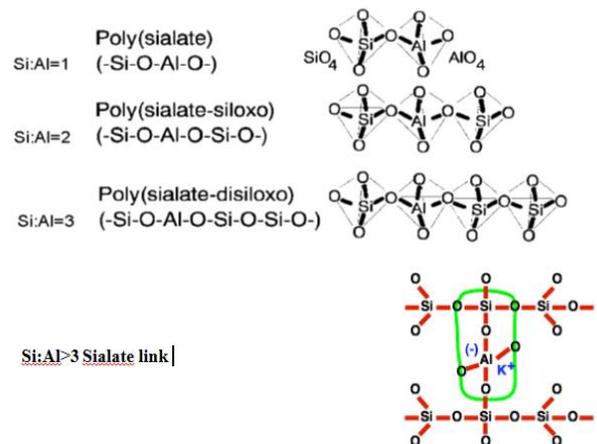


Fig 1 Structural link of silicate

This type of geopolymer will take one of the following three basic forms (where "sialate" is an abbreviation for silicon-oxo-aluminate) (Davidovits 2008): Although the mechanism of polymerization is yet to be fully understood, a critical feature is that water is present only to facilitate workability and does not become a part of the resulting geopolymer structure. In other words, water is not involved in the chemical reaction and instead is expelled during curing and subsequent drying. This is in contrast to the hydration reactions that occur when Portland cement is mixed with water, which produce the primary hydration products

calcium silicate hydrate and calcium hydroxide. This difference has a significant impact on the mechanical and chemical properties of the resulting geopolymer concrete, and also renders it more resistant to heat, water ingress, alkali-aggregate reactivity, and other types of chemical attack (Davidovits 2008; Lloyd and Rangan 2009). The chemical composition of the geopolymer material is similar to natural zeolitic materials, but the microstructure is amorphous instead of crystalline (Palomo et al. 1999; Xu and van Deventer 2000). The polymerisation process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals, which results in a three dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds, as follows (Davidovits 1999):  $M_n [-(SiO_2)_z - AlO_2]_n \cdot nH_2O$  (2-1) Where: M = the alkaline element or cation such as potassium, sodium or calcium; the symbol - indicates the presence of a bond, n is the degree of polycondensation or polymerisation; z is 1, 2, 3, or higher, up to 32. The rapid development of the industry of construction field and consumption of naturally available resources and deterioration of the environment in several raising economies has caused an unsustainable development of the construction industry.

For this reason, using the industrial by-products and waste materials is an important step in environmental sustainability. In total volume of concrete aggregate typically occupies about 65–80% and it plays a vital role in effecting the concrete properties such as workability, strength, stability, and durability. The replacement of waste materials as aggregate in concrete production can consume large amounts of waste materials. This can avoid problems of lack of aggregate in construction sites and reduce eco problems related to mining of aggregate and disposal of waste. There is a growing interest in usage of waste materials as aggregate and respective analysis has been undertaken on the usage of many different waste materials as aggregate substitutes.

Effective research is being made on the use of many materials as aggregate substitutes such as coal ash, blast furnace slag, fiber glass waste materials, waste plastics, rubber waste, sintered sludge pellets and others.

About 67% of production of electricity in Asian nation is extracted from combustion of coal. The total estimation of coal reserves in world is estimated to be 6,641,200 million tones and the same estimation for India to be 106,260 million tones. The demand of coal is expected to increase at quick rate than it had been within the past because of the increase in the price of crude oil and natural gas. The demand of coal during the first half of last century remained constant more or less and now it

is growing in this century. It's the very best linkage impact with thermal power plants, railway locomotives, industry of fertilizers, cement, steel, electricity and a variety of different industries. India is to be continued in sixth largest producer of coal of nearly one hundred million tones with its annual production. The reserves of the low ranking hydrocarbon and lignite coals are more as compared to high ranking coal i.e. anthracite and coking hydrocarbon coals. On the opposite side, the demand of high rank coals is more for metallurgical use and for use as fuel.

Coal could be a brittle, firm, sedimentary, flammable rock derived from vegetable detritus that has undergone several physical and chemical changes throughout the terribly long course of numerous years. It consists primarily of elemental carbon. The standard of coal varies with rank from peat to wood coal, from wood coal to hydro carbon, from hydro carbon to semi-anthracite and from semi-anthracite to coal.

The coal because it comes from mines consists of several impurities such as magnesium sulfate, fire clay, pyrites in the form of sulphurin, and slate. These impurities have higher specific gravity than pure coal and hence, it needs coal washing technique to clean coal before exploitation. Specific gravity of pure coal is 1.2 to 1.7 and for impure coal is 1.7 to 4.9. Therefore, coal should be screened to size and it should be cleansed by jigging or by heavy-media separation. When demand grows, society expects cleaner energy with less pollution associate degree an increasing stress on environmental property. The coal industry acknowledges it should meet the challenge of environmental property and in especially it should reduce its greenhouse emissions if it's to stay a neighborhood of property part of energy future. The qualities of coal need to be assessed only then it are often fittingly utilized in completely different industries.

Indian coal is taken into account to be of inferiority since it contains ash as high as 45%, high wetness content (4–20%), low content of sulphur (0.2–0.7%), and less calorific values (between 2500–5000 kcal/kg) (IEA, 2002). High percentage of ash content in the coal supplied to the power plants not only poses environmental problems but also results in poor performance of plant and high cost for Operation & Maintenance of plant and disposal of ash. Thus, the process of coal washing is necessary from the point of environment and economy. The current put in capability of washeries for coal is regarding 131.24 million-tons each year for each coking and non-coking coal (Energy Statistics, 2013).

The ordinary coal-washing processes results a separation between coal and impurity because of these elements have difference in specific gravities. In finding out the possibilities of improving a quality of coal by washing, thus it is long been common practice of the raw coal mixture separation into coal and impurity by immersing it in an exceedingly resolution with intermediate specific gravity between that of coal and impurity. The portion of the sample with specific gravity but that of the solution floats and therefore the portion with the specific gravity over that of the solution sink. Cleaned coal carried out by the flow of water over a weir and the refuse or impurities sinks to the bottom. Refuse is removed time to time from the washer and stored in bunker storage. This refuse which is stored in bunker storage is called coal washery rejects (CWR).

The generation of rejects from washeries in Coal India Limited (CIL) in 2004-05 was estimated at 2.44 Mt. Accumulated stocks of washery rejects up to March'05 was recorded as 18.15Mt. The Coal Washery Rejects (CWR) are the major environmental hazard issue during the process of Coal Washing. Disposal of this huge quantity of rejects in an environment friendly manner poses a real hazardous problem. Recently, the rejects from the washery has been reused by burning it again in fluidized bed based boiler to raise steam for Power generation. CIL has set up 7nos of 10 MW each FBC based power plants using washery rejects at various locations. Cost of generation varies from Rs.2.5 to Rs.3.5 per kWh due to operating and maintenance of these plants in isolation mode at low PLF. The reuse of rejects could result in saving of 0.2 Mt of raw coal per year. For solving the disposal of large amount of coal washery rejects, the most feasible application can be the reuse of CWR in concrete industry. Hence, this investigation is principally supposed to use the CWR as coarse aggregate substitute in concrete and study the properties of concrete.

### III EXPERIMENTAL PROGRAM

#### 3.1 General

This chapter presents the details of development and making low calcium (ASTM Class F) fly ash and GGBS based geopolymer concrete. In this present investigation normal coarse aggregate has been replaced by mill rejected coal (Coal Washery Rejects) aggregate. First, the materials, mix proportions, manufacturing and curing of the test specimens are explained.

The physico chemical properties of fly ash, ground granulated blast furnace slag, aggregate and water used in the investigation were analyzed based on standard experimental procedures laid down in IS, ASTM and BS codes. The experiments conducted on coarse aggregate (Hard Broken Granite HBG and mill rejected coal) are specific gravity and water absorption, Bulk density & Sieve analysis by using respective codes. The experiments conducted on fine aggregate are specific gravity, moisture content, sieve analysis and bulking of fine aggregate using volume method. The tests conducted on geopolymer concrete are Compressive strength, Split Tensile strength and Flexural strength as per the respective IS, BS and ASTM codes.

#### 3.2 Mixture Proportions

Assume that normal-density aggregates in SSD (Saturated surface Dry) condition are to be used and the unit-weight of concrete is  $2400 \text{ kg/m}^3$ . In this study, take the mass of combined aggregates as 77% of the total mass of concrete, i.e.  $0.77 \times 2400 = 1848 \text{ kg/m}^3$ . The coarse and fine (combined) aggregates may be selected to match the standard grading curves used in the design of Portland cement concrete mixtures.

For instance, the coarse aggregates (70%) may comprise  $776 \text{ kg/m}^3$  (60%) of 20 mm aggregates,  $518 \text{ kg/m}^3$  (40%) of 10 mm aggregates, and  $554 \text{ kg/m}^3$  (30%) of fine aggregate to meet the requirements of standard grading curves. The adjusted values of coarse and fine aggregates are  $774 \text{ kg/m}^3$  of 20 mm aggregates,  $516 \text{ kg/m}^3$  of 10 mm aggregates and  $549 \text{ kg/m}^3$  (30%) of fine aggregate, after considering the water absorption values of coarse and fine aggregates.

The mass of geopolymer binders (fly ash and GGBS) and the alkaline liquid =  $2400 - 1848 = 552 \text{ kg/m}^3$ . Take the alkaline liquid-to-fly ash + GGBS ratio by mass as 0.35; the mass of fly ash + GGBS =  $552 / (1+0.35) = 409 \text{ kg/m}^3$  and the mass of alkaline liquid =  $552 - 409 = 143 \text{ kg/m}^3$ . Take the ratio of sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) solution-to-sodium hydroxide (NaOH) solution by mass as 2.5; the mass of sodium hydroxide (NaOH) solution =  $144 / (1+2.5) = 41 \text{ kg/m}^3$ ; the mass of sodium silicate solution =  $143 - 41 = 102 \text{ kg/m}^3$ .

The sodium hydroxide solids (NaOH) is mixed with water to make a solution with a concentration of 8 Molar. This solution comprises 40% of NaOH solids and 60% water, by mass.

For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows: In sodium silicate solution, water =  $0.559 \times 102 = 57 \text{ kg}$ , and solids =  $102 - 57 = 45 \text{ kg}$ . In sodium hydroxide solution, solids =

0.40x41 = 16 kg, and water = 41 – 16 = 25 kg. Therefore, total mass of water = 57+25 = 82 kg, and the mass of geopolymer solids = 409 (i.e. mass of fly ash and GGBS) + 45 + 16 = 470 kg. Hence, the water-to-geopolymer solids ratio by mass = 82/470 = 0.17. Extra water of 55 litres is calculated on trial basis to get adequate workability.

### 3.3 Compressive Strength test

Compression test is one of the most common test conducted on hardened concrete, partly because it is most important and it is easy to perform further most of the desirable characteristic properties of concrete are qualitatively related to its strength.

The compression test is carried out on specimens like cubical or cylindrical in shape sometimes prisms are also used. The end parts of beam are left intact after failure in flexure and because of the square cross section of the beam this part of the beam could be advantageously used to find out the compressive strength.



Fig.2 Testing of cubes for compressive strength

The compressive strength of concrete is the most important and useful property of Concrete. The compression test was carried out using 2000 KN compression testing machine.

The compressive strength of the GPC was conducted on the cubical specimens for all the mixes after 7, 28 and 90 days of curing as per code . 9 Nos of 150 mm cube specimen were made for each mix and 3 samples in each were cast and tested for 7 days, 28 days and 90 days respectively. The average value of these 3 specimens was taken for study.

The compressive strength ( $f_c$ ) of the specimen was calculated by dividing the maximum load applied to the specimen by the cross-sectional area of the specimen as given below.

$$f_c = P/A$$

Where,  $f_c$  = Compressive strength of the concrete (in N/mm<sup>2</sup>)

$P$  = Maximum load applied to the specimen (in Newton)

$A$  = Cross-sectional area of the specimen (in mm<sup>2</sup>)

### 3.4 Split Tensile Strength test

Splitting Tensile Strength (STS) test was conducted on the specimens for all the mixes after 28 days of curing as per code. Three cylindrical specimens of size 150 mm x 300 mm were cast and tested for each age and each mix. The load was applied gradually till the failure of the specimen occurs. The maximum load applied was then noted. Length and cross-section of the specimen was measured. The splitting tensile strength ( $f_{ct}$ ) was calculated as follows:



Fig.3 Testing of cylinders for Split tensile strength

$$f_{ct} = 2P/(\pi l d)$$

Where,  $f_{ct}$  = Splitting tensile strength of concrete (in N/mm<sup>2</sup>)

$P$  = Maximum load applied to the specimen (in Newton)

$l$  = Length of the specimen (in mm)

$d$  = cross-sectional diameter of the specimen (in mm)

### 3.5 Flexure Strength test



Fig.4 Testing of prisms for Flexure strength

Flexural strength test was conducted on the specimens for all the mixes at different curing periods as per code. Three concrete beam specimens of size 100 mm x 100 mm x 500 mm were cast and tested for each age and each mix. The load was applied gradually till the failure of the specimen occurs.

The maximum load applied was then noted. The distance between the line of fracture and the near support 'a' was measured. The flexural strength ( $f_{cr}$ ) was calculated as follows:

When 'a' is greater than 13.3 cm for 10 cm specimen,  $f_{cr}$  is

$$f_{cr} = (P \times l) / (b \times d^2)$$

When 'a' is less than 13.3 cm but greater than 11.0 cm for 10 cm specimen,  $f_{cr}$  is

$$f_{cr} = (3 \times P \times a) / (b \times d^2)$$

Where,  $f_{cr}$  = Flexural strength of concrete (in N/mm<sup>2</sup>)

$P$  = Maximum load applied to the specimen (in Newton)

$b$  = measured width of the specimen (in mm)

$d$  = measured depth of the specimen at the point of failure (in mm)

$l$  = Supported length of the specimen (in mm)

## IV RESULTS AND DISCUSSIONS

This chapter describes the mechanical properties viz., compressive strength, split tensile strength and flexural strength of GPC incorporating mill rejected coal as coarse aggregate with replacement levels from 0% to 40% respectively. The compressive strength split tensile strength and flexural strength test values of concrete mixes were measured once 7, 28 and 56 days of curing.

### 4.1 Compressive strength

Table 2 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.

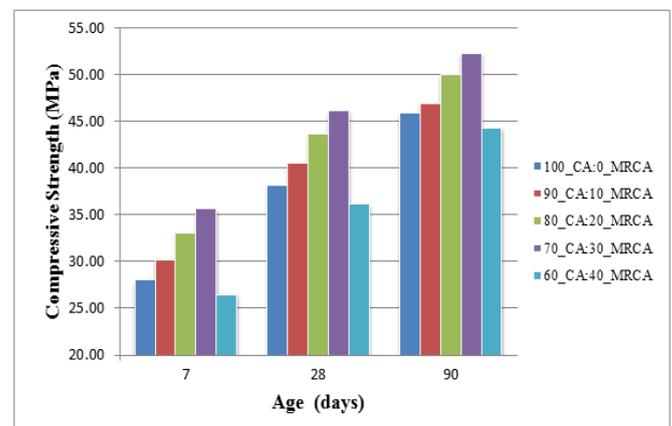
**Table 2** Compressive strength of GPC

| Mechanical property               | Age (days) | Mix type           |       |       |       |       |
|-----------------------------------|------------|--------------------|-------|-------|-------|-------|
|                                   |            | 100:0 <sup>a</sup> | 90:10 | 80:20 | 70:30 | 60:40 |
| Compressive strength, $f_c$ (MPa) | 7          | 28.04              | 30.23 | 33.12 | 35.65 | 26.51 |
|                                   | 28         | 38.25              | 40.53 | 43.66 | 46.21 | 36.24 |
|                                   | 90         | 45.89              | 46.98 | 50.03 | 52.36 | 44.38 |

Where, 100:0<sup>a</sup> = 100% HBG and 0% MRCA

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. It was observed that there was a significant increase in compressive strength with the increase in percentage of MRCA from 0% to 30% in all curing periods. After 7 days of curing, 30% MRCA sample exhibited a compressive strength of 35.65 MPa, whereas after 28 days of curing it was 46.21 MPa and after 90 days of curing it was 52.36 MPa. It is to be noted that the significant improvement in compressive strength is mainly due to the blended of aggregates. From the results it is concluded that MRCA acts as filling material which fills the voids of the concrete and hence makes the concrete dense. From the aggregate properties, it is known that MRCA have lower values of crushing and impact strength when compared to those of HBG. The lower value of crushing and impact strength of MRCA is mainly attributed to the decrease in compressive strength of MRCA based concrete mixes. However, when the percentage MRCA was increased to 40% a drastic fall in compressive strength was evidenced irrespective of the time of curing. The compressive strength values of the mixes with 40% replacement of MRCA were found to be 26.51 MPa, 36.24 MPa and 44.38 MPa respectively after 7, 28 and 90 days of curing. The fall in the compressive strength at 40% MRCA can be explained presumably due to the lower value of crushing and impact strength of MRCA is mainly attributed to the decrease in compressive strength of GPC.

The experimental values obtained are depicted in Fig.4.1. This trend of increase in values of compressive strength with increasing MRCA replacement (0% to 30%) and a further sharp fall in compressive strength was observed at 40% of MRCA.



**Fig 5** Compressive strength versus Age

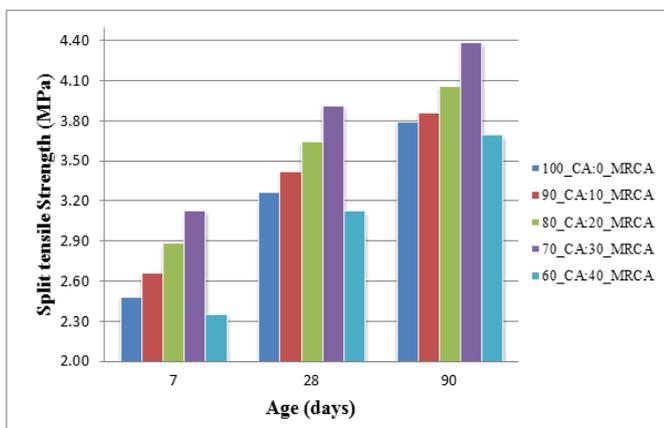
### 4.2 Split tensile strength

Table 3 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 3** Split tensile strength of GPC

| Mechanical property                    | Age (days) | Mix type |       |       |       |       |
|--|------------|----------|-------|-------|-------|-------|
|  |            | 100:0    | 90:10 | 80:20 | 70:30 | 60:40 |
| Split tensile strength, $f_{ct}$ (MPa) | 7          | 2.48     | 2.66  | 2.88  | 3.12  | 2.35  |
|  | 28         | 3.26     | 3.42  | 3.64  | 3.91  | 3.12  |
|  | 90         | 3.79     | 3.86  | 4.06  | 4.38  | 3.69  |

Split tensile strength was also performed by replacing coarse aggregate with from 0% to 40%. The split tensile strength was found to increase with increasing percentage of MRCA up to 30%, independent of the age of curing. A drastic fall of split tensile strength was observed when the MRCA percentage was increased further to up to 40%. The split tensile strength at 30% MRCA was found to be 3.12 MPa after a curing period of 7 days, whereas at 28 and 90 days with 30% MRCA the split tensile strength were 3.91 MPa and 4.38 MPa. It is to be said that MRCA acts as filling material which improves the interfacial transition zone (ITZ) and leads to the improvement of split tensile strength. At 40% replacement of MRCA, the split tensile strength was very low, yielding a value of 2.35 MPa after 7 days of curing. Similarly, at 40% MRCA replacement and after 28 days and 90 days of curing the STS values were observed to be very low yielding values of 3.12 MPa and 3.69 MPa. Hence, it can be recommended to use MRCA at 30% partial replacement of coarse aggregate in order to attain the best results as compare to conventional concrete



**Fig 6** Split tensile strength versus Age

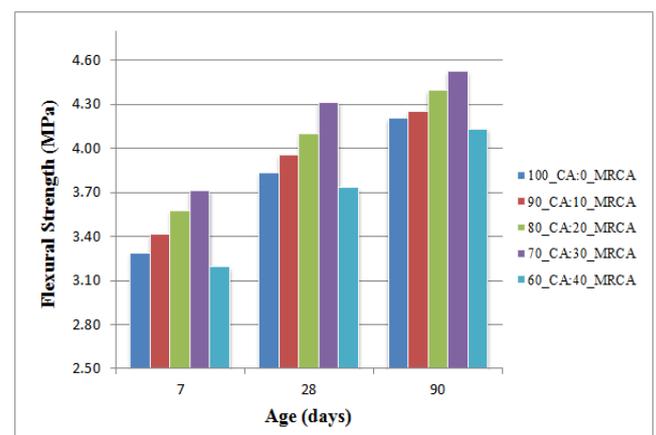
### 4.3 Flexural strength

Table 4 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 4** Flexural strength of GPC

| Mechanical property               | Age (days) | Mix type |       |       |       |       |
|-----------------------------------|------------|----------|-------|-------|-------|-------|
|                                   |            | 100:0    | 90:10 | 80:20 | 70:30 | 60:40 |
| Flexural strength, $f_{cr}$ (MPa) | 7          | 3.28     | 3.41  | 3.57  | 3.71  | 3.19  |
|                                   | 28         | 3.83     | 3.95  | 4.10  | 4.31  | 3.73  |
|                                   | 90         | 4.20     | 4.25  | 4.39  | 4.52  | 4.13  |

Flexural strength was also performed by replacing coarse aggregate with from 0% to 40%. The flexural strength was found to increase with increasing percentage of MRCA up to 30%, independent of the age of curing. A drastic fall of flexural strength was observed when the MRCA percentage was increased further to up to 40%. The flexural strength at 30% MRCA was found to be 3.71 MPa after a curing period of 7 days, whereas at 28 days with 30% MRCA the flexural strength was 4.31 MPa. A significant improvement in flexural strength up to 4.52 MPa was observed after 90 days of curing. It is to be pointed out that MRCA acts as filling material which improves the interfacial transition zone (ITZ) and leads to the improvement of flexural strength. At 40% replacement of MRCA, the flexural strength was very low, yielding a value of 3.19 MPa after 7 days of curing. Similarly, at 40% MRCA replacement and after 28 days and 90 days of curing the flexural strength values were observed to be very low yielding values of 3.73 MPa and 4.13 MPa.



**Fig 6** Flexural strength versus Age

## V CONCLUSIONS

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. 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 concrete. The maximum compressive strength of geopolymer concrete for 7 days, 28 days 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 7 days, 28 days, 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 7 days, 28 days and 90 days curing period is 3.71 MPa, 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.

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