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Experimental Study on Partial Replacement of Cement by GGBS and Fly Ash in Conventional Concrete

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***Abstract:** Cement concrete is widely used in industrial plants, civil infrastructures, wastewater treatment plants and pipelines. It is a highly prone to acid attacks from the surrounding environment. Since acidic environments will accelerate the deterioration of concrete, various types of polymer coating materials are being used to protect the concrete surfaces. Hence an attempt has been made in this investigation on partial replacement of cement with GGBS along with incorporation of fly ash of 20% of the volume of concrete. Various strength parameters of the concrete specimens are tested. The combination used is GGBS with 10%, 20%, 30%, 40% by the weight of cement for M25 grade concrete at an age of 7 days, 28 days and 56 days. Cubes are cast, curried and tested to assess the influence of partial replacement of cement with fly ash and GGBS and then found the optimum content as 20% of GGBS and fly ash 20% from the experimental results. Then final combination is 20% of cement with GGBS along with incorporation of fly ash of 20% percentages of the volume of concrete. The compressive strength values are increased by 10% than those of conventional concrete mixture at a mixture prepared with 20% GGBS and 20% Fly ash. Further increase in GGBS percentage with constant fly ash percentage proved its incompatibility nature where it is shown low strength when compared with controlled concrete mix. X-ray Diffraction (XRD) technique has also been used to get insights into the quality and composition of the concrete, aiding in the assessment of its suitability for specific construction applications.*
***Keywords:** Fly ash, GGBS, workability, compressive strength, split tensile strength, flexural strength, X-ray Diffraction (XRD).*

I. INTRODUCTION

The most predominately used binder in concrete is blended cement. Now a days construction industry is looking for different construction materials as a replacement to conventional concrete in view of its environmental behavior. The Ordinary Portland Cement (OPC) is one of the main ingredients used for the production of concrete and has no alternative in the civil construction industry. Unfortunately, production of cement involves emission of large amounts of carbon-dioxide gas into the atmosphere, a major contributor for greenhouse effect and the global warming, hence it is inevitable either to search for another material or partly replace it by some other material. The search for any such material, which can be used as an alternative or as a supplementary for cement should lead to global sustainable development and lowest possible environmental impact. Substantial energy and cost savings can result when industrial by products are used as a partial replacement of cement. Fly ash, Ground Granulated Blast Furnace Slag, rice husk ash, High Reactive Metakaolin, silica fume are some of the pozzolanic materials which can be used in concrete as partial replacement of cement. A number of studies are going on in India as well as abroad to study the impact of use of these pozzolanic materials as cement replacements and the results are encouraging. Addition of fly ash to concrete has many advantages like high strength, durability and reduction in cement production.

The concrete containing Ground Granulated Blast Furnace Slag (GGBS), on vibration becomes ‘mobile’ and compacts well. Silica fume greatly reduces, or even eliminates bleeding; the particle of Pozzolanic Fly Ash (PFA) is spherical and thus improves the workability. Their inclusion has the physical effect of modifying the flocculation of cement, with a resulting reduction in the water demand. The pore size in concrete is smaller. The fine particles ‘fit in between cement particles, thereby reducing permeability. The Fly ash (FA), Ground Granulated Blast Furnace slag (GGBS), Silica fumes being finer than OPC, less bleeding is observed. The freshly placed concrete is very stable, being very cohesive and having strong internal cohesion. This has a negative effect in the form of plastic shrinkage. The workability increases, and thus water content can be reduced by about 3%. Recent research evaluated the behavior of concrete made with Supplementary Cementations Materials (SCMs) such as fly ash and Ground Granulated Blast-Furnace Slag (GGBS) under a various condition.

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Correlations were found among the source and proportion of the Supplementary Cementations Materials (SCM), curing conditions, concrete set time, maturity, strength development, and cracking potential. The production of GGBS is more environmentally friendly compared to the production of OPC, thus producing a more environmentally friendly concrete than the OPC concrete. In this paper, an attempt has been made to study the effects of GGBS as a constant replacement of cement on durability and mechanical properties of concrete and its scope to address environmental pollution caused by industrial by-products.

II. MATERIALS USED

The physical properties of cement, fine aggregates, coarse aggregates, fly ash, GGBS and water used for mix design of M25 grade of concrete were tested in laboratory and are mentioned below.

A. Cement

Ordinary Portland cement of 53 grade cements conforming to IS 8112-1989 is used for the present experimental investigation. Cement was tested as per the procedure given in IS: 4031 and IS: 4032. The physical properties of the cement used are as listed in Table 1

Table 1 Physical Properties of Ordinary Portland Cement

S. No.	Properties	Test Values
1.	Specific Gravity	3.13
2.	Consistency (%)	30
3.	Initial setting time	90 min
4.	Final setting time	230 min

B. Fine Aggregate

The fine aggregate conforming to IS 383-1970 in zone-II is used in mix. The sand which was locally available and passing through 4.75mm IS sieve size was used as fine aggregate. The physical properties of the fine aggregates are as listed in table below:

C. Coarse Aggregates

The coarse aggregates with nominal maximum size of aggregates as 20mm (60%) and 10mm (40%) as per Indian standard were used. The physical properties of the coarse aggregates are as listed in Table 2

Table 2 Physical Properties of Coarse Aggregates and fine aggregates

S. No.	Properties	Coarse aggregates	Fine aggregate
1.	Specific Gravity	2.84	2.65
2.	Water absorption	0.5%	1.1%
3.	Fineness modulus	7.28	2.62

D. Ground Granulated Blast Furnace Slag (GGBS)

Ground Granulated Blast Furnace Slag (GGBS), also known as slag cement or simply slag, is a byproduct of the iron and steel industry. The GGBS was procured from the JSW cement industry, Chennai.

E. Fly ash

Fly Ash is the finely divided mineral residue resulting from the combustion of powdered coal in Thermal power plants. The fly ash (class F) has been taken from the NTPC Simhadri Thermal power plant situated at near Vishakhapatnam.

Table 3 Physical and Chemical Properties of Fly ash and GGBS

S. No.	Properties	Cement	Fly ash	GGBS
1.	Specific gravity	3.13	2.05	2.85
2.	Magnesia (MgO), %	1.39	1.96	7.73
3.	SiO_2 Content, %	19.35	60.87	34.4
4.	CaO Content, %	68.64	1.110	40.5
5.	Fe_2O_3, %	1.21	6.08	2.62
6.	Al_2O_3, %	4.57	26.47	11.5

The physical and chemical properties of Fly ash and GGBS are shown in Table 3.

F. Water

Potable water was used for mixing and curing which was free from any amounts of oils, acids, alkalis, sugar, salts and organic materials or other substances that may be deleterious to concrete or steel confirming to IS: 3025 – 1964 part 22, part 23 and IS: 456 – 2000 [Code of practice for plain and reinforced concrete]. The pH value should not be less than 6. The solids present were within the permissible limits as per clause 5.4 of IS: 456 – 2000.

III. METHODOLOGY

The aim of this paper is to study the effect of fly ash on compressive strength of concrete by partial replacement of cement with fly ash by 20% constant and varying with 10%, 20%, 30% and 40% of GGBS. The concrete mix of M25 grade was prepared as per IS10262:2009 having mix design ratio as 1:2.13:3 and w/c ratio of 0.45. To carry out the experimental investigation total 30 cubes of size 150mm x 150mm were casted. The compressive strength of specimens is determined after 7days, 28 days and 56 days of curing respectively with surface dried condition as per Indian Standards. Moulds size 150 x 150 x 150mm was used for evaluation of compressive strength. This ultimate load divided by the cross-sectional area of the cube (150mm x 150mm) yields the compressive strength of concrete.

Splitting tensile strength is an indirect method to determine tensile strength of concrete. Splitting tensile strength of concrete was evaluated at age of 7 days, 28 days and 56 days using standard cylindrical specimens of 150mm diameter and 300mm height. Compression Testing Machine (CTM) of 5000 KN capacity was used for the testing of compressive strength of concrete.

When concrete is subjected to bending stress, Compressive as well as tensile stresses are developed at top and bottom fibers respectively. The strength shown by the concrete against bending is known as flexural strength. The standard size of specimen is 150mm x150mm x700mm. The flexural beam specimens are tested at 7 days, 28 days and 56 days. The average of three specimens was reported as the flexural tensile strength. Different mixes with varying combinations of GGBS and fly ash are considered for testing. Various tests are done on concrete at both fresh and hardened stage to evolve the Performance of the concrete. The combinations used are described below.

- **M_1**= Control mix
- **M_2**= 70% OPC+10 %GGBS+20% FA
- **M_3**= 60% OPC+20 %GGBS+20% FA
- **M_4**= 50% OPC+30 %GGBS+20% FA
- **M_5**= 40% OPC+40 %GGBS+20% FA

Figure 1 shows the slump cone test performed, Figure 2 shows the compressive strength test, Figure 3 shows the split tensile strength test and Figure 4 shows the flexural strength test performed in the laboratory. Table 4 gives the mix weighs of various material used per m^3 of concrete.

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Fig. 1 Slump Cone Test

Fig. 2 Compressive Strength Test

Fig. 3 Split Tensile Strength Test

Fig. 4 Flexural Strength Test

Table 4 Quantities of materials used for various mixes for 1 m^3

S. No.	Materials used, kg/m³	Mass of materials for various mixes (in Kg for $1m^3$)				
		M_1	M_2	M_3	M_4	M_5
1	Cement	385.22	269	231	192.5	154
2	GGBS	0.0	38.5	77	115.5	154
3	Fly ash	0.0	77	77	77	77
4	Fine aggregate	821.50	821.50	821.50	821.50	821.50
5	Coarse aggregate	1152	1152	1152	1152	1152
6	Super Plasticizer	4.235	4.235	4.235	4.235	4.235
7	Water	157.6	157.6	157.6	157.6	157.6

IV. X-RAY DIFFRACTION (XRD) ANALYSIS

Divergence could be a physical paradox that's composed in EM radiation warding off limitations in case the scale of the barriers matches to the frequency. This paradox has carried out for the investigation of specimens since the particle plans are positioned at similar stretch to X ray lengths. X rays are EM waves much like light, but whose frequency is more concise (λ=0, 2 to 200 Å). XRD is generated as a reflection at legitimately characterized viewpoints. Each crystalline segment has its self-diffraction picture.

For the XRD assessment we utilize diffraction gadgets, particularly admit to the Bragg–Brentano framework. The basic pattern revolves at a divergent attitude as "θ", even as the sensor revolves at the angle of "2θ".

A series of divergent peak values are inverted by the equipment called diffractogram. Then the range of depth of the divergent X ray is displayed and measured in the form of pulses or second. Along with this, the Bragg angle is also determined in terms of degrees and it is denoted as "θ". Each structure of the specimen has its own divergent image depends on the individual type.

The diffraction system permits overall execution in subsequent research: The details of crystalline structures were found in terms of qualitative and quantitative investigation. The segment alterations were examined for the identification of many factors such as the crystallographic type, the scale of the inner components of the particular specimen and many others. The X ray divergent technique is used to describe and complete the crystalline phases, if the respective phase Imitate extra of 3 to 4% mass. Few software's are used to explain the Bragg's relationship, shown in (1) such as match software, in the Powder Diffraction File (PDF) database.

$$2d\sin\theta = n\,\lambda \tag{1}$$

Where,
d is the spacing between diffracting planes,
θ is the incident angle,
n is an integer,
λ is the beam wavelength.

The fine powder was then sieved through a sieve of 60 micron and portion of the powder passing 60 microns was used for X-ray diffraction testing. X-ray diffraction pattern was recorded with X-ray diffractometer with Cu Kα radiation (λ= 54 Å) at diffraction angle 2θ ranged between 10° to 80° in steps of 2θ = 0.013°. Different phase present in the cement paste at 28days were identified analysing the peaks of X-ray diffraction patterns with the help of 'X' Pert High Score Plus" software tool. Figure 5 illustrates the X-Ray diffraction principle.

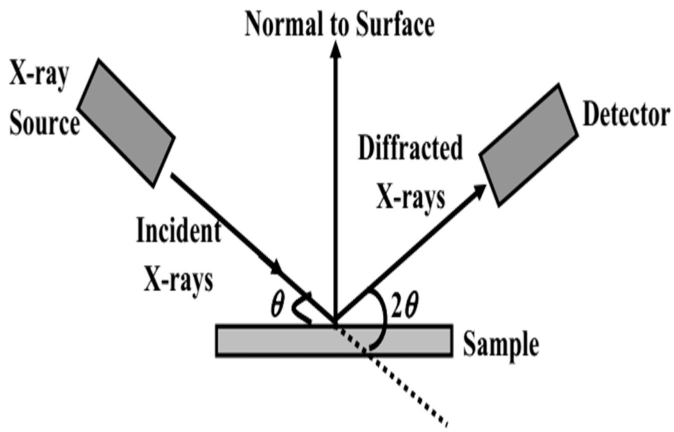

Figure 5 X-Ray Diffraction Principle

V. RESULTS AND DISCUSSIONS

A. *Slump Cone Test*

The slump cone test is being used to examine the workability of concrete; the slump cone testing was carried on all five mixtures. The slump values of various blends are represented in Table 5.

Table 5 Slump values for different % of GGBS and Fly ash

S.NO	Mix Id	% of GGBS	% of Fly ash	Slump in mm
1	M_1	0	0	90
2	M_2	10	20	85
3	M_3	20	20	77
4	M_4	30	20	65
5	M_5	40	20	55

The average value of slump obtained for various mix combinations is plotted in Figure 6.

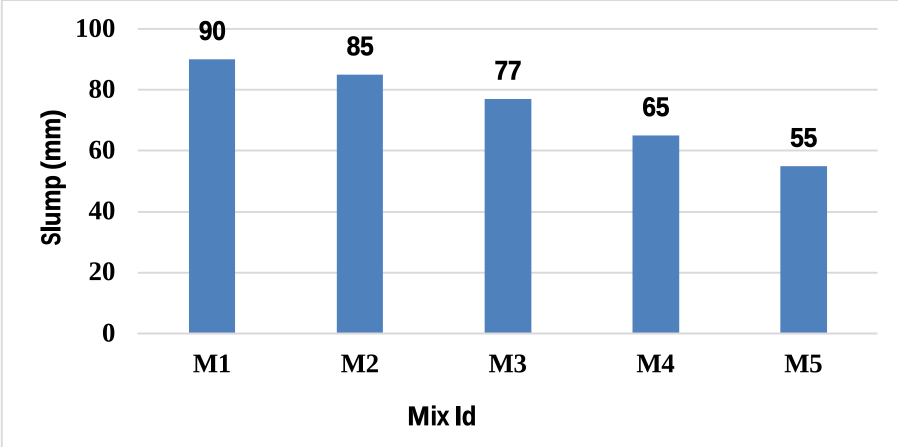

Fig. 6 Influence of GGBS on Slump (mm)

Specimens of M25 grade are cast as per the procedure laid down in IS 456:2000 for the specified mix combinations. After 24 hours, the test specimens are demoulded and placed in fresh water tank for curing. After 7 days and 28 days they are tested for Compressive strength, Split tensile strength, Flexural strength. Based on 28 days strength Optimized % replacement of respective materials is determined

B. *Compressive Strength Test*

The compressive strength test on concrete was done on 150mm x 150mm x 150mm cubes. Testing of the specimens was done at 7 days and 28 days at the rate of three cubes for each mix that particular day. Figure 7 shows the compressive strength variation amongst the mix combinations. The average valued of the 3 specimens is reported as the strength at that particular age.

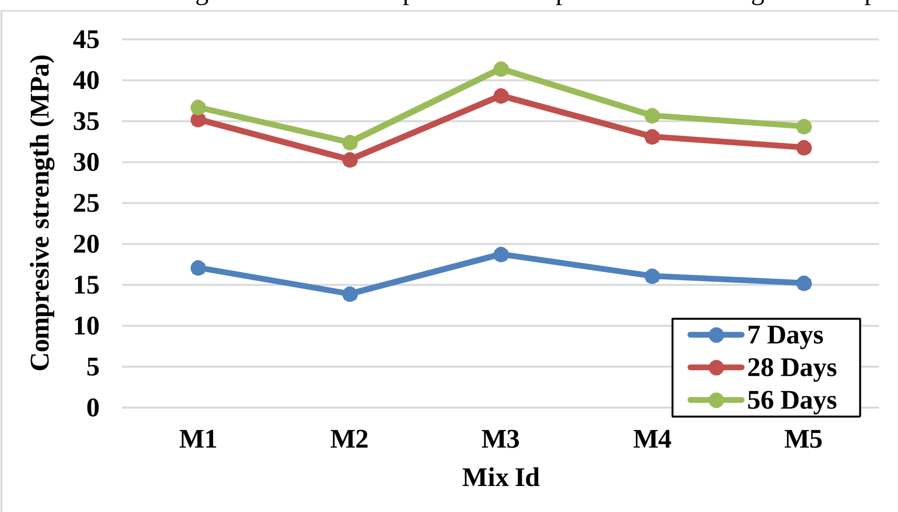

Fig. 7 Compressive Strength for various mixes at 7 ,28 & 56 days

Observations

- Control mix concrete has 28 days compressive strength as 35.25 N/mm^2
- Concrete with 20% replacement of cement with GGBS and 20% Fly ash attained maximum Compressive strength i.e., 38.15 N/mm^2 which is more than 1.9 N/mm^2 when compared with control concrete mix.
- Minimum Compressive strength attained was 30.30 N/mm^2 at which cement is replaced with 10% GGBS and 20% fly ash.
- It is observed that with further increase in the percentage of 20% of GGBS with 20% of Fly ash, Compressive strength is decreasing, indicating incompatibility nature between GGBS and fly ash.

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C. Split Tensile Strength Test

The tensile strength was measured on 150mm diameter and 300mm height cylinders and results were shown in Figure 8. A total of 30 cylinders were cast for the replacement mixes. Three specimens were tested each time for every mix and average value at the particular age was reported as the tensile strength of the concrete.

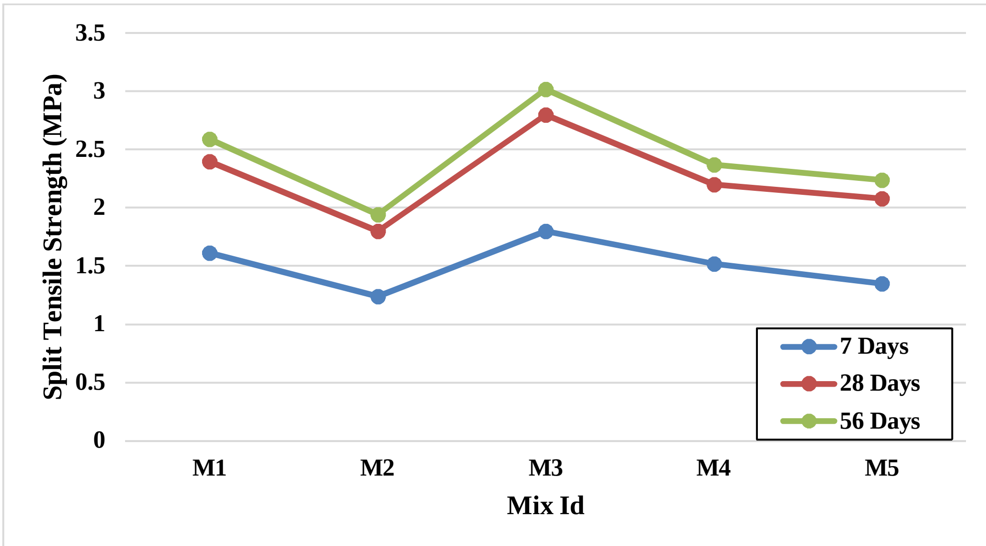

Fig. 8 Split Tensile Strength for various mixes at age 7, 28 & 56 days

Observations

- Control mix concrete has 28 days Split tensile strength as 2.5 N/mm^2
- Concrete with 20% replacement of cement with GGBS and 20% fly ash attained maximum Split tensile strength i.e., 2.80 N/mm^2 which is more than 0.3 N/mm^2 when compared with control concrete mix.
- Minimum Split tensile strength attained was 1.8 N/mm^2 at which cement is replaced with 10% GGBS and 20% fly ash.
- It is observed that with further increase in the percentage 20% of GGBS with 20% of Fly ash, split tensile strength is decreasing indicating incompatibility nature between GGBS and fly ash.

D. Flexural Strength Test

The strength shown by the concrete against bending is known as flexural strength. The standard size of specimen is 150mm x150mm x700mm. The flexural strength variation is depicted in Figure 9.

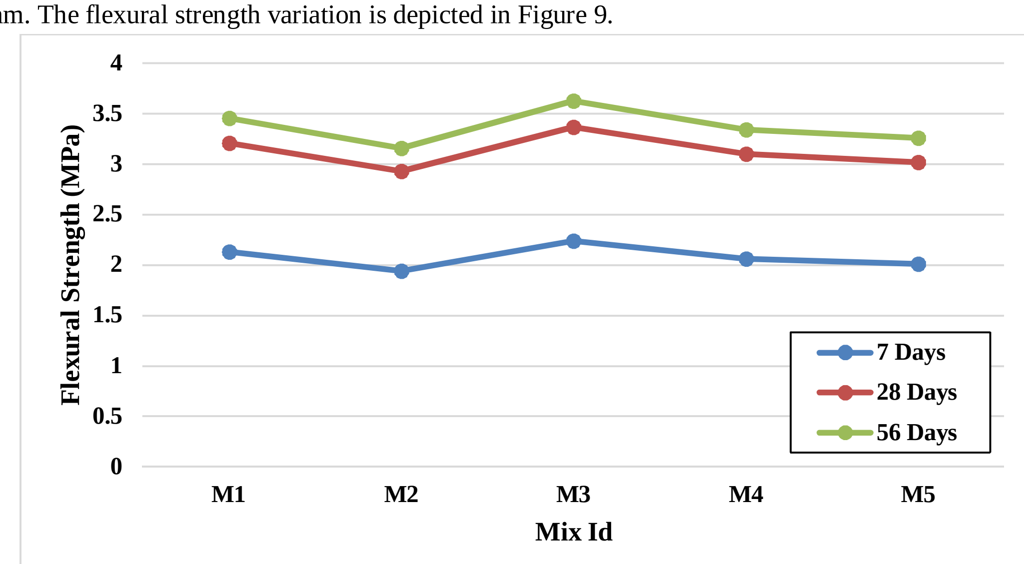

Fig. 9 Flexural Strength for various mixes at age 7, 28 & 56 days

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Observations

- Control mix concrete has 28 days Flexural strength as 3.21 N/mm^2
- Concrete with 20% replacement of cement with GGBS and 20% fly ash attained maximum Flexural strength i.e., 3.37 N/mm^2 which is more than 0.16 N/mm^2 when compared with control concrete mix.
- Minimum Flexural strength attained was 2.93 N/mm^2 at which cement is replaced with 10% GGBS and 20% Fly ash.
- It is observed that with further increase in the percentage of 20% of GGBS with 20% of Fly ash, Flexural strength is decreasing, indicating incompatibility nature between GGBS and Fly ash.

The compressive strength, split tensile strength and flexural strength values for all mix combinations are tabulated in Table 6.

Table 6 Compressive strength, split tensile strength and flexural strength values of various mixes at 7 days, 28 days & 56 days

MIX ID	% of GGBS	% of Fly ash	Compressive strength (MPa)			Split tensile strength (MPa)			Flexural strength (MPa)		
			7 days	28 days	56 days	7 days	28 days	56 days	7 days	28 days	56 days
M_1	0	0	17.10	35.25	36.76	1.61	2.40	2.59	2.13	3.21	3.46
M_2	10	20	13.94	30.30	32.47	1.24	1.80	1.94	1.94	2.93	3.16
M_3	20	20	18.74	38.15	41.40	1.80	2.80	3.02	2.24	3.37	3.63
M_4	30	20	16.12	33.13	35.75	1.52	2.20	2.37	2.06	3.10	3.34
M_5	40	20	15.25	31.82	34.36	1.35	2.08	2.24	2.01	3.02	3.26

E. X-Ray Diffraction (XRD) Analysis

The XRD analysis is studied at room temperature using powder X – Ray diffraction with wavelength of 1.541874Å. Specimens are inspected in an uninterrupted method of 2 theta between 10º-100º at a rate of one second. The X-Ray powder diffraction gives the graph between the intensity of the X – Ray light which is scattered on the sample and angle difference of the deflected X – Rays. The X – Ray powder diffraction was done on two samples i. e; controlled concrete(M1) and Optimum Concrete mix (M3) samples.

1) XRD for Controlled Concrete Mix

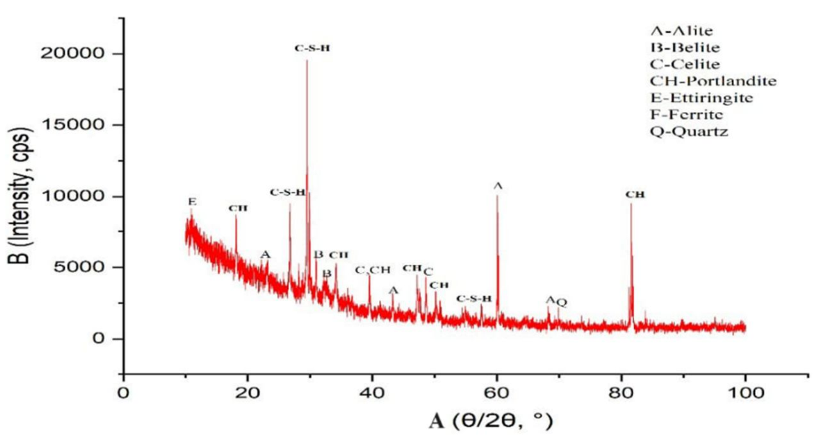

Fig. 10 X-ray diffractogram of controlled concrete(M1)

Figure10 represents the XRD analysis of controlled concrete mix from which following observations are recorded

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Observations

- It can be observed that at age of 28 days for a controlled concrete mix, various phases present in control concrete were Quartz (Q), Alite (A), Bellite (B), Celite (C), Ferrite (F).
- Diffractogram shows a sharp peak of C-S-H (intensity 20000cps) and C_2S(Belite) peaks are observed which are dominant in control concrete indicating strength enhancement.
- Peaks of Alite and Quartz are formed due to the hydration of cement.
- CH (portlandite) denotes the concrete having low porosity.

2) XRD for Optimum Concrete Mix

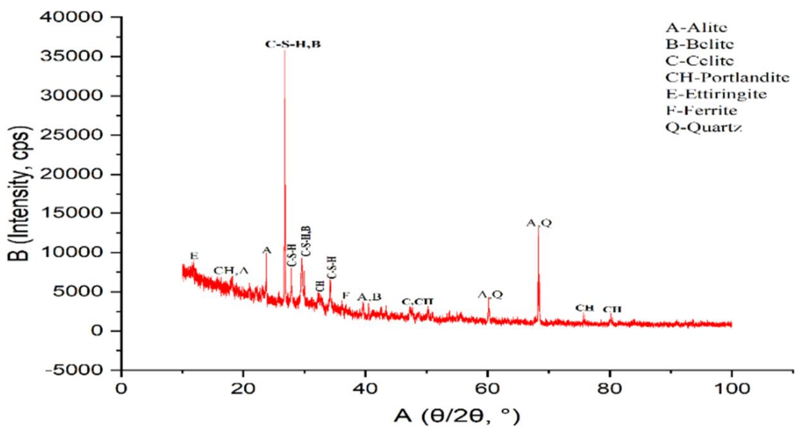

Fig. 11 X-ray diffractogram of optimum concrete(M3)

Figure 11 represents the XRD analysis of optimum concrete mix from which following observations are recorded

Observations

- Highest peak with intensity more than 38000cps was observed indicating huge amount of C-S-H gel formation which is responsible for the strength in concrete
- Few peaks of Alite, Celite and quartz were observed denoting high initial strength
- Peaks of ferrite was observed which is not having significance regarding engineering properties
- CH (portlandite) denotes the concrete having low porosity.

VI. CONCLUSIONS

This experimental study shows that the combination of fly ash and GGBS will enhance the performance of the concrete in terms of Workability & Mechanical properties. The following conclusions were drawn:

1) The Cement replacement by 20% Fly ash and 20% GGBS gives a gradual increase in compressive strength.
2) It can be observed at 7 days Compressive strength of M3 mix (20% FLYASH & 20% GGBS) is more than that of M1 mix (Controlled mix) by 9.59%., 28 days compressive strength of M3 mix is more than that of M1 mix by 8.22% and 56-days compressive strength of M3 mix is more than that of M1 mix by 12.62%.
3) It can be observed at 7 days Split tensile strength of M3 mix (20% GGBS & 20% FLYASH) is more than that of M1 mix (Controlled mix) by 11.80%, 28 days Split tensile strength of M3 mix is more than that M1 mix by 15.66% and 56 days Split tensile strength of M3 mix is more than that M1 mix by 16.66%.
4) It can be observed at 7 days Flexural strength of M3 mix (20% GGBS & 20% FLYASH) is more than that of M1 mix (Controlled mix) by 5.16%, 28-days flexural strength of M3 mix is more than that M1 mix by 4.98% and 56-days flexural strength of M3 mix is more than that M1 mix by 5.0 %.
5) Considering the mechanical behaviour, the optimum mix is M3 mix i.e., Cement replaced with 20% Fly ash and 20% GGBS.
6) It also shown that workability decreases with increase in GGBS %.

7) Further replacement of cement with Fly ash and GGBS shown decreased strength which shows the incompatibility nature of materials used.
8) It is observed that from the XRD Analysis Results, a sharp peak of C-S-H, Bellite which are responsible for early age strength and small peak of CH indicates low porosity which may reduce corrosion.

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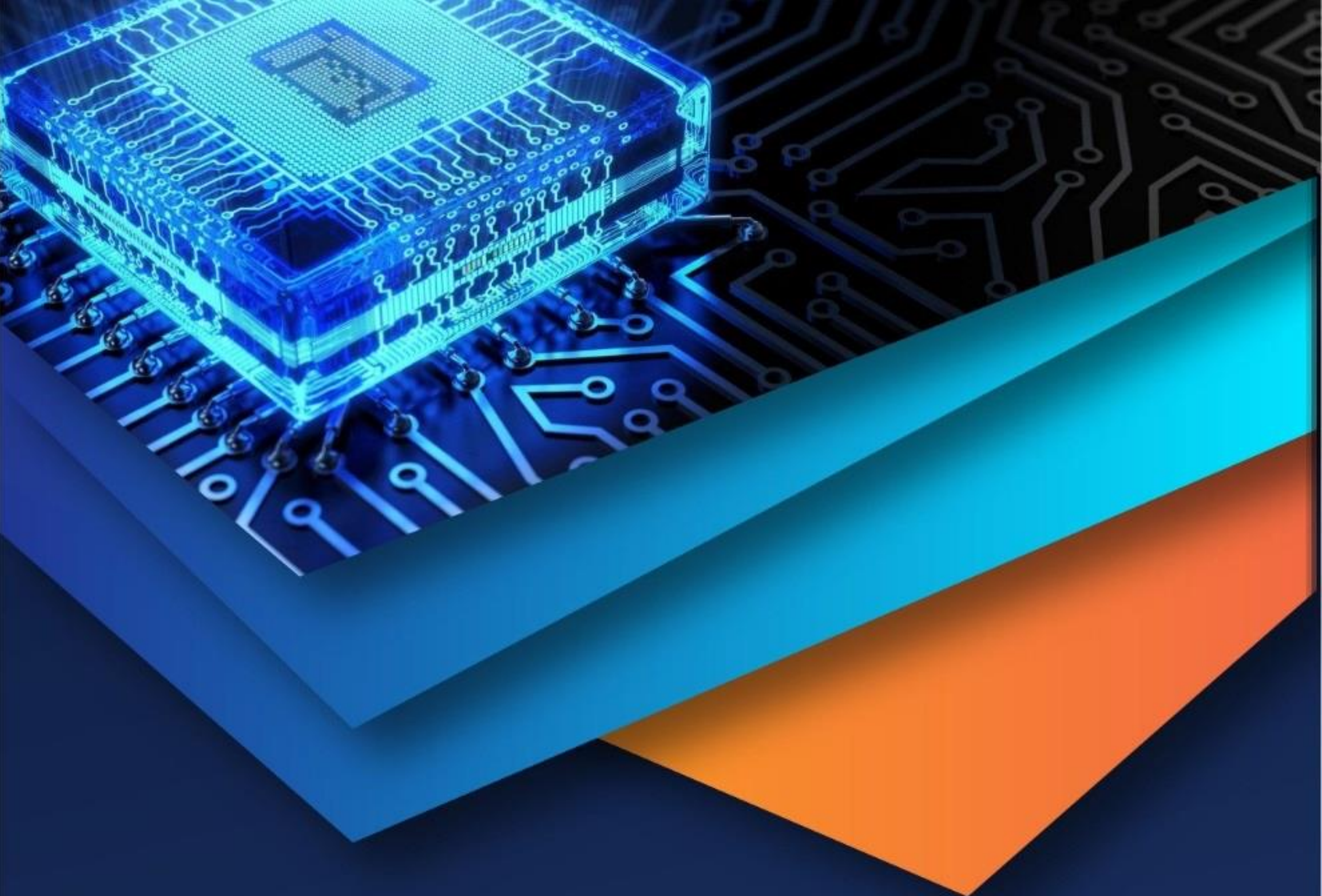

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