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Original Article

Experimental Analysis on GGBS and Fly Ash in Geopolymer Concrete

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***Abstract** - From modest buildings to large dams and reservoirs, concrete is widely used in construction. The second highest product consumed globally is taken as cement. But the trade of cement releases CO_2 into the climate, which significantly contributes to global warming. In contrast to Ordinary Portland Cement (OPC) based concrete, Geopolymer Concrete (GPC) is a unique method of concrete that is produced from industrial wastes like fly ash as well as GGBS. With the use of geopolymer, concrete constituents are replaced and it decreases the amount of cement required in the construction sector. This paper represents the study of mechanical and microstructural features of various GPC mixes. To achieve the various qualities of concrete, cement is substituted for Fly Ash (FA) and ground Granulated Blast Furnace Slag (GGBS) at ratios of 40% and 60%, respectively. In this investigation, fly ash, sodium silicate as well as Sodium Hydroxide (Na2SiO3) are employed to make the concrete mix. To establish the mechanical characteristics of GPC, specimens are cast and allowable to cure for different curing times for M25 and M50 concrete, such as 7 and 28 days at ambient room temperature. GPC is tested under split tension strength, flexural strength as well as compressive strength, which are analysed in this paper. Moreover, it is undertaken to examine the geopolymer specimens' microstructure, phase composition, and heat stability, respectively. Fly ash and GGBS concrete work well at 7 and 28 days compared to the conventional techniques.*

***Keywords** - Geopolymer, Fly Ash, GGBS, Ordinary Portland Cement, Na_2SiO_3, SEM-EDX, Microstructure.*

1. Introduction

A mixture of fine aggregate, water, cement, and coarse aggregates is used to create the man-made material known as concrete. Cement concrete became a popular construction material during the past century. [1]. As a result, there is an increasing demand for natural gas on a global scale as a low-CO_2 energy source. [2] Magnesium (Mg) alloys are the lightest metal structural materials, and as a result, they have many potential applications in the aeroplane, automobile, and electronic business sectors.

This has greatly improved their development in response to the growing concern over energy efficiency and CO2 emission reduction [3]. Due to its importance in infrastructure and building, the manufacture of lightweight concrete has seen significant growth, and its use has been rising globally [4].

Construction sectors are focused on introducing sustainable alternatives to OPC in order to reduce greenhouse gas emissions while maintaining OPC's strength and durability. [5]. Geopolymer, is a subset of organic chemistry, which is the most effective cement substitute in the building industry. Fly ash, GGBS, metakaolin and wood ash are examples of waste by-products that were used to create an amorphous polymer. [6-7]. Superior features of geopolymer include its favourable mechanical properties, toughness, ability to absorb heavy metals and solidification. It combines with the qualities of both: Cement and polymer [8-9]. In order to create Geopolymer Concrete (GC), which has replaced Conventional Portland Cement (CPC) concrete, materials like FA, slag As well as rice husk ash are high in alumino silicate, which is examined, as well as there was a demand for fibre, that increases impact strength as well as energy absorption. [10].

There are issues about the susceptibility of fly ash-based GPC when exposed to actual fire measures when its fire resistance is related to OPC-based concrete. [11]. The potential for creating an environmentally friendly GGBFS-RGP-based geopolymer system after this phase completely evaporated during hydrothermal treatment at 4 bar/8 hours after activating 50% GGBFS and 50% RGP using two different applications of sodium hydroxide solution [12]. Because of the increasing demand for river sand, synthetic sand is utilised in GPC under ambient curing conditions as a replacement material. Further research on flexural has been chosen to use a geopolymer concrete mix [13]. The qualities of geopolymer concrete are excellent in both acidic and salty situations. In comparison to Portland cement, geopolymer manufacturing has higher relative strength, better volume stability as well as superior durability. [14]. Because of its mechanical qualities and benefits over ordinary concrete, fibre reinforced GPC has developed from new material to an effective and extensively used material; nevertheless, because of its higher production cost, its use in the public works sector has been restricted. [15]. Because natural fibres' density and hydrophilic properties determine how workable geopolymer composites the reinforcing hybridisation effect caused by natural fibres in geopolymer concrete is produced [16].

In the creation of GPC, sodium silicate was utilised as an accelerator with steel slag as well as oyster shells as precursors. Due to the mechanical result, it is used as a walling as well as non-loading bearing material [17]. Compared to binary and quaternary blended GPC, ternary blended GPC showed greater resistance to chloride permeability, sorptivity, and HCL damage. [18]. by using GC, industrial by-products will be sustainably used, and it is used as a cutting-edge cementitious material that emits less CO2 than regular concrete [19].

In a recent study, an effort was made to explore the GGBS and Metakaoline-based strength parameters of geopolymer concrete. It demonstrates that the geopolymer reaction is still occurring, albeit more quickly, after 7 days. [20]. Experimental investigations into mechanical and microstructural features of GP paste and concrete based on FA-GGBSHMNS were undertaken. Then the SEM analysis revealed the generated Geo Polymer concrete is more compact, with a dense matrix as well as fewer pores. [21].

In this paper, a thorough analysis of the microstructural and mechanical characteristics of GPC is explored using both FA and GGBS in place of cement. The proposed design offers improved compressive strength, split tensile strength, flexural strength, and lower CO2 emissions than conventional concrete. Thus, this study illustrates that concrete made with fly ash as well as GGBS achieves higher performance in 7 and 28 days than conventional concrete. Moreover, this study proposes the SEM-EDX to determine the materials for surface cracks, impurities and corrosion.

2. Experimental Study

2.1. Materials Used

2.1.1. Fly Ash and GGBS

Figure 1 (a) illustrates the low calcium Class F type FA, which is a coal combustion residue and is removed from the flue gases of thermal power plants using mechanical or electrostatic precipitators. FA has a specific gravity of 2.1, and it is analysed with IS: 3812-1981. It was a waste product which was produced by many industries and other sources. In geopolymer concrete, GGBS is utilised as a curing agent. It is kept in tight bags, as displayed in Figure 1(b). The probability of Alkali-Silica reaction and reinforcing corrosion damages is diminished significantly by the use of GGBS. The GGBS has a specific gravity of 2.6. In this geopolymer concrete, GGBS is utilised mostly in place of cement.

Fig. 1 (a) Fly ash (class F), and (b) GGBS.

2.1.2. Fine Aggregate and Coarse Aggregate

As seen in Figure 2(a), this paper utilises natural M sand as the fine aggregate, which is collected from nearby sources. Fine material is retained on an IS 150 micron sieve after passing through an IS 4.75mm sieve. The aggregate is made up of sand, gravel, and naturally existing crushed and uncrushed stones, as represented in Figure 2(b). It is strong, durable, clear, hard, and dense as possible, free of adherent coating, disintegrated pieces, alkalis as well as other harmful substances. When selecting the coarse aggregate, Avoid flaky and elongated particles. The 20mm sieve passing and 12.5mm retained aggregates from a local crusher are employed in this study.

Fig. 2 (a) Fine aggregate, and (b) Course aggregate.

2.1.3. Water

Concrete mixing and curing are done with potable water, which was near the lab. In this study Small amount of water is taken for mixing of concrete.

2.1.4. Sodium Hydroxide and Sodium Silicate

Figure 3(a) demonstrates the NAOH. To create a solution, sodium hydroxide is diluted with water to the necessary concentration and it has a specific gravity of 2 analysed in this study.

As shown in Figure 3(b), sodium silica is purchased as a gel from a supplier with a specific gravity of 1.69. Sodium silicate as well as sodium hydroxide solutions mix ratio of 2.5:1 is used in this study.

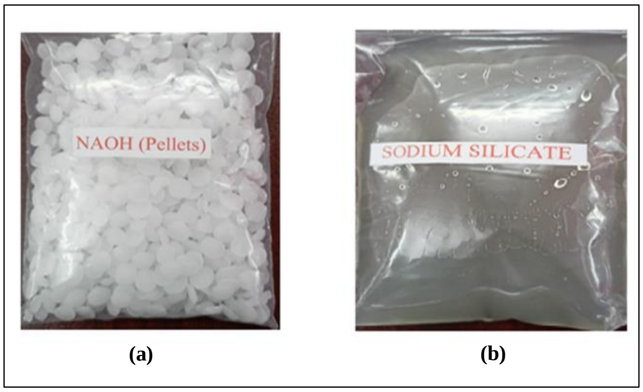

Fig. 3 (a) Sodium silicate, and (b) Sodium silicate.

2.1.5. Super Plasticisers

Super plasticiser, as specified in Figure 4, is used to enhance the material's high workability. To sustain the workability of concrete, it is employed to decrease the water content. The super plasticiser, which is 0.1% by weight of cement and is based on Naphthalene Formaldehyde Polymers, is employed in this study.

Fig. 4 Super plasticiser

3. Preparation of Test Specimen

3.1. Mixing

Initially, all the ingredients were placed in one location before beginning the mixing process and first determined the exact amounts of each ingredient were needed. After the computation of the aggregate amount, the determination of fine aggregate is placed in the mixing tray**.** To prepare the dry mix, the aggregate and sand combination was manually combined in a tray. In the calculated quantity, fly ash was put into the mixing tray.

In order to create an optimal solution of alkaline activators, NAOH and sodium silicate were combined in the measuring cylinder. This solution was then poured into the tray**.** Then, the tray was filled with the necessary amount of water combined with the estimated amount of admixture. This entire mixture was once again combined in the tray, which provided the Geopolymer concrete (which is utilised to create the specimens). All dry ingredients were initially properly blended for three minutes. A stable amount of alkaline activator solution is added to the mixture. To produce a uniform mix and, the mixing is done for five minutes.

3.2. Casting

In this investigation, cement is replaced with various combinations based on an estimated amount of Fly ash and GGBS. Moulds are instantly filled with properly formulated geopolymer concrete. In order to make specimens of thoroughly compacted geopolymer concrete, concrete is poured into three layers and tamped with more than 25 blows for each layer. A well-finished top surface is then formed. Moulds in the sizes of a cube (150mmx150mmx150mm) and a cylinder (150mm dia and 300mm height. To determine compressive strength, fresh concrete is cast into cubes measuring. The preparation of the specimens was followed by the IS 516-1953. With a tamping rod, 25 manual stocks are applied for each layer to produce compaction. There is no additional effort made to create a smooth surface.

3.3. Curing

Moulds were removed after 24 hours and left at room temperature for curing purposes. 38^0C is the average temperature which was tested throughout the curing process. The curing is carried out for 7 and 28 days in M25 and M50 grade concrete.

4. Experimental Test

4.1. Compression Test

The first step is to make a geopolymer concrete mix, including GGBS and fly ash. Cube specimens with a 150mm diameter are prepared to be tested after 7 and 28 days for casting in M25 and M50 concrete. The Cubes are cured at room temperature after casting. Subsequently, the specimens undergo a compression test, as depicted in Figure 5. With compression testing equipment with a 3000KN capability, the cubes are evaluated for compressive strength. Up to the specimen's failure, the load was applied consistently. A horizontal specimen was inserted between the compression testing machine's loading surfaces, and a shock-free force was exerted until the specimen failed. The cubes are broken when the curing period is over in order to determine their strength.

Fig. 5 Compression test setup

4.2. Split Tensile Test

To analyse the splitting tensile behaviour of GPC, cylindrical samples of 200mm in height and 150mm in diameter are constructed. Different fly ash and GGBS percentages are integrated into cylinders. The specimens are evaluated for split tension in a universal testing machine for ambient curing temperature after 7 and 28 days for M25 and M50 grade concrete. This type of concrete is established in the laboratory by compressive testing machine, as represented in Figure 6, the period of 7 and 28 days curing by casting cylinders of size150mm×300mm, as seen in the below figure.

Fig. 6 Split tensile test setup

4.3. Flexural Test

The preparation of beam specimens having a cross-sectional area is performed for the flexure test. The specimens are also cast with GGBS replacement levels ranging from 0 to 40% cement. After exposure, the samples are cured under ambient temperature for 7 and 28 days for M25 and M50 grade concrete. As demonstrated in Figure 7, the specimens are placed through a flexural strength test.

Fig. 7 Flexural strength setup

4.4. Characterisation of Microstructures

Geopolymeric gels are observed to co-exist with C-S-H gels in specimens with fly ash replacement levels of 45% and 60% in M25 and M50 grade concrete, respectively. When GGBS dissolves, calcium and silicon are produced as a by-product, which interact to create a C-S-H gel. High strength is significantly influenced by the manufacture of silicon-aluminates and C-S-H gel structures. A specimen's strength is defined by its denser structures, which are present in specimens with higher GGBS dosages.

5. Result and Discussion

In this paper, the proposed work is compared with existing methods, and the graph is made for Flexural strength, compression strength, and split tensile strength for M25 and M50 grade concrete with different proportions. This study outperforms existing methodologies of split tensile strength, compressive strength, and flexural strength. SEM-EDX is utilised to find the material's cracks and impurities and the chemical composition of raw materials, which are represented below.

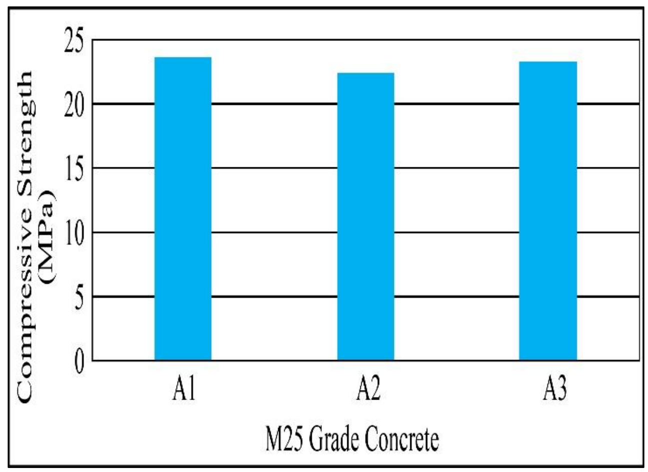

Fig. 8 Compressive strength of cube for 7 days (M25 grade concrete)

Figure 8 specifies the strength of the cube in M25 grade concrete for 7 days, and it is observed that there is a significant decrease with the replacement of fly ash and GGBS at the cube of A2. The compressive strength of A1 attains 24N/mm2, as illustrated in the above figure.

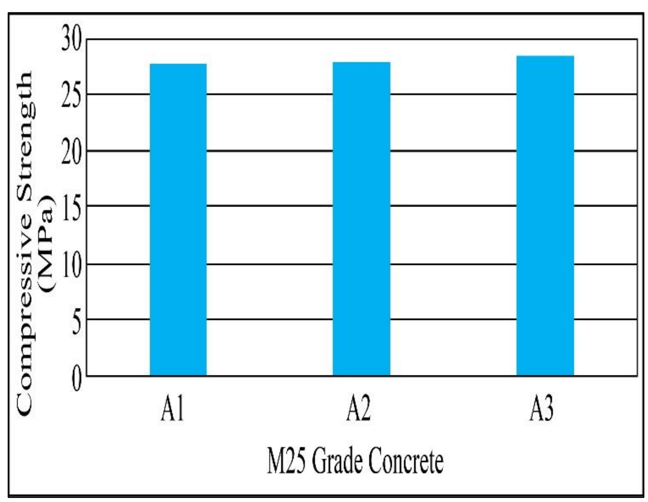

Fig. 9 Compressive strength of cube for 28 days (M25 grade concrete)

Figure 9 it is specifies the compressive strength of the cube in M25 grade concrete for 28 days, which is decreased with the replacement of fly ash and GGBS at the cube of A1. A3 attained a high compressive strength of 28N/mm2, as specified in the figure.

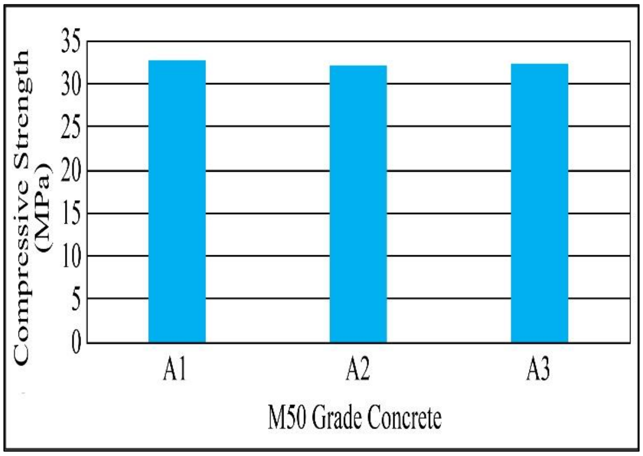

Fig. 10 Compressive strength of cube for 7 days (M50 grade concrete)

M50 grade concrete of 7 days with compressive strength of cube is illustrated in Figure 10; it is observed that there is a significant decrease with the replacement of fly ash and GGBS at the cube of A2. The compressive strength of A1 achieved a high strength of 33N/mm2, as represented in the figure.

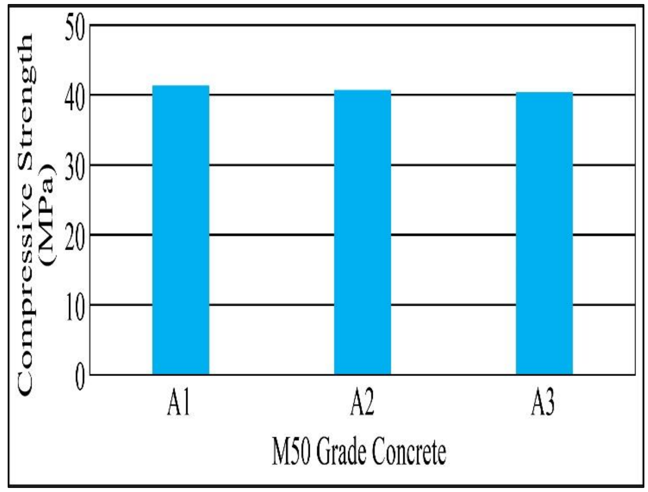

Fig. 11 Compressive strength of cube for 28 days (M50 grade concrete)

Figure 11 depicts the compressive strength of a cube for 28 days made of M50 grade concrete, with cubes of A2 and A3 losing strength as fly ash is substituted with GGBS. The accompanying figure exhibits the high strength of 43N/mm2 attained by A1.

After 7 and 28 days, the compressive strength of M25 and M50 grade concrete is indicated in Table 1. When compared to ordinary concrete, geopolymer concrete obtains a high strength of 40.81N/mm2 in M50 grade concrete.

Table 1. M25 and M50 grade concrete with compressive strength for 7 and 28 days

Mechanical Property	Conventional Concrete				Geopolymer Concrete			
	M25 Grade Concrete		M50 Grade Concrete		M25 Grade Concrete		M50 Grade Concrete	
Compressive Strength(Mpa)	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
	18.15	31.85	27.41	40.67	23.11	32.52	28.07	40.81

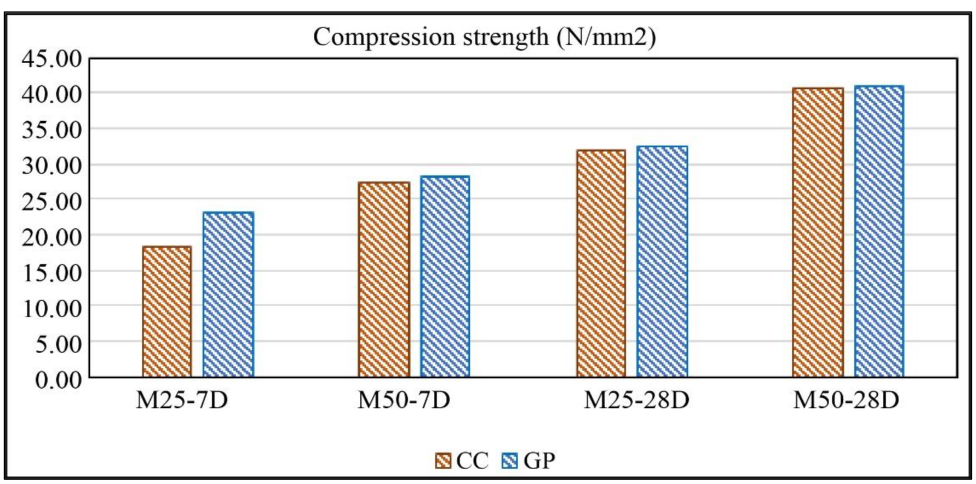

Fig. 12 Comparison graph for compressive strength

The proposed technique of geopolymer concrete achieves a higher strength at M50 grade concrete in 28 days than the conventional concrete, as represented in Figure 12, which provides a higher strength of 40.8N/mm2 than the conventional concrete.

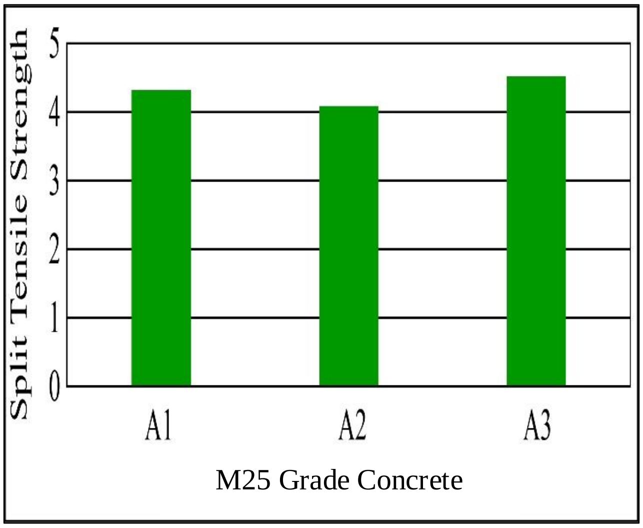

Fig. 13 Split tensile strength of cylinder for 7 days (M25 grade concrete)

Figure 13 specifies the M25 grade concrete of split tensile strength for 7 days as well as analysed that the cylinder of A2 reduces its strength when fly ash with GGBS is replaced. High strength is achieved at 3.3N/mm2 by the cylinder of A3 in M25 grade concrete, as specified in the figure.

It is clearly observed in Figure 14 that the cylinder of A3 loses strength due to the fly ash and GGBS replacement. High split tensile strength attains 4.3N/mm2 at the cylinder of A1, as represented in the figure.

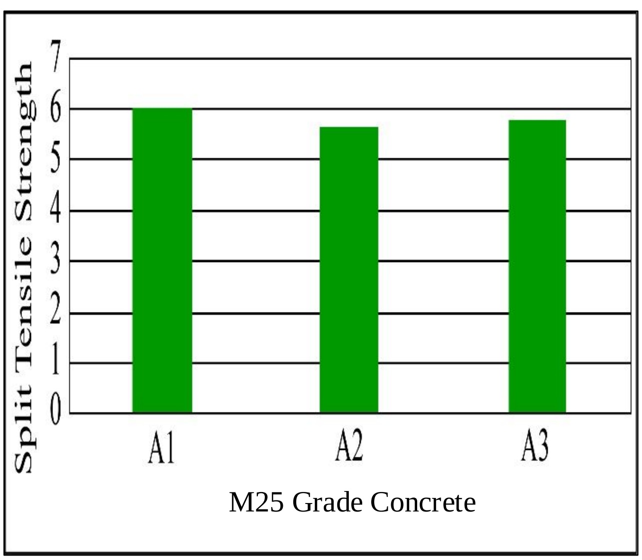

Fig. 14 Split tensile strength of cylinder for 28 days (M25 grade concrete)

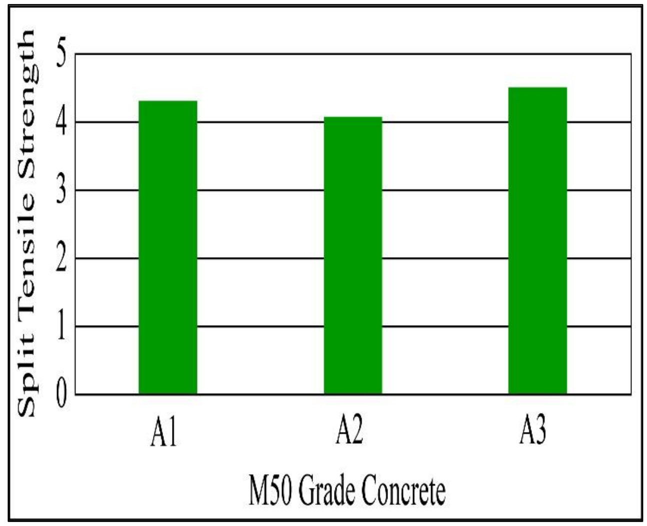

Fig. 15 M50 grade concrete with split tensile strength of cylinder for 7 days (M50 grade concrete)

M50 grade concrete with split tensile strength is attained 4.5N/mm2 by the cylinder of A3, as depicted in Figure 15, for a period of seven days, showing that A3 reaches its high strength when compared to M25 grade concrete. The cylinder of A2 in the preceding figure is reduced upon replacement of GGBS and fly ash.

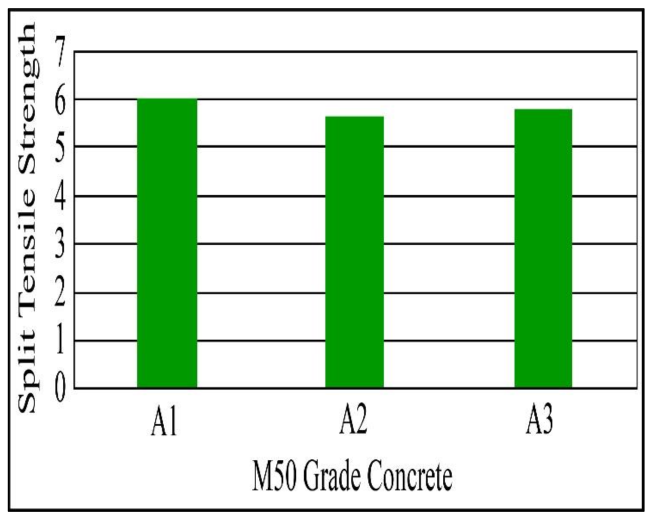

Fig. 16 Split tensile strength of cylinder for 28 days (M50 grade concrete)

Split tensile strength of M50 grade concrete after 28 days appears in Figure 16. It is noted that the cylinder of A2 reduced its strength when fly ash with GGBS was replaced in M50 grade concrete. As a result cylinder of A1 in the composite achieved high strength at 6N/mm2. Figure 17 illustrates the comparison of conventional concrete and geopolymer concrete in split tensile strength. As specified in the above figure, the conventional concrete is less than the geopolymer concrete because geopolymer concrete attains a high strength of 5.83N/mm2 of M50 grade concrete in 28 days.

Table 2. M25 and M50 grade concrete with split tensile strength for 7 and 28 days

Mechanical Property	Conventional Concrete				Geopolymer concrete			
Split Tensile Strength (Mpa)	M25 Grade Concrete		M50 Grade Concrete		M25 Grade Concrete		M50 Grade Concrete	
	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
	2.83	4.20	4.25	5.80	3.02	4.22	4.32	5.83

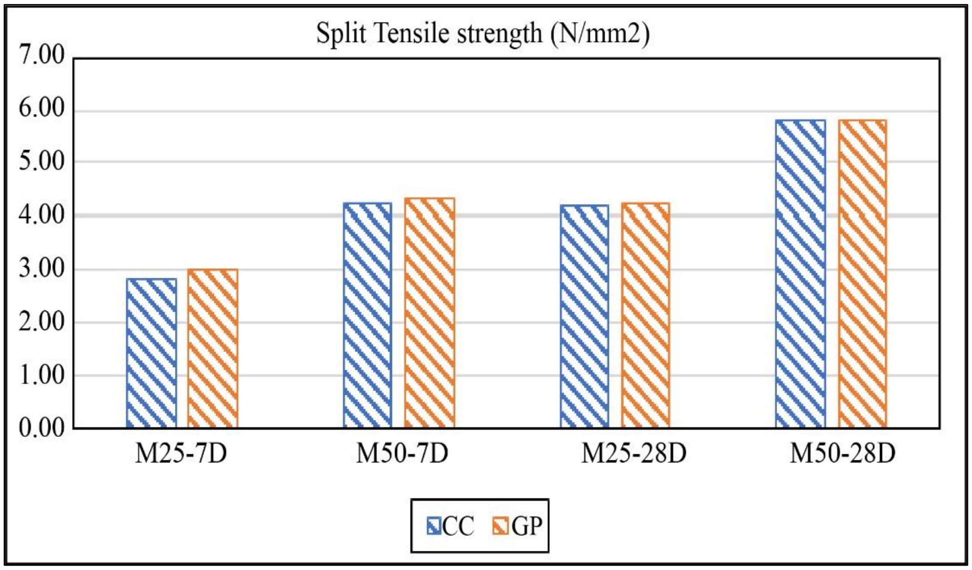

Fig. 17 Comparison of split tensile strength

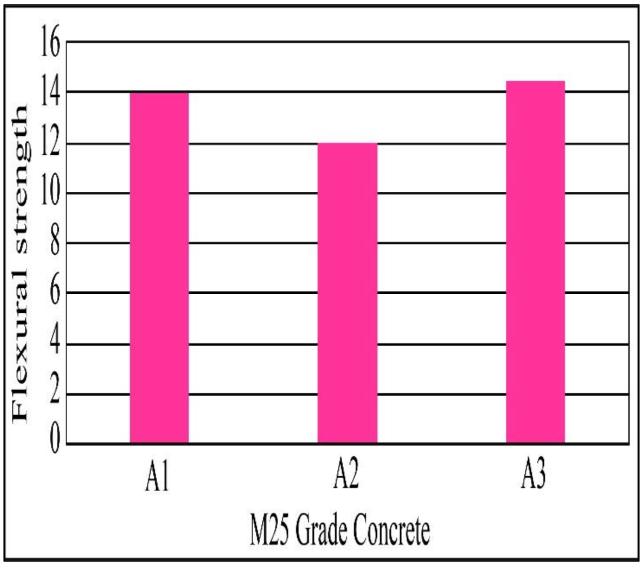

Fig. 18 Flexural strength of beam for 7 days (M25 grade concrete)

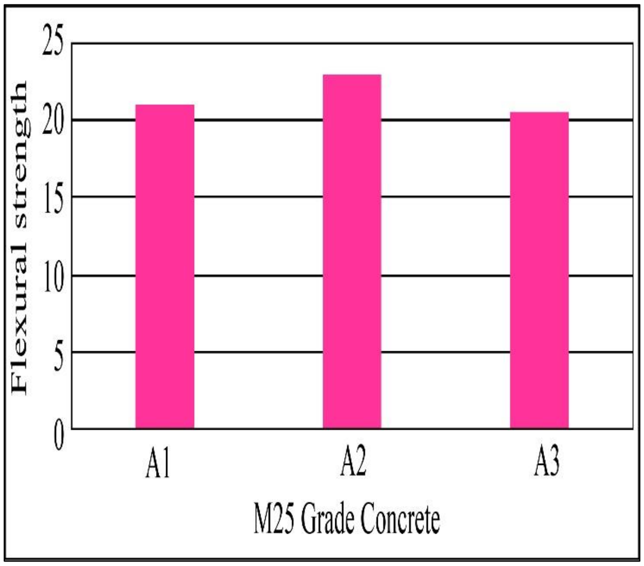

Fig. 19 Flexural strength of beam for 28 days(M25 grade concrete)

Figure 18 represents flexural strength in M25 grade concrete, and it is clear that the beam of A2 reduces its strength when fly ash with GGBS is replaced. The high strength is attained at 14.5 Mpa by the beam of A3, as depicted in the figure.

The M25 grade concrete for 28 days is represented in Figure 19; it achieved its high flexural strength concrete of 24Mpa by the beam of A2 in M25 grade concrete. The beam of A3 is reduced by the replacement of fly ash as well as GGBS.

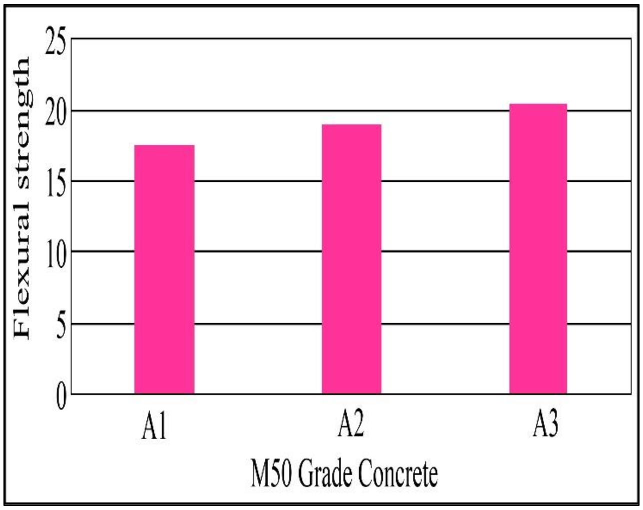

Fig. 20 Flexure strength of beam for 7 days (M50 grade concrete)

Figure 20 denotes the M50 grade concrete with flexural strength of beam for 7 days and it observed that the beam of A1 reduced its strength by the replacement of fly ash and GGBS. A3 achieves its high flexural strength of 21Mpa, as seen in the above figure.

The M50 grade concrete with flexural strength for 28 days is illustrated in Figure 21; the beam of A1 attains its high flexural strength of 24Mpa, as well the beam of A2 reduces its strength by the replacement of fly ash and GGBS as illustrated in the above figure. Table 3 shows the M25 and M50 grade concrete with flexural strengths of 7 and 28 days. In comparison to geopolymer concrete, conventional concrete is found to have a minimum strength of 9.45 MPa in M50 grade concrete at 28 days.

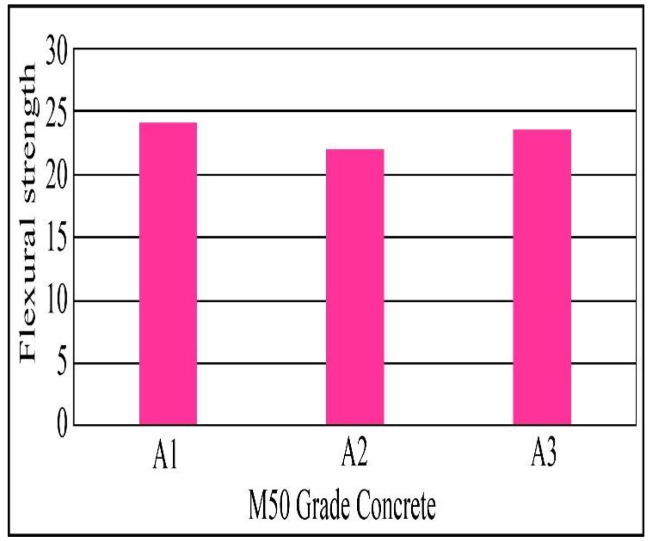

Fig. 21 Flexural strength of beam for 28 days (M50 grade concrete)

Figure 22 illustrates the graph in conventional concrete and geopolymer concrete for flexural strength; from the graph, It can be seen that the GPC achieved a high flexural strength of 9.45Mpa in M50 grade concrete at 28 days, which is higher than the conventional concrete. The chemical composition of raw materials (SiO2, Al2O3, CaO, and Fe2O3) in GGBS and FA is specified in Table 4. SEM image as well as EDM spectrum of geopolymer concrete is obtained for M25 and M50 grade concrete as represented in Figures 23 and 24.

Table 3. M25 and M50 grade concrete with flexural strength of beam for 7 and 28 days

Mechanical Property	Conventional Concrete				Geopolymer Concrete			
	M25 Grade Concrete		M50 Grade Concrete		M25 Grade Concrete		M50 Grade Concrete	
	7 days	28 days	7 days	28 days	7 days	28 days	7 days	28 days
Flexural Strength(Mpa)	7.18	7.60	8.16	9.17	7.28	7.81	8.40	9.45

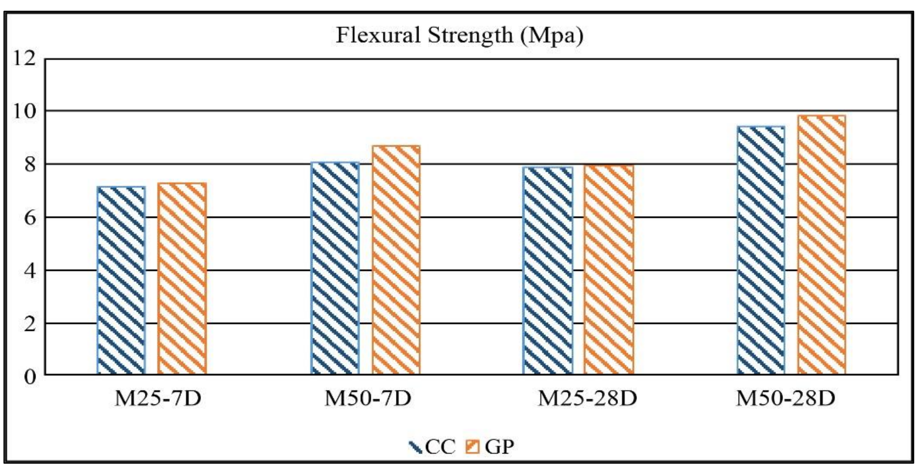

Fig. 22 Comparison of flexural strength

Table 4. Chemical composition of raw materials

Sl. No	Oxides	Fly Ash (%)	GGBS (%)
1	SiO_2	61.92	36.3
2	AI_2O_3	28.1	16.6
3	C_aO	0.89	34.8
4	Fe_2O_3	4.15	1.6
5	Other Traces	4.94	10.7

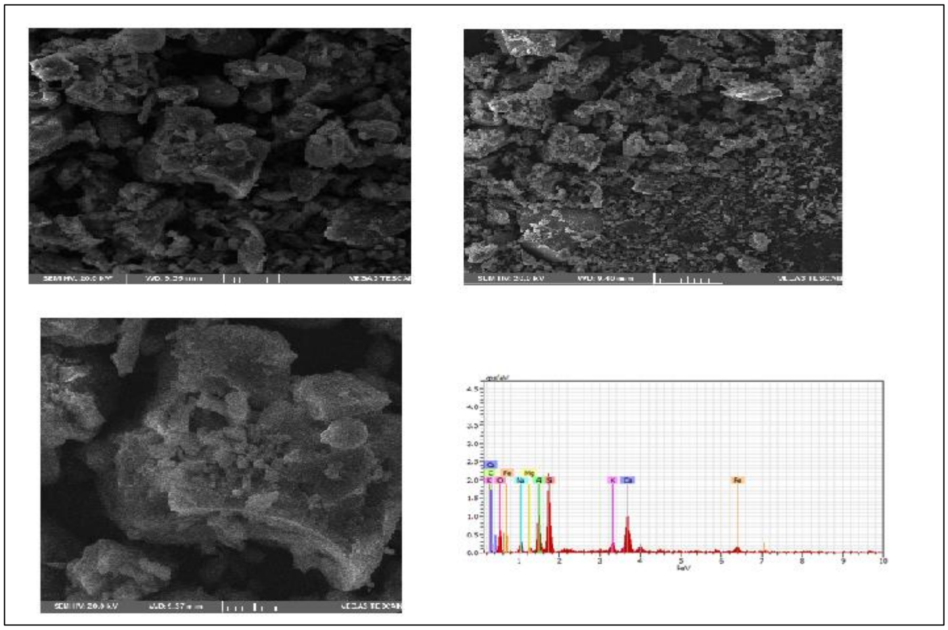

Fig. 23 EDX spectrum and SEM picture of Geopolymer for M25 grade concrete

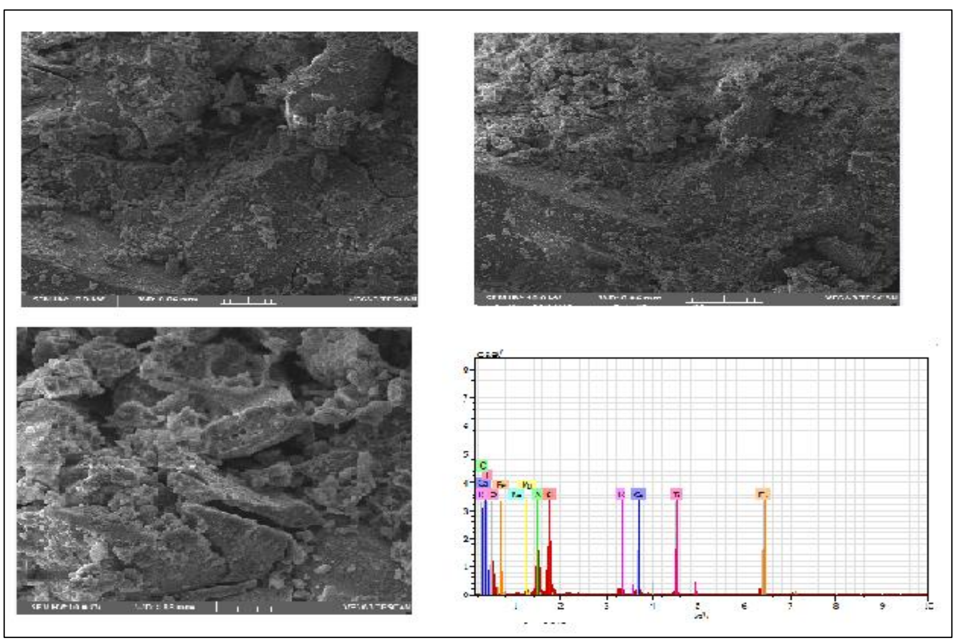

Fig. 24 EDX spectrum and SEM picture of geopolymer for M50 grade concrete

6. Conclusion

Similar to conventional Portland cement concrete, geo-polymer concrete has several applications. The CO2-emitting Portland cement concrete is effectively replaced by geo polymer concrete.

In order to bind aggregate systems comprised of sand and coarse aggregate, fly ash and GGBS can be mixed to form a geopolymeric binder phase. In both the microstructure modification and polymerisation phases of geo polymer concrete, GGBS was successfully used as a mineral additive. The alkaline to fly ash and GGBS ratio is healed at room temperature. The proposed work is utilised to reduce CO_2 emissions and provide better Split tensile strength, Flexural strength, and compressive strength than the original concrete.

SEM-EDX is employed, and it determines the materials for surface cracks, impurities and corrosion. As a result, the high split tensile strength, flexural strength, as well as compressive strength, are achieved in M50 grade concrete at 28 days than the conventional concrete. According to the results, as GGBS rises, C-S-H gel formation becomes more important. Thus, the proposed strategy of replacing cement with 60% fly ash and 40% GGBS is evaluated.

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