Effect of GGBFS as a Partial Replacement of Fine aggregate in Geopolymer Concrete

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Abstract

Concrete is considered as the world's one of the strong, reliable and flexible construction material. Manufacturing of ordinary Portland cement (OPC), Geopolymer concrete is an alternative construction material that has comparable mechanical properties to that of OPC and PPC consisting of aluminasilicates and alkali solutions ground granulated blast furnace slag based geopolymer concrete hardens through a process of geopolymerization. The geopolymer concrete is formed by reacting alkaline solutions with silicon, alumina, and calcium products. Here, a number of experiments were conducted by ambient curing to find the suitable percentage proportion of flyash and ground granulated blast furnace slag (GGBFS) to get the desired strength with conventional concrete. In this study, using geopolymer concrete (GPC) Mix (M1.M2,M3, M4)Kept constant of Cement replacement 70 : 30 (Fly ash : GGBFS). SEM tests were conducted. Alkaline liquids (Sodium Hydroxide and Sodium, Silicate solution) mixed with proper ratio (Ratio of Na_2SiO_3 to NaOH is 2.0). A sodium hydroxide solution was made by dissolving NaOH solid in water. Sodium hydroxide solutions were prepared for 12 molar solid mass depending on the solution concentration. For 12 molar solutions, 480gm of NaOH pellet was mixed in 1000 ml of water. SEM analysis revealed the presence of complete C-S-H formation in Figures (6-9) C-S-H is a crucial cementitious phase that contributes to the strength and durability of concrete. Its presence suggests that the reaction between GGBFS (Fine Aggregate), and the surrounding cementitious materials was successful, leading to the formation of the desired hydration.

Keywords: Compressive strength, Alkaline liquid, Sodium hydroxide, Sodium silicate.

1. Introduction

Concrete is a widely used construction material that solidifies over time and consists of cement, fine aggregates (such as M-sand), and coarse aggregates mixed with water. Portland cement is the most commonly utilized type of cement in concrete production. It finds extensive application in the construction of foundations, columns, beams, slabs, and other load-bearing elements in buildings. The paste used in concrete typically comprises Portland cement, water, and may incorporate supplementary cementing materials like slag cement and admixtures. However, conventional concrete has some limitations. Its tensile strength is relatively low compared to other building materials, and it exhibits less ductility [9].Human safety in case of fire is one of the major considerations in the design of buildings. It is extremely necessary to have a complete knowledge about the behavior of all construction materials before using them in the structural elements [37]. Portland cement (PC) manufacturing is characterized by its high energy consumption and substantial emissions of pollutants and greenhouse gases, contributing approximately 8 % of global CO_2 emissions annually [7].Geopolymer concrete has emerged as a promising substitute for Portland cement, leveraging fly ash–a by-product of thermal power plants–as a key ingredient[33]. Consequently, geopolymer concrete has garnered significant attention in research, with ongoing studies focusing on optimizing mix designs, understanding long-term behaviour, and exploring diverse applications across the construction sector [35-38]. Strength improvement in concrete can be achieved through ambient curing instead of water curing. Various mix combinations of materials have been tested to determine the ultimate compressive strength, flexural strength, and splitting tensile strength of hardened concrete, comparing these values with those of conventional concrete [3]. To achieve this, geopolymer concrete must be capable of curing at ambient temperatures, which was investigated in this study. Previous studies in this field have suggested that the addition of slag in the matrix accelerates the curing process and enables ambient temperature curing [20].

Objectives:

- To determined the optimum percentage replacement of fine aggregate with GGBFS for M30grade Concrete
- To investigate the influence of hardened properties GPC by varying the percentage GGBFS (Fine Aggregate) with constant ratio of sodium silicate to sodium hydroxide solution.
- To identify the factors influencing mechanical properties of GPC
- To assess the microstructural characteristics of geopolymer concrete Containing varying proportions of GGBFS using Scanning Electron Microscopy (SEM),and to correlate observed microstructural features with mechanical performance

2. Materials

2.1 Aggregates.

Locally available aggregates were used comprising of 20mm, 12mm and 6mm and fine-aggregate passing through 4.75 mm all aggregates were in saturated surface dry condition. The course aggregates were crushed granite type and the fine aggregate used in this study was manufactured sand and steel slag

Table -1: Physical characteristics of course aggregate

Sl. No.	Specific gravity	Fineness modulus	Density kg/m^3	
			Loose aggregate	Rodded aggregates
1	2.6	6.961	1230	1510

2.2 Manufactured sand

Locally available manufactured sand (4.75 mm to 75 microns) conforming to Zone II IS: 383[19].

2.3 Steel slag (GGBFS)

Steel Slag as shown in Figure 2 is a waste material and by-product obtained from the steel and iron industry. Steel slag mainly comprises calcium, manganese, magnesium, and aluminum silicates in various combinations [32]. It contains some amounts of iron, imparting high density and hardness, which make it a suitable aggregate for road construction[26]. In processing plants, steel slag is subjected to crushing, grinding, and screening operations to make it readily accessible for various uses

Fig.1.Materials, Flyash, GGBFS, Aggregates,

Fig.2. Steel Slag (Fine Aggregate)

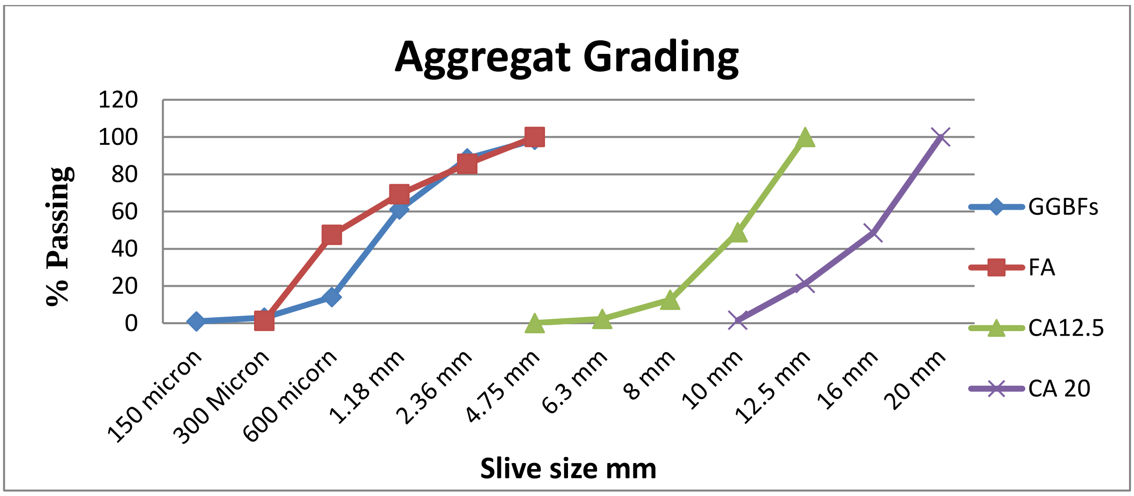

Fig.3. Gradation curves of M-Sand and GGBFs as fine aggregate

Table -2: Physical characteristics of fine aggregate

Materials Properties	Fine Aggregate (M-sand)	Fine Aggregate (GGBFs)
Specific gravity	2.61	2.52
Fineness modulus	2.79	3.35
Bulk density loose	1.511 gm/cc	1.0379 gm/cc
Bulk density Compacted	1.66gm/cc	1.164gm/cc

2.4 Alkali Activator

Alkaline activator substances of Silica are dissolved in strong alkaline conditions with high PH. During the dissolution of the silica and aluminum the alkaline solution is active and plays a main role in the condensation process (Lindgard et al. 2012).Sodium hydroxide, potassium hydroxide, sodium silicate and potassium silicate are the common activators used for geopolymer. Alkaline liquid was framed by mixing sodium-hydroxide (NaOH) solution and sodium-silicate (Na_2SiO_3) solution. Sodium hydroxide solution was made by dissolving NaOH solid in water. Sodium hydroxide solutions were prepared for 12 molar mass of solid depends on the concentration of solution. For 12 molar solution 480gm of NaOH pellet mixed in 1000 ml of water. Where 1M = 40gm of solid in 1000 ml water, during the development of mixing lot of heat get liberated when dissolving NaOH pellet in water. Therefore solution is kept for cool for 24 hour, this duration is required for polymerization process of alkaline liquids [36]

2.5. Sodium- Hydroxide (NaOH)

Caustic soda is the other name to Sodium hydroxide, which is manufactured by the electrolysis of sodium chloride brine in a membrane or diaphragm electrolytic cell (Occidental Chemical Corporation 2000). Paper industry and manufacturers that need an alkaline based material are the largest users and buyers of caustic soda. Sodium hydroxide (NaOH) is accessible in four varieties: beads, flakes, compounders and solid castings. All the forms have the same chemical composition[36]

2.6. Sodium- Silicate Solution (Na_2SiO_3)

Alkali silicates Solutions are also termed as “water glass”. Na_2SiO_3 Solution can be produced in two ways one by dissolving alkali silicate pellets in hot water or second way is hydrothermally dissolving a reactive silica source, into the respective alkali hydroxide solution (PQ Europe 2004).

2.7. Super plasticizer

Super plasticizer significantly improves the workability of the concrete, Conplast SP-430 is based on Sulphonated Naphthalene polymer.

Fig.4. Conplast SP-430

Fig.5. Fresh Concrete

3. Geopolymer Concrete Mix Proportion

3.1 Mixing

Fine-aggregates (GGBFS) and coarse-aggregates were mixed together dry in 80 liters capacity pan mixer for around 2 to 3 minutes. For Saturated surface dried aggregates are used in the mix. Get ready with alkaline liquid and super plasticizer, and the extra water if required to be added depends upon the workability of concrete [13].If the GPC doesn't achieve required slump (80 to 100), discard the sample and prepare the fresh mix once again by repeating the same procedure with different mix proportions.

Table-3: Quantity of materials as per the Mix design

MIX	Cement		Fine Aggregate		Coarse aggregate (20mmdown)	Super plasticizer
	Fly Ash	GGBFS	M SAND	GGBFS		
M1	395	0	784	0	1294	2%
M2	276.5	118.5	548.8	235.2	1294	2%
M3	276.5	118.5	509.6	274.4	1294	2%
M4	276.5	118.5	470.4	313.5	1294	2%

3.2 Curing of geopolymer concrete

After the preparation of fresh concrete the concrete is filled in the moulds and leave them 24 hours in the room temperature and then it is demoulded and kept in oven for curing at the temperature of 600 C for 24 hours [16].

4. Experimental Results and Discussions

4.1 Compressive strength test performed according to IS: 516-Part-1[30].Concrete is primarily employed for structural applications, including foundations, columns, beams, and floors, and as such, it must possess the capacity to withstand the anticipated loads. To evaluate its suitability for these purposes, a concrete cube test is conducted, which determines the compressive strength of the concrete and directly correlates to the designated design strength [10]. The strength behaviour in GPC, of M30 grade concrete with the best combination to replace cement and M-sand by mix M1,M2,M3,M4 which is 70 : 30 % (fly ash : GGBFS).Compressive strength, in turn, plays a significant role in ensuring durability, as higher compressive strength typically leads to improved durability.

Table -4: compressive strength test results

MIX	Cement		Fine Aggregate		Compressive Strength N/mm^2		
	Fly Ash %	GGBFS %	M SAND %	GGBFS %	7Days	14days	28Days
M1	100	0	100	0	10.08	20.6	30.4
M2	70	30	70	30	24.2	28.45	40.2
M3	70	30	65	35	22.06	25.4	30.47
M4	70	30	60	40	20.2	24.8	30.02

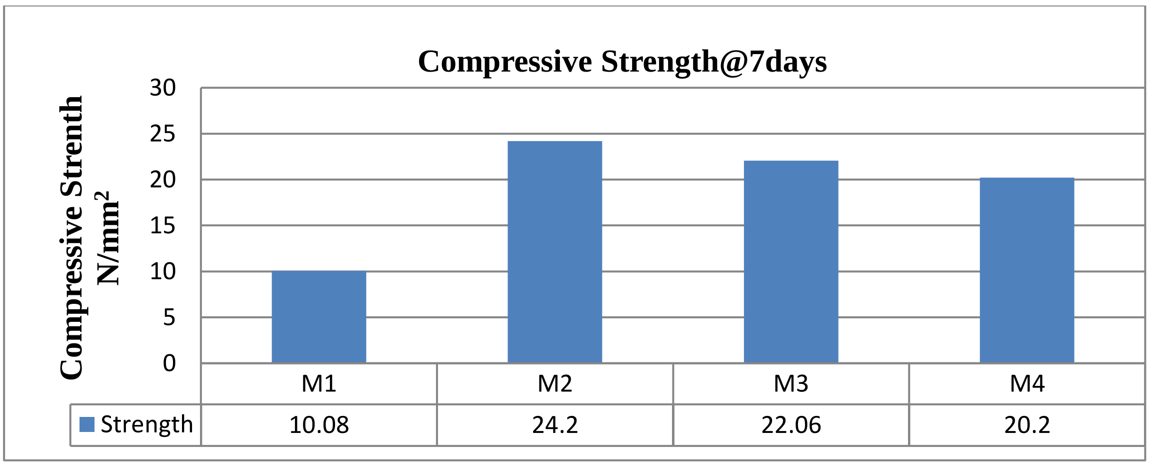

Chart -1: Compressive strength @ 7 days

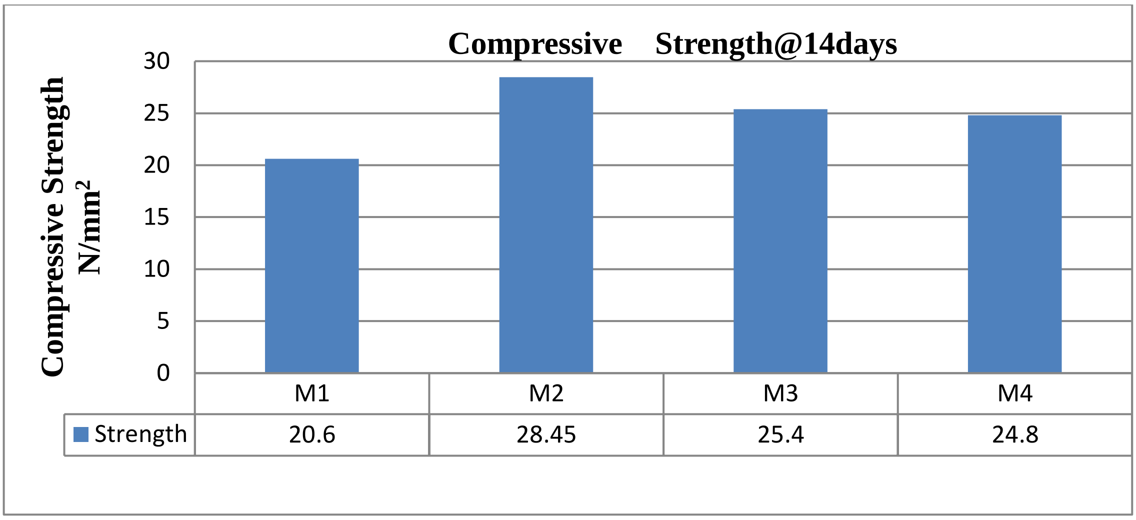

Chart -2: Compressive strength @ 14 days

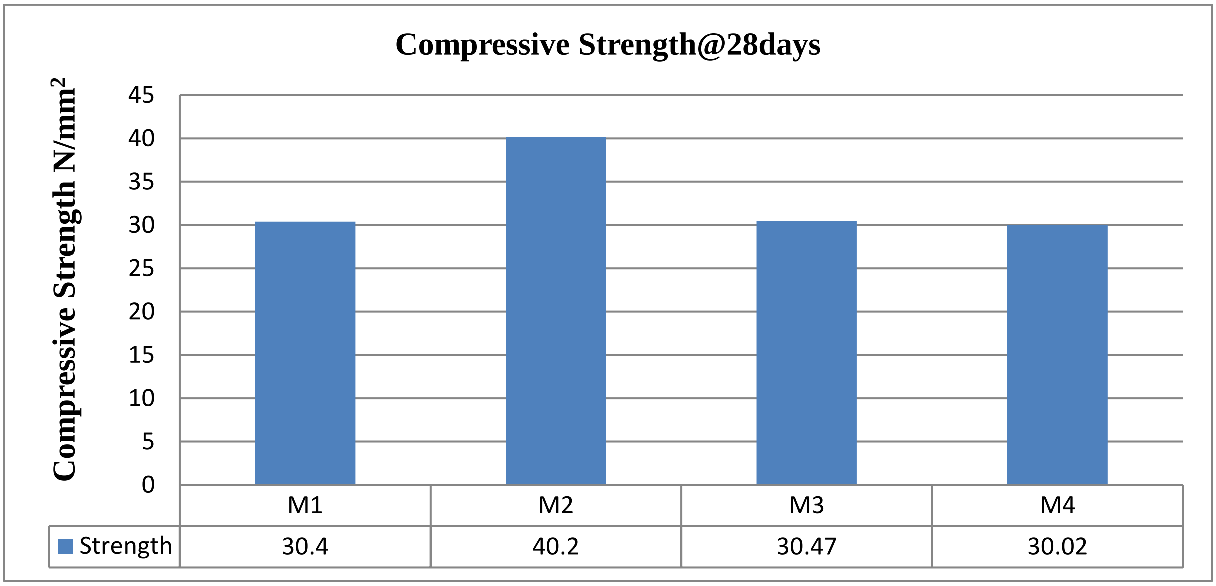

Chart -3: Compressive strength @ 28 days

4.2 Split-Tensile Strength on GPC

Splitting tensile strength test performed according to IS: 516-Part 1[30]. When M-sand is replaced with GGBF Slag and increases in slag percentage, the strength gets weaker. The split tensile strength does not necessarily improve with an increase in steel slag % as shown in results

Cross sectional area of cylinder = [(2xP) / (πxdxL)] N/mm^2

Table -5: Split-Tensile strength test results

MIX	Cement		Fine Aggregate		Split Tensile Strength N/mm^2		
	Fly Ash %	GGBFS %	M SAND %	GGBFS %	7Days	14days	28Days
M1	100	0	100	0	2.13	2.18	2.29

M2	70	30	70	30	2.26	2.56	3.29
M3	70	30	65	35	2.12	2.26	3.52
M4	70	30	60	40	1.5	1.92	3.5

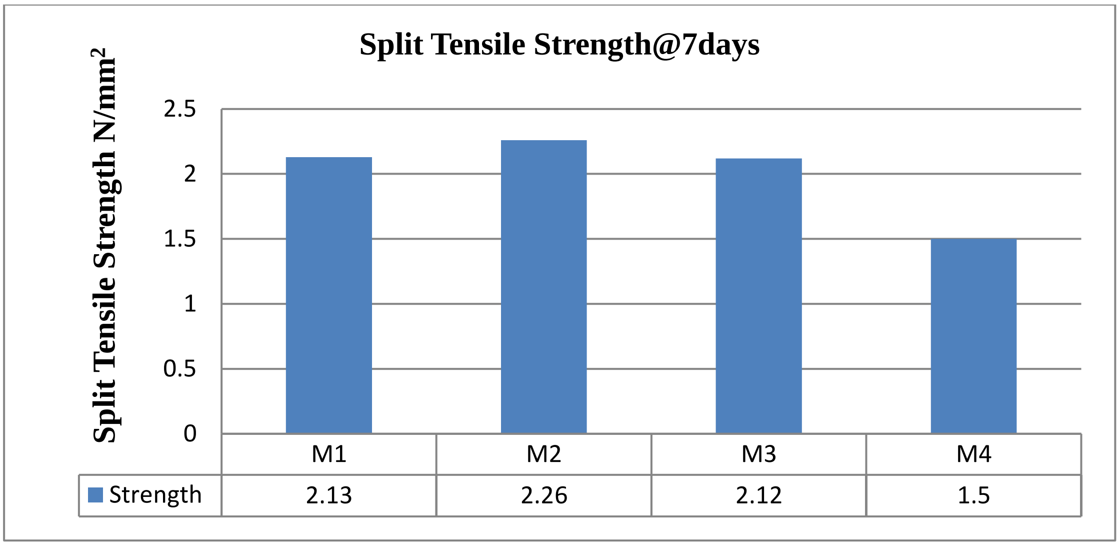

Chart -4: Split-tensile strength @ 7 days

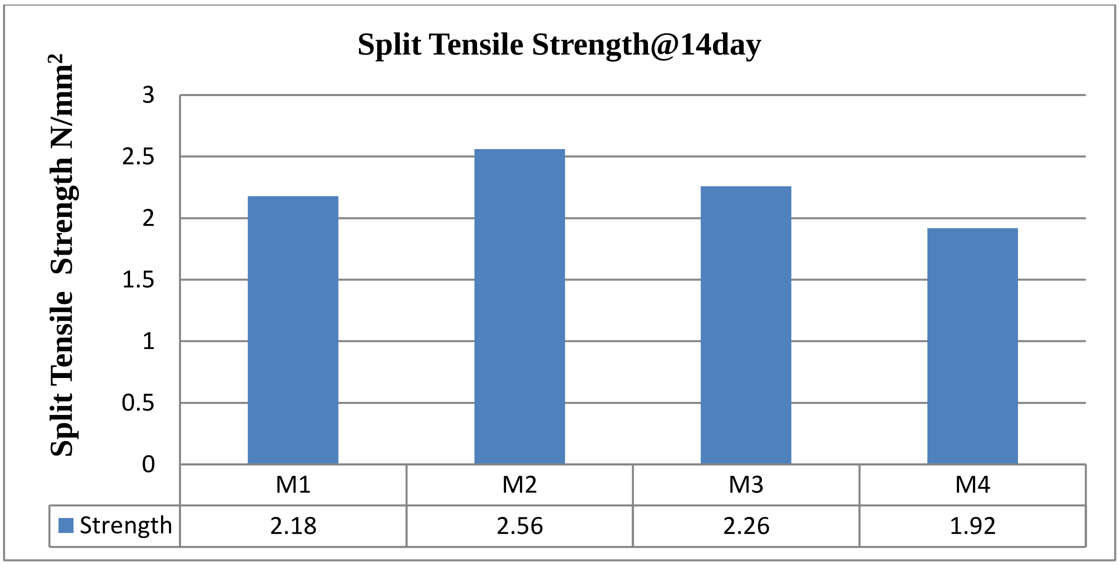

Chart -5: Split- tensile strength @ 14 days

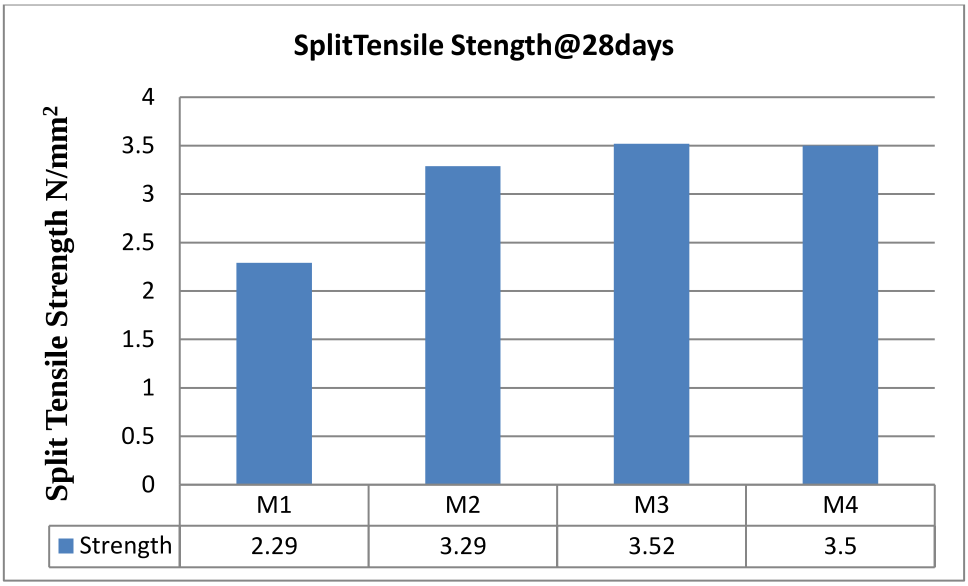

Chart -6: Split tensile strength @ 28 days

4.3 Scanning Electron Microscopy (SEM) analyses

Estimation of Loss of weight when the concrete is subjected to gradual, intermittent cooling and sudden cooling.SEM analysis images of fly ash concrete subjected to sustained elevated temperatures such as 600oC with Mix M1,M2,M3,M4 replacement of cement by fly ash and GGBFS for gradual cooling, intermittent cooling and sudden cooling. Figure 9 is dense as compared to that of fly ash concrete when subjected to elevated temperature. The quality of C-S-H gel in gradual cooling is better as compared to intermittent cooling and sudden cooling. The degradation of strength properties in case of sudden cooling may be due to the thermal shock, which will trend to set in the severe thermal gradients.

Homogeneous distribution of C-S-H formation: The SEM analysis reveals a uniform and complete C-S-H (Calcium Silicate Hydrate) formation throughout the image. The presence of C-S-H indicates that the chemical reaction between GGBFS and the surrounding cementitious materials was successful in producing the desired hydration products. The homogeneous distribution of C-S-H suggests that the GGBFS is capable of contributing to the cementitious matrix uniformly, potentially enhancing the overall strength and durability of the concrete. In conclusion, the SEM analysis confirms the presence of complete C-S-H formation throughout the image, signifying the successful reactivity GGBFS with cementitious materials. Further investigations are needed to understand the influence of these fibrous particles on the overall behavior of the GGBFS in concrete mixes.

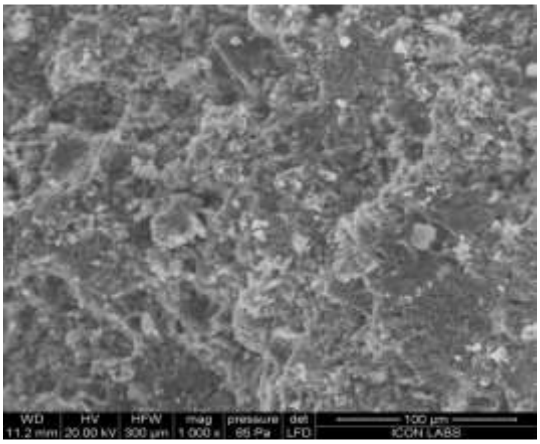

Fig.6: M1 SEM image of GPC

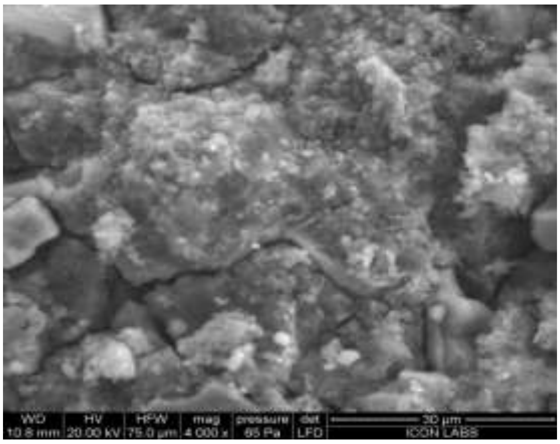

Fig.7: M2 SEM image of GPC

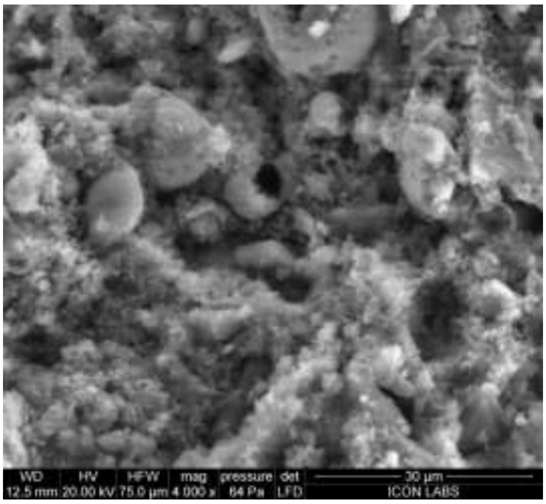

Fig.8: M3 SEM image of GPC

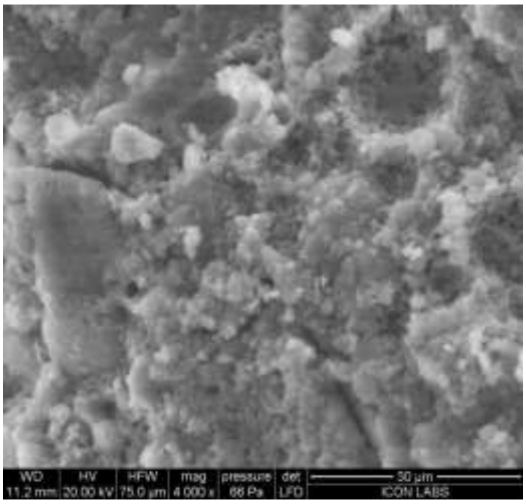

Fig.9: M4 SEM image of GPC

CONCLUSIONS

According to this research work, the following points are observed:

1. As comparing to the fresh properties of the GGBFS based geopolymer concrete at replacement of GGBFS a slump of 80 mm is obtained, which was very good in workability
2. The compressive strength of GPC rises with the addition of GGBFS (Fine Aggregate) in this study, with a faster rate of setting.
3. The split tensile strength of GPC slightly increased by addition of GGBFS (Fine Aggregate) in different proportions.
4. Overall, GPC with fly ash and GGBFS is better for replacement of M30-grade conventional concrete
5. Calcium Silicate Hydrate formation: The SEM analysis revealed the presence of complete C-S-H formation in the image. C-S-H is a crucial cementitious phase that contributes to the strength and durability of concrete. Its presence suggests that the reaction between GGBFS (Fine Aggregate), and the surrounding cementitious materials was successful, leading to the formation of the desired hydration.

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