Physio-Mechanical and thermal performance of fiber reinforced foam concrete using composite binder

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Thesis Supervisor: Dr. Hammad Anis khan

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Dedicated to

My wonderful Parents

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ABSTRACT

The use of industrial waste is considered a promising step towards sustainable and innovative construction. Foam concrete is lightweight and has better thermal insulation due to its porous microstructure; however, that porous nature results in poor mechanical performance of foam concrete.

Refinement of the mechanical performance of CLC can be achieved by substituting a portion of OPC with an additional cementitious material such as GGBFS, and it may be used to help produce concrete with a smaller carbon footprint. This study investigated the impact of using GGBFS as a replacement for OPC and poly-propylene fiber reinforcement on workability, strength in compression and water absorption, split-tensile strength, and thermal conductivity of CLC with the desired density of 950-1000 kg /m3. 20 different mixes were prepared with four different dosages of GGBFS (0, 6, 12, 18, and 24%) and PP fiber (0, 0.15, 0.3, and 0.45%). According to the results, 18% is the ideal substitution rate for cement with GGBFS to obtain the best mechanical characteristics, and the optimal percentage of PP fiber was 0.15%.

Keywords: foam concrete, thermal conductivity, GGBFS, PP fiber.

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LIST OF SYMBOLS, ABBREVIATIONS AND ACRONYMS

OPC	Ordinary Portland cement
GGBFS	Ground Granulated blast furnace slag
CLC	Cellular Lightweight Concrete
CH	Calcium Hydroxide
C-S-H	Calcium-Silicate-Hydrate
SEM	Scanning Electron Microscopy
FA	Fly-Ash
PCE	Polycarboxylate
PP	Polypropylene
SCM	Supplementary Cementitious Material
ASTM	American Society of Testing and Materials
FC	Foam Concrete

CHAPTER 1: INTRODUCTION

1.1 General

CLC has a composition that makes it lightweight and finds several uses in the building industry. Lightweight, quick construction, good thermal and sound insulation, good resistance against freeze-thaw, fireproofing, and high flowability. It can be used for lightweight wall panels, lightweight blocks, floor filling due to its high flowability, filling uneven surfaces, roof insulation, floor screed, etc.

Considering the pore formation method, aerated concrete has two types: air-entrained concrete and foam concrete. Air-entrained concrete is produced with a method in which chemical reactions are used to produce gases inside the mortar, while in foam concrete, air bubbles are incorporated inside the mortar using a suitable foaming agent through a mechanical method. Furthermore, there are two ways to produce foam concrete: post-foaming and pre-foaming. The foaming agent is added straight into the mortar when using the post-foaming procedure, while in the pre-foaming procedure, separate production of foam and slurry takes place and is then combined to introduce air pockets into the mortar.

The porous microstructure of foam concrete makes it lightweight and grants it superior insulation properties against both sound and heat. Given that air has a poorer heat conductivity than a solid matrix, the introduction of tiny air bubbles renders foam concrete a more efficient heat insulator than conventional concrete and bricks. However, this porous microstructure also renders foam concrete mechanically fragile and weak. A byproduct of the iron and steel industries is supplemental cementitious material called ground granulated blast furnace slag (GGBFS) that can be used in place of some cement. The use of GGBFS in cellular lightweight concrete can be beneficial in two ways:

1) Its pozzolanic and filling properties can aid in enhancing the mechanical qualities and longevity.

2) Utilizing it as a partial cement alternative, it can aid in reducing carbon emissions.

New construction practices prioritize factors such as sustainability and energy efficiency when selecting construction materials. Foam concrete stands out as a sustainable and energy-efficient material due to its inherent properties. The physio-mechanical and heat transfer performance of CLC must be carefully studied. It has been demonstrated that adding supplemental cementitious material in place of cement can enhance physio-mechanical performance. However, it is noteworthy that in some studies, the heat-transferring ability of CLC is typically increased in the presence of supplemental cementitious materials [1,2]. On the other hand, fibers like polypropylene fiber can reduce thermal conductivity because polypropylene fiber is a superior heat insulator.

1.2 Problem Statement

Previously, different researchers have tried to incorporate the supplementary cementitious materials and fibers separately; however, there is a dearth of research on how fibers and SCMs work together to affect foam concrete's physio-mechanical and thermal performance. With the inclusion of SCMs, thermal conductivity increases, while fibers like polypropylene can help with better thermal insulation.

This proposed study has tried to incorporate PP fiber and GGBFS as SCM and discussed how the characteristics of CLC are being affected.

1.3 Aims and Objectives

To investigate how PP fiber and GGBFS affect the thermal, mechanical, and physical characteristics of CLC:

1. Evaluate the strength in compression, splitting-tensile strength, water absorption, and flow ability of CLC with the varying percentages of GGBFS and PP fiber.

2. Investigate the microstructure using SEM and thermal conductivity with the inclusion of GGBFS and PP fiber.

CHAPTER 2: LITERATURE REVIEW

2.1 General

Exploration of materials that are lightweight, which might lessen the building's dead weight, is popular. NWC weighs between 2100 and 2500 kg/m3, and lightweight concrete weighs between 300 and 2000 kg/m3 [3]. Several methods can be followed to create concrete with lower weight, such as the use of light-weight aggregate, the avoidance of fines, the use of chemicals that release gas, or mechanical methods that allow air bubbles to form inside the concrete. Figure 1.1 shows the classification of lightweight aggregates that are being used to produce lightweight concrete using lightweight aggregates.

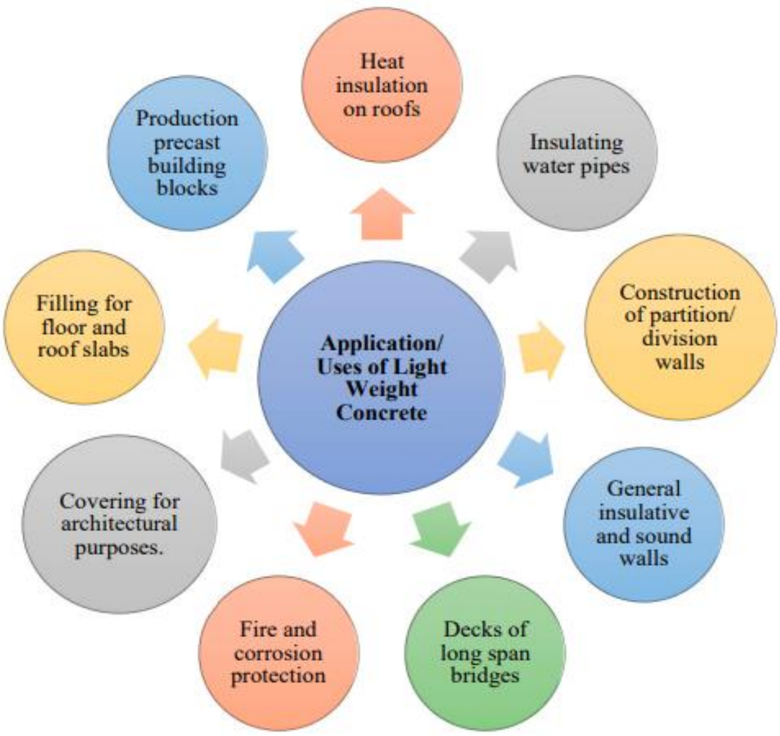


Figure 2.1 Applications of Lightweight Concrete [63]

Because of its special qualities, CLC is a type of material that is lightweight and has several applications in the building business, like excellent thermal and sound insulation, high flowability, low density, and good fire resistance. It contains air bubbles, which results in a porous microstructure. Porous microstructures give foam concrete properties like better insulation against heat and sound. And this porous microstructure makes foam concrete lightweight, depending on the quantity of foam that is being introduced into the mortar.

As the demand for sustainable and thermally efficient systems is increasing in the construction industry, researchers are looking at using CLC instead of conventional concrete. Applications of foam concrete vary as the density changes.

2.2 Previous studies on lightweight concrete

F. Pelisser et al. [4] incorporated waste rubber from tires and produced lightweight concrete with 14% reduction in thermal conductivity. P. Sukontaskull [5] improved the concrete's ability to insulate against heat and sound by using crumb rubber. The author generated low density material where sand was replaced with crumb rubber; in contrast, the control sample had a bulk density of 2530 kg/m3. The control, 20% replacement mix, and 30% replacement mix had corresponding thermal conductivity values of 0.531, 0.304, and 0.296 W/mK. Incorporating crumb rubber led to lightweight concrete and additionally enhanced noise reduction and heat insulation. R.B Karthika et al. [6] incorporated pumice aggregate to make lightweight concrete, in part lieu of coarse aggregate.

In comparison to the reference mix, the author noted higher water absorption with pumice and decreasing trend of density as the amount of pumice aggregate increased. A. Kan et al. [7] produced lightweight concrete using waste EPS. In this study the concrete density was 900-1700 kg/m^3. E. Nangor et al. [8] explored the use of WPE in producing lightweight concrete. Author observed homogenous distribution of PE particles in the mix using microscopy. Mixes with polyethylene showed plastic deformation.

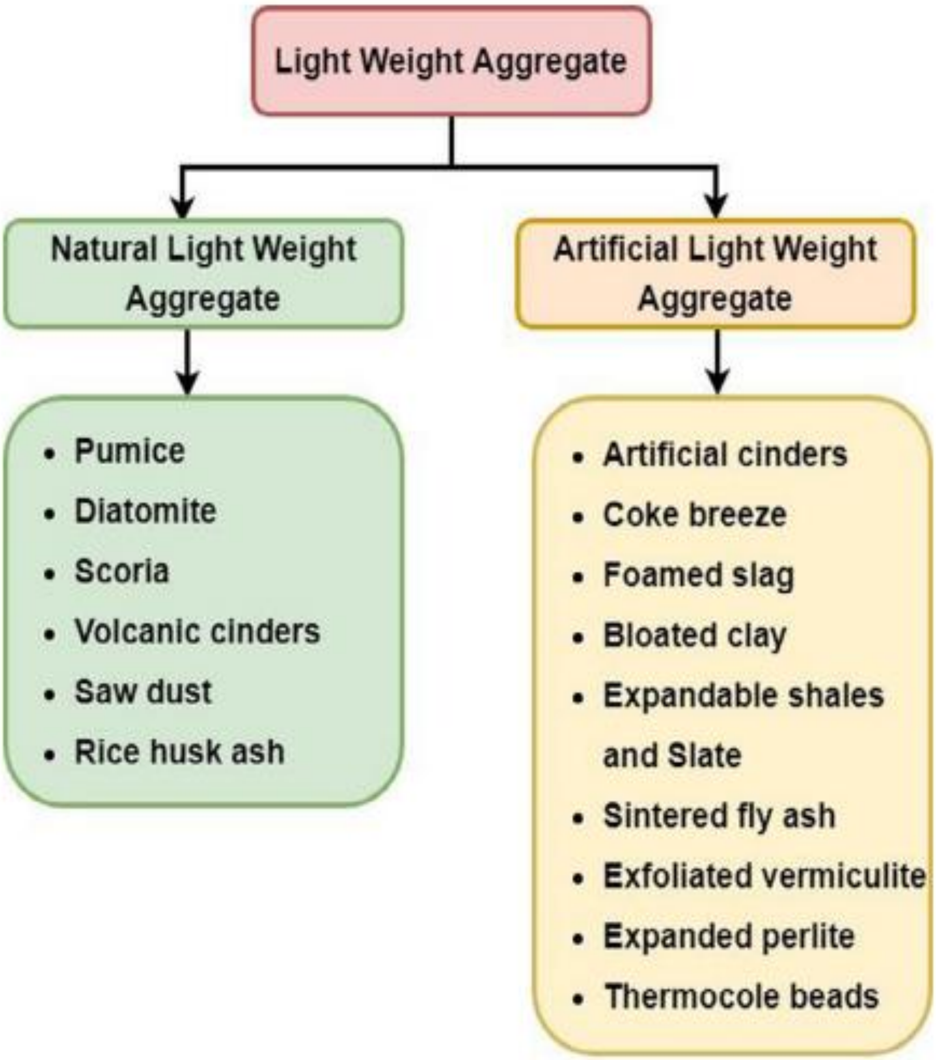


Figure 2.2 Classification of lightweight aggregate [3]

2.3 Foam concrete History

Romans observed that the presence of animal blood helped in improving the workability of mortar [9]. Since animal blood contains proteins that act as surfactants, it can produce bubbles. Axel Eriksson's work in the early 1900s introduced air-entrained materials. However, it was Valore who explored foam concrete comprehensively in 1954 [10]. In late 1970s foam concrete was introduced in oil and excavation industry [11]. After this many scholars have explored the use of foam concrete due to its vast number of applications.

Figure 2.3 Materials for Cellular Lightweight Concrete [12]

2.4 Previous studies on foam concrete

Presence of air bubbles in foam concrete gives it porous microstructure that makes it lightweight, good thermal and sound insulating material [3, 4]. But that porous microstructure makes foam concrete fragile and weak mechanically [15]. Researchers have tried different techniques to enhance foam concrete's mechanical integrity. A product like cellular-lightweight concrete which is lightweight and have enough mechanical performance that is required could easily replace the conventional concrete.

Researchers are trying to look for alternate concrete materials that could contribute to better economical, sustainable and having positive impact on the environment. There are many waste products from industry which can perfectly substitute the conventional binding material like OPC [6,7]. Cement industry causes over 10% of the world wide CO_2 production [18]. With the passage of time demand of cement is increasing day by day [19].

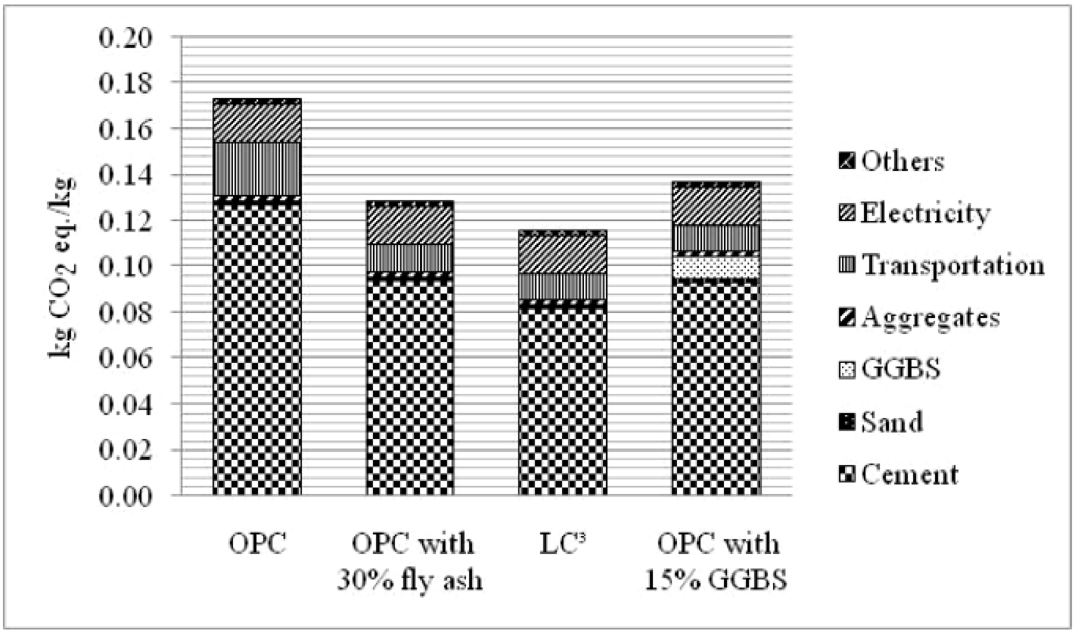


Figure 1.4 CO_2 emissions for M-50 concrete [64]

Jhatial et al. used eggshells in powdered form as a partial substitution to cement along with polypropylene fiber, and reported 34% CO_2 reduction as compared to the controlled mix [20]. Many studies have tried using SCMs to enhance foam concrete's mechanical integrity. Utilizing additional cementitious materials to substitute a portion of cement can decrease the negative effect that OPC has on the environment [21]. The inclusion of supplementary cementitious ingredients in place of a portion of the cement consumes calcium hydroxide (CH) and produces secondary C-S-H, and by utilizing the filling effect, it also raises the standard of concrete., which enhances the longevity [6–8]. Meskhi et al. [24] examined the impact of using micro silica to partially substitute conventional binder on the characteristics of CLC and reported 44% improvement of compression strength and 73% improvement in tensile strength.

Ozturk et al. [25] used different SCMs to replace some quantity of cement and reported improved mechanical & electromagnetic performance in contrast to the reference mixture with all the SCMs where ideal percentages of GGBFS, SF, RHA & FA were 20%, 20%, 10% & 10% respectively. GGBFS is a supplementary cementitious material which is a byproduct of iron and steel industry which can be utilized to substitute the conventional binder. It not only helps in improving the durability of the product but also reduces the carbon footprint of cement industry.

In another study [26] 10% content of RHA increased the compressive strength to 125%**,** and flexure strength 42%, 9.6% increase in thermal conductivity was reported. O. Gencel et al. [1] replaced 15% cement with silica fume found 46% and 88% enhancement of strength in compression and flexural performance respectively and thermal conductivity raised by 4%.

M. Li et al. [27] reported 11% improvement in compressive strength with 40% replacement of cement with ultra-fine slag and observed more uniform pore structure. Aljoumaily et al. [28] found that using GGBFS in place of conventional binder increased compressive strength by 9%. Awang et al. [29] explored the properties of CLC incorporating raw GGBFS in place of some of the cement and found 32%, 46.5%, and 61% enhancement in compression, tensile and flexural performance, respectively, in contrast to the reference group with 30% GGBFS content.

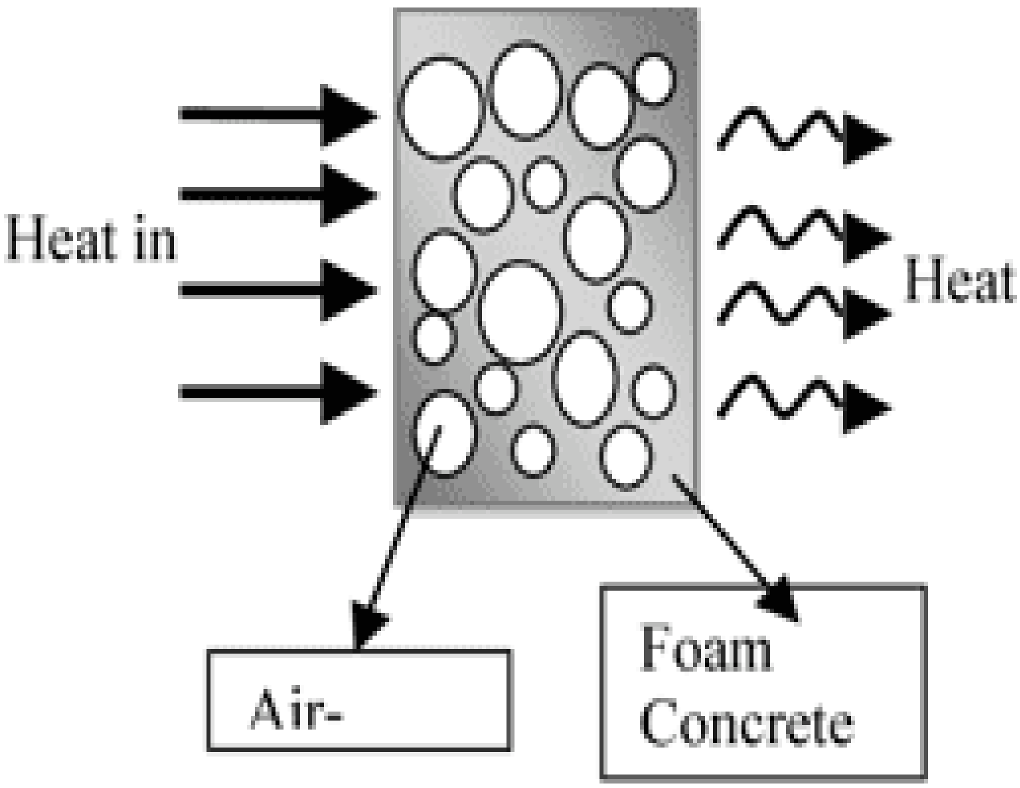


Figure 2.5 Heat Transfer in Foam Concrete [35]

H.S. Gökçe et al [30] studied physico-mechanical performance of CLC incorporating silicafume and flyash at 0, 10 and 20% replacement of OPC.

The strength of compression was said to have risen 4.4 times as of reference mix and with the inclusion of silica fume thermal insulation decreased by 37% as it increased the paste matrix density. E. Ikponmwosa et al. [31] studied the use of saw dust ash . Many studies [23], [28] have reported that use of SCMs like silicafume, flyash, RHA etc. can increase the mechanical efficiency of foam concrete when used partially in place of the conventional binder. Few authors noted enhancement in thermal conductivity while using SCMs [30]. The spongy morphology of foam concrete has an impact on its mechanical properties, which needs to be improved. With the use of SCMs that issue of poor mechanical performance is resolved but thermal insulation is affected.

Additionally, fiber reinforcement can improve foam concrete's properties [20–26]. Exploring the inclusion of different types of fibers in different studies has resulted in improved performance of foam concrete. Several studies have tried to incorporate both natural and synthetic fibers in foam concrete and studied the effect on different properties of foam concrete. Choice of fiber type depends on the different factors like use of the foam concrete and availability of the fiber in that region. O. Gencel et al. [39] used polypropylene fiber and reported 29% reduction in flow, 12% reduction in thermal conductivity, 62% increase in flexural strength and negligible effect on compressive strength. Paper as waste product is also studied as reinforcement in foam concrete [40] which is reported to enhance the flexural strength and sound insulation of CLC. But paper reinforced foam concrete showed poor compressive strength, workability problem due to the water absorption by paper.

With the addition of PP fiber, D. Falliano et al. [41] observed a 300% improvement in flexure strength and a 22 percent rise in strength under compression. K. Lee et al. [42] incorporated polyvinyl alcohol (PVA) fiber and Polyamid (PA) fiber in foam concrete to improve the resistance of against cracking. OPC was replaced with 30% GGBFS.

The optimum quantity of both the fibers was 0.6 kg/m^3. It was reported that PA fiber was slightly better as compared to PVA fiber in flexural performance. Use of natural fibers is also common in foam concrete. Othuman Mydin et al. [43] incorporated natural fibers in foam concrete to study the long term performance.

It was reported that cellulose quantity of the fiber can directly affect the flowability of the mix. If the cellulose quantity is higher, due to higher water absorption flowability will be decreased. More water absorption increases the water demand of the mix. Ramie fiber had the highest cellulose quantity that resulted in lowest flowability. Among the four natural fibers, mixes with Jute fiber showed lowest water absorption.

J. Zhang et al. [44] researched using of coconut fiber, which was a waste, as a reinforcement in foam concrete. Results indicated that presence of coir fiber in foam concrete changed the failure pattern of the specimens. Inclusion of coir fiber changed the brittle nature to ductile behavior. Recommended percentage of coir fiber in this research was 1.5%. Beyond this percentage mixes started to show poor performance.

Cai et al. [45] investigated the functionality of CLC using linear and mesh type polypropylene fibers. It was claimed that the water absorption was unaffected by the addition of PP fibers. Compressive strength was affected negatively with the increasing fiber length. Linear PP fiber performed better as compared to the mesh type fiber in enhancing the mechanical efficiency of CLC.

Natural fibers can help improve the performance of foam concrete, but these fibers are not readily available. Also, these fibers have disadvantages due to their greater absorption of water in comparison to synthetic fibers like PP fiber. Fibers like polypropylene have good thermal-insulating properties. The use of these types of fibers has the advantage of providing extra thermal insulation in foam concrete, along with improved mechanical performance. In addition to the above-mentioned advantages, PP fiber is easily available on the market.

The addition of additional cementitious ingredients and fibers individually to foam concrete has been the subject of numerous investigations. Nevertheless, no research has been done on the combination of the effects of GGBFS and PP fiber for foam concrete in the density range of 950–1000 kg/m3 on the thermal, mechanical, and physical performance.

CHAPTER 3: EXPERIMENTAL PROGRAM

3.1 Raw Materials

Ordinary Portland cement of grade 53 was utilized for this study. Sand, which has a fineness modulus of 2.56, was utilized as fine aggregate with a specific gravity of 2.69, which was determined using ASTM C136 and ASTM C128 respectively. As an additional cementitious ingredient, ground granulated blast furnace slag (GGBFS) was employed. The chemical composition of the cement utilized in this study and ground-granulated blast furnace slag (GGBFS) is presented in Table 3.1. To create a stable foam, a synthetic foaming agent with a specific gravity of 1.05 was utilized. Polypropylene fiber of 12 mm length was used. The mechanical and physical properties of the fiber are available in Table 3.2. A super-plasticizer of the poly-carboxylate ether (PCE) type was utilized to improve the performance and functionality of foam concrete. The main properties of superplasticizers are presented in Table 3.3.

a) PP fibers

b) PCE super-plasticizer

c) Foaming agent

Figure 3.1 Raw Materials

Table 3.1

Chemical composition of binder

Material	OPC	GGBFS
CaO	62.72	38.08
SiO_2	20.95	32.18
Al_2O_3	4.56	8.62
Fe_2O_3	3.08	7.85
SO_3	2.1	3.53
MgO	2.72	5.98
LOI	3.8	2.79

Table 3.2

Mechanical and physical properties of PP fiber

Length/ mm	12
Color	Raw White
Fiber Diameter/ μm	20-45
Tensile Strength / MPa	>400
Melting Point/ °C	~ 165
Crack Elongation/ %	15-35
Ignition Point/ °C	~ 580

Table 3.3

Properties of Super-Plasticizer

Type	Poly-carboxylate Ether (PCE)
Color	White/Yellowish liquid
Density / **Kg/l**	1.05 ± 0.03
Chloride content/ %	<0.1

3.2 Mix Proportions and specimen preparation

Mixtures were made following the formulations presented in Table 3.4. Production guidelines were taken from few related studies on foam concrete [5,7]. Polypropylene fiber (PP fiber) and PCE type super-plasticizer were added to the water in first step and then mixed for 30 seconds. Then, cement, sand and GGBFS were added to that water containing PP fiber and PCE type super-plasticizer and stirred for an additional two min to prepare a uniform slurry. After preparing the slurry, process for foam was started. Foam was created by diluting the foaming agent with water at a 1:50 ratio using a cellular lightweight concrete foam generator. Density of foam was kept 70 g/lit which was recommended by the manufacturer of the foaming agent. For this study pre-foaming method was adopted. After generating a stable foam, It was mixed for an additional minute after being added to the ready slurry. After adding the required quantity of foam, wet density was checked. In accordance with the pertinent tests, foam concrete was put into a variety of-sized molds. Mixing method is explained in the figure 3.2.

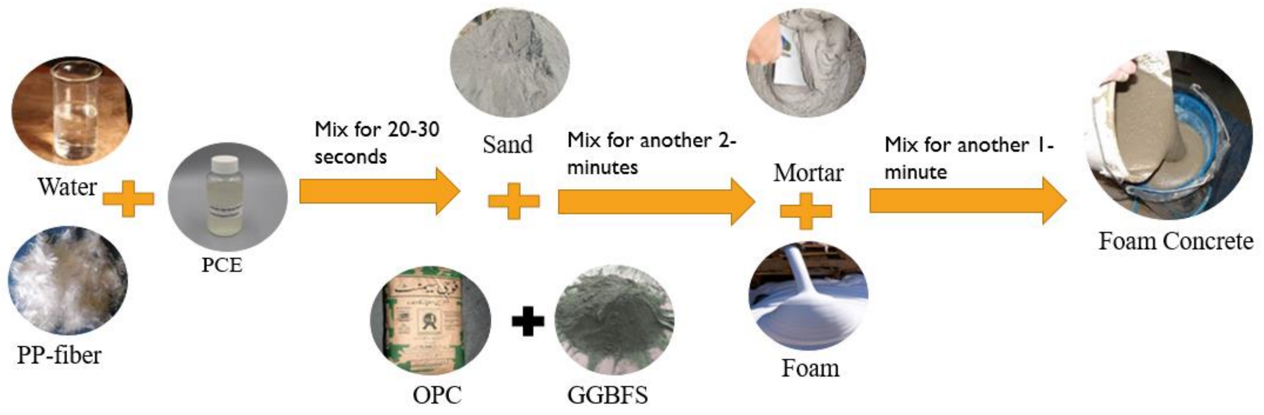


Figure 3.2 Flow chart of mixing

Table-3.4 Mix Proportions*

Mix Id	Cement	GGBFS (%)	w/b	Sand	Fiber Content (%)	Super-Plasticizer (%)	Foam (lit/m^3)
S0P0	370	0	0.36	560	0	0.95	510
S6P0	348	6	0.36	560	0	0.95	510
S12P0	326	12	0.36	560	0	0.95	510
S18P0	303	18	0.36	560	0	0.95	510
S24P0	281	24	0.36	560	0	0.95	510
S0P0.15	370	0	0.36	560	0.15	0.95	510
S6P0.15	348	6	0.36	560	0.15	0.95	510
S12P0.15	326	12	0.36	560	0.15	0.95	510
S18P0.15	303	18	0.36	560	0.15	0.95	510
S24P0.15	281	24	0.36	560	0.15	0.95	510
S0P0.3	370	0	0.36	560	0.3	0.95	510
S6P0.3	348	6	0.36	560	0.3	0.95	510
S12P0.3	326	12	0.36	560	0.3	0.95	510
S18P0.3	303	18	0.36	560	0.3	0.95	510
S24P0.3	281	24	0.36	560	0.3	0.95	510
S0P0.45	370	0	0.36	560	0.45	0.95	510
S6P0.45	348	6	0.36	560	0.45	0.95	510
S12P0.45	326	12	0.36	560	0.45	0.95	510
S18P0.45	303	18	0.36	560	0.45	0.95	510
S24P0.45	281	24	0.36	560	0.45	0.95	510

Mix ID (S6P0.15: GGBFS 6%, Polypropylene fiber 0.15% **by mass of cement)**

3.3 Workability

For this study workability was measured following ASTM C-1437 utilizing a flow table test. [48]. Before every flow measurement it was made sure that flow table is clean. Mold was filled in two layers. Diameter of flow for every formulation was measured before pouring into the molds.

3.4 Water Absorption

60 cubes (150*150*150 mm) were casted in total, 3 for each formulation. Water absorption test was done following ASTM C642 [49].

3.5 Compressive Strength

For compressive test EN-12390 [50] standard was used and for every formulation, three 150 x 150 x 150 mm cubical specimens were cast for the compressive strength after seven days and three for the strength after twenty-eight days.

a) Casted cubes for compression testing

b) Compression test setup

Figure 3.3 Compression Testing

3.6 Split Tensile Strength

For split tensile strength ASTM C469 [51] was followed and 60 cylindrical samples (D=150 mm, H=300 mm) were casted. 3 samples were tested for each formulation at 28-days of age.

$$T = \frac{2P}{\pi \, ld}$$

T= Splitting Tensile Strength in Mega Pascal

P= Maximum load which is as shown by the device in Newton

L= length in millimeters

D= diameter of the cylinder in millimeters

Figure 3.4 Split Tensile Strength Testing

3.7 Thermal Conductivity

For thermal conductivity test ASTM E1530 [52] was followed. Solid specimens of thickness 20 mm and diameter 50 mm were casted for each formulation. The method of using a guarded heat flow meter to determine thermal conductivity was employed.

a) Thermal Concutivity test specimens

b) DTC 300 Thermal conductivity meter

Figure 3.5 Thermal Concutivity Test

3.8 SEM Analysis

Scanning electron microscopy is the technique used to get detailed images where focused beam of electrons is used to scan the target surface of the specimen. For this study SEM analysis is used to analyze the impact of the variables on the air bubbles inside CLC samples.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Workability

Figure 4.1 displays the outcomes of flow diameter (mm) of CLC samples with the varying percentages of GGBFS and PP fiber. Groups 1 through 4 have 0%, 0.15%, 0.3% and 0.45% polypropylene fiber content. And in each group GGBFS varies from 0 to 24%. With the increasing percentage of GGBFS flow diameter is decreasing in all 4 groups. GGBFS has a finer particle as compared to type-1 cement. Consequently with the increasing percentage of GGBFS, water demand increased. Similarly observing the behavior of flow with the increasing polypropylene fiber content, it can be concluded that flow diameter is decreasing. More paste is needed to coat the fiber as the fiber content rises. This affects the workability negatively and results in decreasing flow with the increasing fiber content.

4.2 Water Absorption

The water absorption of different mixes, considered in this investigation, is presented in Figure 4.2. The maximum absorption of water was observed for the reference mix S0P0. With the increasing percentage of GGBFS, between 6-18%, water absorption decreased. The mix, S18P0, which contained 18% GGBFS and 0% PP fibers, showed the greatest decrease in water absorption. Mixes with 24% cement replacement with GGBFS showed a negative effect on water absorption. The addition of PP fibers, particularly at 0.3 and 0.45%, showed increase in water absorption as compared to the mixes of reference group G-1. At higher dosages of PP fiber, dispersion becomes an issue, and the workability of the mix reduces. Similarly at higher dosages of GGBFS, surface area increases, which results in poor workability and causes bubble destruction. The combined effect of PP fiber and increase in surface area due to the higher dosage of GGBFS reduced the workability. This may have caused the generation of micro-pores and interconnected pores. Which also explains the fact that mix with 0.45% pp fiber and 24% GGBFS (S24P0.45) showed highest water absorption of 25%.

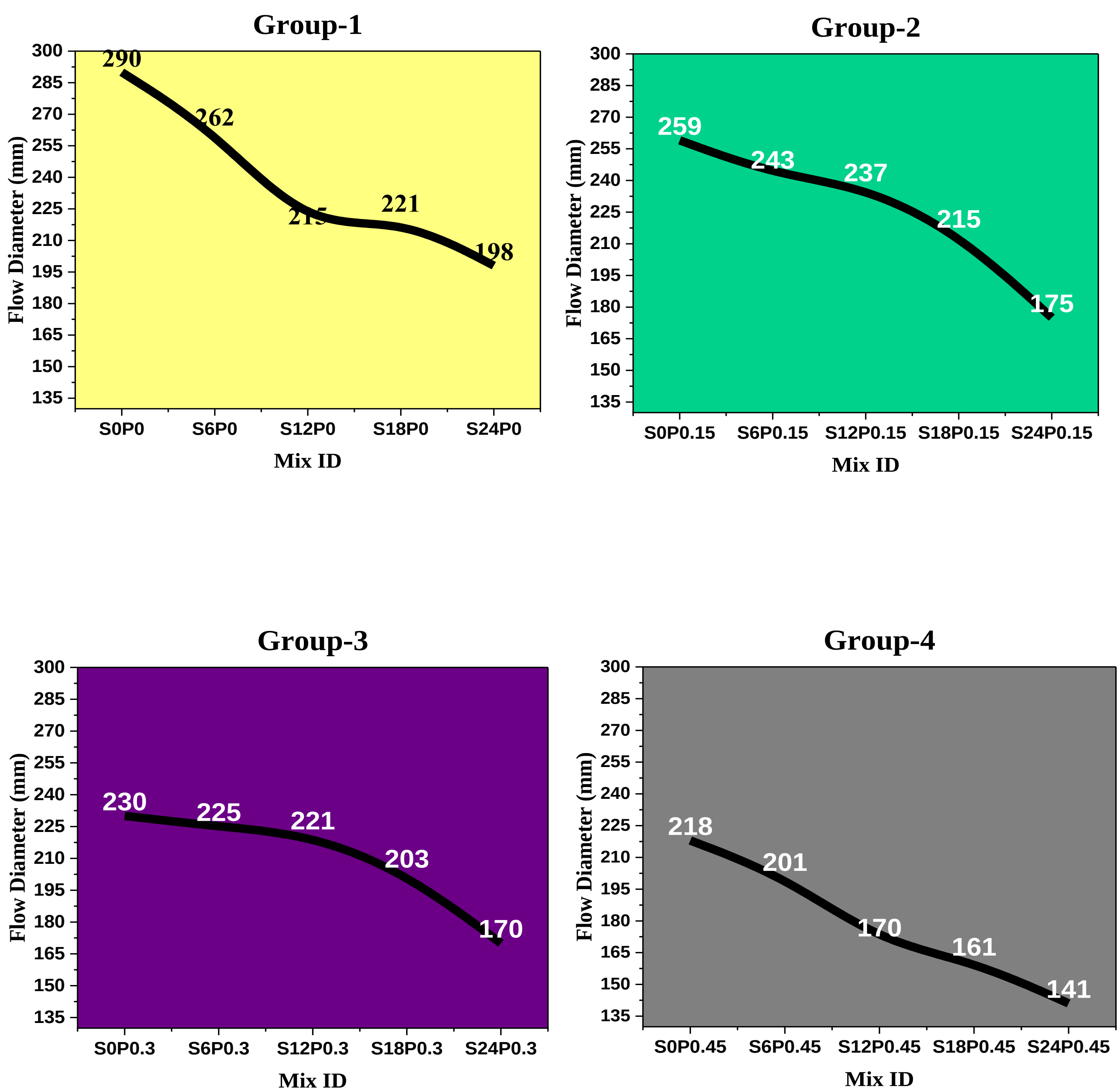


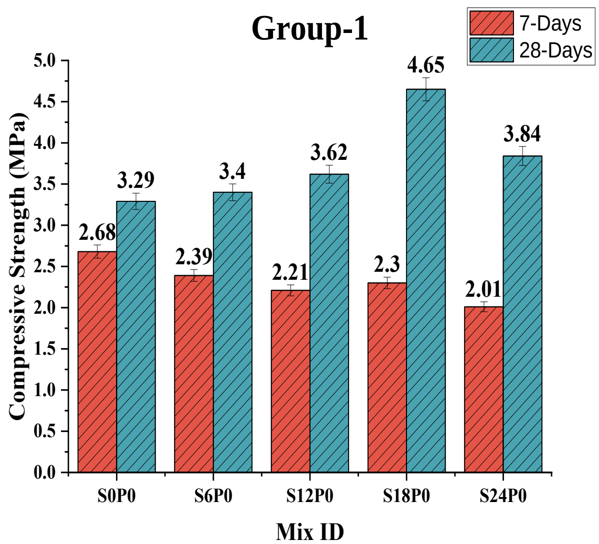
Figure 4.1 Workability of Fresh mixes

4.3 Compressive Strength

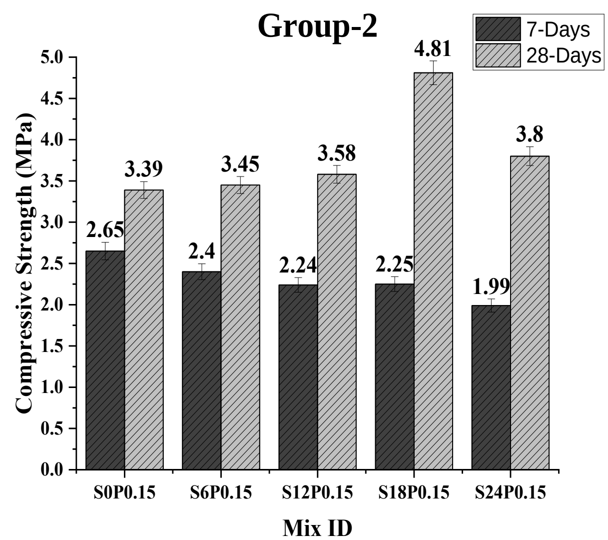
The varying percentages of GGBFS and polypropylene-fiber reinforcement were tried in foam concrete to investigate their impact on the foamed concrete's compressive strength after seven and twenty-eight days; the findings are described in Section 4.3. Figure 4.3 displays the compressive strength outcomes for the different mixes prepared in this study. 7-day compression strength is decreasing as the percentage of GGBFS increases in comparison to the control mix (S0P0). The basic reason behind this behavior is due to the slower hydration of slag than OPC in the beginning [3,4]. In all four groups, the 7-day compressive strength is declining relative to the control sample because GGBFS hydrates more slowly than OPC. It can be inferred from the 28-day compressive strength trend that with the increasing content of GGBFS in the 6–18% range, compressive strength increased. The optimal quantity of cement replacement with GGBFS is 18%. This high strength can be attributed to the C-S-H gel that is formed by the pozzolanic action of GGBFS with portlandite and its filling effect because of the smaller particles [24–26]. $Ca(OH)_2$ is a product that is formed during cement hydration. The reaction between pozzolan (GGBFS) and calcium hydroxide results in the production of secondary C-S-H gel. Additionally, it helps create concrete that is sturdy and long-lasting. Moreover, the heat of hydration for GGBFS is lower as compared to OPC, and this factor can help in the gradual development of strength, resulting in higher ultimate strength [27–29]. When the heat of hydration is low, strength development takes place gradually, resulting in higher ultimate strength. PP fiber improved the compressive strength; however, the effect was marginal.

4.4 Split Tensile Strength

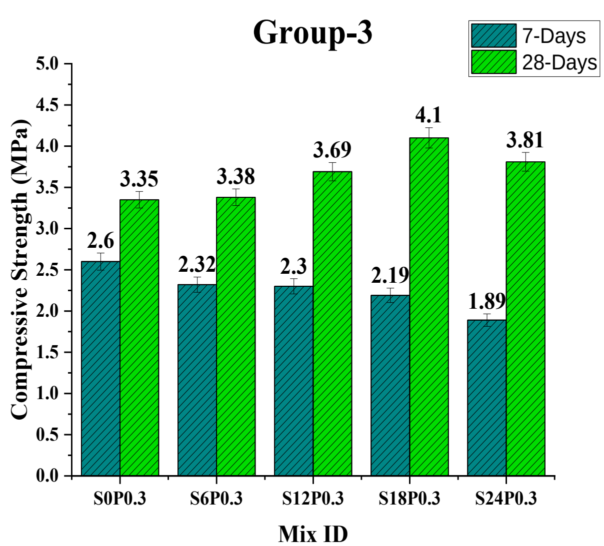
The split tensile strength data are displayed in Figure 4.4. With the increasing percentage of GGBFS, tensile strength is increasing. The pozzolanic and filling effect of GGBFS is the cause of the improvement in tensile strength. The structure of the matrix becomes more dense and strong with the production of C-S-H gel. Similarly, the filling impact of smaller grains of GGBFS contributes to a denser matrix. And including just 0.15% PP fiber, tensile strength increased by 108%. Fiber reinforcement can help in tensile strength improvement through its crack-bridging effect [30, 31].



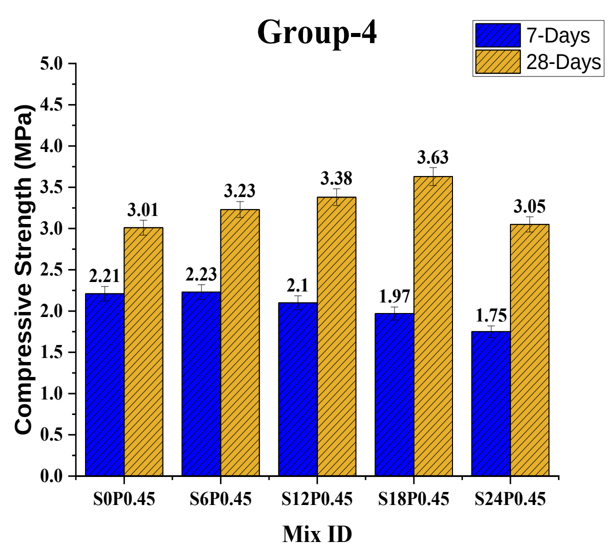
(a) 7 and 28-Days compressive Strength (PP fiber 0%)



(b) 7 and 28-Days compressive strengtl (PP fiber 0.15%)



(c) 7 and 28-Days Compressive Strength (PP fiber 0.3%)



(d) 7 and 28-Days Compressive Strength (PP fiber 0.45%)

Figure 4.2: 7 and 28 Days compressive strength with varying percentages of GGBFS and PP fiber content

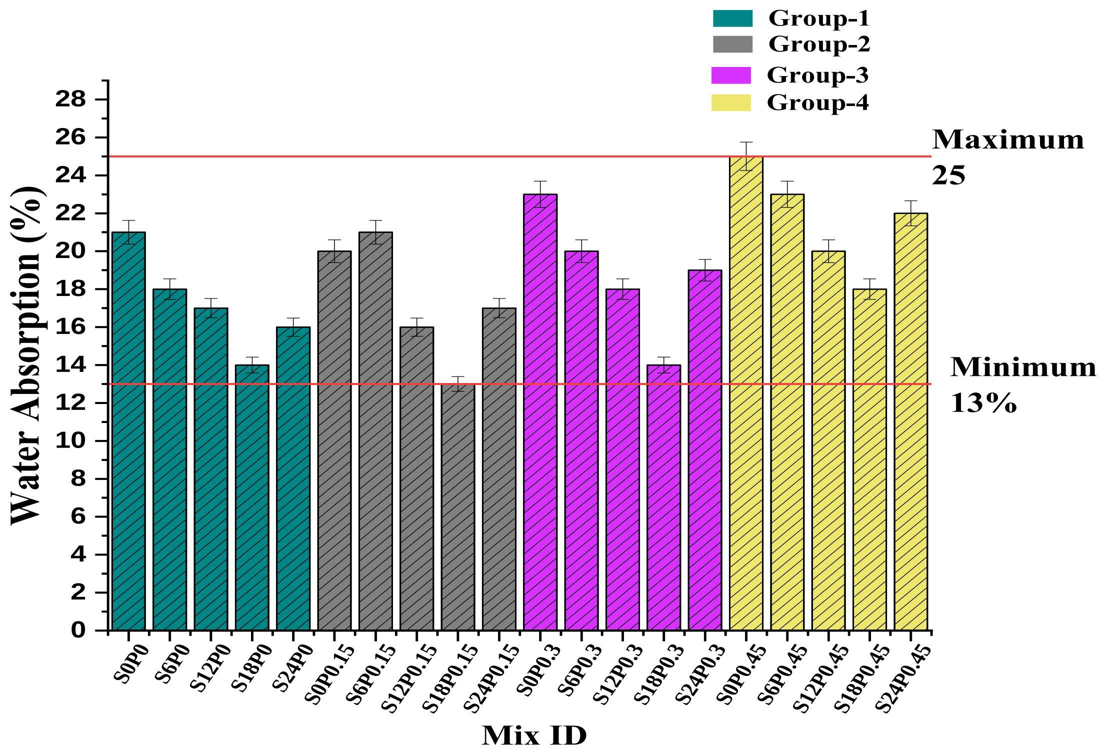


Figure 4.3 Water absorption after 28-Days

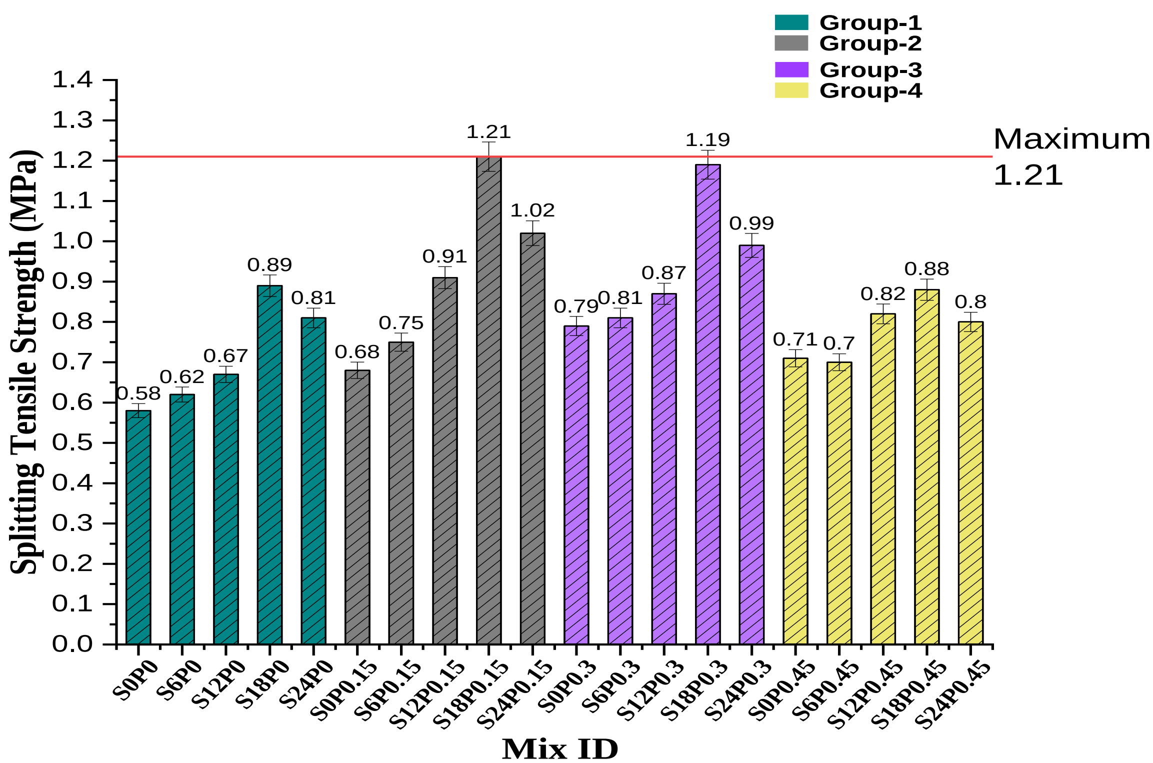


Figure 4.4 28-Days Split Tensile Strength

4.5 Thermal Conductivity

Figure 4.5 depicts the variance in thermal conductivity of the formulations prepared in this study. The trend in Fig. 4.5 indicates that with an increase in the percentage of GGBFS, thermal conductivity increases. The filling effect and pozzolanic activity of GGBFS result in a denser matrix, which may increase the thermal conductivity [32,33]. The addition of PP fiber resulted in a decrease in thermal conductivity. PP fiber halts the transfer of heat and also increases the porosity of the matrix.

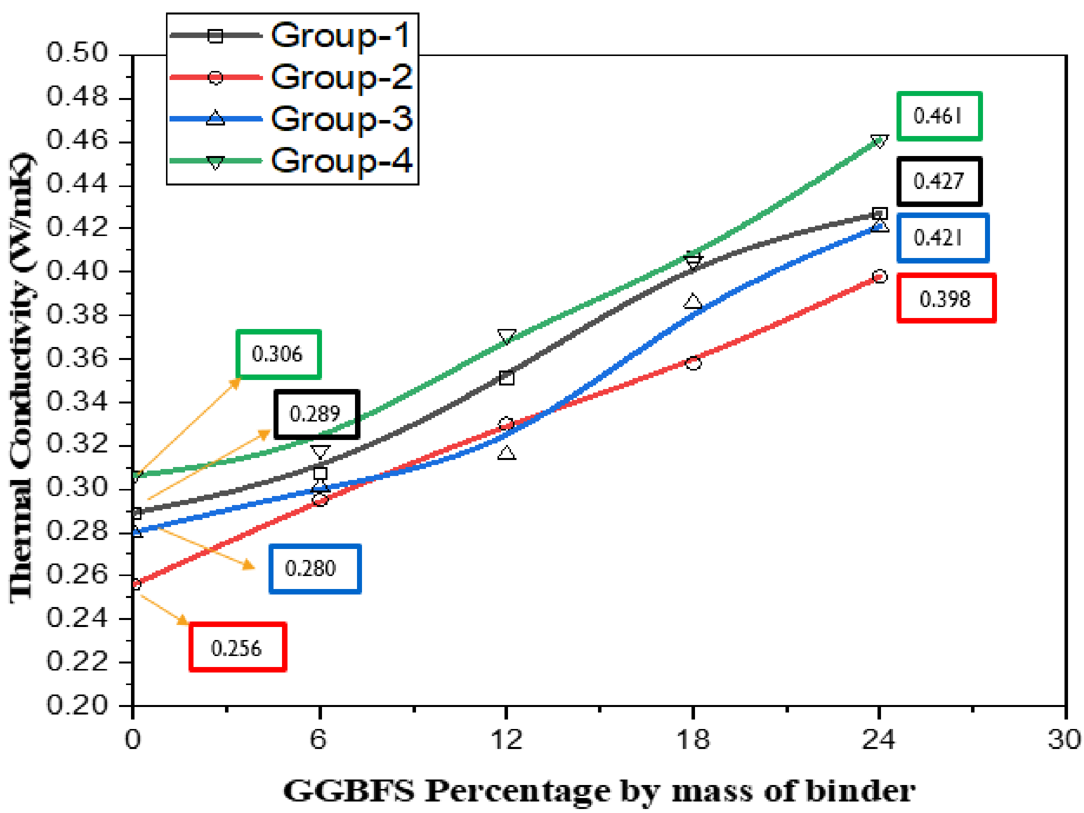


Figure 4.5 Thermal Conductivity after 28-Days

The heat transfer rate of air and PP fiber is lower in contrast to the solid matrix. The lowest heat conductivity of 0.26 was observed for the mix with 0.45% PP fiber and no GGBFS. In all four groups, thermal conductivity is increasing as the replacement level of cement increases from 0 to 24%. Group 4 with the highest PP fiber content showed the highest thermal conductivity. The reason behind this behavior is the poor workability of the mix, as with higher fiber content, dispersion becomes a problem. Poor workability of foam concrete can result in connected pores. Earlier, heat transfer was mainly due to conduction, but now the presence of connected pores causes heat transfer due to the convection process as well.

4.6 SEM Analysis

Comparing the SEM analysis results of two different mixes from Group 1 One with 18% of GGBFS content and the other one with 24% GGBFS content. Figure 4.6 (a) has fewer interconnected pores as compared to Figure 4.6 (b). As the proportion of GGBFS rises, workability is negatively affected, and these results agree with the results presented in Section 4.1. As the workability of the mix decreases, air bubbles start getting damaged, resulting in connected pores. These connected pores affect the performance of foam concrete negatively.

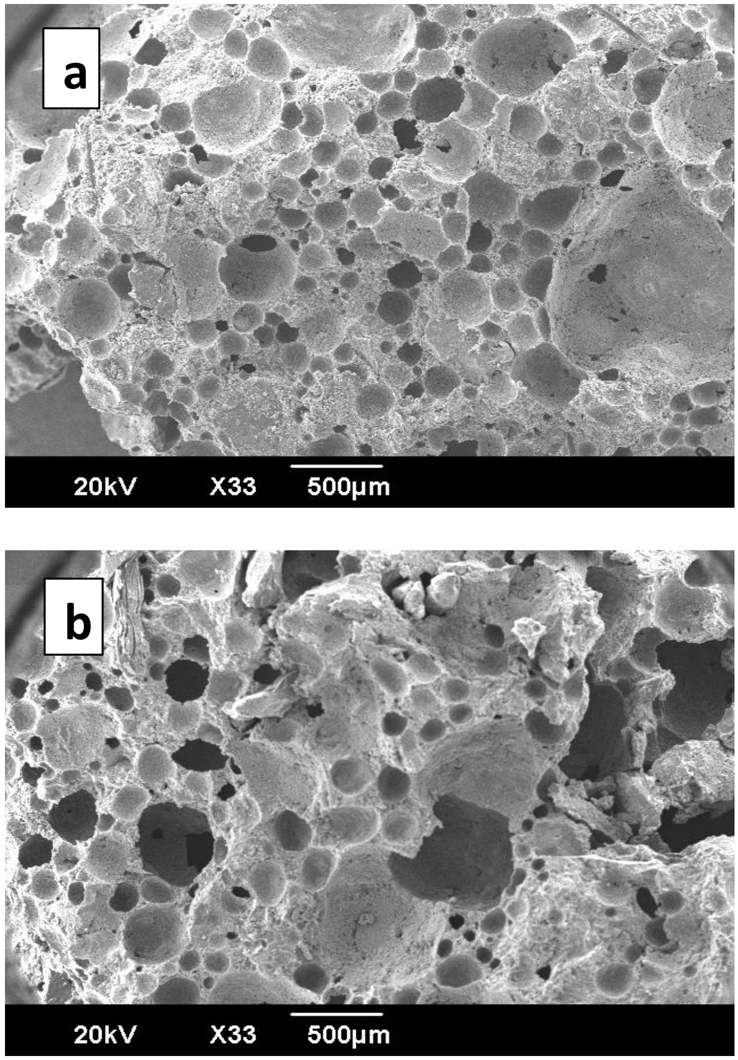


Figure 4.6 SEM images a) Group-1 S18P0 b) Group-1 S24P0

SUMMARY OF RESEARCH WORK

The construction industry is moving towards construction techniques that involve sustainable and innovative materials. Choosing environmentally friendly materials is a current trend. Using industrial products is a step that can impact the environment positively and make construction sustainable.

A suitable foaming agent is utilized to produce cellular lightweight concrete. Foaming agents help to incorporate air bubbles inside foam concrete, which makes it lightweight and gives it a porous microstructure. Foam concrete has a vast number of applications. It can be used to create partition wall panels, concrete blocks, fill uneven surfaces, roof insulation, etc. These applications depend on the foam content that is being introduced inside the concrete to make it lightweight. Porous microstructure makes foam concrete a better insulating material against heat and sound. The porous microstructure of foam concrete contributes to making it lightweight and a good thermal and sound insulator. But this porous microstructure makes foam concrete weak and fragile mechanically.

In this research, slag is partially substituting conventional Portland cement (OPC). With its pozzolanic and filling action, GGBFS, a waste product of the steel and iron sector, functions as an additional cementitious material (SCM) and enhances the qualities of concrete. The second major ingredient in this study is polypropylene fiber, which is used to reinforce the foam concrete. After a literature review, it was observed that there is negligible exploration of the combined effect of GGBFS as a cement substitute, in part in the presence of PP fiber. The study examines the physio-mechanical and thermal characteristics of foam concrete with different GGBFS and PP fiber concentrations.

The main focus of the proposed study is on using GGBFS in place of some ordinary Portland cement (OPC). This approach not only addresses the main problem of foam concrete's subpar mechanical performance, but it also helps reduce the cement industry's carbon impact.

CONCLUSIONS

It was investigated how well foam concrete performed with the varying percentages of GGBFS and PP fiber. The concluding remarks for this study can be summarized as follows:

1. The optimal content for GGBFS as cement replacement was 18%, and for PP fiber, it was 0.15%.
2. With 18% GGBFS content and 0.15% pp fiber, compressive strength increased by 46%, water absorption was reduced by 61%, split tensile strength increased by 108%, and thermal conductivity increased by 24% in comparison to the control sample.
3. Beyond the optimum content of GGBFS and PP fiber, the physico-mechanical and thermal performance of foam concrete were negatively affected, and that was also verified with the SEM images, where a higher number of connected pores were found beyond the optimum level of GGBFS due to the problem of workability.
4. The addition of PP fibers resulted in a reduction in thermal conductivity, while the higher percentage of GGBFS increased heat transfer.

5. Considering the overall performance, the combined effect of PP fiber and GGBFS has resulted in better performance. Where GGBFS was improving the mechanical performance but affecting the thermal conductivity negatively, that effect was taken with the addition of just 0.15% pp fiber (by mass of cement), where it not only reduced the thermal conductivity but also improved the mechanical performance.

FURTURE RESEARCH RECOMMENDATION(S)

It is suggested that in the future following aspects can be explored:

1. It is important to investigate the combined influence of PP fiber and GGBFS on fireproofing and shrinking performance.

2. In addition to that similar studies should be conducted to explore the combined effect of numerous kinds of fibers and SCMs on foam concrete's properties.

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