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Experimental Investigation on Strength Characteristics of Light Weight Foamed Concrete

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ABSTRACT- As part of this study, three distinct batches of foamed concrete were produced: plain foamed concrete (PFC), polypropylene fiber reinforced foamed concrete (PPFC), and basalt fiber reinforced foamed concrete (BFC). Compressive strength, splitting tensile strength, and, flexural strength, were some of the tests that were performed on the specimens. According to the findings of this research, using the optimal foam volume, which was determined to be 20%, results in a specific density of foam concrete that is between 342 Kg/m^2 and $490kg/m^2$ and a compressive strength that ranges from $20N/mm^2$ to 38 N/mm^2. Normal concrete was combined with Styrofoam with an R-13 rating, normal concrete was combined with PFC, normal concrete was combined with PPFC, and normal concrete was combined with BFC. When compared to the PFC specimen, the flexural strength of the BFC specimen was 10 times greater. The BFC beam specimen has shown the highest load bearing capability of the RFC beam samples. In addition, the findings of the experiments indicate that the combination of conventional concrete and BFC has shown the maximum load bearing ability when bent. The combination of standard concrete and PFC has been demonstrated to have the maximum load bearing capability among the compression columns.

KEYWORDS- Plain foamed concrete (PFC), Polypropylene fiber reinforced foamed concrete (PPFC), and Basalt fiber reinforced foamed concrete (BFC), Foamed concrete.

I. INTRODUCTION

Concrete is the construction material that is used up the second most after water all across the planet. It has become possible for today's construction industries to develop new materials and various methodologies in the field of material science that can meet a wide variety of structural and functional requirements. This has been made possible by the progression of technology and ongoing research in a variety of prospective fields. One of them is the creation of structural lightweight concrete, often known as foamed concrete or cellular concrete. This kind of concrete is becoming more popular. The recent years have seen a significant rise in the commercial demand for lightweight aggregate concrete, also known as LWAC. This is mostly because to the several benefits that LWAC has in comparison to traditional concrete. Its use may be found in a broad variety of structures all over the globe, including low-rise and high-rise buildings, bridges, and even offshore constructions [1]. In recent years, a greater amount of focus has been placed on the development of lightweight aggregate concrete as a result of the numerous benefits associated with this building material, including its status as a relatively "green" construction material, energy savings, and environmental friendliness [2, 3]. In heavy structures like tall buildings and bridges, where the self-weight of the structure creates a problem for the designers, it is sometimes necessary to focus on decreasing the weight of the structural element rather than increasing its strength. This is especially the case when reducing the weight of the structural element becomes necessary. Foamed concrete is light in weight, low in cost, and easy to manufacture material with good workability and excellent performance in thermal insulation, acoustic insulation, fire resistance, corrosion resistance, and shock absorption [5]. This is an additional interesting fact that makes foamed concrete a very interesting material.

II. LITERATURE REVIEW

A. *Historical Context and Initial Statements*

In this part, the fundamental concept of foamed concrete, the history of the material, its features, and the tests carried out by earlier researchers are explained in a condensed form. The addition of air in the form of microscopic bubbles produces foamed concrete, which is a kind of concrete that is made up of cement, fine aggregate, and water [7]. The addition of air results in the formation of homogenous voids or pores. It is also known as lightweight concrete or cellular concrete. This kind of concrete is comparable to traditional concrete, except it does not include coarse material. Researchers and manufacturers are working toward the goal of completely replacing standard weight concrete with foamed concrete since it has been discovered that foamed concrete is lighter in weight than normal concrete. The most significant use for it are as an insulating material, a partition wall, filling voids, and for rehabilitation work. It is now possible to use lightweight concrete or foamed concrete as a structural concrete in the modern world thanks to the development of these types of concrete and a better understanding of how they work. In the past, this type of concrete was only used for dividing walls or as an insulation material. It wasn't until almost a century ago that autoclaved aerated concrete was effectively developed in terms of both its technological viability and its potential for commercialization [2]. In the year 1923, Romans began using concrete by entraining air in order to lessen density. Later, in the 1950s, Valore published an outline of foamed concrete. Rudai & Short and Kinniburgh presented the fundamental composition, physical qualities, and applications of lightweight concrete as a result of their extensive study conducted in the 1970s. Significant advancements were made over the course of some time, and now it is being used all over the globe for a broad variety of purposes.

B. Application of Foamed Concrete

The fact that foamed concrete is far less heavy than traditional concrete enables it to find fantastic utility in a wide range of contexts. Structural lightweight concrete was used in the construction, which resulted in a dead load reduction of 20 percent and a reduction in construction cost of 10 percent[5]. In addition, the Calgary Saddledome Stadium, which was constructed for the 1988 Winter Olympics and can be seen in Figure 1, was designed using lightweight concrete so that it would be simpler to transport and assemble.

Figure 1: The Calgary Saddledome Stadium [8]

Figure 2 depicts the structural lightweight concrete panelsthat were used in the construction. In order to create a sound layer for the application of a membrane, a lightweight concrete was used in the construction.

Figure 2: Building site of a house under construction made from white foam concrete blocks [9]

When constructing tall buildings using LWC, it is possible to minimize the quantity of reinforcement and member cross-sections as well as the size of the foundation [4]. Ceramsite is a man-made light aggregate that is distinguished by its unusual combination of a high surface area and a low density. It finds widespread use in the construction of things like highways and bridges as well as homes and other buildings. Ceramsite may be used in place of gravel as the primary concrete aggregate in building structures, which can result in improvements to the building's structural weight, the longevity of the concrete, and its resilience to earthquakes. Because it boosts the road's resistance to wear, it may be used in the road pavement construction process. Additionally, it is used as a wall material due to its low weight, strong strength, excellent temperature resistance and sound insulation, as well as its resistance to fire and radiation [6]. The many applications of foamed concrete are outlined in Table 1, which is organized according to the density.

Table 1: Various application of foamed concrete

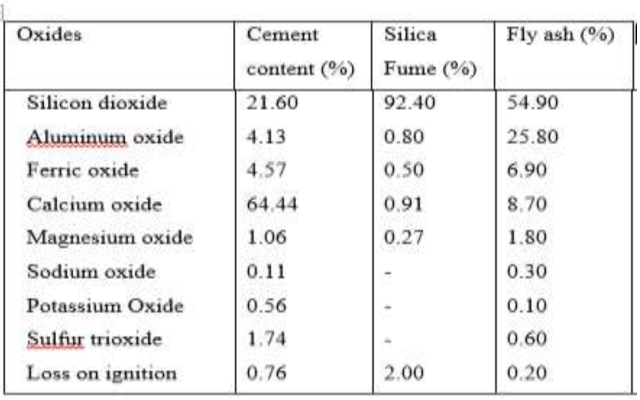
Density (kg/m^3)	Applications
300 - 600	Lightweight and insulating cements for floor foundation, heat insulation and slope for flat roofs, rigid floor foundation, tennis court foundation, interspaced concrete filling, raceways insulation; thermo insulating blocks, steel structures fireproofing, tunnels and pipelines compensating mass, dumps, foundation and coverings, land reclamation and consolidation underground cavities, infill and all types of infill where elevated thermal insulation is required.
600 to 900	Stables and pig-site foundations; industrial foundations, partition and tamponing slabs, ceiling slabs, and lightweight concrete mixed panels.
900 to 1200	Building materials such as bricks for the outside walls, slabs for the interior partitions, concrete and lightweight concrete mixed panels for the covering, and foundations for the elastic floors.
1200 to 1700	Panels which have been prefabricated and are used for filling civil and industrial structures, casting walls, and making garden decorations.

C. Materials

Aluminum oxide, ferric oxide, magnesium oxide, sulfur trioxide, tricalcium silicate, dicalcium silicate, tricalcium aluminate, and tetracalcium aluminoferite are the chemical components of ordinary portland cement (OPC) [14]. Table 2 shows the raw materials as well as the % concentration of cement, silica fume, and fly ash.

The compressive strength of foamed concrete may be improved by including fly ash into the mix. Additionally, it was discovered that the ratio of splitting tensile strength to compressive strength for foamed concrete containing fly ash was comparable to the ratio reported in conventional concrete [15]. It is recommended to utilize fly ash of Class F in accordance with the standards of ASTM C 618. The decrease in particle size that occurs with foamed concrete results in an increase in the material's strength [16]. The strength of foam concrete rises in proportion to the amount of fly ash that is included in its composition [2]. It is clear from looking at Figures 6 that the strength of cellular concrete improves along with an increase in the percentage of fly ash that is present in the mix. It has been shown that adding silica fume to foamed concrete both increases the material's compressive strength and speeds up its performance [17].

Table 2: Chemical composition of OPC [2]



Oxides	Cement content (%)	Silica Fume (%)	Fly ash (%)
Silicon dioxide	21.60	92.40	54.90
Aluminum oxide	4.13	0.80	25.80
Ferric oxide	4.57	0.50	6.90
Calcium oxide	64.44	0.91	8.70
Magnesium oxide	1.06	0.27	1.80
Sodium oxide	0.11	-	0.30
Potassium Oxide	0.56	-	0.10
Sulfur trioxide	1.74	-	0.60
Loss on ignition	0.76	2.00	0.20

There are two ways to produce foam in the foamed concrete mix: the first is called preformed foaming, and it involves preparing the foaming agent in advance by combining water and the foaming agent together, followed by aerating the mixture to create foam. The direct mixing of foam with concrete is the other approach that may be used to generate foam [7].

The yield strength of foamed concrete is significantly impacted by the presence of foam. The density of foamed concrete, as well as its flow behavior and strength, are all dependent on the amount of foam [2]. It is recommended that a foaming agent that meets the criteria of ASTM C869 be used. The ratio of foaming agent to water that is used in the mixture is 1:50. Foaming agents of the protein-based kind are diluted with water at a ratio of 1:40 [2]. It has been shown that lightweight concrete that contains a suitable quantity of air entraining agent has great qualities. These characteristics include extremely high workability, low density, and strong strength. The effectiveness of foam concrete is directly proportional to the quality of the foam as well as the mixing technique.

Because biological contamination would have a negative influence on the quality of foam and concrete generated and would also result in poor long-term strength of concrete, potable water should be used in the preparation of both foam and foamed concrete. If the foaming agent is mixed with hard water, the resulting combination will need an increased amount of foaming agent. In a similar vein, using soft water in the mixture reduces the amount of foaming ingredient that is necessary to produce foam of the appropriate grade. On the other side, adding cold water results in less foam being produced, whilst adding hot water results in more foam being produced than when cold water was used. In conclusion, the addition of hot air has a tendency to rapidly degrade foam

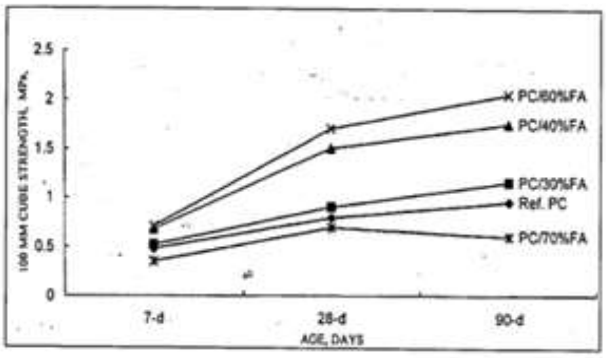


Figure 3: Compressive strength improvement with increasing fly ash concentration.

It can be noticed from Figures 3 that with the increase in the content of fly ash, the strength of cellular concrete increases. Silica fume is used to improve the compressive strength of foamed concrete and accelerates its performance. Due to the characteristics of foam concrete, which include its ability to flow and self-compact, the water-to-cement ratio is significantly higher than that of traditional concrete; it ranges from 0.4 to 0.8. The amount of water that is normally needed for a mixture is normally determined by the composition of the mixture as well as the admixtures. It is possible to use less water and cement in the mixture if a super-plasticizer is included in it. In order to guarantee that the cement completely hydrates, it is essential that the ratio of water to cement be kept at a particular minimum level.

D. *Fiber*

Fibers contribute to an increase in the tensile strength of concrete, as well as a reduction in the fracture width and a modification of the mechanism of failure. It has been established that modified polypropylene fiber reduces the rate of shrinkage as well as the fracture toughness. Modified polypropylene fiber also has a significant influence on flexural strength. When compared to ordinary concrete, the compressive strength of steel fiber concrete rose by up to 25 percent, the splitting tensile strength was shown to be improved by 45 percent, and deflection seemed to decrease, all of which contributed to an increase in the strength. Strength in splitting tensile, flexural toughness, flexural strength, and impact resistance were all significantly increased thanks to the addition of steel fiber . The main influence on compressive strength and splitting tensile strength was shown by polypropylene fiber, steel fiber, and water hyacinth (Eichhornia crassipes) fibers. The conclusion that may be made from employing hybrid steel and polypropylene in lightweight concrete for the design of concrete materials with decreased density and higher ductility for various applications, such as the construction of high-rise earthquake-resistant structures, was reached. The use of polypropylene fiber led to a decrease in slump flow of forty percent, a rise in splitting tensile strength of fourteen and a half percent, and an increase in flexural strength of ten and a half percent. The fact that expanded polystyrene (EPS) contains polypropylene fibers led to a considerable improvement in the material's shrinkage characteristics.

E. *Compressive Strength*

Because several other criteria, such splitting tensile strength and flexural strength, are reliant on this amount, the compressive strength of foamed concrete is a significant criterion to take into consideration. As can be seen in Figure 4, the compressive strength of foamed concrete is affected by both its density and the amount of time it has been allowed to age.

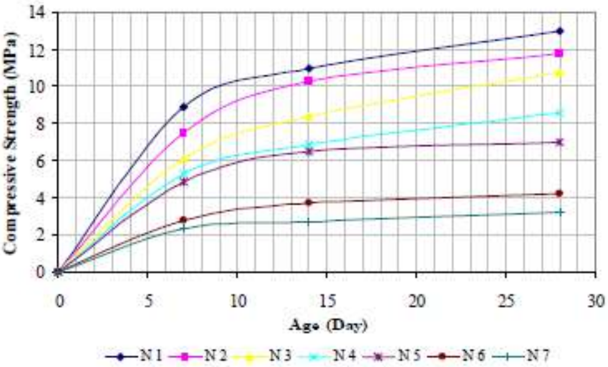


Figure 4: Compressive strength improvement with age and density [30].

For a given density, mixes with finer sand gave better strength than mixes with coarse sand, as shown in Figure 5. This means that the higher the compressive strength, the finer the particle, and vice versa.

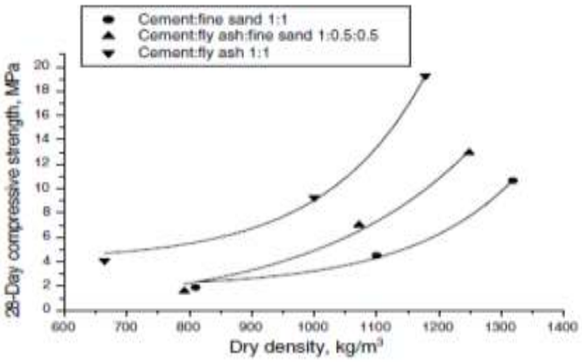


Figure 5: Compressive strength vs density variation for mixes with different sand fines

The compressive strength of foamed concrete seemed to rise exponentially either with the increase in concrete density or with the reduction in foam volume. Additionally, silica fume and polypropylene fiber considerably boosted the compressive strength. Because of the use of the polymer foaming agent, lightweight foamed concrete with a flow value of more than 180 mm was generated, and it was observed that the compressive strength increased more than the usual foamed concrete.

There were four different specimens prepared: lightweight cold-bonded concrete (LWCC), lightweight bentonite concrete (LWBC), lightweight glass powder concrete (LWGC), and normal weight concrete. The compressive strength of lightweight concrete ranged from 42.3 to 55.8 MPa, and the density ranged from 1860 to 1943 kg/m^3 (NWC). According to the findings, which are shown in Figure 6, lightweight concrete made using glass powder concrete had a compressive strength that was more comparable to that of conventional concrete.

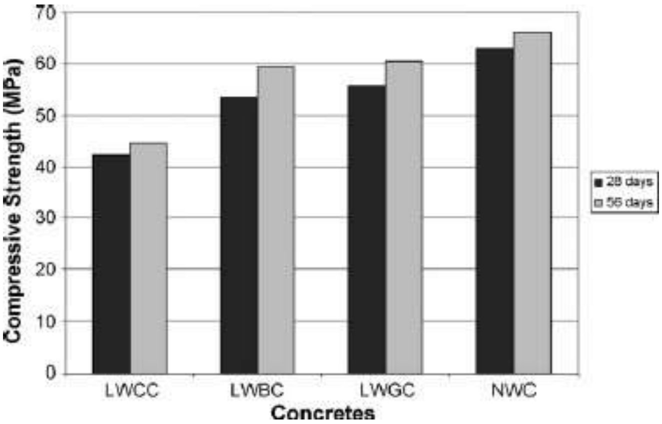


Figure 6: Compressive strength of concrete specimens for 28 and 56 days

F. *Flexural Strength*

The flexural strength of foamed concrete is a highly significant metric to consider since it dictates its usage in structural applications. Studies conducted in recent years demonstrated that the use of fibers in foamed concrete showed great improvement. The results of this study are shown in Figure 7, which demonstrates that the modulus of rupture increases as the volume % of fibers increases.

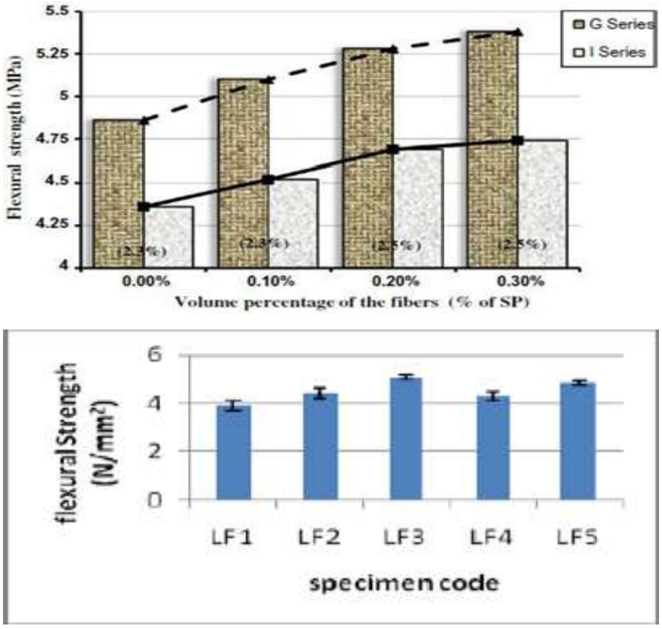


Figure 7: Variation of flexural strength with percentage volume of fiber

LF1, LF2, LF3, LF4, and LF5 all correlate to the volume % of fiber. The graph demonstrates that LF3 has the highest flexural strength, which is proportional to a volume fraction of fiber that is 0.35 percent and a fiber length that is 12 millimeters. The compressive strength of lightweight concrete made from oil palm shell (OPS) determines the flexural strength of the concrete. It was discovered that OPS has a flexural strength that is 17 percent lower than granite concrete after 28 days.

III. EXPERIMENTAL PROGRAM

A. *Introduction*

In this chapter, the specifics of the experimental works, including the materials that were used, the mix design, the mixing technique, the preparation of the formwork, and the testing procedure, are described. In the beginning phases of this experiment, many trial mixes were carried out to discover the optimal mix percentage by maintaining the same level of strength throughout all of the trials. The many experimental examinations that were carried out were carried out using this optimal mix percentage.

B. Components of Foamed Concrete

Following extensive study and analysis, as well as consideration of previous research, it was determined that the use of finer components in foamed concrete mix should be prioritized. This was determined on the basis of the findings of the aforementioned research. Utilized materials included cement, fly ash, silica fume, a water-reducing plasticizer, and fibers.

- ***Ordinary portland cement***

Cement is the component of concrete that is considered to be the most essential. The capacity of a cement to generate an enhanced microstructure in concrete is one of the major aspects that should be considered when choosing a cement. High-performance concrete, in contrast to traditional cement concrete, may include either chemical or mineral admixtures, or both. In addition, the influence of the qualities of the cement on the amount of water that is required is more. Compressive strength at various ages, fineness, heat of hydration, alkali content, tricalcium aluminate (C3A) content, tricalcium silicate (C3S) content, dicalcium silicate (C2S) content, etc. are some of the important factors that play a vital role in the selection of cement. Other important factors include fineness, alkali content, and heat of hydration. In addition to this, it is essential to make certain that the chemical and mineral admixtures are compatible with the cement. It is a powdered substance that, when combined with water to make a paste, gradually hardens. It is a crucial characteristic that there is a chemical reaction that takes place when it is combined with water, and that reaction is called hydration.

Ordinary portland cement (OPC) of the brand name UltraTech Cement that conformed to the requirements of IS-12269-1987 was utilized.

- ***Fly Ash***

Fly ash, also known as flue ash, coal ash, and pulverized fuel ash is a product of coal combustion. It is made up of the particulates (fine particles of burned fuel) that are expelled from coal-fired boilers alongside the flue gases. The substance that makes up fly ash, known as fly ash material, may be collected by using electrostatic precipitators or filter bags while it is still floating in the exhaust fumes. Fly ash particles are typically spherical in form and vary in size from 0.5 micrometers to 300 micrometers. This is because the particles harden quickly while they are still floating in the exhaust fumes. The primary effect of the quick cooling is that very few minerals are given the opportunity to crystallize, and instead, the material that is left behind is mostly amorphous glass that has been quenched. The pulverized coal does, however, include certain refractory phases that do not melt (completely) and instead retain their crystalline structure. As a direct result of this, fly ash is a diverse kind of substance.

According to Standard C618 of the American Society for Testing and Materials (ASTM), there are two different types of fly ash: Class F fly ash and Class C fly ash. The quantity of calcium, silica, alumina, and iron that is included in the ash is the primary factor that distinguishes these classes from one another. The chemical composition of the coal that is burnt has a significant impact on the chemical characteristics of the fly ash (i.e., anthracite, bituminous, and lignite).

Although the criteria of ASTM C618 must be met for the majority of applications, there are certain fly ashes that do not fulfill these standards. In order to be acceptable for use as a cement substitute, fly ash must conform to stringent building requirements; however, the United States does not have any uniform environmental rules in place. Seventy-five percent of the fly ash must have a fineness of 45 micrometers or less, and its carbon content must be less than four percent, as determined by the loss on ignition (LOI) test. In the United States, the LOI must be lower than 6%. Because of the varying performance of the coal mills and the boilers, the particle size distribution of raw fly ash has a tendency to change continuously. This is caused by the fluctuations in performance. Because of this, it is essential that fly ash be treated utilizing beneficiation techniques such as mechanical air classification in order for it to be used in the most effective manner possible to replace cement in the manufacturing of concrete. If, on the other hand, fly ash is utilized in the construction of concrete as a filler to replace sand, then unbeneficiated fly ash that has a greater LOI may also be employed.

Fly ash of class F that was obtained from thermal power plant. It complies with the requirements of ASTM C618–12a.

- ***Silica Fume***

The production of silicon metal or ferrosilicon alloys results in the generation of silica fume as a byproduct. Concrete is one of the most fruitful applications for the utilization of silica fume. It is a highly reactive pozzolan both in terms of its chemical composition and its physical qualities. Concrete that contains silica fume has the potential to be very strong and to last for a very long time. In the event that it is required, silica fume may be easily included into the manufacturing of concrete by contacting one of the many companies that provide concrete admixtures. During the placement, finishing, and curing processes of silica-fume concrete, the concrete contractor has to pay extra close attention to detail.

Silica fume is a kind of ultrafine substance that consists of spherical particles with a diameter of less than 1 micrometer, with 0.15 micrometers being the average. Because of this, the typical cement particle is nearly one hundred times larger than this one. The bulk density of silica fume may range anywhere from 130 (undensified) to 600 kg/m3 and is determined by the degree of densification that takes place in the silo. In most cases, the specific gravity of silica fume will fall somewhere in the range of 2.2 to 2.3. The BET technique or the nitrogen adsorption method are both viable options for determining how much specific surface area silica fume has. In most cases, it falls somewhere in the region of 15,000 to 30,000 m^2/kg.

Silica fume, which was provided by my friend from Bangalore, was used.

- ***Foam***

As can be seen from Figure 8, the synthetically based foam concentration employed under this research is the CreteFoam

CMX brand and is a synthetic based.

Figure 8: Foam concentrate

Figure 9: Foam output

They can be stored for longer, don't emit any offensive odors, and function admirably in a wide range of environments. When foam is included into the concrete mixture, it greatly expands the volume of the concrete while simultaneously reducing its mass. Foam is a common source of concrete bubbles or voids. The foam's bubbles leave holes when it dries. Therefore, it is crucial to comprehend the process by which bubbles develop and dissipate during the hardening of concrete. Foam concentrate and water were mixed at a ratio of 1:50. The foam was produced using the foam producing equipment seen in Figure 9. Making foam required only two ingredients and a few minutes of gentle mixing in the pressure container: foam concentrate and water. The next step is to plug the machine in and turn it on, at which point the pressure within the container will increase and foam will be produced.

A foam-making machine may produce both low and high foam densities. Bentonite and Metakaolin were also included during first trial mixes, which boosted the overall performance of foamed concrete.

- ***Fiber***

The abbreviation PPF stands for polypropylene fibre, which is a kind of linear polymer synthetic fiber that may be made by polymerizing propylene. It is also resistant to corrosion and has a low weight, a high strength, a high toughness, and a high strength to weight ratio. The PPF finds widespread use in a variety of fields, including the building industry, the energy sector, the garment business, and the preservation of the environment. In recent years, there has been a rise in the number of instances in which basalt fibers have been used to enhance the hardened qualities of concrete. A shift in the hardened condition of the concrete is brought about as a consequence of the addition of these fibers to the concrete. However, these fibers also have an effect on the fresh qualities of the concrete, notably the workability of the concrete. In this particular experiment, both polypropylene and basalt fibers were used.

- ***Water***

Tap water is used for mixing the concrete constituents.

C. Mix Design

Mix design may be described as the process of choosing acceptable elements of concrete and calculating their relative proportions with the goal of generating concrete of a specified minimum strength and durability while minimizing the amount of money spent on doing so. Mix design is also known as mix formulation. In order to determine the optimal mix percentage, a number of tests were carried out. Plain foamed concrete (PFC), polypropylene fiber concrete (PPFC), and basalt fiber foamed concrete were all made using the usual mix design (BFC).

- ***Mixture Proportions***

For foamed concrete, we cannot go with coarse aggregate because these will sink into foam. A ratio of 1:2 of cement to sand was used. Table 3 provides the information that is needed to fully understand the mix proportions for PFC, PPFC, and BFC. The ratio of water to cement was kept constant at 0.50, while the amount of foam was kept at 20% throughout all of the mixes.

Table 3: Mix proportion ((kg/m^3)

Mix	Cement	Silica fume	Fly ash F %	F A	Foam	Water	Super-plasticizer	Fiber %
M1 (PFC)	340	0	0	680	68	170	0.6	0
M2 PPFC	340	17	5	680	68	170	0.65	0.75
M3 (BFC)	340	34	10	680	68	170	0.75	0.7

- ***Details of Mixing Process***

In the beginning, a concrete mixer was used to perform a dry mixing process with the various components, such as cement, fly ash, and silica fume. Water and super plasticizer were combined and blended together. After some time had passed, one half of the liquid component of the mixture was added to the dry component, and the mixer was allowed to run until the lumps were broken up. After that, the second half of the water that had been reserved was added, and the mixture was stirred for a total of two minutes. After that, foam was added, and the mixture was mixed once more before being allowed to sit for three minutes. At this stage in the process, the fibers that are part of the mix design were added, and it was blended for another two minutes after that.

- ***Casting and Removal from the Mould***

Casting of foamed concrete specimens is a crucial stage since the output of the specimen produced has an indirect impact on the findings. The fabrication of the specimens was optimized by the use of the necessary procedures. Before casting, form oil was applied to the cylinders and molds to prevent concrete from adhering to them. This was done before the casting process began. Because foamed concrete can level itself and compress itself on its own, vibration was not necessary throughout the construction process. After the concrete was placed, the surface was leveled so that it would have a smooth finish. After that, the samples were left alone for a period of one day to mature. After 24 hours, the specimens were removed from the molds using the appropriate equipment, and then they were sent to the curing chamber to complete the curing process.

D. Procedures for the Preparation and Evaluation of Specimens

- ***Compression Tests***

The compressive strength test is the most essential of all of the compression tests because it provides insight into the qualities that define the concrete. For the compression test, standard size cylinders with dimensions of 4 inches by 8 inches were used. Casts were taken from three distinct batches: PFC, PPFC, and BFC, with three specimens taken from each batch for a particular combination. After 24 hours of casting, the specimens were removed from the molds and placed in the curing chamber to complete the curing process. After seven days, the specimens were taken out and allowed to air dry for at least twenty-four hours. In a similar fashion, samples that required to be examined after 28 days were removed from the curing chamber, allowed to air dry for 24 hours, and then submitted for testing. The specimens were trimmed at the top so that the surface would be uniform. The casting process and the testing procedure both adhered to the specifications of IS 516. The cylinders were put through their paces in the compression testing equipment. The machine's specimen size could be altered, and a constant rate of loading of 5.2 KN/s was successfully maintained. After the failure of the specimen, the load bearing capacity in kN and the strength in MPa were measured and recorded.

- ***Splitting Tensile Test***

The split tension test is used for tensile testing on concrete since direct tension testing on ceramic-based materials is difficult to execute because there is no practical means to grab the samples. This makes the split tension test the preferred method. When casting the specimens and conducting the tests, Standard cylinders of size 6 inches diameter and 12 inches long were used. Casting was done using three distinct batches of PFC, PPFC, and BFC, with three specimens of each type for the given combination. A universal testing equipment, like the one seen in Figure 11., was used to evaluate each specimen.

Figure 11: Splitting tensile strength test set-up

Following the casting process, the specimens were allowed to set for a full day. After a casting period of twenty-four hours, the specimens were removed from the molds and stored in a humid curing chamber. When the specimens had been cured for a total of 28 days, they were removed from the curing chamber and allowed to air dry for 24 hours. Castings of the specimens were performed and examined in accordance with the requirements outlined in IS 516. Apply the load continuously without shock at a rate within the range 1.2 to 2.4 MPa/sec. The specimen of foamed concrete was then placed inside of the split tension set-up. Each concrete cylinder was then spread out in a horizontal position, and a load was applied to one of the long sides. This results in a cylinder that is subject to a consistent tensile tension across its whole. It is possible to calculate the splitting tensile strength of the specimen by applying the following equations:

$$F_{ct} = = \frac{2P}{\pi \mathrm{DL}}$$

Where,

F_{ct} = splitting tensile strength, N/mm^2
P = maximum applied load, N
D = diameter of the cylinder, mm
L = height/Length of the cylinder, mm.

- ***Flexural Strength Test***

In order to investigate the foamed concrete's flexure behavior, a flexure test was carried out on the concrete made with different fibres. Castings were done of standard samples measuring Effective span of the beam (400mm) and b= Breadth of the beam (100mm). Casting was done in three distinct batches: PFC, PPFC, and BFC, with each batch contributing three specimens to the mix. The casting technique and testing procedure were carried out in accordance with the requirements published by IS 516. Following the casting of the specimens, they were left to harden for a period of one day.

After a period of 24 hours, the specimens were demolded and then sent to a facility that specializes in wet curing. After the specimens had been cured for 28 days, they were removed and allowed to air dry for 24 hours before being tested. After that, the edges were ground to make the surface as even as possible. On the supports, which had a clear span, the specimens were allowed to rest. Flexural strength is calculated using the equation:

$$F=PL/(bd^2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 3$$

Where,

F= Flexural strength of concrete (in MPa).
P= Failure load (in N).
L= Effective span of the beam (400mm).
b= Breadth of the beam (100mm).

IV. RESULT AND DISCUSSION

In this chapter, the findings of the numerous tests that were carried out in the laboratory on PFC, PPFC, and BFC specimens are presented. The findings contain a description of the mechanical parameters, including their density of concrete, compressive strength, splitting tensile strength, and flexural strength.

A. Compressive Strength and Density of concrete

Figure12 illustrates the relationship between compressive strength and unit weight for PFC, PPFC, and BFC. The compressive strength of PFC with a density of 1490–1540 kg/m^3 ranges from 31 –34.5 N/mm^2, whereas the compressive strength of PPFC with a density of 1520–1602 kg/m^3 ranges from 32–36 N/mm^2 and the compressive strength of BFC with a density of 1645–1760 kg/m^3 ranges from 32–39 N/mm^{2}as shown in table 4. It has been observed that the compressive strengths of PFC and PPFC are practically same, however the compressive strengths of BFC are much greater. The BFC has the highest compressive strength when compared to the PFC and PPFC. It is observed that density and compressive strength increases with fibre types as shown in figure 12.

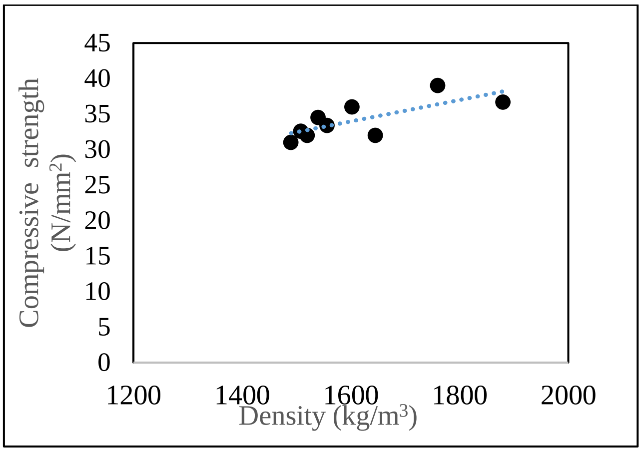


Figure 12: Compressive strength vs density for PFC, PPFC and BFC

Table 4: Compressive strength (N/mm^2) of PFC, PPFC and BFC

B. Splitting Tensile Strength

Mix	Density (kg/m^3)	Compressive strength (N/mm^2)
PFC		
M1	1490	31
M2	1508	32.6
M3	1540	34.5
PPFC		
M1	1520	32
M2	1556	33.4
M3	1602	36
BFC		
M1	1645	32
M2	1880	36.7
M3	1760	39

The values of the PFC, PPFC, and BFC specimens' splitting tensile strengths are shown in Table 5. When compared to the value that was determined by making use of equations (28), (4), (5), and (6), the values that were obtained from experimentation are much greater.

Table 5; Splitting tensile strength (N/mm^2) PFC, PPFC and BFC

	Sample 1	Sample 2	Sample 3	Average
PFC	2.62	2.85	2.67	2.71
PPFC	3.45	3.37	3.52	3.44
BFC	4.82	4.49	4.65	4.65

Figure 13 illustrates a graph depicting the splitting tensile strength vs the unit weight for PFC, PPFC, and BFC. It is plain to observe that each of the three examples has a distinctively different splitting tensile strength. PFC has a splitting tensile value of around 2.71 N/mm^2, PPFC has a value of 3.44 N/mm^2, and BFC has a value of 4.65 N/mm^2. These values are based on a unit weight of 1512 kg/m^3. When compared with PFC and PPFC, the splitting tensile strength of basalt foamed concrete is shown to be the highest.

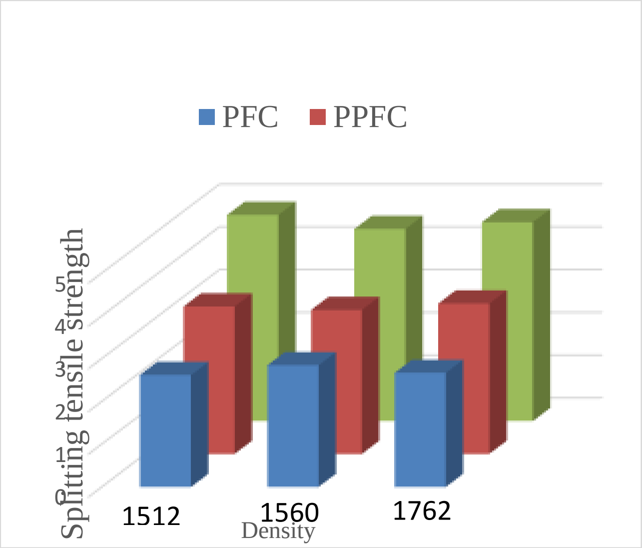


Figure 13: Splitting tensile strength vs density for PFC, PPFC and BFC

The mechanism of failure of the PFC is shown in figure 14, which depicts the splitting tensile test loading. At the point of the initial fracture, it was noted that the PFC had totally failed; the load at which it cracked and the load at which it yielded were found to be the identical for this specimen. It was noticed that the first fracture in PPFC was comparable to the first crack in PFC; nevertheless, it was observed that specimens carried at least fifty percent greater stress following the first break. In a similar manner, the first fracture that was seen for BFC occurred at the same load as that which was recorded for PFC; however, the stress that was carried by the specimen after the first break was observed to be one hundred percent higher than that which was found for PFC.

Figure 14: PFC failure pattern of concrete sample

Following the failure of the test specimens, they were crushed and sliced apart so that the failure surface could be seen. The BFC had a difficult time breaking into two separate sections. The fact that basalt fibers were successfully adhered to the concrete on both sides of the failing surface is evidence of the basalt fiber's higher efficacy. The distribution of the fibers in PPFC and BFC are shown in Figure 15, along with their orientations.

Figure 15: Crack pattern of concrete made with PFC, PPFC and BFC.

The failure plane for PFC was seen to be straight, or precisely at the center, but the failure plane for PPFC deviated slightly from the center line, and the failure plane for BFC was observed to be irregular. However, the failure plane for PFC was observed to be straight. It was discovered that the distribution of fiber throughout the whole length of the longitudinal cross-section was consistent for both PPFC and BFC. It was observed that some of the fibers were aligned vertically, while others were inclined at an angle; nonetheless, the majority of the fibers were found to be parallel to one another.

C. *Flexural Strength*

The flexural strength of samples made of PFC, PPFC, and BFC are shown in Table 6. It is clear to observe that the average flexural strength of PFC specimens is 1.75 N/mm^2, whereas that of PPFC specimens is 2.89 N/mm^2, and that of BFC specimens is 3.75 N/mm^2.

Table 6: Flexural strength (N/mm^2) of PFC, PPFC and BFC

	Sample 1	Sample 2	Sample 3	Average
PFC	1.60	1.84	1.8	1.75
PPFC	2.92	2.80	2.95	2.89
BFC	3.99	3.58	3.75	3.77

Figure 16 presents a plot depicting the relationship between flexural strength and density for PFC, PPFC, and BFC. It is clear from looking at the figure that the flexural strength of fiber-reinforced foamed concrete is much greater than that of plain foamed concrete, in particular basalt fiber reinforced foamed concrete. This is the case for all types of fiber-reinforced foamed concrete. BFC demonstrates a strength that is over ten times that of PFC.

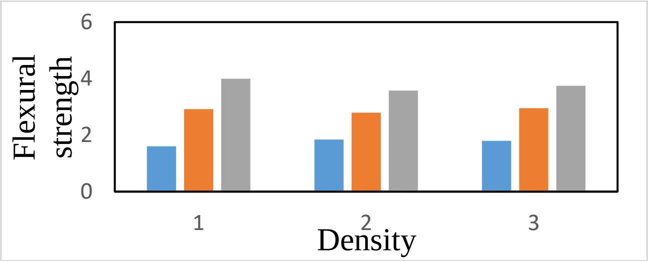


Figure 16: Flexural strength vs density for PFC, PPFC and BFC

The PFC sample method of failure is shown in Figure 17. It was observed that specimen I, as well as specimens II and III, failed in flexure. A single fracture failed to propagate through the middle of each of the three specimens.

Figure 17: Cracks pattern of PFC concrete specimen I, II and III

When it came to PPFC specimens, specimen I and specimen IV showed a failure pattern that was quite similar to one another, while specimens II and III were seen to have the same failure mechanism. Figure 18 demonstrates that Specimen I failed in flexure and had similar fracture spacing throughout the specimen. It was discovered that Specimen II had a single crack opening, and it broke apart when subjected to flexure. The pattern of failure shown in specimen III is quite similar to the one seen in specimen II. It was discovered that the surface had a single fissure in the middle of it. It was observed that Specimen IV had two cracks, one of which was located in the middle of the specimen and the other of which was located on the left side of the specimen. The crack in the middle of the specimen was significantly wider than the cracks that were found on the left side of the specimen. It was observed that the fractures in PPFC specimens were broader than those in BFC specimens, although having fewer cracks overall. On the other hand, the load bearing capability of PPFC specimens is lower than that of BFC specimens.

Figure 18: Cracks pattern of PPFC concrete specimen I. II and III.

For the BFC specimens, specimen I, III, and IV exhibit a pattern of failure that is quite similar, although specimen II had a failure mechanism that was just slightly different from the other examples. The fracture spacing in Specimen I was uneven, as can be shown in Figure 19; several cracks were seen, each with a crack width that was less than the crack width of PPFC; and finally, the specimen failed in flexure. It was observed that Specimen II had a single fracture opening along with several minor hairline cracks spread out throughout the surface of the beam, and it failed when subjected to flexure. The failure mode of specimen III is the same as the failure mode of specimen I; the surface displays many fissures in various locations.

Figure 19: BFC specimen I, II and III

V. CONCLUSION

Following comprehensive experimental investigation, the following findings were formed based on the test results from the study:

The optimum foam volume of 20 percent and a water-cement ratio of 0.5, it is possible to obtain the optimum mix proportion design for PFC, PPFC, and BFC. This can be accomplished.

Based on the mechanical parameters of PFC, PPFC, and BFC, including compressive strength, splitting tensile strength, and flexural strength, basalt fiber reinforced (BFC) offers the highest compressive strength.

It was found that the BFC had the highest tensile strength possible, which was 4.65 N/mm^2.

The flexural strength of BFC, which was measured at 3.77 N/mm^2, was found to be the greatest among all three groups. This value is approximately twice as high as that of PFC.

Ultimately, basalt fiber foamed concrete displayed all of the qualities that conventional concrete has; thus, its usage in structural applications is highly recommended.

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