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RESEARCH ARTICLE

Characterization and Image Processing Analysis on Polypropylene Fiber Reinforced Foamed Concrete

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Abstract

Objectives: The research explores the effect of adding polypropylene fiber in foamed concrete. **Methods/Analysis:** The manuscript discusses the mechanical and durability properties of polypropylene fiber reinforced foamed concrete. Fly ash, copper slag, and polypropylene fiber were admixed for strengthening the foamed concrete. The experimental analysis is carried out with polypropylene fibers at 0%, 0.25%, 0.5% and 0.75% by volume of concrete. Image processing analysis through MATLAB was done to validate the mechanical and durability properties. **Findings:** The results showed that, the optimum quantity of fiber reinforcement is found to be 0.25%. There was an increase in compressive, split tensile strength and flexural strength of 13.6%, 16.7%, and 30%, respectively, with 0.25% fiber. The durability test results suggest that these values are acceptable for constructing durable concrete structures limited to non-structural applications. The results were validated using image processing analysis through MATLAB software. Economic analysis showed that the foamed concrete reduces the structural dead load by almost 35.3%. **Novelty/Improvement:** It is recommended that the polypropylene fiber reinforced foamed concrete would be feasible for durable concrete structures limited to non-structural applications.

Keywords: Foamed concrete; Polypropylene fiber; Shrinkage; Image processing; Structural viability

1 Introduction

The utilization of lightweight concrete has several notable benefits, including an enhanced strength to weight ratio, improved tensile strain capacity, and a reduced coefficient of thermal expansion. These advantages can be attributed to the presence of air gaps inside the concrete[(1)].

Foam concrete is a great component with unavoidable uses and requirements in today's fast-paced world. With skyscrapers reaching for the sky and requiring a well-insulated and fire-resistant structure, the demand for innovative materials is excellent, and foam concrete with the right foaming agent and appropriate fiber added in the right proportion may help construction keep up with the fast-paced world[2]. Many countries use foam concrete for roadways, fillers, and insulation. However, the usage of foam concrete as a construction material is quite limited, at least in a developing country like India. This investigation finds the various features of foam concrete with and without polypropylene fiber. Using polypropylene fiber in foam concrete will increase the strength characteristics and reduce the use of depleting natural ingredients of concrete[3], thus creating an environmentally friendly environment.

In recent times, foamed concrete has garnered significant attention as a viable option for both thermal insulation and structural applications. Foamed concrete comprises a concrete mixture that incorporates pre-prepared foam, leading to the formation of a closed void structure within the solidified composite. Foamed concrete, a variant of cellular concrete, garners significant global interest among builders. Foamed concrete is a lightweight composite material characterized by its exceptional workability. Despite the potential applications of foamed concrete in thermal and acoustic insulation, flame protection, and blast viscosity, its limited mechanical and physical qualities significantly restrict its employment in concrete buildings[4]. Similar to other types of concrete, it exhibits a significantly lower tensile strength compared to its compressive strength, differing by several orders of magnitude. In addition, the hardening mixture exhibits a propensity for notable shrinkage because of a considerable amount of entrapped air within its composition. Like traditional concretes, the flexural and tensile strength of foamed concrete is typically between 15 and 35 percent of its compressive strength[5]. Various types of concrete fibers exhibit reduced shrinkage cracks and enhanced mechanical properties, particularly in terms of tensile and flexural characteristics[6].

The utilization of cement, fine sand, and distinct, evenly distributed micro or macroscopic air cells forms the fundamental basis for the advancement of a diverse array of lightweight composites[7]. As a result, foamed concrete offers the above benefits while also lowering construction costs and allowing for lightweight, sustainable designs. Engineers have used a variety of innovative technologies that are both advantageous and environmentally friendly to improve the goal compressive strength by at least 25 MPa. When producing high-strength concrete, it is recommended to use a low water to binder ratio (w/b) and incorporate fly ash, silica fume, and ultrafine silica powder as alternatives to sand. This is achieved by substituting finely dispersed pozzolanic raw materials for fine aggregate[8]. The incorporation of micro- and nano-fibers in fiber-reinforced concrete has been found to enhance the structural integrity of the microstructure, particularly in thinner cell walls[9]. The inclusion of fibers in foamed concrete has been found to enhance its flexural strength and effectively reduce shrinkage loads.[10]

This work explores the production of foamed concrete by using foaming agent. In order to improve the weak mechanical properties of foamed concrete, polypropylene fiber is introduced in the fraction of 0%, 0.25%, 0.5% and 0.75% by volume of concrete. Though the fiber reinforced foamed concrete is found common in the literature, very few standard works are available in polypropylene fiber reinforced foamed concrete. Also, this work performs image processing analysis for the validation of mechanical and durability properties of foamed concrete. In addition, this work carryout out the economic analysis of foamed concrete.

2 Methodology

2.1 Materials and Mix proportions

Material preparation, manufacture, and curing are all steps in making foamed concrete. Cement, fine aggregate, fly ash, foamed foam, polypropylene fibers, and water are the major ingredients of foamed concrete. Foam concrete is formed with a 1:1 cement-sand ratio and a 10% fly ash by weight of cement and 10% copper slag by weight of cement were added to the concrete. Polypropylene fiber is added to the concrete with various percentages as 0%, 0.25%, 0.5% and 0.75% by volume of concrete to study its characteristic effects. This mixture uses a synthetic foaming agent with a 1 kg foaming agent dosage of 30 liters of water. Foaming agent is utilized in foam concrete at a rate of 40% by volume.

Ordinary Portland cement of 53 Grade was used. A locally available high-rise foaming agent made of theoretical latex foam was used in the study. Figure 1 shows the foaming agent preparation for foamed concrete.

2.2 Mix Proportions by target density

Target Density P = C+FA+F+W

Where

P – Normal Density of Concrete (kg per m^3)

C – Quantity of Cement (kg per m^3)

FA – Quantity of Fine Aggregate (kg per m^3)

F – Quantity of Foam (Liters per m^3)

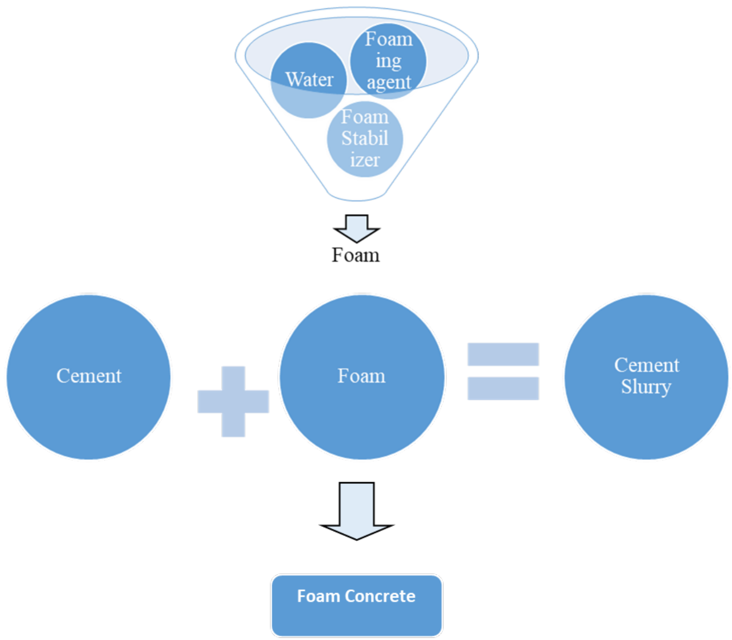

Fig 1. Preparation of foaming agent

W – Quantity of Water (Liters per m^3)

Density required = 1600 kg/m^3 with a CM 1:3 Mix

2400 = 400 + 1200 + F + 200

F = 600 L/m^3

Trial 1

The 1st trial using the mix ratio 1:3:1.5:0.5 (C:FA:F:W) produced a concrete density of 1400 kg/m^3. Thus, adjustment to the foam content is required to produce the required density of concrete.

Trial 2

The 2nd trial used a similar mix ratio, but reducing foam content to 400 l/m^3 produced a concrete density of 1530 to 1550 kg/m^3. Thus, further reduction in foam content was required.

Trial 3

The 3rd trial using the mix ratio 1:3:0.75:0.5 (C:FA:F:W) produced concrete with a density of 1600 $\pm$ 10 kg/m^3. Foam content is 300 l/m^3. This tolerance is within the acceptable limits, and thus the final mix proportion was fixed at 1:3:0.75:0.5 (C:FA:F:W) and is shown in Table 1.

Table 1. Total quantity of materials

Material	Volume (1 m^3)	Volume (0.1129 m^3)
Cement	400 kg	45.19 kg
M-Sand	1200 kg	135.48 kg
Foam	300 L	33.87 L
Water	200 L	22.58 L

3 Results and Discussion

3.1 Fresh state properties

The key characteristics of foamed concrete in its fresh state include flowability and density. The consistency of the freshly mixed mortar was determined through the conduction of a flow table test, as outlined in the ASTM C1585 – 13 standard and presented in Table 2. The initial step was the introduction of freshly prepared foamed concrete into an inverted slump flow cone, without the application of compaction or vibration.

3.2 Flowability and Fluidity

In this study, the flowability of latex foamed concrete mixes was assessed using the measurement of slump diameter. The study revealed that the flowability of the fiber-free mix had a smaller slump diameter compared to the mix containing fiber. The slump flow values obtained for the fiber-reinforced mix were found to be lower compared to those obtained without the inclusion of fibers, as illustrated in Table 2. The observed phenomena can be attributed to the orientation effect of the fibers, as well as the inclusion of fly ash and copper slag in the concrete mixture. These factors have resulted in an enhanced workability of the material. Also, the observed outcomes can be attributed to the characteristics of polypropylene fibres and the remarkably low density of the cementitious system. This distinguishes it from conventional concretes and previous investigations on foamed concretes with higher density, where the inclusion of fibres resulted in reduced workability.[(11)]

Table 2. Properties of the freshly foamed concrete

Dosage of fiber	Sample Consistency	Stability	Inverted slump cone spread value (mm)	Slump value (mm)
0%	1.04	1.021	468	223
0.25%	1.05	1.035	442	190
0.5%	1.06	1.037	446	180
0.75%	1.05	1.028	447	177

Slump cone spread values may be ascribable to the presence of fibers. This effect can be dealt with adding superplasticizer to the mix with polypropylene fiber.

3.3 Consistency and Stability

The fresh latex foamed concrete exhibited a high level of consistency, as indicated by a measured ratio of fresh density to defined density that was maintained close to unity. Furthermore, the concrete demonstrated minimal segregation and bleeding. The stability of a material's hardened density can be characterized by measuring its fresh density. The density of the foamed concrete samples was determined to be 1460 kg/m^3 for the mix without fibers. In the mixes with fibers, the densities were measured to be 1490 kg/m^3, 1506 kg/m^3, and 1540 kg/m^3 for fiber concentrations of 0.25%, 0.5%, and 0.75%, respectively.

The density (unit weight) of latex foamed concrete is determined by measuring its fresh density in a container with a known volume. The incorporation of fibers led to a marginal reduction in the initial density of the latex foamed concrete specimens. Nevertheless, these outcomes can be ascribed to the relatively low specific gravity of the polypropylene fibers. The specific gravity of cement is higher compared to polypropylene, resulting in a bigger increase in the total density of the latex foamed concrete[(12)].

3.4 Drying shrinkage

The shrinkage measurement was performed using a device fitted with a dial gauge that had a precision of 0.002 mm. For this experiment, prisms with dimensions of 100 × 100 × 400 mm were utilized. The shrinkage strain measurements were conducted in accordance with the ASTM C157-2008 standard. Following the demolding process at the 24-hour mark, shrinkage nails were affixed onto the surface of the prisms subsequent to their removal from the mould. The data collection involved measuring individuals at three distinct ages (3, 7, and 28) under various curing circumstances. A pair of specimens were prepared for every test condition.

Tran et al.[(13)] revealed that when compared to plain foamed concrete, polypropylene was able to enhance concrete strength and decrease drying shrinkage. The findings elucidate that the drying shrinkage values are elevated in mixtures without polypropylene fibers compared to those containing fiber additives. The data exhibit a range of (160–610) micro strain for the mixtures without polypropylene, and these values exhibit a drop to (150–550) micro strain upon the introduction of polypropylene within the time frame of 3 to 28 days. The drying shrinkage of all mixtures progressively increases over time until the 28th day. Water-cured specimens exhibit a marginal reduction in drying shrinkage. This analysis highlights a significant observation, which aligns with the previously observed patterns for mixtures containing polypropylene and those without it, as well as for various curing conditions at different stages of development. Figure 2 demonstrates that the incorporation of polypropylene fiber into concrete results in a marginal reduction in shrinkage of the mixtures during the drying period, as compared to mixtures that do not contain polypropylene fiber. This phenomenon can be attributed to the reaction between fly ash and copper slag, which results in the consumption of a greater amount of free water within the system. Consequently, there is a reduced amount of water available for evaporation during the shrinkage process. The deduction may be made that the inclusion of foamed concrete mix results in reduced porosity and a more refined pore structure. This, in turn, facilitates water loss by self-desiccation rather than diffusion into the surrounding environment.

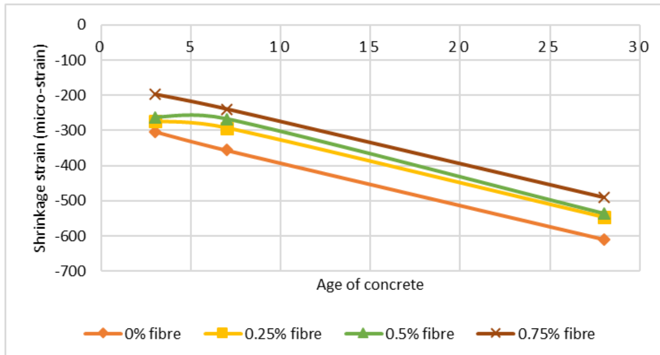

Fig 2. Drying shrinkage vs. Age of concrete

3.5 Compressive strength of mortar

For testing the strength property of cement, mortar cubes (70mm side) are cast and cured. The cubes are tested on the 3rd, $7^{th}$and 28th day of curing. The test results are tabulated in Table 3.

Table 3. Average compressive strength of mortar cubes

Age of concrete (days)	Average compressive strength (MPa)
3	27
7	42
28	55

3.6 Compressive strength of concrete

To determine the compressive strength of foamed concrete, cube specimens of 150x150x150mm dimension were cast and tested. The compressive strength of foamed concrete typically declines progressively as the number of trapped bubbles increases. However, the strength can be improved by incorporating fibres into the concrete matrix [14]. The 7-day and 28-day compressive strength test was tested for different fiber contents (0% to 0.75%). The results were tabulated in Table 4 to understand the varying trend of the compressive strength due to the addition of polypropylene fibers. Researchers [15,16] revealed that, in order for the foamed concrete to be suitable for structural purposes, it must possess a compressive strength of at least 25 MPa after 28 days. In this study a compressive strength of 26.6 MPa was achieved for the 0.25% of polypropylene fiber addition. The compressive strength decreases while an increase in fiber content beyond 0.25% is noted. Due to the excess addition of foam, the Target Density of 1600 kg/m^3 was not achieved. But the collapse of foam during mixing and addition of fiber is difficult to predict and compensate. Hence, careful control is necessary while mixing the foam with the cement slurry.

The same difficulties found while casting the compressive cube specimens can be found in these cylindrical specimens. The tabulated results denote an increase in compressive strength of 13.6% with the addition of 0.25% fiber. Further addition of fiber indicated a decreasing trend in the compressive strength of concrete. There was a decrease of 2.13% and 11.11% with the addition of 0.5% and 0.75% fibers, respectively. This reduction in compressive strength is significant and reduces the application of this mix to a large extent.

3.7 Tensile strength test

The experiment involved conducting a 28-day tensile strength test on concrete cylinders with varying fiber contents ranging from 0% to 0.75%. The dimensions of the cylinders were 100x200mm. The obtained data from the experiment were organized and shown in Table 4. The tensile strength of fibre reinforced foamed concrete has been enhanced in comparison to normal foamed concrete mix. The ACI[17] proposed using fibres to enhance the splitting tensile strength during the initial stages of concrete curing. The majority of the fiber reinforced foamed concrete can meet the minimum requirement of 2 MPa specified by ASTM C330[18] for structural concrete. The addition of polypropylene fiber greatly enhanced the tensile strength of the foamed concrete. The tabulated results denote an increase in tensile strength of 17.8% with the addition of 0.25% fiber. Further addition of fiber indicated a decreasing trend in splitting tensile strength of concrete. Hence, the addition of 0.25% polypropylene fiber can be considered beneficial to the chosen mix.

3.8 Flexure strength test

The flexure test was performed on beams of 500x100x100mm dimension. One set was normal foamed concrete with 0% fiber addition; the other set had the optimum fiber concentration of 0.25%. Table 4 denotes an increase of 30% in the flexural strength due to the addition of 0.25% polypropylene fiber. The flexural strength of foamed was assessed by incorporating several types of fibres, including polyolefin[19], polypropylene[20], and waste tyre steel fibres[21], into the base mixture prior to the addition of foams. The addition of these fibres resulted in a slight improvement in the flexural strength of foamed concrete. In this study, it proves that polypropylene fiber's ability to enhance the tensile properties of the foamed concrete. Further addition of polypropylene fiber shows a 18.3% increase in flexural strength compared to the control mix for the 0.25% fiber in the mix.

Table 4. Mechanical properties of polypropylene fiber reinforced foamed concrete

Dosage of fiber	Average compressive strength (N/mm^2)		Density (kg/m^3)	Tensile strength(N/mm^2)	Flexural strength(N/mm^2)
	7 days	28 days	28 days	28 days	28 days
0%	13.33	23.4	1460	1.91	2.3
0.25%	20.5	26.6	1490	2.25	2.72
0.50%	18.3	22.9	1506	1.82	2.25
0.75%	17.1	20.8	1540	1.78	2.18

3.9 Sorptivity

The property of sorptivity (S) pertains to the ability of a porous substance to absorb and transport water through capillary action. The sorptivity for the elapsed time (t) is computed and the outcomes are depicted in Figure 3. A higher sorptivity rate was noted during the early stages of observation, followed by a progressive decline with time which is in agreement with Akindahunsi et al.[22]. The sorptivity of the fiber-reinforced foamed concrete was found to be higher compared to the sorptivity of the fiberless concrete.

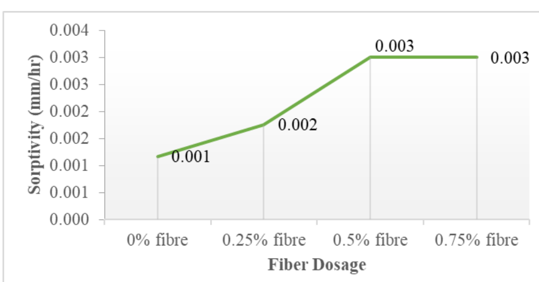

Fig 3. Sorptivity of foamed concrete

According to the prescribed acceptance threshold for durability indexes, the acceptance requirements for sorptivity in millimeters per hour (mm/hr) in laboratory concrete ought to be below six after a 24-hour observation period. The test findings demonstrated that the sorptivity of the concrete falls within the permissible range, suggesting its durability.

3.10 Water absorption

The current trend and need for research have shifted to the concrete's durability in construction practice. Foamed concrete mix is porous, thus paving a chance for being permeable. Shahidan et al.[23] found that the foamed concrete absorbs water upto 24%. Water absorption of the concrete mix was calculated during the 24 hours of observation, and the rate of water absorption at 24 hours is depicted in Figure 4. The foamed concrete mixes showed almost 16% water absorption, but the water absorption rate is considerably low as a fibre matrix inside the concrete. It means that the foamed concrete averaged in durability behavior.

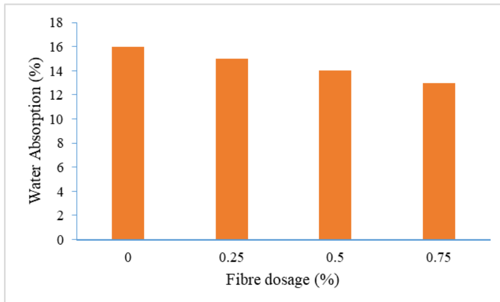

Fig 4. Water absorption of the foamed concrete

3.11 Water absorption per unit area of the Inflow surface

The determination of water absorption characteristics on the Inflow surface is achieved using the sorptivity test, which calculates the water absorption per unit area. This test provides insights into the impact of concrete pores on water absorption. Due to the inherent permeability of concrete, the rate of water absorption per unit area of the incoming surface of foamed concrete is somewhat elevated. Contrarily, the incorporation of fiber enhances the mechanical characteristics of concrete, although it does not mitigate its porosity. Moreover, these fibers indirectly facilitated an increased uptake of water. The test results are depicted in Figure 5.

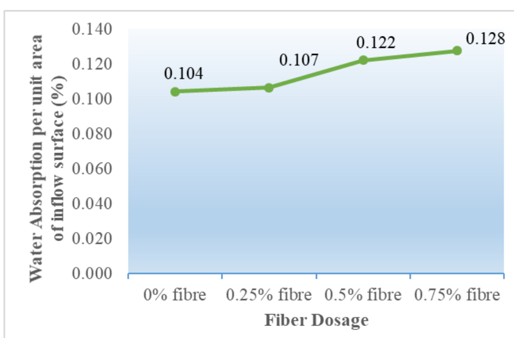

Fig 5. Water absorption per unit area of inflow surface

3.12 Porosity

The spaces within foamed concrete have the potential to be occupied by either air or water. It is widely acknowledged that there exists a direct correlation between the porosity of concrete and its strength, such that an increase in porosity leads to a decrease in strength. Nevertheless, the composition of the mixture was adjusted in such a way that its strength closely resembled that of the traditional mixture. The figure presented in Figure 6 illustrates the porosity of the concrete. A comparison was made between the porosity of foamed concrete and fiber reinforced concrete. The experimental findings indicated that the inclusion of randomly oriented fibers resulted in a reduction in the porosity of concrete. The closing of air-voids within concrete is commonly attributed to the random distribution of fiber material [24].

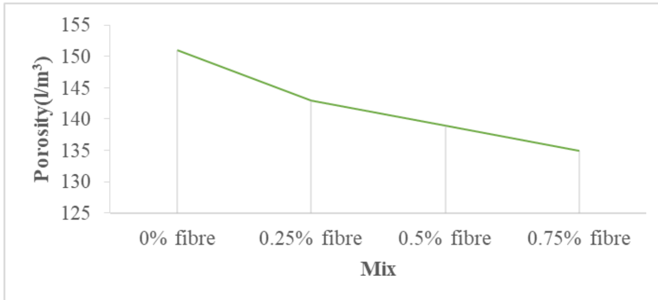

Fig 6. Porosity of the foamed concrete

The durability test results indicate that these values are acceptable for constructing durable concrete structures [25] limited to non-structural applications.

3.13 Image processing

Image processing analysis is further done through the MATLAB interface to quantify the experimental observations. The real-time colored images of concrete taken physically through a high-resolution camera were given as the input by an algorithm. The points of interest were cropped in an interactive mode using the MATLAB functional tool. The images were processed using interpolation methods, and the background illuminations were approximated further. Image adjustment is then conducted on the enhanced image to increase the visibility of objects of interest. Image adjustment increases the image's contrast by mapping the input image's intensity values to new values.

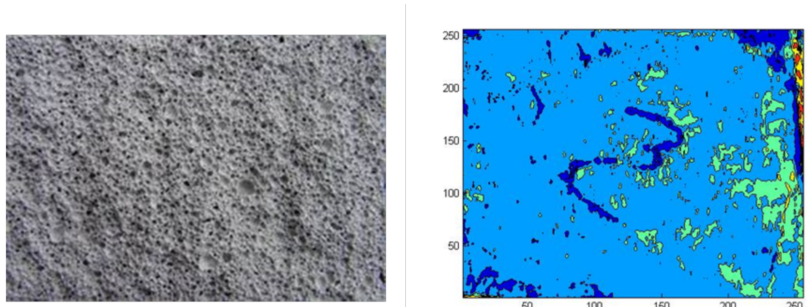

Fig 7. Actual and processed image of foam concrete without fiber

To achieve good results for quantifying the presence of voids, pores and fibers in concrete, numerical information is obtained from each point in the image, and a computer image processing algorithm is developed [20]. This phase is carried out as a sequence of processes when the input image is converted to a binary output image.

The volume of the concrete composition is determined through the analysis of the aggregate intensity, cement content, fiber presence, and pore characteristics [26]. In this way, the image processing of the acquired image of the concrete specimen is performed. Figure 7 shows the filtered, processed image of foamed concrete without fiber. The presence of blue color over a larger area indicates more air voids. Figure 8 shows the processed output image obtained for foamed concrete with fiber. In Figure 8, randomly oriented fiber blocked the air voids, and the blue colour region is hidden out by the yellow region, which indicates fibers and aggregates. In this way, a better foamed concrete was prepared, and the results were validated.

4 Viability as a Structural Concreting Element

The addition of polypropylene fibers over 0.25% does not influence the compressive strength of the concrete, which is an essential characteristic of any structural member. Although the increase in tensile and flexural characteristics has applications in

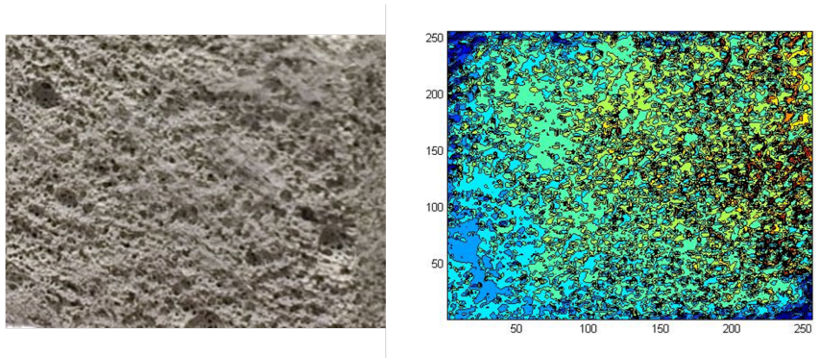

Fig 8. Actual and processed image of fiber-reinforced foam concrete

some fields, the polypropylene fiber reinforced foamed concrete is limited to non-structural concreting. Thus finding application for this concrete is somewhat tricky, owing to its increased cost.

5 Application of Foamed Concrete

The reduction in compressive strength significantly limits the application of this concrete. Though the strength of the given mix is considerably less, Foamed concrete requires long periods of curing to attain ultimate strength. It is another drawback of utilizing foamed concrete. The increase in Tensile and Flexural strength would make this concrete fit to withstand an increased shear at higher altitudes due to wind force. Thus, they may be used in constructing wall panels (blocks) in multistorey structures. The decrease in density greatly influences its strength factors and thereby its applications. The density may be as low as 600 kg/m^3, three times less than ordinary bricks. Thus, they can reduce the dead load of walls in framed structures by almost three times. It will reduce the cross-section of structural elements required to offer stability to the structure, thereby being economical in the material used and cost.

6 Conclusions

The investigation explores the effect of polypropylene fiber on mechanical and durability characteristics of foamed concrete. The following conclusions were drawn from the study.

- The average slump flow values obtained for the fiber-reinforced mix were lower than that of the mix without fibers due to the orientation effect of the fibers and the presence of fly ash and copper slag in concrete, which led to more excellent workability.
- The values of drying shrinkage are higher from (160–610) macrostrain mixes without polypropylene fibers than those for fiber mixes; the values decreased from 150–550microstrain.
- There is an increase in compressive, split tensile strength and flexural strength of 13.6%, 17.8%, and 18.3%, respectively, with 0.25% fiber. Further addition of fiber indicated a decreasing trend in the strength of concrete.
- The durability test results indicate that these values are acceptable for constructing durable concrete structures limited to non-structural applications.
- The image processing analysis through the MATLAB environment indicated more air voids in the foamed concrete without fiber. However, the randomly oriented fibers affected the air voids to some extent. This result is in line with the experimental observations.
- Based on the economic analysis, the only viable option for foamed concrete is applied as concrete blocks in wall construction, which reduces the structural dead load by almost 35.3% and makes material utilization economical.
- Determining the ultimate strength requires further testing of specimens for the 56th day and 90th day. The variation of cementitious material should be the following field of research for sufficiently increasing the strength economically.

Based on the conclusion, it is recommended that the polypropylene fiber reinforced foamed concrete would be feasible for durable concrete structures limited to non-structural applications.

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