Performance evaluation of natural fiber reinforced high volume fly ash foam concrete cladding

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Abstract. The major shortcoming of concrete in most of the applications is its high self-weight and thermal conductivity. The emerging trend to overcome these shortcomings is the use of foam-concrete, which is a lightweight concrete consisting of cement, filler, water and a foaming agent. This study aims at the development of a cost-effective high-volume fly-ash foam-concrete insulation wall cladding for existing buildings using natural fiber like rice straw in different proportions. The paper reports the results of systematic studies on various mechanical, acoustic, thermal and durability properties of foam-concrete with and without replacement of cement by fly-ash. Fly-ash replaces 60 percent by weight of cement in foam-concrete. The water-solid ratio of 0.3, the flier ratio of 1:1 by weight, and the density of 1100 kg/m\textsuperscript{3} (approx.) are fixed for all the mixes. Rice straw at 1%, 3% and 5% by weight of cement was added to improve the thermal and acoustic efficiency. From the investigations, it was inferred that the strength properties were increased with fly-ash replacement up to 1% rice straw addition. In furthermore, addition of rice straw and fly-ash resulted in improved acoustic and thermal properties.

Keywords: foam-concrete; wall cladding; strength properties; thermal properties; acoustic properties; durability

1. Introduction

Builders all over the world are giving more importance to the use of foam-concrete because of growing trends in environment-friendly and energy-saving considerations in buildings. A well-insulated building reduces energy consumption by keeping warm in the winter and cool in the summer. Therefore, materials with lower thermal conductivities are preferred to reduce heat loss. Foam-concrete is a light-weight concrete with density varying from 400 kg/m\textsuperscript{3} to 1800 kg/m\textsuperscript{3} and is well-known for its thermal resisting property. Due to its reduced weight, the labour cost during construction and transportation is less compared to conventional concrete (Amran \textit{et al.} 2015). The use of foamed concrete in composite construction is demonstrated by increased flexural capacity when used in steel tubular sections (Assi \textit{et al.} 2003).

Different methods used to generate foam are mixed-foaming method and pre-foaming method. In the pre-foaming method, foam is generated separately and in mixed-foaming method foaming agent is directly added with the ingredients and the foam is generated during mixing. In the present study, pre-foaming method is adopted (Raj \textit{et al.} 2019). Ramamurthy and Nambiar (2006) investigated the characterization of air-voids on the structure of foam-concrete by finding few variables such as spacing of voids, size and volume, and studied the effect of these variables on strength. They concluded that, at higher foam volume, strength was reduced due to merged air bubbles. Protein and synthetic-based foaming agents are two types of widely used foaming agents. The protein-based foaming agent has been reported to produce greater compressive strength and smaller isolated spherical air bubbles compared to synthetic foaming agent (Panesar 2013, Falliano \textit{et al.} 2009, Falliano \textit{et al.} 2018). Also, the protein-based foam was appropriate for foam-concrete with densities ranging from 400 to 1600 kg/m\textsuperscript{3} and the synthetic foam was suitable for densities around 1000 kg/m\textsuperscript{3} (Nandi \textit{et al.} 2016). Based on this, in the present study protein-based foaming agent was adopted. Electromagnetic wave absorption properties of foam concrete fabricated by adding the plant and animal protein based foaming agent into ordinary Portland cement paste was carried out (Lv \textit{et al.} 2015). They observed that the thickness and filling ratio have a great influence on the electromagnetic wave absorbing properties. Mehmet \textit{et al.} (2019) carried out high-temperature effects on the foamed concrete with foam solution prepared by properly mixing sulfonate based foam agent with water. They observed that the void structures reduce the high-temperature effects and 40 % by vol. foam solution could be mixed with concrete where high strength of foamed concrete is non-mandatory.

Usubharatana and Phunggrassami (2015) investigated the application of agricultural wastes namely rice straw, bagasse, coconut coir and corn cobs as thermal insulation materials. The results indicated that rice straw fiber, bagasse fiber and coconut coir fiber can be effectively used as thermal insulation materials and corn cob could not be used as a thermal insulation material because of the presence of unformed fiber. Rice straw is the vegetative part of the rice plant which makes up about half of the yield. These straws
are cut during or after the process of the grain harvest and mainly used as fodder for domestic animals and the remaining is burnt or ploughed under the soil. Burning causes air pollution and ploughing may cause fungal growth. Despite many advantages of foam-concrete, its main drawbacks are shrinkage and lower strength. To overcome this, rice straw can be effectively used for improving the thermal insulation and shrinkage resistance properties of foam-concrete. Jun et al. (2013) reported that the mechanical properties of concrete decreased with the addition of straw, though the addition of CaCl$_2$ and Al$_2$(SO$_4$)$_3$ improved the bonding between concrete and rice straw. Moreover, Morsy et al. (2011) investigated the effect of NaOH treatments on the physical and mechanical properties of rice straw. The test results revealed that the treated straw particles have better adhesion with the cement matrix than the untreated particles. Also, it was reported that the addition of 6% CaCl$_2$ to treated or untreated straw cement composites resulted in the best hydration values and the highest increase in compressive strength.

Jones and Cathy (2005) investigated the use of fly-ash in foam-concrete as a substitute for cement and coarse fly-ash as a substitute for aggregate and observed an increased strength. Failure mechanism of foam concrete with different densities and made of cement and fly ash with compressive strength between 9 and 24 MPa with cold formed steel double C-Channels embedment was carried out (Liu et al. 2017). A higher strength of 23.04MPa was obtained for foam-concrete with 50% fly-ash replacement (density of 1600 kg/m$^3$) (Gowri and Anand 2018). Reisi et al. (2017) studied the effect of silica fume and the volume of foam on the strength properties of foam-concrete. It was found that the strength properties increased with silica fume and decreased with foam content. The silica fume in foam-concrete reacts with free carbohydrate and form C-S-H and leads to higher compressive strength. Nambiar and Ramamurthy (2006) suggested that the inclusion of fly-ash helps to achieve a more uniform distribution of air voids than fine sand and improves the compressive strength of foam-concrete. By using fly-ash based cellular lightweight concrete, the density is reduced considerably without affecting the strength by appropriate mix design (Nambiar and Ramamurthy 2006), and also reduces the thermal conductivity (Saygılı and Baykal 2011). In the present study, 60% of cement was replaced with class F fly-ash. Apart from the addition of mineral admixtures, it was observed that the addition of fibers in foam concrete improved the strength, durability and thermal properties (Raj et al. 2020, Aravind et al. 2020, Madhwani et al. 2020).

Generally, the aggregates of size less than 4.75 mm is used in the production of foam-concrete. Lim et al. (2014) investigated the feasibility of replacing river sand by quarry waste in Light Weight Foam-Concrete (LFC) and found that incorporating quarry waste reduces the fluidity and increases the compressive strength and thermal conductivity of LFC. It was reported that sand with a maximum size of 2 mm, and with 60 to 95% passing the 600-micron sieve gives higher strength.

The present study reports the development of a cost-effective high volume fly-ash foam-concrete insulation wall cladding for existing buildings using natural fibers like rice straw under different proportions. The study aims at the preparation of foam-concrete of density range from 1050-1150 kg/m$^3$, by making use of industrial and agricultural waste products such as fly-ash and rice straw. Various tests to assess the thermal insulation capacity, mechanical strength, noise absorption, water absorption, and acid resistance are carried out. The study also recommends the best proportion of straw that can be adopted for better insulation in buildings.

### 2. Methodology

#### 2.1 Mix compositions

The present experimental program was also aimed to reduce the embodied carbon dioxide by replacing 60% cement with fly-ash (Jones et al. 2017). For studying the performance of the wall cladding developed various properties like compressive strength, flexural strength, thermal conductivity, sound absorption, water absorption and acid resistance of foam-concrete were investigated. A mix with constant w/s ratio of 0.3 and c/s ratio of 1:1(by weight) was selected. The density of foam-concrete is approximately fixed as 1100kg/m$^3$, as it was difficult to control the foam volume in concrete, and hence varies between 1050 to 1150 kg/m$^3$. Table 1 presents the nomenclature used for the various mixes.

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Mix</th>
<th>Nomenclature</th>
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<tbody>
<tr>
<td>1</td>
<td>0FA</td>
<td>0RS</td>
</tr>
<tr>
<td>2</td>
<td>0FA+1%RS</td>
<td>1RS</td>
</tr>
<tr>
<td>3</td>
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</tr>
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<td>7</td>
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</tr>
<tr>
<td>8</td>
<td>60%FA+5%RS</td>
<td>5RSF</td>
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</table>

### Table 1 Details of nomenclature used

Cement: Ordinary Portland Cement (OPC) conforming to IS 12269 (2013) is used for the study. Fig. 1(a) shows the XRD result of cement which indicates the presence of large amount of CaO. It has a specific gravity of 3.15 and a consistency of 30%.

Fine Aggregate: Sand which is finer than 300 $\mu$m with a specific gravity 2.65 is used to improve the stability of foam, and also to increase the strength of foam-concrete.

Fly-ash: Class F fly-ash is used to gain high strength and to achieve a more uniform distribution of bubbles (specific gravity 2.1). Fig. 1 shows the XRD result for fly-ash and cement. The higher amount of amorphous silica in fly-ash justifies its pozzolanic activity.

Water: Fresh, clean, potable water is used for mixing purposes.

Foaming agent: A protein-based foaming agent is used
for better stability of foams (Panesar 2013, Falliano et al. 2009, Falliano et al. 2018). Its vegetable protein extract with chemical characterization of Ethoxylate and properties are reported in Table 2.

Additive: Chopped and treated rice straw of length 1-2 cm is used as a random discrete additive to reduce the shrinkage and improve the thermal efficiency.

Superplasticizer: Poly master glenium SKY 8233, a high-performance superplasticizer based on polycarboxylic ether, is used to improve the workability.

### 2.3 Treatment of rice straw

For getting better bonding rice straw is treated with 4% concentration NaOH, by soaking it for 24 hrs. After 24 hrs of immersion, the rice straw is washed with tap water to make its pH 7, and is then dried at a temperature of 60°C for 24 hours. Fig. 2 presents the SEM images of treated and untreated rice straw.

From Fig. 2, it can be observed that NaOH treatment removed the oil, waxes and extractives from the surface of rice straw, and also amorphous constituents such as lignin and hemicelluloses. In the treated rice straw the presence of parenchyma cells can be observed, which enhances the overall roughness of the surface (Harada et al. 2001).

### 2.4 Preparation of foam-concrete specimen

Foam-concrete is prepared by mixing a measured volume of foam into the base mix. The foam is produced by a foam generator by adding foaming agent and water in the proportion of 1:30 by weight under a pressure of 450 kPa to attain a foam density of 40 kg/m³. The ratio of cement to sand used is 1:1, and the water to solids ratio is fixed as 0.3 by performing various trials. The weight of cement and sand required for the design density is calculated from Eq. (1) (Amran et al. 2015).

$$1000 = \left(\frac{X}{Da}\right) + X\left(\frac{2}{Da}\right) + \left(\frac{x}{a}\right) + X\left(\frac{2}{Da}\right) + \left(\frac{X}{c}\right) + X\left(\frac{X}{Da}\right) + X\left(\frac{X}{c}\right) + Vf$$

(1)
Table 3 Flow test values

<table>
<thead>
<tr>
<th>% Fly-ash</th>
<th>% Rice straw</th>
<th>Flow value</th>
<th>Flow value after addition of superplasticizer</th>
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<td>0%</td>
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<td>1%</td>
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<td>-</td>
</tr>
<tr>
<td>3%</td>
<td>3%</td>
<td>67%</td>
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</tr>
<tr>
<td>5%</td>
<td>5%</td>
<td>38%</td>
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</tr>
</tbody>
</table>

Fig. 3 Mini-slump cone

where \(x\)=cement content in kg/m\(^3\), \(Dc\)=relative density of cement, \(w/c\)=water/cement ratio, \(D_s\)=relative density of sand, \(w/as\)=water/fly-ash ratio, \(a/c\)=fly-ash/cement ratio, \(V\)=volume of foam, \(w/s\)=water/sand ratio, \(D_p\)=relative density of fly-ash, and \(s/c\)=sand/cement ratio (Saje et al. 2011).

Rice straw (1%, 3%, and 5%) by weight of cement, cement, and sand are mixed in a mortar mixer for 2 min and then water is added gradually and mixed for another 5 min. Finally, foam (40% of total volume) is added, and the mix is poured into the steel mould for casting. For the compressive strength test, the specimens are cast in the 50 mm cube moulds. The same size cubes are used for evaluating water absorption and acid resistance properties. For the thermal conductivity test, claddings of size 45 cm×30 cm×1.8 cm are used. The same procedure is repeated for specimen preparation of 60% of cement replacement with class F fly-ash (FA).

2.6 Test procedures

2.6.1 Mechanical properties

Compressive strength (IS 2250, 1981), modulus of rupture (Eq. (2)) and breaking strength (Eq. (3)) are the mechanical properties studied to evaluate the performance of the specimens. The modulus of rupture and breaking strength are determined as per IS 13630-Part 6 (2006). The test specimen is placed on two supporting rods, and the central load is applied at an increasing stress rate of \(±0.2\) N/mm\(^2\).

Modulus of rupture = 3FL/(2bh\(^2\))

Breaking Strength = FL/b

where \(L\)=span between supports, \(F\)=breaking load, \(h\)=thickness of the plate, and \(b\)=width of the plate.

2.6.2 Durability properties

Water Absorption

The water absorption test is performed after 28 days of curing after oven-drying the specimens for 110°C for not less than 24 hours. The samples are covered with wax, except at the bottom area to prevent air from entering into the void during immersing. The initial weights of the cubes are measured and the cubes are placed in the container in such a way that its top faces, as cast, in contact with the water. The weights of the cube after 15, 60, 240 and 1440 min are noted. The rate of water absorption (\(A_T\)) in grams/100 cm\(^2\) is obtained from Eq. (4) (ASTM C1403-13 1997).

\[
A_T = (W_f - W_0) \times 10000/(L_1 \times L_2)
\]

where \(L_1\)=average width of the test surface of the specimen cube in mm, \(W_f\)=weight of specimen at time \(T\) in grams, \(L_1\)=average length of the test surface of the specimen cube in mm, and \(W_0\)=initial weight of the specimen in grams.

Drying shrinkage

Due to the absence of coarse aggregates, foam-concrete showed higher shrinkage compared to conventional concrete. Rectangular prisms of 40 mm×40 mm×160 mm are used for testing drying shrinkage. Spherical balls are attached on the two ends of the specimen. Change in length is determined as per IS 6441-Part II (1972) and RILEM_ACC 5.2 (1992). The variation in length is calculated in percentage using Eq. (5).

\[
\text{Drying shrinkage } \% = \left[\frac{(H_2-H_1)}{L_o}\right] \times 100
\]

where \(L_o\)=original linear dimension of the specimen, \(H_2\)=linear dimension in each day, and \(H_1\)=first reading of linear dimension.

Acid resistance

5 cm cubes are used to assess the acid resistance. After 28 days of curing, specimens are placed in 1% \(H_2SO_4\) solution. In the meantime, another set of specimens are immersed in pure water. The compressive strength tests are performed according to Appendix A of IS 2250 (1981) (reaffirmed 2000).

2.5. Workability of foam-concrete

The workability of foam-concrete is assessed by the consistency test of fresh concrete using a mini-slump cone apparatus (Fig. 3). Flow values obtained are shown in Table 3. It is observed that the addition of 5% rice straw reduced the workability to low value, which necessitates the addition of 0.1% superplasticizer by weight of cement. The flow values of 0-20%, 20-40%, 40-60%, 60-80% and 80-120% described correspondingly as Very Low, Low, Medium, High and Very High workabilities (Nambiar and Ramamurthy 2008). The improved workability in fly-ash based mixes is due to the nearly perfect and tiny spherical shape of fly-ash. Cement and sand particles have sharp and angular shape, whereas the tiny spherical shape of fly-ash acts like ball bearings to lubricate the mix.
2.5.3 Functional properties

Thermal conductivity

Thermal conductivity test is performed after 28 days of curing (ASTM-C 177-9 1997). A schematic representation of the test set up is shown in Fig. 4 and the actual set-up is shown in Fig. 5. Claddings are oven-dried to remove all moisture present in it and the specimens (45 cm×30 cm×1.8 cm) are placed on either side of the heating plate, ensuring uniform contact with the cooling plates.

The guard heater input is provided in such a way that there is no radial heat flow, which is adjusted by checking thermocouple readings. The thermocouple readings and the input to the central heater (current-voltage) are recorded for every 10 min until the steady-state condition is attained. The thermal conductivity is calculated using Eq. (6).

\[ k = \frac{Q L}{2 A (T_s - T_i)} \text{ W/mK} \]  

where \( A \) is the metering area of the specimen, \( Q \) is heat flow, \( T_s \) is cold plate temperature, \( T_i \) is hot plate temperature and \( L \) is the thickness of the specimen.

Sound absorption test

A circular cylinder of 3 cm diameter and 1.8 cm thickness is used for performing the sound absorption test. Two-microphone method using an Impedance tube is used to evaluate the sound absorption coefficient. Fig. 6 shows the schematic representation of the impedance tube used for sound absorption test. The sound absorption test is performed in the frequency range of 500 Hz to 3000 Hz to have a better understanding on the material sound absorption capacity as per the ASTM C384-04 (1988). In Fig. 6 (1)-(4) represent microphones, (5) is frequency analyser, (6) is the amplifier, (7) is a signal generator, (8) is the specimen, and (9) is the loudspeaker.

3. Results and discussion

3.1 Mechanical properties

3.1.1 Compressive strength

Fig. 7 shows the 28-day compressive strengths of the foam-concrete with 1%, 3%, and 5% rice straw with and without fly-ash. The compressive strength of fly-ash based foam-concrete was found to increase by 7.8% compared to the control specimens with addition of 1% rice straw. Similarly, a 20.4% increase in the compressive strength was observed for 1RS mix compared to 0RS. Up to 1% rice straw, fly-ash replaced foam-concrete showed higher compressive strength and then reduced considerably compared to the normal concrete. The same result was observed by Morsy (2011) and he reported that at low levels of inclusion, rice straw prevents the growth of cracks and at the higher level it increases the porosity of the composite material. From Fig. 7 it is observed that 0RSF and 1RSF mixes have comparatively higher compressive strength than...
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Fig. 10 SEM image of the foam-concrete with rice straw

Fig. 9 SEM images of foam-concrete with and without fly-ash

Fig. 11 Variation of the modulus rupture of the mixes with % Rice straw and with/without Fly ash

When fly-ash is added to a cement paste, the gain in strength is initially caused by the cement hydration and fly-ash acts as filler. As time goes by, fly-ash begins to contribute to strength, while a certain percentage of fly-ash will always act as filler. It is evident from Fig. 8 that the compressive strength of fly-ash based mixture increases over a much longer period than that of a mixture that does not contain fly-ash. In the mixes, 3RSF and 5RSF, un-hydrated fly-ash was observed inside the specimen which did not contribute much to the strength during the initial 60 days. After 60 days, however, the reaction started and a sudden increase in strength was observed in the 3RSF specimens, whereas the increase was found to be gradual in the 5RSF specimens. Fig. 9 represents the SEM images of foam-concrete with and without fly-ash. Foam-concrete with fly-ash showed uniformly distributed spherical air voids compared to those without fly-ash. Fig. 9 portrays the hydrated product in foam-concrete after a period of one year. Fly-ash replaced foam-concrete shows a dense...
hydrated structure when compared to the control specimen (0RS-0% rice straw).

3.1.2 Breaking strength and modulus of rupture

Figs. 11 and 12 reports the trends of the flexural strength versus % rice straw and fly-ash. 45×30×1.8 cm cladding samples were tested after 28 days of curing. The modulus of rupture and breaking strength of foam-concrete without rice straw (0RS) were observed to be 1.78 N/mm² and 85 N. Furthermore, when cement was replaced with fly-ash (0RSF), the breaking strength and modulus of rupture of the cladding was found to be increased by 9.2%. Compared to the 0RS mix, the modulus of rupture and breaking strength increased by 5% and 9% respectively for the 1RS and 2RS mixes. In fly-ash replaced foam-concrete, there was a 6% increase in the breaking strength for 3RSF mix due to the pozzolanic property of fly-ash which imparts the strength for many months after placement. Foam-concrete with 3% rice straw showed higher flexural strength compared to other mixes. Fig. 10 shows the SEM image of foam-concrete with rice straw which illustrates the bond between rice straw and foam-concrete.

3.2 Durability properties

3.2.1 Rate of water absorption

The main factors which influence water absorption are foam volume, paste content, pores, and voids. Formations of voids and pores are different for different percentage fiber inclusions. Both fibres and voids influence the rate of water absorption. Rice straw itself is porous in nature, and it accelerated the flowability of the fluid molecule (Morsy 2011). As shown in Figs. 13 and 14, water absorption increased with an increase in percentage rice straw content. Foam-concrete with 1%, 3%, 5% rice straw dosages does not show a higher percentage of water absorption compared to the control specimen, which can be attributed to the NaOH treatment of the straw. The replacement of cement with fly-ash increased water absorption when compared to the base mix. This variation can be due to the presence of higher capillarity pores resulting from a higher paste content (Jitchaiyaphum et al. 2011). In both specimens, the increased rate of water absorption was found to be desirable up to 60min after which it is getting reduced.

Variation of compressive strength with water absorption of fiber-added foam-concrete is illustrated in Fig. 15. It can be observed that at lower percentage fiber content, the compressive strength increased with water absorption, irrespective of conventional concrete.

3.2.2 Drying shrinkage

Foam-concrete showed higher shrinkage compared to conventional concrete because of the absence of coarse aggregates. Fiber inclusion may overcome these drawbacks.
faced by foam-concrete. Falliano et al. (2019) stated that the shrinkage is influenced by the amount of fiber present in the mix, and the higher amount, the greater will be the shrinkage resistance. Fig. 16 shows the variation of shrinkage with percentage rice straw and fly-ash and indicates that an increase in the percentage of rice straw leads to a decrease in drying shrinkage. These results are consistent with the findings of Falliano et al. (2019). Fibers can retain water, and hence it delays the rate of water evaporation and lessens the drying shrinkage (Falliano et al. 2019, Saje et al. 2011, Morsi 2011). For the addition of rice straw by 1%, 3%, and 5%, the corresponding decrease in shrinkage was found to be 11%, 32%, 40.45% respectively. While replacing cement with fly-ash, shrinkage was found to be increased. A similar observation of an increase in shrinkage with fly-ash replacement was reported by Nambiar and Ramamurthy (2009). Low shrinkage resisting capacity of fly-ash and higher volume of shrinkable paste makes the specimens more shrinkable.

### 3.2.3 Acid resistance

The compressive strength values obtained for the foam-concrete cubes preserved in pure water and sulphuric acid are shown in Fig. 18. All the specimens preserved in sulphuric acid (Fig. 17) showed a reduced strength compared to the control specimen due to deterioration, a surface phenomenon that started at the surface of the concrete and progressed inwards. Foam-concrete with fly-ash showed a remarkable increase in compressive strength when cured in water up to 90 days due to pozzolanic reaction. With up to 1% rice straw, the foam-concrete specimen with fly-ash replacement (0RSF, IRSF) showed higher compressive strength compared to the control mix. With over 1% rice straw, the compressive strength was found to have reduced with fly-ash replacement. The reduction in compressive strength is quite visible in all the rice straw added specimens subjected to acid. This was due to the decay of rice straw in acid, which made the concrete more porous and hence allowed enhanced ingress of acid into the specimen. However, the reduction in strength is not noticeably significant in water-cured specimens due to the efficiency of the NaOH treatment provided to rice straw beforehand. Hence, the developed claddings are not recommended for use in acid rain prone areas.

### 3.3 Functional properties

#### 3.3.1 Thermal conductivity

In this study, thermal conductivity of foam-concrete with and without fly-ash and rice straw is conducted. Test results indicated that when 60% cement is replaced with fly-ash, the thermal conductivity values reduced, which may be due to the cenospheric particle morphology of fly-ash particles. Cenospheres are the hollow ash particles that are formed during coal combustion at high temperatures. It has large particle size with a thin wall of thickness less than 10% of the diameter. 1-2% of the total weight of fly-ash
fields.


due to the reflection of the sound waves.

### 3.4 Cost analysis

To check the economical viability of the developed wall cladding a cost comparison study has been made with the available normal foam concrete panel. Table 4 shows the material cost analysis of foam-concrete claddings with and without fly-ash replacement. A 38% reduction in material cost was found in developed fly-ash replaced foam-concrete wall claddings. Fig. 21 shows the schematic representation of an exterior wall cladding system.

### 4. Conclusions

The present paper reports the development of a wall cladding for thermal insulation in buildings. It is made up of natural fiber, rice straw, incorporated into high volume fly-ash based foam-concrete. Various experiments were performed to determine the mechanical, durability and functional properties of the developed wall cladding containing different percentages of rice straw and fly-ash. The results are compared with control specimens. and the following conclusions can be drawn.

- From the study, it is observed that, at low levels of rice straw content, fibers enhance the flexural strength and compressive strength by resisting the growth of cracks. However, at higher fiber contents, an increased porosity of the composite material, a corresponding loss of compressive strength and flexural strength can be observed.
- The thermal conductivity of the cladding is found to decrease with an increase in the rice straw content and with fly-ash replacement.
- Shrinkage property of foam-concrete is found to improve with rice straw content.
- Sound absorption increases with percentage of rice straw content, and at a frequency range of 500-1500 Hz fly-ash replaced foam-concrete shows higher sound absorption compared to the control specimen.
- Up to 1% rice straw addition, fly-ash replacement increases the acid resistance.
- The replacement of cement with fly-ash and the

### Table 4 Cost analysis for foam-concrete panel

<table>
<thead>
<tr>
<th>Materials</th>
<th>Developed Fly-ash replaced foam-concrete wall cladding</th>
<th>Normal foam-concrete wall cladding</th>
<th>Quantity/m²</th>
<th>Price/m²</th>
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<td>Fly-ash</td>
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</tbody>
</table>

contains these particles. Demirboga (2003) also reported that reduction in thermal conductivity is due to reduced density of concrete. Heat transfer through certain materials depends upon the thickness and the thermal conductivity of the material that is used (Mahlia et al. 2007). As shown in Fig. 19, the specimen with rice straw showed reduced thermal conductivity, because of its hollow structure and cellulose content. Compared to the control specimen, the reduction in the thermal conductivity was about 19%, 30% and 33% respectively, for foam-concrete with 1%, 3% and 5% rice straw (1RS, 3RS and 5RS). Fly-ash replaced foam-concrete showed a reduction in conductivity of 28%, 34% and 36% for 1RSF, 3RSF and 5RSR.

### 3.3.2 Sound absorption test

The sound absorption coefficients of foam-concrete at different frequencies are shown in Fig. 20, which shows that rice straw has a considerable effect on the sound absorption capacity of foam-concrete. It was observed that for all frequencies, the sound absorption coefficient increases with an increase in the percentage of rice straw content. This can be attributed to the higher porosity that resulted from the addition of rice straw. Fly-ash does not have a significant effect on sound absorption property at a frequency range of 1500-2500 Hz. At a frequency range of 500-1500 Hz fly-ash replaced foam-concrete showed higher sound absorption compared to the control specimen. All specimens showed an increase in sound absorption at a middle-frequency range. However, at lower and higher frequencies, the sound absorption coefficient kept reduced
addition of rice straw increases the rate of water absorption when compared to the base mix. It is recommended to provide a water repellent coating to the external cladding.

- Considering strength, durability and functional property, the IRSF mix can be effectively used as a cost-effective, energy-efficient thermal insulation.

From the study it is observed that the developed cladding is efficient in terms of thermal conductivity and sound absorption. The strength and durability issues due to the incorporation of foam and fibers can be improved by sandwiching the developed cladding between a thin layer of cement paste or any other material which have low thermal conductivity like calcium silicate boards. Apart from this, a waterproofing coating can also enhance the strength and durability aspects of the developed cladding.

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Data availability statement

All data, models and code generated or used during the study appear in the submitted article.

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