Thermal Insulation by Fiber Added High Volume Flyash Aerated Concrete Wall Cladding

Amritha Raj, Maheshwar Kotwal, Dhanya Sathyan, and K. M. Mini

Abstract The goal of this research is to develop a sustainable environment-friendly thermal insulation aerated concrete cladding using rice straw, silica fume, fly ash, and cement. Silica fume and rice straw were added to improve the strength and functional properties of aerated concrete. The strength and thermal properties of aerated concrete with various foam volumes are investigated in this study. A numerical analysis of thermal insulation capacity is also carried out using the COMSOL software. For all specimens, the w/s ratio is fixed to 0.55. The result shows that the mix with 20% foam volume is best in terms of desirable compressive strength and thermal conductivity.

Keywords COMSOL multiphysics · Building simulation · Rice straw · Aerated concrete · Thermal insulation

1 Introduction

Before 1950, most of the houses and buildings were made of mud and stones and coating of walls was also done with mud and straw. But these construction materials take more area (walls width) and lack strength. With the advancement in construction technology, concrete is mainly utilised as a construction material because of its good construction performance. Aerated concrete is an innovative, economical solution for thermal insulation in building [1]. The main source of energy in modern times is from thermal power plants. When the energy (electricity) is generated from coal combustion, some waste products are formed, known as,

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G. C. Marano et al. (eds.), *Proceedings of SECON'21*, Lecture Notes in Civil Engineering 171, https://doi.org/10.1007/978-3-030-80312-4_57

Coal combustion products (CCP). Coal combustion products include bottom-ash, gypsum, fly-ash, etc. The disposal of coal combustion products (CCP) has become a very big threat to the environment these days [2]. Researchers and Scientists are trying enormously to find different ways towards the utilisation of fly ash. One of the ways is utilizing this waste product in the construction industry effectively. The advantages of using fly ash in construction purpose include energy-saving, cost-saving, low CO_2 content, etc. If some proportion of cement is replaced with fly-ash, it will help to reduce the greenhouse gas emission. Also, the concentration of poisonous components like lead and cadmium is lower in fly ash [3]. The replacement of sand with fly ash in cement outcomes an increase in strength for a given density [4]. According to the research by Jones and McCarthy [5], the utilization of fine fly ash as a partial substitution to the cement and use of coarse fly ash as a substitution to fine aggregate reduces the drying shrinkage and heat of hydration to a great extent. Majorty of the structures in India are not using thermal insulation materials in buildings results in higher energy consumption to achieve the desired temperature inside a room.[6]. Materials having low thermal conductivity have a high resistance to heat stream and thus their use in construction can decrease the amount of transfer of heat into buildings. Aerated concrete is known for its better properties of thermal insulation. Aerated concrete is light in weight and its thermal conductivity lies in the reach between 0.10 to 0.70 W/m K [7, 8]. The use of aerated concrete on the global scale was about 5.6% in Australia, North America, and Africa and in Europe it is about 33.3%. In Asia, it is because of the lack of awareness and confidence of people in this material [9]. Also the proper availability of required technology to manufacture is not available. [10]. But now in recent times, builders, civil engineers, contractors, all over the world are giving more importance to the use of foam-concrete because now people are more concerned about the environment and energy conservation. A well-insulated building reduces energy consumption by keeping rooms warm in the winter and cool during the summer. So, materials having lower thermal conductivities are preferred to reduce heat loss. Since the aerated concrete is made by blending foam into the cement-based slurry, the density and the porosity are the variables that affect the thermal conductivity of the aerated concrete [11]. Despite having many benefits of foam-concrete, the main drawbacks of aerated concrete are shrinkage and lower strength. To overcome this drawback of aerated concrete, rice straw can be effectively used for improving the thermal insulation and shrinkage resistance properties of foam-concrete [12]. Studies were done on the thermal conductivities of the wall the panels produced using the combination of rice husk and gypsum revealed that the conductivity of the panels decreases and almost diminishes with the increase of the amount of rice husk [13, 14]. So our research work aims to develop a sustainable environmental-friendly thermal insulated aerated concrete wall cladding using cement, silica fume, rice straw and fly ash.

2 Experimental Details

2.1 *Materials and Mix Proportions*

Fresh clean potable water, Class F fly ash of specific gravity 2.1, Silica fume, protein-based foaming agent (Ethoxylate of vegetable protein), and Ordinary Portland cement (OPC) 53 grade satisfied the codal provision of IS 12269:2013 [15] are used to make aerated concrete cladding. Compositions of mixes used are shown in Table 1.

2.2 *Details of Study*

Aerated concrete specimens are produced by mixing the mortar (mix of fly ash, cement, silica fume, and water) with the measured volume of foam. A foam generator is used to produce foam. To make a stable foam, foaming agent and water in a weight-to-weight proportion of 1: 30 is combined and 450 kPa pressure is applied. The 28-day compressive strength of aerated concrete cubes of size 50 × 50 × 50 mm is determined using a universal compression test machine according to Appendix A of IS 2250:1981 [16]. Thermal conductivity tests are carried out using hot guarded equipment in accordance with ASTM C 177–97 [17].

3 Results and Discussion

3.1 *Compressive Strength*

Figure 1 shows the compressive strength of aerated concrete cubes with and without fibre after 28 days of curing. It's been observed that as the percentage of

Table 1 Mixture compositions used

Mixes	20FR0	30FR0	40FR0	50FR0	20FR1	30FR1	40FR1	50FR1
Density	925	800	675	425	925	800	675	425
Water (kg/m^3)	636.9	558	478.5	398.2	636.9	558	478.5	398.2
Cement (kg/m^3)	492	431	370	308	492	431	370	308
Rice straw(kg/m^3)	0	0	0	0	5.79	5.79	5.79	5.79
Silica fume (kg/m^3)	87	76	65	54	87	76	65	54
Fly ash (kg/m^3)	579	507	435	362	579	507	435	362
Foam (% of total volume)	20	30	40	50	20	30	40	50

*20FR1—20%foam, F—fly ash, R1—With rice straw foam volume increases, strength decreases. There is 55 to 88.1% reduction in strength is observed when the percentage of foam content increased from 20 to 50. At the point when the foam volume is 20%, 30%, 40%, and 50% corresponding 28 days strength acquired are 5.44, 4.48, 3.472, and 2.4 MPa, respectively (with-out fiber). Compressive strength is discovered to be reduced with the fiber addition. The percentage reduction in compressive strength due to straw addition found to be increased with % foam volume. The percentage reduction in strength because of the addition of straw is, 18.7%, 58.5% and 72.5% respectively for 30%,40%, and 50% foam volume. The strength reduction is due to the results of increased porosity. Mix with 20% foam volume got desirable compressive strength.

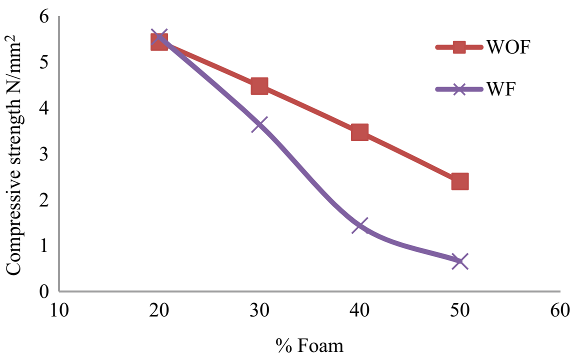
3.2 Thermal Conductivity

Thermal conductivity is observed to be diminished with foam volume (Fig. 2). Higher-density aerated concrete shows higher conductivity. Also observed that the addition of rice straw reduced the conductivity further. The cellulose content, and hollow structure of rice straw results reduction in conductivity. Thermal conductivity is found to be reduced from 0.099 to 0.073 W/mK when foam volume increased from 20 to 50%. For fiber added mix the corresponding reduction is from 0.09 to 0.069 W/mK.

3.3 Rate of Water Absorption

Figures 3 and 4 shows the variation of water absorption with time. It is observed that aerated concrete with lower density absorbs more water than higher density. Therefore, it can be concluded that aerated concrete with lower density is less durable than aerated concrete with higher density. Also, it is observed that addition fiber increases the porosity there by the water absorption. The mixes without fiber

Fig. 1 Variation of compressive strength with percentage foam volume



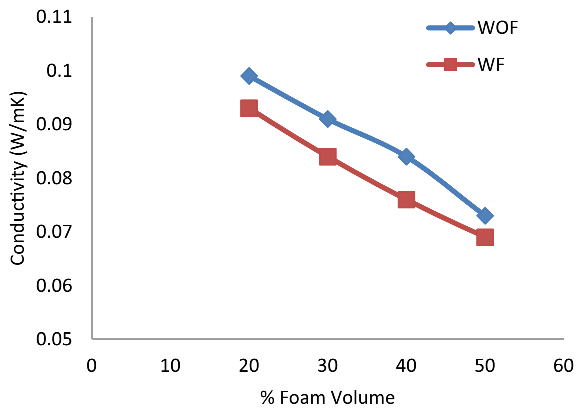


Fig. 2 Variation of thermal conductivity with percentage foam volume

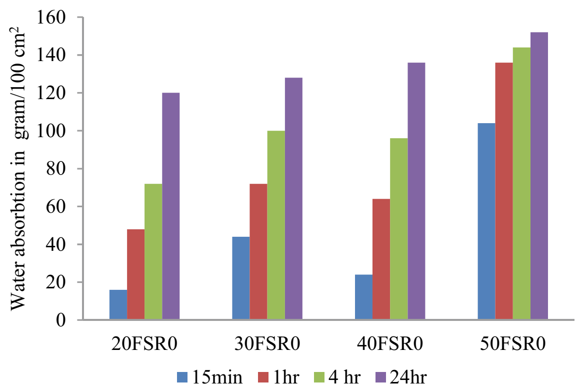


Fig. 3 Variation of water absorption with time

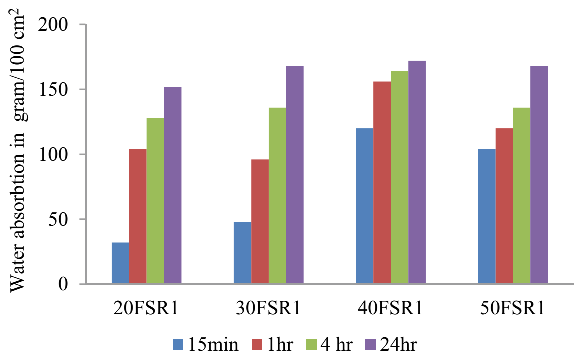


Fig. 4 Variation of water absorption with time

have a 24 h water absorption value in the range of 120–152 gm/100 cm^2 and with fiber the range increased to 152–168 gm/100 cm^2. In Fig. 4 it is observed that when foam volume increases, there is a slight increase in water absorption only. This increase in water absorption regardless of foam volume reveals that only some of the air voids are fully or partially filled.

3.4 Numerical Analysis

To find the effectiveness of the insulation panel, a study was done using COMSOL Multiphysics software. A 3D single-room building is modelled. Figure 5 shows the dimensions of the model developed. A 20 mm insulation panel, 230 mm thick brick masonry, Concrete roofing, wooden windows and doors are also provided. Parameters used to model building are the convective heat transfer coefficient inside the room is 8.29 W/(m^{2}K) and for Outside 34 W/(m^{2}K). The outcome shows that the mix 20FR1 is optimum in terms of thermal conductivity and desirable compressive strength. Thermal conductivity of 0.30 W/(mK), 0.806 W/(mK), 2.10 W/(mK) 0.093 W/

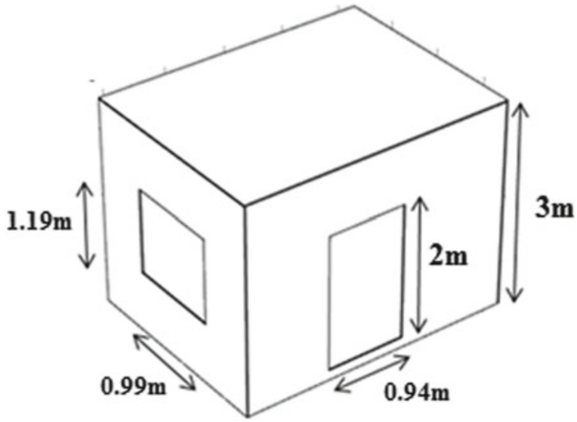


Fig. 5 Dimensions of the building model

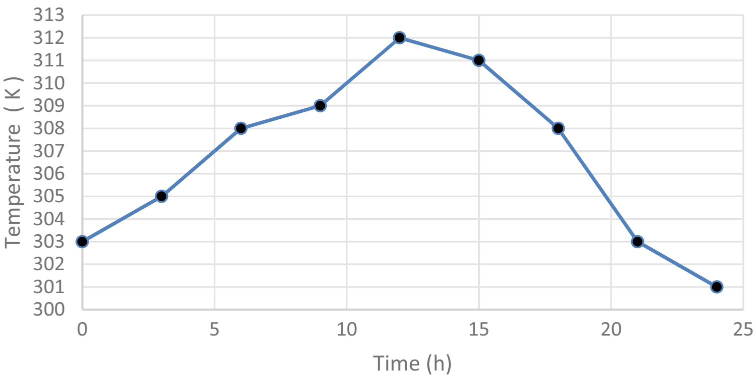


Fig. 6 Outside temperature given

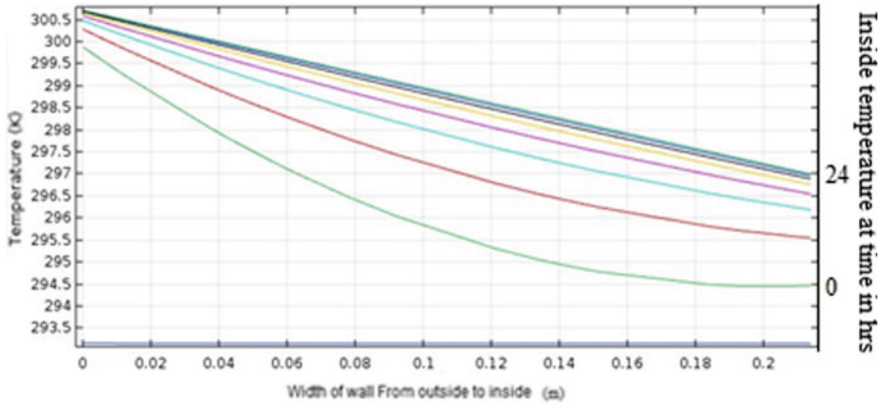


Fig. 7 Temperature variation across the wall

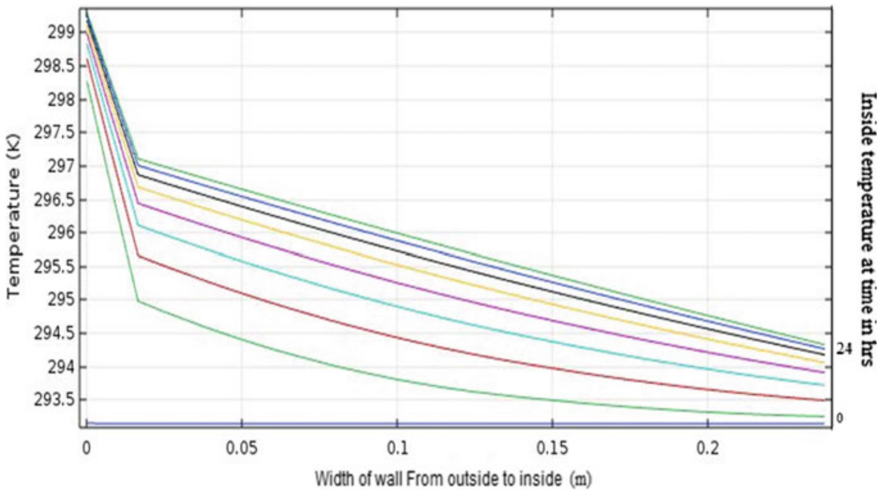


Fig. 8 Temperature variation across the wall with insulation

(mK), and Thermal capacity of 2390 J/(kgK), 800 J/(kgK), 1050 J/(kgK),757 J/(kgK) are given for Wood, Brick wall, concrete and Insulation panel respectively [18]. Heat transfer by conduction convection and radiation are considered.

Figure 6 shows the outside climatic temperature with time. (randomly taken daytime temperature in Chennai India). Figures 7 and 8 shows the corresponding temperature variation across the wall with and without insulation panel. In Fig. 8 sudden linear drop of temperature up to 0.02 m due to the presence of insulation. In Figs. 7 and 8 yellow colour line shows the temperature across the building at the highest outside temperature of 312 K. there was a 3 K difference in temperature was observed for a building with and without an insulation panel. For a building without an insulation panel, temperature variation across the wall (brick wall) corresponding to the input temperature profile varies from 294.5 to 297 K. And for the insulated wall, it will range from 293.5 to 294.5 K.

4 Conclusions

According to the research, the panel developed can be beneficially used as external wall cladding in the building by providing proper water resisting coat.

- Compressive strength was found to be reduced with foam volume. A mix with 20% foam volume was found to give better heat resistance and desirable compressive strength.
- The rate of water absorption and thermal resistance was found to increase with foam volume and fibre content. Aerated concrete with lower density was found to be less durable than higher density.
- It was discovered that the addition of rice straw to foam concrete enhanced its thermal properties.
- In terms of thermal and strength properties, the 20FR1 mix can be effectively used for wall cladding.
- From the numerical simulation, it was discovered that by using aerated concrete wall cladding, we can maintain a comfortable temperature inside the structure.

Acknowledgements The authors are thankful for the monetary help given by the Department of Science and Technology (TMD / CERI / BEE/2016/032).

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