Porous and heat analysis for foam block used in building wall restoration

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Abstract. Using COMSOL Multiphysics software, a thorough porosity and heat analysis is performed to examine the thermal performance and insulating qualities of foam blocks used in building wall restoration. The main goal is to comprehend how the foam block's temperature changes over time, emphasizing both its usefulness as an insulator and its heat transmission properties. The investigation showed that the foam block's exterior layer quickly absorbed heat during the early heating stages, indicating its effectiveness in storing thermal energy. Heat progressively moved within as the heating process went on, demonstrating the material's capacity to efficiently transfer thermal energy from the exterior to the interior. A consistent temperature distribution was seen during the advanced heating phases, highlighting the foam block's superior thermal conductivity and stability.

1 Introduction

To preserve structural integrity and increase energy efficiency in both residential and commercial structures, building wall repair is essential. Foam blocks are one example of an innovative material that has garnered a lot of attention lately because of their great insulating qualities and lightweight design. Because of its porous structure and several advantages over other materials in terms of thermal performance and simplicity of installation, foam blocks are a great option for wall restoration projects. Cement, sand, and a variety of additives—such as lightweight aggregates like expanded polystyrene (EPS) beads—compose foam blocks. These substances help foam blocks have high porosity and low density, which affects the blocks' mechanical and thermal characteristics. Foam blocks' porous nature is essential to their functionality since it influences the material's overall insulating capacity as well as the mechanisms for heat transmission [1-3].

Foam blocks are a great option for wall rehabilitation because of their superior thermal insulation qualities. The main factors that affect how well foam blocks work as insulators are their thermal conductivity, specific heat capacity, and thermal diffusivity. Minimal heat transmission through the material is ensured by low thermal conductivity, which lowers

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energy consumption for heating and cooling while maintaining pleasant interior temperatures [4-6]. The ability of a material to absorb and retain heat, acting as a buffer against temperature changes, is indicated by its specific heat capacity [7-9]. Lower values indicate higher insulation performance. Thermal diffusivity, which combines thermal conductivity, density, and specific heat capacity, shows how rapidly heat propagates through the material [10–12].

The performance of foam blocks is significantly influenced by their structural features, such as porosity and pore size distribution, in addition to their thermal qualities. The strength, longevity, and moisture resistance of the material are influenced by the distribution of pores. The structural integrity and thermal efficiency of foam blocks are improved by a homogeneous pore size distribution, which makes them more appropriate for wall repair applications [13–15].

The purpose of this study is to do a thorough thermal and porosity investigation of foam blocks used in building wall restoration. We may gain a better understanding of foam blocks' appropriateness for improving the durability and energy efficiency of rebuilt walls by assessing their thermal and structural attributes. Architects, engineers, and construction professionals looking to maximize building materials for sustainable and effective wall repair may find great value in the research findings.

2 Methodology

Model Development
1.1. Geometry and Domain
Foam Block Geometry: The foam block's geometry is created based on typical dimensions used in building wall restorations. The block is modeled as a three-dimensional porous medium with specified pore size distribution.

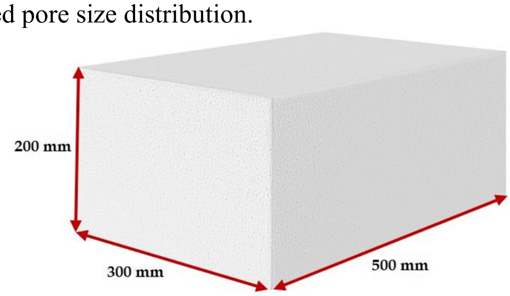

Fig. 1. The size of a block made of foam plaster material used for building walls.

Computational Domain and Boundary Condition: The computational domain includes the foam block and the surrounding air. The dimensions are chosen to ensure that boundary effects do not influence the results significantly.

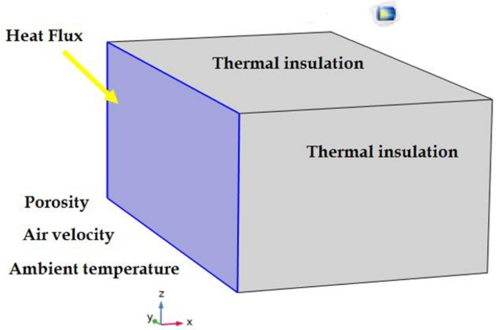

Fig. 2. Boundary condition.

Table 1. Finite elements used in the calculation.

Property	Variable	Value	Unit
Density	ρ	574	kg/m³
Heat capacity at constant pressure	C_p	1100	J/(kg·K)
Thermal conductivity	k	$k_{(phi)}$	W/(m·K)
Porosity	ε	0.2	1
Diffusion coefficient	D	$D_{w(phi)}$	m²/s

1.2. Meshing

Mesh Generation: To precisely represent the intricate pore structure inside the foam block, a high-resolution tetrahedral mesh is created. To guarantee precise resolution of temperature gradients and fluid movement, mesh refinement is done in the vicinity of the borders and inside the pores.

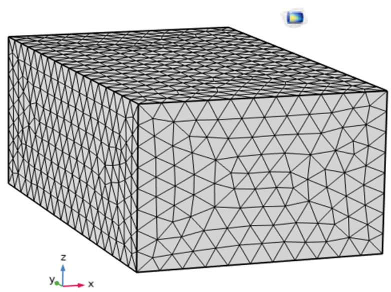

Fig. 3. Finite element model.

Mesh Independence Study: A mesh independence study is conducted to ensure that the results are not sensitive to mesh size. Multiple mesh densities are tested, and the optimal mesh is selected based on a balance between accuracy and computational cost.

Table 2. Finite elements used in the calculation.

Elements type	Domain elements	Boundary elements	Edge elements
Number of elements	830375	220542	8485

3 Governing Equations

The governing equations for mass, momentum, and energy conservation are resolved by the CFD analysis:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \boldsymbol{u}) = 0 \tag{1}$$

Momentum Equation (Navier-Stokes):

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u u) = -\nabla p + \nabla \cdot (\mu \nabla u) + \boldsymbol{F} \tag{2}$$

Energy Equation:

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot \big(u(\rho E - p)\big) = \nabla \cdot (k \nabla T) + S \tag{3}$$

where ρ is the density, u is the velocity vector, p is the pressure, μ is the dynamic viscosity, E is the total energy, k is the thermal conductivity, T is the temperature, and S represents source terms.

Porous Media Model: The foam block is modelled as a porous medium with specified permeability and porosity. The Ergun equation is used to describe the flow resistance within the porous structure:

$$\Delta P = \frac{150(1-\epsilon)^2}{\epsilon^3}\frac{\mu\vartheta}{d_p^2} + \frac{1.75(1-\epsilon)}{\epsilon^3}\frac{\rho\vartheta^2}{d_p} \tag{4}$$

where ΔP is the pressure drop, ϵ is the porosity, μ is the dynamic viscosity, v is the superficial velocity, and d_p is the particle diameter [24-25].

4 Results

The findings of a heat and porous study of a foam block used to restore building walls, carried out with COMSOL Multiphysics software, are shown in this section. In order to comprehend the thermal performance and insulating qualities of the foam block, the analysis focuses on the temperature distribution over time within it. During the first 200 and 400 seconds of heating, the foam block's surface temperature progressively rises. Near the heated surface, the temperature gradient is steep, suggesting that the heat is mostly focused at the outer layer.

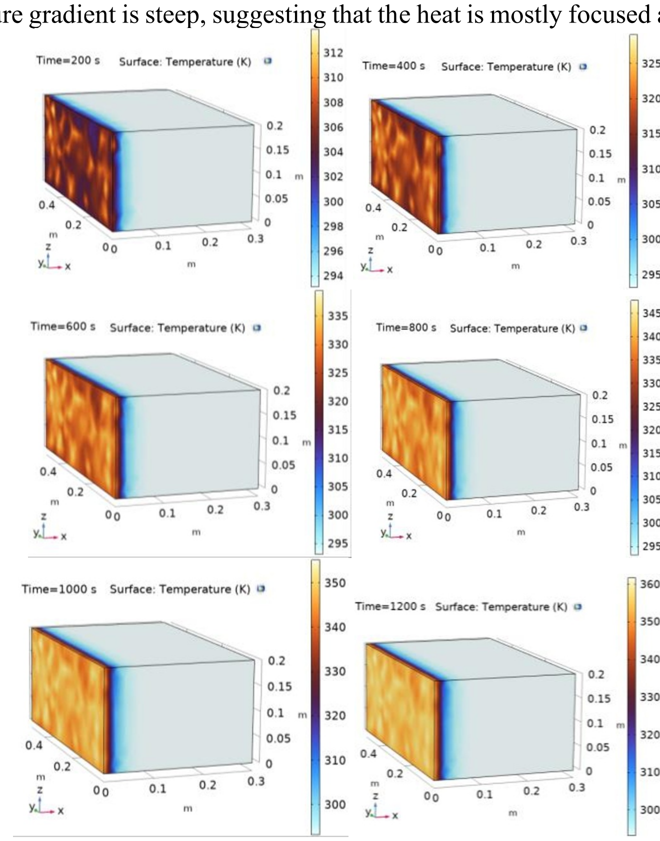

Fig. 4. CFD analysis foam block for building wall on the COMSOL Multiphysics.

Time = 200 s: Most of the interior is still relatively chilly, with surface temperatures ranging from 294 K to 312 K.

Time = 400 s: The surface temperature rises to 325 K, a further increase in temperature. The fact that very little heat enters the inside indicates that the majority of the thermal energy is absorbed by the outer layer of the foam block.

The temperature distribution starts to spread more evenly throughout the foam block's surface and gradually seeps deeper into the substance as heating continues (600 and 800 s).

600 seconds is the time. There is a 295 K to 335 K temperature range at the surface. There is still a noticeable temperature disparity close to the surface even as the heat begins to disperse inside.

800 seconds is the time. The surface can get as hot as 345 K. There is greater evidence of heat penetration, since a slow rise in temperature is shown further into the foam block.

The temperature distribution within the foam block becomes more consistent in the latter heating phases (1000 and 1200 seconds), suggesting efficient heat transmission and thermal conductivity.

Time = 1000 s: There is a gradual increase in surface temperature, from 300 K to 350 K. Better heat distribution within the foam block is seen by the decreased temperature gradient between the interior and outside.

Time = 1200 s: There is a notable rise in both the internal and surface temperatures, with the surface reaching as high as 360 K. This suggests that a more consistent thermal equilibrium has been reached by the foam block.

The thermal performance of the foam block is greatly influenced by its porous structure. Better heat absorption and dispersion are made possible by the high porosity, which is essential for efficient thermal insulation in building wall repair. The high porosity of the foam block's outer surface allows it to quickly absorb heat, allowing the surface temperature to rise quickly. The fact that the heat begins to spread inside shows how well the material transfers heat from the exterior to the interior thanks to its thermal conductivity. The more consistent temperature distribution indicates that the foam block can withstand prolonged heating times. The findings show that foam blocks are a very efficient way to insulate building walls from heat.

5 Conclusions

The investigation in this publication shows how foam blocks used in building wall restoration have substantial thermal performance and insulating qualities. The study carefully investigated a foam block's temperature distribution over time using COMSOL Multiphysics software to comprehend its heat transmission properties. The foam block showed a sharp temperature gradient at the surface during the first two heating phases (200 and 400 s), with temperatures ranging from 294 K to 325 K. This demonstrates how well the foam block captures thermal energy since the outer layer absorbs heat fast.

Heat began to permeate inside during the intermediate heating stages (600 and 800 s), with surface temperatures rising to 345 K. The slow penetration of the foam block emphasizes how well it disperses heat energy from the exterior to the interior, improving its insulating qualities.

The temperature distribution within the foam block became more uniform throughout the advanced heating phases (1000 s and 1200 s), with surface temperatures peaking at 360 K. This homogeneity suggests effective thermal conductivity and heat transmission, guaranteeing the foam block's long-term thermal stability.

The foam block's high porosity greatly enhances its thermal efficiency by facilitating efficient heat diffusion and quick heat absorption. This quality is essential for preventing heat loss via walls and preserving interior thermal comfort. As such, foam blocks work incredibly well as insulators in building wall rehabilitation efforts.

The foam block's capacity to maintain a consistent temperature distribution over time highlights its potential as a dependable insulator. By guaranteeing that buildings can maintain constant interior temperatures, this feature improves energy efficiency and lowers heating and cooling expenses.

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