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# The Impact of Layered Surfaces of 3D Printed Structures on the Heat Transfer Process#

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## ABSTRACT

The energy performance of 3D printed buildings has been of great interest. This study focuses on the layer-by-layer surface shapes of 3D printed buildings and simulates the effect on the heat transfer process. The results demonstrate that the layered surface leads to a periodic fluctuation in surface temperature, with an average surface temperature closer to the ambient temperature. Although the surface heat flow decreases, the total surface heat transfer increases. According to the results, the layered surface affects the surface temperature distribution and surface heat transfer, which cannot be directly ignored in the study.

**Keywords:** 3D printed structure, layered surface shape, heat transfer, surface temperature

## 1. INTRODUCTION

The 3D printing building is a relatively new form of construction, and numerous studies have been conducted to assess the potential benefits of this technology [1, 2]. The thermal performance of 3D printed walls has a significant impact on energy consumption and carbon emissions of the buildings [3, 4]. In a changing outdoor environment, thermal mass affects the temperature changes and the heat flow through the envelope [5]. Reducing the thermal conductivity of the material can improve the thermal insulation of the wall.

Due to the layer-by-layer printing process, layered shapes inevitably appear on the surface of 3D printed structures [6]. It is necessary to investigate the effect of this surface shape on the heat transfer process. Despite the extensive research on the thermal conductivity of 3D printing materials, there has been a notable absence of studies investigating the heat transfer properties in considering their geometry. In these studies, the heat transfer process and thermal resistance values of 3D printed structures were calculated using the same formulas as conventional concrete walls, which is not conducive to accurately assessing the energy efficiency of 3D printed walls. However, given the increased workload entailed in establishing the geometric model, it is necessary to propose a modification method to simplify the geometric model of the 3D printed structure.

This work aims to examine the impact of layered geometry on the thermal performance and heat transfer process of 3D printed walls. Additionally, an equivalent calculation method for simplified geometrical models is proposed to fill the current research gap in this field.

## 2. METHODS

### 2.1 Physical model

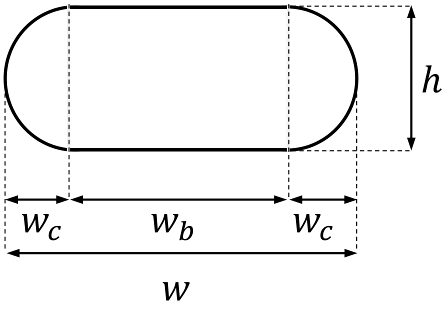

*Fig. 1 The geometry model of the 3D printed filament*

A geometrical model of the 3D printed structure was established. The model referred to the literature [7], which simplified each layer of printed filament into the structural unit shown in Fig. 1. The parameters in Fig. 1 allow the definition of structural units with different heights and widths.

Eq. (1) and Eq. (2) give the quantitative relationships between the parameters.

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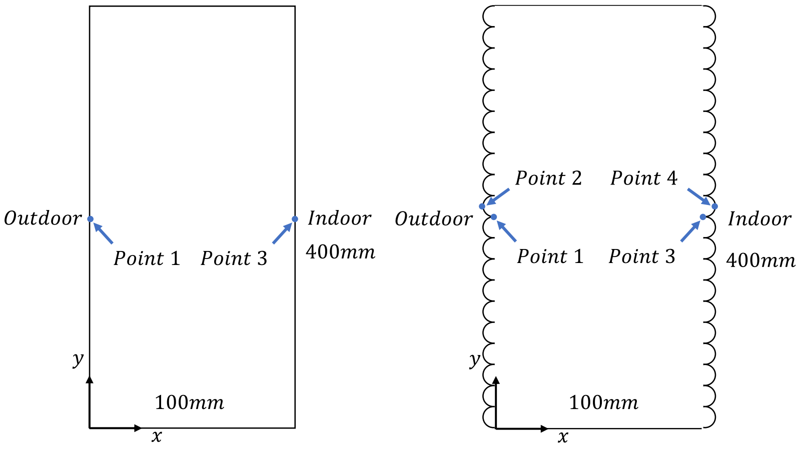


(a) Flat surface (b) Layered suface

*Fig. 2 Large diagram*

$$w = 2w_c + w_b \quad (1)$$

$$w_c = \frac{h}{2} \quad (2)$$

This study considered the flat and layered surfaces, corresponding to $w_c$ = 0 mm and $w_c$ = 10 mm, respectively. The height $h$ of each layer is 20mm. Fig. 2 illustrates the established physical models.

The transient conductive heat flow through the 3D printed structure can be defined as follows:

$$\rho_m c_p \frac{dT}{dt} = \lambda_m \nabla^2 T \quad (3)$$

Where $\rho_m$ is the density of the 3D printed material, $\mathrm{kg/m^3}$; $c_p$ is the specific heat, $\mathrm{J/(kg \cdot K)}$; $\lambda_m$ is the thermal conductivity, $\mathrm{W/(m \cdot K)}$; $T$ represents the temperature, $\mathrm{K}$.

Table 1 lists the thermal properties of the 3D printed material obtained from the experimental tests.

Table 1

Thermal properties of the 3D printed material.

| | Thermal conductivity | Density | Specific heat |
|---|---|---|---|
| 3D printed concrete | 1.637 | 2481.3 | 890 |

The simulation set a constant temperature differential between the external and internal environments to reduce the complicated effect of environmental changes on the results. Therefore, the structure will attain a stable equilibrium following the transient heat transfer.

In the first case, the ambient temperature of the outdoor side is set to 36°C, while the indoor side temperature is set to 26°C, maintaining a temperature difference of 10°C. In the second case, the outdoor side temperature is 0°C, the indoor side temperature is 20°C, and the temperature difference is 20°C. Adiabatic boundary conditions are imposed on the top and bottom surfaces of the structure. The initial temperature was identical to that of the outdoor environment.

In the first case, the convective heat transfer coefficient on the exterior is set to 19.0 $\mathrm{W/(m^2 \cdot K)}$, while the interior value is 8.7 $\mathrm{W/(m^2 \cdot K)}$. In the second case, the convective heat transfer coefficient on the exterior was 23.0 $\mathrm{W/(m^2 \cdot K)}$.

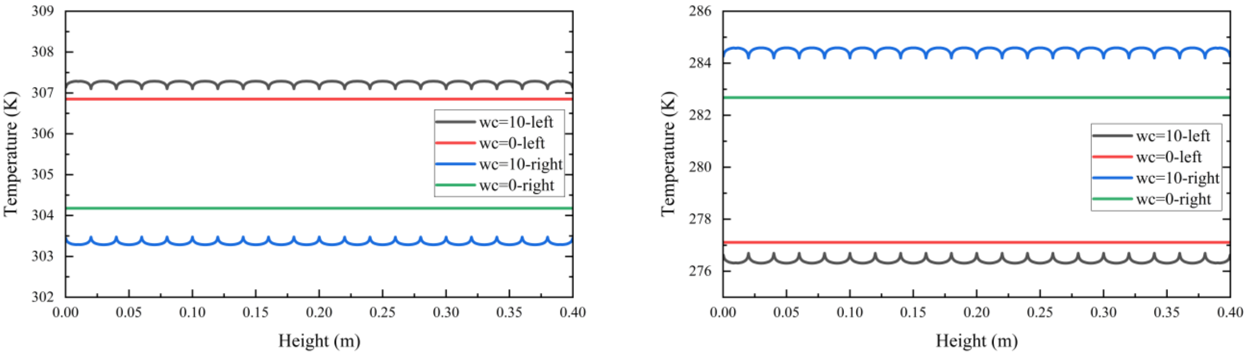
### *2.2 Simulation settings*

The simulation used ANSYS-Fluent software. A time step of 300 seconds is employed to simulate the temperature change over 24 hours. The convergence criterion is set to be less than $10^{-8}$.

A grid independence analysis was conducted, in which four distinct grid settings were subjected to comparative analysis. As the number of grids increases, the discrepancy in the simulation results diminishes. The grid number 100×600 was selected as the grid setup for subsequent simulations.

## 3. RESULTS AND DISCUSSION

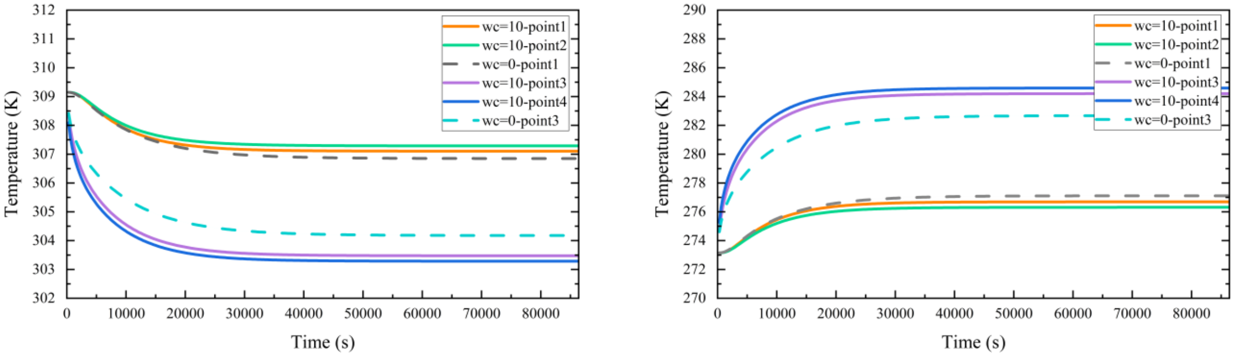
The surface temperature at the steady state is presented in Fig. 3. The results indicate that the temperature of the layered surface exhibits a periodic variation corresponding to the surface shape. The temperature difference between the highest and lowest points on the raised surface is less than 1°C. Although the temperature difference due to surface shape is not significant, it is nevertheless crucial to assess the influence of surface shape. Upon reaching a steady state, the mean temperatures of flat and layered surfaces diverge, particularly on the indoor side in Case 2, where



(a) Case 1

(b) Case 2

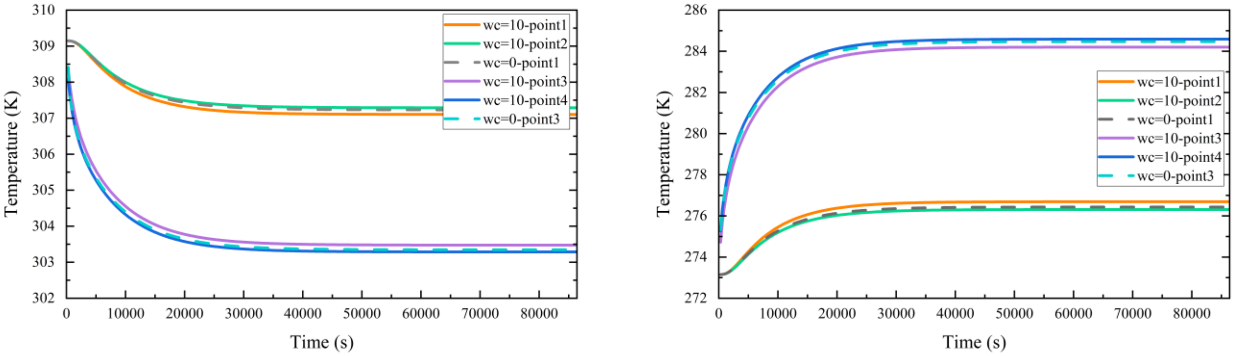
*Fig. 3 Physical model for numerical solution*



(a) Case 1

(b) Case 2

*Fig. 4 Surface temperature variation during the simulation*



(a) Case 1

(b) Case 2

*Fig. 5 Effectiveness of applying simplified models*

a temperature difference of approximately 2°C can be observed.

Fig. 4 gives the temperature changes at these four points during the simulation. It can be seen that different surface shapes present different temperature trends. The structure with layered surfaces ends up presenting temperatures closer to the environment. The mean temperature differential between the layered surface and the surrounding environment diminishes, thereby reducing the heat flow along the thickness direction than the flat surface. However, considering the increase in surface area, the total heat transfer through the layered surface increases and is greater than that of the flat surface.

The surface shape has a considerable impact on both the transient thermal response and the steady-state temperature distribution of the structure. Nevertheless, incorporating surface shape into the modelling process adds to the complexity of the study, particularly given that 3D printed structures frequently exhibit intricate contour shapes. Consequently, simplifying the surface shape is a viable approach.

In order to accurately predict the average surface temperature and average surface heat flow, it is essential to implement corrections to the simplified heat transfer process. The thermal resistance of the structure affects the steady-state temperature distribution and changes due to the presence of the layered surface. The equivalent thermal resistance can be defined as $R = \frac{R_0}{\alpha_s}$. By calculating the thermal resistance values for layered surfaces and plat surfaces with different heights and widths, the following computational equation for $\alpha_s$ can be derived:

$$\alpha_s = \frac{V + h \cdot w_b}{2A \cdot w} \quad (4)$$

Where $A$ is the surface area of structural unit, $\mathrm{m}^2$; $V$ is volume of structural unit, $\mathrm{m}^3$.

Temperature changes during transient heat transfer in the simplified structure are also need to be corrected. The shape change mainly affects the surface area and the volume in the heat transfer calculation equation. The temperature response can be corrected using the following coefficient:

$$\alpha_t = \left(\frac{V}{A}\right) \Big/ \left(\frac{V_0}{A_0}\right) \quad (5)$$

Where $A_0$ is the surface area of plat structural unit, $\mathrm{m}^2$; $V_0$ is volume of plat structural unit, $\mathrm{m}^3$.

The correction values are independent of the ambient temperature or surface convection settings. The simulation results using the correction formula are shown in Fig. 5. It can be seen that the simplified simulation results are in good agreement with the simulation results before simplification.

## 4. CONCLUSIONS

This work aims to assess the effect of the layered surface on the heat transfer properties of 3D printed structures. A geometrical model of the 3D printed structure was developed, and two surface geometries were considered.

The presence of layered surface affects the heat transfer process. Simulation results show that the temperature of the layered surface exhibits a fluctuation period that is consistent with the surface shape. The temperature differential between the layered surface and the surrounding environment is less than that observed between the flat surface and the environment. The calculated equivalent thermal resistance is higher than the corresponding thermal resistance of the planar structure. This effect is more pronounced than the effect of the increased thickness of the structure due to the bumps.

The proposed correction method is an effective means of simplifying the calculations and is capable of predicting both the temperature change and the temperature distribution on the layer-by-layer surface. Consequently, this study can serve as a reference for the precise calculation of heat transfer in 3D printed walls.

## ACKNOWLEDGEMENT

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