Study on Thermal Performance of Single-layer and Multi-layer Stone Aluminum Honeycomb Composite Panels

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Abstract. The stone aluminum honeycomb composite panel is light in weight and large in ductility. It is a sustainable building thermal insulation material. It can be used as an insulation wall for ordinary buildings and prefabricated buildings, so that the exterior walls of the building can be light, high-strength and heat-insulated. However, the current application of stone aluminum honeycomb composite panels is still rare in practice, because the reasonable core size and number of layers with the best structural optimization, the least heat transfer, and the strongest applicability are difficult to determine. In this paper, the three basic heat transfer mechanisms of heat conduction, thermal convection and heat radiation of stone aluminum honeycomb composite panel structure are systematically analyzed. Under the premise of convective heat transfer of gas in honeycomb core cavity, the surface radiation exchange of honeycomb core cavity is established. The heat and the heat transfer of the cavity and the air in the cavity play a leading role in the heat transfer mechanism. The effects of parameters such as honeycomb core layer, core size, core height and core wall thickness on heat transfer performance under steady-state heat transfer conditions were studied by experimental methods. Stone aluminum honeycomb composite panels were tested under different temperature conditions. The equivalent thermal conductivity of the structure. Based on the ANSYS finite element analysis software, based on the experiment, the fluid-solid coupling heat transfer model of stone aluminum honeycomb composite board was established to simulate the steady-state heat transfer performance of composite sheets under single-layer and multi-layer honeycomb core materials, and to study the core body. The variation of the effective thermal conductivity under different boundary conditions and different geometric parameters, the simulation results are basically consistent with the experimental results, and the results of the empirical formula are also consistent. The results show that under the condition of satisfying the feasibility of the construction process within the fixed height, the height of the honeycomb core layer, the size of the core, and the height of the core can be appropriately reduced to reduce the thermal conductivity.

Keywords. Stone aluminum honeycomb composite panel; equivalent thermal conductivity; finite element method; thermal response; heat transfer mechanism.
1. Introduction
Natural stone has a beautiful appearance, green and environmentally friendly natural decorative effect, and is the most economical, and has been widely used in buildings at home and abroad. However, natural stone is more prone to brittle failure, so the thickness and width of the sheet will be affected. Because natural stone has obvious disadvantages, its own weight is large, it is not easy to construct, and it is easy to be brittle. In recent decades, domestic and foreign stone manufacturers and stone machinery manufacturers have been increasing the research and development of stone manufacturing and technology to reduce the thickness of stone. Try to maximize the advantages of natural stone itself. The ultra-thin stone honeycomb composite panel maintains the beauty of natural stone, combines the advantages of stone flakes with the advantages of aluminum honeycomb panels with stronger impact resistance physical properties and flexural strength, eliminating the disadvantage of brittleness of stone flakes. The ultra-thin stone aluminum honeycomb composite board has the lowest structural weight and excellent specific strength. Compared with the aluminum plate, the maximum surface can be 1.5m*4.5m without adding reinforcement. Moreover, researchers have found that the hexagonal honeycomb is a structure that provides the highest compressive strength in the case of the same materials. At the same time, since the aluminum foil and the aluminum plate have the same thermal expansion coefficient, the aluminum honeycomb composite panel is not used during use. There will be uneven deformation. The honeycomb core material can separate the board surface into small independent spaces, which have a certain blocking effect on the air flow, thereby affecting the transmission of sound waves and heat, so that the purpose of sound insulation, heat insulation and noise reduction can be achieved.

1.1. Features of stone aluminum honeycomb panel
The aluminum honeycomb composite panel structure takes advantage of the natural honeycomb and I-shaped composite beam structure. The composite panel skin is made of aluminum sheet with high structural strength, and the section has good bending resistance. The core layer mimics the structure of the natural honeycomb, is light in weight, but has high shear resistance and good stability. The optimized design of the skin and core layer makes the honeycomb panel have the advantages of natural honeycomb and I-beam structure respectively:

1). The weight of the natural stone is lighter than the natural stone, and the strength and rigidity are larger than the natural stone. The structure is not easy to be unstable, and the bending, folding, shearing and wind pressure resistance are good. The 15mm thickness, 1.0mm panel, and 0.8mm bottom plate of the stone aluminum honeycomb composite panel has an areal density of only 6kg/m2; the weight is only about 1/7 of the whole body panel, and can even be used as a ceiling decoration. The intermediate core layer is a hollow hexagonal honeycomb core connected to each other, and the structure composed of the skin is like a plurality of I-beam connections, and the cavity is filled with air gas to provide a buffer for the sealed air under pressure. The shear strength is high, and the honeycomb core is fixed on the panel to make the plate more stable, which makes the overall specific strength, pressure resistance and light weight. Its anti-wind pressure ability is also very superior, and the deformation is relatively small, and it is not easy to bend.

2). Sound insulation, heat insulation and noise reduction performance. The honeycomb core is covered by the panel, the air in the cavity reduces the flow, and the small space formed prevents the heat from being transmitted and causes the sound waves to constantly reflect in this local area, reducing the energy. In recent years, the development of aluminum honeycomb panels, its noise reduction ability can reduce the high Hertz, high decibel sound to 100-3200Hz, 20-28dB.

3). Good decoration, easy installation and good durability. The keel splicing, dry hanging construction, light weight, good ductility, not easy to break, easy to splicing, improve installation efficiency and reduce installation cost. Can be mosaic, and the color difference can be controlled in a larger range. The marble composite board is divided into several parts by the original board, generally 3 or 4 points, and the area of the slab after cutting is several times. The cutting board has a small color difference and can be used in a large area, and the appearance is more beautiful. The aluminum honeycomb panel used as the curtain wall panel has good air pollution resistance and weathering
resistance, and can be widely used in newly built and rebuilt buildings, public buildings, and civil buildings.

1.2. Analysis of heat transfer mechanism
The stone aluminum honeycomb composite panel is composed of a top and bottom skin and an intermediate aluminum honeycomb core. The skin has an inner and outer layer, the inner skin is an aluminum plate, connected to the honeycomb core, and the outer skin is a slate. The splint in the middle of the multi-layer stone aluminum honeycomb composite board is an aluminum plate. The outer surface of the honeycomb panel is heated in a steady state heat transfer condition. The surface of the outer skin of the honeycomb is radiated and heat exchanged, and most of the heat is reflected back to the natural environment, and the other part of the heat is transferred to the skin. In the heat transfer analysis, steady-state heating is performed at both ends of the composite plate to create a temperature difference between the upper and lower surfaces of the test piece. The tiny pores in the honeycomb core "capture" the air, and the convection in the heat transfer process hardly exists, and can be regarded as a cavity. The internal air is stationary, so it can be considered that natural convection has no effect on the thermal conductivity of the honeycomb composite panel. The literature [1-3] ignores the natural convective heat transfer of the air. The comparison of the literature [4] shows that the thermal conductivity of the gas is very large. In the literature [5], the argument that the heat conduction of air in the honeycomb cavity contributes little to the equivalent thermal conductivity of the honeycomb core is proposed. In the literature [6], the air heat conduction in the honeycomb cavity was neglected during the experiment. In experiments in other literatures, air heat conduction within the honeycomb cavity was chosen. Therefore, in this experiment, it is also chosen to ignore the convective heat transfer of the gas in the honeycomb core cavity.

2. Measurement of Thermal Conductivity of Stone Aluminum Honeycomb Composite Panel
There are many types of aluminum honeycomb: a range of bees (aluminum foil) thickness (0.03-0.10) mm, and honeycomb side length (1.5-30) mm are divided into various honeycomb specifications, which are 0.03/5, 0.04/5, 0.05/4, 0.04/2, 0.05/3 and other specifications. The relationship between the density $\rho_c$ of the pure aluminum honeycomb core and the honeycomb wall thickness $t_s$ and the bee side length $C$ is:

$$\rho_c = \frac{4126(t_s/C)}{C}$$

Figure 1. Honeycomb plate heat transfer model

Where: $\rho_c$ is the density of the aluminum honeycomb core, kg/m$^3$; $t_s$ is the thickness of the bee wall mm; $C$ is the side length of the honeycomb, mm.
The panel used for the stone aluminum honeycomb composite board used in this paper is a 300 mm×300 mm natural marble board, and the thermal conductivity is determined to be 2.8 w/m·K. The honeycomb core is made of aluminum honeycomb core, and the thickness of the aluminum foil and the side length of the bee are respectively taken as (0.03/5), (0.1/4), and (0.1/6). The panel of the honeycomb panel is made of aluminum, the thermal conductivity is 209w/m·K, and the thickness of the panel is 1mm. The adhesive is made of modified epoxy resin. The thickness is 0.2-0.4 mm and its thermal conductivity is 0.22 w/m·K. In this experiment, the thermal conductivity of the material was determined by steady-state heat transfer method, the hot plate temperature was 35 °C, and the cold plate temperature was -20 °C. The specific experimental parameters and experimental results are as follows:

| Test piece specifications (mm) | Core size (mm) | Core wall thickness (mm) | Core height (mm) | Honeycomb panel thickness (mm) | Thermal Conductivity (w/m·K) | Thermal conductivity of stone composite insulation board (w/m·K) |
|-------------------------------|----------------|-------------------------|-----------------|-------------------------------|-----------------------------|---------------------------------------------------------------|
| 0.03/5                        | 5              | 0.03                    | 5               | 1                             | 1.43                        | 0.098                                                        |
| 0.03/5                        | 5              | 0.03                    | 10              | 1                             | 1.59                        | 0.104                                                        |
| 0.1/4                         | 4              | 0.1                     | 5               | 1                             | 0.048                       | 0.076                                                        |
| 0.1/4                         | 4              | 0.1                     | 10              | 1                             | 0.054                       | 0.082                                                        |
| 0.1/6                         | 6              | 0.1                     | 5               | 1                             | 0.039                       | 0.067                                                        |
| 0.1/6                         | 6              | 0.1                     | 10              | 1                             | 0.042                       | 0.071                                                        |

From the experimental results in the above table, we can see:

1) The higher the core height, the lower the thermal conductivity, and the better the thermal insulation performance of the composite panel. In the same case of the skin, the honeycomb core adopts a splint of different thickness or height, and the heat transfer coefficient is different. The higher the height of the core, the larger the gas volume in the cavity leads to the decrease in the density of the composite plate, and the greater the thermal conductivity. This is because, depending on the sample sample used, since the hexagonal structure of the honeycomb core is open, the internal air is in direct contact with the honeycomb wall and the upper and lower panels. The higher the space is, the larger the space is, and the larger the air is. Large, the density is reduced, and the thermal conductivity increases due to the increased air flow space.

2) The larger the wall thickness of the core, the better the thermal conductivity. The honeycomb core material is aluminum foil, and its thermal conductivity is nearly 70 times that of still air, so the larger the wall thickness, the higher the thermal conductivity. However, an increase in thickness increases the overall bending stiffness and buckling load, so proper wall thickness is required.

3) Under the same conditions, as the aperture size, ie the size of the core, increases, the proportion of air volume in the volume of the honeycomb increases. The thermal conductivity of the air is lower than the thermal conductivity of the honeycomb wall, resulting in a decrease in the total thermal conductivity, but the tendency to decrease is getting smaller and smaller. As the core size increases to a certain extent, it will cause air convection in the core, thereby increasing the thermal conductivity.
3. Analysis of Stone Aluminum Honeycomb Composite Board Ansys Software

3.1. Description of the problem
The single-layer stone aluminum honeycomb panel is composed of five parts, the first part is a marble board with a thickness of 5 mm, and the second part is an adhesive layer with a thickness of 1 mm (the adhesive condition exists at the joint of each part, here to simplify the calculation, All statistics are in this layer), the third part is an aluminum panel with a thickness of 1 mm, the fourth part is a honeycomb core with a core height of 10 mm, and the fifth part is a 1 mm thick aluminum panel. The thermal conductivity of the aluminum panel is 209 w/m·K, the thermal conductivity of the marble slab is 2.8 w/m·K, the thermal conductivity of the adhesive layer is 0.22 w/m·K, and the thermal conductivity of the honeycomb core layer is 2.0 w/m·K, the thermal conductivity of the aluminum honeycomb is about 1.59 w/m·K, and the thermal conductivity of the stone aluminum honeycomb is about 0.104 w/m·K. The geometric model is shown in Figure F1, and the simplified computational geometry model is shown in Figure F2. Heating condition: the upper part of the first part is subjected to steady-state heat treatment at 35 °C, and the lower surface of the fifth part is subjected to steady-state heat treatment at minus 20 °C.

3.2. Finite element analysis of single-layer stone aluminum honeycomb composite board

3.2.1. Finite element model of single-layer stone aluminum honeycomb composite board. In the APDL (ANSYS Parametric Design Language) software, a solid heat transfer solid model of stone aluminum honeycomb composite panels was created. Referring to Fig. 3, the red unit indicates a marble panel, the blue unit indicates an adhesive layer, the green unit indicates a honeycomb core layer, and the pink unit indicates an aluminum panel.
Figure 3. Honeycomb unit model of single-layer stone aluminum honeycomb composite board

The model in Figure A consists mainly of six units, the first unit is a marble panel, the second unit is an adhesive layer, the third unit is an aluminum panel, and the fourth unit is a partial whole consisting of a honeycomb core and air in the chamber. The fifth unit is an aluminum panel. The parameters are as described above.

The simulation and simulation calculation is divided into two steps. The first step is to analyze the heat transfer of the air in the honeycomb cavity in the ANSYS AIM simulation software to study the heat conduction effect of the air in the honeycomb composite panel cavity. The second step: based on the calculation of air heat transfer, the temperature of the upper surface of the first unit is set to be equal to 35 °C, the radiation heat transfer condition is set on the lower surface of the second unit, and the lower surface of the fifth unit is set to minus 20 Degree convection boundary, (the model has the condition that the heat flow rate value is zero except for the upper and lower surfaces, and the side of the simulation model is adiabatic condition to prevent heat dissipation and lead to deviation of experimental results.) Steady heat transfer of stone aluminum honeycomb composite board Anatomy.

The temperature field distribution of the finite element element of the single-layer stone aluminum honeycomb composite panel has no obvious phenomenon of thermal convection of air. Therefore, we can ignore the influence of air heat convection on the temperature of the honeycomb composite panel. A heat transfer mechanism is established in the stone aluminum honeycomb composite panel to control the heat conduction in the honeycomb cavity, the heat conduction of the honeycomb body and the radiation heat transfer in the honeycomb core cavity.

3.2.2. Calculation and analysis of single-layer stone aluminum honeycomb composite panels with different honeycomb core heights. A finite element model of composite plates with different honeycomb core thicknesses was established. When the honeycomb core heights were 5 mm, 10 mm, and 15 mm, the other conditions were the same. The temperature cloud diagram of the three kinds of honeycomb core gradient height stone aluminum honeycomb composite panels is shown in the figure.

Figure 4. Temperature cloud diagram of honeycomb core height of 5mm, unit: °C
Figure 5. Temperature cloud diagram of honeycomb core height of 10mm, unit: °C

Figure 6. Temperature cloud diagram of honeycomb core height of 15mm, unit: °C

Analysis of the results: Comparing the three temperature clouds, it can be seen that as the honeycomb core is increased, the heat is transferred from the upper surface of the first unit to the lower surface of the fifth unit. Therefore, we can draw a simple conclusion: appropriately increasing the height of the honeycomb core layer can reduce the thermal conductivity of the stone aluminum honeycomb panel, because as the height of the honeycomb core increases, the volume of air in the honeycomb core cavity increases, and the air also affects the composite panel transmission. Comparing the latter two temperature clouds can also be found that increasing the height of the honeycomb core cannot effectively reduce the thermal conductivity, so the honeycomb core height cannot be blindly increased in order to improve the thermal insulation performance, and the compression resistance of the honeycomb panel may be lowered. At the same time, we can consider increasing the thickness of the panel to reduce the heat transfer coefficient of the composite panel, but increasing the height of the honeycomb core from an economical angle is a good choice to reduce the thermal conductivity of the composite panel.

3.2.3. Calculation and analysis of single-layer stone aluminum honeycomb composite panel with different honeycomb core wall thickness. A finite element model of composite plates with different honeycomb core thicknesses was established. The core thicknesses were 0.1 mm, 0.2 mm, and 0.3 mm, and the other conditions were the same. The temperature field distribution of the three kinds of honeycomb core thickness of the stone aluminum honeycomb composite panel is shown in the figure.
Figure 7. Temperature cloud diagram of the core of the stone aluminum honeycomb panel composite board with a thickness of 0.1mm, unit: °C

Figure 8. Temperature image of the stone aluminum honeycomb panel composite panel with a thickness of 0.2mm

Figure 9. Temperature cloud diagram of stone aluminum honeycomb panel composite board with a thickness of 0.3mm, unit: °C

Analysis of the results: Obviously, as the thickness of the core of the honeycomb core increases, the heat is transferred from the upper surface of the first unit to the lower surface of the fifth unit. The main factor leading to this cause is that the aluminum foil has a higher thermal conductivity than the air heat transfer coefficient. During the heat transfer of the honeycomb body, the third unit has more heat passing through the honeycomb wall than the gas passing through the chamber. Therefore, it is not preferable to reduce the heat transfer coefficient of the stone aluminum honeycomb composite panel by increasing
the wall thickness of the honeycomb core. At the same time, it is also a general choice to improve the thermal insulation performance by reducing the thickness of the honeycomb core. The thin wall thickness of the honeycomb has too much influence on the compressive performance of the stone aluminum honeycomb composite panel.

3.2.4. Calculation and results analysis of single-layer stone aluminum honeycomb composite panels with different honeycomb core sizes. For the side length of the regular hexagonal honeycomb core of the stone aluminum honeycomb composite panel, three finite element models of composite panels with different honeycomb core lengths were established, and the side lengths were 4 mm, 5 mm, and 6 mm, respectively, and the other conditions were the same. The temperature field distribution of the three-honeycomb core-sized stone aluminum honeycomb composite panels is shown in the figure.

![Figure 10. Stone aluminum honeycomb panel composite panel honeycomb core length of 6mm temperature cloud, unit: °C](image)

![Figure 11. Temperature cloud diagram of stone aluminum honeycomb panel composite board with side length of 5mm, unit: °C](image)
Figure 12. Temperature cloud diagram of stone aluminum honeycomb panel composite board with side length of 4mm, unit: °C

Analysis of results: Comparing the three temperature cloud images, as the size of the honeycomb core decreases, the heat is transferred from the upper surface of the first unit to the lower surface of the fifth unit, but it is only suitable for representing the finite unit, and the infinite unit cannot be used. However, it can be confirmed that the volume of air in the cavity is increased, which has an effect on reducing the thermal conductivity of the honeycomb panel and improving the thermal insulation performance of the honeycomb composite panel.

3.3. Comparative analysis of heat transfer between single-layer and multi-layer stone aluminum honeycomb composite panels

In the APDL, a three-dimensional model of coupled heat transfer of three models of stone aluminum honeycomb composite panels was established, as shown in the figure.

The total height of the model is 18mm, the height of the honeycomb core in the model A cavity is 10mm, the model B has two honeycomb cores, the middle unit is aluminum panel, the thickness is 1mm, and the honeycomb core height is 4.5mm. Model C has three honeycomb cores. The middle two units are aluminum panels with a thickness of 1 mm and a honeycomb core height of 2.66 mm. The other parameters are the same.

The temperature cloud diagram of the single, double and triple layer stone aluminum honeycomb composite panels of the honeycomb core is shown in the figure.

Figure 13. Temperature cloud diagram of single-layer stone aluminum honeycomb composite panel, unit: °C
Figure 14. Temperature cloud diagram of double-layer stone aluminum honeycomb composite panel, unit: °C

Figure 15. Temperature cloud diagram of three-layer stone aluminum honeycomb composite panel, unit: °C

Analysis of the results: As the number of honeycomb core layers increases, the amount of heat transferred from the first unit to the lowermost unit gradually decreases, and the addition of aluminum panels in the honeycomb core accounts for most of the factors. But in reality, most of it is uneconomical. The cost of the first aluminum panel is relatively high, and the cost of the process is also increasing, but we can take this option in some special cases, or we can take other cheap panels in the honeycomb core to replace the aluminum panel. At the same time, it can be concluded that properly setting the number of layers in the honeycomb core can reduce the thermal conductivity of the stone aluminum honeycomb composite panel, thereby enhancing the thermal insulation performance of the stone aluminum honeycomb panel, and optimizing the thermal insulation performance and economy.

4. Future Work and Conclusions
1) Appropriate increase of the number of layers in the honeycomb core can reduce the thermal conductivity. The insulation coefficients of the two layers and the three layers are not much different. For the economic period, the number of layers is generally not more than two. In addition, the intermediate core layer can be set to other boards with better thermal insulation properties or cheaper boards, such as foam boards, in order to improve the thermal insulation performance and economic optimization of the stone aluminum honeycomb panels.

2) Properly increasing the height of the honeycomb core layer can reduce the thermal conductivity, but it cannot be blindly increased. Experiments have shown that increasing the height of the honeycomb
core layer increases the thermal conductivity, because the height of the honeycomb core increases. The phenomenon of hot convection in the air in the honeycomb chamber is more obvious.

3) Properly increasing the size of the honeycomb core can reduce the thermal conductivity. As the size of the honeycomb core increases, the volume of air in the honeycomb cavity increase. The same cannot be increased too much, one may affect the physical properties of the honeycomb composite panel, and the second may increase the thermal convection of the air in the cavity, which is disadvantageous for the honeycomb composite panel.

4) In general, appropriately increasing the height of the honeycomb core layer, increasing the core size, increasing the core height and the number of core layers can appropriately reduce the thermal conductivity and improve the thermal insulation performance of the stone aluminum honeycomb panel.

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