Influence of Thermal Alternation on the Interface between Insulation Layer and Bonding Mortar

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Abstract. The safety of the external thermal insulation system has been widely concerned by people. In this paper, strain gauges and temperature sensor are preset at the interface of bonding layer/insulation layer, bonding layer/mortar layer. The interface stress variation rules of graphite polystyrene board, polystyrene board and homogeneous board were studied under 30 times of thermal alternating environment and the test results were analyzed in combination with physical properties of the materials. The results show that the strain at the interface of the samples composed of three kinds of thermal insulation materials increases with the increase of the number of thermal alternating cycles. The total interfacial strain of the sample composed of homogeneous board is the largest, and that of graphite polystyrene board is the smallest.

1. Introduction

The external thermal insulation system is widely used in building energy-saving projects, and the stability of the system has attracted much attention during use. The external insulation system is subjected to rain and snow erosion, solar radiation and other factors, which may cause hollowing, fall off, crack and other phenomena. The shedding of the insulation board directly affects the thermal insulation performance of the external thermal insulation system, and sometimes causes personal injury and property damaged. The safety of the external thermal insulation system has attracted wide attention, and the reasons that cause the insulation layer to fall off are complex. Factors such as large thermal stress between the substrate and interface performance degradation may cause the insulation layer to crack or fall off. In China, the hot summer and cold winter zone, it is hot in summer and cold in winter, so it is of practical significance to study the stability and durability of external thermal insulation system in thermal alternating environment.

At present, the experimental study on the influence of thermal alternating environment on the external thermal insulation system is mainly reflected in the performance change of the monomer material under the freeze-thaw cycle and the bonding strength between insulation layer and structural layer. Sicat et al. studied the effect of freeze-thaw cycle on the elastic modulus of thermal insulation materials[1]. Li et al. studied the changes of water absorption and thermal conductivity of polyurethane and phenolic foam boards under freeze-thaw cycles, and found that the water absorption and thermal conductivity of the two thermal insulation boards increased linearly with the increase of freeze-thaw times[2]. Shi et al. studied the bonding properties of polymer cement mortar for external thermal insulation systems under freeze-thaw environment[3]. Yin studied the effects of freezing and
2. Materials and Methods

2.1. Sample preparation
The insulation board is selected from graphite polystyrene board (GEPS), polystyrene board (EPS) and homogeneous board. Graphite polystyrene board and polystyrene board are organic thermal insulation materials. Graphite polystyrene board is a foamed plastic board modified by adding graphite and other additives to polystyrene. Polystyrene board is made of polystyrene, which is extruded to produce continuous closed-pore foam plastic board. Homogeneous board belongs to composite thermal insulation material, which uniformly distributes expanded polystyrene foam particles and pores in inorganic cementitious materials. The three kinds of thermal insulation materials are all provided by a manufacturer in Hefei, and their performance parameters are shown in Table 1. The graphite polystyrene board, polystyrene board and homogeneous board were processed into board surface size of 70mm×70mm.

The bonding surface of the 70mm×70mm×20mm mortar test block was polished smoothly, and the bonding surface was wiped with alcohol to ensure that there was no stain. A strain gauge and a temperature sensor were placed in the middle of the bonding surface of the mortar test block, and then connected with wires, and the joints were wrapped with insulating tape to ensure the complete contact of copper wires. When wiring the final connection, mark it with label paper to correspond to the data of the channel port and the corresponding measuring point. According to the above operation, the strain gauges and temperature sensors on the insulation board and mortar interface were arranged.
Polymer powder, Ordinary Portland cement, medium sand and water were mixed and stirred according to 1:40:60:24 to obtain bonded mortar.

Put the 4mm high wooden frame on the cement mortar test block, mix the prepared binding mortar evenly and put it into the wooden frame and wipe it flat. Then put the insulation board on the bonding mortar and press it lightly in the vertical direction to make the mortar test block bond fully with the insulation layer, and take out the wooden frame.

Before the cycle test, the samples were placed in an environment of 25°C±2°C and 50% relative humidity for 48h. The strain gauge and temperature sensor were arranged as shown in Figure 1.

### Table 1. Materials performance parameter

| Materials            | Specific heat [J/kg·K] | Density [kg/m³] | Conductivity [W/(m·K)] | Thermal expansivity [°C⁻¹] | Elastic modulus [MPa] |
|----------------------|------------------------|-----------------|-------------------------|---------------------------|----------------------|
| Homogeneous board    | 1.52                   | 180             | 0.065                   | 8.0×10⁻⁵                  | 10.3                 |
| Graphite polystyrene board | 1.47                   | 20              | 0.032                   | 2.0×10⁻⁵                  | 10.2                 |
| Polystyrene board    | 1.38                   | 20              | 0.038                   | 6.0×10⁻⁵                  | 11.3                 |
| Bonding mortar       | 1050                   | 1600            | 0.93                    | 1.2×10⁻⁵                  | 4900                 |

![Figure 1. Schematic diagram of strain gauge and temperature sensor arrangement](image)

#### 2.2. Method

In this experiment, three kinds of samples were subjected to thermal alternating cycle, and the strain at the interface was measured by AFT-CM-10 static strain instrument. The static strain instrument was placed in an environment of 25°C and 60% humidity, and the strain value at the interface was recorded with an accuracy of 1με.

AT4708 multichannel temperature tester was used to measure the temperature change at the interface. The temperature sensing wire was connected to the instrument, and the temperature sensor was fixed at the interface. The temperature measuring instrument was placed in an environment of 25°C and 60% humidity, and the temperature value at the interface was recorded with an accuracy of 0.1°C.

After the experiment started, the static strain instrument and temperature tester were set up to collect data automatically every 5min. This set of test uses RS-485 interface router as data converter, connecting computer and static strain gauge respectively. The lead wire of the strain gauge was directly connected to the static strain instrument to measure the strain at the interface.

#### 2.3. Thermal alternating test

In this test, the samples were placed in the frozen stored at -13°C±1°C for 16h, and then put in a constant temperature constant wet box at 23°C and 60% relative humidity for 8h. This is one cycle test, and the number of cycles is 30. The typical test temperature loading curve is shown in Figure 2.
3. Results and Discussion

3.1. Strain analysis of the interface between homogeneous board and bonding mortar

It can be seen from Figure 3 that, the cooling period is from 1 min to 150 min. At the beginning of the experiment, the strain of strain gauge increases with the increase of time, and the strain decreases with the increase of time after reaching the maximum value. From the overall trend, the strain of strain gauge fluctuates. At first, the temperature of the outer surface of the homogeneous board decreases quickly, and the temperature of the inside of the homogeneous board decreases slowly. Due to the temperature difference between the inside and the outside, the homogeneous board has a tendency to deform and the interface strain gauge has strain. As time increases, the internal temperature and external temperature gradually approach -13°C. At low temperature, the material at the interface has a tendency to shrink and deform, while, the materials on both sides of the interface are different and their deformations are different, and the strain gauges appear strain. Since the large elastic modulus and small deformation of the bonding mortar, the strain of the strain gauge is mainly affected by the internal and external temperature difference. The temperature difference between the inside and outside of the sample increases from 1 min to 25 min, and the temperature difference between inside and outside decreases from 25 min to 40 min, so the strain on the strain gauge increases at the started of the test, and then decreases.

In the low temperature and constant temperature period from 150 min to 960 min, the strain of the strain gauge is in a fluctuating state, and the strain fluctuation amplitude is 50 με. Since the frozen stored works intermittently, the refrigeration will be suspended when the frozen stored temperature reaches -14°C, and the refrigeration will be started when the frozen stored temperature is lower than -12°C. Therefore, the temperature difference fluctuates between the outer surface of the homogeneous board and the interface. The strain fluctuation is mainly due to the hysteresis of the surface and internal temperature of the homogeneous board. In this period, the temperature difference between the inside and outside is small, resulting in small strain and small fluctuation range.

In the heating period from 960 min to 1200 min, the strain of the strain gauge gradually increases to the maximum value and then decreases. When heating up, the external temperature of the sample increases rapidly, but the internal temperature changes slowly, causing the internal temperature gradient to change. According to the thermal stress theory, the strain is proportional to the temperature difference and thermal expansion coefficient[15]. At this time, the temperature difference between inside and outside of interface gradually increases, and the homogeneous board and bonding mortar expand, so the strain of the strain gauge shows an upward trend. The temperature difference between the inside and outside is the largest at 1000 min, and the strain of the strain gauge reaches the maximum. Subsequently, as the internal temperature increases, the temperature difference between the inside and the outside gradually decreases, and the thermal expansion of homogeneous board and bonding mortar becomes smaller, which leads to the decrease of strain.
In the constant temperature period from 1200min to 1440min, the strain of the strain gauge is in a fluctuating state, and the strain fluctuation amplitude is 30με. At this period, the temperature difference between inside and outside is steadily, and the expansion of the homogeneous board and the bonding mortar is stable, so the strain of the strain gauge is also stable.

3.2. Strain analysis of the interface between graphite polystyrene board and bonding mortar

It can be seen from Figure 4 that, the cooling period is from 1min to 150min. At the beginning of the experiment, the strain of strain gauge increases with the increase of time, and the strain decreases with the increase of time after reaching the maximum value. From the overall trend, the strain of strain gauge fluctuates. The main reason is that there is a temperature difference between the outer surface and the inside of the graphite polystyrene board at the beginning of the test, the graphite polystyrene board has a tendency to deform and the interface has strain.

In the low temperature and constant temperature period from 150min to 960min, the strain of strain gauge decreases with the increase of time, and the strain in a fluctuating state after reaching the minimum value. The interface is directly affected by temperature, and the deformation is larger by cold shrinkage, so the strain value of strain gauge will continue to decrease. When the deformation reaches the maximum, the temperature difference between the inside and outside of the interface is very small, so the strain of the strain gauge fluctuates steadily.

In the heating period from 960min to 1200min, the strain of the strain gauge gradually increases to the highest value, and then decreases. As the temperature rises, the interface temperature difference gradually increases, the graphite polystyrene board and the bonding mortar expand, and the strain of the strain gauge increases. Subsequently, as the internal temperature increases, the temperature difference between the inside and the outside gradually decreases, and the thermal expansion becomes smaller, resulting in a decrease in strain.

In the constant temperature period from 1200min to 1440min, the strain of the strain gauge is in a fluctuating state, and the strain fluctuation amplitude is 24με. At this period, the temperature difference between inside and outside is steadily, and the expansion of the graphite polystyrene board and the bonding mortar is stable, so the strain of the strain gauge is also stable.
3.3. Strain analysis of the interface between polystyrene board and bonding mortar

It can be seen from Figure 5 that, the cooling period is from 1 min to 150 min, and the strain of the strain gauge is in a fluctuating state, and the strain fluctuation amplitude is $21 \mu \varepsilon$. The main reason is that there is a temperature difference between the outer surface and the interior of the polystyrene board, the polystyrene board has the tendency of deformation, and the interface has strain. Compared with the other two kinds of thermal insulation materials, the elastic modulus of polystyrene board is larger and the deformation is relatively small, so the strain curve of strain gauge is stable.

In the low temperature and constant temperature period from 150 min to 960 min, the strain of strain gauge increases with the increase of time, and the strain in a fluctuating state after reaching the maximum value. With the decrease of temperature, the thermal expansion coefficient of polystyrene board is different from that of bonding mortar, the cold shrinkage deformation increases and the strain of strain gauge increases. Subsequently, as the internal temperature increases, the temperature difference between the inside and the outside gradually decreases, and the thermal expansion becomes smaller, resulting in a decrease in strain.

In the heating period from 960 min to 1200 min, the strain of the strain gauge gradually increases to the highest value, and then decreases. As the temperature rises, the interface temperature difference gradually increases, the polystyrene board and the bonding mortar expand, and the strain of the strain gauge increases. Subsequently, as the internal temperature increases, the temperature difference between the inside and the outside gradually decreases, and the thermal expansion becomes smaller, resulting in a decrease in strain.

In the constant temperature period from 1200 min to 1440 min, the strain of the strain gauge is in a fluctuating state, and the strain fluctuation amplitude is $20 \mu \varepsilon$. At this period, the temperature difference between inside and outside is steadily, and the expansion of the polystyrene board and the bonding mortar is stable, so the strain of the strain gauge is also stable.

![Figure 5. Interface strain-time-temperature difference curve of polystyrene board sample](image)

3.4. Influence of cycle times on the interface strain between the insulation board and the bonding mortar

With the increase of the number of thermal alternating cycles, the strain gauge at the interface between the insulation board and the bonding mortar becomes larger and larger. During a single cycle, the thermal expansion coefficient of the insulation board and the bonding mortar are different, so the shrinkage and expansion of the insulation board and the bonding mortar are different. Under continuous cyclic fluctuations, the interface changes with temperature, and the strain of the strain gauge continues to accumulate and release, and the strain that has not been fully released at the end of a cycle will be carried to the next cycle, and the amount of deformation is gradually accumulated so that the strain of the strain gauge will rise by cycle. As the number of cycles increases, the interface between the insulation board and the bonding mortar deteriorates to a certain extent due to fatigue, resulting in a decrease in the strain value of the strain gauge.

The interface strain between homogeneous board and bonding mortar is the largest. The main reason is that the homogeneous board has high specific heat capacity, strong heat storage capacity,
large inertia and greater deformation, so the strain gauge at the interface of the homogeneous board and the bonding mortar has the largest strain. It can also be understood that the coefficient of thermal expansion of the homogeneous board is higher than that of the other two insulation boards, and the deformation is larger after heating, which leads to the large strain of the strain gauge on the interface.

4. Conclusions
Based on the test results, the following conclusions can be drawn:

(1) As the number of thermal alternating cycles increases, the amount of strain at the interface of the sample composed of selected insulation material increases.

(2) After 30 thermal alternating cycle tests, it is found that the total interface strain of the sample composed of homogeneous board is the largest and that of graphite polystyrene board is the smallest.

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