Weatherability Temperature Field and Temperature Stress Simulation of Inorganic Mortar Compound Panel with Insulation and Decoration Based on Actual Engineering Model

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Abstract. Finite element simulation software can explore the heat transfer and deformation of complex shapes and can be used as an auxiliary tool for large weathering tests. Based on the results by ANSYS software, this paper explored temperature field and temperature stress field of inorganic mortar compound panel with insulation and decoration (IMCP), considering weather resistance experiment based on practical engineering. The paper holds that the relevant regulations should provide the mortar adhesion area reinforcement of IMCP may be not less than 80%. Moreover, in order to adapt to the temperature deformation, the width of the joint of IMCP should also be specified and recommended not be less than 5 mm.

1. Introduction
The Inorganic Mortar Compound Panel with Insulation and Decoration (IMCP) is platy product, which is prefabricated in the factory and recombined by inorganic mortar insulation material, decorative panels, adhesives and connecting parts, with the functions of insulation and decoration and excellent fireproof performance. As progressive measure of industrial assembly technology, insulation decorative panels meet the technological trends. The weathering test of building materials is an encryption combination of artificial simulation of high temperature rainfall and thermal-cold cycle. Practice has proved that large-scale weathering test is closely related to wall material safety and durability. Weatherability is one of the issues to be studied in IMCP, but large-scale weathering test requires more stringent test conditions and longer time. The finite element numerical simulation, intuitive and convenient, can get a temperature filed close to any shape, any time and consider the influence of complex shape on temperature distribution. ANSYS, the general-purpose finite element numerical simulation software, enables data sharing and exchange with most computer-aided design software, and be widely used in railway, petrochemical engineering, machinery manufacturing and other fields. According to the pilot project model, this payer has simulated the local heat transfer of IMCP, analysed the temperature field and temperature stress under the weathering test conditions through ANSYS model building.

2. Simulation analysis of local heat transfer
IMCP is composed of the panel, the fixing member and adhesive mortar. By analysis of fixing members at the composite panel wall surface and intersection portions of convex windows, and effect of air layer on heat transfer, this simulation provides a basis for simplification of wall models under the weathering conditions, increases the computational feasibility, shortens the calculation time. The calculation model consists of external ambient temperature, composite panels, fixing members, adhesive mortar, plastering mortar, building walls and indoor ambient temperature elements. The model mesh is divided into five layers from the outside to the inside, which are respectively the insulation decorative composite panel, the fixing members, the air, the adhesive mortar layer, the wall and the fixing members located between composite panel and wall. The software simulates the heat exchange of IMCP with thickness 40 mm and 60 mm in winter and summer. The outdoor temperature is 30.8 °C in summer, -2.0 °C in winter, and the indoor temperature is 26 °C in summer and 18 °C in winter. Physical properties are assigned via software. As shown from the wall temperature distribution Figure 1 obtained from simulation, the metal fastenings are weak parts of insulation, the temperature of the part of contact with the wall is lower than that of other parts, but the material insulation performance is not significantly affected; although the air layer in the mortar interval is beneficial to the insulation, the heat insulation performance is not increased significantly because of the thin thickness. According to Figure 2, the heat transfer direction of the wall in summer is opposite, but the temperature curve is similar to that in winter. The metal fastening does not significantly affect the thermal insulation performance of the material, and the air layer in the adhesive paste is also insignificant for improving the thermal insulation performance. The temperature profile of 60 mm IMCP is similar to 40 mm. The metal fastening has no significant effect on the heat transfer of the wall, and the effect of the air layer is also limited.

3. Numerical simulation under weathering conditions
The Industry Standard of the PRC Code, Materials of External Thermal Insulation Systems Based on Insulation Decorative Panel (JG/T 287 — 2013), has stated clearly the test samples and test steps of large weathering test. The samples are made of concrete walls and tested external insulation system, with about 0.5 m² concrete wall used as the base layer and 0.24 m² window opening on the wall. The test steps include thermal rain cycle, thermal-cold cycle, freeze-thaw cycle and tensile bond strength test. After analysis of the external insulation system weathering test and ANSYS simulation, Chinese scholar concluded that the results of weathering simulation and test results have good correlation [1]. In this paper, part of standard floors of high residence was selected, and ANSYS is used to simulate the heat rain cycle, thermal-cold cycle, freeze-thaw cycle on temperature field and temperature stress. Figure 1 and Figure 2 show that the temperature of the wall substantially changes along the thickness direction of the system itself, and therefore the simulation assumes that the materials in each layer is uniform, continuous and isotropic, the material layer is connected tightly, inter-layer thermal resistance is ignored, the insulating layer joint is not considered and thought to be continuous and the anchor bolt thermal bridge is not considered. Performance parameters and thickness of the materials of each layer are mentioned in Table 1. The software analysis process involves building finite element model, applying loads, solving and post processing. Firstly, preliminary analysis of the local models of the pilot building including the outer wall are carried out (Figure 3, Figure 4). The sizes of one outer wall and window holes follow the requirements of large weathering test samples. Figure 4 shows the balcony is used as an outer wall member, and its temperature field and temperature stress change are similar to those of bay windows. To simplify the computational effort, the balcony is cancelled, the bay window is retained and the cell density is manually controlled.

| Material parameters       | Density / [kg/m³] | Thermal conductivity / [W/(m·K)] | Specific heat capacity [ J/(kg·K)] | Modulus of elasticity / [Pa] | Poisson's ratio | Thermal expansion coefficient / [°C] | Thickness / [mm] |
|---------------------------|-------------------|----------------------------------|------------------------------------|-----------------------------|----------------|-------------------------------------|-----------------|
| RC                        | 2300              | 1.74                             | 920                                | 20.0×10⁹                    | 0.20           | 1.0×10⁻⁵                            | 200             |
| Mortar coat               | 1600              | 0.93                             | 1050                               | 4.9×10⁹                     | 0.28           | 1.2×10⁻⁵                            | 20              |
| Bonding mortar IMCP       | 1800              | 0.93                             | 1050                               | 4.9×10⁹                     | 0.28           | 1.2×10⁻⁵                            | 5               |
| IMCP                      | 160               | 0.05                             | 1550                               | 17×10⁹                      | 0.18           | 1.4×10⁻⁵                            | 40              |

The boundary conditions in contact with the exterior wall of the wall are simplified according to the steps of the weathering test. The IMCP is positioned in the test chamber, and the convective heat transfer coefficient in the chamber environment is taken as 8.7 W/(m²·K) (at watering cycle stage, 3000 W/(m²·K) is taken); the convective heat transfer coefficient of the interior facing of the wall is the same as that of the exterior facing of the IMCP [2]. Due to the high internal sealing of the test chamber, there is only the change in ambient temperature, and the effect of radiative heat transfer on heat transfer is ignored.

For the purpose of the temperature field calculation of the wall, the internal temperature of the wall is first determined at t = 0. Different initial conditions have greater influence on calculation results for the first few cycles, and the influence will become increasingly smaller after several cycles. The temperature field and temperature variation regularity of each structural layer of the wall can be obtained through cycles, the amount of data and the amount of calculation is large, so initial conditions of weathering test in “Materials of External Thermal Insulation Systems Based on Insulation Decorative Panel (JG/T 287 — 2013)” are simplified: 1) Within 4-6h of thermal rain cycle, the temperature inside and outside the wall is the same, and after 2 h, wall temperature at each point is basically near 25 °C. Assume that the temperature in the wall is equal at the initial time of each cycle, and after the initial node temperature is set to 25 °C, I thermal rain cycle is simulated. 2) From
the 10 h to 24h of the thermal-cold cycle, the wall temperature is always maintained at –15 °C, and the indoor temperature is always maintained at 25 °C; assume that steady state heat transfer is reached after 14h, the temperature at each node in the wall at the initial time of each cycle is obtained, and one thermal-cold cycle simulation is conducted. 3) The freeze-thaw cycle follows the same rules as the thermal rain cycle and the thermal-cold cycle. The temperature at each node in the wall is obtained by steady-state analysis at the initial time of each cycle, and a cycle simulation is performed [3].

Figure 5. Inner surface temperature field of 40 mm IMCP.
The wall temperature field of thermal rain cycle, thermal-cold cycle and freeze-thaw cycle of 30 mm, 40 mm and 50 mm thick IMCP is obtained through simulation. Due to the large number of load steps, the internal surface temperature field of the insulating layer at the thermal rain cycle time point 10800 s, thermal-cold cycle time point 86400 s, and freeze-thaw cycle time point 25200 s is selected, and the different colours correspond to the respective temperature bands. Figure 5 is the internal surface temperature field of 40 mm thick IMCP. According to the temperature field simulation diagram, the following conclusions can be drawn: 1) When the thickness of the insulating layer is the same, the temperatures at nodes of the inner surface of the insulating layer away from the window are almost the same; the window part is affected by the hole, and the window edge isotherm gradually decreases from the outside to the inside. 2) As the thickness of the insulating layer increases, the heat-insulation capacity of the wall gradually increases, and the amount of increase gradually decreases. Take the thermal rain cycle as an example, when the thickness of the insulating layer is 30 mm, 40 mm, and 50 mm respectively, the temperature of the inner surface of the insulating layer away from the window is 24.5701 °C, 23.8592 °C and 23.5589 °C respectively, and the heat insulation effect is obvious. 3) The thickness variation of the insulating layer has little effect on the diffraction range of the hole temperature. Through the time history post-processing of the simulation results, the thermal insulation effect of the entire circulation process of the insulating layer can be visually displayed. In this paper, five nodes are selected from 40 mm thick complex panel, i.e. the node 1 on the outer surface of the insulating layer, node 2 on the inner surface of the insulating layer, node 3 on the outer surface of the levelling layer, node 4 on the inner surface of the levelling layer, and node 5 on the concrete surface (Figure 6). According to the temperature curve, the following conclusions are drawn: 1) the nodes at the window are susceptible to the ambient temperature. The thermal insulation effect of the adhesive mortar is very limited, and the temperature change curve is very close to the temperature change of the wall structure; 2) because the convection coefficient is small and the heating time is too short, the node temperature of the outer decorative surface and outer surface of the insulating layer cannot reach the ambient temperature quickly, and at the heating section (or cooling section) and the constant temperature section, the temperature curve is always in the rising (or falling)
stage; 3) the thickness variation of the insulating layer has little effect on the temperature diffraction range caused by the hole. As the thickness of the insulating layer increases, the temperature difference between the inner and outer surfaces of the insulating layer and the inner and outer surfaces of the entire external insulation system gradually increases; 4) the insulation effect of the external insulation system is more obvious. The node temperature of concrete inner surface fluctuates, about 8 °C for thermal rain cycle and thermal-cold cycle, and about 10 °C for freeze-thaw cycle.

4. **Numerical simulation of wall temperature stress under weathering conditions**

Bonding mortar plays an important role in the connection of IMCP and wall. The difference in thermal expansion coefficients causes a large temperature stress in the adhesive mortar when the temperature changes. When the temperature stress is larger than the adhesive force, the safety and reliability of the system will be affected adversely. Through the ANSYS numerical simulation of the IMCP system of different thickness and different position, the temperature stress distribution regularities of adhesive mortar under the weathering conditions can be analysed. In this paper, the indirect method in ANSYS 10.0 thermal stress is used to conduct simulation solution of the thermal stress of the external thermal insulation system. The steps include establishing a finite element model, applying a temperature load, adding material performance parameters, applying loads and solving and post processing. The thermal stress and displacement under different insulation thicknesses are mainly post-processed.

When temperature load is applied, the boundary conditions and initial conditions in contact with the facing are the same as the simulation of temperature field. The greater the temperature difference between the inside and outside of the wall, the greater the temperature stress. The simulation analysis uses the stress and displacement under the maximum temperature difference during the cycle. The thermal rain cycle temperature is 70 °C, time point is 3750 s, thermal-cold cycle is 50 °C, time point is 1200 s, freeze-thaw cycle is -20 °C and time point is 1650 s. The original temperature of the wall temperature field is taken as 25°C. Figure 6 shows the temperature field of the internal surface of thermal rain cycle insulating layer of 40mm IMCP. Through the thermal coupling
simulation under the weathering test conditions, the stress distribution and displacement distribution of the insulating layer and the adhesive mortar show the following characteristics: 1) Stress distribution regularity and displacement distribution regularity of IMCPs and adhesive mortar under the thermal rain cycle, thermal-cold cycle and freeze-thaw cycle are basically the same. 2) When the thickness of the insulating layer is the same, the temperature stress on the inner and outer surfaces of the adhesive mortar is similar to that on the window portion (excluding the boundary); the window portion is sharply enlarged, the window corner reaches the maximum, and becomes smaller outward. As the thickness of the insulating layer increases, the temperature stress experienced by the adhesive mortar layer decreases. 3) When the thickness of the insulating layer is the same, the displacement at the window and the corner is significantly increased, but the displacement at the portion away from the window and the corner is small. The thermal conductivity of the window portion changes greatly, the temperature changes drastically, and the displacement increases significantly. The corner portion undergoes a larger displacement due to geometric discontinuities and weak constraint. As the thickness of the insulating layer increases, the range of influence of the window on temperature stress and deformation becomes larger. Major factors influencing the temperature stress simulation are complicated and related to the factors such as elastic modulus, Poisson's ratio and thermal expansion coefficient of the material, and correlative factor coupling relationship has to be further explored.

5. Conclusion
Finite element simulation software can easily explore the heat transfer and deformation of complex shapes, can be used as an auxiliary tool for large weathering tests. On the basis of the results of ANSYS software analysis, external corners of walls, door and window openings and surroundings are the wall temperature stress concentration zones. To reduce the effect of temperature stress, it is recommended that the relevant regulations should provide that the mortar adhesion area reinforcement of IMCP may be not less than 80%. Moreover, in order to adapt to the temperature deformation, the width of the joint of IMCP should also be specified, and recommended not be less than 5 mm.

6. References
[1] Bo H. 2009 Study on durability and evaluation of external insulation system for building exterior wall (Wuhan: Huazhong University of Science and Technology)
[2] Huang Z and Tu F 2011 Technological theory and application of external insulation (Beijing: China Building Industry Press)
[3] Liu D. 2014 M 2014 Housing Science 9 26–28

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