論文内容の要旨

論文題目　Thermal fatigue life experiment and analysis of an interface betwee concrete and adhesive mortar in an external wall tile structure

（外壁タイル構造におけるコンクリート／接着モルタル間界面の熱疲労実験と解析）

氏名　Thiti Mahaboonpachai

This study aims to estimate the life of external wall tiles under a thermal cyclic load, and also to propose a guidance to develop adhesive mortar for the external wall tile construction in the future. In the first objective, failure mechanism of the external wall tile structure under the thermal cyclic load could be understood in terms of interfacial crack propagation during the increase of thermal loading cycles. After the first objective, the guidance to develop adhesive mortar for the external wall tile construction against the thermal loads was shown in terms of relationships between the interfacial thermal stress level and mortar properties.

Based on these objectives, the current research was divided into two main parts. The first one was the development of the analytical model based on a finite element method (FEM), and the other one was the application of the developed model. In other words, the current research developed the analytical model for quantitatively estimating the life of the external wall tile structure, and for proposing the guidance to develop a durable material for the external wall tile construction.

The external wall tile structure consists of three materials that are concrete, adhesive mortar, and tiles, and polymer-cement mortar (PCM) is commonly used as the adhesive material for tile construction. Between these material layers, bi-material interfaces are formed inevitably. From field observations, the interface between concrete and PCM was often found as the failure locations of the external wall tile structure, and most of the tile delamination areas were found at the building walls that face to sunshine directions. From this information, the interface between concrete and PCM was realized as a potentially weak location under solar radiation.

From the field observations, therefore, the interface element in FEM was developed for the thermal fatigue analysis in order to study the interfacial failure under the thermal load in this study. In order to develop the interface element for such a purpose, the interfacial resistance in terms of interface fracture toughness and S-N diagrams was investigated. To investigate the interface fracture toughness, the constitutive material model of the interface elements was proposed, and its corresponding values, having a relation to the interface fracture toughness, were calibrated with four experiments that have a different ratio of shear to tensile stress, which is defined as a phase angle. With the proposed method, the interface fracture toughness of the interface between concrete and PCM in the external wall tile structure was successfully obtained for the whole range of phase angles, and the constitutive material model of the interface element for stress analysis was obtained simultaneously. Regarding the interfacial resistance under the cyclic load, a stress-life approach was applied to construct the S-N diagrams of the interface between concrete and PCM. After the interfacial resistance investigation, the interface element was developed for the thermal stress analysis, and the obtained S-N diagram was modified for the constitutive material model of the interface element under the thermal cyclic load.

Then, the developed interface element was applied to analyze the interfacial crack propagation of the tile structure under both the thermal monotonic load and the thermal cyclic load. The experimental methods in a laboratory scale, namely the monotonic heating experiment and the cyclic heating experiment, were invented for reproducing the interfacial delamination of a tile structure under thermal loads, and for checking the validity of the developed interface element. The experimental results in terms of the length of interfacial crack propagation under a given thermal load were compared with the analysis results. With the proposed constitutive material model, the analysis results agreed with the experimental ones under thermal monotonic load, and it is good for rough estimation of the interfacial life under the thermal cyclic load.

In order to understand more in real situation, the developed interface element was, then, applied to analyze the external wall tile structure under solar radiation. The temperature on tile surfaces in the field was investigated, and modified to be the thermal boundary condition on the tile surfaces in the FE analysis. Three models, namely normal case, high tensile case, and high shear case, were simulated in FEM. Each model had different mechanical boundary conditions that might be possible in the reality.

In the normal case, there was no initial defect assumed in the analysis. In this analysis, low interfacial stresses were observed in both normal and shear directions of the interface element. The analysis results implied that the external wall tiles are not harmful to the external wall tiles under a normal condition that is assumed to have no initial defect in the structure. It is agreed with the reality that most of the external wall tiles have their life longer than 30 years.

For high tensile case, the initial defect was assumed at the interface between concrete and PCM in order to generate tensile stress concentration above the initial crack tip. In this case, the maximum tensile stress level was 2.3 times higher than the normal case, but the tensile stress level was not harmful to the structure in comparison with the tensile bonding strength of the PCM. In other words, although high tensile case presents in the reality, tensile bonding strength of the PCM is good enough to prevent the failure under the thermal load.

In the last case, the initial defect was assumed at the gout location between two tiles. As a result, the PCM could expand during heating in the shear direction of the interface element, while the concrete was fixed. The severity occurred in this high shear case, because the interfacial shear stress was high enough to cause a fatigue failure at the interface under thermal cyclic loads during the building’s life.

In reality, such kind of defect that causes high shear stress condition is difficult to prevent, because it commonly occurs due to shrinkage of adhesive mortar or due to poor workmanship. In order to reduce the severity of that condition, suitable adhesive mortar can be used. Therefore, the analytical model was further utilized to study the effects from parameters, related with the properties of adhesive mortar, on the thermal stress at the interface in order to propose the guidance to develop the adhesive mortar in the future.

The effects on the thermal stress from Young’s modulus, thermal expansion coefficient (TEC), and thermal conductivity were investigated. It has been found that Young’s modulus and TEC were the parameters that significantly affect to the interfacial shear stress level in the external wall tile structure. The shear stress level at the interface between concrete and adhesive mortar under high shear stress condition could be significantly reduced by using suitable Young’s modulus and TEC of mortar in the external wall tile construction. In other words, in order to reduce the severity of the external wall tile structure, such as high shear condition, Young’s modulus and TEC are the keys to develop adhesive mortar in the future.