- Technical Paper -

ESTABLISHMENT OF TEST METHOD THAT CAN COMPARE ADHESIVE STRENGTH BETWEEN PLASTER MORTAR AND CONCRETE AT THE LABORATORY LEVEL

Peiyi ZHANG *1, Atsushi TERAMOTO *2, Takaaki OHKUBO *3 and Ryouta KONDOU *4

ABSTRACT

This study proposed the new experimental method that can evaluate the durability of adhesive strength between plaster mortar and concrete substrate at the laboratory level. In this method, a cyclic thermal load is applied on a part of the plaster mortar surface as a means to accelerate degradation. The experimental results show that the adhesive strength of the loaded part decreases significantly. In addition, the deformation and interfacial stress of the mortar/substrate adhesion system under this thermal cycling load conditions were calculated by finite element analysis.

Keywords: plastering mortar, adhesive unity, accelerated degradation, thermal cycle, interfacial stress

1. INTRODUCTION

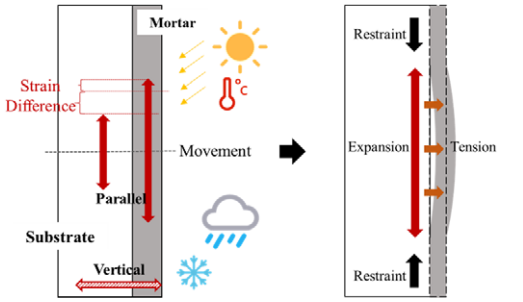
Plastering mortar is widely used in finishing material on RC building exterior wall, however, it could be cracked and exfoliated after long years of use. The deterioration of these plastering mortars not only reduces the durability of the RC elements, but also cause the plasters to fall and hurt pedestrians.

Preventing peeling through the use of decorative materials and construction methods that have been assessed for safety is currently effective [1]. The precondition of being able to apply different treatment methods to the easily damaged parts and the hardly damaged parts requires a reliable evaluation system.

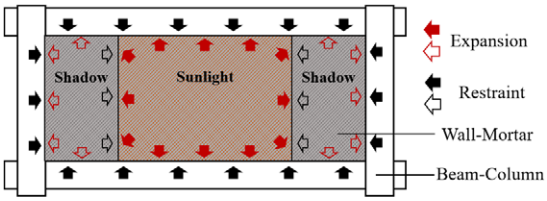
When the laminated structure composed of the concrete substrate and mortar is exposed to changing external environment, each layer will produce different volume changes due to thermal and hygroscopic expansion, which will cause interlayer stress. In particular, the relative movement between the mortar and substrate concrete caused by daily thermal change, which caused by sunlight, will eventually lead to fatigue damage. In those case, cracks have mainly been occurred by the in-plain stress and peeling have mainly been caused by the stresses in both directions (in-plane and out-of-plane), as shown in Fig. 1(a).

In order to properly conduct the durability evaluation of plaster mortar, it is necessary to reproduce above deterioration mechanism which caused by wet-dry and heat–cool cycles. Such accelerated deterioration test is standardized in Japanese Society of Finishing Standard M-101. The specific method is as follows.

1) Irradiate the infrared lamp for 105 minutes up to specimen's surface temperature becomes 70 ° C.



a. Relative movement between the layers



b. Two kinds of restraint.

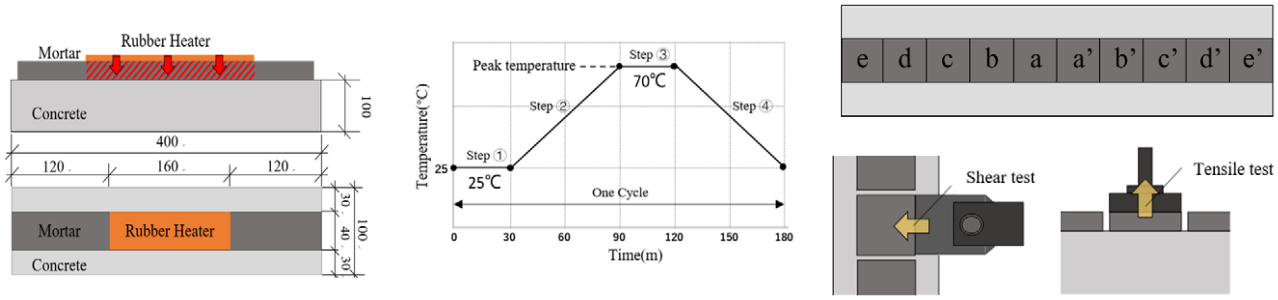
Fig.1 Failure mechanism of adhesive unity

2) Sprinkle for 15 minutes.
3) 1) and 2) as one cycle and continue for 300 cycles

However, in this accelerated deterioration method, the entire specimen is subjected to the high-temperature history and water supply, hydration of the plastering mortar could be accelerated adhesive strength at the interface increases.

Focusing on the accelerated deterioration method described above, the situation might be different from

*1 Graduate student, Graduate School of Engineering, Hiroshima University, JCI Student Member
*2 Assistant Professor, Graduate School of Engineering, Hiroshima University, JCI Member
*3 Professor, Graduate School of Engineering, Hiroshima University, JCI Member
*4 4th Grade, Undergraduate School of Engineering, Hiroshima University.



a b c

Partial thermal cycling degradation experimental Adhesive strength test

Fig.2 Mortar / Substrate Adhesive Strength Evaluation System

the plastering mortar which of the actual RC wall. In this method, the restraint body is only substrate concrete. On the other hand, the plaster mortar in the real structure is restrained by the mortar in the unheated area and surrounding columns and beams as shown in Fig. 1(b).

In this paper, a new accelerated test method which considering the restraint by the surrounding members is proposed. As a method, a thermal load is applied to only a part of the mortar, and the thermal expansion is restricted to the mortar other than the thermal loaded part. And the validity of the proposed method was experimentally verified. In addition, the numerical analysis was performed to understand the stress state of our new test method.

2. EXPERIMENT

2.1 Accelerate degradation method

The specimen is shown in Fig. 2(a) and consist of the 100×100×400 mm concrete substrate and the 40×10×400 mm plastering mortar.

In order to reproduce the degradation conditions in reality, a partial thermal cycle loading was applied for only in central area of plaster mortar. The mixture proportions of the plaster mortar and concrete substrates are shown in Table 1. The mix-proportions and the pretreatment of the plastering surface refer to the Japanese plastering work specification [2].

Table 1 Composition of the specimens

Composition of the plastering mortar

Mortar	Water	Cement	Fine Aggregate	S/C	W/C
Pre-mixed mortar	tap water	OPC	S: Crushed sand	2.5	0.5

Composition of the concrete substrate

Strength (N/mm³)	Slump (cm)	W/C (%)	Weight (kg/m³)				
			Water	Cement	Fines	Coarse	Admixture
36	18	44	180	410	798	887	3.32

Table 2 Experimental parameters

Parameters	Load width	Interface	Cycles	Test
Level	16cm	Rough EVA	50	shear test tensile test
	40cm			shear test

The substrate concretes were casted to the mold, which size is 100×100×400 mm, and demolded the next day after casting, and then cured in 20℃ water for more than two months. These concretes need to be sufficiently dried to reduce errors caused by drying shrinkage in the experiments. Before plastering, dried for more than a week at 40℃.

In order to improve the adhesion of the mortar, a series of pretreatments such as polishing-cleaning-applying adhesives are required on the plastered surface. Use the roughest sandpaper to roughen the surface of the substrate and acetone is used to remove dust and grease, which all improved the adhesion of the mortar. Finally, apply EVA to the surface two hours prior to plastering. This is an adhesion promoter with ethylene-vinyl acetate resin as the main component. It can prevent the water movement of the mortar to the concrete, which will suppress the hydration of the mortar and decrease in adhesion.

Plastering mortar is fragile in the early stage of curing, so it is left in place for two days after pouring and then moved to an environment of 20℃ and 60% humidity for 28 days until the degradation experiment begins.

Rubber heater are used to provide thermal loading. This is due to its excellent flexibility, it can be used in close contact with the specimen. The rubber heater is fixed to the mortar with high temperature-resistant double-sided tape. By connecting to the control equipment to control the temperature, heating time and number of cycles, the cycle of load is shown in Fig.2 (b). The maximum-temperature of 70℃ is determined based on the most severe load conditions that the exterior wall may be subjected to in summer. Set the number of cycles to 50 based on the affordability of the weakest part.

In order to confirm that "partial" heating of the specimen was a necessary condition for accelerated deterioration, a method of heating the entire specimen using a same rubber heater and temperature history was also implemented. The effect of partial heating and whole heating on degradation is described in 2.3.2. The experimental parameters are shown in the Table 2.

2.2 Evaluate the adhesive strength

As described Chap.1, the peeling of the mortar is caused by the restraint stresses which work for in-plane

and out-of-plane. Therefore, in order to evaluate the adhesion of the mortar to the concrete, the adhesive strength test for evaluating the both directions were conducted.

As shown in Fig. 2 (c), the vertical strength test using a tensile tester approved by the Japan Society for Finishings Technology, and direct shear test for measuring in-plane strength were performed. The mortar was evenly cut into 10 parts of 40mm×40mm using grinder and tested one by one from the end before testing.

The adhesion strength is given as follows:

$$a = N/A_0 \quad (1)$$

where,

a : adhesion strength [N/mm^2]

N : maximum shear/ tensile force [N]

A_0 : area [mm^2]

2.3 Experimental result

Fig. 3 shows the temperature change of the mortar surface under thermal loading cycle. As shown in Fig.3, it was confirmed that a proper temperature is given to the mortar surface by the rubber heater.

2.3.1. Adhesion strength in different directions

Due to the symmetry of the specimen, the average value at a location equidistant from the heated part was used. For example, the average of a and a' as the adhesive strength of the middle part A, and similarly divide the adhesive strength of specimen into five parts for evaluation, from the center to the end are respectively represented by A, B, C, D, E as shown in the Fig. 4.

Fig.5 (a), (b) shows the adhesion strength of the specimens after degradation over 50 cycles of thermal loading compared to the initial value. The adhesive strength of the central part (A, B) of the specimens subjected to the thermal load is significantly reduced, while the unloaded part (C, D, E) hardly changed. Among them, the decrease in the adhesive strength of the loaded boundary area B is slightly larger than the load center A, it can be clearly observed in both shear and tensile tests.

The rate of the strength changes between each position of the two tests is shown in Fig. 5(c). They have a similar trend. It can be considered that no matter which strength test method is used, it is possible to evaluate whether the adhesive strength of the specimen after being accelerated deterioration by the thermal cycle loading method is decreased.

In addition, in both tests, the adhesive strength of

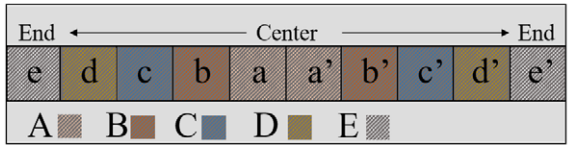
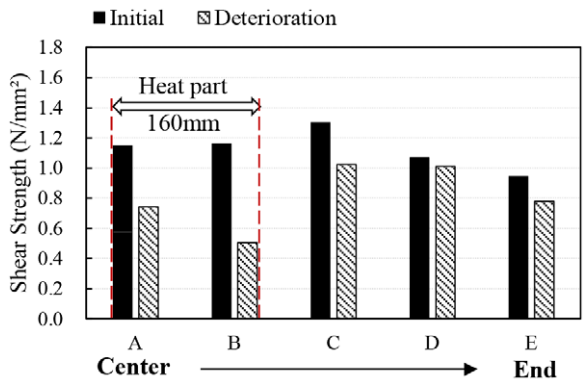
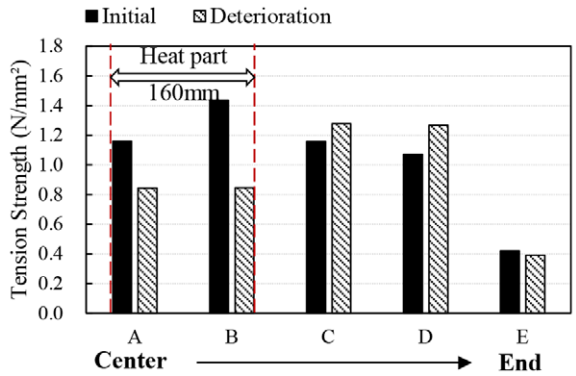


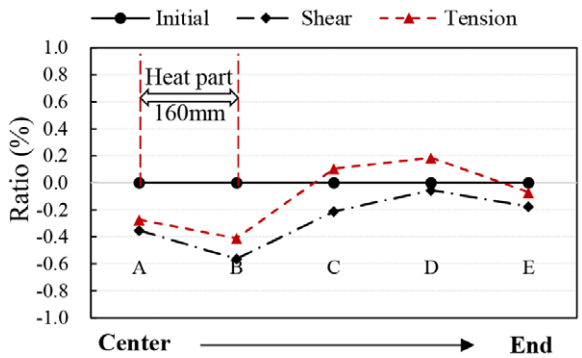
Fig.4 Contrast zones of adhesive strength



a. Direct shear test (in parallel direction)



b. Direct tensile test (in vertical direction)



c. Rate of change in adhesion strength after degradation

Fig.5 Adhesive strength in different directions

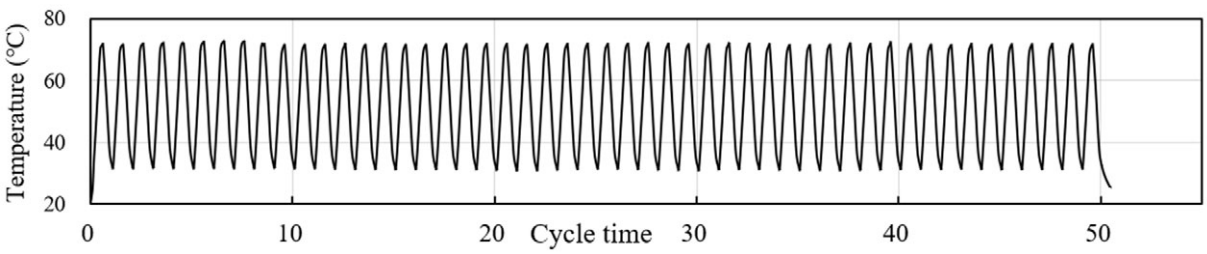
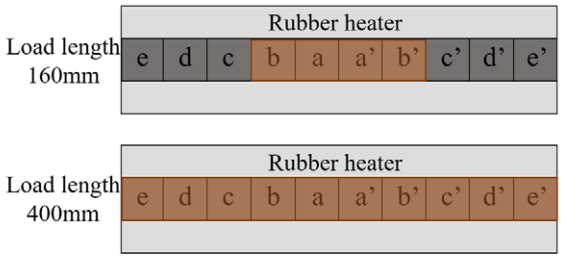
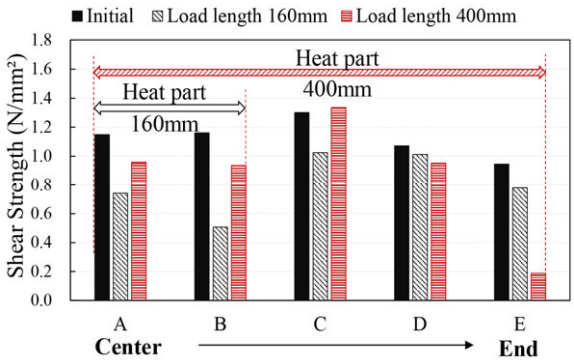


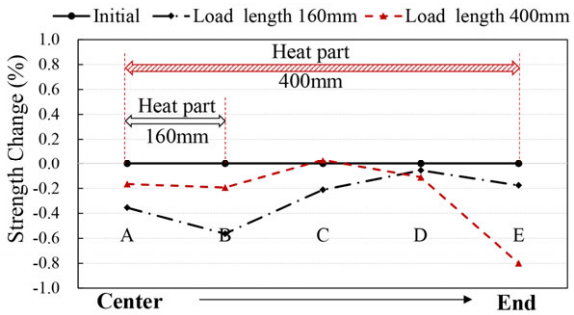
Fig.3 Temperature change of the mortar surface during degradation



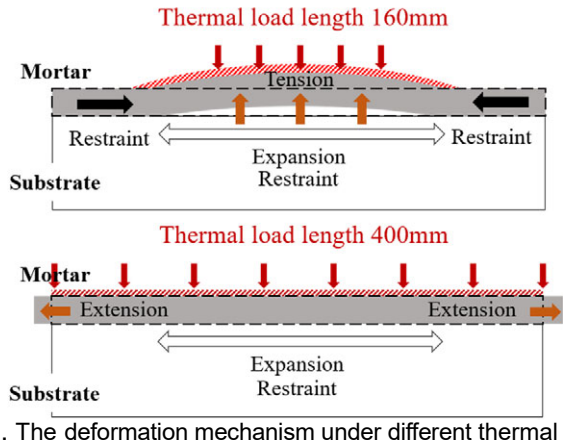
a. Different thermal load lengths



b. Results of adhesion strength



c. Rate of change in adhesion strength after degradation



d. The deformation mechanism under different thermal load lengths

Fig.6 Adhesive strength changes under different thermal load lengths

the end of the specimen E was lower than other parts, especially in the tensile test. Although there is a possibility of error, it is more likely to be the curled deformation of the mortar due to drying shrinkage [3].

2.3.2. Partial thermal load and whole load

In order to prove the reproducibility of the partial thermal loading experiment to the real degradation environment, the whole thermal loading experiment was performed as a control group. Two types of thermal load lengths of 160 mm and 400 mm were applied to the specimens by controlling the length of the rubber heater, as shown in Fig.6(a). The initial adhesion strength values of the specimens subjected to thermal loading of two lengths after degradation are shown in Fig. 6(b).

Compared the change of the adhesion strength after degradation, the middle part (A, B) of the specimens subjected to partial thermal load significantly decreased, while the other parts only decreased slightly. On the other hand, whole load specimens showed more obvious damage only at the end. This is clearer in the change rate of the adhesive strength after degradation as shown in Fig. 6(c)

Considering that the decrease in the strength of the end under the condition of the whole load is due to the fact the deformation of the mortar under load is not restricted and tends to extend to both ends. This method cannot reproduce the deterioration of real walls. Therefore, it is considered that the method of heating at the center, which can degrade the target location, is superior as accelerated deterioration.

3. NUMERICAL ANALYSIS

In this section, the numerical analysis was conducted to study the stress state of the adhesion interface between the plastering mortar and concrete under thermal cycle loading based on the experimental conditions. For this analysis, the 3D-FEM program ANSYS Workbench was used.

3.1 Mathematical model & Calculation conditions

The 3D-FEM model who has the same size as the specimen consisting of three components, concrete, plastering mortar and adhesion interface was made as shown in Fig.7. And the same thermal load, the maximum temperature was 70℃ was applied. And also, as in the experiment, two types of heating places were used: the middle and the whole. However, since the purpose of this analysis is to understand the stress distribution when the temperature rises, heating cycle were not given.

The model was calculated by transient thermal and transient structural analysis. Although the specimens were placed freely on the floor in the experiment, considering the actual structure, we set the concrete bottom surface in the model as a fixed constraint, which is more convenient for calculation.

The material parameters of concrete and mortar components are set according to the "Standard Specifications for Concrete Structures -2007" [4], as shown in Table 3. In addition, it is necessary to provide

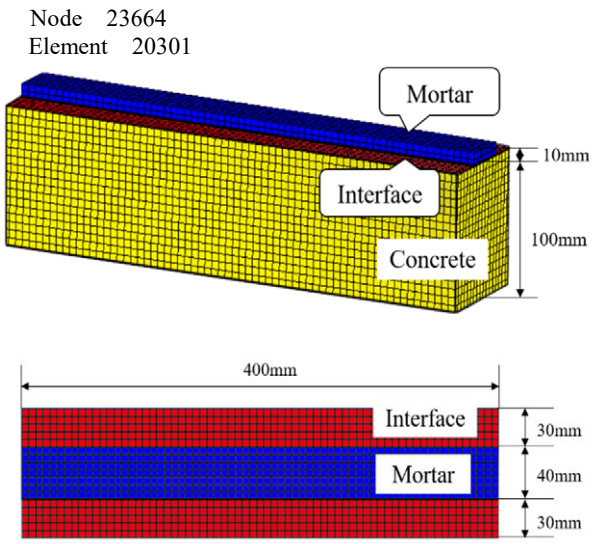


Fig.7 Simulation model

Table 3 Model material parameters		
Parameter	**Concrete**	**Mortar**
Density(kg/m³)	2300	2100
CTE (1/°C)	1.10E-05	1.50E-05
Young's Modulus (GPa)	28	20
Poisson's Ratio	0.2	0.2
Tensile Yield Strength (Pa)	2.78E+06	3.50E+06
Compressive Yield Strength (Pa)	3.00E+07	3.96E+07
Isotropic Thermal Conductivity(W/m*°C)	1.6	1.5
Specific Heat(kJ/kg*°C)	0.7	0.6
Separation-Distance based Debonding		**Interface**
Maximum Normal Stress (Pa)		1.05E+06
Maximum Tangential Stress (Pa)		9.73E+05
Artificial Damping Coefficient(s)		0.001

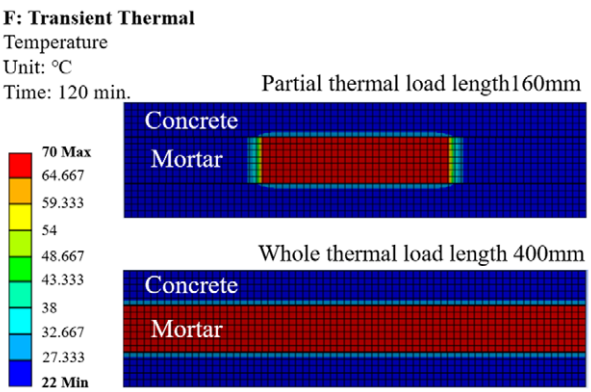


Fig.9 Temperature distribution at 120 min

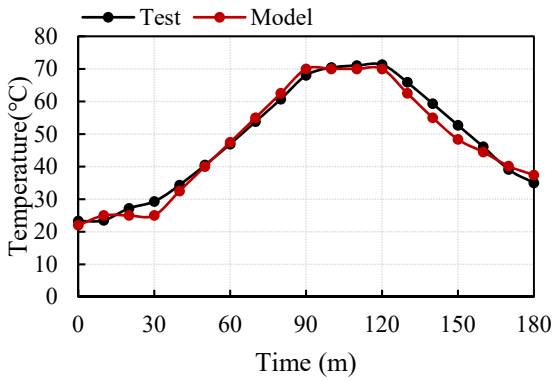


Fig.8 Temperature change of heating part

an adhesive material to the interface between mortar and concrete. The maximum normal and tangential contact stresses are based on the averaged initial bond strength obtained in our preliminary experiments. However, the decrease in adhesive strength due to cycling thermal loads were not considered.

3.2 Temperature distribution

Fig. 8 is the temperature change of the mortar surface of the specimen and the model during a same thermal load cycle. The coincidence of temperature change trend can prove that the load conditions of the model are basically consistent with the experiment. It is the same as the experimental result. The temperature distribution of the model at 120 min. after peak temperature load of 70 ° C for 30 minutes is shown in Fig. 9. Due to the low thermal conductivity of concrete, it can be observed that the temperature rise only occurs around the loaded portion. The model under partial thermal load has almost no temperature rise in the surrounding mortar.

3.3 Interfacial stress

As described Chap.1, the failure of the mortar/ substrate adhesion system is caused by a combination of the in-plane and out-of-plane stresses at the interface. Fig. 10 shows the equivalent stress at the interface under the thermal loads of different widths at 120 minutes. Unlike the stress generated by the model subjected to partial thermal load is concentrated at the center of the mortar, the stress of the model subjected to the whole load is concentrated at ends.

This is consistent with what was described earlier in Fig. 6(d). The expansion caused by the heating of the mortar is constrained by the surrounding area tends to deform in the vertical direction so that the stress is concentrated on the loaded part, while the mortar not constrained by the surroundings tends to deform toward both ends and the stress is concentrated at the ends.

In addition, not only the central part of the load, but also the stress concentration in the edge region. And because the adhesive strength of the central part will gradually decrease with the increase of the number of thermal cycles, the stress concentration part will also

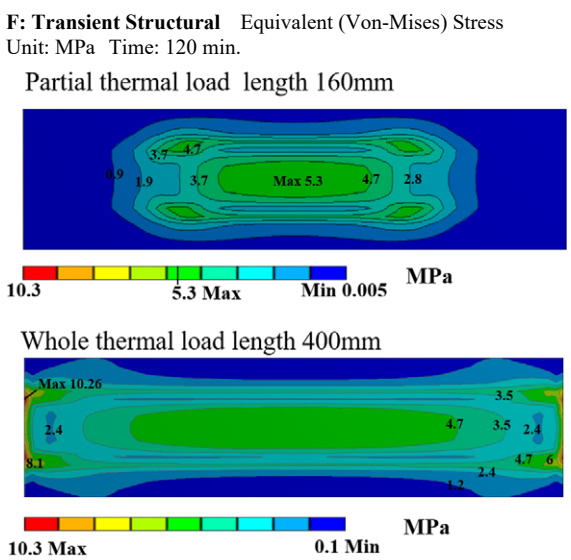


Fig.10 Equivalent (Von-Mises) Stress (MPa) in interface at 120 min

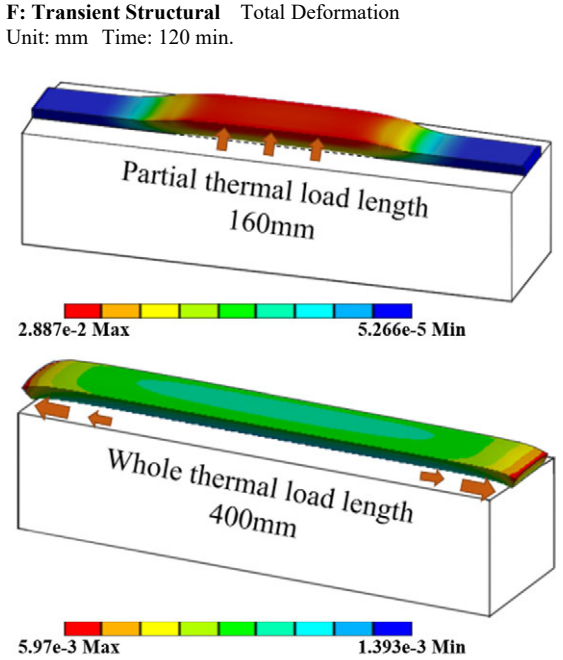


Fig.11 Maximum deformation of mortar

move from the load center to the load edge. This may explain the phenomenon that the decrease in the adhesive strength of the corresponding region B is slightly greater than A in the experimental results, which proved the correlation between the generation of stress and the mechanism of reduction in adhesive strength, so the monitoring of interfacial stress will be essential in future experiments.

3.4 Deformation of plastering mortar

The maximum deformation of the mortar under one thermal loading cycle is shown in Fig.11. The deformation results are the same as those described above. It can be observed that the deformation results of the model mortar subjected to partial thermal load are consistent with the actual plastering mortar of external walls.

4. CONCLUSIONS

In this study, we proposed a new accelerated deterioration method required for evaluating the durability of plaster mortar. The conclusions reached are as follows:

(1) The effectiveness of partial thermal load conditions has been proven, and the restraints provided by the surrounding parts of the mortar are essential to reproduce the real degradation environment in the laboratory.

(2) The change in the adhesive strength between the mortar and the substrate was clearly observed in both the direct tensile test and the direct shear test.

(3) Numerical analysis using the 3DFEM model confirmed that the in-plane and out-of-plane stresses were concentrated in the area where the adhesive strength was reduced by the partial heating method. In addition, it was confirmed that the stress concentration occurred at the edge of the load portion where the joint strength decreased most during the experiment.

However, for the validity of this evaluation method, it is necessary to show that a mortar with high durability and a mortar with low durability could be appropriately evaluated. In addition, it is also important to make the correspondence between the number of cycles given during the experiment and the actual service life. And also, it is important to consider the change in allowable stress due to fatigue of the bonded surface in future numerical analytical studies.

REFERENCES

[1] Japanese Architectural Standard Specification — JASS15 Plastering Work, Architectural Institute of Japan, 2019

[2] The Guide of Avoiding the Peeling Wall-panel Plan, Japan Society for Finishings Technology, 1994 Japanese Architectural Standard Specification — JASS15 Plastering Work, Architectural Institute of Japan, 2019

[3] J.F. Georgin, J. Ambroise, J. Péra , J.M. Reynouard, " Development of self-leveling screed based on calcium sulfoaluminate cement: Modelling of curling due to drying," Cement & Concrete Composites 30 (2008) 769–778

[4] Japan Society of Civil Engineers: Standard Specifications for Concrete Structures -2007