# Experimental Investigation on Anti-detachment Strengthening Technology for Exterior Wall Ceramic Claddings of Existing Buildings

Jinjing Pan[1,a], Jing Liu[2,b], Xuan Wang[1,c], Zihua Zhang[1,d], Feng Yang[2,e*], Shunbi Xu[1,f], Yaqi Zhang[3,g], Hongfei Lin[4,h], Chao Chen[5,i], Yang Xuan[6,j]

[1]Ningbo University, Ningbo, China
[2]Zhejiang Heli Construction Special Technology Co., Ltd, Ningbo, China
[3]Ningbo Second Technician College, Ningbo, China
[4]Ninghai County Housing Management Center, Ningbo, China
[5]Haining Real Estate and Housing Security Management Service Center, Jiaxing, China
[6]Jinhua Jindong District Rural Construction Service Center, Jinhua, China

**ABSTRACT:** To study the effect of anti-detachment strengthening technology for ceramic claddings, several experiments were performed to obtain the failure mode and bonding strength of the strengthened hollow ceramic claddings system exterior wall, and were compared with the unreinforced system. The results indicated that using a transparent polymer waterproof coating layer as a covering material in strengthening technology could effectively improve the failure mode and adhesive strength of the hollow ceramic cladding system on the exterior wall.

## 1 Introduction

Ceramic claddings are widely used in the exterior wall decoration engineering of urban buildings in China due to their economy and beauty. Affected by factors such as environment and construction quality, ceramic claddings may experience hollowing, detachment, and even cause casualties after serving for a period, which poses a significant threat to urban public safety [2,3,5]. The main goal of building maintenance is to maintain the original functionality, structural integrity, and aesthetic conditions of the building, which is the key to long-term development[1]. Timely maintenance of building exterior walls could prevent casualties and economic losses[8]. The existing external wall maintenance mainly adopts the overall or partial replacement method, which causes problems such as a long construction period, construction waste and dust, and potential safety hazards in demolition operations.

This study presents an anti-detachment strengthening technology for ceramic claddings by adding anchor nails to hollow areas and covering the system with transparent polymer coatings without removing the original ceramic claddings. This technology has the advantages of safety, durability, environmental protection, and economic rationality. The building industrialization and low carbonization trends in the development of the building industry are investigated[4,6,7,9,10]. However, this technology is still in its early stages of development and does not have the foundation for large-scale application.

For this purpose, this article conducted the pull-off test to obtain the failure mode and bonding performance of the strengthened exterior wall ceramic cladding system and analyzed the applicability of transparent polymer waterproof coatings as the covering materials.

## 2 Experimental program

### 2.1 Materials

The specification of 45 mm×95 mm white tiles, transparent polymer waterproof coating, ISO standard sand, and P.O.42.5 ordinary Portland cement were used in this experiment. M5 cement mortar board was configured as the base plate to simulate the deteriorated mortar layer in engineering practice, the surface of the board was constructed with ceramic claddings, and the mix proportion of cement mortar board was shown in Table 1. The mechanical properties of transparent polymer waterproof coating KS are presented in Table 2.

[a]panjinjing1208@163.com, [b]306387054@qq.com, [c]wangxuan@nbu.edu.cn, [d]zhangzihua@nbu.edu.cn, [e*]339246038@qq.com, [f]xushunbi@nbu.edu.cn, [g]413088741@qq.com, [h]9999359@qq.com, [i]444674270@qq.com, [j]183700530@qq.com

**Table 1.** The mix proportion of cement mortar board (kg/m³).

| Design strength | Water | Cement | Sand |
|---|---|---|---|
| M5 | 300 | 230 | 1450 |

**Table 2.** The mechanical properties of transparent polymer waterproof coating KS.

| | Tensile strength (MPa) | Tensile bond strength (MPa) | Peel strength (N) |
|---|---|---|---|
| KS | 22.50 | 5.82 | 200.20 |

### 2.2 Sample preparation

Different loading areas (150 mm×150 mm, 45 mm×95 mm) were considered as parameters to simulate the detachment of multiple and single ceramic cladding, and a set of strengthened with transparent polymer waterproof coating and unreinforced samples (1 in each group, a total of 4 samples) were set up to conduct pull-off test. The sample number consists of a coating layer and loading area, where "KS" represents a transparent polymer waterproof coating, "DZ" represents an uncoated layer, "unit" represents the detachment of multiple bricks (the loading area is 150 mm×150 mm), and "single" represents the detachment of a single brick (with a loading area of 45 mm×95 mm).

M5 cement mortar boards were used as the base plate in the pull-off test, and the ceramic claddings were constructed on the surface of the base plate. To simulate the actual detachment of the ceramic claddings and control the failure mode, the non-sticking zone was set up on the back of the brick in advance with adhesive tape. The anchor nails were arranged at the four corners of the sample. The sample's central area was where the ceramic cladding was easy to fall off, and the sample was designed as the minimum reinforcement unit in the strengthening technology. To study the reinforcement effect, the pull-off test was carried out in the central area. The layout of the ceramic claddings and the diagram of the loading area are shown in Figure 1.

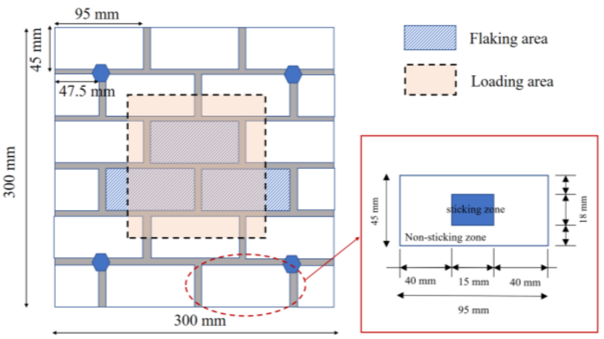



**Figure 1.** Sample for the pull-off test.

### 2.3 Test setup and instrumentation

The pull-off tests were conducted by using a displacement control mode with a loading rate of 5.5±0.7 mm/min, and the testing device is shown in Figure 2. The loading device was composed of 8 clamps, 8 sets of fixing screws and nuts, 2 sets of screws, and a support plate. The C-type clamps were fixed on the support plate by 8 sets of screws and nuts, the support plate was connected with the lower chuck of the testing machine by a screw, and the upchuck of the testing machine was applied force to the drawing block through the screw. Among them, the clamp simulates the reinforcement effect of the anchor nails in the strengthening technology.

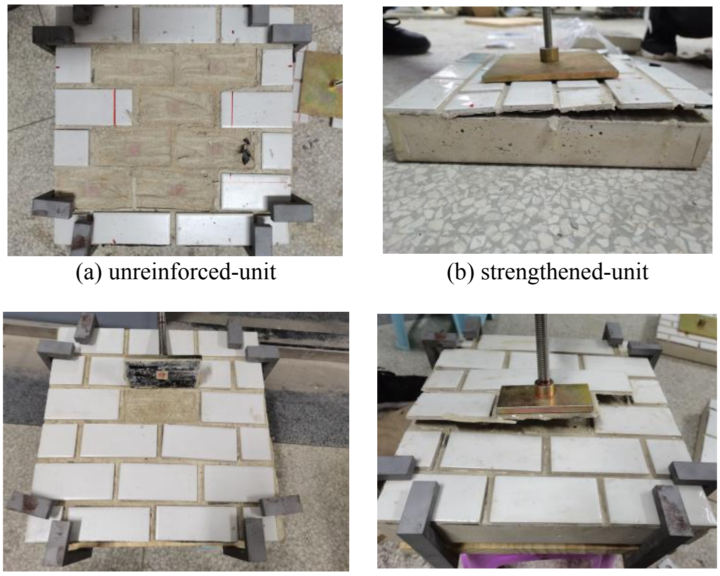
**Figure 2.** Setup for pull-off test.

## 3 Experimental results and analysis

### 3.1 Failure mode

When loading the unit with the area of 150 mm×150 mm, the ceramic claddings in the loading area of the sample without reinforcement with transparent polymer waterproof coating fell off due to weak bonding force, and the tiles in the surrounding area of the loading zone did not flake off, as shown in Figure 3a. For the strengthened sample, due to the enhanced connectivity of the tiles after the coating curing, the entire finishing layer, including the mortar joint, was separated from the base plate due to the perfect integrity of the layer after reinforcement. There is no glue fracture or damage to the mortar joint between the tiles, as shown in Figure 3b.

When the single zone was loaded, a single tile fell off in the loading area for the sample without reinforcement, as shown in Figure 3c. The sample strengthened with transparent polymer waterproof coating shows that the loaded single tile was associated with the surrounding tiles due to the connection built by the coating when the associated direction was random, as shown in Figure 3d.



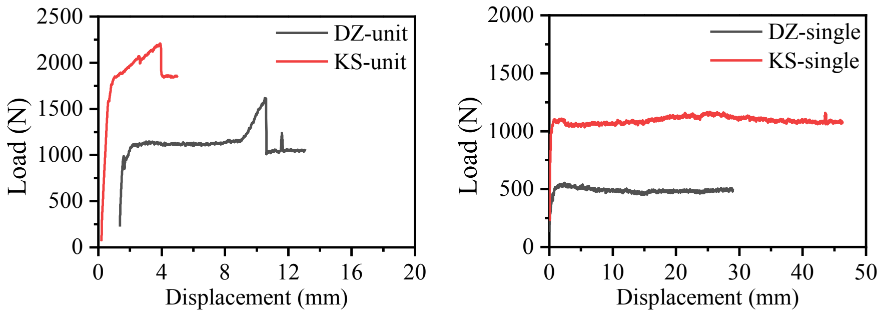
(a) unreinforced-unit (b) strengthened-unit

(c) unreinforced-single (d) strengthened-single

**Figure 3**. Failure modes of samples in the pull-off test.

### 3.2 Load-displacement curves

When loading the unit with an area of 150 mm×150 mm, the curve kept a linear rise in the early loading stage, then decreased rapidly after reaching the peak load. The sample strengthened with transparent polymer waterproof coating maintains a higher residual bearing capacity level than the unreinforced sample, as shown in Figure 4a. The displacement is minimal before the peak load when the single zone was loaded. After the peak load, the force decreased slightly but maintained a certain level when the displacement increased rapidly, as shown in Figure 4b.




(a) unreinforced sample (b) strengthened sample

**Figure 4.** Load-displacement curves of samples before and after strengthening.

### 3.3 Normal bonding performance

The test results of the normal bonding strength of samples in each group were shown in Table 3, and the calculation of bonding strength was carried out as follows:

$$\tau_{\max} = \frac{F}{S} \quad (1)$$

where $\tau_{max}$ = bonding strength, $F$ = peak load, and $S$ = loading area.

**Table 3.** The normal bonding performance of samples.

| Sample | Peak load (N) | Normal bonding strength (MPa) |
|---|---|---|
| DZ-unit | 1614.9 | 0.072 |
| KS-unit | 2210.2 | 0.098 |
| DZ-single | 553.7 | 0.129 |
| KS-single | 1166.1 | 0.273 |

## 4 Parameter analysis

As shown in Figure 5, for the sample with a loading area of 150 mm×150 mm, the bonding strength of the sample strengthened with transparent polymer waterproof coating increased by 36% compared with that of the sample without reinforcement, which was 116.6% for the samples with a loading area of 45 mm×95 mm. It is because the transparent polymer waterproof coating could improve the bonding strength of the ceramic claddings to a certain extent. It was worth noting that transparent polymer waterproof coating could also change ceramic claddings' failure mode and enhance the tiles' connectivity.

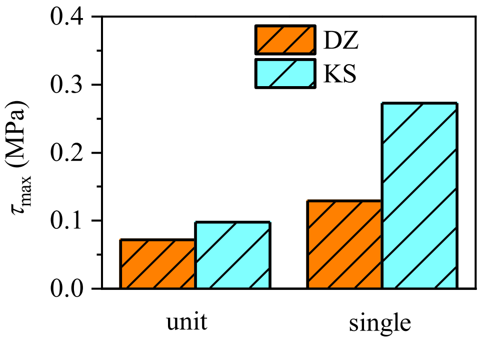



**Figure 5.** Effect of reinforcement on the sample in the pull-off test.

## 5 Conclusions

(1) The debonding failure pattern of the sample strengthened by transparent polymer waterproof coating differs from that of the sample without reinforcement, and the integrity of ceramic claddings is strengthened by coating.

(2) Strengthening transparent polymer waterproof coating improves the bonding strength between tiles and base plate.

(3) Transparent polymer waterproof coating could be selected as the cover material in the anti-detachment and strengthening technology for exterior wall ceramic claddings of existing buildings, which can not only improve the reinforcement effect of the system to a certain extent but also prevent the hollow phenomenon of the tiles aggravated by water seepage.

(4) The mechanical properties of the covering material, arrangement, and effect of anchors in the strengthening technology proposed in this study remain to be studied.

## Acknowledgement

This study was supported by the Zhejiang Provincial Natural Science Foundation, (Grant No. LQ21E080006), Natural Science Foundation of Ningbo City, China (Grant No. 2021J093 and 202003N4139), Ningbo Social Investment Construction Research Plan Project (Grant No. 2022-2-22). and the Science and Technology Innovation 2025 Major Project of Ningbo (Grant No. 2021Z104).

## References

1. Awasho T T, Alemu S K. Assessment of public building defects and maintenance practices: Cases in Mettu town, Ethiopia[J]. Heliyon, 2023, 9(4).
2. Bauer E, Pavon E, Barreira E, et al. Analysis of building facade defects using infrared thermography: Laboratory studies[J]. Journal of Building Engineering, 2016, 6: 93-104.
3. de Freitas S S, de Freitas V P, Barreira E. Detection of façade plaster detachments using infrared thermography–A nondestructive technique[J]. Construction and Building Materials, 2014, 70: 80-87.
4. Lo K. China's low-carbon city initiatives: the implementation gap and the limits of the target responsibility system[J]. Habitat International, 2014, 42: 236-244.
5. Lourenço T, Matias L, Faria P. Anomalies detection in adhesive wall tiling systems by infrared thermography[J]. Construction and Building Materials, 2017, 148: 419-428.
6. Mu Y, Liu Z, Wang F, et al. Carbonation characteristics of γ-dicalcium silicate for low-carbon building material[J]. Construction and Building Materials, 2018, 177: 322-331.
7. Sheng J, Qi D, Yan H, et al. Experimental Study on Low Carbonization of Green Building Based on New Membrane Structure Solar Sustainable Heat Collection[J]. Sustainability, 2022, 14(24): 16629.
8. Tan Y, Li G, Cai R, et al. Mapping and modeling defect data from UAV-captured images to BIM for building external wall inspection[J]. Automation in Construction, 2022, 139: 104284.
9. Yung E H K, Chan E H W. Implementation challenges to the adaptive reuse of heritage buildings: Towards the goals of sustainable, low carbon cities[J]. Habitat International, 2012, 36(3): 352-361.
10. Zhang N, Luo Z, Liu Y, et al. Towards low-carbon cities through building-stock-level carbon emission analysis: a calculating and mapping method[J]. Sustainable Cities and Society, 2022, 78: 103633.