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Adhesion Stability According to Adhesion Area of Traditional Tile Gluing Method

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Abstract: In this study, verification was conducted through experiments to identify problems caused by traditional attachment methods in order to highlight the need for a suitable attachment method for new tile types according to changes in materials, production technology, and demand. The stability of adhesion strength was evaluated by subdividing the size of the adhesion area and adhesion strength measurement method for the country-type attachment method. The adhesion area on the back of the tile was divided into 60% and 80%, and the test specimens used in the experiment were tested for partial adhesion strength (Ta-1), overall adhesion strength (Ta-2), and adhesion strength after splitting (Ta-3), and the results were derived. As a result of conducting the adhesion test presented in the current national building standard tile specification (KCS 41 48 01) for 80% of the backfill area, the average adhesive strength was 0.85 N/mm^2, and the standard strength was 0.39 N/mm^2. However, as a result of the arithmetic average test of the adhesive strength of all tiles or cutting of the entire tile, rather than the partial adhesion test method of the mortar-attached part, it was confirmed that the adhesive strength was about −20% less than the current KCS 0.39 N/mm^2.

Keywords: tile adhesion; mortar method; adhesion area; adhesion strength; overall tile

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1. Introduction

Tile has served as an important finishing material for a long time in building construction at home and abroad. Tiles of various types and sizes are used as aesthetic elements of buildings in exterior building materials, as well as interior bathrooms, living rooms, and kitchens. Compared with the traditionally used paint, texture coating, and wallpaper, the tile system using adhesive on a concrete substrate has lower building maintenance costs and is less expensive than construction using granite or laminated glass sheets [1]. Tiles attached to a concrete substrate must maintain the tile's ability to resist cracking and falling off due to long-term exposure to internal and external environments. For various types of tiles applied to the interior and exterior of buildings, the adhesion strength to the concrete base is a very important variable in terms of future durability [2–7]. After being exposed to the external environment (wind, rain, moisture, pollutants) for a long period of time, tiles experience a decrease in shear strength of up to 50% within the first 100 cycles due to cracks on the substrate or a decrease in adhesion strength [8]. As a result of investigating the peeling phenomenon at the interface of tiles attached to a concrete substrate with polymer–cement mortar (PCM), it was confirmed that cracks at the interface propagated to a length of about 3 mm when the temperature of the tile surface was 100 °C [9]. The relationship between the adhesion strength of tiles to exterior walls under three types of laboratory conditions (tile setting pressure, adhesive internal space, and adhesive open time) was investigated, and all three factors were found to have a significant effect on tile adhesion strength [10]. It was

explained that a 30% reduction in the adhesive area of tiles on a concrete substrate can account for more than 70% of the system's ability to resist external deformation [11].

Tiles that were mainly used in multi-family bathrooms are now preferred for large tiles (250 × 400 mm, 300 × 600 mm), which are more than 20 times larger in area and weight than in the past (100 × 100 mm and 150 × 150 mm) in Korea [12,13]. The tile attachment technology is still a backward country-type attachment method (Thick-Bed technology) [14,15], and the construction technology that was attached to small tiles in the 1970s and 1980s is still being used today, as shown in Figure 1. Therefore, it is time to verify the safety standards for tile attachment, such as whether attachment stability can be secured with 80% attachment area, which is the arbitrary limit of the construction method, and whether it meets the attachment strength standards suggested by the building standard specification. In order to secure the attachment stability of tiles, advanced countries such as Europe and the United States are constructing with a compression method (polymer–cement) that expresses 95% of the attachment area (total area) of the tile's back surface and a strength of 1.0 N/mm^2 or more [11,12]. In Korea, the attachment area is less than 70% due to the mortar attachment method and less than half of the attachment strength (0.39 N/mm^2) of advanced countries [12–14]. The proper adherence area of the country-type attachment method cannot be found anywhere, and the only piece of literature, Architectural Technology Guideline published by the Architectural Institute of Korea, describes it to be 80% filled [12]. In this study, when the tiles (250 × 400 mm, 300 × 600 mm) preferred by residents are recently attached using the country-type attachment method, we would like to verify whether the attachment stability of the tiles can be secured during the construction of the maximum attachment area with 80%.

Figure 1. Types of bathroom wall tile defects.

2. Experimental Program

2.1. Tile Test (KS)

KS L 1001 [16] was tested after selecting two tiles of T-1 tile 300 × 600 mm and T-2 tile 250 × 400 mm as experimental ceramic tiles (absorption rate of 18% or less) for the study of tile attachment safety standards. The physical properties of the absorption rate test, crack resistance (autoclave) test, abrasion resistance test, bending strength test, and chemical resistance test were carried out with five items of high importance, as shown in Figure 2. The T-1 and T-2 tiles met all KS standards, and the evaluation results are shown in Table 1.

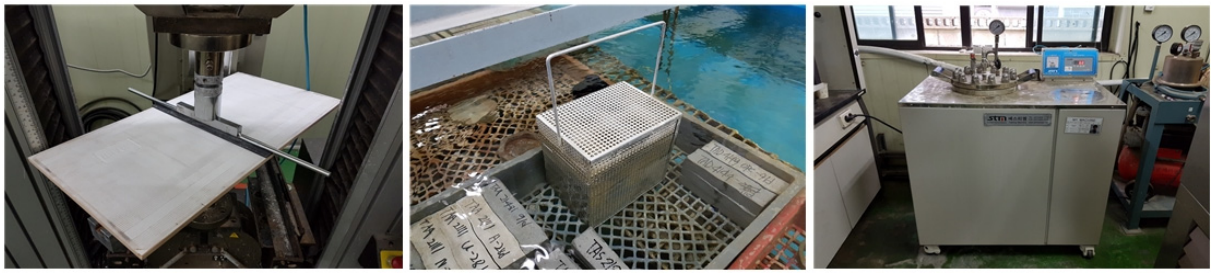


Figure 2. Tile KS test status to be used for actual verification experiment.

Table 1. Tile KS test comprehensive evaluation result.

Type / Test	Absorption Rate (%)	Crack Resistance	Wear Resistance (g)	Bending Strength (N/cm)	Chemical Resistance
T-1	11.7	clear	0.05	120.8	clear
T-2	13.2	clear	0.03	103.7	clear
standard	18 ↓	cracks	0.1 ↑	12 ↑	no discoloration

2.2. Pressure Setting with Pressure Experiments to Press and Glue Tiles

In the mortar method, a hard-cut attachment mortar is placed on the back of the tile and pressed on the concrete background, and the pressing pressure (force) appears differently depending on the physical conditions, such as the height and age of the worker. In addition, since the bathroom wall must finish the entire sealing height of more than 2300 mm, the pressing force is expressed differently depending on the position attached to the lower, middle, and upper parts. Accordingly, the force (N) and time-pressed when attaching one sheet of T-2 tile (250 × 400 mm) to the concrete wall were measured for four adult male experimenters. As a result of the experiment, the average of the upper section (1650~2300 mm) was 64.5 N with a duration of 5.5 s, the average of the intermediate section (950~1700 mm) was 116.8 N with a duration of 8.5 s, and the lower section (300~1050 mm) was 83.3 N with a duration of 6.8 s, respectively. The total average of the wall section was confirmed to be 88.2 N, 6.9 s, and the detailed experimental status is shown in Figure 3.

Figure 3. Pressurization test for tile pressing according to wall height.

2.3. Adhesion Area Verification Method

During the process of verifying attachment safety according to the cement mortar [KS L 5200] backfill 80 ± 3% and 60 ± 3%, the mortar is pressed and spread during the six-second pressurization process with a 10 kg weight on the tile. The important point is that at this time, the verification process of whether the mortar formed on the back of the tile is secured with 80 ± 3% and 60 ± 3% of the adhesion area intended by the actual experimenter should be preceded. Due to the nature of the mortar method, thermal imaging camera equipment was used as a verification method for the adherence area of the back of the tiles (solid), where the adherence area was not visible after adherence. After taking a photo with a thermal imaging camera, the image of the back of the tiles was overlapped using the AutoCAD program to connect the outer boundary with a polyline to check the spherical area. The detailed verification status is shown in Figure 4.

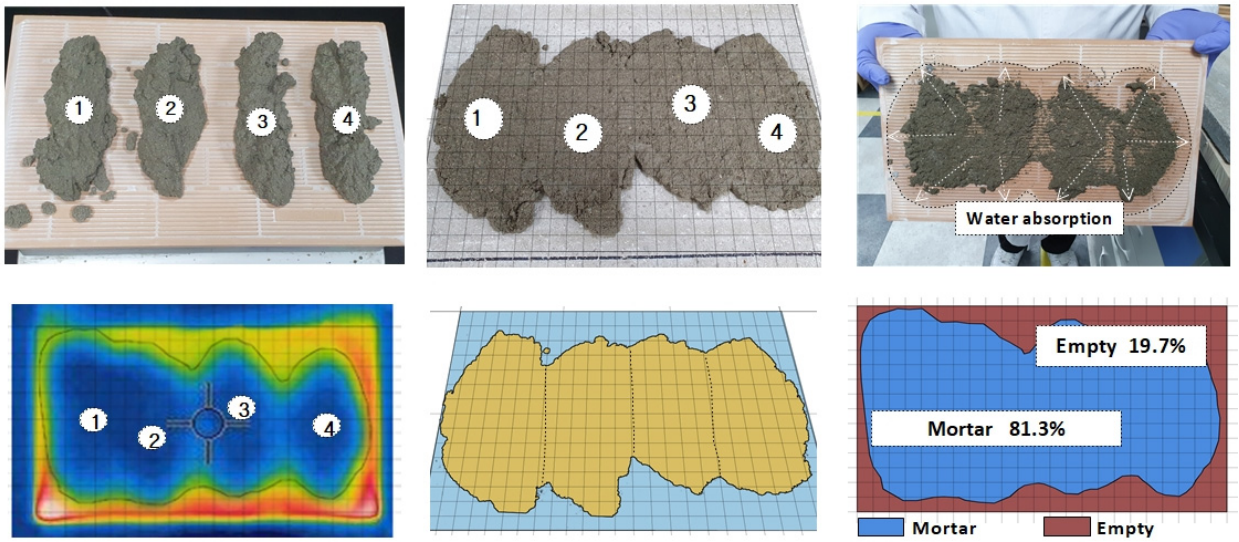


Figure 4. Observation and area calculation after mortar construction.

2.4. Experimental Verification Method

The detailed experimental methods are shown in Table 2 and Figure 5. [Ta-1] The base concrete to be tested was based on the KS L ISO 13007 standard [17,18], and the mortar above the concrete base specimen 500 × 500 mm was attached in the form of a 400 g/spot standard. It was pressurized with a weight of 10 kg on the tile for about 6 s to produce a test, and then it was fully cured in the air at standard conditions (23 ± 2 °C), relative humidity (50 ± 5%), and 28 days. The partial attachment strength test (Ta-1) was calculated as three average values by measuring the partial attachment strength after cutting the part attached to the back of the tile to the concrete surface using the current construction standard specification [19] for 3.6.3 overall attachment strength test method. [Ta-2] The strength experiment of the overall adhesion was tested by attaching a specially manufactured attachment equal to the tile's overall size (250 × 400 mm) to the front of the tile, targeting a total of two attachment areas of 80 ± 3% and 60 ± 3%. The base concrete was carried out using the same concrete and mortar attachment method and pressurization as the partial adhesion strength (Ta-1) experiment. In the experiment,①80 ± 3% and②60 ± 3% were filled. The same attachments as the tile size (250 × 400 mm) were attached on the two adhering area specimens attached with epoxy adhesive, then they were left in a standard state for 24 h and increased at a constant rate of (250 ± 50) N/s to measure the adhesion strength according to the adhering area. [Ta-3] After cutting the entire tile, the partial adhesion strength experiment was to attach a total of 40 attachments, eight wide and five long, to the tile overall for a total of two attachments, 80 ± 3% and 60 ± 3%, and then the entire tile area to the concrete surface was cut with a grinder to separate the surrounding tiles and measure each adhesion strength of 40 places for the total tile area, and it was calculated as an average value.

Table 2. Adhesion stability test plan according to the area of attachment mortar.

	Distinction	Tile Size	Adhesion Area (%)		Attachment Size (mm)	Curing
		250 × 400 mm	60	80		
[Ta-1]	Partial adhesion strength test	■		■	50 × 50	28 days standard curing
[Ta-2]	Overall adhesion strength test	■	■	■	250 × 400	
[Ta-3]	Partial adhesion strength test after cutting the entire surface	■	■	■	50 × 50	

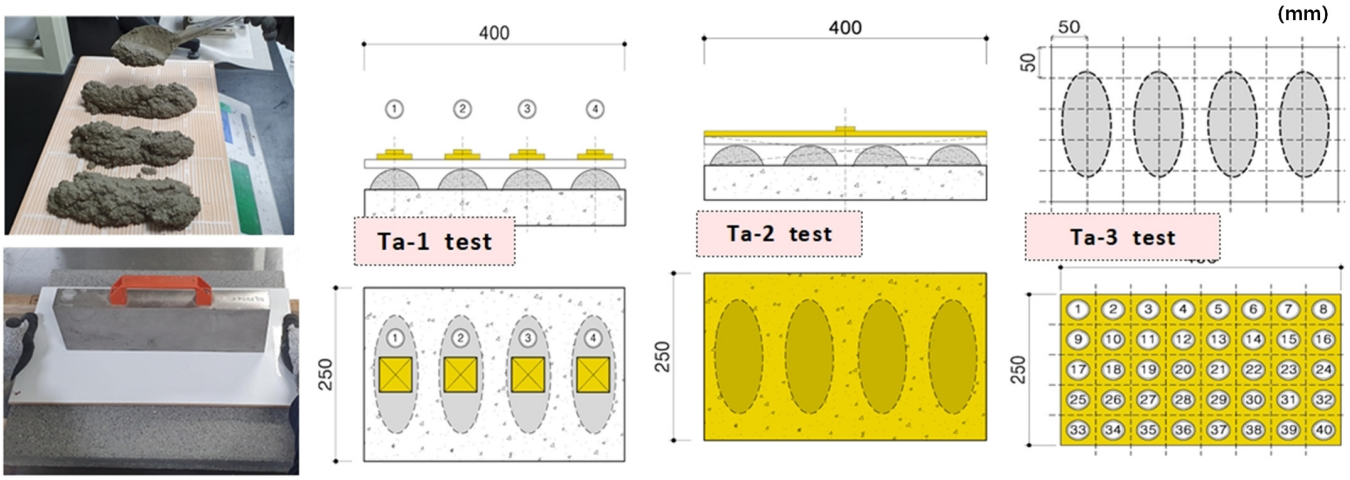


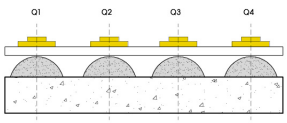
Figure 5. Attachment stability test status (mm) according to mortar attachment area from Table 2.

3. Test Results

3.1. Partial Adhesive Strength (Ta-1) Experiment Results

The results of the partial adhesion strength test for four parts attached with mortar of 400 g/spot on the concrete specimen (500 × 500 mm) were measured, as shown in Table 3, and the average adhesion strength was 0.85 N/mm^2, which is more than 217% higher than the 0.39 N/mm^2 standard suggested by the standard specification (KCS, [19]). However, looking at the deviation of the attachment strength between the two corners of the adhesion strength and the two centers of the center, the average adhesion strength (Q2, Q3) of the tiles that were heavily pressurized was measured at 1.18 N/mm^2, while the average adhesion strength of the corners (Q1, Q4) was 0.45 N/mm^2, which more than doubled, as shown in Figure 6. The results of observing the back of the tile after the partial adhesion strength test are shown in Figure 7, and it was confirmed that the Q2 and Q3 parts of the tile back surface were eliminated in the form of more than 90% of the sticking mortar, while Q4, the corner part of the tile, was eliminated with less than 30% of the adhesion between the sticking mortar and the parent body, which is the tile-holding part. Due to the nature of the cement mortar method, it is believed that the density of the mortar is lower at the corners than at the pressurized part of the tile.

Table 3. Partial adhesion strength test result.

Distinction	Adhesion Strength (N/mm^2)						Note
	Q1	Q2	Q3	Q4	Average (SD)	Overall Average	
FT-1	0.76	1.43	0.93	0.14	0.82 (0.46)	0.85	
FT-2	1.06	1.44	1.51	0.14	1.04 (0.55)		
FT-3	0.21	1.12	1.44	0.24	0.70 (0.54)		

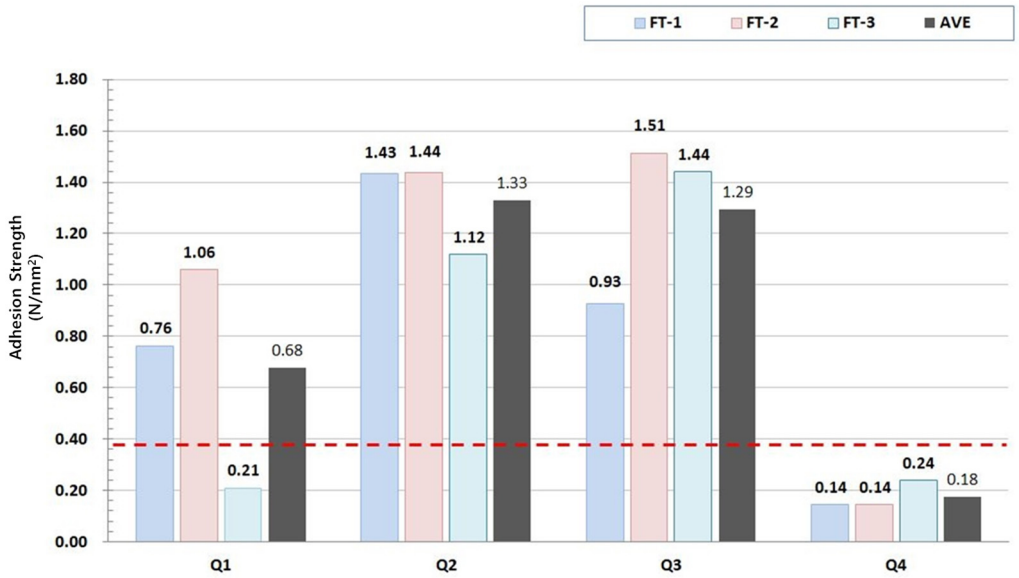


Figure 6. Partial adhesion strength test result.

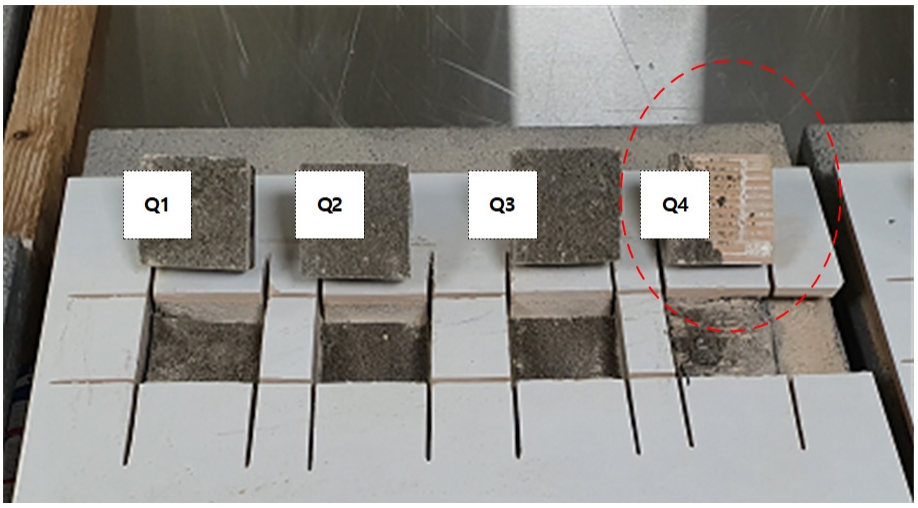


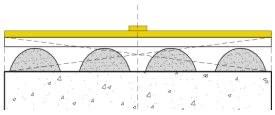
Figure 7. Current status of partial adhesion strength test.

3.2. Overall Adhesive Strength (Ta-2) Experiment Results

The adhesion strength was measured by attaching a specially manufactured attachment equal to the tile size (250 × 400 mm) to the front of the tile for ① 80 ± 3% RX1 and ② 60 ± 3% RX2, which were attached to the concrete specimen (500 × 500 mm) by attaching a mortar of 400 g/spot. The experimental results are shown in Table 4, and the average adhesion strength of 80 ± 3% RX1 was measured to be 0.17 N/mm^2, and it was 0.10 N/mm^2 for 60 ± 3% RX2, respectively. It was confirmed that RX1 was −81% (0.17 N/mm^2) and RX2 was −88% (0.10 N/mm^2) compared with the average adhesion strength (0.85 N/mm^2) of the previous partial adhesion strength (Ta-1) as shown in Figure 8. The significantly low strength results of Ta-2 appear to be related to various factors. Usually, the construction thickness of the tile-attached mortar is 12–24 mm at the construction site in Korea, and considering this, it was intended to adjust the thickness of the attached mortar as much as possible based on 15 ± 3 mm for the same height conditions as possible. It was difficult to adjust the horizontal height of the four types of mortar to 15 mm based on both corners in the process of pressing with the palm of the experimenter who attached the tiles and the shaking. Therefore, it is presumed that it was eccentric in a relatively high area rather than the same horizontal height during the pulling-out process, as shown in Figure 9. It is believed that the empty space acts as a lever in the pulling process, so the

force of the adhesive strength of the four mortars could not have been expressed. Unlike the results of the experiment with the small size of the attachment (Ta-1), concentrated stress is generated in the center of the test body in the pulling-out process using the attachment (250 × 400 mm). The bending phenomenon that occurs in the process of pulling the parent body (concrete attachment surface) and the attachment (250 × 400 mm) combined with the tile due to concentrated stress is believed to have resulted in a relatively increased adhesion stress (②, ③) before the intervention of the mortar (①, ④) (Figure 10).

Table 4. Overall adhesion strength test results.

Distinction	Adhesion Strength (N/mm^2)						Note
	1st	2nd	3rd	4th	5th	Average (SD)	
RX1 (250 × 400 mm, 80%)	0.17	0.16	0.19	0.18	0.17	0.17 (0.01)	
RX2 (250 × 400 mm, 60%)	0.10	0.11	0.09	0.12	0.11	0.10 (0.01)	

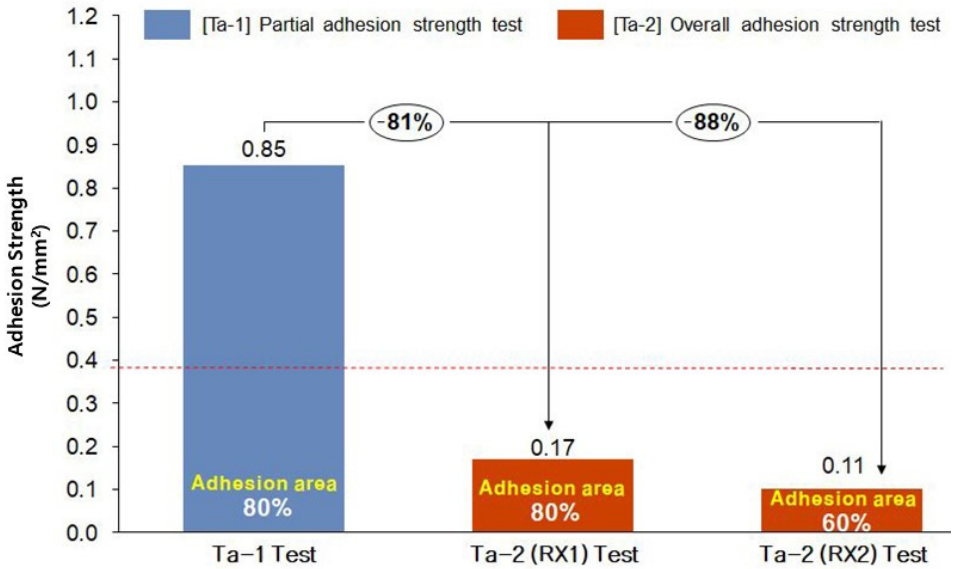


Figure 8. Overall adhesion strength test results.

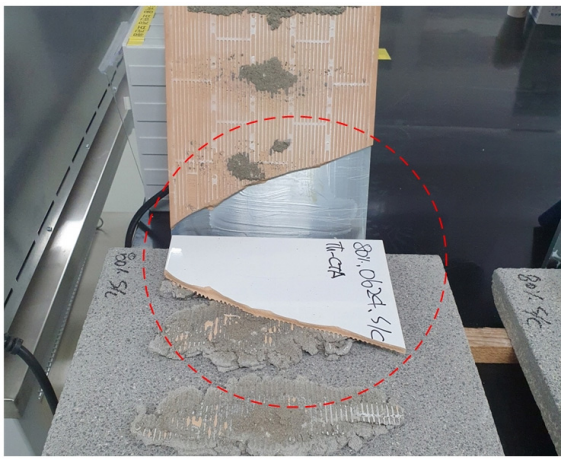


Figure 9. Current status of overall adhesion strength test.

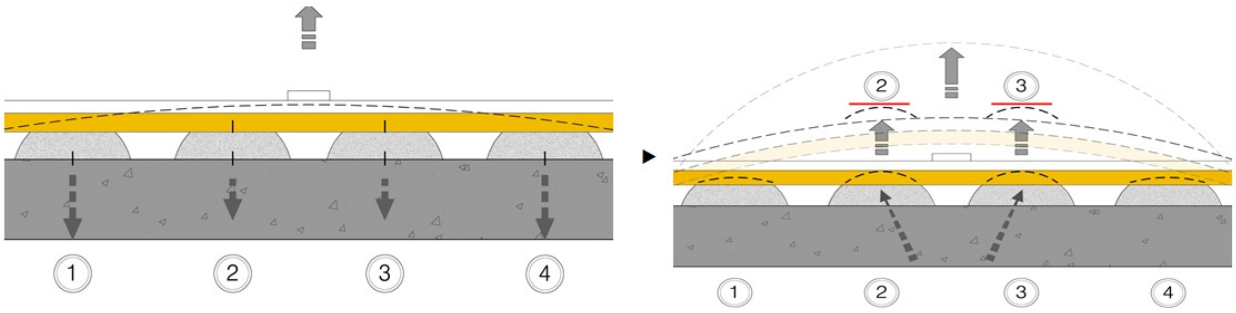


Figure 10. Theoretical phenomena of experiments using specially designed attachments.

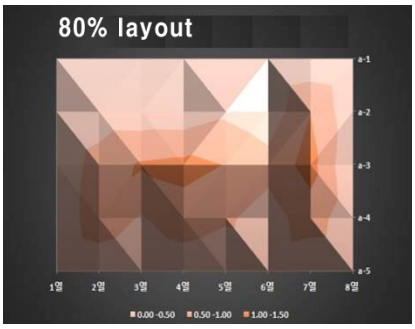
3.3. Partial Adhesive Strength (Ta-3) Experiment Results after Splitting

With a tile size of 250 × 400 mm and an adhesive area of 80% (±3) 50 × 50 mm of the overall tile, the adhesion strength was expressed in 26 (65%) of the 40 parts of the No. 1 specimen, and the average adhesion strength was measured at 0.31 N/mm^2 (Table 5). The adhesion strength of the No. 2 specimen was expressed on the mortar attachment surface of 15 (37.5%) of the total 40 subjects, and the average adhesion strength was measured at 0.31 N/mm^2 (Table 6). The adhesion strength of the No. 3 specimen was expressed in 24 (60%) of the total 40 mortar attachments, and the average adhesion strength was measured to be 0.29 N/mm^2 (Table 7). In the part where adhesion could be measured, 26 (65%) of 40 for the No. 1 specimen and 24 (60%) of 40 for the No. 3 specimen were measured, but in the case of the No. 2 specimen, the partial adhesion strength of 15 (37.5%) of the total 40 subjects was measured compared to the other two experiment subjects. Nevertheless, the result was similar to that of the four tests of the partial adhesion strength experiment (Ta-1), and due to the nature of the mortar method, the highest adhesion was found around the center of the specimen, as the most pressure was generated in the middle of the tiles. The attachment strength at the central part of the floating mortar was 0.98 N/mm^2 (X3, Y3), 1.12 N/mm^2 (X4, Y3), 1.44 N/mm^2 (X5, Y3), and 0.75 N/mm^2 (6, Y3). The average adhesion strength of the four areas was 1.07 N/mm^2, which was found to be about 174.35% higher than the current KCS standard of 0.39 N/mm^2. With a tile size of 250 × 400 mm and an adhesive area of 80% (±3), 50 × 50 mm, of the overall tile, adhesion strength was expressed in a total of 65 (54.1%) of the three 120 subjects, and the overall average was measured to be 0.31 N/mm^2. The arithmetic average measurement of the total adhesion strength, including 80% of the adhesion area of the tile 250 × 400 mm attached mortar and 20% of the empty area, was finally confirmed to be an average of 0.31 N/mm^2, which is about −20.5% less than 0.39 N/mm^2 based on the KCS building standard, and the detailed test status is shown in Figure 11.

Figure 11. Status of partial adhesion strength test after cutting for whole tile.

Table 5. Attachment strength test result after front cutting (80% covered area result-1).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.00	0.00	0.00	0.00	0.00	0.00	0.13	0.00	0.02(0.04)	Overall
Y2	0.00	0.20	0.19	0.16	0.40	0.17	0.99	0.13	0.28(0.29)	average
Y3	0.00	0.71	1.06	1.14	0.99	0.69	1.19	0.00	0.74(0.45)	0.31
Y4	0.14	0.81	0.45	0.81	0.59	0.25	0.78	0.13	0.50(0.28)	N/mm^2
Y5	0.14	0.15	0.00	0.14	0.00	0.16	0.00	0.00	0.06(0.07)	
Average	0.06	0.37	0.34	0.45	0.39	0.25	0.62	0.05		26
(SD)	(0.07)	(0.32)	(0.40)	(0.44)	(0.38)	(0.23)	(0.47)	(0.06)		measurable



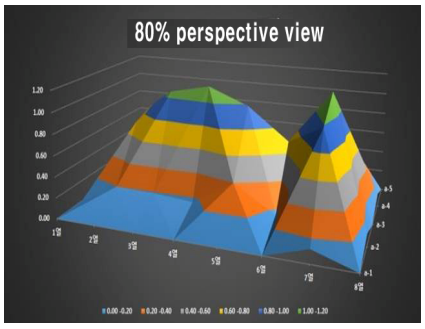
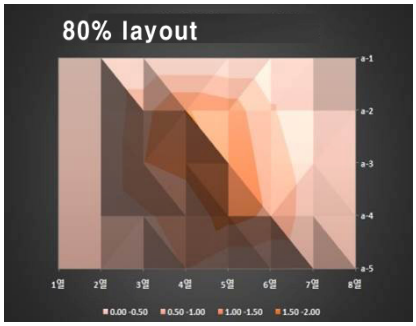


Table 6. Attachment strength test result after front cutting (80% covered area result-2).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00(0.00)	Overall
Y2	0.00	0.00	0.84	1.53	1.29	0.57	0.00	0.00	0.53(0.59)	average
Y3	0.00	0.00	**0.98**	**1.12**	**1.44**	**0.75**	0.24	0.00	0.57(0.54)	0.31
Y4	0.00	0.00	0.41	0.73	1.19	0.89	0.21	0.00	0.43(0.43)	N/mm^2
Y5	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.06(0.17)	
Average	0.00	0.00	0.45	0.78	0.79	0.44	0.09	0.00		15
(SD)	(0.00)	(0.00)	(0.41)	(0.52)	(0.65)	(0.37)	(0.11)	(0.00)		measurable



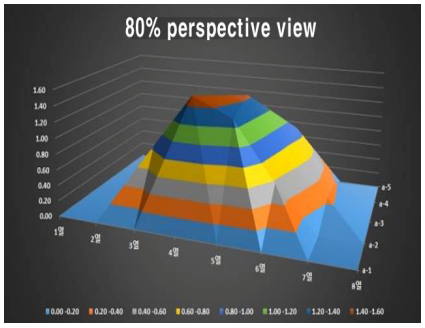
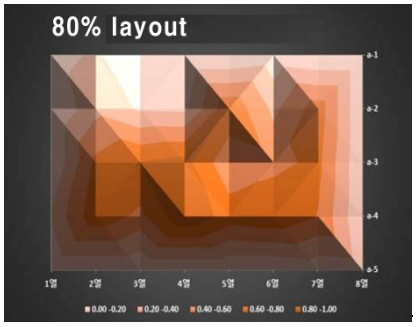
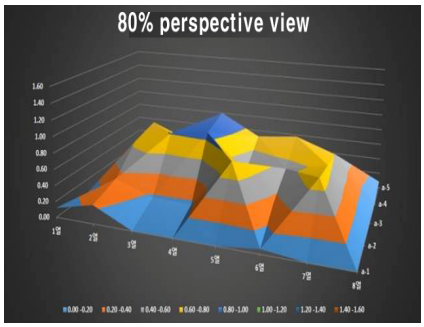


Table 7. Attachment strength test result after front cutting (80% covered area result-3).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.12	0.23	0.00	0.00	0.00	0.06	0.00	0.00	0.05(0.08)	Overall
Y2	0.00	0.34	0.17	0.16	0.77	0.35	0.71	0.00	0.31(0.28)	average
Y3	0.00	0.65	0.81	0.88	0.44	0.54	0.65	0.00	0.50(0.31)	0.29
Y4	0.23	0.74	0.55	0.97	0.71	0.77	0.59	0.00	0.57(0.29)	N/mm^2
Y5	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.08	0.02(0.03)	
Average	0.07	0.39	0.31	0.40	0.38	0.34	0.40	0.02		24
(SD)	(0.09)	(0.27)	(0.32)	(0.43)	(0.33)	(0.29)	(0.031)	(0.03)		measurable





After cutting with a tile size of 250 × 400 mm and an adhesive area of 60% (±3) 50 × 50 mm of the overall tile, the adhesion strength in 40 parts was measured. The No. 1 specimen was measured at an average of 0.20 N/mm^2 at 14 locations (Table 8), the No. 2 specimen was measured at an average of 0.28 N/mm^2 at 14 locations (Table 9), and the No. 3 specimen was measured at an average of 0.26 N/mm^2 at 16 locations (Table 10), respectively. In the measurement process (Figure 12), the empty area for the No. 1 specimen was found to be a total of 32 parts in the top (1) and bottom (Y5) columns of the tile, and the empty area for the No. 2 specimen was found to be a total of 20 adhesives (mortar) in the leftmost (X1 column) and the rightmost end (X8 column) of the tile. In this area, adhesive strength could not be measured. In summary, for specimen having a 60% attachment area, the average adhesion of three experiments with 60% (±3) tiles was 0.25 N/mm^2, which was measured to be −24.0% lower than the average adhesion of 0.31 N/mm^2 of 80% (±3) and −35.9% lower than the building standard specification (KCS, [19]). The comprehensive test results for the two types of adhesion areas (60% and 80%) and the three types of adhesion strength methods are presented in Table 11 and Figure 13.

Table 8. Attachment strength test result after front cutting (60% covered area result-1).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00(0.00)	Overall
Y2	0.00	0.23	0.16	0.36	0.95	0.43	0.71	0.00	0.35(0.31)	average
Y3	0.00	0.27	1.02	0.40	0.97	0.92	0.52	0.00	0.51(0.39)	0.20
Y4	0.00	0.00	0.38	0.00	0.89	0.00	0.00	0.00	0.16(0.30)	N/mm^2
Y5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00(0.00)	
Average	0.00	0.50	0.91	0.95	1.56	1.47	1.65	0.00		14
(SD)	(0.00)	(0.12)	(0.38)	(0.19)	(0.46)	(0.37)	(0.31)	(0)		measurable

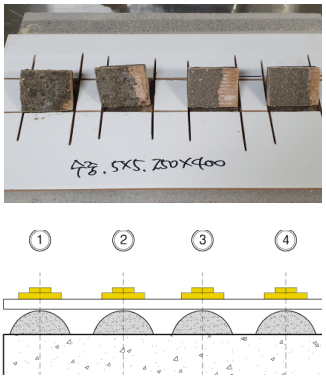
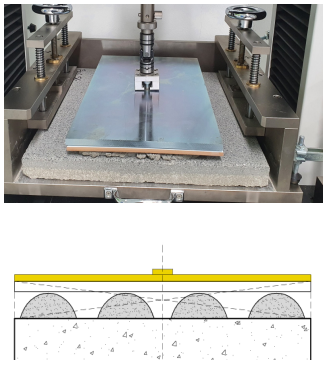
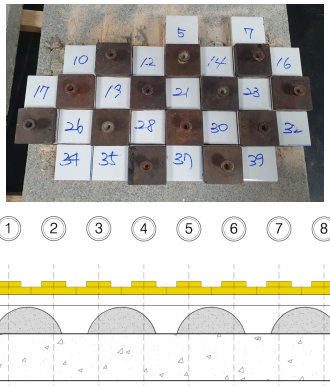
Table 9. Attachment strength test result after front cutting (60% covered area result-2).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00(0.00)	Overall
Y2	0.00	0.00	0.86	0.00	0.90	0.51	0.68	0.00	0.37(0.38)	average
Y3	0.00	0.00	1.07	1.01	1.00	1.00	0.74	0.00	0.60(0.48)	0.28
Y4	0.00	0.00	0.94	0.40	0.95	0.68	0.63	0.00	0.45(0.38)	N/mm^2
Y5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00(0.00)	
Average	0.00	0.00	1.17	1.08	1.57	1.64	1.81	1.60		14
(SD)	(0.00)	(0.00)	(0.47)	(0.40)	(0.47)	(0.39)	(0.34)	(0.00)		measurable

Table 10. Attachment strength test result after front cutting (60% covered area result-3).

Distinction	X1	X2	X3	X4	X5	X6	X7	X8	Average (SD)	
Y1	0.00	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.03(0.07)	Overall
Y2	0.00	0.18	0.47	0.65	0.00	0.00	0.85	0.00	0.27(0.32)	average
Y3	0.00	0.41	1.21	0.94	0.97	0.78	0.75	0.00	0.63(0.42)	0.26
Y4	0.00	0.00	0.77	0.47	0.88	0.81	0.00	0.00	0.37(0.38)	N/mm^2
Y5	0.00	0.00	0.00	0.21	0.00	0.00	0.00	0.00	0.03(0.07)	
Average	0.00	0.52	1.09	1.21	1.41	1.52	1.72	1.60		16
(SD)	(0.00)	(0.16)	(0.46)	(0.33)	(0.43)	(0.39)	(0.39)	(0.00)		measurable

Table 11. Comprehensive comparison table by tile adhesion test results.

	① Partial adhesionstrength test result [Ta-1]	② Overall adhesionstrength test result [Ta-2]	③ Attachment strength testresult after front cutting [Ta-3]
Distinction			
Attachment	50 × 50 mm	250 × 400 mm	50 × 50 mm
Result	80% 0.85 N/mm^2	0.17 N/mm^2	0.31 N/mm^2
	60% -	0.10 N/mm^2	0.25 N/mm^2

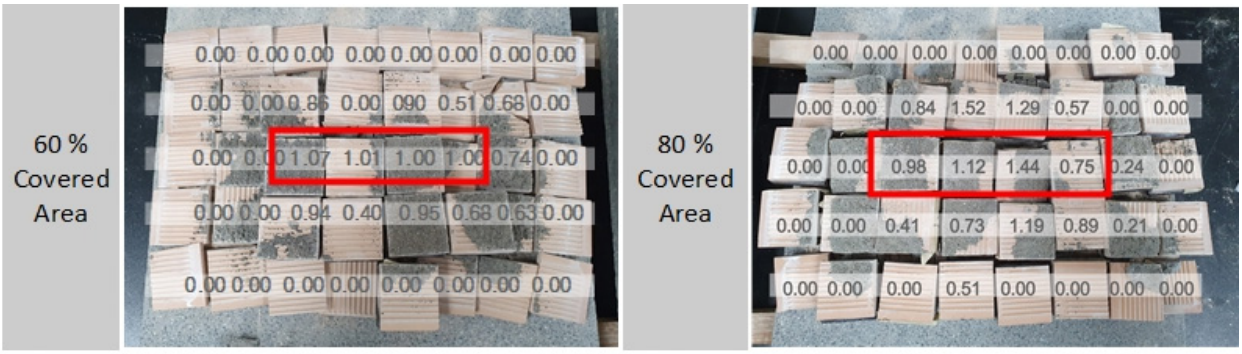


Figure 12. Current status of comparative specimens with 60% and 80% covered area (Red box: where the adhesion strength is highest).

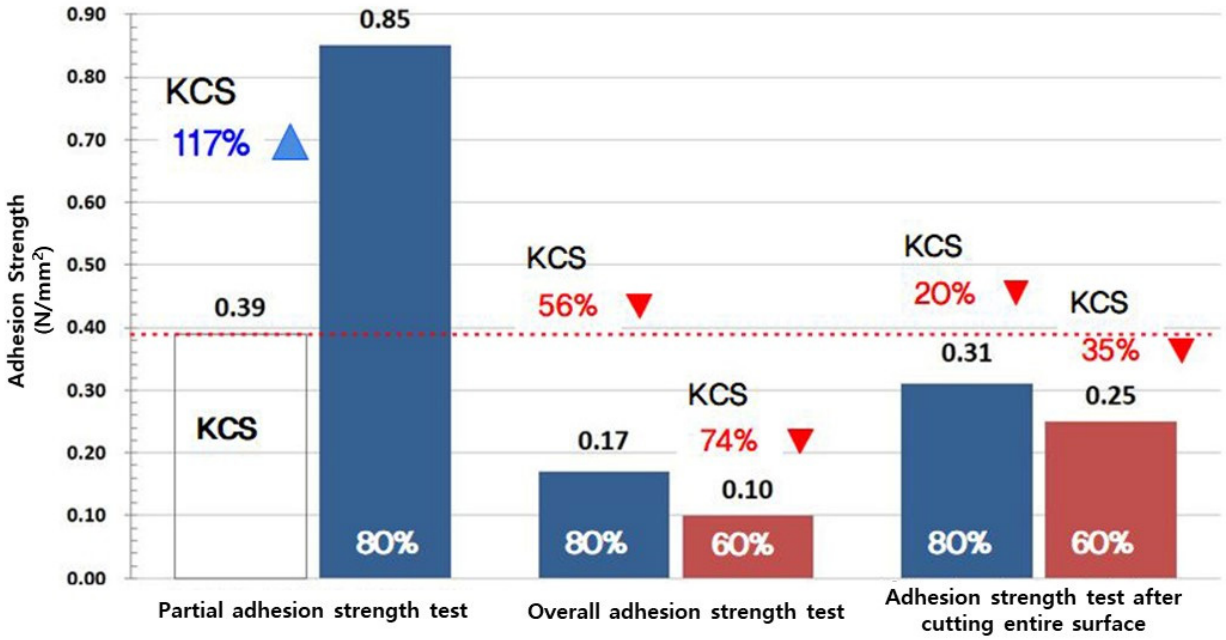


Figure 13. Comprehensive comparison table by tile adhesion test results.

4. Conclusions

1. Most of the bathroom wall tiles of apartment houses are being constructed using the mortar method, but the lack of attachment area for large tiles does not even fill the 80% mortar (adhesive), which is the minimum attachment area, so lawsuits for construction defects are constantly occurring every year. Tile adhesive strength was measured in three ways: ① partial adhesion strength measurement (KCS based on construction specification, 80% adhesion area), ② overall adhesion strength measurement (60% and 80% adhesion area), and ③ partial adhesion strength measurement (60% and 80% adhesion area) after cutting the overall tile to 50 × 50 mm size.
2. As a result of the experiment for [Ta-1], the partial adhesion strength averaged 0.85 N/mm^2 for four areas attached by the mortar having 80% of the adhesion area, which was more than 217% higher than the 0.39 N/mm^2 suggested by the Korea Construction Specification (KCS). Looking at the shape of the destruction, it was confirmed that the Q2 and Q3 areas of the tile's back face were eliminated in the form of more than 90% of the mortar, but Q4, the corner of the tile, confirmed that the combination of the mortar and the parent body, which is the tile-holding part, was eliminated with less than 30% adherence.
3. As a result of the experiment for [Ta-2], the average adhesion strength of RX1 with an 80 ± 3% tile attachment area of 250 × 400 mm was measured to be 0.17 N/mm^2, and the

average adhesion strength of RX2 with 60% (±3) tile attachment area of 250 × 400 mm was measured to be 0.10 N/mm^2. Compared with the average adhesion strength of 0.85 N/mm^2 of the partial adhesion strength [Ta-1], RX1 was −81% (0.17 N/mm^2), and that of RX2 was −88% (0.10 N/mm^2), which was significantly lower. In the process of the experiment, a pin was fastened to one point in the center of the test body among four (80%) attached mortar and was drawn. As the central point's concentration stress was a bending phenomenon that pulls the attachment on the parent (concrete substrate) + tile, the attachment area of the middle attachment mortar decreased first. It is judged that the adhesion of the edge attachment mortar was not expressed and had been eliminated.

4. As a result of the experiment [Ta-3], the partial adhesion strength with 80 ± 3% attachment area after cutting the overall title to 50 × 50 mm, the strength of 65 places (54.1%) was expressed in three experiments (120 places in total), and the overall average was measured to be 0.31 N/mm^2. The average value of the total adhesion strength, including an 80% adherence area of the attached mortar and 20% of the empty area, was found to be an average of 0.31 N/mm^2, which is about −20.5% less than 0.39 N/mm^2 based on the KCS building standard.

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