A Study of the Field Test Method for the Adhesive Performance Evaluation of Self-Adhesive Waterproofing Sheets

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Abstract: In the field of waterproofing concrete structures, the use of self-adhesive waterproofing sheets has become a popular technique for ensuring long-term waterproofing performance. One important characteristic of such sheet materials is maintaining their stable adhesion strength over an extended period. Adhesion testing serves as a crucial method for assessing the long-term adhesion performance. However, a standardized test method, including equipment and criteria, for directly measuring the adhesion strength of waterproofing sheets applied to onsite concrete walls has not yet been established. Therefore, reliance on laboratory evaluation results has been the only option thus far. In this study, a field-applicable adhesion measurement device was developed in an effort to provide a quality control method for self-adhesive waterproofing sheets and to demonstrate the validity of a standardized evaluation method utilizing this device. The developed adhesion measurement device was designed based on the principle of the peel-out test in compliance with the requirements outlined KS F 4934, where the test specimen backing plate can slide into a 1:1 ratio at the same distance as the rise of the tension jig when the tension jig is raised at a 45° angle. By utilizing this device, the adhesion strength values of self-adhesive waterproofing materials applied in the field were compared with those obtained using a laboratory universal testing machine (Salem, MA, USA) (UTM) on the test specimens. Comparative analysis yielded that the standard deviation of the results varied for the tested waterproofing materials, and the overall standard deviation for the UTM measurements was 0.17, while it was 0.18 for the portable field measurement equipment. The results of the comparison indicated that when limited to the scope of the KS measurement method specifications, the possibility for a wider scope of usage can be made possible with more data and studies.

Keywords: adhesion; peel-out; self-adhesive waterproofing sheet; concrete waterproofing; adhesive strength performance; test method

1. Introduction

In general, sheet-type waterproofing materials are commonly applied to the vertical surfaces of concrete structures. To ensure the continuous performance of sheet-type waterproofing materials, it is crucial to maintain the long-term adhesion between the substrate and the waterproofing material [1,2]. Consequently, many countries have established quality standards for adhesion strength in sheet-type waterproofing materials to manage their performance. The adhesion strength management of sheet waterproofing is typically conducted by physically detaching the sheet material attached to the substrate in a laboratory setting to measure the adhesion strength. However, direct measurement of the adhesion strength for waterproofing layers applied onsite is less prevalent [3].
As a result, while sheet-type waterproofing materials undergo quality testing by accredited testing agencies to obtain adhesion strength test reports prior to their delivery to the construction site, there are no established test methods or criteria for verifying the adhesion strength after completion of onsite installation. This situation leads to an inability to compare adhesion strength values obtained through laboratory testing with those observed in actual construction settings [3].

To address the challenges associated with onsite adhesion strength evaluation of self-adhesive waterproofing sheets, researchers and practitioners have conducted various studies on the subject. Several researchers have investigated the effects of environmental conditions on the adhesion performance of self-adhesive waterproofing sheets during onsite installation. For instance, Chenwi et al. explored the impact of prolonged exposure to saline water on the adhesion strength of polyurea [4]. Previous research by Hedulian et al. explored the general assessment of the adhesion strength indicators of polymer–cement repair materials onto the concrete base and the degree of the repeatability of the results [5]. Liu et al. provided an extensive study on the topic of the curing process and the thermal failure of the adhesive-bonded structures based on the damping measurement using quantitative electromechanical impedance [6]. Kim et al. studied the effects of different wet surface conditions on the adhesion strength of the synthetic polymer rubberized gel waterproofing materials and proposed a new method and experimental regime to assess the adhesion performance of the waterproofing material [7].

In construction sites, sheet waterproofing materials and their adhesion methods can be broadly classified into bond-type adhesion and self-adhesive methods. Bond-type adhesion involves using bonding agents such as asphalt-based or epoxy-based adhesives to attach materials like asphalt sheets, synthetic rubber sheets, and polyvinyl chloride (PVC) sheets to the substrate [8]. On the other hand, self-adhesive methods involve the factory application of a tacky and flexible rubber asphalt-based adhesive layer to the sheet material, allowing for direct attachment to the substrate without the need for additional adhesives.

Recently, self-adhesive waterproofing sheets have been widely used in the external waterproofing of concrete structures, primarily on vertical surfaces, due to their adhesive flexibility and the convenience of direct attachment without the use of separate adhesives [9]. This method aims to facilitate the structural response of the system and expedite the installation process.

However, when self-adhesive waterproofing sheets are installed onsite, they are exposed to environmental conditions for a certain period. Prolonged exposure to direct sunlight and temperature fluctuations during the summer season can cause issues such as blistering and delamination of the waterproofing layer, as depicted in Figure 1 [10].

![Figure 1](image-url)

**Figure 1.** Onsite delamination of self-adhesive waterproofing sheets on vertical surfaces during the summer season. (a) Sheet condition after prolonged exposure to summer monsoon; (b) delamination on vertical wall due to deflection.

To address the issue of deflection in self-adhesive waterproofing sheets, some cases employ a method where structural steel fasteners, as shown in Figure 2, are used to forcibly...
restrain and secure the sheets to the structure at the top or intermediate joints of the waterproofing layer [11].

![Termination Bar and Waterproofing Layer](image.jpg)

**Figure 2.** Termination bar anchoring for sheet waterproofing material on wall using structural steel fasteners.

In the Republic of Korea, for such self-adhesive waterproofing sheets, the adhesion strength is typically measured in the laboratory, according to the attachment strength measurement method specified in KS F 4934 [12]. However, there is currently no established method to assess the adhesion strength at actual construction sites.

The difficulty in measuring the adhesion strength of sheet waterproofing materials at construction sites stems from the variety of sheet types available (such as asphalt-based, synthetic rubber-based ethylene propylene diene terpolymer (EPDM), and synthetic polymer-based PVC, ethylene-vinyl acetate (EVA), high density polyethylene (HDPE), etc.), as well as the presence of polymer film layers on the sheet surface. Attaching the required equipment for adhesion strength measurement, known as attachments, often necessitates the use of epoxy adhesives without solvents [9]. However, these epoxy adhesives do not adhere firmly to the polymer film, leading to detachment of the attachments during strength measurements at the adhesive boundary [13].

Currently, construction practices heavily rely on the skills of workers, lacking appropriate evaluation methods for quality management. Therefore, it is necessary to demonstrate the ability to secure a stable adhesion strength for self-adhesive waterproofing sheets and establish suitable onsite adhesion quality assessment methods to enhance reliability in the waterproofing industry [13].

This study proposes a new model of an evaluation method that involved developing a field adhesion strength measurement equipment for waterproofing sheets in order to assess the adhesion strength after the installation of self-adhesive waterproofing sheets at a construction site [14]. A total of six representative types of self-adhesive waterproofing sheets commonly used in domestic construction sites were selected for experimentation. These included two types of rubberized asphalt-based sheets, two types of butyl rubber-based sheets, and two types of adhesive synthetic rubber-based sheets. Hybrid types or modified asphalt waterproofing sheets were excluded to ensure controlled variables.

The experimental methods and conditions were designed to closely resemble real onsite environments. Firstly, deflection resistance tests and shear adhesion strength measurements were conducted on the self-adhesive waterproofing sheets to investigate the causes of deflection. Secondly, an analysis was performed on the phenomena related to delamination through adhesion strength measurements, aiming to understand the underlying principles of adhesion strength manifestation. Lastly, a key focus of this study was to verify whether the onsite adhesion strength measurement equipment aligned with measurements obtained from the laboratory equipment (UTM) for the purpose of introducing the onsite adhesion strength measurement equipment to actual construction sites.
2. Material and Methods

When a liquid droplet exists on a solid surface, the angle formed between the liquid–gas interface and the liquid–solid interface is a measure of how well the solid surface can be wetted by the liquid. When a liquid droplet is present on a solid surface, the balance of two forces determines the shape of the liquid droplet. One force is cohesion, which refers to the attractive forces between the molecules within the liquid itself, and this force tends to make the liquid droplet spherical. The other force is adhesion, which refers to the attractive forces between the liquid and the solid, and this force tends to spread the liquid droplet widely on the solid surface. Therefore, the shape of the liquid droplet is determined by which of these two forces is dominant [15]. Figure 3 below illustrates this concept.

![Figure 3. Contact angle due to surface tension.](image)

The contact angle, as shown in Figure 3, is the angle measured on the inside of the liquid between the liquid–gas interface and the liquid–solid interface. Therefore, when cohesion is dominant, the contact angle increases (close to a sphere), and when adhesion is dominant, the contact angle decreases (spreads widely). When a liquid exhibits a small contact angle and spreads completely on the solid surface, it is referred to as hydrophilic, and significant wetting occurs. The solid surface is said to be hydrophilic. On the other hand, when the liquid exhibits a large contact angle, with minimal wetting occurring on the solid surface, and water droplets roll on the surface, it is referred to as super-hydrophobic. In this case, the liquid exists as separate nearly spherical liquid droplets on the solid surface [15]. Based on these principles, for adhesive strength measurement, it is important to clearly outline the key parameters to develop a quantitative measurement method with minimal influence from the fewest variables possible. For this, reference to existing adhesion strength measurement methods and outlining the key principles of these methods is required.

2.1. Types of Adhesion Strength Measurement Methods for Self-Adhesive Waterproofing Sheets (Laboratory Testing Methods)

For adhesion peel testing, various methods exist, including the roller drum peel method and 90° and 180° peel adhesion testing. These methods, as shown in Figure 4, are employed to measure the adhesion strength. While there may be slight variations in certain test conditions, such as the sample size and testing speed, the testing methods remain consistent across both domestic and international standards [16,17].

However, all existing adhesion strength testing methods, including those shown in Figure 4, require the use of an UTM or specialized peel testing equipment, where the force is applied vertically. Currently, there are no specific testing standards available to measure the adhesion strength of waterproofing sheets adhered to vertical concrete surfaces.

The only relevant adhesion strength testing standard for waterproofing sheets is the peel-out test specified in KS F 4934, which does not allow for testing on vertical surfaces. The roller drum peel method shown in Figure 4a, the American Society for Testing and Materials (ASTM D 3167) [18], is the most similar to the peel-out test method in KS F 4934 and can be considered a Korean adaptation of that method. In this method, when the waterproofing sheet is pulled by the crosshead, the substrate moves in proportion to the distance the sheet is peeled.
The 180° peel method shown in Figure 4b [19] requires the sample to be peeled off the concrete surface while maintaining a 180° angle. This makes it difficult to secure the sample to the testing equipment. Even if the sample is attached, when measuring in the vertical or horizontal directions, the uneven concrete surface can affect the applied load on the measurement area due to the movement of the crosshead. Additionally, due to Newton’s third law of motion (action–reaction principle), if the ends of the waterproofing sheet are not securely fixed, there is a risk of the testing equipment hanging on the sheet when the crosshead pulls a portion of the sheet with greater adhesion strength than the load of the testing equipment. This can lead to measurement errors. Furthermore, the results obtained may differ from the quality inspection results specified in KS F 4934.

The 90° peel method shown in Figure 4c, is the method outlined in ASTM D6862-11 [20], where the tested specimen is affixed to the grips of the testing machine with the adhesive bond area exposed. The test is performed at a specified peel angle (90° degrees) and at a constant crosshead speed (commonly 300 mm/min). The testing machine pulls the adherends apart until the adhesive bond fails and records the maximum force required for peeling. It is important that the crosshead moves upward while the sliding plate connected to the wire beneath the specimen maintains the same movement speed as the crosshead. However, to measure a sample adhered to a concrete substrate, both the main body of the testing equipment and the crosshead need to move simultaneously and consistently.

### 2.2. Peel-Out Test Method and Calculation of Measurement Results

The calculation method for the peel-out test measurement results, as specified in KS F 4934, is described in Figure 5. The test specimen is passed through a sliding jig, and one end that is not adhered to the test substrate is fixed to the tension testing device, ensuring a peel angle of 90° ± 5°. The sheet is then peeled by 20 mm, excluding the initial peel length, and gradually pulled at a tensile speed of 100 mm/min.

For the peel-out test, the load–peel length curve is divided into four equal sections beyond the initial peel length of 20 mm, as shown in Equation (1). The peel load values (P1, P2, P3, P4, and P5) at the intersection points (Pi) of the division lines and the load curve are read as the measurement values of the test specimen. The result is based on the average value that is calculated from measurements taken on five specimens [4].

\[
F = \frac{\sum_{i=1}^{5} P_i}{5 \times 50},
\]

where

- \( F \) = Adhesive Strength (N/mm);
- \( P_i \) = Force (N).
(P1, P2, P3, P4, and P5) at the intersection points $(P_i)$ of the division lines and the load curve are read as the measurement values of the test specimen. The result is based on the average value that is calculated from measurements taken on five specimens [4].

\[ F = \frac{\sum P_i \times d_i}{n}, \quad (1) \]

where $F$ = Adhesive Strength (N/mm); $P_i$ = Force (N).

Figure 5. Peel-out test method and measurement result calculation.

2.3. Development of Onsite Adhesion Strength Measurement Equipment

When measuring the adhesion strength of waterproofing sheets adhered to concrete surfaces in the field, it is necessary to measure the force of the sheet peeling vertically from the concrete substrate. However, applying the roller drum peel method can be challenging due to the inability to move the substrate when measuring the adhesion strength of the waterproofing sheets attached to actual concrete walls or floors.

Among the existing methods, the $90^\circ$ peel method ensures that the peel length of the sample and the distance traveled by the crosshead are equal. By drawing a graph depicting the relationship between the crosshead’s movement and the distance between the test specimen’s backing cellulose fiber reinforced cement (CRC) board as shown in Figure 6, it is observed that the graph precisely follows a $1:1$ ratio at a $45^\circ$ angle. Based on this observation, the testing equipment was designed assuming the movement of the crosshead at a $45^\circ$ angle while peeling the sample. The graph represents a theoretical measurement process during a peel-off of a waterproofing sheet, where the relevant data of the linear regression line for the crosshead displacement relative to the displacement occurring on the CRC board (blue line, marked by blue circles for the intersection points $(P_i)$ for Equation (1)) is demarcated by the red area.

Therefore, the adopted approach for direct onsite measurements is based on the $90^\circ$ peel method or a modified roller drum peel method as the foundation. To propose and develop the onsite adhesion strength measurement equipment, several important factors were considered. Firstly, the movement of the equipment during measurements should not transfer its weight onto the sample. Secondly, lightweight design was prioritized to ensure mobility for onsite measurements. Thirdly, the equipment should allow for immediate confirmation of measurement results at the site. Lastly, the ability to measure the adhesion strength of self-adhesive waterproofing sheets applied to vertical surfaces was a key focus. Taking these considerations into account, a design was created as shown in Figure 7, and a physical prototype was produced as depicted in Figure 8.
Some important factors that influence the adhesive peel strength include the specimen thickness, the measurement speed, and the onsite temperature. Among these factors, a
higher measurement speed results in a higher adhesive peel strength measurement. In the case of KS F 4934, the specified measurement speed was 100 mm/min, which corresponds to the vertical movement speed of the tension jig. However, for the developed onsite equipment, considering that the tension jig moved at a 45° angle, the distance traveled by the tension jig differed by $\sqrt{2}$ due to the trigonometric calculations. To align the measurement speed with the UTM, it was set to 141 mm/min. Preliminary measurement results showed very similar values to the adhesive peel strength measured by the UTM for the same sample. Based on these results, further testing was conducted.

3. Comparison of the Adhesion Evaluation According to the UTM Device Measurement Method and the Field Equipment Measurement Method

3.1. Experiment Design and Method

In this study, we used self-adhesive waterproofing sheets that are commonly applied in external waterproofing construction. We selected a total of six samples, including two types each from three different categories of rubberized asphalt-based, butyl rubber-based, and adhesive synthetic rubber-based waterproofing sheets. The adhesion strength of these samples was measured according to the attachment strength measurement method specified in KS F 4934 under laboratory conditions ($23 \pm 3$ °C, $65 \pm 5$% relative humidity).

The experimental results were obtained for multiple test materials, as shown in Table 1. Based on these results, standard adhesion strengths were designated for each category, which were then utilized as the fundamental data for this study.

Table 1. Specimen Types.

<table>
<thead>
<tr>
<th>Type</th>
<th>Specimen Labels</th>
<th>Primer Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rubberized Asphalt</td>
<td>A-1, A-2</td>
<td>Asphalt</td>
</tr>
<tr>
<td>Butyl Rubber</td>
<td>B-1, B-2</td>
<td>Butyl</td>
</tr>
<tr>
<td>Polymer Adhesive</td>
<td>C-1, C-2</td>
<td>Asphalt, None</td>
</tr>
</tbody>
</table>

3.1.1. Laboratory Adhesion Strength Measurement Using UTM

In this experiment, the adhesion strength of the self-adhesive waterproofing sheets was determined according to the specifications of KS F 4934. Firstly, the primer specified by the manufacturer was applied to CRC boards and allowed to cure for 4 h at room temperature. Then, the self-adhesive waterproofing sheets were attached and pressed using a roller. The prepared test specimens were installed in the UTM device, as shown in Figure 9, and allowed to stabilize for at least 1 h at 20 °C. The adhesion strength was measured at an elongation speed of 100 mm/min. Ten measurements of adhesion strength were conducted for each of the six sample types, and the average value excluding the maximum and minimum values was considered as the adhesion strength.

Figure 9. Peel-out test equipment (UTM); (a) specimen undergoing thermal treatment, (b) adhesion measurement (UTM).
To ensure that the tensile performance of the polymer film used as the upper layer of the self-adhesive waterproofing sheets did not affect the physical properties of the polymer adhesive layer, fabric tape was attached to the upper surface of the film. This reinforcement prevented the polymer film from fracturing or elongating during the experiment, thus controlling the variables.

3.1.2. Measurement of Field Adhesion Using the Field Attachment Device

To measure the field adhesion, a portable device specifically designed for this purpose was used under the same temperature conditions as the previous adhesion strength measurements. Due to the unpredictable nature of the atmospheric conditions at the field site compared to the controlled laboratory conditions, the portable device was placed inside a temperature-controlled chamber to maintain a consistent temperature. The measurement results obtained from the portable device were then compared with the results obtained from the UTM device.

Under room temperature conditions, the primer specified by the manufacturer was applied to CRC boards and allowed to cure for 4 h. Subsequently, the self-adhesive waterproofing sheets were attached to the primed CRC boards using a roller for compression, following the same procedure as described earlier. The prepared test specimens were installed in the field attachment device, as shown in Figure 10, and allowed to stabilize for at least 1 h at temperatures of 5 °C, 10 °C, 20 °C, 30 °C, and 40 °C. The adhesion strength was measured at an elongation speed of 141 mm/min.

![Figure 10](image_url)

**Figure 10.** Peel-out test equipment (field equipment) (a) specimen undergoing thermal treatment, (b) adhesion measurement (field equipment).

To ensure that the performance of the film layer did not affect the compound layer, fabric tape was applied to the upper surface of the film. Similar to the measurements conducted using the UTM device, ten measurements of adhesion strength were performed for each type of self-adhesive waterproofing sheet. The average value, excluding the maximum and minimum values, was calculated as the adhesion strength.

3.2. Tensile Strength Measurement for Controlling Variables

The peel-out test method is the only method available to physically remove the self-adhesive waterproofing sheet from the substrate and assess the adhesion strength. It is a type of tape adhesion peel test performed at a 90° angle. However, there are some issues in the measurement process that need to be addressed and improved.

Figure 11 illustrates the phenomenon of errors occurring between the test substrate and the test specimen during the peel-out test process of the self-adhesive waterproofing sheet attached to the CRC board. Figure 12 shows that when the adhesion strength of the polymer adhesive layer was higher than the tensile strength of the upper polymer film, the elongation of the polymer film led to a difference in the bonding area and the elongation length of the self-adhesive waterproofing sheet, causing the angle between the test substrate and the tensile jig to deviate from 90°. To control the variables in the test method due to the different test materials, fabric tape was applied to the upper polymer film of the
self-adhesive waterproofing sheet to reinforce and restrain the film from elongating at the grip of the UTM and the field equipment, which allows a more consistent localized adhesive strength measurement of materials with high elongation properties such as the polymer self-adhesive waterproofing sheet, whereas testing without the tape reinforcement would yield highly inconsistent results, as the tensile force would localize only at the contact point of the waterproofing sheet and the jig. The fabric tape used had a tensile strength of 5.0~6.0 N/mm and an elongation rate within the range of 510%.

Figure 11. Peel-out measurement errors that occur when measuring.

Figure 12. Reduced specimen width which frequently occurs during peel-out testing.
3.2.1. Tensile Strength Measurement with and without Fabric Tape Reinforcement for Variable Control

In this evaluation, the tensile strength was measured with and without the reinforcement of fabric tape to assess the ability to restrain the elongation of the polymer film. The measurement results are presented in Table 2 and Figure 13.

Table 2. Comparison of the tensile strength between the fabric tape-reinforced and unreinforced samples (unit: N/mm).

<table>
<thead>
<tr>
<th>Specimen Types</th>
<th>A-1</th>
<th>A-2</th>
<th>B-1</th>
<th>B-2</th>
<th>C-1</th>
<th>C-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced tensile strength</td>
<td>5.7</td>
<td>3.3</td>
<td>4.3</td>
<td>13.6</td>
<td>14.6</td>
<td>10.4</td>
</tr>
<tr>
<td>Fabric tape tensile adhesive strength</td>
<td>6.9</td>
<td>8.0</td>
<td>9.2</td>
<td>16.6</td>
<td>14.4</td>
<td>11.7</td>
</tr>
<tr>
<td>Reinforcing effect (%)</td>
<td>120</td>
<td>242</td>
<td>214</td>
<td>122</td>
<td>98</td>
<td>112</td>
</tr>
</tbody>
</table>

According to the results, compared to the unreinforced test specimens, A-1 showed a difference of approximately 120% in tensile strength, A-2 of 242%, B-1 of 214%, B-2 of 122%, C-1 of 98%, and C-2 of 112%.

Figure 14b shows a comparison of the extracted raw data from the recorded load and displacement during the measurement process for the test specimens with fabric tape applied. The selected range corresponded to the interval of 0–70 mm, which was the range where the load values were measured during the peel-out test. We examined how much deformation occurred from the point where the initial tension was applied to the selected measurement range. The obtained graph is shown in Figure 15, where all six types of specimens showed a maximum load before stabilizing at a constant load value in the range of approximately 20 mm. It can be concluded that the polymer film layer with a minimum elongation of 200% or more and the fabric tape with an elongation rate of approximately 5–10% were combined to restrain the elongation of the polymer film and provide consistent resistance to the applied load, resulting in an elongation rate of approximately 15–20%.
3.2.2. Peel-Out Test with and without Fabric Tape Reinforcement

In this evaluation, the peel-out test was conducted on the six types of specimens in the laboratory using UTM equipment, with different upper fabric tape reinforcement conditions. The tests were performed under a temperature condition of 20 °C maintained inside the temperature chamber of the UTM. The results for each type of specimen are presented in Table 3 and Figure 16.

Table 3. Comparison of the adhesive strength between the fabric tape-reinforced and unreinforced samples (unit: N/mm).

<table>
<thead>
<tr>
<th>Specimen Types</th>
<th>A-1</th>
<th>A-2</th>
<th>B-1</th>
<th>B-2</th>
<th>C-1</th>
<th>C-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced adhesive strength</td>
<td>2.2</td>
<td>2.6</td>
<td>2.3</td>
<td>2.1</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Fabric tape-reinforced adhesive strength</td>
<td>3.0</td>
<td>3.5</td>
<td>2.4</td>
<td>2.6</td>
<td>3.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Figure 16. Comparison of the adhesive strength with and without fabric tape installed.

Figure 15. Load-displacement graph with or without fabric tape.
Table 3. Comparison of the adhesive strength between the fabric tape-reinforced and unreinforced samples (unit: N/mm).

<table>
<thead>
<tr>
<th>Specimen Types</th>
<th>A-1</th>
<th>A-2</th>
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<th>B-2</th>
<th>C-1</th>
<th>C-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unreinforced adhesive strength</td>
<td>2.2</td>
<td>2.6</td>
<td>2.3</td>
<td>2.1</td>
<td>2.7</td>
<td>1.6</td>
</tr>
<tr>
<td>Fabric tape-reinforced adhesive strength</td>
<td>3.0</td>
<td>3.5</td>
<td>2.4</td>
<td>2.6</td>
<td>3.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Figure 16 shows the measurement results, indicating that when the fabric tape was attached to the polymer film for measurement, the adhesive strength increased by an average of approximately 0.5 N/mm. No decrease in the cross-sectional area due to the elongation of the polymer film was observed. However, in the case of C-2, no significant change in the adhesive strength was observed.

By using the fabric tape as originally intended, the elongation of the polymer film was restrained, allowing for the measurement of the pure adhesive strength of the polymer adhesive layer in the original self-adhesive waterproofing sheet. Therefore, the peel-out test was consistently conducted with the fabric tape attached for measuring the adhesive strength exerted by the polymer adhesive layer.

3.3. Comparison of Measurement Results between Test Equipment

To control the variables during the experiment, a preliminary process was conducted, and peel-out tests were performed on the same specimens using both UTM equipment in the laboratory and portable equipment for onsite use. Once the testing was conducted with the respective methods, the results of the measurements were compared.

3.3.1. Measurement Using UTM Equipment

Evaluation was conducted using the UTM equipment at a temperature of 20 °C maintained inside a temperature chamber for over one hour, with an extension rate of 100 mm/min. The results of the measurements are presented in Table 4. Representative graphs and peel-out patterns for each specimen, drawn automatically by the dedicated program during the UTM measurement, are shown in Figure 17.

Table 4. Peel-out measurement results using UTM equipment (unit: N/mm).

<table>
<thead>
<tr>
<th>Specimen Types</th>
<th>A-1</th>
<th>A-2</th>
<th>B-1</th>
<th>B-2</th>
<th>C-1</th>
<th>C-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel-out Strength</td>
<td>3.0</td>
<td>3.5</td>
<td>2.4</td>
<td>2.6</td>
<td>3.2</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Figure 17. UTM equipment measurement peeling load-displacement graph—experimental condition 20 °C: (a) load-displacement result for A-1 and A-2 specimen, (b) load-displacement result for B-1 and B-2 specimen, (c) load-displacement result for C-1 and C-2 specimen.
As shown in Figure 17, characteristic graphs for the peel-out strength measurement process at 20 °C under constant temperature conditions were observed for each material. Among the graphs obtained from measuring a total of 10 specimens, one representative graph was selected from those in which the graphs of at least two or more specimens overlapped.

The rubberized asphalt-based materials, A-1 and A-2, as well as the butyl rubber-based materials, B-1 and B-2, exhibited similar graph shapes. On the other hand, the adhesive synthetic rubber-based material, C-1, showed a resistance load against peel-out that was more than twice as high as that of C-2. This comparison of the representative graphs provides insights into the distinctive behavior and performance of each material during the peel-out testing process.

The difference here was that the rubberized asphalt and pressure-sensitive synthetic rubber series maintained a linear peeling pattern during the peeling process, with the polymer adhesive layer appearing in a narrow bonding area. On the other hand, the butyl rubber series maintained the bonding and elongation state of the polymer adhesive layer across the entire surface, not in a linear fashion, and Figure 18 confirms that this elongated polymer adhesive layer remained under tension.

When examining the surface condition of the polymer adhesive layer after peeling in other specimens, it can be observed that the sheet exhibited a wrinkled appearance and formed a blister-like shape due to air entrainment during the bonding process. However, in the case of C-2, the surface of the polymer adhesive layer after peeling showed the presence of air bubbles. This can be attributed to the insufficient continuity of the air layer that was entrapped during the production process, resulting in a lack of stress transfer in the polymer adhesive layer during the cohesive resistance process against the applied tensile force during peeling.

3.3.2. Measurement Using the Field Equipment

To assess the adhesive strength as part of quality control in the field after the installation of the self-adhesive waterproofing membrane, the field equipment was developed.
To evaluate its suitability for field application, the field equipment was compared to the UTM device under the same conditions. The measurement was conducted in a controlled environment at 20 °C for over one hour, and the specimens were evaluated using the portable equipment at an inclination angle of 45° and an elongation rate of 141 mm/min, as shown in Figure 19a. The results obtained using the portable equipment are presented in Table 5.

![Figure 19](image_url)

**Figure 19.** Experiment method using field equipment; (a) specimen in temperature chamber, (b) measurement and data analysis of field equipment testing method.

<table>
<thead>
<tr>
<th>Specimen Types</th>
<th>A-1</th>
<th>A-2</th>
<th>B-1</th>
<th>B-2</th>
<th>C-1</th>
<th>C-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peel-out Strength</td>
<td>3.0</td>
<td>3.5</td>
<td>2.4</td>
<td>2.6</td>
<td>3.2</td>
<td>1.5</td>
</tr>
</tbody>
</table>

The results of the adhesive strength measurement using the portable equipment showed that the automatically recorded graphs and measured values from the portable equipment’s measurement program were similar to those obtained from the UTM device. Additionally, the peeling characteristics of the specimens were observed to be consistent. The experimental result graphs under each condition were captured from the portable equipment’s measurement program and are presented in Figure 20.

![Figure 20](image_url)

**Figure 20.** Field equipment measurement peeling load–displacement graph—experimental condition 20 °C; (a) load-displacement result for A-1 and A-2 specimen, (b) load-displacement result for B-1 and B-2 specimen, (c) load-displacement result for C-1 and C-2 specimen.

### 3.3.3. Peel-Out Test Evaluation Results

To assess the level of discrepancy between the portable equipment used for onsite measurements and the laboratory equipment, peel-out tests were conducted on the same samples under identical conditions using both the portable equipment and the UTM in the laboratory. It was found that the results obtained from both devices were similar, indicating a good level of agreement between them.
Figure 21 compares the results obtained at 20 °C, demonstrating that even with different specifications and methods, the measurements from both the UTM and the portable equipment aligned accurately. The standard deviation of the results varied for each sample, ranging from 0.26 to 0.42 for A-1, 0.17 to 0.36 for A-2, 0.05 to 0.12 for B-1, 0.21 to 0.22 for B-2, 0.08 to 0.16 for C-1, and 0.03 to 0.10 for C-2. The overall standard deviation for the UTM measurements was 0.17, while it was 0.18 for the portable field measurement equipment.

![Figure 21. Comparison of the adhesive strength according to measuring equipment.](image)

### 4. Conclusions

To establish quantitative quality control standards for self-adhesive waterproofing sheets used in construction, it is essential to develop onsite inspection equipment with evaluation capabilities equivalent to laboratory equipment. While construction standards such as KS F 9001, KS F 9003, and KS F 9006 have been established, there is a lack of quantitative inspection methods and criteria for the post-construction assessment of self-adhesive waterproofing sheets, relying solely on the skills of the installers.

Therefore, in this study, to establish a standardized testing method for measuring the adhesive strength of onsite installed self-adhesive waterproofing sheets, a comparison was made between the laboratory measurement method and the onsite measurement method, including the test results and quality criteria. The following conclusions were drawn:

During the peel-out test, it was observed that discrepancies occurred between the test substrate and the test sample. When the adhesive strength of the adhesive layer was higher than the tensile strength of the upper polymer film, differences in elongation occurred between the adhesive area and the self-adhesive waterproofing sheet due to the elongation of the polymer film. Additionally, deviation from the 90° angle between the test substrate and the tensile jig was observed. To control these variables, fabric tape was used to reinforce and restrict the elongation of the polymer film, allowing for the measurement of the pure adhesive peel-out force.

Among the factors affecting the peel-out force, such as the sample thickness, the testing speed, and the onsite temperature, the testing speed showed a significant impact. Higher testing speeds resulted in a higher peel-out strength. To account for the difference in the displacement due to the movement of the tensile jig at a 45° angle in the onsite equipment compared to the vertical movement in the UTM, a testing speed of 141 mm/min was selected for the onsite measurements to match the UTM speed. As a result, the peel-out strength measurements from the onsite equipment closely matched those obtained from the UTM for the same samples. However, the results presented in this study should not...
yet be taken to state that the method is empirical. There are multiple factors that will need to be taken into consideration, and surely modifications to the equipment are mandatory. The purpose of this article is to simply provide the information that such a method called “onsite/in-situ field equipment for measuring adhesive strength of installed waterproofing method” is important and is in development. Also, the results of repeated testing have shown that the equipment is capable of reproducing results that otherwise would have been yielded using a UTM machine at a reliable rate. However, in-situ installed waterproofing materials are not conveniently placed all the time such that a clean and reliable specimen can be acquired at any moment and place. These specimens could be exposed in areas dangerous to reach for researchers, areas where the equipment may not fit, may not be able to secure the correct angle, submerged, etc. These factors will need to be identified and addressed with further studies.

It is crucial to consider the behavior of the polymer adhesive layer, which relies on time-dependent properties, during the material production process. Enhancements should be made to ensure long-term waterproofing performance, resistance to sagging, and long-term adhesion strength by improving the resistance to viscoelastic deformation of the polymer adhesive layer. Solutions for these challenges are already known in the industry but require collective efforts from stakeholders and organizations for practical implementation.

This study focused on selected representative samples from each category, totaling six types, and may not fully represent all the self-adhesive waterproofing sheets used in the domestic market. Therefore, further research is needed to validate and supplement the findings of this study using a larger sample size.


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Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
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<tbody>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>CRC</td>
<td>Cellulose Fiber Reinforced Cement</td>
</tr>
<tr>
<td>EPDM</td>
<td>Ethylene Propylene Diene Terpolymer</td>
</tr>
<tr>
<td>EVA</td>
<td>Ethylene–Vinyl Acetate</td>
</tr>
<tr>
<td>HDPE</td>
<td>High Density Polyethylene</td>
</tr>
<tr>
<td>KS</td>
<td>Korean Standard</td>
</tr>
<tr>
<td>PVC</td>
<td>Polyvinyl Chloride</td>
</tr>
<tr>
<td>UTM</td>
<td>Universal Testing Machine</td>
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</table>
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