Evaluation of Adhesion Characteristics According to Chemical Deterioration Conditions and Recycled Material Content of Butyl Rubber Compound Waterproof Sheet

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Abstract: This study sought to investigate the adhesion strength reduction of reclaimed butyl rubber self-adhesive waterproofing sheets after exposure to a chemical erosion environment. Ranges from 0 to 45% mixture ratio (with changing intervals of 5% ratio) of reclaimed butyl rubber replaced the new rubber content of commercial butyl rubber self-adhesive waterproofing sheets for testing, based on the optimal results for the reclaimed butyl rubber content in order to ensure performance that meets the standard criteria. The research results confirmed that performance degradation was relatively greater when exposed to an acidic environment that was responsible for chemical deterioration. It was also confirmed that, given the deterioration environment described above, the reclaimed butyl rubber content should be limited to 44% so as to ensure an adhesion performance similar to that of the untreated test sample (reclaimed butyl rubber content of 67%). Based on the above results, it was suggested that the optimal mixing range of reclaimed butyl rubber should be up to 44% of the total rubber content, considering performance degradation after field application in the production of self-adhesive waterproofing sheets.

Keywords: chemically deteriorated; self-adhesive waterproofing sheet; reclaimed butyl rubber; adhesion performance

1. Introduction

The self-adhesive waterproofing sheet has adhesive characteristics which allows it to be completely bonded and attached to a surface that requires waterproofing [1,2]. In general, self-adhesive waterproofing sheets are classified into rubberized-asphalt-based, butyl-rubber-based, and natural-rubber-based waterproofing sheets according to the materials used [3,4]. Among them, the butyl-rubber-based waterproofing sheet is the most widely used waterproofing product in the market due to its excellent adhesion and durability, as well as its low thermal sensitivity [5-7]. The butyl-rubber-based self-adhesive waterproofing sheet is generally made from a mixture of asphalt and butyl rubber [8,9]. In this regard, in compound production, asphalt accounts for about 50% of the total weight, and the content of butyl rubber is less than 20% in the majority of the butyl rubber self-adhesive waterproofing sheets produced in South Korea [10]. This asphalt-centered production process results in a de-oiling phenomenon in which the asphalt oil contained in the compound is lost as oil is adsorbed to the outside and removed from the raw material with time after the installation of the waterproofing sheet; this, in turn, leads to a decrease in the durability...
of the entire waterproofing layer [11]. In the previous research conducted regarding the composition of raw materials for self-adhesive waterproofing sheets, the ratio of butyl rubber content was set to 45% of the total weight and the ratio of the reclaimed butyl rubber to the new butyl rubber was adjusted, as shown in Table 1 [12].

### Table 1. Advanced research mixing plan.

| Item                          | Butyl rubber | Reclaimed butyl rubber | wt %  |
|-------------------------------|--------------|------------------------|-------|
| #1                            | 45           | 0                      |       |
| #2                            | 40           | 5                      |       |
| #3                            | 35           | 10                     |       |
| #4                            | 30           | 15                     |       |
| #5                            | 25           | 20                     |       |
| #6                            | 20           | 25                     |       |
| #7                            | 15           | 30                     |       |
| #8                            | 10           | 35                     |       |
| #9                            | 5            | 40                     |       |
| #10                           | 0            | 45                     |       |
| Reclaimed butyl rubber        |              |                        |       |
| replacement ratio to total    |              |                        |       |
| rubber content %              |              |                        |       |
| 0                             | 11           | 22                     |       |
| 11                            | 22           | 33                     |       |
| 22                            | 33           | 44                     |       |
| 33                            | 44           | 56                     |       |
| 44                            | 56           | 67                     |       |
| 56                            | 67           | 78                     |       |
| 67                            | 78           | 89                     |       |
| 78                            | 89           | 100                    |       |

Performance evaluation was conducted on the specimens for each mixing ratio in accordance with ‘KS F 4934: 2018 Self-adhesive rubberized asphalt sheet’, and the results confirmed that all items, except for adhesion-related performance, met the quality standards specified in the relevant criteria [13]. It is interpreted that the content of reclaimed butyl rubber does not have a broad impact on the physical properties of the self-adhesive waterproofing sheet; however, it has a crucial impact on a specific performance—that is, the adhesion property [14,15]. According to the findings, the adhesive strength (with CRC board surface) and peel strength (between sheet joint) tended to decrease as the rubber content increased, as shown in Figure 1. It was also confirmed that, in the absence of additional additives and modified mix design research, performance degradation below the KS quality standards occurred from specimens #7 and #8 with a reclaimed rubber content of more than 67% to 78% compared to the total rubber content.

![Figure 1. Adhesive strength test (peel-out) result according to reclaimed butyl rubber content.](image)

The above results presented in the previous research may suggest that it is possible to ensure quality assurance up to reclaimed butyl rubber ratios of 56% (#6) and 67% (#7) compared to the total rubber content. However, the results were obtained without considering the factors of performance degradation when exposed to harsh environmental conditions in field application. Therefore, this study set the replaced mixture ratio of new butyl rubber and reclaimed butyl rubber to the same conditions as in the previous study to maintain consistency. In addition, considering that the butyl rubber self-adhesive waterproofing sheet is applied to underground structures, the scope was limited to applying the underground chemical deterioration environmental conditions instead of excluding the thermal deterioration conditions due to solar radiation, and performance reduction
was analyzed according to chemical erosion environment exposure [16,17]. For the analysis of degradation rate, the study focused on changes to the waterproofing sheet adhesive strength, and based on this, suggested a range of recycled butyl rubber content that can satisfy the performance standards set in ‘KS F 4934: 2018 Self-adhesive rubberized asphalt sheet’.

2. Materials and Methods

2.1. Specimen Production

(1) Basic mixing ratio settings

The basic mixing ratio applied in this study is presented in Table 2 below, and the ratios were derived such that the scope of application of the results derived from the study can be determined with clarity. Currently, various types of self-adhesive waterproof sheets exist in Korea, and in the case of compounds, different raw materials and mixing ratios are applied by each manufacturer [18]. The basic mixing ratio suggested here was set by referring the manufacturer specifications during actual production and has been confirmed to satisfy all the quality standards set by KS.

| Raw Material Name | wt% | Weight (g) | Note |
|-------------------|-----|------------|------|
| 1 Butyl rubber    | 45  | 1350       |      |
| 2 Carbon black    | 19  | 570        |      |
| 3 Inorganic fillers | 15 | 390        |      |
| 4 Polybutene      | 17  | 510        |      |
| 5 Coupling agent  | 4   | 120        | Mixing in Lab (3L kneader) |
| Total             | 100 | 3000       |      |

(2) Range settings for raw materials used

As shown in the basic mixing ratio given in Section (1), the materials used in this study were composed of butyl rubber, carbon black, inorganic fillers, polybutene, and a coupling agent; a total of 6 raw materials, including reclaimed butyl rubber to replace the new butyl rubber, were used. In general, the self-adhesive waterproofing sheet is made by mixing 8 to 10 raw materials [19,20]. However, in this study, the use of functional additives was avoided in order to investigate the effects of an increase in the ratio of reclaimed materials to new materials on the self-adhesive waterproofing sheet. The physical properties of each raw material used in the present research are shown in Tables 3–7 below.

Table 3. Butyl rubber properties used in the study.

| Test Item       | Unit | Properties       | Standards                  |
|-----------------|------|------------------|----------------------------|
| 1 Mooney viscosity | -    | 47.0–54.0        | (1 + 8); ISO 289 / ASTM D1646 |
| 2 Unsaturation   | mol% | 1.6 ± 0.2        | -                          |
| 3 Volatile       | wt%  | 0.300            | ISO 248 / ASTM D5668       |
| 4 Ash            | %    | 0.30             | ISO 247 / ASTM D5667       |
Table 4. Carbon black properties used in the study.

| Test Item       | Unit     | Properties |
|-----------------|----------|------------|
| 1 Particle size | nm       | 22         |
| 2 Surface area  | M²/g     | 134        |
| 3 DBP absorption| mL/100 g | 100        |
| 4 PH value      | pH       | 3.5        |

Table 5. Inorganic fillers properties used in the study.

| Test Item       | Unit      | Properties   |
|-----------------|-----------|--------------|
| 1 Crystal system| -         | Monoclinic   |
| 2 Form          | -         | Columnar crystal |
| 3 Hardness      | -         | 2.5~3.5      |
| 4 Specific gravity| -         | 2.59        |
| 5 Moisture      | %         | 0.50         |

Table 6. Polybutene properties used in the study.

| Test Item         | Unit                | Properties |
|-------------------|---------------------|------------|
| 1 Molecular weight| Min                 | 1420       |
| 2 Viscosity       | cSt@100 °C          | 820        |
| 3 Flash point     | °C                  | 235        |
| 4 Pour point      | °C                  | 5          |
| 5 Moisture        | Wt-ppm              | 20         |

Table 7. Coupling agent properties used in the study.

| Test Item       | Unit    | Properties |
|-----------------|---------|------------|
| 1 Softening point| °C      | 96~106     |
| 2 Ash           | %       | 2.0        |
| 3 Density       | g/cm³   | 1.0~1.2    |

(3) Mix design

The mix proportion for the test sample composition was designed to replace the new butyl rubber in units of 5% based on the basic mixing ratio, which is the same as the mix proportion designed in the previous research. Therefore, the mix design was applied, as shown in Table 1.

(4) Mixing plan

Prior to the experiment, the process of mix proportion was carried out according to the planned mix design. Following the fabrication of test samples for each mixing ratio, the samples were subjected to chemical aging treatment. The adhesion performance (peel-out) evaluation was conducted on the chemically treated test sample, and the performance change characteristics were then examined. The overall research flow is shown in Figure 2.
(5) Test sample composition

As there is no official manufacturing standard for the production of experimental specimens for this testing, specimens were prepared using a Kneader compounder, an item of rubber-material-only compounding equipment used for research by actual manufacturers. This compounder is a minimized version of the equipment used in the production of butyl rubber self-adhesive waterproof sheet, and it is designed specifically to be used by manufacturers to mix small amounts for research purposes. Table 8 shows the specifications of the kneader for experimental mixing used in the study.

Table 8. Kneader specifications.

| Equipment Name | Purpose                  | Specifications          |
|----------------|--------------------------|-------------------------|
| Kneader        | Rubber compounding       | Volume (L): 3           |
|                |                          | Size (mm): 1905 × 820 × 2257 |
|                |                          | R.P.M.: 40.2            |
|                |                          | Heater Cap. (KW): 6     |

The test sample mixing sequence and status are shown in Figure 3. The test compound produced via the kneader mixer was processed and pressed using a hydraulic press into a waterproofing sheet material in order to complete the test sample fabrication.
In general, a non-exposure waterproofing method that does not expose a waterproofing layer, due to the installation of a separate protective layer and reclamation after the installation of the waterproofing layer, is applied as a method using the self-adhesive waterproofing sheet in the waterproofing market for construction. Therefore, in this study, deterioration conditions resulting from UV rays and heat were excluded from the deterioration treatment condition settings for the prepared test samples, and only chemical aging conditions in the ground were applied in the research. Accordingly, deterioration treatment on the test sample was conducted in accordance with ‘KS F 4935: 2008 Sealer of injection type for water leakage maintenance of adhesive flexible rubber asphalt series’ (hereafter, KS F 4935), which stipulates both the chemical environment of the concrete surface to which the waterproofing material is applied and the underground chemical aging conditions inside the soil, among the Korean Industrial Standards (hereafter, KS) related to waterproofing materials for construction [21]. Meanwhile, most of the waterproofing-related standards, including KS F 4935, stipulate that the deterioration treatment period should be 168 h (7 days). However, in this study, the treatment period was set to 21 days in accordance with the ‘Korea, Ministry of Land, Infrastructure and Transport of specification standard 2010’, which sets the chemical water (brine) treatment period three times longer than the period set in the standard [22]. In this context, it would be appropriate to apply the quality testing methods and criteria specified in the standard specification, which require higher levels than those specified in the KS related to non-exposure methods, for a comparison of quality stability in the long term. Table 9 and Figure 4 show the specimen deterioration treatment method and period applied for this study [23].

**Figure 3.** Test sample mixing status. (a) Kneader used in research; (b) Compounding part; (c) Raw material input; (d) Mixing; (e) Hydraulic press; (f) Test sample.

### 2.2. Test Methods

(1) Deterioration treatment
Table 9. Specimen deterioration treatment method.

| Item   | Division                      | Condition                                | Period (Day) | Relevant Standards                                                                 |
|--------|-------------------------------|------------------------------------------|--------------|------------------------------------------------------------------------------------|
| Alkali | As specified in KS M ISO 6353-2 (R34) | Calcium hydroxide saturated in 0.1% sodium hydroxide aqueous solution | 21           | (Utility-pipe conduit of Ministry of Land, Infrastructure and Transport Quotation) |
| HCl    | As specified in KS M ISO 6353-2 (R13, R19, R37) | 2% solution                             |              | KS F 4935: 2003 Sealer of adhesive flexible rubber asphalt series                   |
| HNO₃   | As specified in KS M ISO 6353-2 (R13, R19, R37) | 2% solution                             |              |                                                                                   |
| H₂SO₄  | As specified in KS M ISO 6353-2 (R32) | 10% solution                            |              |                                                                                   |

Figure 4. Specimen deterioration treatment status. (a) Five types of chemical treatment; (b) After washing, dry for 24 h in a constant temperature chamber at 20 °C.

(2) Test

The test was conducted with two test items: adhesive strength (with CRC board surface) and peel strength (between sheet joint). For adhesive strength, an oil-based primer was applied to a cellulose reinforce cement board (CRC board) with a thickness of 9 ± 1 mm. After drying for two hours or more under standard conditions, a test sample with a width of 50 mm and a length of 150 mm was produced, and a 60 mm part in the longitudinal direction was treated with a release paper and attached to the base specimen (base plate for test) in order to fabricate the specimen. After fabrication, the specimen was placed at room temperature for two hours. As shown in Figure 5, the fabricated specimen was fixed to the attachment jig, and one end, which was not attached to the base plate, was then fixed to a tensile test device. After that, a 20 mm part was peeled off with the peel angle set at 90 ± 5°, and then the sheet was peeled off at a tensile rate of 100 mm/min. The adhesive strengths of five specimens were measured, and the peeling load-peeling length curve was divided into four equal parts at a point where the peel angle is 90 ± 5°, except for the initial peeling length of 20 mm. This was in order to read the peeling load value $P_i$ ($P_1$, $P_2$, $P_3$, $P_4$, and $P_5$) at a point of intersection (point t) between the bisectrix and the loading curve and represents the average value of the five specimens calculated by using Equation (1). Figure 6 shows the specimen fabrication and test status.
Figure 5. Peel-out (with CRC board surface) test method.

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

(1)

\[ F = \text{Adhesive strength (N/mm)} \]

\[ P_i = \text{Peeling load value at point t (N)} \]

Figure 6. Peel-out (with CRC board surface) test specimen preparation and test status. (a) Test preparation; (b) Test status.

For the peel strength, the release paper of the 110 × 50 mm test sample was attached with the adhesive side facing down, and another test sample was then stacked up by 50 mm on it. In a standard condition, the 10 mm part of both ends, which was not adhered to, was mounted on a tensile tester, and the tensile load was measured at a tensile rate of 200 mm/min with an interlocking interval of 100 mm; the strength was then calculated by using Equation (2). Figure 7 shows the specimen fabrication and test status.

\[ T_B = \frac{P_B}{W} \]  

(2)

\[ T_B: \text{Adhesive strength (N/mm)} \]

\[ P_B: \text{Maximum load (N)} \]
W: Width of the specimen (50 mm)

Figure 7. Peel-out (between sheet joint) test specimen preparation and test status. (a) Preparing for the test. (b) Test status.

3. Results and Analysis

3.1. Results

The results of the test conducted after the chemical treatment on the test samples for each mixing ratio are as follows. Both the adhesive strength (with CRC board surface) and the peel strength (between sheet joint) had the tendency to decrease as the reclaimed butyl rubber content increased, as summarized in Tables 10 and 11. The adhesive strength results shown in Table 10 confirmed that it is possible for the plain specimen to ensure performance up to a reclaimed butyl rubber ratio of 56% (#6) compared to the total rubber content. However, when exposed to hydrochloric acid (HCl) and sulfuric acid (H_2SO_4) environments, the plain specimen can ensure performance up to a reclaimed butyl rubber ratio of 44% (#5), but there are difficulties in ensuring quality assurance when the reclaimed butyl rubber content exceeds the limits.

Table 10. Adhesion performance with CRC board surface.

| Item  | #1  | #2  | #3  | #4  | #5  | #6  | #7  | #8  | #9  | #10 |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Plain | 1.86| 1.83| 1.73| 1.65| 1.58| 1.53| 1.44| 1.36| 1.29| 1.18|
| HCl   | 1.76| 1.72| 1.69| 1.64| 1.55| 1.41| 1.23| 1.00| 0.70| 0.35|
| HNO_3 | 1.78| 1.74| 1.73| 1.69| 1.62| 1.51| 1.35| 1.14| 0.87| 0.53|
| H_2SO_4 | 1.80| 1.76| 1.73| 1.67| 1.58| 1.44| 1.26| 1.03| 0.76| 0.45|
| Alkali | 1.82| 1.80| 1.78| 1.75| 1.67| 1.58| 1.46| 1.31| 1.13| 0.91|
| NaCl  | 1.83| 1.81| 1.79| 1.76| 1.70| 1.63| 1.48| 1.41| 1.26| 1.10|

---Below quality standards.

The peel strength results shown in Table 11 confirmed that it is possible for the plain specimen to ensure performance up to a reclaimed butyl rubber ratio of 67% (#7) compared to the total rubber content. However, the plain specimen can ensure performance up to a reclaimed butyl rubber ratio of 44% (#5) when exposed to hydrochloric acid (HCl), nitric acid (HNO_3), and sulfuric acid (H_2SO_4) environments, except for sodium chloride (NaCl), but only up to a reclaimed butyl rubber ratio of 56% (#6) in an alkaline environment. However, it is difficult to ensure quality assurance when the reclaimed butyl rubber content exceeds the limits.
The comparison of changes in adhesive strength and peel strength due to acid treatment also revealed that it is possible to ensure performance up to a reclaimed butyl rubber ratio of 44% (#5) or less under all treatment conditions (hydrochloric acid (HCl), nitric acid (HNO₃), and sulfuric acid (H₂SO₄)), except for nitric acid (HNO₃), as shown in Figures 8–10. When compared to the plain specimen, the chemically treated specimens showed a decrease in the reclaimed butyl rubber content to ensure the adhesive strength from 56% (#6) to 44% (#5). In addition, the reclaimed butyl rubber content to ensure peel strength decreased significantly from 67% (#7) to 44% (#5).

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Table 11. Adhesion performance between sheet joint.

| Item   | #1  | #2  | #3  | #4  | #5  | #6  | #7  | #8  | #9  | #10 |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Plain  | 1.82| 1.76| 1.73| 1.65| 1.62| 1.54| 1.50| 1.43| 1.38| 1.32|
| HCl    | 1.70| 1.67| 1.63| 1.58| 1.50| 1.36| 1.19| 0.97| 0.68| 0.34|
| HNO₃   | 1.73| 1.70| 1.68| 1.64| 1.57| 1.47| 1.31| 1.11| 0.85| 0.52|
| H₂SO₄  | 1.75| 1.72| 1.68| 1.63| 1.54| 1.40| 1.23| 1.00| 0.74| 0.44|
| Alkali | 1.79| 1.77| 1.75| 1.72| 1.65| 1.56| 1.43| 1.29| 1.11| 0.90|
| NaCl   | 1.80| 1.78| 1.76| 1.73| 1.67| 1.60| 1.51| 1.39| 1.24| 1.08|

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Figure 8. Adhesion performance test result of the HCl-treated sample.

Figure 9. Adhesion performance test result of the HNO₃-treated sample.
Figure 10. Adhesion performance test result of the H$_2$SO$_4$-treated sample.

Figure 11 shows the test result of the alkali-treated specimen. It was found that it is possible to ensure adhesive strength at a reclaimed butyl rubber ratio of 67% (#7), which is the same condition as the plain specimen; the reclaimed butyl rubber content required to ensure peel strength was found to be 56% (#6), which is an increase from 44% (#5), the reclaimed butyl rubber content needed to ensure adhesion performance under acid treatment conditions. This suggests that the performance degradation of butyl rubber is relatively low in an alkaline environment. In addition, it was confirmed that it is possible for the sodium chloride (NaCl)-treated specimen shown in Figure 12 to ensure adhesion performance and peel strength at a reclaimed butyl rubber ratio of 67% (#7), which is the same condition as the plain specimen, and that the performance degradation of butyl rubber is relatively low in a sodium chloride environment.

Figure 11. Adhesion performance test result of the alkali-treated sample.
However, it was confirmed that a reclaimed butyl rubber content of 56% (#6) poses difficulties in ensuring proper performance due to performance degradation when exposed to chemically deteriorated environments, and the reclaimed butyl rubber content that can meet all five chemical aging conditions applied in this study was found to be 44% (#5).

3.2. Analysis of Results

The overall test results are as follows. In terms of adhesive strength, the maximum reclaimed butyl rubber content to ensure the performance of the plain specimen was 56% (#6) based on the previous research, as shown in Figure 13. However, it was confirmed that a reclaimed butyl rubber content of 56% (#6) poses difficulties in ensuring proper performance due to performance degradation when exposed to chemically deteriorated environments, and the reclaimed butyl rubber content that can meet all five chemical aging conditions applied in this study was found to be 44% (#5).

The peel strength also showed a similar tendency to that of the adhesive strength. As shown in Figure 14, a maximum butyl rubber content to ensure the performance of the plain specimen was 67% (#7). However, it was confirmed that a reclaimed butyl rubber content of 67% (#7) poses difficulties in ensuring proper performance due to performance degradation when exposed to the actual chemical deterioration environment, and the reclaimed butyl rubber content that can meet all five chemical aging conditions applied in this study was found to be 44% (#5). This result suggests that, in the actual mix design using reclaimed butyl rubber, the value of performance degradation due to deterioration factors should be considered in order to ensure proper performance.

Figure 12. Adhesion performance test result of the NaCl-treated sample.

Figure 13. Adhesion performance test result (Crc board surface).

Figure 14. Maximum butyl rubber content to ensure the performance of the plain specimen.
It was confirmed that the adhesion property of the sheet material compound decreases when the reclaimed butyl rubber content of the self-adhesive waterproofing sheet increases. In particular, when the reclaimed butyl rubber content is 100%, the rate of performance degradation is more than 74% compared to that of the plain specimen under chemically deteriorated conditions. In the case of new butyl rubber, adhesion performance is determined based on the material properties of the rubber itself, but in the case of reclaimed butyl rubber, other raw materials are included in the composition, which results in lowered adhesion strength.

The adhesive strength and peel strength were found to be below the performance standard when the ratio of reclaimed butyl rubber content to the total rubber content is limited to 44%.

Figure 14. Adhesion performance test result (between sheet joint).

Figure 15 shows a comparison between the scope of reclaimed butyl rubber content to ensure adhesion performance suggested in the previous research and that of proper content considering the deterioration factors derived from the present research. As shown in the figure, the application of a reclaimed butyl rubber replacement ratio of up to 67% to the total rubber content makes it possible to ensure adhesion performance when deterioration factors are not taken into consideration. However, when exposed to chemical deterioration factors, the performance degrades as the reclaimed butyl rubber content increases. This suggests that proper performance can be ensured only when the reclaimed butyl rubber content is limited to 44%.

Figure 15. Result of the quality assurance.

4. Conclusions

This study sought to investigate the performance change characteristics (deterioration characteristics), according to the reclaimed butyl rubber content in a chemically deteriorated environment, when the rubber material of the self-adhesive waterproofing sheet was changed from a new material to reclaimed butyl rubber, thereby suggesting a proper range for the reclaimed butyl rubber content in order to ensure adhesion performance. The major findings of this study are summarized as follows.

1. It was confirmed that the adhesion property of the sheet material compound decreases when the reclaimed butyl rubber content of the self-adhesive waterproofing sheet increases. In particular, when the reclaimed butyl rubber content is 100%, the rate of performance degradation is more than 74% compared to that of the plain specimen under chemically deteriorated conditions. In the case of new butyl rubber, adhesion performance is determined based on the material properties of the rubber itself, but in the case of reclaimed butyl rubber, other raw materials are included in the composition, which results in lowered adhesion strength.

2. The adhesive strength and peel strength were found to be below the performance standard when the ratio of reclaimed butyl rubber content to the total rubber content...
exceeded about 56%. This is because, in the case of new butyl rubber, the homogeneously structured rubber layer can fundamentally respond to the deterioration environment, whereas reclaimed butyl rubber, due to the presence of other material compositions, cannot respond uniformly to the deterioration environment. That in turn results in reduced strength, and the effects of chemical deterioration are greater if the mixture ratio of reclaimed rubber is higher.

(3) It was confirmed that when exposed to acidic environments such as hydrochloric acid, nitric acid, and sulfuric acid, compared to alkali or sodium chloride treatment among chemical degradation environments, the performance degradation rate was relatively higher. In order to select a material with stable quality performance considering the degree of deterioration of the material due to deterioration conditions, the content of reclaimed butyl rubber must be limited to 44% or less. Performance exceeding the KS national quality standard was confirmed to be obtainable. Through the above results it is suggested that the appropriate mixing range of regenerated butyl rubber is up to 44% compared to the total rubber content, considering the performance degradation due to the elapse of sealing after field application when manufacturing self-adhesive waterproofing sheet.

This study is significant in that it suggests the minimum mixing range of reclaimed butyl rubber in order to ensure performance in a chemically deteriorated environment in relation to the utilization of reclaimed butyl rubber for the production of self-adhesive waterproofing sheets. The mixing range suggested in this study is expected to be used as data applicable to the mix design for the practical application of self-adhesive waterproofing sheets using reclaimed butyl rubber. However, this study has its limitation in that functional additives are excluded from the basic mix design. Therefore, in the future, additional research is needed in order to expand the range of reclaimed butyl rubber content based on the performance improvement effect via functional additives. In addition, there is a need to conduct research regarding performance change characteristics applied with physical deterioration factors (cracking behavior, fatigue resistance performance, etc.) in addition to the chemical deterioration factors established in the present research.

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Abbreviations

KS: Korean Industrial Standards.

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