Greenhouse Test Results for Two Years of Sheet-shaped Root Barrier Materials Apply to Green Roof System for Sustainable Building Construction

Jang, Dae-Hee¹ Kim, Hyeon-Soo¹ Choi, Soo-Kyung²*

Building & Urban Research Division, Korea Institute of Construction Technology, Ilsan Gu, Goyang, 411 712, Korea ¹
Department of Architecture, Hanseo University, Haemi Myun, Seosan, 356 706, Korea ²

Abstract

Recently, As a part of urban forestation, the introductions of green roofs into public projects has been actively driven. Supported by this policy, the sizes of domestic green roof-related markets have been rapidly expanding and many types of root barrier materials developed in Korea or abroad are being commercially distributed. In this study, root barrier tests were conducted over two years with nine types of sheet type waterproof materials that are the most commonly used as root barrier layers in green roof systems. The test conditions prepared considered the climates, natural features and vegetation in Korea and the results and related root barrier performance were verified. From the results of this study, the necessity to improve the joint part of root barrier sheets and forming methods has been identified and a measure to improve domestic root barrier testing methods was proposed.

Keywords : green roof system, sheet-shaped root barrier materials, resistance to root penetration, greenhouse

1. Introduction

Recently, Both the central government and the local autonomous entities have been active in introducing green roof systems as one of the green space restoration programs for urban areas. With such policies receiving much attention, green roof-related businesses are expanding rapidly and a lot of root barrier materials, developed in or outside Korea, are being circulated in the market.

A green roof system generally consists of a structural part and a planting foundation. The structural part includes a frame, insulation and waterproofing layers; the planting foundation includes root barrier, drainage, soil filter and terrestrial soil layers. The structural part has been researched for a long time, and specifically waterproofing issues have been a significant research subject in the architectural field. There is thus a system established so that each constituting layer of the structural part can be verified as to its performance[1,2]. But, the planting foundation has been researched and developed mainly in the landscaping field, so there was a tendency of research toward the setting of planting[3,4,5].

Since the architectural and landscaping fields have researched techniques of green roof systems independently to one another, research on root barriers, which is in the boundary between the fields, has been little. Damage to the structural part caused by roots of plants was not a serious issue at first when green roof systems were introduced but has taken shape as time passed and is now the main issue in question[6,7,8,9].

Water leakage from a waterproofing membrane
occurs frequently despite the root barrier installed in a planting foundation, and the principal cause of the leakage is that root barrier materials available on the market have been used without being verified in terms of performance.

Current tests of other countries on resistance to root penetration are conducted in the following way: a trial planting foundation is installed in a test container, and the related vegetation is planted and observed continually for one to four years[10]. This method itself does not have any significant weakness as it has been verified for decades. But the climate and other natural characteristics of the country concerned can impact seriously on tests for evaluating resistance to root penetration. All the root barrier materials available on the market need to be tested and verified strictly under planting conditions of the country where root barriers are used[11].

In this study, sheet-typed waterproofing membranes which are used commonly in green root systems were tested as to their resistance to root penetration for two years (June 11, 2008 to June 21, 2010) in a greenhouse under conditions reflecting the climate and other natural characteristics of Korea and was verified by checking if they were actually resistant to root penetration.

This study, as a preliminary test to establish the KS Test Method (KSF4938:2010) for evaluating resistance to root penetration, aimed to draw the methodology of test and to verify if the test was suitable. This study was differentiated from previous researches by Nagatsu[a, Kwon et al.[13], Oh et al.[14], Pyo et al.[15] and Tanaka et al.[16] in that they were carried out individually whereas this study conducted comparative evaluation for root barrier materials available on the market.

2. Specimens

2.1 Root barrier materials

Generally, sheet-shaped root barriers are composed of more than two materials. That’s because they are made to be both waterproof and resistant to root penetration for the purpose of a simple process of green roof system construction.

Table 1 shows the overview of root barrier sheets of nine types selected for the test on resistance to root penetration, and sheets of one type as the control group. Since the test specimens of this study were limited to root barriers used in the planting foundation of a green roof system, waterproofing capacity of combined waterproofing root barrier materials was not tested. All the products used as root barriers for green roof systems in Korea were examined, and those having been used actually at site and processed to be a sheet shape were selected as the test specimens.

<table>
<thead>
<tr>
<th>No.</th>
<th>Composition of root barrier materials</th>
<th>Thickness</th>
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<tbody>
<tr>
<td>1</td>
<td>PVC Sheet + PET Fabrics, Thickness: 1.5mm</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>EDPM Sheet, Thickness: 1.5mm</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>LDPE Sheet, Thickness: 0.4mm</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>PVC Sheet + PET Film, Thickness: 1.0mm</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cu Sheet + Glass fiber + Al Sheet, Thickness: 2.3mm</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>PET Film, Thickness: 1.0mm</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>PVC Sheet + Al Sheet + PET Film, Thickness: 1.0mm</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Al Sheet + Fiber Reinforced HDPE, Thickness: 2.5mm</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>EVA Sheet + Inorganic Coating, Thickness: 1.6mm</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Improvement Asphalt Sheet, Thickness: 1.7mm</td>
<td></td>
</tr>
</tbody>
</table>

The specimen No.1 is a combined waterproofing root barrier sheet composed mainly of polyvinyl chloride (PVC). The sheet is reinforced with polyester (PET) inside. A dry process is applied so that sheets are joined by heat sealing without adhesives. Sheets are not stuck to the concrete by an insulation method and so not influenced by the
behavior of the structure.

The specimen No.2 is a combined water proofing-root barrier sheet composed mainly of ethylene propylene diene monomer (EPDM). Since it can be used at temperatures ranging from -50 °C to 150 °C, it shows little change in quality even under severe climate conditions. Sheets are joined by doublesided tape and adhesive.

The specimen No.3 is a root barrier sheet made primarily from low density polyethylene (LDPE) and bitumen. It is ultraviolet-proof. In case sheets 8 m in width are overlapped with one another by 1.5 m, they bond together seamlessly. They were, however, joined by butyl tape in this study.

The specimen No.4 is a root barrier sheet in which PVC sheet is coated with PET film. Sheets are joined by sealing material and the joined area is laminated with PET film tape for reinforcement.

The specimen No.5 is a root barrier sheet improved in tensile and tearing strength by inserting glass fiber between very thin copper sheet and aluminum sheets. Sheets are joined by root barrier tape of the same material and the joined area is coated with urethane paint for reinforcement.

The specimen No.6 is a self-adhesive root barrier sheet made primarily from PET film. Sheets are joined by PET film tape.

The specimen No.7 is a self-adhesive root barrier sheet in which PVC sheet is laminated with aluminum sheet and then coated with PET film.

The specimen No.8 is a combined water proofing-root barrier sheet strengthened by inserting fiber reinforced high density polyethylene (HDPE) between aluminum sheets. Sheets are joined by root barrier tape of the same material.

The specimen No.9 is a composite sheet of linear low density polyethylene (LLDPE) and ethylene vinyl acetate (EVA), covered by melting adhesion on both sides with polyester fiber non-woven fabric and coated with cement-polymer modified waterproofing material. Sheets are joined by hot melting adhesive.

The specimen No.10, as the control group, is an improved asphalt sheet with a 1.7 mm thickness.

2.2 Containers

The container for the test on resistance to root penetration was designed to have a double structure consisting of inner and outer containers as shown in Figure 2. The inner container was fabricated with punching metal (2.0 mm in thickness, 6.0 mm in diameter of a hole) made of zinc coated steel so that roots could continue to grow even when they penetrated the root barrier sheet. The outer container had a hinge on each side in which the surfaces met at a right angle so that the sides could open, allowing observers to check if there was root penetration, from the outside without taking the inner container.

Between the inner and outer containers was rock wool with a 50 mm thickness designed to hold water at all times, so as to prevent roots from stopping to grow in case roots penetrated the root barrier sheet.

Figure 1. Testing containers
2.3 Construction of root resistance sheets

An actual process of the green roof system was applied when root barrier sheets were installed: sheets were overlapped, having four joints on the sides (*1), two joints on each side of the floor (*2), and T-shaped one joint on the center of the floor (*3) as shown in Figure 2.

The specimen with the root barrier sheet to be coated with waterproofing paint (No.9) had a joint on the center to pause the installation so that the coating material could be applied at more than 24-hour intervals.

Considering the fact that root growth can vary according to planting conditions, three specimens for each root barrier sheet (two specimens for the control group) were made.

![Figure 2. Construction of root resistance sheets](image)

2.4 Plant and soil

Plants, roots of which grow vigorously according to the standards for designing green roof systems for buildings set up by the Ministry of Land, Transport and Maritime Affairs of Korea and which are used as the plants for tests on resistance to root penetration by the FLL guidelines of Germany, were examined and two species of plant (one herb and one arbor) were selected as the test plants of this study. Plioblastus pygmaed Mitford A was selected as the herb (Plant A) and Pyracantha angustifolia as the arbor (Plant B).

Roots of the herb (Plioblastus pygmaed Mitford A) tend to grow horizontally while roots of the arbor (Pyracantha angustifolia) are likely to grow vertically, so it was considered that experiments could be conducted on root penetration of various directions towards the joints.

As shown in Figure 3, twelve herbs and four arbors were planted together in a single test container under the condition that there was no interference in growth between the plants. Then, root penetration was observed regularly in all the directions.

The test soil was perlite and peat moss mixed in the ratio of 3 to 1 which is commonly used in the planting foundation of a green roof system.

![Figure 3. Plant and soil](image)

2.5 Installation and maintenance of specimens

The specimens in which root barrier sheets were positioned and test plants were planted were installed in a greenhouse of the cactus research institute in Ilsan, Gyeonggi-do, Korea (Figure 4). Since long-term resistance to root penetration had to be tested within two years, the greenhouse setting was applied to the experiment for uniform and vigorous growth of plants.

The humidity and the temperature in the greenhouse were measured at fifteen-minute intervals for the initial three months for the...
purpose of checking precisely the fluctuations in humidity and temperature. Figure 5 shows daily average humidities and temperatures.

The side walls of the greenhouse were opened during the day in summer so that the temperature inside was prevented from rising too high and there was no significant difference between inside and outside temperatures. But the temperature inside was maintained about 5°C higher than the outside temperature after the middle of September. During the outdoor exposure experiment, the temperature in the greenhouse was kept to be around 20°C in order to prevent any hindrance to plant growth.

The specimens were checked more than three times every week: the humidity and the temperature were checked; the plants were watered (after checking the moisture meter); and pest control and weed control measures were taken.

The places of the specimens in the greenhouse were changed every month for the initial three months and after that, every third month based on the idea that growth condition of plants would be affected largely by their locations in the greenhouse.

3. Review of test results

3.1 Test methods

On June 11, 2008, thirty two specimens (three specimens for each of the ten types, two specimens for the control group) were fabricated and installed in a greenhouse. Tests on resistance to root penetration were conducted according to the following schedule.

In the first (July 11, 2008) and the second (August 12, 2008) tests, two sides of each outer container were opened and the rock wool between the inner and outer containers was taken out, and the specimens were observed with the naked eyes from the outside to check if there was root penetration.

In the third (September 18, 2008), the fourth (December 15, 2008), and the fifth (May 20, 2009) tests, the inner containers of the specimens were taken out and the rock wool was removed so that root penetration up to the four sides and the bottom of each specimen could be observed.

In the sixth test (June 21 to June 24, 2010), the specimens were disassembled and plants and soil inside were all removed, and the root barrier sheets were observed to check if roots of the plants penetrated the sheets.
3.2 Midterm test results

3.2.1 1st test

The first test was carried out on the day one month after installation of the specimens, namely, July 11 in 2008. Any root penetration was not found in all the specimens.

3.2.2 2nd test

The second test was carried out on the day two months after the installation, August 12, 2008. Like the process of the first test, only the two side walls of each test container were opened and the specimens were checked to find any root penetration. Figure 6 shows the results of the second test.

Penetration of roots of Plant A was found in all the three No. 2 specimens (a, b, c) and all the No. 10 specimens (the control group). The result proves that in case root barrier materials have no capacity of resistance to root penetration, roots can cause damage within three months from installation.

Root penetration of Plant A was found in only one (b) of the No. 3 specimens, (No.2-b) side (No.3-b) side (No.10-b) side

Figure 6. 2nd Test results

3.2.3 3rd test

The third test was done three months after the installation, September 18, 2008. The inner containers of the specimens were taken out and the four sides and bottom of each specimen were observed. Figure 3 shows the results of the third test.

The roots of Plant A that had penetrated the root barrier sheets in all the three No. 2 specimens (a, b, c) and all the No. 10 specimens grew sharply on the sides and bottoms of the specimens.

Root penetration of Plant A was found in only one (b) of the No. 3 specimens in the second test, but was found on the sides and bottoms of all of the three No. 3 specimens (a, b, c) in the third test.

Penetration of Plant A was found in only one (b) of the No. 5 specimens and one (b) of the No. 8 specimens had root penetration of Plant A on the bottom of the specimen.

One (b) of the No. 6 specimens had root penetration of Plant A on its sides.

3.2.4 4th test

The fourth test was carried out six months after the installation, December 15, 2008. Also in this test, the inner containers of the specimens were taken out and the four sides and bottom of each specimen were observed. Figure 8 shows the results of the fourth test.

One (b) of the No. 2 specimens and one (b) of the No. 3 specimens grew sharply on the sides and bottoms of the specimens.

Root penetration of Plant A was found in only one (b) of the No. 3 specimens, (No.6-b) side (No.8-b) bottom (No.10-b) side

Figure 7. 3rd Test results

One (b) of the No. 5 specimens and one (b) of the No. 8 specimens had root penetration of Plant A on the bottom of the specimen.

One (b) of the No. 6 specimens had root penetration of Plant A on its sides.

Root penetration of Plant A was found in only one (b) of the No. 3 specimens, (No.2-b) side (No.2-b) bottom (No.3-b) side (No.3-b) bottom (No.5-b) bottom (No.6-b) side

Figure 8. 4th Test results
No new penetration of roots was found in the specimens.

The roots of Plant A that had penetrated the root barrier sheets of the No. 2 and No. 3 specimens (a, b, c) were found to continue to grow on the sides and bottoms of the specimens.

The roots of Plant A that had penetrated the bottom of one (b) of the No. 5 specimens were observed to continue to grow.

The roots of Plant A that had penetrated the bottom of one (b) of the No. 6 specimens were observed to continue to grow.

In the third test, one (b) of the No. 8 specimens had penetration of small roots on the bottom but in this test, the roots were not found probably because they withered.

The No. 10 specimens had too many roots penetrating the surfaces, so it was impossible to separate the containers from the water retention material (rock wool). No more mid-term observation was conducted after that.

3.2.5 5th test

The fifth test was carried out eleven months after the installation, May 20, 2009. Like the process of other tests, the inner containers of the specimens were taken out and the four sides and bottom of each specimen were observed. Figure 9 shows the results of the fifth test.

The roots of Plant A that had penetrated the root barrier sheets of all of the No. 2 and No. 3 specimens (a, b, c) were observed to continue to grow on the sides and bottoms of the specimens.

The roots of Plant A that had penetrated the bottom of one (b) of the No. 5 specimens were found to keep growing.

One (6) of the No. 6 specimens had root penetration on its sides in the fourth test, but in the fifth test, the two specimens (b, c) had root penetration of Plant A on their sides and bottoms and the other specimen (a) had root penetration only on its sides.

Root penetration of Plant A was found on the sides and bottom of one (b) of the No. 8 specimens.

3.3 Results of final test (6th test)

The sixth test was carried out twenty four months after the installation of the specimens, for four days from June 21 to June 24, 2010. In this test, the test containers were disassembled completely; the plants and soil were all removed; and the inside and outside of the root barrier sheets were observed thoroughly. Figure 10 shows the results of the sixth test. The results of the first to sixth tests with all the specimens are summarized in Table 2.

All the No. 1, No. 4 and No. 7 specimens did not have any root penetration in the five mid-term tests from June 11 2008 to May 20, 2009. In the sixth test (June 21 to June 24, 2010) one year after the fifth test (May 20, 2009), roots penetrating the containers through the joints between the sheets were found in all of the specimens. The root barrier sheets of the specimens, which are composed primarily of PVC, were seen to have adequate capacity of resistance to root penetration.

It was, however, thought that to secure long-term resistance to root penetration; it is required
to improve the methods to bond sheets for more stable joints between the sheets.

From the second test (August 12, 2008), root penetration was found in all the three No. 2 specimens that included the root barrier sheets of synthetic polymer. The inner containers of the specimens were taken out and observed in the sixth test (June 21, 2010). The roots of Plant A penetrated the sheet bodies and joints between the sheets. Additional measures to improve resistance to root penetration need to be taken in case these materials are used in green roof systems.

Root penetration was observed in all of the No. 3 specimens from the initial test (August 12, 2008). But in the sixth test (June 22, 2010) in which the inner containers were taken out, the penetration was not found on the sheet bodies which had merely a 4 mm thickness. In case sheets of this type are overlapped with one another by 1.5m, the joined areas of the sheets bond together seamlessly. They were, however, joined by butyl tape in this study and so caused the roots of Plant A penetrate all of the joints. It was therefore considered that sheets of this type require seamless bonding of the joints between sheets for more stable capacity of resistance to root penetration.
Table 2. Greenhouse test results for root barrier materials

<table>
<thead>
<tr>
<th>No.</th>
<th>Test period &amp; test results</th>
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</thead>
<tbody>
<tr>
<td>a</td>
<td>b</td>
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<tr>
<td>1</td>
<td>O</td>
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<td>2</td>
<td>O</td>
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<td>9</td>
<td>O</td>
</tr>
<tr>
<td>10</td>
<td>O</td>
</tr>
</tbody>
</table>

[Index] O : Not show root penetration, X : 1 : Show root penetration in main material sheets, X : 2 : Show root penetration in joints, X : 3 : Damage of painted film layers

One of the No.5 specimens was found to have root penetration on the joint on the bottom from the third test (September 18, 2008), but the other two specimens did not have any root penetration in the sixth test (June 23, 2010) in which the inner containers were taken out and observed.

The No.6 specimens had root penetration only in the sides of one specimen (b) until the fourth test (December 15, 2008), but had root penetration of Plant A in all the three specimens after the fifth test (May 20, 2009). In the sixth test (June 23, 2010) in which the inner containers were taken out and observed, it was found that the root penetration was all through the joints between the sheets. For this type of sheets, the methods to bond sheets need to be revised for more stable joints between the sheets.

The No.8 specimens included root barrier sheets in which fiber reinforced HDPE was inserted between aluminum sheets. Root penetration was found in only one (b) of the No. 8 specimens from the third (September 18, 2008) to the fifth (May 20, 2009) tests, but in the sixth test (June 23, 2010), was found to be through the joints between the sheets in all of the specimens.

Besides, the b specimen had root penetration of Plant A that was made through the sheet body on the bottom of the specimen.

No root penetration to the outside was found in all the three No. 9 specimens until the fifth test (May 20, 2009). In the sixth test (June 21, 2010), the roots of Plant A were found to penetrate the waterproofing coating paint in all the specimens but failed to penetrate the root barrier sheets.

4. Conclusion and Suggestion

In this study, tests on resistance to root penetration were conducted for two years (June 11, 2008 to June 21, 2010) with root barrier sheets of nine types used in green roof systems. The conditions of test were set up by considering the climate, other natural characteristics and the setting of planting of Korea. Test containers were designed and fabricated so that the test plants could grow properly during the test period and it could be easy and simple to check regularly from the outside of the containers if there was root penetration.
penetration. In the sixth test (June 21 to June 24, 2010), two years after the commencement of the first test, the test containers were disassembled and the root barrier materials were observed thoroughly. The results of observation are as follows:

1) No root penetration was found on the sheet bodies of the test materials, but the roots of Plioblastus pygmaed Mitford A, were observed to grow, penetrating most of the joints between the sheets, To use such root barrier sheets in green roof systems, it is absolutely imperative that the methods to bond root barrier sheets are reinforced and improved in order for stable joints between the sheets.

2) Of the test materials, those with waterproofing coating paint of urethane were found to have serious damage caused by root penetration of Plioblastus pygmaed Mitford A. In case such combination of root barrier sheet and waterproofing coating is applied in green roof systems, the coating paint is likely to fail to function well.

It is necessary to enhance techniques to separate the functions of waterproofing and root penetration resistance from the aspect of performance-based designing. In addition, a waterproofing membrane needs to be located below a root barrier layer.

Root penetration of the arbor Pyracantha angustifolia was not found in most of the test specimens, That’s why many of the root barrier materials pass the FLL(The German Landscape Research, Development and construction Society) tests with ease. The FLL guidelines stipulate that results of tests (resistance to root penetration) with Pyracantha coccinea be separated from those with plants characterized with vigorous rhizome growth (for example, bamboo). It is considered that this stipulation reflects the position of makers than that of building owners (users) and shows the situation of Germany where light green roofs requiring little maintenance are common, unlike Korea.

The planting conditions of tests on resistance to root penetration need to be the most severe possible, considering the impact of invasive species on the sites of green roof systems, The results of this study prove that one species, Plioblastus pygmaed Mitford A, is sufficient as a test plant for tests on resistance to root penetration in Korea.

References


