Aging of rolled erosion control products for channel erosion control

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ABSTRACT: The purpose of this study was to investigate the aging effects of environmental factors on rolled erosion control products (RECPs). Seven RECPs made of natural, synthetic or composite materials were evaluated. Used (installed in channels of a field laboratory for 3 years) and unused (stored in a limited climate-controlled laboratory for 3 years) samples of each product were tested to determine 10 physical properties, including mass per unit area, thickness, tensile strength, stiffness, light penetration, resilience, water absorption, swell, specific gravity and smolder resistance. The results indicate that all materials exhibited a significant loss of tensile strength after 3 years of use. Used materials of the natural type showed a 68% strength loss whereas the composite and synthetic types had smaller strength losses in the range of 37-61%. Other property testing results showed less conclusive or inconsistent trends, which implies that tensile strength is a critical and reliable property for use to evaluate the aging effects on RECPs.

KEYWORDS: Geosynthetics, Erosion control, Environmental factor, Turf reinforcement mats


1. INTRODUCTION

In recent years, rolled erosion control products (RECPs) have become a popular best management practice for channel erosion control and the control of urban stormwater. RECPs, which are often referred to as geotextiles or erosion control blankets, are typically designed as a temporary measure to facilitate the growth of natural vegetation on bare sites while turf reinforcement mats (TRMs), although a subset of RECPs, are available for permanent use in channels. The notion of using RECPs for channel erosion control is based on the complementary strengths deriving from the RECP and vegetation. At the early stage, after new RECPs have been installed to protect bare channel surfaces, their primary role is to provide strength. As the RECPs age the vegetation growing through them takes over the role of major protector of the channel.

In accordance with the policies of the Clean Water Act, the US Environmental Protection Agency has already designated TRMs and vegetated swales as stormwater best management practices. As a result, RECPs for channel protection are in high demand as more construction site operators seek National Pollutant Discharge Elimination System Phase II compliance (Theisen 2005). The recommendation for the establishment of vegetation on construction sites indicates that the erosion control industry needs a durable TRM or any other erosion control mat that will support vegetation to an acceptable extent (Nelsen 2005). Theisen (2005) has pointed out that the use of RECPs has more than tripled since 1996 and many sophisticated RECPs have been developed by the industry. Despite this, the functional longevity of these RECPs is still not well documented.

The erosion control industry uses the term TRM to describe permanent RECPs that have a minimum lifespan of 3 years and a maximum of 50 years. Vegetation is expected to establish substantially and become part of an integrated erosion control system with any remaining TRM material 3 years after the TRMs were installed. Therefore, it is important to know whether a TRM can remain viable for at least 3 years while vegetation becomes established.

The objectives of this study were: (1) to characterize the aging effects of environmental factors on RECPs for channel erosion control by measuring physical properties; and (2) to identify critical physical properties that could be used for aging evaluation. Seven RECPs that could be used as TRMs for channel erosion control were evaluated.
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These RECPs were made of natural, synthetic or composite materials. Both used (installed in channels of a field laboratory for 3 years) and unused (stored in a limited climate control laboratory also for 3 years) samples of each product were tested for 10 physical properties, including mass per unit area, thickness, tensile strength, stiffness, light penetration, resilience, water absorption, swell, specific gravity, and smolder resistance.

2. ENVIRONMENTAL FACTORS

In channels, there are numerous degradation mechanisms that might act on erosion control materials, including oxidation, hydrolysis, radioactivity, and physical, chemical and biological actions. According to Thiesen (2005), the durability of an erosion control material is directly related to its functional longevity. Microbial activity, ultraviolet (UV) degradation and chemical degradation can result in material breakdown which reduces durability. Among the environmental factors, UV light and elevated temperature are considered to be most critical ones because the chain scission of polymers is initiated by the nanometer waves of UV radiation penetrating the polymer in parallel with the elevated temperature (Lied and Hake, 1989; Koerner et al. 2005). High temperature and temperature cycling cause stress changes and adversely affect the stress-strain characteristics of the geotextile by reducing its strength due to wear and tear in the fibers. Long-term elevated temperatures can also reduce the blanket’s strength in most cases.

During heavy rainfall, the very high stresses that are generated by deep channel flows can cause mechanical wear and tear to RECPs. Stormwater runoff can induce strains in the RECPs and wet them to cause property changes. The presence of water in this form is continuous and, although it promotes the growth of vegetation in the soil to form a permanent vegetative blanket, it might also combine with the temperature and UV light to cause photo-oxidation of the polymers.

In addition, human factors such as maintenance operations or vehicles running off pavement, which are not necessarily environmental factors, are common causes that damage or weaken RECPs in roadside channels. Therefore, it is essential to understand the environmental factors that can cause damage to RECPs because there are also many other unpredictable factors on roadside channels that can cause further damage.

3. TEST PROCEDURES

3.1 Materials

The seven tested RECPs, each made by a different manufacturer, are listed in Table 1. They were made from three types of materials: natural, synthetic and composite, as described by Holland (2002) and are briefly described below.

- Natural mats: natural blankets/mats made of short-term degradable natural materials such as jute, coir, straw, and wood fibers.
- Synthetic mats: synthetic mats that are resistant to degradation and made of fibers consisting of polymer chains with chemical bonds.
- Composite mats: permanent three-dimensional synthetic mats combined with degradable natural materials.

The used RECP samples were randomly collected from channel RECPs that had been installed at the Hydraulic Sedimentation and Erosion Control Laboratory (HSECIL) of Texas Transportation Institute for the 3 years from 2001 to 2003. HSECIL is located in Bryan, Texas, USA at a latitude of approximately 30° 38’ N and altitude of 77 m above mean sea level. The monthly rainfall and temperature during 2001 and 2003, as recorded by a nearby airport, are summarized in Table 2. Seeding was applied when the RECPs were installed and vegetation was established over nearly 100% when these used RECPs were sampled. It should be noted that some vegetation residues and soils were tightly attached or adhered to the used RECPs collected from the field. Separation of residues and soils from RECP samples was done gently without apparent damage to the structure of the samples. Any excessive attempt to separate field materials from RECP samples could impose unwanted damage and so the used RECPs were tested with some residues attached. On the other hand, samples of unused RECPs were collected from materials stored for 3 years in an indoor facility at HSECIL that did not have temperature and humidity controls. The unused RECPs in their original rolls were wrapped in

<table>
<thead>
<tr>
<th>Material type</th>
<th>Tested product</th>
<th>Raw material</th>
<th>Material construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural</td>
<td>NAU</td>
<td>Excelturf</td>
<td>Compressed interlocking fibers</td>
</tr>
<tr>
<td>Synthetic</td>
<td>SYN-I</td>
<td>Polypropylene</td>
<td>Bi-axially oriented nets mechanically bound together by polypropylene stitching</td>
</tr>
<tr>
<td>Composite</td>
<td>SYN-II</td>
<td>Polypropylene</td>
<td>Polypropylene fibers mechanically stitched</td>
</tr>
<tr>
<td></td>
<td>COM-I</td>
<td>Polypropylene + coir</td>
<td>Coconut fibers bound by double polypropylene netting</td>
</tr>
<tr>
<td></td>
<td>COM-II</td>
<td>Polypropylene + coir</td>
<td>Uniformly distributed excelsior fibers with polyamide filaments forming a net on one side and polypropylene on the other</td>
</tr>
<tr>
<td></td>
<td>COM-III</td>
<td>Polypropylene + Excelturf</td>
<td>Double extruded plastic mesh with interlocking excelsior fibers</td>
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<tr>
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<td>COM-IV</td>
<td>Polypropylene + coir</td>
<td>Triple synthetic netting bound with 30% coir and 70% straw fibers</td>
</tr>
</tbody>
</table>

Geosynthetics International, 2008, 15, No. 4
plastic bags and protected from moisture and sunlight at room temperature. The unused RECPs were completely unrolled for random sampling.

3.2. Methods

Although it is difficult to measure durability directly, testing of physical properties allows comparisons to be made between the different RECPs with regard to the aging effects of environmental factors. Physical property testing was also used to monitor changes that may occur after an RECP has had some kind of exposure (Shukla 2002). Many physical property tests have been developed and published by the American Society for Testing and Materials (ASTM). Therefore the RECPs were evaluated by physical property testing in this study. The test matrix is presented in Table 3. Detailed information of all physical property tests, related equations, required steps to calculate property values, and units have been published by Khanna (2005). The main results from each physical property test and its relation to longevity, test procedures, expected property changes with time, and the associated null hypothesis (intended to be rejected) are described below:

3.2.1. Mass per unit area
Mass per unit area was measured by weighing a fixed area of the material based on ASTM D5261. UV radiation could cause the polymer chains to break and in turn reduce the weight of the material. Heat and stormwater runoff may also induce wear and tear of the fabric, which will ultimately reduce the weight of the fabric. The null hypothesis is that the mass per unit area of RECPs will increase after 3 years of use for erosion control.

3.2.2. Thickness
Using the ASTM D5199 method, the thickness of the geotextiles was measured as the distance between the upper and lower surfaces of the material at a specified normal pressure (Driver and Kostielney 1997). In the case of erosion control, the thickness is usually equated with an eventual supportive matrix for root entanglement after vegetative growth. The thickness property is affected in a similar way to the mass per unit area of the material.

### Table 2. Means of temperature (°C) and monthly rainfall (mm) during this study

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<tr>
<th></th>
<th>Jun</th>
<th>Feb</th>
<th>Mar</th>
<th>Apr</th>
<th>May</th>
<th>Jun</th>
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</tbody>
</table>

*Recorded by the Easterwood Airport in College Station, Texas, USA, approximately 10 km south of HISECL.

### Table 3. Number of RECP samples tested for each used and unused condition

<table>
<thead>
<tr>
<th>Material name</th>
<th>Mass per unit area</th>
<th>Thickness</th>
<th>Resilience</th>
<th>Stiffness</th>
<th>Tensile strength</th>
<th>Specific gravity</th>
<th>Water absorption</th>
<th>Swell</th>
<th>Light penetration</th>
<th>Smolder area</th>
</tr>
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<tr>
<td>NAE-1</td>
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<td>32</td>
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<td>2</td>
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<td>10</td>
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<td>2</td>
<td>3</td>
<td>10</td>
<td>3</td>
<td>3</td>
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<tr>
<td>COM-II</td>
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<td>12</td>
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<td>2</td>
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<td>3</td>
<td>3</td>
</tr>
<tr>
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<td>COM-IV</td>
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<td>10</td>
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</tbody>
</table>

*For stiffness testing, 16 for machine direction and 16 for cross direction.

*For tensile strength testing, five for machine direction and eight for cross direction.
UV radiation, heat and stormwater could induce wear and tear of the fabric, and therefore, reduce the thickness of the materials. However, the thickness could increase due to inclusion of soil and organic material into the netting. The null hypothesis is that the thickness of the RECPs will decrease after 3 years of use for erosion control.

3.2.3. Resilience
Resilience is a measure of the impact of cyclic loadings on the RECPs. This is relevant to the ability of the RECPs to protect newly developing seedlings from damage during loading (Rickson 2002). It is described as the erosion control blankets’ ability to spring back into shape in a specified period of time (Driver and Kostielney 1997). Resilience was measured using the method defined in ASTM D5199. The entanglement of soil and vegetation residue in the fiber netting, and the effect of wear and tear could reduce the ability of the material to regain its original shape. The null hypothesis is that the resiliency will increase after 3 years of use for erosion control.

3.2.4. Tensile strength
The measurement of tensile strength followed the ASTM D5035-95 method that quantifies the tensile strength of a material by peak force per unit width of material (kN/m) stretched. The latest standard is ASTM D6818-02. Koepern (2005) stated that tensile strength is the single most important property of a geotextile. According to Sprague and Goodrum (1994), long-term tensile resistance is the most common property related to the durability in geotextiles. Due to specific geometry and irregular cross-sectional area, the tensile strength of geosynthetics cannot be expressed conveniently in terms of stress; hence, it is redefined as the peak load that can be applied per unit width. The basic test steps are: (1) securing the geotextile within a set of clamps or jaws; (2) placing this assembly in a mechanical testing machine; and (3) stretching the geotextile in tension until failure occurs. During the extension process, both load and deformation are measured, and therefore, a graph of stress (usually given as load per unit width) plotted against strain (calculated as deformation divided by original specimen length) curve can be generated. From the stress–strain curve, four values are obtained: maximum tensile stress (referred to as the geotextiles’ strength), strain at failure (often given as maximum elongation or simply elongation), toughness (work done per unit volume before failure, usually taken as the area under the stress–strain curve) and modulus of elasticity (slope of the initial portion of the stress–strain curve). Tensile modulus (Myles and Carswell 1986) is the slope of the geosyntthetic stress–strain or load–strain curve, which indicates the deformation required to develop a given stress (load) in the material. The null hypothesis is that the tensile strength will increase after 3 years of use for erosion control.

3.2.5. Stiffness
Stiffness, or resistance to bending, is measured by the blanket’s capacity to form a cantilever beam without exceeding a certain amount of downward bending under its own weight (Shukla 2002). A RECP with a low stiffness value adapts to the land beneath for intimate surface contact (Rickson 2002). In this study, stiffness was measured using the method defined in ASTM D1388. The stiffness of a used material may increase as the mass of the material increases due to inclusion of the soil and vegetation residue. Furthermore, high temperatures and UV rays can harden the material to a substantial extent and reduce the flexibility and the ability of the material to maintain an intimate contact with the surfaces underneath. The null hypothesis is that the stiffness will decrease after 3 years of use for erosion control.

3.2.6. Light penetration
The method of ASTM D6567 was used to measure light penetration. Light penetration is a property used to quantify the openness of a RECP (Rickson 2002). A light source is placed inside a box on one side of the specimen and the light penetrating through the specimen is measured from the other side. The null hypothesis is that the light penetration will decrease after the materials have been used for erosion control for 3 years.

3.2.7. Water absorption
Water absorption testing followed the ASTM D1117 method. According to Rickson (2002), the significance of the water-holding capacity for erosion control is due to the effect on the weight of the geotextile. Natural products typically have high water-holding capacities and wet ones can become about five to six times their original weight. However, pure synthetic products have very low water-holding capacities and gain very little weight, which may adversely affect their erosion control performance. From the sense of seed germination, RECPs with a high water-absorption capability are preferred. Without adequate moisture, the planted seeds may perish and little vegetation can grow. In addition, as the weight of the product increases due to the wetness, the contact between RECPs and the soil is enhanced. The null hypothesis is that the water absorption will decrease after the materials have been used for erosion control for 3 years.

3.2.8. Swell
Swell testing also followed the ASTM D1117 method. Swell is a property related to water absorption and associated dimensional changes (Rickson 2002). The swell test (Driver and Kostielney 1997) is related to water absorption and a low swell value is preferred for RECPs. If the swell is less than the blanket will be able to keep the moisture closer to the soil where seeds can use it for germination. The swell behaves in a similar manner to the water absorption and hence the swell is expected to increase with time in use. The null hypothesis is that the swell will decrease after the materials have been used for erosion control for 3 years.

3.2.9. Specific gravity
Specific gravity is the ratio of the density of a RECP to the density of water. When a RECP is used for erosion control, its specific gravity is expected to increase with
time in a similar manner to mass per unit area and thickness because of the inclusion of the soil and organic residue. The specific gravity was measured using a procedure in accordance with ASTM D792. The null hypothesis is that the specific gravity will decrease after the materials have been used for erosion control for 3 years.

3.2.10. Smolder resistance

This test was conducted in accordance with ECTC-TASC 00197 (ECTC 2007). Smolder resistance is an evaluation of the resistance of the organic material to ignition by a smoldering cigarette (Rickson 2002). It is determined by allowing a cigarette to completely burn on the top of a RECP sample in a fume hood (Driver and Kostelney 1997). This property is important because degradable erosion control blankets are susceptible to flammability by cigarettes. In this test, smolder area was estimated. The distance from the cigarette ash to the maximum reach of the smolder was measured. Short distances that indicate a high smolder resistance are desirable. The null hypothesis is that the smolder area will decrease after the materials have been used for erosion control for 3 years.

3.2.11. Statistical analysis

Statistical analysis was conducted by a paired t-test to compare the means of the two sample groups. Physical properties of used and unused RECPs. The significance level (α) of 0.05 was set for one-tail hypothesis testing.

4. RESULTS AND DISCUSSION

Means of each physical property of the used and unused RECPs are presented in Table 4. The t-test P-values of physical property comparison between used and unused RECPs are presented in Table 5. The P-values less than 0.05, which indicate significant physical property changes are shown in bold typeface. As noted in Section 2.1, some vegetation residues and soils were tightly attached or adhered to the RECPs collected from the field. Hence, physical property values of used RECPs represent a compound condition of the RECPs, residue and soils.

The results can be grouped in two categories: (1) physical properties with consistent changes for all RECPs; and (2) physical properties without consistent changes. Tensile strength was found to be the only property with statistically significant, consistent changes and it was reduced for all used RECPs. This finding supports the assertion of Koerner (2005) that tensile strength is the single most important property for geosynthetics. Table 6 also shows that NAT-1, a natural RECP, exhibited a strength reduction of 68% from 0.44 to 0.14 kN/m, the highest strength loss percentage among all RECPs and the lowest remaining strength after 3 years. Synthetic and composite RECPs had a strength reduction in the range of 37 to 61%, and all strength of unused and used mats were greater than or equal to 0.44 kN/m. In particular, both of the used synthetic RECPs, SYN-I and SYN-II, still had high tensile strengths at 3.45 kN/m (38% strength loss) and 4.12 kN/m (45% strength loss), respectively.

Table 4: Physical property test results (mean)

<table>
<thead>
<tr>
<th>Property</th>
<th>Condition</th>
<th>Measured area (mm²)</th>
<th>Thickness (mm)</th>
<th>Resistance (%)</th>
<th>Shrinkage (%)</th>
<th>Tenacity (kN/m)</th>
<th>Specific gravity</th>
<th>Water absorption (%</th>
<th>Erosion (cm)</th>
<th>Light transmission (%)</th>
<th>Smolder area (cm²)</th>
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<tbody>
<tr>
<td>NAT-1</td>
<td>Unused</td>
<td>229.96</td>
<td>2.03 ± 0.76</td>
<td>77.76</td>
<td>100.01</td>
<td>1.70</td>
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<td>SYN-I</td>
<td>Unused</td>
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<td>0.44 ± 0.00</td>
<td>67.14 ± 0.00</td>
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<tr>
<td>SYN-I</td>
<td>Used</td>
<td>580.00</td>
<td>0.14 ± 0.00</td>
<td>57.14 ± 0.00</td>
<td>100.00</td>
<td>0.70</td>
<td>0.14</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

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It is clear that synthetic RECPs outperformed natural and composite ones in tensile strength, and the natural type was the weakest. The implication for application of RECPs is that for a channel subject to severe erosive forces, synthetic and composite RECPs should be considered. Fresh natural RECPs may remain viable initially but deteriorate quickly after they have been installed in the field for 3 years. For more severe erosion conditions, synthetic RECPs may be the only type that can be considered.

Two other physical properties that showed a consistent trend of change (either statistically significant or insignificant) were water absorption and light penetration (Tables 4 and 5). Although both properties followed hypothesized changes by rejecting the null hypothesis, their reliability for evaluating the effects of aging may not be as high as that of tensile strength for the following reasons. First, tensile strength relies on the bonding strength of connected structures of the original RECPs. Attached or adhered field materials on collected RECP samples tended to be patchy and not continuously connected, and therefore, should contribute little to tensile strength. Second, both water absorption and light penetration are inherently correlated with the quantity and dimension of physical objects and therefore, are highly affected by attached or adhered field materials.

The remaining physical properties (mass per unit area, thickness, stiffness, resilience, swell, specific gravity, and smolder resistance) showed inconclusive, inconsistent results, which can be attributed in part to the compound effect contributed by the attached or adhered field materials. Therefore, these properties (mass per unit area, thickness, stiffness, resilience, swell, specific gravity, and smolder resistance) should not be used for predicting field aging effects.

During the field sample collection processes, the researchers realized that the experimental design of the present study, which used field samples would not be able to compare clean RECPs between used and unused samples. However, the intrusion of field materials into RECPs was deemed an important environmental process and should be included in the testing. Using field samples could capture most of the physical, chemical, and biological effects of environmental factors. On the other hand, a different experimental design that used field samples free from vegetation and soil attached could study how other environmental factors affect physical properties over time. A limitation of such an experimental design is that it does not include the vegetation and soil effects.

5. CONCLUSION

The aging effects of environmental factors were studied by measuring ten physical properties of seven used and unused RECPs made of natural, synthetic, and composite materials. Unused samples were collected from RECPs stored in a limited climate control laboratory for 3 years and the used samples were obtained from RECPs installed for 3 years in channels at a field laboratory. It was found that tensile strength was the only property that showed
consistent and statistically significant changes. All RECPS showed a significant tensile strength reduction after 3 years of field exposure. The natural RECP, NAT-I, had a strength reduction of 68% from 0.44 to 0.14 kN/m, which was the highest strength loss percentage among all RECPS and the lowest remaining strength. Synthetic and composite RECPs had strength reductions in the range 37 to 61%, and all strengths of unused and used RECPs were greater than or equal to 0.44 kN/m. Both used synthetic RECPs, SYN-I and SYN-II, still had high tensile strengths at 3.45 kN/m (38% strength loss) and 4.12 kN/m (45% strength loss), respectively.

As Koerner (2005) mentioned, tensile strength is the single most important property for geotextiles and the results of the present study support Koerner’s assertion because tensile strength was the only predictable property for all types of RECPs investigated. This suggests that tensile strength is a reliable property for evaluating the aging effects on RECPs.

This study was limited by the number of different types of RECPs investigated and its experimental design. Future research should focus on quantifying tensile strength reductions for different types of RECPs after they have been used. A greater number of different products should be studied to increase validity. Furthermore, an experimental design using unused RECPs free from field materials should be attempted to allow comparisons between the present results and those generated from this different experimental design.

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ABBREVIATIONS
ASTM American Society for Testing and Materials
COM-I First tested RECP made of combined synthetic and natural materials
COM-II Second tested RECP made of combined synthetic and natural materials
COM-III Third tested RECP made of combined synthetic and natural materials
ECTC Erosion Control Technology Council
HSEC Hydraulic, Sedimentation and Erosion Control Laboratory
NAT-I Tested RECP made of short term degradeable natural materials
RECP Erosion control product
SYN-I First tested synthetic RECP that are resistant to degradation
SYN-II Second tested synthetic RECP that are resistant to degradation
TRM Turf reinforcement mat

REFERENCES

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Aging of rolled erosion control products for channel erosion control


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