PROJECT REPORT

Evaluating The Longevity and Condition of the Geotextiles Used in The Past in Geo-Infrastructures Constructed with Recycled Concrete Aggregate

by

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ABSTRACT

Due to the increasing interest in the use of recycled concrete aggregate (RCA) as an unbound base course in a pavement structure, Virginia Department of Transportation (VDOT) identified a need for in-depth research in order to investigate the clogging potential of highway underground drainage systems that consist of corrugated and perforated pipe embedded in 57 stone that is wrapped around with nonwoven geotextile. The content described in this report is associated with an ongoing study, where GMU, with VDOT's support, has constructed a field implementation test site. The site includes two unpaved road test sections where the unbound base course is constructed with 100% RCA and 100% virgin aggregate (VA). Both sections include underdrain systems (a.k.a edgedrains, sidedrains, and French drains) with nonwoven geotextile that is in direct contact with unbound base course.

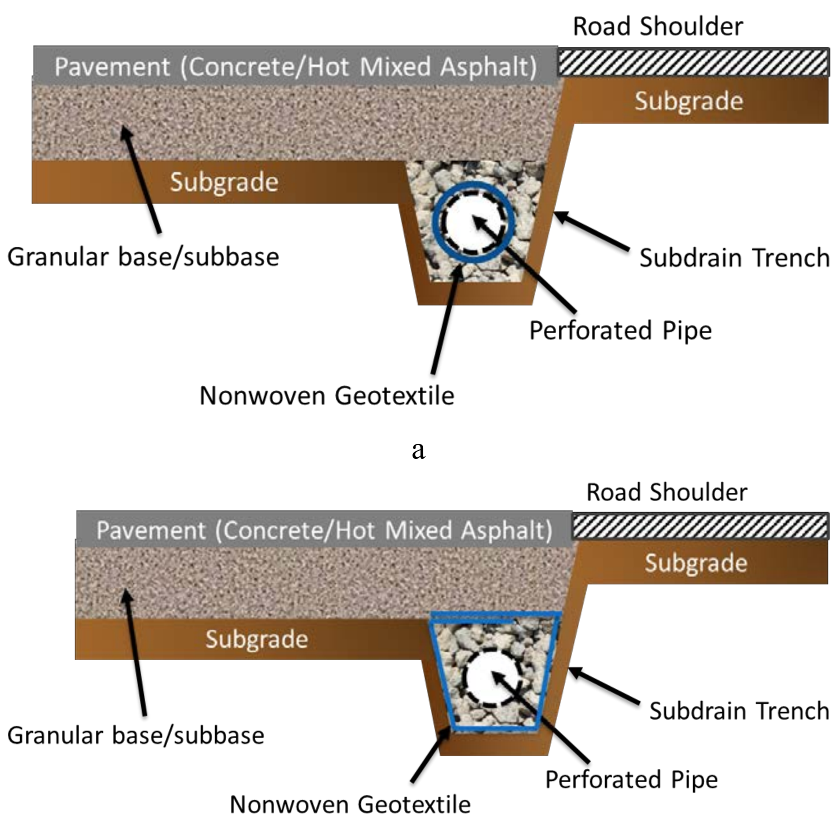
The research described in this report was developed by Drs. Tanyu and Abbaspour to complement GMU/VDOT's ongoing field study. The Recycled Material Research Center's (RMRC) support provided the opportunity to exhume geotextile samples from the field implementation site at a period (9-months service life) that is not covered in GMU/VDOT research. The information gained from RMRC support allows GMU to increase the data resolution and to capture any potential trends during the first year of underdrain service. As part of the research presented in this report to RMRC, exhumed geotextile samples from field were analyzed using permittivity test and microscopic imaging to evaluate and quantify the occurrence of physical and chemical clogging, respectively.

The permittivity results show that the nonwoven geotextile sample exhumed from both RCA and V.A. sections experienced a reduction in serviceability due to both physical and chemical clogging. At the end of 9-month service life, the reductions for the RCA section are in the order of 45% and 8% and for the V.A. section, they are 25% and 7% for chemical and physical clogging respectively. These values indicate that after 9-months of being in service, neither physical nor chemical clogging of the geotextile nor combination of the two clogging mechanisms pose significant restrictions in the flow and filtration capacity of the underdrain system. These are promising observations and to the best of the authors' knowledge, such observations have not before reported in the literature.

1. INTRODUCTION

Creating granular base aggregate from recycled concrete aggregate (a.k.a. crushed concrete or RCA) has been an interest to many state department of transportation agencies for the last decade and more. However, when roads are constructed with drainage or reinforcement systems that contain geotextile components, one of the concerns has been associated with physical and/or chemical clogging of the geotextile due to the migration of fines and/or chemical precipitation of calcium-based compounds from RCA.

The general configuration of a underdrain for roadway applications has changed over the past two decades. In the older configuration (Figure 1a), the perforated pipe is wrapped around with nonwoven geotextile and embedded in a trench filled with drainage coarse aggregate (Hansen, 1995; Snyder and Bruinsma, 1996; Ceylan et al., 2013; Iowa DOT, 2016; Kim et al., 2016). However, in the more recent configuration (Figure 1b), the nonwoven geotextile wraps around both the drainage aggregate and perforated pipe (e.g. UD-4 subdrain, VDOT, 2008). In both cases, the clogging of geotextile and loss of serviceability (as defined by the ability of the geotextile to permeate flow) can pose a detrimental effect on the over the service life of the road pavement.



a

b

Figure 1. Typical cross-section of a roadway with side-drain with, (a) old and (b) new design of underdrains

In the years prior to 2013 and due to the increasing interest in the use of RCA in pavement design, the Virginia Department of Transportation (VDOT) identified a need for in-depth research in order to investigate the clogging potential of highway underdrains with the purpose of introducing possible provisions to their specifications in order to allow the use of RCA in roadway construction (Tanyu and Abbaspour, 2020). Currently, multiple DOT specifications limit the use of RCA in highway pavements (FDOT, 2012; MDOT, 2012; Iowa DOT, 2016; MnDOT, 2016; VDOT, 2016). These limitations are directly related to the concerns about the loss of serviceability of underdrain systems (Figure 1) as a result of chemical clogging. The typical underdrain configuration includes a perforated pipe (generally a 4 or 6-inch in diameter) embedded in course aggregate wrapped around with nonwoven geotextile. All new pavement systems constructed under the jurisdiction of the VDOT are required to include the installation of this underdrain system. If clogged, the reduction in serviceability of underdrain can potentially jeopardize the service life of the transportation infrastructure (roads and highways). Therefore, the current VDOT specification limits the use of RCA in presence of any drainage system.

To answer the research needs of VDOT and address the discrepancies in the existing literature, Dr. Burak Tanyu of George Mason University developed a research study to investigate the clogging potential of a nonwoven geotextile by RCA. This study included multiple phases and components. The first phase of this research project included laboratory-scale testing and simulation and was funded by the Virginia Transportation Research Council (VTRC). These simulations consisted of the nonwoven geotextile/RCA interactions under saturated and unsaturated flow conditions. The findings from the first phase of this research was published in November 2020 (Report Number VTRC 21-R12) (Tanyu and Abbaspour, 2020).

Based on the findings of laboratory-scale simulation tests, two major clogging phenomena associated with hydraulic compatibility of RCA and drainage geotextile were identified. These phenomena are physical clogging (as a result of internal instability of RCA and occurrence of suffossion) and chemical clogging (due to chemical reaction and solid precipitate formation within geotextile fibers). Two models were developed for evaluating the hydraulic compatibility of RCA and drainage geotextiles based on the clogging mechanism. A clogging criterion (hydraulic conductivity ratio) is introduced based on long-term filtration tests under a saturated condition in which the clogging is dominantly controlled by a physical phenomenon. Additionally, a tufa precipitation kinetics model was developed to estimate the reduction in infiltration rates of the RCA/geotextile system under unsaturated and periodic rainfall events (wet/dry cycles in which the chemical phenomenon is dominant). The former condition (saturated flow in a base layer) may occur in a real-life application in case of very high intensity and long duration rainfall events. Whereas the latter condition was found to be prevalent during low-intensity and periodic rainfall events (especially seasonal changes in summer, autumn, and winter).

The following summarizes the findings from GMU's past study on the hydraulic compatibility of RCA and nonwoven geotextiles used for filtration/drainage:

1. Hydraulic conductivity of RCA does not change with aging and the values obtained from RCA with approximately 8% fines are in the order of 10^{-3} to 10^{-4} cm/sec. These hydraulic

conductivity values, in most cases, are comparable to the hydraulic conductivity of Virgin Aggregates (V.A.) with similar gradation.

2. In saturated conditions, some of the fines within RCA migrate onto the geotextile but not to an extent that creates physical clogging (no flow condition). Gradation of the RCA and the permittivity characteristics of the geotextile play important factors to minimize the migration of fines, therefore creating RCA gradation with high internal stability will minimize the suffossion susceptibility and the concerns associated with physical clogging. Evaluation of grain size distribution of an RCA base layer that has been in service for some time allows the evaluation of the internal stability conditions of the initially selected gradation and susceptibility of such layer to the occurrence of suffossion.

3. Calcareous tufa (calcium-based crystals that may grow on the geotextile) is derived by diagenetic calcite precipitation followed by dominant gypsum formations. The evaporation condition that may result in precipitation becomes active due to wetting and drying cycles of the unbound base course, Therefore, unsaturated (or partially saturated) conditions pose a more critical scenario than saturated conditions in terms of the potential to chemically clog geotextiles. In general, tufa generation from RCA appears to be much faster within the first three months compared to six months and beyond.

4. The flow characteristics of the RCA base and nonwoven geotextile are affected by the occurrence of both physical and chemical clogging phenomena. However, during the simulation period in the laboratory, the magnitude of the physical migration of fines and precipitation of tufa occurrences were not significant to pose a detrimental threat to the ability of the nonwoven geotextile to permeate flow and the overall service life of the underdrain system.

The occurrences of both phenomena are expected in a highway system and therefore the previous observations from the laboratory-scale study needs to be confirmed in tests conducted in the field where there is significantly more redundancy due to the scale effect. Considering the importance of such verification, the authors constructed a field implementation test site with the support of the VDOT. This test site consisted of an unpaved section constructed using RCA as base course material and a duplicate section (unpaved) constructed with V.A. as a control section. These sections are meant to simulate an actual roadway with underdrain systems. In each section, two underdrains are installed conforming to the VDOT UD-4 edgedrain configuration (VDOT, 2008). During this field study, the intent is to exhume nonwoven geotextile samples in every 6 months and analyze the exhumed samples under a microscope to understand the extent of the chemical clogging that happens in a real-life application. Findings of this study are expected to help VDOT and other DOTs across the country to determine if the existing provisions in their specifications can be implemented to lift the restrictions of the use of RCA as unbound base course/subbase material. The duration of the field monitoring study with VDOT will be three years to confirm if over time the conditions become stable or continue to change. Such long-term observation is critical considering the fact that most roadway systems are expected to have a service life of 20 to 25 years and in some circumstances the roadways are continued to be in service many more years than initially expected (Thompson et al., 2012).

The research described in this report was developed specifically to complement the ongoing field study. The main goal of the research portion that is supported by the Recycled Material Research Center (RMRC) will help in providing additional information to capture the changes that occurs within the first year of the roadway system. Such observation is important because the previously completed laboratory study by GMU indicated that many of the changes occur during the first 9-months that the RCA is placed in the ground and then the tufa precipitation appears to be slowing down with time. The additional information that is obtained from the field is aimed to be combined with the models developed from the laboratory scale tests and data obtained from the ongoing field study. The combined data and information will enable the researchers and practitioners to project and predict the loss in serviceability of the nonwoven geotextile/RCA base systems with higher accuracy. The increased accuracy will help integrate the sustainable practice of using recycled material such as RCA in the construction of highways.

2. PURPOSE AND SCOPE

The original objective of this research was to reach out to the several state departments of transportation agencies within the U.S., who have used RCA with geotextile previously and to coordinate with them to exhume those geotextiles to investigate the conditions of the geotextiles after being in service for 15 to 20 years (or even more). This information would remarkably complement the previous laboratory research and ongoing field study to help better define whether or not in the long term, the conditions within the RCA base course severely change from what will be observed from the VDOT research project.

The first task of the envisioned research was to identify and document sites that are of interest, based on the available information in the literature. Fourteen (14) states were identified that had reported cases of highway construction; in which, RCA material was used as base course/subbase layer within the last 5 to 15 years (FHWA, 2003; Gonzalez and Moo-Young, 2004; Bennert and Maher, 2008; Saeed and Hammons, 2008; Van Dam et al., 2011; Edil et al., 2012; Ceylan et al., 2013; Chen et al., 2013; Ceylan et al., 2015; Townsend et al., 2016; Wong and Maher, 2018; Cackler, 2018; Snyder et al., 2018). The researchers communicated with the DOTs officials and engineers of these 14 states. Although these DOTs were identified because there are publications that stated that such roadways were constructed in these states; unfortunately, no field site with RCA and nonwoven geotextile could be located when the key personnel was contacted. This issue primarily occurred because in most agencies the personnel that has been involved in the construction of these historical roadways have already retired and the records associated with such detail do not exist.

The issue of potentially not being able to locate a DOT site was foreseen in the research proposal submitted to RMRC. In the limitations section of the proposal, it was stated that if a suitable site cannot be determined after 6 months of the proposed beginning of the project, the researchers will redirect the study to focus on exhuming two nonwoven geotextile samples from GMU/VDOT's test site sections constructed with 100% RCA and 100% V.A. These problems were communicated with the RMRC director, Dr. Tuncer Edil. With the approval of RMRC, the research scope and goals were readjusted to include the assessment of two nonwoven geotextile samples from the ongoing GMU/VDOT field study. The permission to exhume these geotextiles from the GMU/VDOT site has been obtained from VTRC prior to mobilizing to the site.

The previous GMU laboratory study showed that the rate of chemical clogging is higher during the first 9 months of the simulations. Considering the findings of the past study and in order to have meaningful results for this research, geotextile samples were exhumed at the end of the 9-month field aging period (9 months from the end of construction). By comparing the data obtained from this study (9-month clogging data) to the 6-month and 12-month data that are obtained for VDOT (as part of the field study), a more in-depth understanding of the extent of the physical and chemical clogging during the first year of construction can be obtained.

Based on the revised objective and scope of the study, the following list shows the major research tasks completed as part of this study:

1 Visiting field site and exhuming one geotextile sample from an unpaved section constructed using 100% RCA and one geotextile from unpaved 100% V.A. section (total of two samples).

2 Conducting permittivity tests on geotextile samples in order to evaluate the occurrence of physical clogging.

3 Evaluating the exhumed geotextile sample under a stereomicroscope for the occurrence of chemical growth (which also involved carefully cleaning the geotextile surface as needed for the accuracy of the analyses).

4 Obtaining microscopic imaging of the geotextile surfaces.

5 Conducting image analyses on the microscopic images and determining the surface area covered with tufa.

3. METHODS

3.1. Descriptions of the Test Site

To compare the performance of the underdrains in roadways constructed with 100% RCA base course and different blends of RCA and V.A., seven test sections (paved and unpaved) were constructed with identical dimensions and configurations using different materials for VDOT field research as summarized below and shown in Figure 2.

- Test section 1 - 100% RCA, Paved
- Test section 2 - Blend 1 (40% RCA + 60% V.A.), Paved
- Test section 3 - Blend 2 (20% RCA + 80% V.A.), Paved
- Test section 4 - 100% RCA, Unpaved
- Test section 5 - Blend 1 (40% RCA + 60% V.A.), Unpaved

- Test section 6 - Blend 2 (20% RCA + 80% V.A.), Unpaved
- Test section 7 - 100% V.A., Unpaved

Construction of sections without asphalt overlay (Unpaved) enables the GMU team to directly compare the results of the field study to the previous laboratory tests (which did not include asphalt overlay either). The design included the construction of concrete curbs as section dividers (Figures 2 and 3) to isolate sections from each other and prevent runoff of the infiltration water from one section into another. In order to prevent interference of groundwater with the test results and infiltration of rainwater from the base into the subbase, a geomembrane layer (Figure 4) was installed over the subbase layer before placement of the base course to isolate the base course and subbase layers at each section. All test sections include UD-4 type underdrains (Figures 5 and 6) installed on both sides. The drainage pipes within the underdrain systems are connected to collection tanks (Figure 7). All base course materials were compacted to a minimum of 95% of maximum dry density obtained using standard effort compaction in the laboratory (VDOT, 2016).

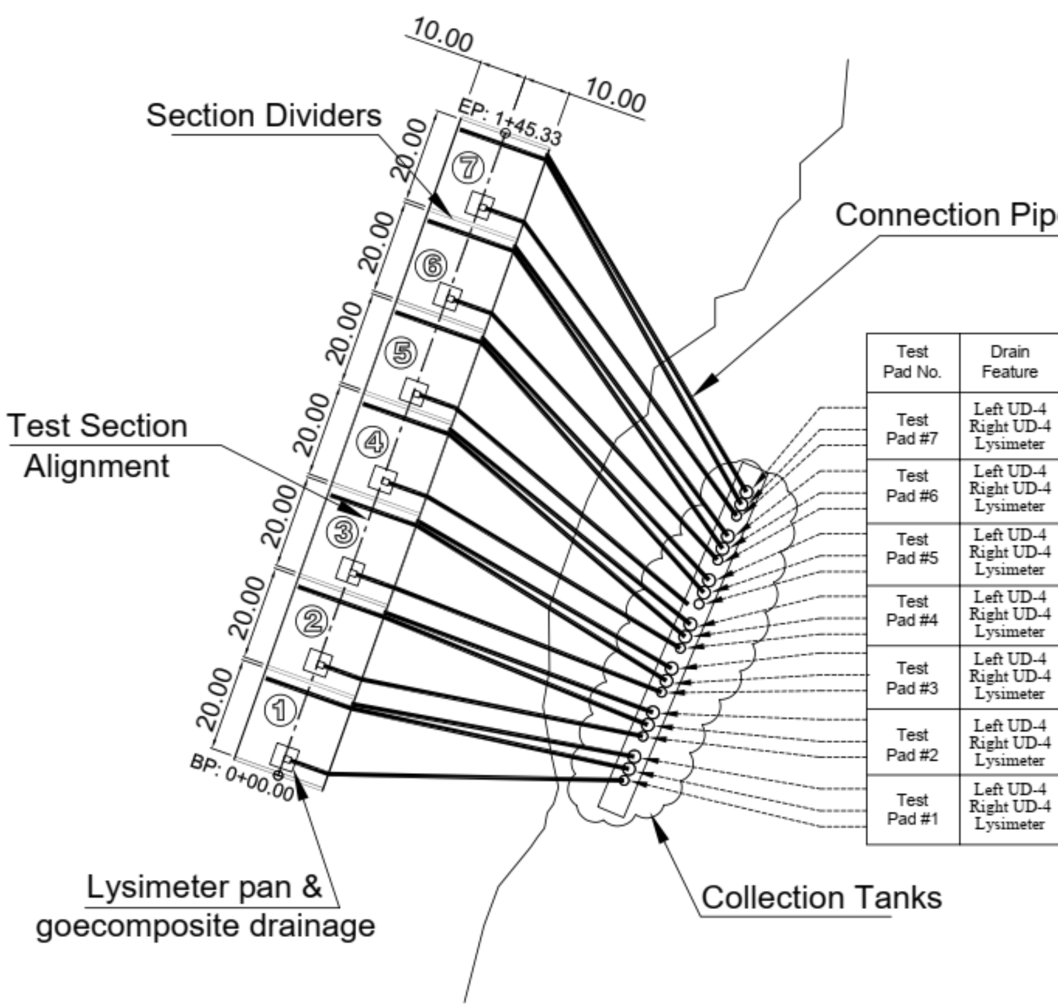


Figure 2. Schematic plan view of the designed test sections (dimensions are in feet)

Figure 3. Installed section dividers

Figure 4. Installation of the 40 mil HDPE geomembrane liner

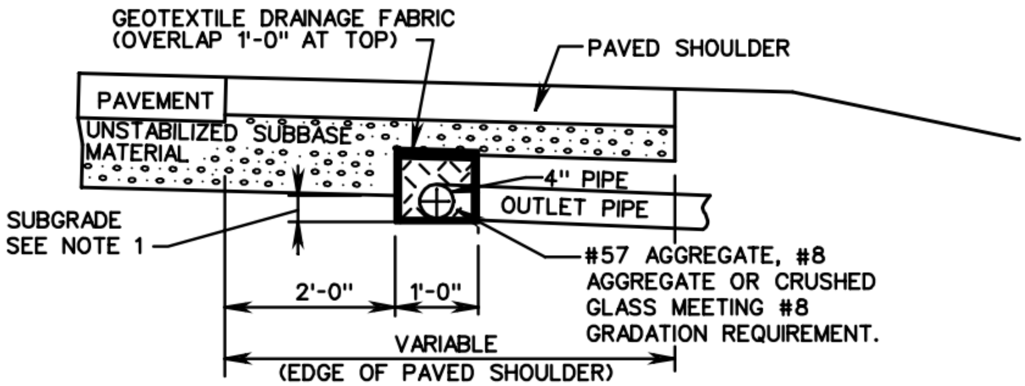
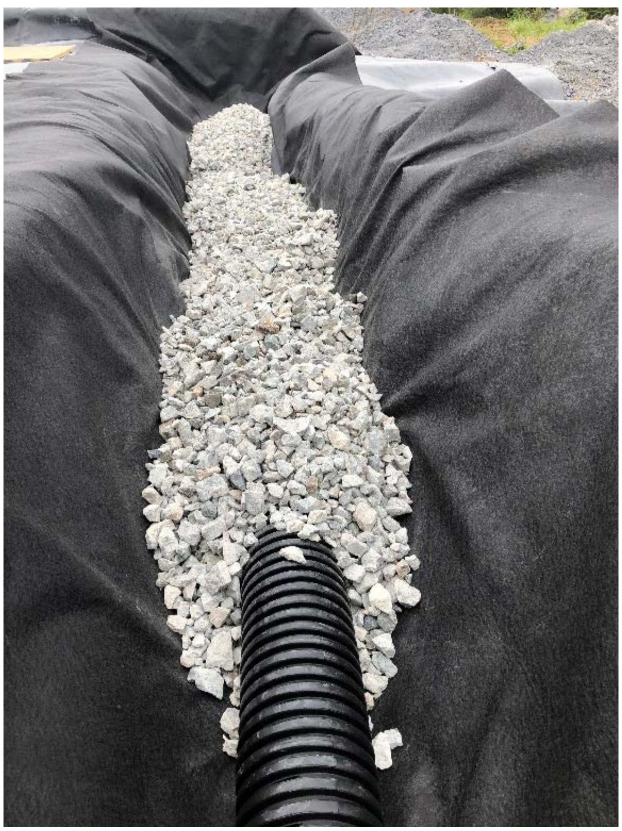


Figure 5. VDOT standard pavement UD-4 underdrain detail (Not to Scale)



(a)

(b)

Figure 6. Installation of UD-4 underdrains (a) perforated pipe embedded in 57 stone inside nonwoven geotextile envelope, (b) closure of the nonwoven geotextile envelope

Figure 7. Collection tanks connected to underdrains (two 100-gallon tanks) for each side

3.2. Material Characterization

3.2.1. RCA and V.A. Aggregate

The physical properties of materials were evaluated by based on the index and select geotechnical properties. These properties include grain size analyses (in accordance with ASTM D6913/D6913M, 2017; ASTM D7928, 2017), specific gravity and water absorption of coarse and fine particles (per ASTM C127, 2012; ASTM C128, 2012), Atterberg limits (per ASTM D4318, 2010), and compaction characteristics using standard effort (per ASTM D698, 2012).

3.2.2. Nonwoven Geotextile

The geotextile used in this study was a nonwoven geotextile that satisfies the filtration design requirements for VDOT UD-4 edgedrain configuration (VDOT, 2016).

3.3. Chemical Analysis

Chemical analyses included the evaluation of both the liquid and solid RCA samples. The solid-phase analysis included the measurements of mortar content (MC) of RCA particles. MC of RCA was measured following acid treatment procedure as explained by Tanyu and Abbaspour (2020). The liquid phase analyses included measuring pH, electric conductivity (EC), and total leached concentrations (TLC) of elements. The pH and EC of the leachate solutions obtained from RCA were measured using pH and conductivity meter probes. The element concentrations in the leachates were measured via inductively coupled plasma-atomic emission spectroscopy (ICP-OES) using in-house capabilities.

3.4. Monitoring Program

3.4.1. Meteorological Data

A weather station was installed at the site to collect the meteorological data (Figure 8). The weather station consisted of a temperature/relative humidity sensor, a Davis rain gauge, a barometric pressure sensor, and a water level sensor. The weather station is connected to a 3G remote monitoring station that enables researchers to monitor and download data remotely.

3.4.2. Instrumentation and Monitoring of Test Sections

Volumetric moisture content sensors were installed at the center of each section (Figure 9) and connected to the data logger (Figure 10) to monitor the seasonal changes in the moisture content and temperature within the base course material. In order to be able to observe any clogging, deposition of any residue, or any other damages to the drainage pipes, pipes and outlets are monitored using a borescope at the time that geotextile samples are exhumed for clogging analyses.

Figure 8. Installed weather station at the test site

Figure 9. Installation of volumetric moisture content sensor within the base course

Figure 10. Data logger pole for all volumetric moisture content sensors

3.5. Geotextile Evaluation Process

3.5.1. Geotextile sampling (exhuming process)

Exhuming geotextile samples required the following steps:

1- Marking the location of geotextile sampling on the base material
2- Removal of base course until the geotextile is exposed
3- Carefully brushing the top of the geotextile and cutting a square sample
4- Covering the sampling spot with new geotextile including a minimum of 6-inch overlap
5- Replacing the base course material and compacting it (using hand tamping and vibratory plate).

Exhumed samples are preserved and transported to the GMU laboratory for further investigations. Figures 11 and 12 show geotextile exhuming process.

(a) (b)

(c) (d)

Figure 11. Process of (a) removing base material over the geotextile using a brush, (b) exposed base course aggregate, (c) the exhumed geotextile and (d) placement of the new geotextile while maintaining a minimum of 6-inch overlap with the old geotextile

(a) (b)

Figure 12. Compaction of the new material placed over the exhumed geotextile with (a) hand tamping and (b) with jumping jack

3.5.2. Permittivity Tests

The permittivity of virgin and exhumed geotextiles were determined following the procedures listed in ASTM D4491. Geotextile samples were initially air-dried prior to laboratory analysis. A circular sample was cut off from the larger sample (Figures 13 and 14) and was soaked for a minimum of 24 hours. Then they were placed into the permittivity test chamber. Tests were started with an applied head of 10 mm until flow was stabilized. After which applied head was increased in 10 mm increments to measure the permittivity of the samples at higher flow discharges.

(a) (b)

Figure 13. Appearance of the geotextile sample exhumed from unpaved RCA section after 9 months (a) before and (b) after permittivity test

Figure 14. Geotextile sample exhumed from unpaved V.A. section after 9 months (a) before and (b) after permittivity test

3.5.3. Microscopic Imaging and Image analyses

The geotextile samples were cleaned prior to microscopic imaging by initially air-drying. The surface of the geotextile was cleaned using an archeologist brush and smooth air blow technique. After removing all of the loose particles, the remaining residuals were further evaluated under a microscope to determine whether the residuals have the known morphology of the RCA tufa (a result of chemical precipitation) or they resemble the deposits due to particle migration and entrapment (physical clogging). Deposits that were determined to be a result of physical migration of fines were removed using the same brushing and air-blowing technique. The remaining deposits with the morphology of the RCA tufa, are considered to be the result of chemical precipitation and accounted for in the image analyses process.

The microscopic imaging was conducted using a Leica M125 C microscope with a built-in 5 MP HD digital camera (Figure 15). Continues microscopic images with a small overlapped area on each consecutive picture were taken from a point of interest with a magnification of 40 on both sides of the sample and images were stitched together using Leica LAS EZ software to create a larger image. In order to quantify the percentage of the areas covered with crystals, these large images were then analyzed using Leica LAS X software. This process allowed the surface area covered with precipitate deposition to be identified and quantified based on the calculated unit surface of various areas. Average values and standard deviations for both sides of the same geotextile specimen are reported in this report.

Figure 15. Leica M125 C microscope with a built-in 5 MP HD digital camera with a geotextile sample under analysis

4. RESULTS AND DISCUSSIONS

4.1. Material Characterization

4.1.1. Physical Properties of Aggregate

All materials used in this study (RCA and V.A.) were characterized to document their relevant geotechnical properties such as grain size distribution, Atterberg's limits, specific gravity, and compaction. To assure the accuracy and repeatability of tests, repeat tests were conducted (duplicates and triplicates tests) and results are presented herein. Figures 16 and 17 show the grain size distribution of RCA and V.A., respectively.

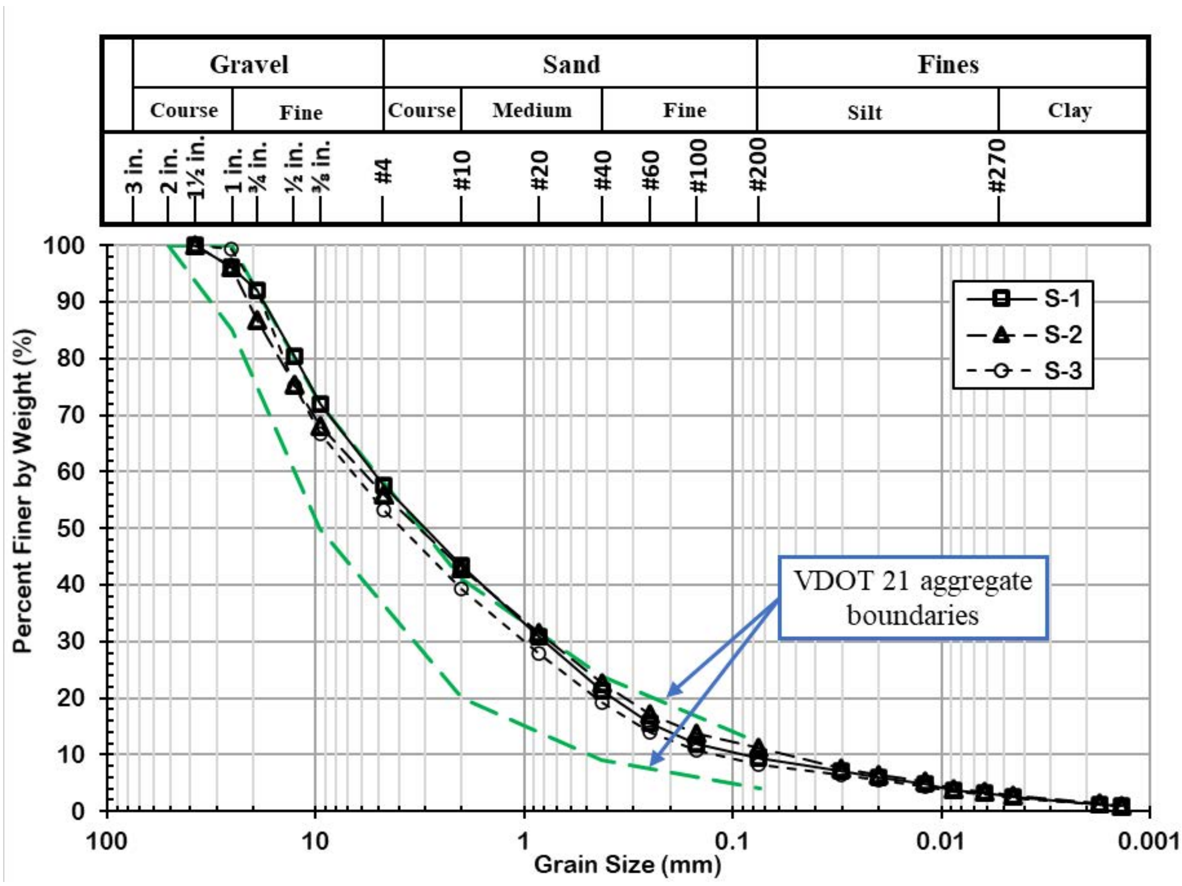


Figure 16- Grain size distribution of 100% RCA material (triplicate results)

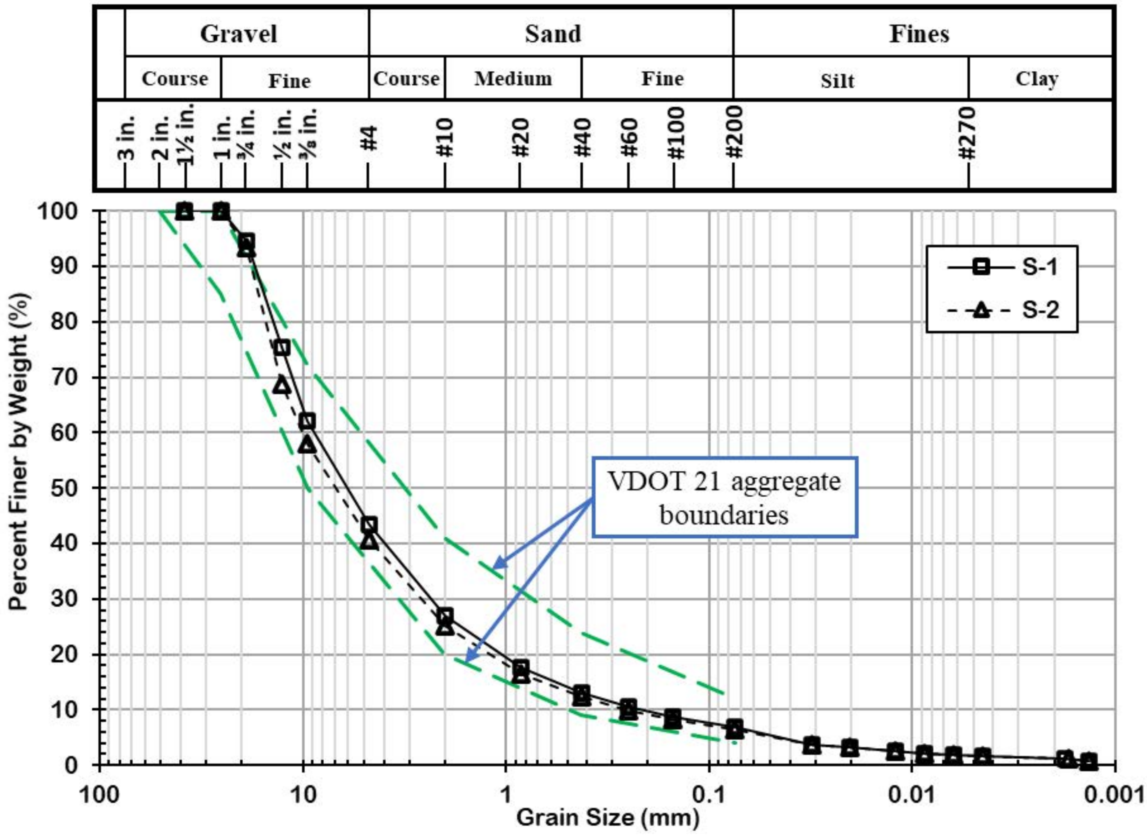


Figure 17- Grain size distribution of 100% V.A. (duplicate results)

All of the aggregate materials tested are determined to be non-plastic and classified as well-graded sand and gravel with silt in accordance with the unified soil classification system (ASTM D2487, 2011). As it can be seen from Figures 16 to 17, materials fit into the boundaries of the VDOT 21 aggregate. However, the fines content varies noticeably among the different materials. V.A. has an average percent passing No. 200 sieve about 6.75% whereas the percent passing of No. 200 sieve for RCA is measured to exceed 9.6% (maximum and minimum values of 11.2% and 8.3%, respectively).

From the previous laboratory study, it was concluded that fines content of more than 9% can increase the potential for physical clogging of the geotextile. Therefore, the sections constructed with RCA are prone to migration of fines and deposition within the geotextile fibers. Table 1 summarizes all other physical and mechanical properties of the materials.

Table 1- Properties of rock base material used in this study

Properties	***100% RCA***	***100% V.A.***
Specific Gravity for Coarse Aggregate (per ASTM C127)		
Specific Gravity (OD)	2.23	2.65
Specific Gravity (SSD)	2.39	2.66
Apparent Specific Gravity	2.65	2.69
Water absorption (%)	7.10	0.60
Specific Gravity for Fine Aggregate (per ASTM C128)		
Specific Gravity (OD)	1.86	2.46
Specific Gravity (SSD)	2.16	2.56
Apparent Specific Gravity	2.64	2.72
Water absorption (%)	15.70	4.20
Atterberg Limits (per ASTM D4318)		
Liquid Limit (%)	37	18
Plastic Limit (%)	36	17
Plasticity Index (%)	N.P.	N.P.
Compaction using Standard Effort (per ASTM D698)		
ω_{opt} (%)	16.0	8.0
γ_{dmax} (lb/in^3)	113.2	137.6
Permeability (per ASTM D2434) (cm/s)	7.3×10^{-4}	6.3×10^{-2}
Mortar Content (%)	26.9	3.1

Notes:

1. N.P.=non-plastic
2. Permeability values are measured under an applied hydraulic gradient of 1
3. N.A.=not applicable

4.1.2. Chemical Properties of Aggregate

Solid samples of RCA and V.A. were tested for leachate test and concentrations of a suite of elements were measured including but not limited to Aluminum (Al), Calcium (Ca), Chromium (Cr), Copper (Cu), Iron (Fe), Potassium (K), Magnesium (Mg), Sodium (Na), Silicon (Si), Zinc (Zn), and sulfur (as sulfate ion SO_4^{2-}). A previous laboratory study showed that among these elements, calcium and sulfate ions are the most important (major) elements that contribute to the formation of tufa from RCA (Abbaspour and Tanyu, 2019a, 2020, 2021; Tanyu and Abbaspour, 2020). The next most important (minor) elements that can potentially contribute to tufa formation in small quantities are magnesium, potassium, and silicon. Therefore, in the current study, the results of these elements are presented in the evaluation of chemical properties and tufa precipitation potential. A summary of the batch test results are presented in Table 2. The recorded leached concentrations for Ca and $SO_4^{2-}$for RCA material are within the expected range observed in the previous laboratory study.

Table 2. Results of batch leach test on rock base materials

Element	***Concentration/Unit***	***Minimum Detection Limit***	***RCA***	***V.A.***
Al	μg/l	0.1	85	913
B	μg/l	0.1	47	7
Ba	μg/l	0.1	64	192
Ca	mg/l	0.1	38	7
Cr	μg/l	0.5	68	3
Cu	μg/l	0.1	9	4
Fe	μg/l	10	12	136
K	mg/l	0.1	5	1
Mg	mg/l	0.1	3	1
Na	mg/l	0.1	7	6
Si	μg/l	40	6052	1964
SO_4^{2-}	mg/l	0.1	57	6
Zn	μg/l	0.5	4	6
pH	-	-	11.3	9.8
EC	μS/cm	-	223	53

However, the concentrations of leached Ca and Mg from V.A. are much higher than the concentrations observed from 100% V.A. that was used in the previous laboratory study (5.0 and 0.25 mg/l, respectively). This indicates the presence of calcareous rock (limestone and/or dolostone) within the V.A. aggregate used in the present field study. A limited fizzing effect was also observed when V.A. material was treated with HCl acid (submerged in HCl Acid) and a weight loss in the order of 2.5% was measured. Despite the existence of some impurities (calcareous rocks) in the V.A. material, the material is still considered somewhat inert when compared to RCA as the calcareous constituents in V.A. are significantly lower than the RCA (2.5% by weight in V.A. in comparison to 27% mortar content in RCA material).

4.1.3. Nonwoven Geotextile

Mirafi 140N (55mil) is used in this study to construct the test pads. This geotextile meets the VDOT requirements for geotextiles specified for drainage systems as outlined in VDOT Specifications Section 245.03 (c). Properties of the nonwoven geotextile are listed in Table 3 as reported by the manufacturer.

Table 3. Properties of the nonwoven geotextile used in the construction of test pads (manufacturer values)

Mechanical Properties	***Test Method***	***Unit***	***Minimum Average Value***
Grab Tensile Strength	ASTM D4632	kN (lbs)	0.53 (120)
Grab Tensile Elongation	ASTM D4632	%	50
Trapezoid Tear Strength	ASTM D4533	kN (lbs)	0.22 (50)
Puncture Strength	ASTM D4833	kN (lbs)	0.30 (65)
CBR Puncture Strength	ASTM D6241	kN (lbs)	1.33 (300)
Apparent Opening Size (AOS)	ASTM D4751	mm (U.S. Sieve)	0.212 (70)
Permittivity	ASTM D4491	sec^{-1}	1.8
Permeability	ASTM D4491	cm/sec	0.21
Flow Rate	ASTM D4491	$l/min/m^2$ ($gal/min/ft^2$)	5500 (135)

4.2. Meteorological Data

Figures 18 to 20 show the daily averages for temperature, relative humidity, and rainfall for the site from December 1, 2020, to December 1, 2021, as recorded by the deployed weather station at the site. The data shows that the site has received over 830 mm (32.7 inches) of rain in the course of one year. The highest daily rain events were observed during August and September.

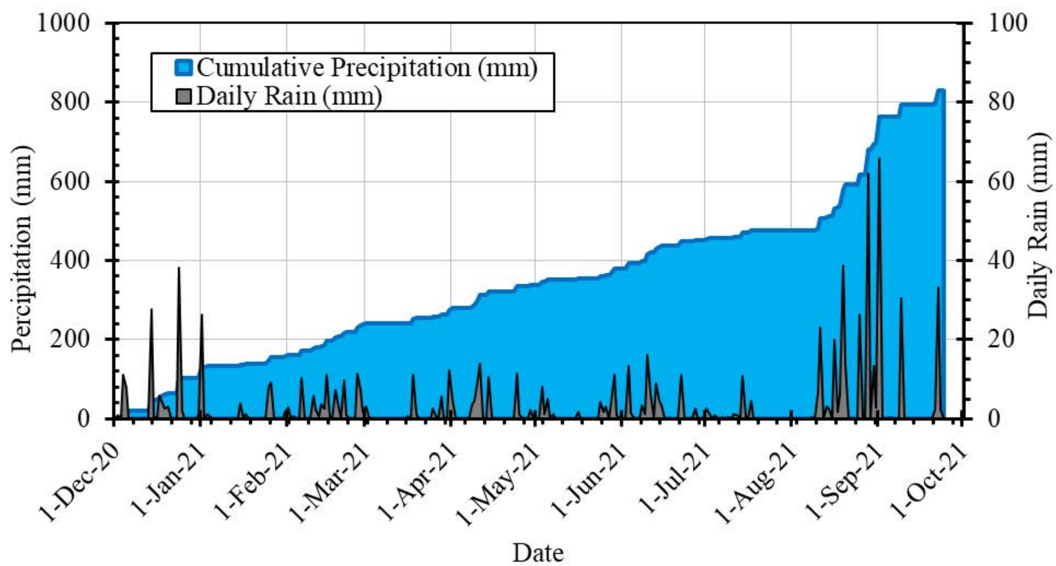


Figure 18. Rainfall events and accumulated precipitation quantities for the field test site as recorded by the deployed weather station

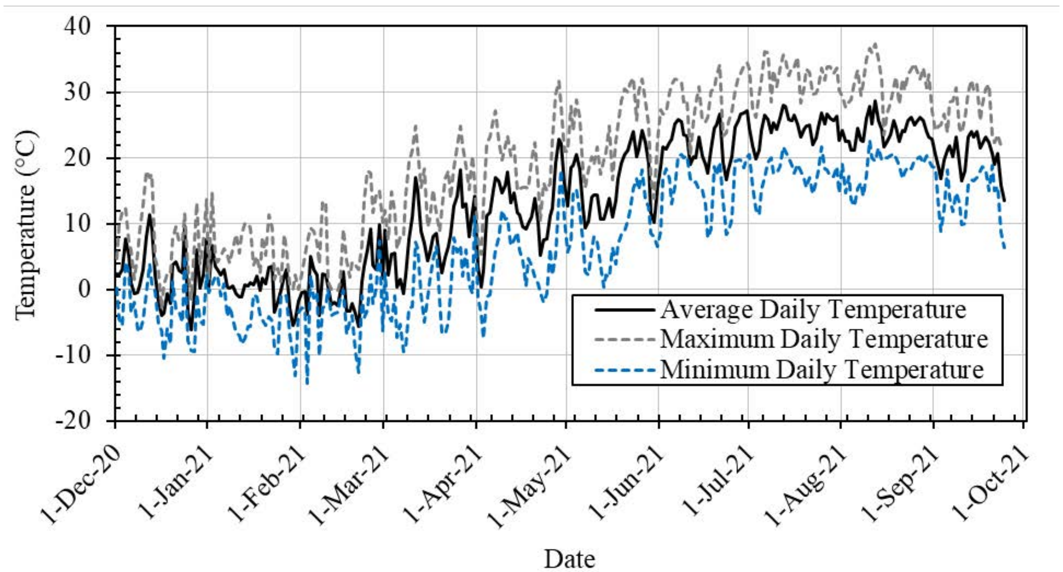


Figure 19. Average, maximum, and minimum daily temperature during the first year of the study

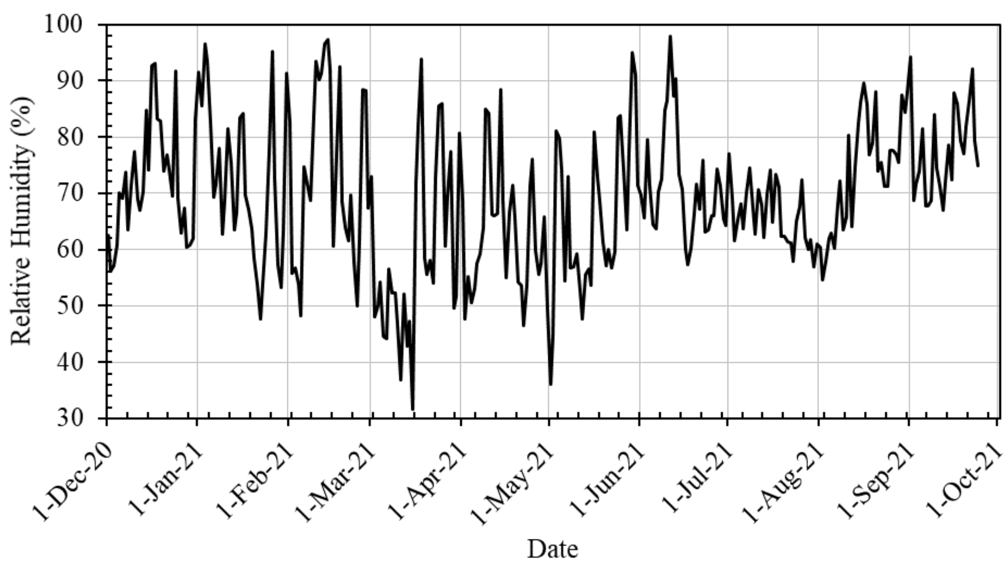
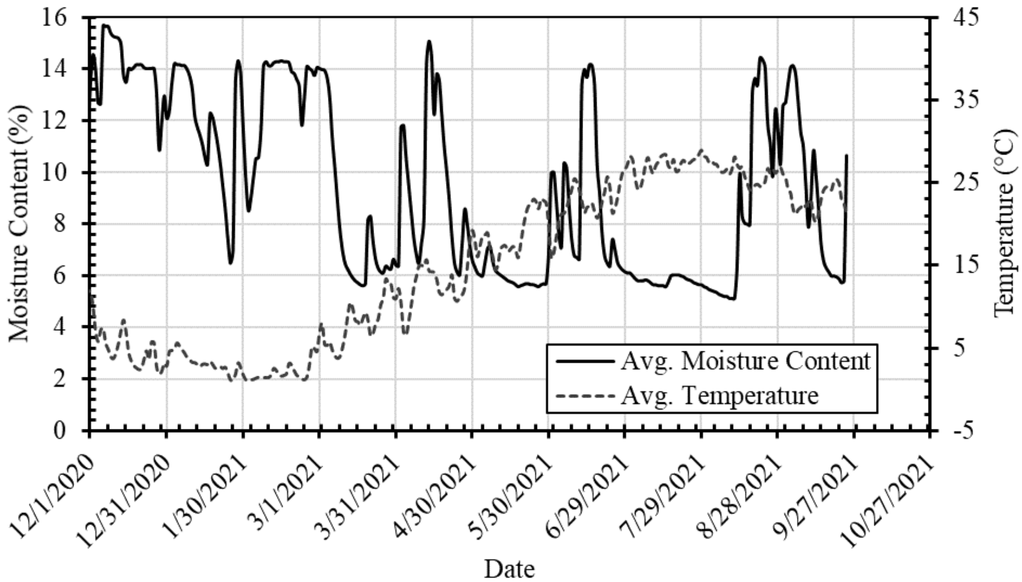


Figure 20. Recorded relative humidity at the test site during the first year of the study

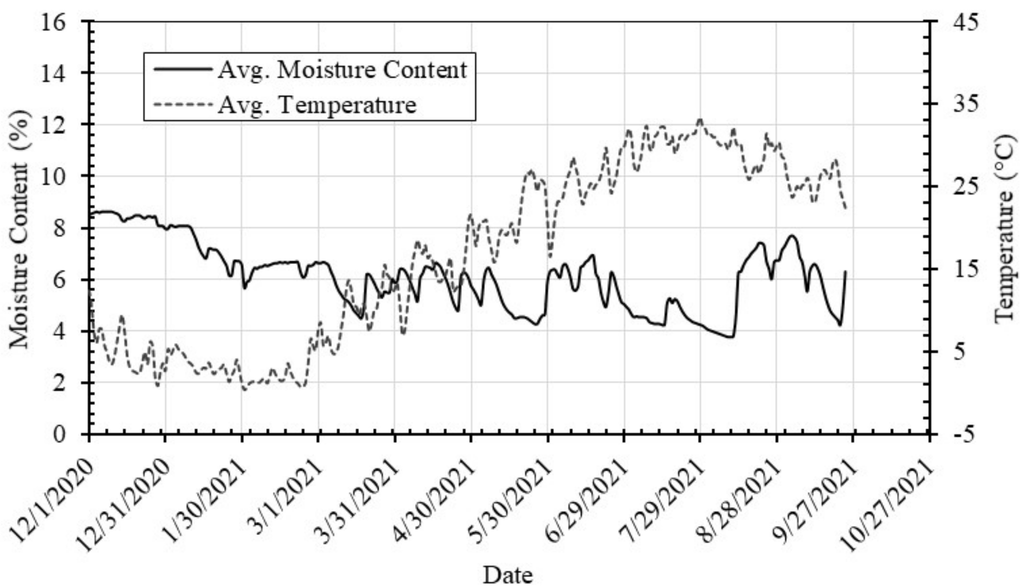
The maximum temperature of 37.4°C (99.3°F) was observed on August 12, 2021, and minimum temperature of -14.3°C (6.3°F) was observed on February 3, 2021. Relative humidity (RH) data at the site shows that the air RH during the past year is mostly above 70% with multiple peaks of above 95% relative humidity throughout the wet seasons. The driest period had occurred during the month of March with the lowest recorded RH of 31% and the next driest season is during July and August with RH consistently below 70%. The values of RH also correspond to the low rainfall recording during the same periods.

4.3. Variation in Moisture Content of the Site

When the recordings of the moisture content sensors installed in the sections are compared (Figure 19), it can be seen that at any given time, the RCA section has higher moisture content than the V.A. section. Also, the RCA section experiences larger variation between wet peaks and dry drops with differences exceeding 6% of moisture content. The retained moisture within the base course material is directly related to the moisture absorption of the material (Table 1). Higher absorption values naturally mean higher water content retained in the section.



(a)



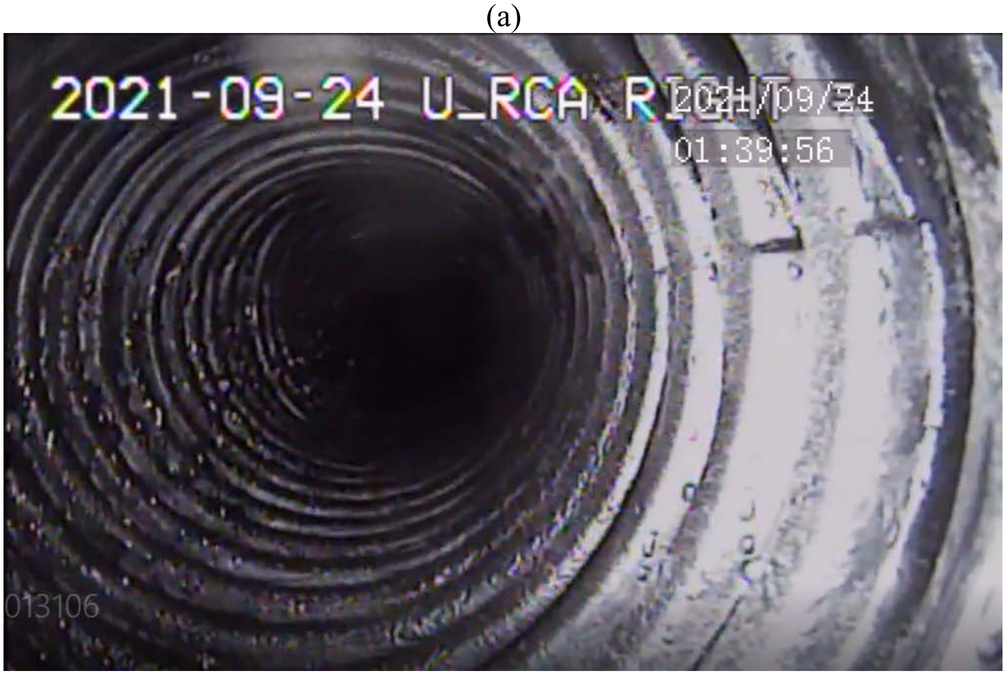
(b)

Figure 19. Daily average moisture content and temperature in the base course of unpaved sections with (a) RCA and (b) V.A.

4.4. Borescopy

Figure 20 shows examples of the images taken from drainage pipes and outlets of the test pads when geotextile samples were exhumed. Based on the recorded images and videos from the borescopy, any type of deposition or damage within the drainage pipes was not observed by the researchers.

(a)



(b)

Figure 20. Example images from borescopic observations of drainage pipes (a) perforated pipe in the left edgedrain of the paved RCA section and (b) PVC outlet pipe of the same drain

4.5. Geotextile Evaluation Process

The results of the geotextile evaluation process included permittivity tests to evaluate physical clogging and microscopic analysis to evaluate the chemical clogging. Table 4 summarizes the results of these processes.

Table 4. Summary of the evaluation processes for a reduction in serviceability due to physical and chemical clogging phenomena in geotextile samples exhumed after 9-month of service life

Sample	Test Duration	Physical Clogging			Chemical Clogging	
		Ψ_R	$1-\Psi_R$	$R_{physical\ serviceability}$	S_{tufa}	$R_{chemical\ serviceability}$
RCA-U	9	64.0%	36.0%	30.0%	4.3%	6.6%
V.A.-U	9	70.0%	30.0%	25.0%	4.5%	7.2%

Notes:

1. Ψ_R: permittivity ratio between used geotextile and virgin geotextile (%)
2. $1- \Psi_R$: reduction in permittivity values (%)
3. $R_{physical\ serviceability}$: reduction in serviceability of the geotextile due to physical clogging (%) (Abbaspour et al., 2018; Abbaspour and Tanyu, 2019b)
4. S_{tufa}: surface area of geotextile covered with tufa deposition (Abbaspour and Tanyu, 2021)
5. $R_{chemical\ serviceability}$: reduction in serviceability of the geotextile due to chemical clogging (%) (Abbaspour and Tanyu, 2021).

The permittivity results show that the geotextile sample from the RCA section experiences physical clogging about 55% at the end of the ninth month with $R_{physical\ serviceability}$ values of 45.8%. However, the reduction in permittivity for the geotextile sample exhumed from the V.A. section was only 10% which leads to an 8.3% reduction in serviceability due to physical clogging. These results suggest the existence of internal instability for the RCA material used in this study.

When compared to the data obtained from the samples after 6-month service life (Table 5), it can be seen that the $R_{physical\ serviceability}$ values for the RCA section have changed from 30% after 6 months of service to 45.8 at the end of 9 months of service. The values for $R_{physical\ serviceability}$ for the V.A. section during the same three-month period have changed from 25% to 8.3%. Although, it can be imagined some fines migration might have occurred during this period, the observed variation patterns (increase for RCA sample and decrease for V.A. sample) can be mainly attributed to the variability of the geotextile samples collected from two different locations within each section.

Microscopic imaging and image analyses show that the surface area of geotextile samples exhumed from either section covered with tufa remains under 4.8%. This value corresponds to a reduction in serviceability of a maximum of 8.1% based on the correlation suggested by Abbaspour and Tanyu (2021) as a result of the chemical precipitation of tufa. Although this level of reduction in serviceability is practically negligible at this stage, it does confirm the occurrence of such phenomena within the RCA section as well as the V.A. section. This observation corroborates with the high levels of Ca concentrations in the leachate from the V.A. section as reported by Tanyu and Abbaspour (2022).

Table 5. Reduction in serviceability due to physical and chemical clogging phenomena measured from analyzing samples exhumed from the same test sections after 6-month of service life (data from Tanyu and Abbaspour, 2022)

Sample	Test Duration	Physical Clogging			Chemical Clogging	
		Ψ_R	$1-\Psi_R$	$R_{physical\ serviceability}$	S_{tufa}	$R_{chemical\ serviceability}$
RCA-U	6	64.0%	36.0%	30.0%	4.3%	6.6%
V.A.-U	6	70.0%	30.0%	25.0%	4.5%	7.2%

The current study is intended to complement the GMU's ongoing VDOT field study. The data presented here will be part of the overall report that will be written for VDOT. The sampling frequency for the VDOT field study is biannual. Therefore, the study supported by RMRC provided an opportunity to collect an additional sample and increase the resolution of the data by decreasing the gap between 6-months and 12-months samples. The ongoing field study is unique and will provide very valuable information that could be a benefit to all DOTs who have an interest in using RCA adjacent to systems that contain nonwoven geotextiles. Therefore any additional data that could be obtained is of great importance.

A more comprehensive correlation will continue to be made as the geotextile samples will be exhumed throughout the study. However, based on the observations made in this study, it can be concluded that in the short term, physical clogging appears to be more prevalent than chemical clogging. However, it is important to note that at this stage, neither physical clogging of the geotextile nor chemical clogging nor combination of the two do not pose significant restrictions in the flow and filtration capacity of the underdrain system.

5. CONCLUSIONS

Following conclusions can be listed based on the observations made from the evaluation of exhumed nonwoven geotextile samples from underdrains of road test sections that are constructed with 100% RCA and 100% V.A. as unbound base course material:

1- During the first 9 months of the service life, geotextile samples exhumed from both RCA and V.A. sections experienced some physical clogging. However the data from the exhumed geotextiles after 6 and 9 months of being in service did not show a clear trend.

2- For the nonwoven geotextiles exhumed from the 100% RCA section, the physical clogging appeared to have increased from 6 to 9 months, For the nonwoven geotextiles exhumed from the 100% V.A. section, the physical clogging values were less in 9 months compared to what was observed after 6 months.

3- The data from 9 months appear to indicate that sections constructed with 100%RCA could have higher physical clogging but such observation is not supported by the data from 6 months. Therefore, additional (long-term) observations are needed.

4- During the first 9 months of the service life, geotextile samples exhumed from both RCA and V.A. sections also showed the occurrence of tufa precipitation and the quantitative assessment of these precipitations indicated similar quantities for both sections.

5- Occurrence of tufa precipitation in geotextile installed within the V.A. section is due to the fact that V.A. material consists of trace amounts of rocks with calcareous origin. Batch leachate extraction test also confirmed leaching of alkali metals from V.A. material.

6- It appears that during these early stages of underdrain service life, physical clogging is a prevalent phenomenon in comparison to the chemical clogging phenomenon.

7- It is shown that the effect of physical clogging, chemical clogging, or a combination of the two is not significant enough during the first 9 months of underdrain service life to alter the drainage performance of the infrastructure.

8- Observations from the field study suggest lower levels of occurrence for both physical and chemical clogging than the laboratory study during the same service life.

9- The observed variation in the data is mainly attributed to the sampling from different locations within the test section. The field study offers a large redundancy in the geotextile surface due to the larger size of the material placed in the ground as opposed to the small sample sizes in a laboratory-scale study. For the same reason, a larger variation in the results can be expected when field samples are compared to the laboratory samples.

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REFERENCES

Abbaspour, A., Tanyu, B. f., 2021. Chemical clogging and geotextile serviceability in subdrains adjacent to recycled concrete. Geosynthetics International 28, 402–420. https://doi.org/10.1680/jgein.20.00051

Abbaspour, A., Tanyu, B.F., 2020. Parameters Affecting Tufa Precipitation from Recycled Concrete Aggregate, in: Reddy, K.R., Agnihotri, A.K., Yukselen-Aksoy, Y., Dubey, B.K., Bansal, A. (Eds.), Sustainable Environment and Infrastructure, Lecture Notes in Civil Engineering. Springer International Publishing, Cham, pp. 71–81. https://doi.org/10.1007/978-3-030-51354-2_7

Abbaspour, A., Tanyu, B.F., 2019a. Tufa precipitation from Recycled Concrete Aggregate (RCA) over geotextile: Mechanism, composition, and affecting parameters. Construction and Building Materials 196, 317–329. https://doi.org/10.1016/j.conbuildmat.2018.10.146

Abbaspour, A., Tanyu, B.F., 2019b. Evaluate hydraulic compatibility of geotextile and RCA in underdrain systems under turbulent flow regime, in: Geosynthetics Conference 2019. IFAI, Houston, Texas, U.S.A.

Abbaspour, A., Tanyu, B.F., Aydilek, A.H., Dayioglu, A.Y., 2018. Methodology to evaluate hydraulic compatibility of geotextile and RCA in underdrain systems. Geosynthetics International 25, 67–84. https://doi.org/10.1680/jgein.17.00034

ASTM C127, 2012. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Coarse Aggregate. ASTM International, West Conshohocken, PA.

ASTM C128, 2012. Standard Test Method for Density, Relative Density (Specific Gravity), and Absorption of Fine Aggregate. ASTM International, West Conshohocken, PA.

ASTM D698, 2012. Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft3(600 kN-m/m3)). ASTM International, West Conshohocken, PA.

ASTM D2487, 2011. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System). ASTM International, West Conshohocken, PA.

ASTM D4318, 2010. Standard Test Method for Liquid Limit, Plastic Limit, and Plasticity Index of Soils. ASTM International, West Conshohocken, PA.

ASTM D6913/D6913M, 2017. Standard Test Methods for Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis. ASTM International, West Conshohocken, PA.

ASTM D7928, 2017. Standard Test Methods for Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis. ASTM International, West Conshohocken, PA.

Bennert, T.A., Maher, A., 2008. The use of recycled concrete aggregate in a dense graded aggregate base course (Final Report No. Final Report No. FHWA-NJ-2008-002). New Jersey Department of Transportation Bureau of Research and Technology, Rutgers University, Piscataway, NJ.

Cackler, T., 2018. Recycled Concrete Aggregate Usage in the US (Summary Report No. Summary Report-Contract No. DTFH61-12-H-00010). Office of Pavement Technology Federal Highway Administration, Iowa State University, Ames, IA.

Ceylan, H., Gopalakrishnan, K., Kim, S., Steffes, R.F., 2013. Evaluating Roadway Subsurface Drainage Practices (Final Report, IADOT-IHRB Project TR-643). Iowa Department of Transportation, Ames, IA, U.S.A.

Ceylan, H., Kim, S., Gopalakrishnan, K., Steffes, R., Yang, B., 2015. Evaluating Roadway Subsurface Drainage Practices - Phase II (Final Report, IADOT-IHRB Project TR-662). Iowa Department of Transportation, Ames, IA, U.S.A.

Chen, J., Tinjum, J., Edil, T., 2013. Leaching of Alkaline Substances and Heavy Metals from Recycled Concrete Aggregate Used as Unbound Base Course. Transportation Research Record: Journal of the Transportation Research Board 2349, 81–90. https://doi.org/10.3141/2349-10

Edil, T.B., Tinjum, J.M., Benson, C.H., 2012. Recycled Unbound Materials (Final Report, MN/RC 2012-35). Minnesota Department of Transportation, Saint Paul, Minnesota.

FDOT, 2012. Drainage Handbook Exfiltration Systems. Office of design, drainage section, Tallahassee, FL.

FHWA, 2003. Summary of Michigan Recycled Concrete Aggregate Review [WWW Document]. Recycled Concrete Aggregate Federal Highway Administration National Review. URL http://www.fhwa.dot.gov/pavement/recycling/rcami.cfm (accessed 7.10.16).

Gonzalez, G.P., Moo-Young, H.K., 2004. Transportation applications of recycled concrete aggregate (FHWA state of the Practice National Review No. FHWA-HRT-04-024). Federal Highway Administration and U.S. Department of Transportation.

Hansen, W., 1995. Use of recycled concrete in Michigan (Final Report, No. 48109-2125). University of Michigan, Ann Arbor, MI.

Iowa DOT, 2016. Standard Specifications with GS-15002 Revisions [WWW Document]. Electronic Reference Library - Iowa Department of Transportation - April 19, 2016. URL http://www.iowadot.gov/erl/current/GS/Navigation/nav21.htm (accessed 7.9.16).

Kim, S., Ceylan, H., Gopalakrishnan, K., Yang, B., 2016. How Are the Subsurface Drainage Outlets in Iowa Roadways with Recycled Concrete Aggregate Base Performing?, in: Geotechnical and Structural Engineering Congress 2016. Presented at the Geotechnical and Structural Engineering Congress 2016, American Society of Civil Engineers, Phoenix, Arizona, U.S.A., pp. 1295–1302.

MDOT, 2012. Standard specifications for construction. Michigan Department of Transportation, Lansing, MI.

MnDOT, 2016. Standard specifications for construction. Minnesota Department of Transportation, Saint Paul, Minnesota, U.S.A.

Saeed, A., Hammons, M.I., 2008. Use of Recycled Concrete as Unbound Base Aggregate in Airfield and Highway Pavements to Enhance Sustainability, in: Airfield and Highway Pavements. Presented at the Airfield and Highway Pavements 2008, American Society of Civil Engineers, Bellevue, Washington, United States, pp. 497–508. https://doi.org/10.1061/41005(329)43

Snyder, M., Bruinsma, J., 1996. Review of Studies Concerning Effects of Unbound Crushed Concrete Bases on PCC Pavement Drainage. Transportation Research Record: Journal of the Transportation Research Board 1519, 51–58. https://doi.org/10.3141/1519-07

Snyder, M.B., Cavalline, T.L., Fick, G., Taylor, P., Gross, J., 2018. Recycling Concrete Pavement Materials: A Practitioner's Reference Guide (Reference Guide No. Reference

Guide-Contract No. DTFH61-12-H-00010). Office of Pavement Technology Federal Highway Administration, Iowa State University, Ames, IA.

Tanyu, B., Abbaspour, A., 2022. Suitability of Using Crushed Concrete Adjacent to Geotextiles in Underdrain Systems Second Phase: Field Trial Before Implementation Part I: Construction and End-of-One-Year Evaluations (Unpublished Report). Virginia Transportation Research Council, George Mason University, Charlottesville, VA.

Tanyu, B., Abbaspour, A., 2020. Evaluation of Use of Crushed Hydraulic Cement Concrete (CHCC) as an Additive to Base Course/Subbase Material (Final Report No. Final Report No. FHWA/VTRC 21-R12). Virginia Transportation Research Council, George Mason University, Charlottesville, VA. https://doi.org/10.13140/RG.2.2.32533.96483/2

Thompson, P.D., Ford, K.M., Arman, M.H.R., Labi, S., Sinha, K.C., Shirole, A.M., 2012. Estimating life expectancies of highway assets Volume 1: Guidebook (NCHRP Report 713 No. NCHRP Report 713). Transportation Research Board, Purdue University, West Lafayette, IN.

Townsend, T., Chadik, P., Gupta, N., Kluge, M., Vinson, T., Schert, J., 2016. Concrete debris assessment for road construction activities (Final Report No. BDV31-977–48). Florida Department of Transportation, Tallahassee, FL.

Van Dam, T., Smith, K., Truschke, C., Vitton, S., 2011. Using Recycled Concrete in MDOT's Transportation Infrastructure–Manual of Practice.

VDOT, 2016. 2016 Road and Bridge Specifications. Virginia Department of Transportation, Richmond, VA.

VDOT, 2008. Road and Bridge Standards, 2015th ed. Virginia Department of Transportation, Richmond, VA.

Wong, J., Maher, A., 2018. Increasing the Recycling of Materials Used for Highway Construction (Preliminary Investigation (PI-0051) No. Preliminary Investigation (PI-0051)). Caltrans Division of Research, Innovation and System Information.