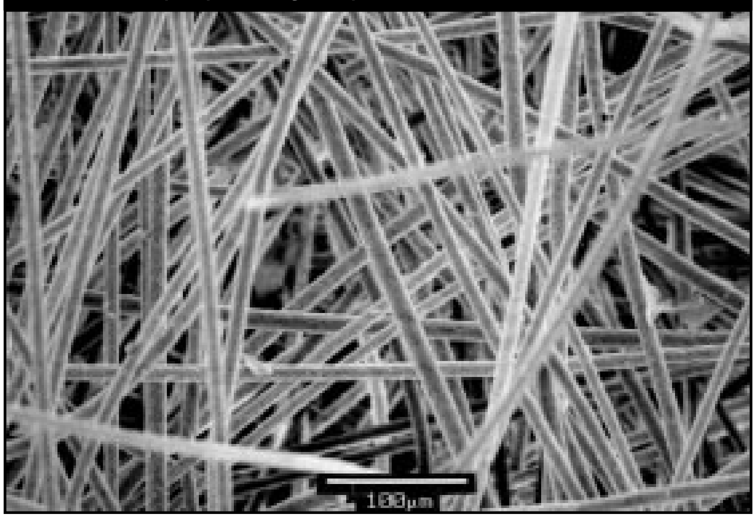
TECHBRIEF

Durability of Geosynthetics for Highway Applications

Report Nos. FHWA-RD-97-142, 97-143, 97-144, and 00-157
FHWA Contact: Al DiMillio, HRDI-08, (202) 493-3035

Nonwoven polyester geosynthetic.



Introduction

The research results described herein are included in four volumes on the subject of Durability of Geosynthetics for Highway Applications. Various aspects of geosynthetic durability were addressed in order to develop procedures that could be used to predict long-term strength losses of geosynthetics used in highway applications. This information is essential to designers for allowing tensile capacity for geosynthetics used primarily in mechanically stabilized earth (MSE) retaining walls, reinforced soil slopes, and foundation stabilization.

The study was conducted in stages, each stage building on the knowledge previously gained. The main objectives addressed were to: (1) develop testing protocols necessary to quantify any strength reduction due to aging or stress (stress cracking only) mechanisms for polymeric reinforcement materials (geosynthetics), and (2) develop testing protocols for confined stress-strain testing, which could more accurately characterize key engineering properties.

The results of the experimental tasks are discussed on the following pages.

The Structures research and technology program aims to foster increased durability of new bridges and observable increases in the service life of existing structures, placing an emphasis on increasing highway safety while preserving the environment. The program focuses on researching nondestructive evaluation technologies to identify structural deficiencies and support bridge management systems. It also uses high-performance materials to repair and rehabilitate the existing inventory of deficient bridges. This find it and fix it program is supplemented by research which examines all aspects of bridges and foundations, including planning, design, construction, management, maintenance, inspection, and demolition.

Specific expertise areas include bridge coatings, bridge infrastructure, bridge management, nondestructive evaluation, corrosion protection, foundations, scour, geotechnical research, high-performance materials, aerodynamics, seismic research, and structures instrumentation.

U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology

Turner-Fairbank Highway Research Center

6300 Georgetown Pike
McLean, VA 22101-2296

Stress Cracking Potential of HDPE Geogrids
(Report No. FHWA-RD-97-142)

Overview

This study was initiated to allay voiced concerns (in 1991) that stress-cracking potential was not being considered in developing the allowable tension load capacity for design when using high-density polyethylene (HDPE) geogrids.

Stress cracking is a potential mode of failure occurring in thermoplastic materials that are under a sustained stress significantly lower than the material's room temperature yield strength, resulting in quasi-brittle fracture of the material. This is also known as slow crack growth and environmental stress cracking (ESC) when in contact with certain aqueous solutions.

The extensive laboratory study developed testing and interpretation protocols to measure the potential for stress cracking for intact and damaged HDPE geogrids.

Major Conclusions

The detailed laboratory results and analyses demonstrated that for the one presently available commercial HDPE geogrid:

- Stress cracking is a potential failure mode for HDPE uniaxially drawn geogrids at their nodes only, which are not highly drawn. Rib areas, which are highly drawn, are not prone to stress cracking.

- Stress cracking is a less stringent or equal consideration than creep rupture in developing allowable tensile capacity for ***intact*** geogrids.

- Testing protocol for ***damaged*** geogrids using a Notched Constant Testing Load (NCTL) procedure was developed, since the reduced stress crack-derived allowable tensile capacity may be lower than projected, simply by applying a construction damage reduction factor.

- Damage to the geogrid can be significantly limited by using a backfill with a maximum grain size on the order of 20 mm to limit damage to levels that are not likely to significantly initiate stress-cracking failures at lower levels than those indicated by creep testing.

Further Actions Recommended

- The results and engineering recommendations from this narrowly focused study were, in general, sufficiently clear to preclude additional developmental studies.

- The NCTL testing procedure could be submitted to an appropriate American Society for Testing and Materials (ASTM) committee for potential adoption as a standard method. A similar testing method for geomembranes is being considered.

Impact of Results

- Removed a potential major obstacle to the cost-effective use of HDPE geogrids for in-ground reinforcement.

- Provided additional technical justification for the currently used backfill specifications for HDPE soil reinforcement.

- Provided the first research results on the synergy between stress, aging, and construction damage.

Development of Protocols for Confined Extension/Creep Testing of Geosynthetics for Highway Applications
(Report No. FHWA-RD-97-143)

Overview

The research was initiated to develop a testing protocol to characterize the confined stress-strain response of geosynthetic materials used as tension-carrying reinforcement for in-ground applications. Current testing methods for stress-strain properties are conducted in an unconfined mode, which does not mimic the actual field conditions and is believed to be, for some materials, overly conservative. The benefits of using confined stress-strain testing to improve characterization of design properties should allow considerable material savings in tensile load applications.

Major Conclusions

The research, which included development of a proposed testing protocol, concluded that:

- Soil confinement creates beneficial effects for the stress-strain response of geosynthetic materials, particularly for nonwoven geotextiles.

- For nonwoven geotextiles, stiffness and, therefore, modulus are significantly enhanced as a result of confinement. Thus, the use of unconfined stress-strain properties in designs with nonwoven geotextiles appears to be overly conservative. Increases of 50 to 400 percent for the modulus have been measured.

- The effect of confined stiffness on woven geotextiles and geogrids is considerably smaller, but not necessarily insignificant. Increases of 5 to 30 percent have been measured.

- Confined extension testing should be performed to determine the modulus and peak strength of nonwoven geotextiles and could be used to more accurately determine the properties of all geosynthetic reinforcement materials. Unconfined stress-strain testing should be relegated to Quality Assurance/Quality Control (QA/QC) functions.

- Confined creep rupture testing should be performed to determine the long-term strength of nonwoven geotextiles.

- Confined extension and/or confined creep rupture testing ***must*** be conducted when calibrating instrumentation to be used in field monitoring and for assessing input parameters for numerical analyses. The use of this testing technique is essential in calibrating in situ stress conditions from field instrumentation.

Further Actions Recommended

- The confined extension/creep testing protocol should be submitted to the appropriate ASTM committee for consideration and tentative adoption.

- Select geosynthetic materials could be tested as a follow-up, using the protocol testing equipment and the more complex Unnotched Constant Load (UCL) test device developed by Boyle and the test device developed by Whittle et al., to assess how the confined extension test results relate to the actual response of geosynthetic reinforcement in simulated field conditions.

- The American Association of State Highway and Transportation Officials (AASHTO) T-15 Committee should consider the incorporation of confined stress-strain properties for design, especially in conjunction with the use of nonwoven geotextiles.

Impact of Results

The results demonstrated that the most cost-effective geotextile—the nonwoven type—has significantly stronger stress-strain properties than previously measured using conventional unconfined testing methods. This should promote the use of the most cost-effective geosynthetic available.

Testing Protocols for Oxidation and Hydrolysis of Geosynthetics

(Report No. FHWA-RD-97-144)

Overview

The research was initiated to develop laboratory testing and interpretation protocols to assess strength losses of geosynthetics due to "aging" phenomena. Consideration and quantification of these losses are required by the AASHTO specifications in order to determine the allowable tension load resistance of geosynthetic materials over their design life. Prior to the publication of this study, no testing or interpretation protocols were available to the profession, and it was common practice to assess a large default reduction coefficient to determine the allowable tension load.

The existing polymer literature identified oxidation as the primary aging degradation mechanism for polyolefin thermoplastics (polypropylene [PP] and high-density polyethylene [HDPE]) and hydrolysis for polyester (PET) geosynthetics.

The literature further indicated that antioxidants are added as stabilizers to polyolefin thermoplastics to protect them during high-temperature processing and long-term exposure to degradation mechanisms, such as exposure to ultraviolet (UV) radiation and/or oxygen-rich regimens (such as in-ground).

Existing literature indicated that polyester geosynthetics degrade in any aqueous environment, the rate of degradation being more rapid for low molecular weight (M_n) products in highly acidic and alkaline in situ regimens.

The research under these tasks was divided into phases.

The first phase provided baseline chemical and physical characteristics for the commercial geosynthetics used in the program, as well as defining the scope of the long-term experimental degradation program carried out under Phase 2. It further defined and characterized typical in-use environments.

Phase 2 focused on the modification of existing procedures, protocols, and techniques for determining thermo-oxidation (for PP and HDPE) and hydrolytic degradation (for PET) of commercial geosynthetics and the performance of limited preliminary experiments using the developed and/or modified techniques to assess potential degradation rates and required testing periods.

Phase 3 consisted of the implementation of a long-term systematic experimental program with sufficient exposure variables to permit the calculation of degradation rates over usage time under conditions consistent with end-use environments.

Major Conclusions, Phase 1 and Phase 2

The major aspect of Phase 1 and Phase 2 dealt with determining the applicability of available chemical and physical characterization methods and the development and/or modification of long-term testing protocols to determine strength losses attributable to oxidation and hydrolysis as a function of time. The following major conclusions were reached.

With respect to polymer characterization of geosynthetics:

- Oxidation Induction Time (OIT) measurements were found to be reasonably effective as a measure of oxidative stability, but did not provide a quantitative estimate of the concentration of multi-component antioxidant additives. Comparative OIT measurements between geosynthetics are of no value in assessing oxidative degradation resistance.
- Hindered amine light stabilizer (HALS)-type antioxidants cannot be monitored by standard OIT methods. The newer High-Pressure OIT should be investigated further in this regard.
- High-Performance Liquid Chromatography (HPLC) was found to be an ineffective method for routine monitoring of antioxidant content.
- Measurement of molecular weight (or intrinsic viscosity) and Carboxyl End Group (CEG) number are the key polymer tracking methods in degradation studies for PET geosynthetics.
- Scanning electron microscopy (SEM) is effective in visually examining surface morphology for evidence of oxidation—typically circumferential cracking or hydrolysis—that is evidenced by fiber surface erosion.

With respect to laboratory incubation time/temperature and methods:

- Incubation with multiple temperatures (minimum of three) is necessary for determining degradation rates.
- Incubation temperatures for PP and PET geosynthetics should generally be less than the 80∫C required for HDPE geosynthetics, resulting in an even longer incubation time.
- Oxidative incubations should be conducted in circulating air ovens, which provide a more uniform regime.
- Hydrolysis incubations should be conducted in aqueous media and in heated reactors in which the solution is constantly stirred. Again, incubation in excess of 3 years is necessary to produce significant degradation at the lesser required temperatures.

Major Conclusions, Phase 3

- For PP and HDPE, the long-term incubation studies validated that the oxidative degradation process can be divided into main phases as predicted by the Basic Auto-Oxidation Scheme (BAS). During Phase 1—the induction period—the antioxidants are consumed with no appreciable tensile strength loss. In Phase 2, after the substantial consumption of the antioxidants, the oxidative degradation process progressively reduces the tensile strength.
- The length of the induction period, which is dependent on antioxidant levels and type, controls the useful life of the geosynthetic. The depletion of antioxidants can be monitored by OIT measurements.
- Unstabilized polyolefin products have relatively short useful lives.
- Modified Arrhenius modeling techniques have been developed to analyze laboratory oxidative incubation data and predict tensile strength degradation rates.
- Antioxidant depletion is also a function of the burial regime, specifically the oxygen concentration and the amount of transition metal present.
- Products such as most slit-film PP geosynthetics develop ini-

tial cracks during the manufacturing process. Oxidation studies for such materials cannot be conducted at elevated temperatures.

- Given the required degradation of incubation to obtain meaningful results, accelerated degradation testing methods using pressure and a full oxygen atmosphere to reduce incubation time should be developed further. The research program demonstrated the viability of such an approach.

- For PET, the long-term incubation studies validated that conventional Arrhenius modeling techniques can be used to analyze hydrolysis data and predict tensile strength degradation rates.

- Tensile strength degradation rates for PET are accelerated in pH environments greater than 9 and in acidic environments of less than 3.

- PET commercial geosynthetics produced with low molecular weight (low intrinsic viscosity) and/or high CEG will degrade at a faster rate. Typically, these are nonwoven products.

- Hydrolytic degradation for PET can be tracked by viscosity measurements.

Implementation of the Research Findings in Current Practice

- The practical effect of the research findings has been to quantify, for the first time, strength loss as a function of time and environment.

- Rational test-based Reduction Factors for Aging are now used to determine the allowable tensile strength of a geosynthetic in Federal Highway Administration (FHWA) practices and are being implemented worldwide.

- Background and recommendations were published in an FHWA Geotechnology Technical Note, "Degradation Reduction Factors for Geosynthetics," issued May 15, 1997.

- For the FHWA-recommended material specifications for geosynthetics used as reinforcements, QA/QC and minimum acceptable polymer characteristics have been updated with respect to desirable polymer characteristics. These requirements have been incorporated into the guideline specifications for MSE walls and reinforced soil (RS) slopes contained in Report No. FHWA-SA-96-071, *Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines.*

Further Actions Recommended

- The developed protocols for oxidative and hydrolytic testing should be submitted to ASTM for tentative adoption as standards.

- The polymer characterization methods, OIT, MI (Melt Flow Index), CEG, and viscosity require standardization or minor/major revision where ASTM methods are available. Industry should be advised/encouraged to publish these polymer index properties as part of their Technical Information Sheets. The Geosynthetic Research Institute (GRI), which has conducted some developmental work on these methods, should be encouraged to submit revised ASTM standards.

- Liaison activities with the European CEN TC189/WG5 Committee that is preparing standards and test methods for geosynthetics should be continued. These will be finalized for implementation in the next few years and are likely to have a worldwide impact. North American input is essential to protect U.S. producers from standards contrary to U.S. specification practices.

Long-Term Durability of Geosynthetics Based on Exhumed Samples From Construction Projects
(Report No. FHWA-RD-00-157)

Overview

This study was initiated to develop a databank detailing the oxidative and/or hydrolytic performance based on retrieved geosynthetic materials from construction works. The databank included both mechanical and polymer characteristics to potentially serve both as a performance benchmark for the laboratory-based predictions previously developed and for future retrieval programs.

A total of 24 geosynthetic samples from 12 locations were exhumed and tested for this task. Industry laboratories working under the auspices of the Industrial Fabrics Association International (IFAI) (their trade association) were called on to provide measured data for the mechanical and polymer properties of typical current geosynthetics.

Major Conclusions

The results, analyses, and conclusions may be summarized as follows:

- For significant field degradation to occur (by oxidation or hydrolysis), retrieval sites need to be 30 or more years old. Such sites will not become available until the end of this decade.

- A successful retrieval program requires that the level of construction damage be established during construction or soon thereafter, and that full polymer characterization be available for the product used.

- Measurement methods for key polymer index properties must be standardized for future comparisons. Industry and academic polymer laboratories were seldom able to match polymer test properties from the same sample.

- Small decreases in viscosity were measured in all of the retrieved PET geosynthetics (all less than 20 years old), suggesting low levels of strength loss due to hydrolytic degradation. The rate inferred was consistent with rates developed in the study documented in Report No. FHWA-RD-97-144.

- For PP and HDPE geosynthetics, no oxidative degradation leading to strength loss was measured or could be inferred. Consistent decreases in OIT suggest that not all of the antioxidant had been consumed in the less than 20 years prior to retrieval. This finding is consistent with the findings in Report No. FHWA-RD-97-144, which suggests that during the induction period, antioxidants are consumed with no strength loss.

Further Actions Recommended

Additional retrieval programs should be initiated within the next few years, focusing on the four to six sites sampled under this program where multiple previous retrievals were made. The standardization of polymer index test methods and their disclosure in manufacturer literature and compliance certification should be promoted.

Researcher—This study was performed by Earth Engineering and Sciences Inc. (E2Si), Baltimore, MD. Subcontractors: GeoSyntec, Atlanta, GA, and Polytechnic University, Brooklyn, NY. Contract No. DTFH61-91-C-00054.

Distribution—This TechBrief is being distributed according to a standard distribution. Direct distribution is being made to the Resource Centers and Divisions.

Availability—With the exception of Report No. FHWA-RD-00-157, which will be available in the near future, copies of the other reports are currently available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A limited number of copies will be available from the R&T Report Center, HRD-11, FHWA, 9701 Philadelphia Court, Unit Q, Lanham, MD 20706, telephone: (301) 577-0818, fax: (301) 577-1421.

Key Words—Geosynthetics, geogrid, geotextile, durability, oxidation, hydrolysis, testing protocols for durability, confined extension, confined creep, confined stress-strain, reinforcement, chemical degradation, polypropylene, high-density polyethylene, polyester.