EVALUATION OF POLYESTER REINFORCEMENT FOR LONG TERM DURABILITY

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ABSTRACT: Durability of reinforcements is the key concern of the design engineering community as well as the producers of reinforcements. Measuring and evaluation techniques have evolved greatly in recent years with the introduction of the award winning SIM creep method and with greater understanding of chemical composition contribution to long term performance of polymers and their derivatives high tenacity yarns. This paper reports the results of an integrated yarn and product evaluation employing both SIM and conventional creep techniques and presents detailed durability analysis of the same materials in terms of carboxyl end groups, molecular weight and hydrolysis.

1 INTRODUCTION

In 1988 Cooke and Rebenfeld reported the need for care in selecting or preparing the several engineering polymers for earthworks. The two key polymers, olefin and polyester, possess a wide range of finished product capability and both are readily capable of achieving superior performance in the engineering properties of creep, resistance to chemical attack and durability that the designers and builders of earthworks must address. It is well known that for polyester, highly drawn fiber has high strength, high elastic modulus, low extension, and reduced creep under load. In formulations with low CEG and high molecular weight, these fibers are also highly resistant to chemical attack and are very resistant to hydrolysis in earthen structures. The civil engineering community can be confident that, when the proper polymer has been chosen, the reinforcement product will be eminently fit for use. As it is a given that the polymer can be fit for use, the challenge becomes an assessment of products to attest that the correct product from the correct polymer is in hand. This paper is a report on the process of verifying polyester yarn materials and the resultant geosynthetic products to be fit for use as reinforcements in earthen structures.

On the occasion of the founding of a new producer, a program was undertaken to evaluate and qualify candidate high tenacity multifilament polyester yarns for the production of high strength geotextiles and geogrids. This was a cooperative effort on the part of the yarn producer and the manufacturer of the geosynthetic reinforcements. A major component of the effort focused on shared information of creep test results based on the Stepped Isothermal Method (SIM) and conventional techniques used to evaluate the creep performance of the yarn and the products to develop composite creep curves for the manufactured geosynthetics. SIM is an accelerated protocol that generates long-term predictions in a very short period. For polyester, Finnigan demonstrated in 1977 that high tenacity polyester achieved stable and predictable creep deformation at the period of one minute to 100 hours while Holtz et al concluded that 70% of the total geosynthetic creep strain occurs within 3 days of sustained loading.

Evaluation of the long-term durability properties was carried out initially with testing to establish the Carboxyl End Groups (CEG) and Molecular weight (Mw) for the yarn. Manufactured products were subsequently evaluated for resistance to hydrolysis, chemical and bacteriological attack.

A concern was the absence of widely agreed durability testing methodologies for high strength geosynthetics. For example: the GRI methods GG7 and GG8 are not widely practiced in North American labs, are not repeatable in the fiber producers labs and there is no effort to adopt these protocols at ASTM or ISO. EPA 9090, which is widely used to evaluate geomembranes suitability, and is used to evaluate reinforcements, is not an effective tool to evaluate high strength geosynthetics. Finally, the European community has adopted a group of short-term ISO methods for hydrolysis, chemical and biological resistance. The solution was to test across a broad spectrum and our challenge was to correlate data from a widely disparate set of test methods.

2 CREEP

The high molecular weight and semi crystalline morphology of Polyethylene Terephthalate (PET) industrial fibers provide the basis for excellent long-term resistance to deformation (creep) over a wide variety of loading conditions and ambient temperatures. (Wool et all) Excellent creep resistance supports use of PET fiber as a leading reinforcement in geosynthetic reinforcements, in numerous rope applications and as the primary carcass reinforcement in passenger tires worldwide.

Fiber, geosynthetic reinforcement, rope and tire manufacturers serve varying service conditions and measure very different aspects of PET creep but the basic techniques are similar. The fiber (or assembly) is loaded to a percentage of its breaking strength greater than the expected service level or the load is cycled about a target level for a given number of cycles. Times to failure or retained strength after loading are the primary outputs. Marine hawsers have been tested at 75% of rated load for 1000 hours, well above any expected tow experience; off shore mooring lines (for oil drilling platforms) are tested to withstand the projected 50-year storm (100,000 cycles between 30 and 60% of breaking load) and to predict 20-year wave cycle experience (De Pellegrin et all). Tire manufacturers evaluate PET for tire sidewall reinforcement at lower loading levels (10-15% of breaking) but require low deformation over a range of temperatures up to 100 C. (Rim et all) Geosynthetic yarns and products are tested at a range of loads (ramp and hold) to determine a short term tensile behavior envelope and then, in SIM, they are tested at varying loads in a progressively elevated temperature regime including: high loads that exceed the service level, loads at the service level and loads well below service level to establish a creep envelope predicting very long term performance (75 to 100 years). Conventional creep testing of geosynthetic reinforcements applies similar loads at a single (20C) or a few temperature points (20, 30, 40 C).

Several types and manufactures of yarn were evaluated in the initial phases to develop geosynthetic creep strain curves for the yarns. A primary yarn was chosen as the best fit for cost and performance and prototype geogrids and geotextiles were produced. These products were tested using SIM for comparison of their creep behavior against the initial yarn curves.

Test results yielded good conformation of yarn and product creep curves in this initial part of the development and evaluation process. Curves for yarn and product developed by the SIM method were superimposed and found to conform satisfactorily and attested to the value of the SIM methodology in evaluating yarn selection, product construction, prototype assessment and development of creep performance expectations.

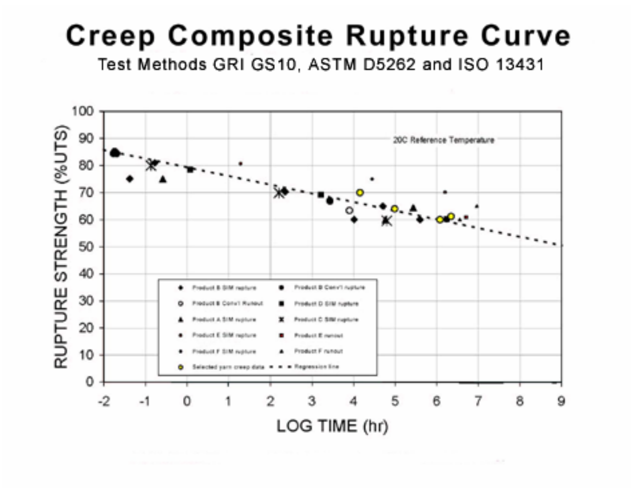

Figure 1

When full-scale production was started, products continued to be tested using both standard unconfined creep and SIM. These concurrent conventional creep and SIM tests produced additional confirmation of expected product performance. When superimposed, the characteristic curves for unconfined creep and the SIM curves were consistent and repeatable as was expected.

It is interesting to note that creep characteristics for families of similar high strength polyester yarn which are outside the established boundaries of CEG >30 and Mw <25,000 display similar creep curves to the plots for the preferred yarn and final product.

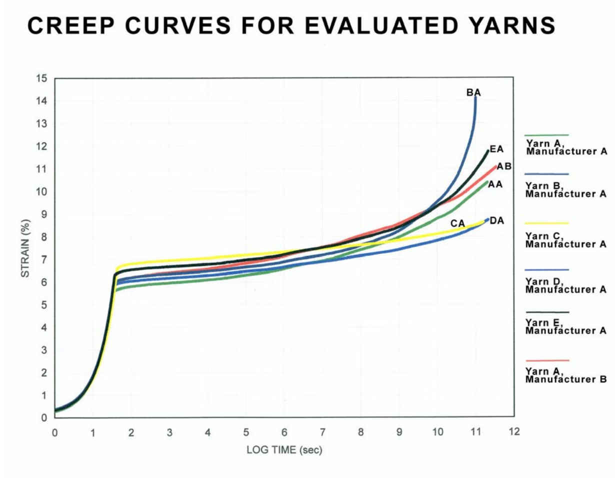

Figure 2

3 CEG AND MW

In the United States, maximums and minimums for molecular weight and carboxyl end groups are the key characteristics attesting to long-term durability for polyester yarns. Finnigan, Rebenfeld, Koerner, Allen and finally Elias have demonstrated that the highly drawn polyester fiber produced from the proper polymer yields a complex molecule with excellent creep characteristics as well as high resistance to hydrolysis, chemical attack and high pH. Elias et al, in their work for the FHWA (Federal Highway Administration), verified the technology base of the polyester producing community. The resultant FHWA Geotechnology Technical Note brought the question of suitability of engineering polymers to a conclusion in the USA by establishing parameters that, if met, assured the engineer that the products would perform admirably in the long term. For polyester the thresholds are a maximum of carboxyl end groups at 30 and a minimum molecular weight of 25,000. Using this criteria for polyester, we were able to pre-qualify yarns with assurance that the chemical resistance of the polyester yarn will be such that the products will perform throughout the design life.

4 CHEMICAL, BACTERIOLOGICAL AND HYDROLYSIS RESISTANCE.

Chemical degradation, especially hydrolysis, is often cited but poorly understood. Long-term behavior of PET fibers used in the manufacture of geosynthetics can be susceptible to chemical degradation; however, correctly selected PET fibers used in the manufacture of geosynthetic reinforcements are impervious to chemical attack for all practical purposes. Several studies, both historic and current, (Elias, Han-Yong Jeon) have demonstrated the vulnerability of lightly drawn (low fiber tenacity), low molecular weight PET fiber. Elias also demonstrates that high molecular weight; highly crystalline structure fiber with low CEG is admirably suitable for reinforcements as the fiber is virtually invulnerable to chemical degradation.

Chemical degradation on PET fibers can be divided in two major groups. First is the degradation caused by neutral and low pH, where the fibers are degraded by molecular breaks in the chain of the polymer. The second mechanism, which occurs at higher pH, is molecular weight degradation and erosion of the fiber. The end result of both degradation mechanisms is the reduction of section on the fiber and therefore the reduction of tensile properties on long-term exposure.

For PET the degradation at low levels of pH is insignificant even in environments with extremely low pH. Most of the literature references and the experimental evidence leads to the conclusion that polyester fiber at pH lower than 7 and in temperature ranges that resemble actual field conditions will not have a substantial degradation in long term exposure. (De Pellegrin, Bright, Myles and Navarrete et all.)

In North America, the several producers of polyester yarn for geotechnical products evaluate polymers, fibers and yarn by a variety of techniques including intrinsic viscosity (ASTM D4603), and hydrolysis resistance (ASTM D2455) as well as gel permeation chromatography. Each of these firms employs protocols that are reliable, repeatable and reproducible within their own laboratories. These proprietary test protocols vary from the CEG and Mw methods associated with GRI GG7 and GG8 although results and conclusions are not in conflict. GG7 and GG8 have not proven to be reproducible or repeatable in the yarn manufacturing community or in the third party geosynthetic testing community.

Another current methodology used in the USA geosynthetic community for evaluation of chemical resistance and hydrolysis is a modification of the EPA 9090 test method. Initially this method was designed to evaluate the compatibility of liners and specific leachates obtained from landfills and the test method uses the concept of elevated temperature to accelerate degradation. It is well known that the combination of heat (relatively high heat), moisture and high pH can initiate hydrolysis in polyester. The process of hydrolysis can be highly controlled and is employed in textile manufacture to enhance dye ability and other apparel like performance attributes not associated with geosynthetics. Testing for hydrolysis is useful to separate those polyester products that are unfit for geosynthetics from the correct products as was demonstrated by Elias et al. Lightly drawn polyester filament with low molecular weight was shown as clearly vulnerable to hydrolysis while highly drawn, high Mw, purposely produced polyester fiber was not affected by hydrolysis inducing conditions. Reddy et al (12) also demonstrated that high tenacity polyester reinforcements were relatively insensitive to elevated temperatures.

Is interesting to note that the polyester that showed the highest degradation during the experiments of FWHA (Elias et all) was a non-woven fabric with well-known low tenacity and low Mw, obviously not suitable for reinforcement applications. This is also evident when low tenacity and low Mw non-woven was used for reinforcement in the early days of reinforcement of soils with geosynthetics in France. The reported degradation of those PET non-woven used in high pH after 17 years were as high as 50 % of the initial reported strength of the material. (Allen, Tony M. Bathurst, R.J. et all.). Jeon et al came to the same conclusions in 2003 reporting that poor choice in polymer and additive packages resulted in very poor performance in non-woven produced from polypropylene as well as very poor performance for non-woven produced from the wrong PET fiber. (Han-Yong, Jeon)

FHWA (Elias et all) made clear the requirement of active stirring of the solutions and other laboratory conditions. In this portion of the experiment, the maximum effort to insure the most severe conditions required active stirring to prevent the test solution from separating into layers of components and neutralllizing the components. It is reasonable to assume that unless the engineered polyester is exposed to sustained high temperature, high pH and moisture it is unlikely that the hydrolysis process will cause any noticeable degradation of the reinforcement. When the conditions of the application of polyester geosynthetics are taken into account, that is modest temperatures, moderate pH and some moisture presence it is reasonable to ignore the chimera of hydrolysis.

In Europe, a there is a similar approach, but with a clear differentiation in the tests for chemical attack and hydrolysis.

The North American approach employs the 9090 procedures for a wide spectrum of characteristics over an extended period of time. The European test method tries to correlate 3 conditions, acid and alkaline medias and neutral pH with distilled water over a relatively short term. This test also uses the concept of increased temperature to intensify the attack of the chemicals used.

However, there is an important difference in the elevated temperature used by the European approach. While the resistance to liquids with high or low pH is executed in temperatures around 60 degrees Celsius, the hydrolysis test is carried out at 95 degrees Celsius. The extreme temperature exaggerates the degree of attack by the chemicals present in the bath. In addition the temperature influences the behavior of the polymer due to prolonged exposure to high temperature and water. These conditions are rarely found on job sites and in fact are hard to find around the planet. Data drawn from extreme tests provide a useful index for comparative values but have no relevance to conditions of use in construction

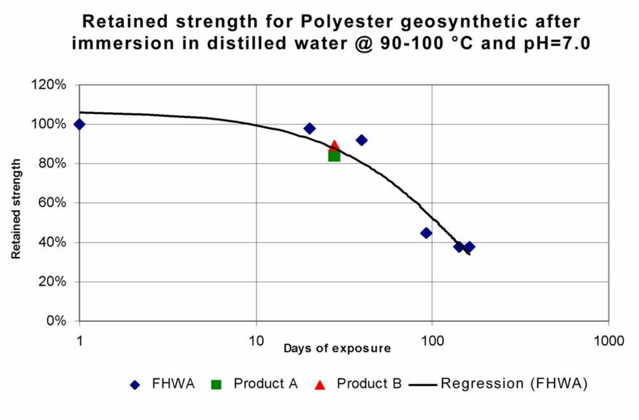

Figure 3

For the evaluation of the proposed yarns for the family of products the protocol selected was the European approach due to the relative short term and accuracy that these tests provide.

Figure 4 and 5 shows the relationship of the data for the conditions of high pH, low pH and neutral pH in relation with the FWHA and other manufacturers polyester testing. Several yarns tested for other manufacturers fall below the line of the experimental results from FHWA, making evident the conclusion of FHWA (Elias et all) that high molecular weight and low CEG were reasonable criteria for polyester long-term performance.

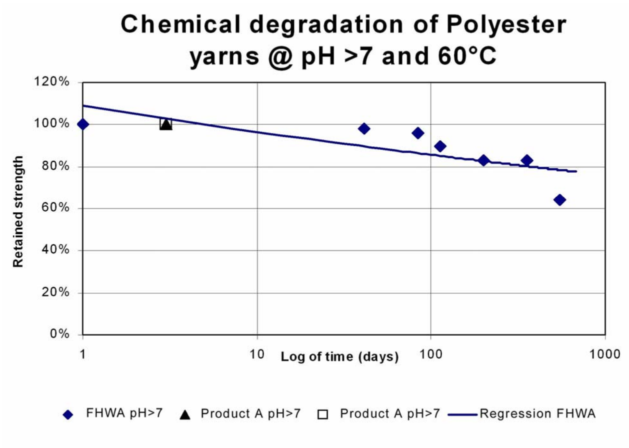

Figure 4

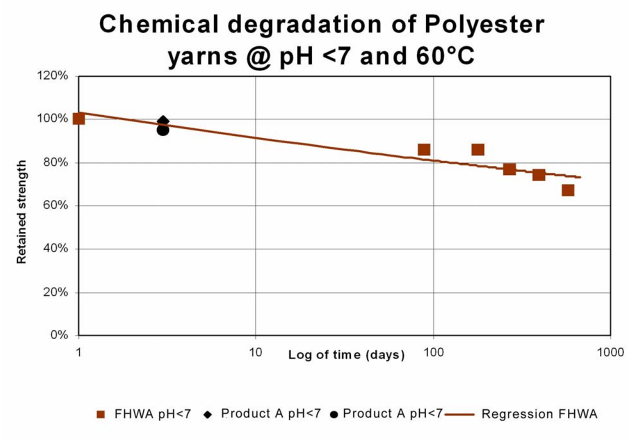

Figure 5

In Europe there is an effort to model protocols on hydrolysis, chemical resistance and biological resistance specifically for geosynthetics. The models are short term and the results are extrapolated. The results have good correlation and repeatability and can be compared with the creep data and also with the CEG and Mw data developed by the yarn manufacturer. It can be argued that durability would be better demonstrated by models that more closely resemble the actual conditions of burial for geosynthetics. For example: controlled burial of specimens with problematic soils (soils such lateritic soils, highly contaminated soils, calcium carbonate or cement modified soils… etc…) would quantify the effects of field conditions on reinforcement products over time. Until those models are available it is reasonable to assume that unless the engineered polyester is exposed to all 3 conditions of sustained high temperature, a high pH and moisture, it is unlikely that the hydrolysis process will cause any significant degradation of the reinforcement. As a general rule climatic conditions that result in high soil temperatures such as deserts are usually associated with dry climates while conditions that result in wet soils such as rain forests are usually associated with modest soil temperatures. It is further reasonable to conclude that the natural world does not easily generate conditions of high temperature, high moisture and high pH conducive to the hydrolysis process.

5 BIOLOGICAL EVALUATION OF CANDIDATE POLYESTERS

Concern on the part of the geosynthetic community on the possibility of degradation of geosynthetics by attack of biological entities is inexplicable in view of the lack of evidence of such an attack. The possible damage exerted on any geosynthetic can be summarized in two groups, microbiotic and macrobiotic organisms.

Geosynthetics are not a food source and do not attract animals and insects (macrobiotics) and the concerns about possible damage is limited to digging burrows and colonies or an effort to pass through the geosynthetic to reach a food source. There is little evidence of this problem. For reinforcements, the typical position of the geosynthetics is under or between layers of highly compacted soil, and damage produced by any macrobiotic organism will be minimal and less problematic than the damages caused by the process of installation damage.

With respect to microbiologic attack, there is strong evidence that even in the harshest environments the damage caused by bacteria and fungi are negligible. There are no references that present damage caused by microorganisms to high tenacity PET. There is some evidence of bacterial attack on stabilizers and coatings that contain organic and degradable chemicals such as PVC perhaps degrading the coating on a geogrid. The principal function of geogrid coatings are UV and installation damage protection and once the reinforcement product is in place, possible degrading of the coating has no impact on the function of the reinforcing element, the polyester fiber. Polyester is not degraded by bacteria. This is due to the high molecular weight and high crystalline structure of the polymer. (Bright) and reduction of strength in the reinforcement geosynthetic can be attributed to installation damage.

Our evaluation of the yarn and products was to use BS EN 12225 in which specimens are buried for a prescribed period and then tested. Results are compared to retained (unaltered) samples of the geosynthetic. The results showed negligible variation between retained and buried samples.

6 CONCLUSION

SIM is an outstanding tool for the evaluation of creep characteristics of candidate yarns as well as the prediction of long-term performance of soil reinforcements.

SIM is an outstanding tool for the evaluation of creep characteristics of high strength geosynthetics as well as the prediction of long-term performance of soil reinforcements.

The FHWA Geotechnical Technology Note is an excellent guide to the best selection of sol reinforcement products.

PET fiber of high molecular weight and limited carboxyl end groups is a superior product for soil reinforcement applications.

The correct polyester products (high Mw and low CEG) exhibit minimal vulnerability to chemical attack.

The correct polyester products (high Mw and low CEG) exhibit no vulnerability to biological attack.

Accelerated testing with elevated temperatures, high concentrations of moisture and extreme pH ranges are useful in developing index values characterizing yarns and products that are candidates for soil reinforcement.

In soils, the conditions of the test protocols unique combination of high temperature (50 C +), high pH (9 + higher) and high moisture is rare.

The broad scope testing program provides detailed third party verified information for design.

The broad scope testing program correlates with the data gathering and record keeping provisions of the CE Mark and ISO 9000 – 2002 programs.

7 REFERENCE

Allen, Tony M (1991), Determination of Long Term Tensile Strength of Geosynthetics: A State of the Art Review, Proceedings of the Geosynthetics 91 Conference Vol 1 pg 351-379

Allen, Tony M. Bathurst, R.J. et all. Global Level of Safety and Performance of Geosynthetics Walls: an Historical Perspective. Geosynthetics International (2002) Vol. 9, Nos. 5-6.

Bathurst, R.J. (2003), Reinforcement Load in Geosynthetic Walls and the case for a New Working Stress Design Method, Proceedings of the 56th Annual Canadian Geotechnical Conference etc, The Mercer Lecture

Bright, D.G. (1994), Polymeric Behavior of Geosynthetic Products, Proceedings of the Structural Geogrids For Waste Containment Applications Seminar pgs

Cooke, T. F. & Rebenfeld, L. (1988), Effect of Chemical Composition and Physical Structure of Geotextiles on Their Durability, Geotextiles and Geomembranes (1988) Vol 7 Pgs 7—22

De Pellegrin, I. (1999), Manmade Fiber Ropes in Deepwater Mooring Application, Proceedings of the Offshore Technology Conference, OTC 10907

Elias, V. (1997), Corrosion/Degradation of Soil Reinforcements for Mechanically Stabilized Earth Walls and Reinforced Sol Slopes, FHWA Demonstration Project 82 Reinforced Soil Structures MSEW and RSS, Publication No. FHWA - SA - 96 - 072

Finnigan, J.A(1977), The Creep Behavior of High Tenacity Yarns and Fabrics used in Civil Engineering Applications, Proceedings of the International Conference on the use of Geosynthetics Vol 2 April Paris,

Han-Yong, Jeon (2003), Weatherability and Drainage Properties of Duplicated Nonwoven Geotextiles for Waste Landfills, Proceedings of the 56th Annual Canadian Geotechnical Conference etc , Session 4E

Holtz, R.D., W. R. Tobin, W. W Burke (1982), Creep Characteristics and Stress-Strain Behavior of a Geotextile-Reinforced Sand, Proceedings of the Second International Conference on Geotextiles Las Vegas Vol. 3

Koerner, R.M., Lord, A. E. Jr & Halse, Y. H. (1988), Long-Term Durability and Aging of Geotextiles, Geotextiles and Geomembranes Vol 7 pgs 147-158

Myles, B.M. (2003), Creep and Creep Rupture, Personal communication

Navarette, F, Reddy, D.V. And Lai, P. Creep of Geogrid Reinforcement for Reteining Walls Backfills. Proceedings of the Geosynthetics conference 2001, Portland OR Pgs 567-578

TRI Environmental – Creep and creep-rupture behavior of Xtex, Inc. Geosynthetics, April 2003

TRI Environmental – test report for Hydrolysis resistance BS EN ISO 12447, July, 2003

TRI Environmental – test report for Resistance to weathering BS EN ISO 12960, July, 2003

TRI Environmental – test report for Chemical Resistance BS EN ISO 12224, July, 2003

TRI Environmental – test report for Microbiological resistance to soil burial BS EN 12225, July, 2003

TRI Environmental – test report for UV Resistance ASTM D 4355, July, 2003

Thornton, S. J. (1997), The Stepped Isothermal Method for Time - Temperature Superposition, Proceedings of the Creep and Assessment of Geosynthetics for Soil Reinforcement Seminar, ERA

Rim, P., Nelson, C.J. (1994), Dimensionally Stable PET for Passenger Radial Tires, journal of

Voskamp,W., van Vliet, F., Retzlaff, J. (2001), Residual Strength of PET after more than 12 years creep loading, Landmarks in Earth Reinforcement-Ochiai et al. (eds.) 2001 Swets & Zeitlinger ISBN 90 2651 863 3pgs. 165-170

Voskamp, W. & van Vliet F. (2001), Variation in Creep Rate at Constant Loading of PET Geogrid Strapping, Proceedings of the International Symposium on Earth Reinforcement, Kyushu, Japan Balkema

Voskamp, W. & Risseeuw, P. (1987), Method to Establish the Maximum Allowable Load Under Working Conditions of Polyester Reinforcing Fabrics, Geotextiles and Geomembranes Vol 6 Pgs 173-184

Voskamp,W. (1997), Proposed Method To Determine the Safety Capacity of Reinforced Soil Structures During the Lifetime, Earth Reinforcement, Ochiai, Yasufuku & Omine (eds) pgs 1075-1080 1997 Balkema, Rotterdam, ISBN 90 5419 8339

Wool, R.P., Statton, W.O. (1979), Properties and Molecular Constitution of Fibres, Academic Press, London, Applied Fibre Science pgs 10-16