GRIPS, CLAMPS, CLAMPING TECHNIQUES, AND STRAIN MEASUREMENT FOR

Testing of Geosynthetics

PETER E. STEVENSON, EDITOR

ASTM

STP 1379

STP 1379

Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics

Peter E. Stevenson, editor

ASTM Stock Number: STP1379

ASTM
100 Barr Harbor Drive
West Conshohocken, PA 19428-2959

Printed in the U.S.A.

Library of Congress Cataloging-In-Publication Data

Grips, clamps, clamping techniques, and strain measurement for testing of geosynthetics / Peter E. Stevenson editor
p. cm.—(STP; 1379)
"ASTM Stock Number: STP1379."
Papers presented at a symposium held January 28, 1999, Memphis, Tenn., sponsored by ASTM Committee D-35 on Geosynthetics.
Includes bibliographical references.
ISBN 0-8031-2854-1
1. Geosynthetics—Testing I. Stevenson, Peter E., 1940– II. ASTM Committee D-35 on Geosynthetics. III. ASTM special technical publication; 1379.

TA455.G44 G754 1999
624.1´8923—dc21 99-058001

Peer Review Policy

Each paper published in this volume was evaluated by two peer reviewers and at least one editor. The authors addressed all of the reviewers' comments to the satisfaction of both the technical editor(s) and the ASTM Committee on Publications.

To make technical information available as quickly as possible, the peer-reviewed papers in this publication were prepared "camera-ready" as submitted by the authors.

The quality of the papers in this publication reflects not only the obvious efforts of the authors and the technical editor(s), but also the work of the peer reviewers. In keeping with long-standing publication practices, ASTM maintains the anonymity of the peer reviewers. The ASTM Committee on Publications acknowledges with appreciation their dedication and contribution of time and effort on behalf of ASTM.

Printed in Philadelphia, PA
January 2000

Foreword

This publication, *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics,* contains papers presented at the symposium of the same name held in Memphis, Tennessee, on 28 January 1999. The symposium was sponsored by ASTM Committee D35 on Geosynthetics. The symposium chairman was Peter E. Stevenson, Stevenson and Associates and the co-chairman was Sam R. Allen, TRI/Environmental.

CONTENTS

Overview

For me, the work reported in this publication began with confusing test results. The first purpose of the research reported here is to provide the reader with the tools to understand the problems and techniques in testing and reporting data for strong reinforcement products. The second purpose of the work is to point the way to a repeatable and reproducible test methodology for those strong products. The tests in question were performed on the first edition of prototype high-strength geotextiles and the results were quite different than those expected. The lab was highly skilled, managed by the mechanical engineering department of a local university, routinely employed by the aerospace industry, and comfortable with high-strength, high-modulus materials. The problem was elongation. Test results of 20 to 30% extension for products with strengths of 100 to 1000 kN/m were two to three times expectation.

The mystery was soon resolved through consultation with an experienced geosynthetic lab. Comparison of results, test methods, and testing technique revealed that the mechanical engineering lab had adopted the test protocol described in ASTM D 4595, literally. The geosynthetic lab pointed out that reinforcements were typically tested by an amended protocol familiar to many in the geosynthetics industry, but not evident in the language of the test procedure. This experience initiated a research project on tensile testing methodology. The objective of the research was, and is, the development of a repeatable and reproducible test protocol for strong and very strong geosynthetics. The product range addressed in the research in this publication spans grids and fabrics from 35 to 1200 kN/m.

The research presented in the following articles identifies several problems with ASTM D 4595 and its ISO counterpart ISO 10319. The investigation into the causes of the incorrect results previously discussed led to a review of 183 papers on testing, all written before 1995. Selected papers are listed in the bibliography to this overview. These selected papers identified eleven concerns with testing protocols for strong and reinforcing products and cast doubt on the reliability of the data generated by these test methods. Kelkar enumerates the eleven issues. Most important, in a 1998 paper published by GRI, the test lab accreditation agency, GAI LAP of GRI, ranks D 4595 as the least consistent test protocol in the geosynthetic inventory. Reproducibility and repeatability are the core problems. The influence of pre-stressing or pre-loads makes accuracy an additional problem. Also, in 1998 the ISO subcommittee on mechanical properties, TC38/SC21/WG3, resolved that a separate test protocol should be developed for the testing of strong reinforcements. The tensile test task group of the ASTM D-35 committee on Geosynthetics proposes to include protocols for high-strength materials within the D 4595 umbrella.

One might expect that, after fifteen years, the D-35 committee on Geosynthetics would have developed consistent test methodologies for reinforcements, but this is not true, and our European counterparts have not progressed farther than we. How can this be? The answer lies in the evolution of the test protocols, geosynthetic products, and the industry. My personal recollection of the test method history begins with Alan Haliburton and his proposal to D-18 that a wide strip test for geosynthetics would be palatable to civil engineers and perhaps could serve to generate design information. Work began immediately in North America and Europe, resulting in the early editions of D 4595 and ISO 10319. Along the way there were some noteworthy events. First, nonwovens held a huge influence on the industry with upwards of a 70% market share that continued into the late 1980s. Today's reinforcing products were largely unknown. Specimen size and shape, particularly width, were developed to accommodate nonwoven geotextiles. The 200-mm width was developed to minimize the

Poisson's effect or necking influences in nonwoven specimens. A small gage of 100 mm was selected as an effective tool for the labs with minimal negative effects on nonwoven fabrics and weak woven products, such as those produced from olefin-based slit tapes. Second, the general efficacy of the test for a majority of geotextiles was proven in a series of round robins. Interesting, D 4595 and ISO 10319 are not the normal nonwoven testing reference as the industry approaches the year 2000. Much, if not most, nonwoven product data are published citing the Grab test. A Grab test, ASTM D 4632, is easier to perform and is often used in internal quality control as well as in published data.

During the period that ASTM D 4595 and ISO 10319 were adapted for a broad spectrum of geosynthetics, work was performed on strong and new products to be used as reinforcements. In 1986 Myles published research on wide-width testing of high-strength geotextiles and presented an article on the reporting of test data. GRI developed and published test methods GRI, GG1, and GG2 to facilitate testing of geogrids and grid junction strength. These precursors of the work published in this volume clearly identified problems in testing and reporting data for reinforcements. Peggs, Skochdopole, and Kelkar, among others in this volume, revisit the arguments, and Peggs and Skochdopole present solutions to the dilemma of trying to develop a practical test method while reporting information in consistent, clear, and meaningful terms.

During the 1980–1995 period, the geosynthetics industry experienced significant growth. Products evolved, and applications, such as walls, requiring strong products came to the forefront and stronger fabrics and grid structures were introduced. These products immediately experienced difficulties with the test protocols in D 4595 and ISO 10319, most notably gripping problems. Many innovations were tried and innovative solutions to the problems and influences of grips on test results continue in this volume. Grips, problems with grips, and solutions to gripping problems are the primary focus issues for the papers by Koerner, Elvidge, Jones, Müller-Rochholz, Thornton, Skochdopole, Kelkar, and Farrag. One of the early solutions to gripping problems was the introduction of capstan or roller clamps and rollers. These work quite well in producing ultimate strength data. However, rollers require very long specimens, which creates havoc with the twin concerns of grip separation and specimen gage. When testing a nonwoven, the gage is 100 mm. In this instance, 100 mm stands for the separation of clamps as well as the area to be observed for extension. When roller clamps and very long specimens are introduced, grip separation becomes much different. Thornton and Kelkar discuss gage length and the influence of varying specimen lengths on reported test results. Sample size and its influence on results is also discussed by Müller-Rochholz, Skochdopole, and Chang. Further, the concepts of gage become complex with long specimens. ASTM has five distinct definitions of gage length. Originally, for the nonwoven tests, gage length and jaw separation were the same. With the introduction of long specimens a different definition was applied to gage length: the original length of that portion of the specimen over which strain or change of length is determined. This means the adoption of the convention in which one observes extension over only a portion of the specimen. Does similar convention exclude consideration of Kelkar's first and second modulus, despite the reasonableness of his argument? Peggs discusses other confusions over terms. The concern over true gage length and effective gage length might seem unnecessary, except that gage governs test speed and measures extension. Small changes in gage have a significant effect on results. Further, gage must be observed at the same point from specimen to specimen, as variability in the locus of observation will also influence results. Repeatability is a formidable task when using roller specimens that are 200-mm wide and 1800-mm long with grip separations that vary between 250 to 500 mm. Jones, Skochdopole, and Kelkar report that optical devices solve the problem of repeatable gage. According to the test protocols, for geosynthetics the observed gage length remains 100 mm.

In the abstract, extension can be accurately measured by many techniques, including cross head movement, LVDTs, and optical devices. Chew argues that LVDTs can influence test results if care is not exercised. Nonetheless, in the realm of strong product tensile testing, LVDTs are most serviceable in horizontal applications as discussed by Chew, Farrag, and Chang. Jones discusses the unsuitability of LVDTs for vertical tensile test applications. It seems that mounting LVDTs to geosynthetics requires a two-stage test. The first stage is to sufficiently stress the material to permit the mounting of the device for measuring extension. The second stage measures extension with the mounted device. Accuracy seems likely to suffer and Skochdopole and Kelkar present data to support Jones to that effect. Jones, Skochdopole, and Kelkar offer viable extension measurement techniques that are not dependent upon prestressing, and Skochdopole offers two ways to present non-prestressed data in a format that permits comparison to historical records of data acquired with prestressing. As discussed by Peggs, Müller-Rochholz, Thornton, Skochdopole, Kelkar, and Greenwood, the problem is the need for accuracy at low strains. Low strain data represent the potential for deformation in a reinforced, earthen structure and also defines the initial loading phase of the creep curves to determine long-term properties.

In conclusion, there may be more work necessary to demonstrate the problems with the test protocols when applied to strong materials: but in my opinion, a great deal of such work is unnecessary. The problems and the solutions are presented in this publication and the references it cites. What is necessary is for the few who are not interested in better and more accurate testing to restrain their objections, or at least offer data that are based on work of their own that will contribute to and direct the resolution of the problems. I thank the authors of papers for the ASTM Symposium on Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics for the hard work and great effort they exerted to make this publication meaningful.

Bibliography

These authors developed the initial list of concerns about the test procedures.

Veldhuijzen R., and Van Zanten, Eds., pp. 61–78, A. A. Balkema, Old Post Road, Brookfield, VT 05036-9704.

Bais-Singh, Smita, Goswami, and Bhuvanesh, C., 1996, "Deformation Behavior of Spun-Bonded Nonwovens: Measurement," *Proceedings of INDA-TEC 96,* International Nonwovens Conference, Hyatt Regency Crystal City, Crystal City, VA, pp. 29.1–29.19.

Brand, E. W. and Pang, P. L. R., 1991, "Durability of Geotextiles to Outdoor Exposure in Hong Kong," *Journal of Geotechnical Engineering,* Vol. 117, No. 7, pp. 979–1000.

Craig, B., "Use of Geosynthetic Materials with Improved Reinforcement Capabilities ," Report on the joint BGS/IGS meeting 4 December, 1996, University of Manchester, Ground Engineering, April, 1997.

Fakher, A., Jones, C. F. J. P., & Zakaria, N.-A. B., "The Influence of Dimensional Analysis on the Interpretation of Model Loading Tests on Reinforced Ground," *Proceedings of the International Symposium on Earth Reinforcement,* Fukuoka, Kyushu, Japan 12–14 November 1996, Hidetoshi Ochaii, Noriuyki Yasufuk, Kiyoshi Omine, Eds. A.A. Balkema Publishers, Old Post Road, Brookfield, VT 05036-9704.

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 Fabrics in Geotechnics,* L'Ecole Nationale Des Ponts et Chaussees, Vol. 2, Paris, France, April, 1977, pp. 305–309.

Haliburton, T. A., Anglin, C. C. and Lawmaster, J. D., "Testing of Geotechnical Fabric for Use as Reinforcement," *Geotechnical Testing Journal,* Vol. 1, No. 4, pp. 203–212.

Jones, C. F. J. P., Fakher, A., Hamir, R. and Nettleton, I. M., "Geosynthetic Materials with Improved Reinforcement Capabilities," *Proceedings of the International Symposium on Earth Reinforcement,* Fukuoka, Kyushu, Japan 12–14 November 1996, Hidetoshi Ochaii, Noriyuki Yasufuku, Kiyoshi Omine, Eds. A.A. Balkema Publishers, Old Post Road, Brookfield, VT 05036-9704.

Leschinsky, D. and Fowler, J., "Laboratory Measurement of Load Elongation Relationship of High-Strength Geotextiles," *Geotextiles and Geomembranes,* Vol. 9, No. 2, pp. 145–164.

Myles, B. and Carswell, I. G., "Tensile Testing of Geotextiles," *Proceedings of the Third International Conference on Geotextiles,* Vol. 3, Vienna, Austria, April 1986, pp. 713–718.

Pan, N., Chen, H. C., Thompson, J., Englesby, M. K., Khatua, S., Zhang, X. S., and Zeroinian, S. H., "Fiber Initial Modulus as a Function of Fiber Length," The Fiber Society, General Technical Conference, Hotel Viking, Newport, RI, October 14–17, 1996.

Rowe, R. K. and Ho, S. K., "Determination of Geotextile Stress-Strain Characteristics Using a Wide Strip Test," *Proceedings of the Third International Conference on Geotextiles,* Vol. 3, Vienna, Austria, April 1986, pp. 885–890.

Sissons, C. R., "Strength Testing of Fabrics for Use in Civil Engineering," *Proceedings of the International Conference on the Use of Fabrics in Geotechnics,* L'Ecole Nationale Des Ponts et Chaussees, Vol. 2, Paris, France, April, 1977, pp. 287–292.

Stevenson, P. E. and Skochdopole, T. R., "The Testing of Geosynthetic Reinforcements," *Proceedings of the 6th International Conference on Geosynthetics,* Vol. 3, Atlanta, GA, March 1998, pp. 529–537.

Van Leeuwen, J. H., "New Methods of Determining the Stress-Strain Behaviour of Woven and Non Woven Fabrics in the Laboratory and in Practice," *Proceedings of the International Conference on the Use of Fabrics in Geotechnics,* L'Ecole Nationale Des Ponts et Chaussees, Vol. 2, Paris, France, April, 1977, pp. 299–304.

Peter E. Stevenson
Stevenson and Associates
Easley, SC 29642
Symposium Chairman and STP Editor.

Grips, Clamps, and Clamping Techniques

Ian D. Peggs[1]

Geosynthetic Stress-Strain Curves: Practical Features and Observations

---

Reference: Peggs, I. D., "**Geosynthetic Stress-Strain Curves: Practical Features and Observations,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: The features of the ideal elastic-plastic stress-strain curve compared with practical curves are discussed with reference to conventional materials engineering and geosynthetic materials testing practices. Uniaxial and biaxial test curves are compared and referenced to the modes of failure of the two types of test specimens. A comparison of the well-defined yield points in HDPE geosynthetics with the smoother elastic-plastic transitions in LLDPE and PP is presented, together with methods that define artificial yield points. Considerations for the use of one, rather than two, gage length values for the determination of yield and break strain properties during uniaxial tension tests are presented. Plane stress and plain strain behavior of geosynthetics in laboratory uniaxial tests and in the field are compared together with their significance in the stress crack testing and elongation performance in HDPE geomembranes. Reference is also made to the measurement of strain and its significance during the shear testing of seams.

Keywords: geosynthetics, tension tests, seam tests, elastic modulus, gage length.

Introduction

Stress-strain curves and their determination for plastics are fundamentally no different than those for metallic and other materials. In fact, steels show very similar yield points to that demonstrated by high density polyethylene (HDPE). An ideal stress-strain curve would show perfectly elastic, perfectly plastic behavior as shown in Figure 1. Clearly this is never achieved, as neither is the elastic, perfectly plastic curve, shown in Figure 2. A model curve, similar to that for steel on which are based definitions of most mechanical properties in metallurgy and materials science, might be as shown in Figure 3.

[1]I-CORP INTERNATIONAL, Inc. 6072 N. Ocean Blvd., Ocean Ridge, Florida, USA.

Figure 1 - *Perfectly Elastic, Perfectly Plastic Curve*

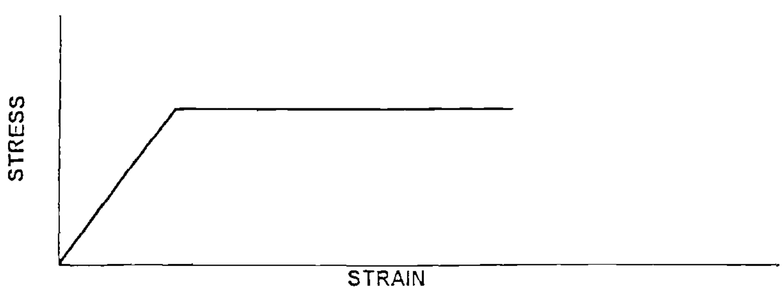


Figure 2. *Elastic, Perfectly Plastic Curve*

The initial linear portion of the curve is the elastic region. The slope of this segment of the curve is the Young's, or elastic modulus. The end of the linear portion of the curve is the limit of proportionality. The elastic limit is the point at which a permanent set (plastic deformation) occurs. The peak immediately after this is the yield point, defined by the yield stress and yield strain. The maximum in the curve is the ultimate stress, while the end point (before the curve drops vertically after the specimen breaks) is defined by the break stress (not termed the ultimate stress) and break strain. Clearly, failure should be considered to occur at the ultimate stress.

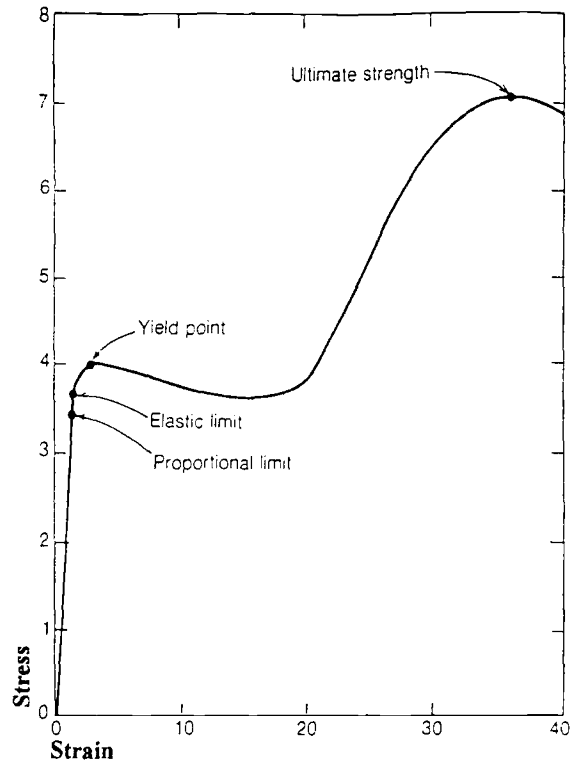


Figure 3 - *Typical Stress/Strain Curve of Low Carbon Steel*

Stress-Strain Curve Characteristics

When there is some "settling-in", taking up of slack, or removal of crimp in fibers, at the beginning of the curve, as shown in Figure 4, an elastic modulus can still be measured from the slope of the linear portion of the curve, but the strain parameters need adjustment by the amount of strain at the zero-stress extrapolation of the elastic section of the curve. However, the modulus measured (the slope of the curve) is independent of the settling-in strain. The "settling-in" strain (B in Figure 4) is termed the toe compensation.

In both metals (Figure 5) and plastics (Figure 6, ASTM Test Method for Tensile Properties of Plastics {metric} D 638), when there is no well-defined yield point, the limit of usable elastic behavior is defined by a yield strength or by an "offset yield strength" at a specified "offset" strain, often 0.01% or 0.2% for metals, and 0.1% for plastics – point F in Figure 4, point Y in Figure 5, and point r in Figure 6. This is contrary to the practice in geotextiles and geogrids where the "offset" strain (ASTM Test Method for Effects of Temperature on Stability of Geotextiles D 4595) is the toe-compensated strain (Figure 7). In relation to other materials and their properties, care must be taken when using this term for geotextiles and geogrids.

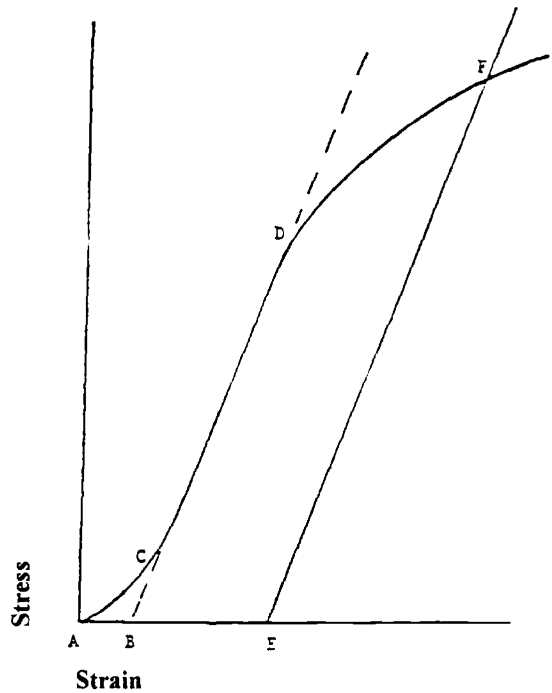


Figure 4 - *"Settling-in" (Toe Compensation) at Start of Curve (ASTM D 638)*

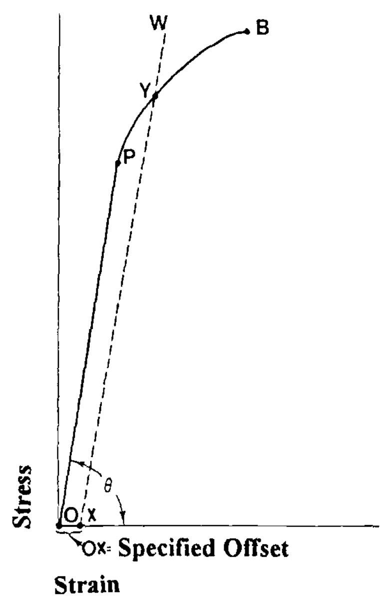


Figure 5 - *Using Offset Strain (x) to Define a Yield Point (y) in Metals*

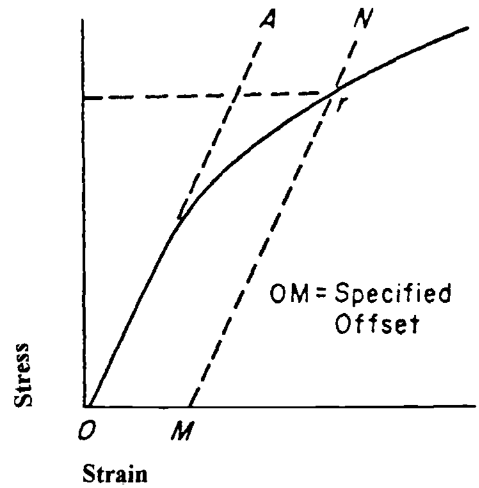


Figure 6 - *Offset Yield Point (r) in Plastics (ASTM D 638)*

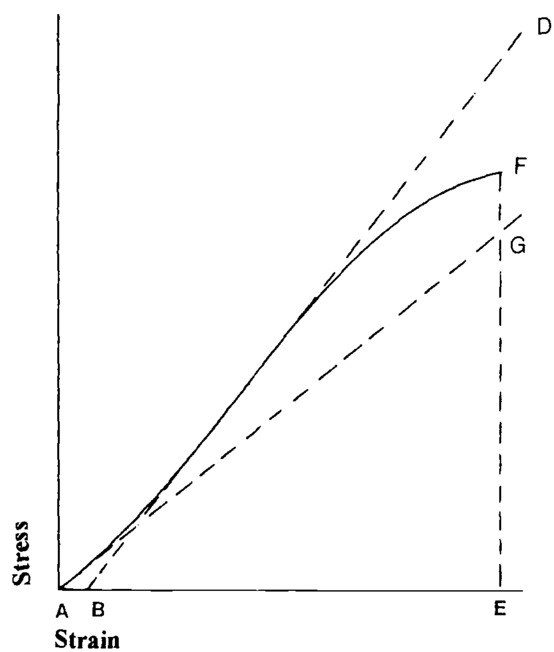


Figure 7 - *Determination of "Offset" (AB) Tensile Modulus (ASTM D 4595)*
Note: The offset tensile modulus is the same as the elastic modulus in this figure and the previous figures.

The typical stress-strain curve of high density polyethylene (HDPE) geomembranes (Figure 8) has modified features compared to those shown in Figure 3. There is a "settling-in" segment to the curve, which can be relatively significant. The primarily elastic (pre-yield) region is not linear, therefore it is very difficult to measure an elastic modulus, and therefore there is no limit of proportionality. However, the yield point is very well defined. There is a well-defined plastic segment to the curve, but at some point the slope of the curve increases resulting in identical ultimate and break stresses (simply described as the break stress since there is no maximum in the curve) and the break strain. The increase in slope has often been ascribed to "strain-hardening" in the HDPE, but this is not so. It simply represents the point at which one end of the growing yielded region starts to "rob" material from the widening shoulders of the dog-bone specimen or from the unyielded material held in the grip - thus the strength of the material appears to increase. Hence, the conventionally reported break parameters are, in fact, a feature of the test method/specimen and are not fundamental properties of the material.

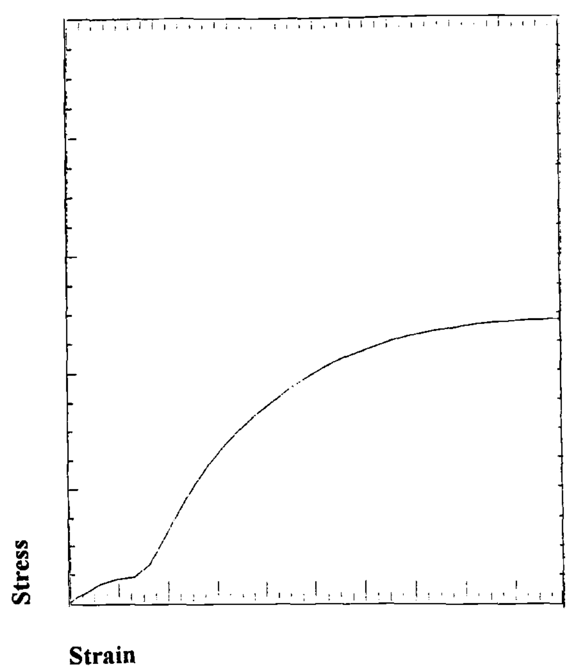


Figure 8a - *Pre-yield Segment of HDPE Curve*

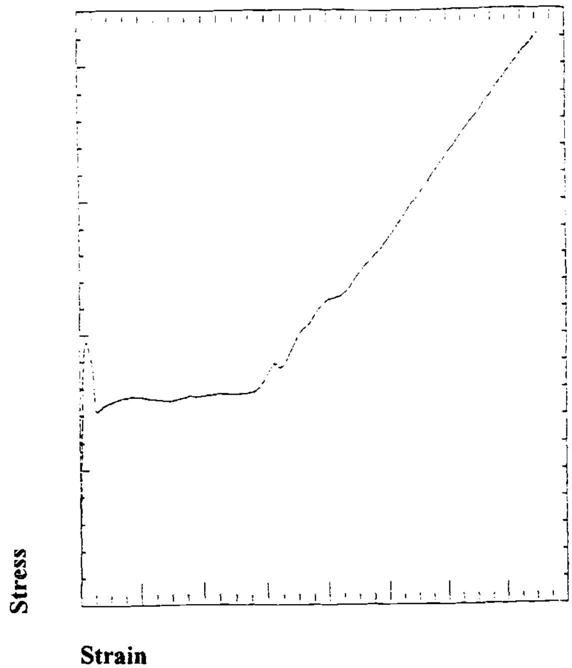


Figure 8b - *Complete HDPE Curve*

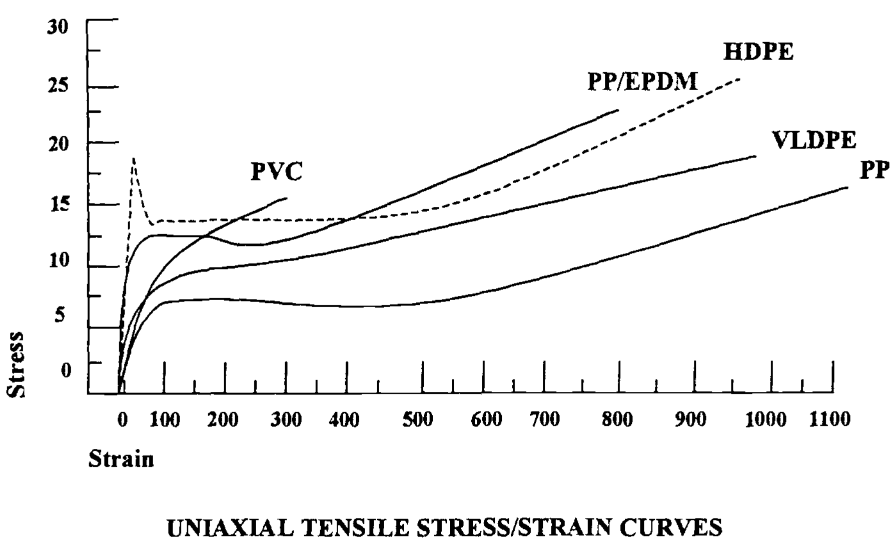


Figure 8c - *Several Geomembranes*

If an elastic modulus is required, it can only be presented as the tangent at the point of inflection (maximum slope) in the pre-yield portion of the curve, and this can only be accurately generated from a computer-generated curve, at the steepest section between two adjacent data points. Due to the difficulty of easily measuring a reproducible elastic modulus, its use has essentially been discontinued – secant modulus is generally preferred.

Clearly, though, the uniaxial stress-strain curve can only be used for design purposes when service stresses are uniaxial, such as might occur in geogrids. It should never be used for geomembranes, where sideways contraction to a major stress is restricted. The significance of such perpendicular stresses is shown (Figure 9) in thicker uniaxial test specimens perpendicular to the applied uniaxial stress. Biaxial stresses in the field generate plane strain conditions, whereas the uniaxial tensile test is carried out under plane stress conditions. Therefore, biaxial tensile tests are required to simulate field performance of geosynthetics. Typical biaxial stress-strain curves for a number of geomembranes are shown in Figure 10. The distinct yield point in HDPE is eliminated and break strain is significantly lower. This does not mean that yielding does not occur. Examination of failed biaxial specimens shows that a small lense-shaped segment of yielding occurs, its orientation and size determined by the minimum thickness orientation of the specimen. Once yielding has occurred, break in the yielded region occurs by the development of lense-shaped breaks that are normal to the major axis of the yielded segment since the strength of oriented material normal to the direction of orientation is relatively low. This is shown clearly at the end of the gage length of the thick HDPE dogbone specimen in Figure 9. However, it is clearly extremely important to know when yielding will occur, particularly if it is significantly before break occurs. Failure of the geomembrane should be considered to occur at yield, not break. Note that surface scratches, other mechanical damage, and surface texturing will influence the location of yielding. However, these types of features practically rarely influence the yield stress and strain of the specimen, but do significantly affect the break parameters.

A secant modulus (between the toe-compensated strain and a specific strain – see Figure 11) is frequently presented for those materials that show no yield point. This is often done at a number of strains for geomembrane materials such as PVC that display a very uniform (decreasing slope with increasing strain) stress-strain curve. Secant moduli are frequently generated for geomembranes such as VLDPE, LLDPE, and fPP, that show distinct quasi-elastic and quasi-plastic regions. However, at a single strain they give absolutely no indication of stress-strain performance. As such they can only be used for specification and QC purposes, since individual secant moduli give no indication of the slope of the curve prior to the secant strain. If QC is of prime interest, only the break stress and break strain are significantly affected by the internal and surface microstructure and surface geometry of the specimen/material. Yield parameters could effectively be ignored!

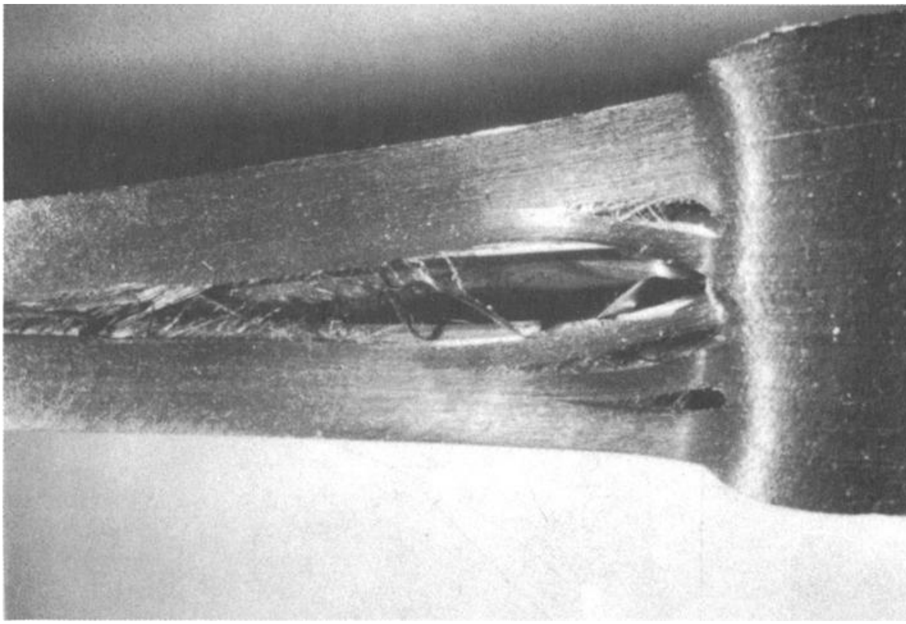


Figure 9 - *Separation Normal to Tensile Stress at End (Right) of Yielded Segment (Left) of Thick HDPE Pipe Dogbone Specimen*

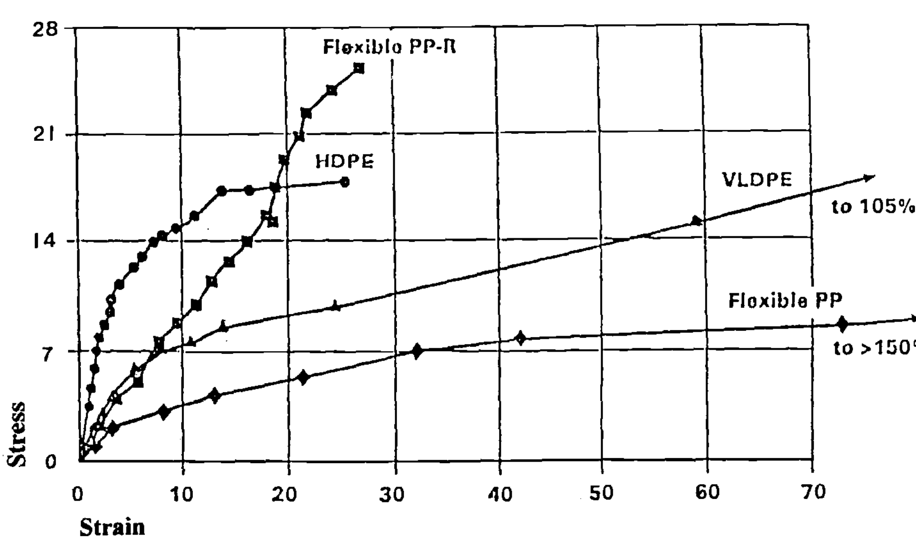


Figure 10 - *Biaxial Curves of Geomembranes*

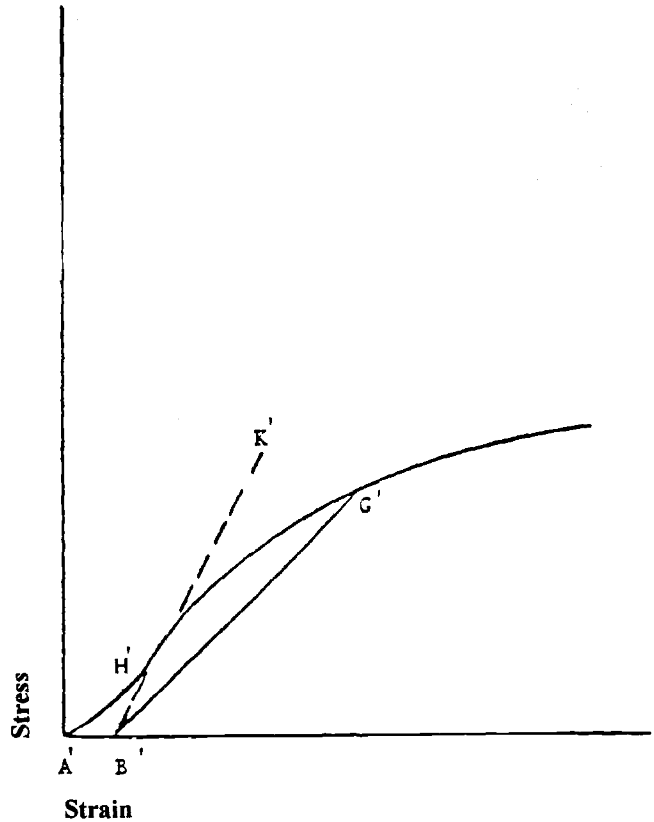


Figure 11 - *Determination of Secant Modulus at G After Toe Compensation (ASTM D 638)*

However, in ASTM D 4595 the secant modulus is described a little differently (Figure 12), using the zero, not the toe-compensated, strain point. This will give lower values of secant modulus than the toe-corrected method. It should also be noted that the line through A" M" in Figure 12 identifies two points on the stress-strain curve as having the same secant modulus, even though the tangent moduli at these two points are quite different. Thus, the significance of the secant moduli must be very carefully considered.

Other parameters defined in ASTM D 4595, primarily for higher strength geotextiles and geogrids, are segment modulus, offset tensile modulus, and tangent point.

The segment modulus, sometimes termed the chordal modulus, is the slope between any two points on the stress-strain curve. This modulus value must also be treated with care since the stress path between the two strain points is only generalized.

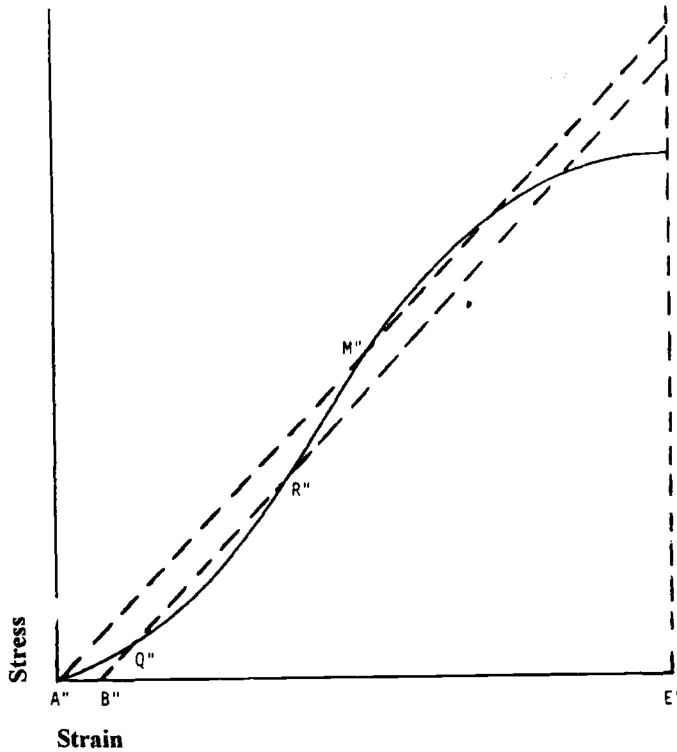


Figure 12 - *Construction Line (A" M") for Secant Modulus (ASTM D 4595)*

The offset tensile modulus is the same as the tensile or elastic modulus previously described – perhaps the word "offset" is not needed.

The tangent point is defined as: "...the first point on the force-elongation curve at which a major decrease in slope occurs."

This is the point of inflection, the steepest part of the curve, the point at which the elastic modulus might be measured, as shown in Figure 11 (Point H'). However, the discussion paragraph in ASTM D 4595 states that the tangent point is: "...determined by drawing a tangent line passing through the zero axis and the proportional elastic limit. The point from the zero force axis that the force-elongation curve first touches the tangent line is the tangent point."

As evident in Figure 13, if significant toe compensation is required, it may not be possible to draw a line through the origin that is tangential to either the proportional or elastic limits. Even without toe compensation it would not be possible to draw a line through the origin that is tangential to the elastic limit shown in Figure 3. And, if there is some linearity to the primarily elastic region of the curve, logically the tangent point should be in the middle of that segment, not at the end of it where the slope of the curve starts to decrease. The point at the end of the linear segment is the limit of proportionality so needs no further definition. Thus the explanation of the definition needs some modification, or could simply be omitted – the definition itself is adequate.

Figure 13 is presently being circulated with ASTM D 4595 as the standard is being reviewed. It shows a "tangent modulus" which is identical to the offset tensile modulus, the tensile modulus, and the elastic modulus. This term could be omitted. However, its use to clarify the fact that there is no linear segment of the stress-strain curve, and that this is the slope at the point of inflection (e.g. point H' in Figure 11), may be most appropriate.

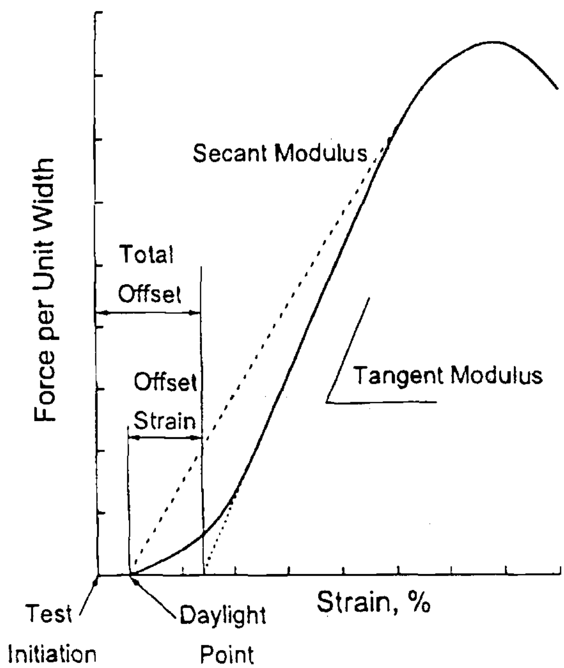


Figure 13 - *Stress-Strain Curve with Complete Test Results (ASTM D 4595 review)*

In general, it appears that the terminology of tensile testing for geosynthetics needs to be somewhat rationalized.

The measurement of yield and break strains for geomembranes is typically (ASTM D 638 as modified by NSF 54) done using two specimen gage lengths (33 mm for yield strain, and 64 mm for break strain), but only when grip displacement is used for a measure of the gage length. Remote measurement of strain is far preferable and is far more accurate. Giroud [1] states that grip separation may overestimate the yield strain by as much as 50%. The justification for two gage lengths, which makes calculations more time consuming and makes specifications less consistent and less understood by inexperienced designers, is questionable. Since the selection of a geometric gage length to measure break strain in a dogbone-shaped specimen is arbitrary at best, any one number is just as inappropriate as another. And since the knowledge of yield strain is of little practical use (I suspect not one lot of material has been rejected solely as a result of low or high values), any convenient number could be used. That number may just as well be the length of the narrow section of the specimen, 33 mm.

Stress Crack Testing

The distinction between plane stress and plane strain tests is of major significance in an assessment of the stress cracking resistance of polyolefins (PE and PP, primarily). A uniaxial tensile test is performed under plane stress conditions. In order to best assess the stress cracking resistance of a polyolefin, a notch must be placed in a face (not edge) of a uniaxial tensile specimen (ASTM Test Method for Evaluation of Stress Crack Resistance of Polyolefin Geomembranes Using Notched Constant Tensile Load Test D 5397). The notch performs two functions. It forces failure to occur at a specific location in the gage length of the specimen. But, most importantly, in a thin specimen, at the root of the notch, it generates the plane strain conditions that are needed for such a failure mechanism to occur, and reproduces the conditions that occur in the field. Under plane stress a tensile specimen will simply creep until ductile failure occurs. Under plane strain, the notch propagates in a quasi-brittle manner (with no macro-ductility) if the material is susceptible to stress cracking. However, when the stress in the remaining ligament increases above the ductile/brittle transition point (knee) in the stress rupture curve, the specimen does fail by yielding and ductile elongation. Normally, it is not necessary to measure the associated strain.

Only when it is required to evaluate the influence of surface features such as textures and welds should stress crack tests be performed without a notch.

Geomembrane Seam Testing

When shear tests are performed on strip specimens cut from across geomembrane seams, very weak bond strengths may not be detected due to the large seam shear area, and the low cross sectional area of the geomembrane that always cause break to occur in the geomembrane. Thus, failure of the geomembrane prevents a valid challenge to the bond strength of the seam [3]. The bond strength is more challenged (albeit marginally) by performing a peel test. However, a shear test will provide very useful durability information if the break strain of the geomembrane is measured adjacent to the seam, to ensure that any mechanical treatments of the surface, and the thermal energy imparted to the geomembrane during welding, have not adversely affected the ductility of the geomembrane [2]. If the ductility is reduced, the stress cracking resistance of the seam area may be reduced. Therefore, it is necessary to use grips that facilitate the measurement of a reference gage length – grips that grip the specimen across its full width (except for reinforced material tested by the "grab" method) and that have a defined edge. Cam-action clamps are not desirable, since an accurate gage length cannot be defined.

The seam specimen should be held such there is an equal distance between the edge of each clamp and the nearer edge of the seam (Figure 14). When the tensile force is applied, the majority of the strain will occur in the geomembrane, not in the seam. The latter is insignificant. The thinner, or more "damaged" geomembrane segment will yield or fail first, thus the grip displacement represents the condition of that segment of geomembrane. Provided the grip displacement exceeds a specific distance, expressed as a percentage (say 100% for HDPE) of the original "gage length" (usually 25 mm) between the edge (g) of the grip and nearer edge (s) of the seam (Figure 14), the seam can be considered acceptable. Such a procedure is appropriate for all geomembrane materials, provided appropriate elongation values are used, but it is considered absolutely essential for HDPE geomembrane, due to its notch sensitivity.

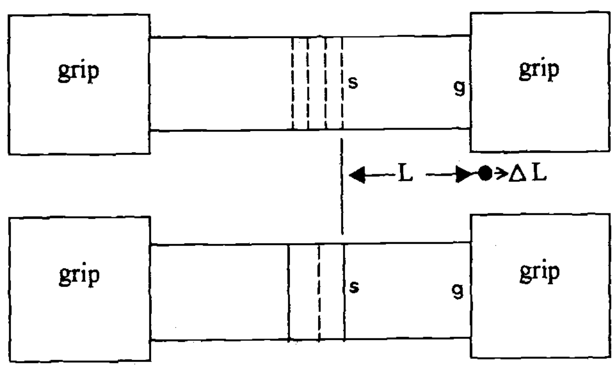


Figure 14 - *Measurement of Shear Strain for Geomembrane Seam Specimen*

Conclusions

The parameters defined and measured during the tension testing of geosynthetics have been identified and compared with those conventionally used in metals and bulk plastic materials (as opposed to fabricated product) testing. There are inconsistencies in the terminology, for example "offset" and "tangent modulus", that could be modified to avoid confusion.

The institution of a single gage length for the determination of yield and break strains in geomembrane uniaxial tension tests is recommended.

The need to measure adjacent geomembrane strain in a geomembrane seam shear test has been identified and a method for its determination has been presented.

Acknowledgement

Thanks to Larry Flynn at GeoSyntec Consultants for providing Figures 8a and 8b.

References

[1] Giroud, J.P., "Mathematical Model for Geomembrane Stress-Strain Curve with a Yield Peak", *Geotextiles and Geomembranes,* 1994, Vol. 13 No. 1, pp. 1-22.

[2] Peggs, I.D., "Evaluating Polyethylene Geomembrane Seams", Geosynthetics '87, IFAI, Roseville, MN, 1987, pp. 505-518.

[3] Peggs, I.D., "A Reassessment of HDPE Geomembrane Seam Specifications", Geosynthetics: Applications, Design and Construction, Balkema, Rotterdam, 1996, pp. 693-696.

George R. Koerner[1]

Wide-Width Geomembrane Testing

Reference: Koerner, G. R., **"Wide-Width Geomembrane Testing,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Geomembranes are the most widely used components of liner and cover systems throughout the world. Arguably they are the most critical components of such systems. Millions of square meters of geomembrane have been used as liquid barriers over the past 20 years. However, there is debate over how to properly determine the performance tensile characteristic of these materials. This paper attempts to shed some light on obtaining uniaxial performance responses of commercially available geomembranes via ASTM D 4885, Standard Test Method for Determining Performance Strength of Geomembranes by the Wide Strip Tensile Method.

Over the past ten years since the test method was issued, several inconsistencies have been identified with the method. Such inconsistencies make it difficult for laboratories to generate comparable results while utilizing the standard. Areas of concern are specimen preparation, clamping, strain rates and data reduction. It is hoped that the paper may help promote uniform and consistent wide-width geomembrane testing. This paper contends that wide-width geomembrane testing is a performance test and that it should only be used for the purpose of design and research.

Keywords: geomembrane, testing, wide width, performance and design

Introduction

There are several uniaxial index tension tests conducted on geomembranes to determine tensile behavior. These short-term tests utilize small geomembrane specimens and are used routinely for quality control of the manufacturing process. Such standard index test methods are as follows:

- ASTM D 638-96, Standard Test Method for Tensile Properties of Plastics,(8.01),
- ASTM D 751-95, Standard Test Method for Coated Fabrics, (9.02) and
- ASTM D 882-91, Standard Test Method for Tensile Properties of Thin Plastic Sheeting (Strip Tensile), (8.01).

---

[1] Assistant Director—Geosynthetic Institute, 475 Kedron Ave., Folsom, PA Research Associate Professor, Drexel University, Philadelphia, PA

The reason for the different test methods is probably based on performance variations resulting from different polymers and manufactured structures. Koerner [3] wrote an provocative paper in which he pointed out that results from these three index test vary widely, are not comparable and focus on the maximum stress obtained at very high strain rates. Since polymers are viscoelastic materials, stress is heavily dependent on strain rate as pointed out by White and Kolbasuk [6] and Lord, Soong and Koerner [4]. High strain rates are nonconservative and should be accounted for through reduction factors in the design process. This is assuming that one approves of using index properties for design at all. Another criticism with index tests are that they concentrate stress on the center of the specimen, resulting in a single rather than two-dimensional response which is unlike that observed in the field. These issues all suggest that wider-width specimens are desirable from a design perspective. Hence the rationale behind wide-width performance testing for geomembranes.

Background

In 1988, the American Society of Testing and Materials (ASTM), committee D-35 on Geosynthetics issued ASTM D 4885, Standard Test Method for Determining Performance Strength of Geomembranes by the Wide Strip Tensile Method. This standard was subsequently reapproved in 1995. The test was developed to assist in the determination of the performance strength of geomembrane by subjecting a 200 mm wide geomembrane specimen to tensile loading at a strain rate of 1 mm per minute.

ASTM D 4885 is a test that few people conduct due to its unmanageability. The end products of the tests are stress versus strain plots from which tensile stress, strain and modulus are obtained. The specimen shape is generally in the form of a rectangle, 200 mm wide and 240 mm long. A gage length of 100 +/- 3 mm is set at the beginning of the test and a strain rate of 1 mm per min. is employed during testing. Since the standard requires 6 specimens to be tested in each direction , a total of twelve tests are required for a report. Therefore a standard report on one geomembrane ties up a continuous rate of extension tensile testing device for one to two weeks. In addition, the testing area should be maintained at 21 +/- 2 °C and 60 +/- 10% relative humidity over this test period.

Specimens are generally cut from across the roll width of the sample and marked according to machine direction. Good success at blanking out specimens has been accomplished with the aid of a clicker press and die or a cutting table. Both techniques yield tolerance compliant specimens with perpendicular sides free of burrs or deep scratches. Burrs or large imperfections have been shown to decrease elongation results. However, such decreases are not nearly as significant as with index tests which use narrower specimens. Specimen preparation is more complicated with scrim reinforced materials. These material obtain their strength from the scrim. Therefore the yarn count in the test direction needs to be duplicated throughout the replicate sequence. In addition the yarn within the gage length should be taught. If the geomembrane plies or spread coating were applied to a loose scrim, the elongation result will vary through the replicate sequence.

The thickness of each specimen is measured via ASTM D 5199 Standard Test Method for Measuring Nominal Thickness of Geotextiles and Geomembranes prior to testing. Thickness values are used to convert strength values to stress values. The thickness is also instrumental in calculating modulus. Two percent secant modulus is used frequently because it is straightforward and considers an axis origin correction. Such a correction should be considered because specimens are not preloaded in wide width geomembrane testing. Hence if specimens are not perfectly placed in the grips, a small initial offset could be experienced and needs attention during data reduction.

Specimens are gripped in the CRE tensile testing device with a variety of grips that will be discussed in the next section of this paper. Grip slippage is checked by drawing a line with a china marker at both the upper and lower grip-to-geomembrane interfaces. The line will move away from the grip faces depending on the elongation characteristics of the geomembrane as the test proceeds. However, it should do so uniformly. Specimens that break at or along the jaws are discarded. The remnant china marker line shall aid in so-called jaw break determinations by delineating were failure originated.

Merry and Bray [5] discuss a Poisson effect near the edge of the specimen that is often realized during testing. This is indicative of the specimen necking inward and the china marked line tailing off at the edges of the specimen-clamp interface. Gourc et. al. [2] have conducted research in regards to changing the shape of the specimen to overcome the lateral contracting strain to elongation strain due to in-line end stretching forces when the sides are free of contact. Specimen shape has been altered from a wide strip to crosses or oversized specimen widths. Results from this work resulted in unpredictable results which often failed in the grips. Hence, rectangle specimens are still recommended for rudimentary testing.

Specimens are loaded to failure at a rate of 1 mm per minute. This represents a one percent strain rate which is ten times slower than the default rate of ASTM D4595 Standard Test Method for Determining Performance Tensile Strength of Geotextiles using Wide Strip Testing. Due to the large elongation of some geomembrane specimens, a single test can take several hours to conduct. In addition, some specimens (e.g. LLDPE and VFPE) can not be brought to failure within the travel distance of conventional continuous rate of extension machines. Most of these apparatuses are limited to a maximum travel of half a meter which represents a strain of about 500%.

Maximum tensile strength for each specimen is calculated as follows:

$$af = Ff / ws$$

where: af = tensile strength, (kN/m),
Ff = breaking force, (kN), and
ws = specimen width, (m).

The corresponding percent elongation is calculated as follows:

$$ep = (\Delta L / Lg) * 100\%$$

where: ep = elongation, (%),
ΔL = extension, (mm), and
Lg = initial gage length, (mm).

2% secant modulus is calculated as follows:

$$Jsec = F / (ws * 0.02 * t)$$

where: Jsec = 2% secant modulus, (kPa),
F = load at 2 mm deflection, (N)
ws = specimen width, (m), and
t = thickness, (m).

The above nomenclature is directly from the standard. It is unorthodox and deserves consideration for editorial revision in the next draft of the standard.

Figures 1-3 show different wide-width geomembrane responses as per ASTM D 4885. Figure 1 shows the effect of changing the strain rate on a 1.5 mm HDPE specimen. As the strain rate increases the yield stress increases and the break strain decreases. Figure 2 shows the response of flexible geomembranes. Depending on the resin density

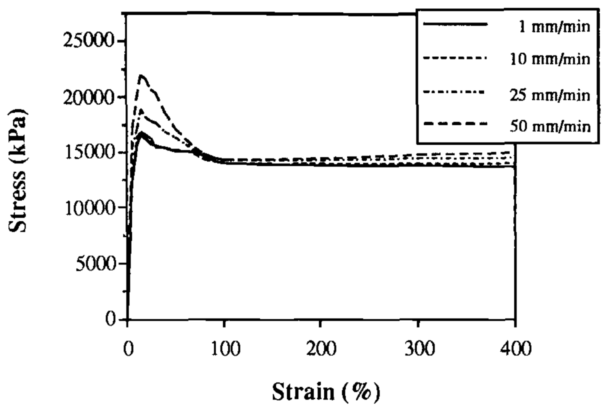


Figure 1. *Wide-width Stress Strain Response of 1.5 mm HDPE at Different Strain Rates*

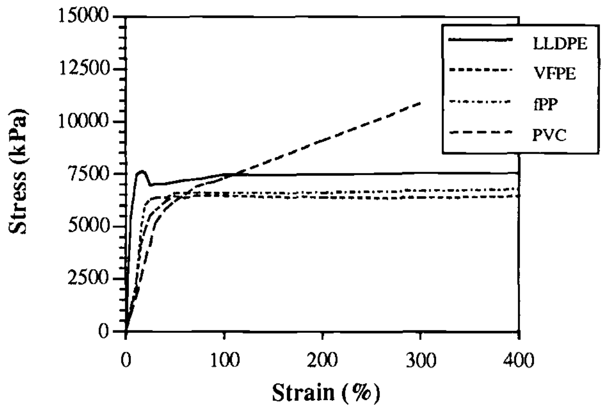


Figure 2. *Wide-width Stress Strain Response of Very Flexible Geomembranes*

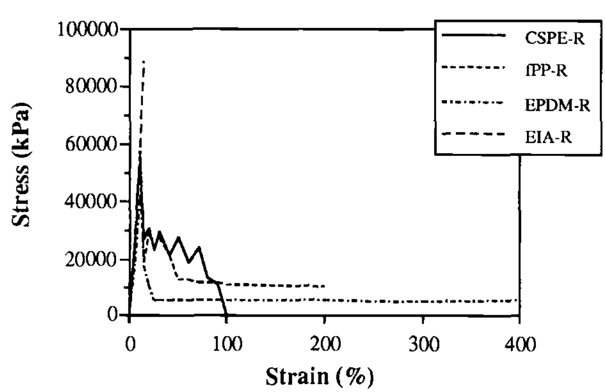


Figure 3. *Wide-width Stress Strain Response of Scrim Reinforced Geomembranes*

of polyethylene, yield may be observed. VFPE with a density below 0.931 g/cc did not show a yield whereas LDPE with a density of 0.937 g/cc exhibited a pronounced yield at 15% strain. The higher density also contributed to a higher stress response. Figure 3 shows the response of different scrim reinforced geomembranes. The response is heavily dependent on the type of scrim utilized. The manufactures can vary the strength of these geomembranes depending on scrim type and pick count. It should be noted that in some cases the geomembrane plies remain intact after the scrim breaks.

Gripping

Specimens are gripped in the CRE tensile testing device with mechanical or hydraulic grips. Grips for holding the test specimen between the fixed frame and moveable crosshead should be self aligning by way of a universal connection joint. As such, the specimen will freely move into alignment as soon as any load is applied so that the long axis of the test specimen will coincide with the direction of the applied force through the center line of the grip assembly. A test specimen should be held in such a manner that slippage is minimized. This property should be balanced with the fact the grip faces should not initiate geomembrane failure at either grip interface.

Gripping geomembranes correctly is a great challenge due to a large range of strengths and elongation characteristics. Flexible geomembranes like LLDPE and PVC have strengths under 12,500 kPa and strains greater than 400%. On the opposite end of the spectrum, scrim (nylon, polyester, Kevlar®, etc.) reinforced geomembranes which have strengths over 70,000 kPa and strains less than 15%. Obviously the same grips are not used over such a wide range of material properties. Furthermore different CRE and load cell combinations may be warranted. CRE and load cells should be selected so as to function within 10 to 90% of their calibrated range.

In the early nineteen eighty, rather crude modified metallurgical grips were used for wide-width geomembrane tensile testing. An example of such grips can be seen in Figure 4. They consisted of fastening wood, Plexiglas or metal blocks, (outriggers) to geomembranes by adhesive and mechanical means. The outriggers are centrally mounted into a set of metallurgical grips which in turn are placed in a CRE apparatus. When slippage invariably occurred in the outriggers, auxiliary C clamps would be fastened to them on an as needed basis. This primitive clamping procedure was abandoned due to stress concentrations, slippage and grip influences that made repeatability difficult and the fact that it was very labor intensive. This practice is currently unacceptable.

In 1982, B. Christopher was task force leader of D-35 committee set out to develop a standard for wide width tensile testing of geosynthetics. The grips featured in Figure 1 of ASTM D 4595 and the appendix of ASTM D4885 are mechanical wedge grips. Various geometric movable asymmetric wedge inserts are push up against a tooled steel housing which is sloped at an angle of 14 degrees. Such grips are shown in Figure 5. The wedge inserts are adjusted by four evenly spaced bolts which are threaded through the housing. The asymmetric nature of these grips has proved to be a limitation. The wedge invariably caused a stress concentration at the edge of the housing where the geomembrane exited the grip. To relieve this stress concentration, rubber inserts are adhered to the housing and the wedge. This helps but does not eliminate the problem. Unloading the grip is difficult. The top grip at times needs to be disassembled from the loadcell and the wedge stuck with a mallet to release it from the housing. Over the course of performing the test the wedge sets itself very tightly in the housing.

Sanders grips, pictured in Figure 6, have the advantage of being symmetric and having interlocking male-female serrations which help distribute the load through the grip face. They are an improvement over the asymmetric wedge grips and are still used in geomembrane wide width testing. The degree of serration can be varied from 1 to 5 mm. A variation of the Sanders grips is the split barrel grips described in GRI-GG6 [1], Grip Types for Use in Wide Width Testing of Geotextiles and Geogrids.

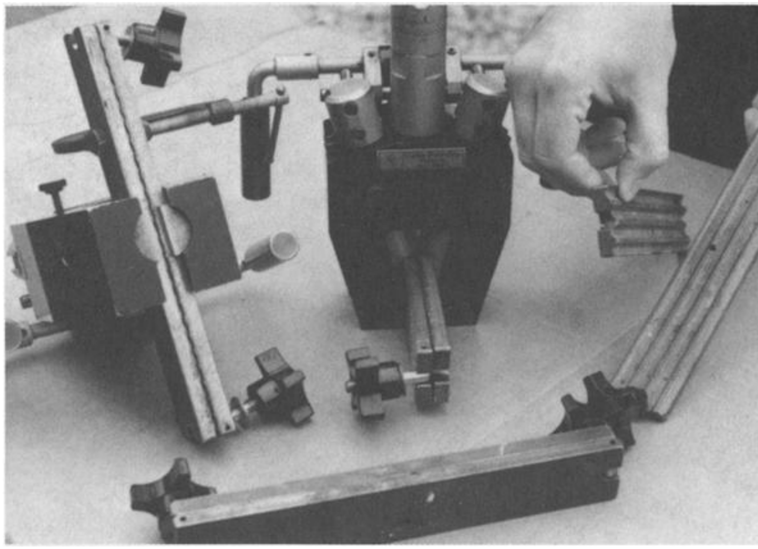


Figure 4. *Photograph Metallurgical Grips Modified with Outriggers*

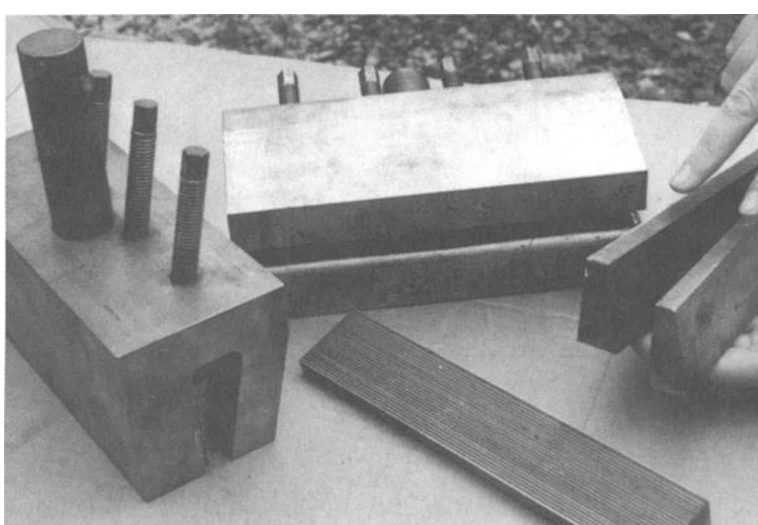


Figure 5. *Photograph of Asymmetric Wide-width Clamps with Wedge Inserts*

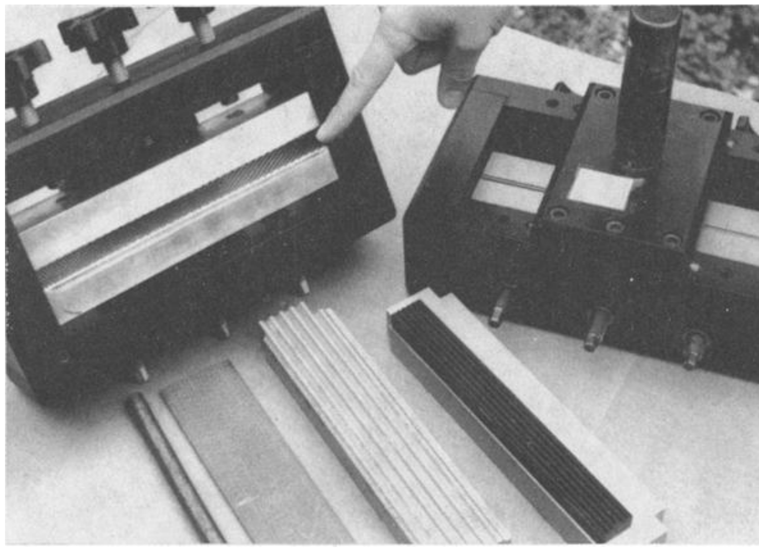


Figure 6. *Photograph of Curtis Box Grips with Several Different Grip Faces*

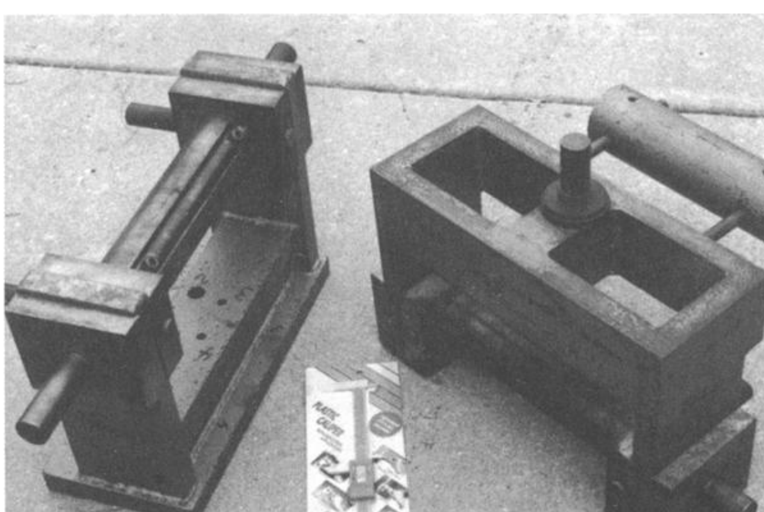


Figure 7. *Photograph of a Pair of Capstan Roller Grips with and Plastic Caliper for Measuring Strain at Discrete Intervals*

Epoxy or soft wedge grips are rarely used when testing geomembranes. Epoxy, resin and quick drying low melting temperature metal alloys all have a difficult time bonding to geomembranes particularly polyethylene. Furthermore, lengthy specimen preparation procedures required for this gripping method renders it time consuming and inappropriate for most wide width geomembrane testing.

Grip surfaces that are deeply scored or serrated with a pattern similar to those of a coarse file have been found satisfactory for most thermoplastics. Finer serrations have been found to be more satisfactory for harder plastics, such as thermoset materials. The serrations should be clean and sharp. However, grip breakage is unacceptable. Serrations should not abrade the geomembrane to the point that it breaks prematurely. Other techniques that have been found useful are flat surface grips which are forced together with several (3 to 5) hydraulic or pneumatic cylinders. Such cylinders react off a rigid grip face which distributes an even pressure to the specimen. Cylinder pressures range from 2 to 6 MPa. Note that when dealing with high pressures of this nature, special health and safety precautions are required.

Other techniques that have been found useful are gluing thin pieces of emory cloth or rubber to the grip face. Such techniques need to be investigated thoroughly on an individual basis prior to use. Elongation responses can be influenced by shear stresses induced in various durometer rubbers. In addition, the adhesive bond which binds the emory cloth or rubber to the grip face must be stronger than the material being tested. In the case where the bond is inadequate, the glue will shear and render the test invalid.

Inquiry into over 50 geosynthetic laboratories in the United States indicates that Curtis® geo-grips are used in the majority of these laboratories for a large variety of wide width geosynthetic testing. A photograph of Curtis® geo-grips or box grips is shown in Figure 6. These versatile grips consist of an oversized aluminum alloy housing with three hydraulic cylinders. Controls activate the cylinders and slide grip inserts within the housing. Each grip is shaped like a box. The grips have a capacity of 45 kN. They can accommodate specimens up to 200 mm wide and 25 mm thick. The hallmark of the grips is ease of specimen loading. An optional foot activated hydraulic controller further facilitates specimen replacement. Grip inserts of many sizes and shapes are available. Exchanging grip face inserts requires some mechanical ability but is manageable by most lab technicians. Like all of the grips previously described, cross head movement recorded from the CRE is used to calculate strain when using these grips.

Capstan roller grips as describe in GRI-GG6, Grip types for use in Wide Width Testing of Geotextiles and Geogrids [1], are rarely used for testing conventional geomembranes. The loads required to test these material do not warrant such elaborate grips. However, on rare occasion when very strong scrim reinforced geomembranes (geomembranes used as primary liners for double hulled super tankers, geomembrane for inflatable dams, etc.) are tested, roller grips may be needed. A photograph of a set of Capstan roller grips is shown in Figure 7. To encourage slippage about the roller grips they are either chromed or polished. In addition, rub sheets of HDPE are used between geomembrane wraps to facilitate slippage as the specimen tightens upon itself in the grips. The use of smooth rollers and rub sheets results in smooth rather than jagged stress strain curves. Such curves are reproducible and easily interpreted.

It is generally recognized that most laboratories physically massage specimens during the preloading process when using roller grips. This process minimizes the necessity for origin correction during the data reduction process and aligns the specimen so that it accepts load uniformly. The practice also effectively removes 1-5% of the early strain.

Whenever roller grips are utilized, an direct deformation measuring device is required to measure the elongation of the geomembrane with respect to its original gage length. Deformation can be measured with contact transducers or dial indicators. More sophisticated non contact infrared monitors or video targeting devices have also been used with success. Most extensometers give a display output and feed information into a IEEE interface which is hooked up to a computer or X-Y plotter. Such devices range in cost from $ 1,500 to $ 40,000.

Experience with a lightweight Mitutoyo calipers obtained from Thomas Scientific (800) 345-2100 cat # 6411H15 has shown that cost is not always directly related to performance. These plastic calipers work very well for the vast majority of our needs. The plastic caliper is mounted on the geomembrane with a dab of hot melt glue. Small amounts of the glue with a low melting temperature appear to be nonintrusive, strong, and quick setting. The caliper's resolution is 0.1 mm and range from 0 to 150 mm. These plastic calipers are safer to use than metal LVDTs. On several occasions technicians have had to avoid projectile LVDTs that have become airborne when unexpected rupture of the geotextile was encountered. Once an LVDT or caliper is thrown across the room it rarely can be brought back into calibration. It is much easier to discard a $35 caliper versus a $1,500 LVDT.

Summary

Wide-width tension testing of geomembranes is tedious and time-consuming. However, results from this testing are important for proper design of landfill liners, covers and surface impoundments. The type of testing described in this paper can be characterized as performance in nature. It is definitely not for quality control or quality assurance.

The practice of width tension testing of geomembranes has evolved steadily since the early 1980. The vast majority of laboratories in our industry are utilizing symmetric wedge grips which are equipped with various grip face surfaces. When using such grips, strain is monitored via crosshead movement. It is assumed that slippage within the gauge length is minimal.

The most significant factor affecting geomembrane performance while testing in this mode is strain rate. This variable is fixed in the present standard at 1 mm per minute. The author is of the opinion that since this is a performance test, a designer should have the alternative of selecting a site-specific strain rate. Default strain rates from 1% to 10% are suggested.

Acknowledgment

The author wishes to thank the Geosynthetic Institute and its member organization for the support of the work contained in this paper. The author would also like to thank Fred Struve and Robert Koerner for their insight, guidance and review associated with this paper.

References

[1] GRI GG6, "Grip Types for Use in Wide-width Testing of Geosynthetics" GRI Test Methods And Standards, Folsom, PA, 1996, pp. 124-128.

[2] Gourc, J.P., Leclercq, B., Benneton, J. P., Duron, M., Puig, J. and Delorme, F., "Tensile Strength Behavior of Geomembranes: Contribution to Define a Unique Standardized Test", Proceedings 3rd IGS Conference, Vienna, Austria, 1988, pp. 1299-1304.

[3] Koerner, R. M. "Selected Notes on Geomembranes," Innovations in Geotechnical Engineering Proceedings, April 18-19, Harrisburg, PA, ASCE and PENNDOT, 1985, pp. 100-117.

[4] Lord, A. E. Jr., Soong, T. Y., and Koerner, R. M., "Relaxation Behavior of Thermally-Induced Stress in HDPE Geomembranes," Geosynthetics International, Vol. 2, No. 3, IFAI, St. Paul MN, 1995, pp. 626-634.

[5] Merry, S. M.. and Bray, J. D., "Geomembrane Response in the Wide Strip Tension Test," Geosynthetics International, Vol., No. 4, IFAI, St. Paul, MN, 1996, pp. 517-536.

[6] White, D. and Kolbasuk, G., "Specifying and Testing Tensile Properties of Semi-Crystalline Geomembranes," GFR, Vol. 8, No. 1, IFAI St. Paul, MN, 1990, pp. 18-21.

Jochen Müller-Rochholz[1] and Christian Recker[2]

Tensile Strength and Clamping of Geogrids

Reference: Müller-Rochholz, J. and Recker, C., **"Tensile Strength and Clamping of Geogrids,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract:
Through the development and application of high strength geosyntetics, the problem of clamping during the tensile test has become an important theme. The construction of clamping systems is decisive for obtaining a value as close as possible to true tensile strength. For this purpose the theoretical demands on an ideal clamping system are depicted and the development stages of the clamps are shown. The results of tensile tests with different clamping systems are given in Table 1. Infrared images are given to show stress/strain inhomogenity.

Keywords: Geogrids, Tensile strength, Testing, Creep

Introduction

Tensile tests on materials determine the maximum stress transferred through a specimen from one grip to the other. Failure in, or caused by, grips lead to invalid results. The highest value measured with accurate devices is the closest to the true strength.

Geosynthetic structures, high strength grids

For reinforcement of soil geosynthetic structures of the following types are used

---

[1]Professor, Dr.-Ing., University of Applied Sciences Münster and Institut für textile Bau- und Umwelttechnik GmbH, Gutenbergstr. 29, D-48268 Greven, Germany.
[2]Dipl.-Ing., Institut für textile Bau- und Umwelttechnik GmbH, Gutenbergstr. 29, D-48268 Greven, Germany, http://www.tbu-gmbh.de

Table 1

	Polymer	max F in kN/m	Figure
plane woven / knitted	PES	120...1 200	1
woven/knitted grids with coating	PES/Aramide	35. ..1 200	2
extruded and stretched grids	HDPE	30 200	3
linear elements with secondary cross links	PES+HDPE	100.....800	4

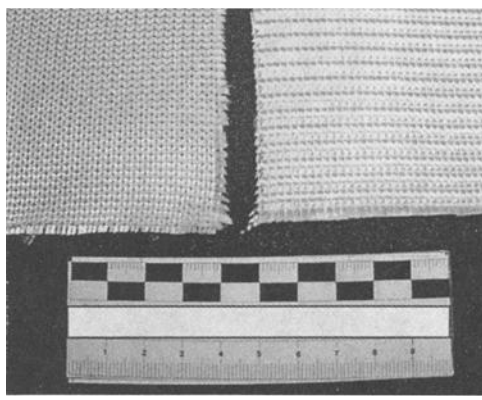


Figure 1 – *plane woven product*

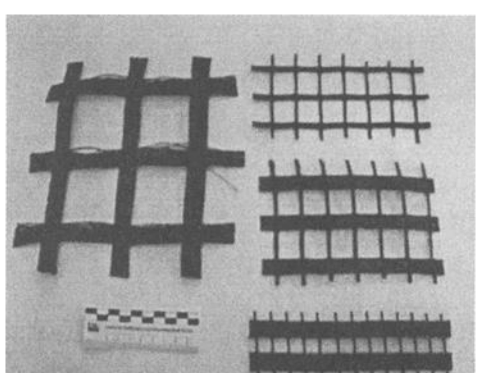


Figure 2 – *knitted geogrid (PET, Aramide)*

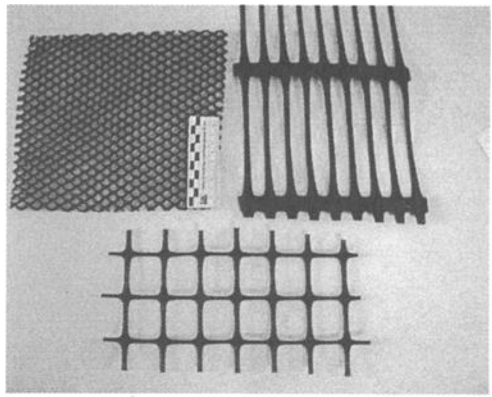


Figure 3 – *extruded / stretched Polyolefinegrids*

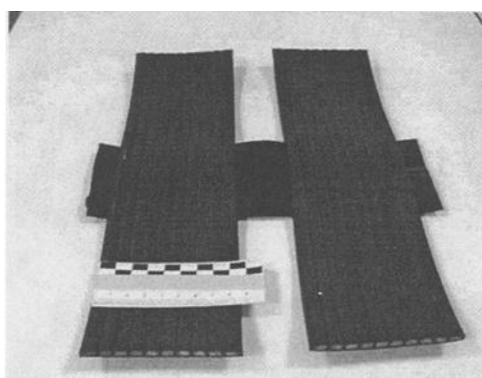


Figure 4 – *linear elements*

Testing problems increase with increasing strength, decreasing deformation at rupture and sensitivity to lateral stresses. Accordingly the most difficult structures for testing are high strength grids, and fabrics made of high modulus and high tenacity fibres such as polyester (PES) or Aramides.

Optimal clamping - generic -

A textile geogrid consist of fibres forming a yarn, yarns forming bundles and bundles forming strands. They reach the maximum strength, when, theoretically, each strand, bundle, yarn, and fibre is stressed uniformly and comes to failure in the same moment. In all real world tests this can not be achieved. There may be internal stresses in a bundle, there may be a different stress in one strand caused by slight slippage in the clamps or a stress/strain offset caused by clamping.

The infrared images (see figures 5 and 6) show local heat generation in the places of higher deformation during the test (or higher friction).

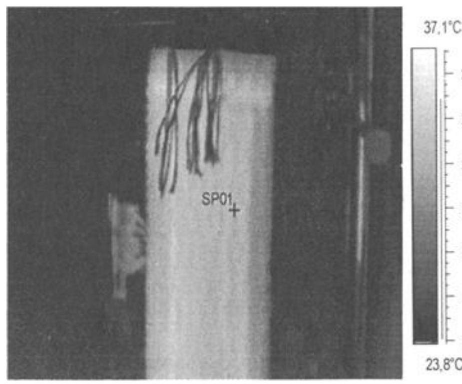


Figure 5 – *Infrared image of Tensile Test at c. 60 % of ultimate load.*

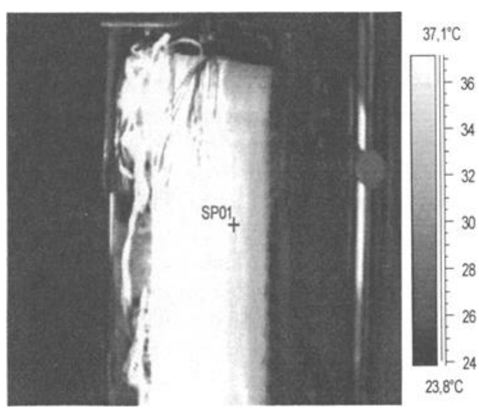


Figure 6–*IR-image at rupture (hotspots are light)*

For many materials it is normal to employ a "dog bone" shaped specimen, figure 7, to insure a break between the clamps and eliminate or reduce any effect by the clamp system. For geotextiles you cannot cut bone-shaped specimens (see figure 3,4,5 and 6). And, as illustrated by the same figures sample size is long and wide as dictated by the clamping technique and the test methods ISO 10319 and ASTM D4595.

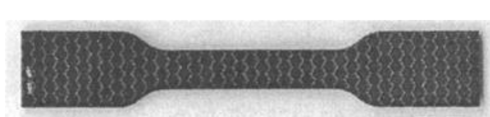


Figure 7 – *bone shaped specimen for steel, polymer sheets etc.*

Some extruded grids may be clamped by form grips, if the cross-elements are thicker than the strings/strands (see figure 8).

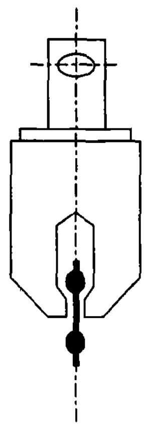


Figure 8 – *form grips for extruded grids*

On the other hand, textile grids must be clamped in the shape produced and in the standard-test width of 200 mm, so when attempting to use conventional or form grips to clamp a textile grid the stresses in the clamps in the tensile direction are superimposed on the lateral stresses from the clamping. This biaxial stress status leads to rupture at lower tensile stresses than for uniaxial stress state.

During the tensile test a deformation jump occurs at the entrance to the clamp, where the deformation of the specimen in front of the clamp (at forces close to maximum) is close to the ultimate strain, while the deformation of the specimen inside the clamp is close to zero. This also leads to notching effects and to lower sustainable stresses.

The ideal clamping would occur, when a deformable grip would allow a longitudinal strain decrease from the entrance to grip end analogue to the stress strain behavior of the material (see figure 9) and when we have a uniform lateral stress on all elements of the specimen (see figure 10) and a uniform prestressing of all elements in test direction (see figure 11)

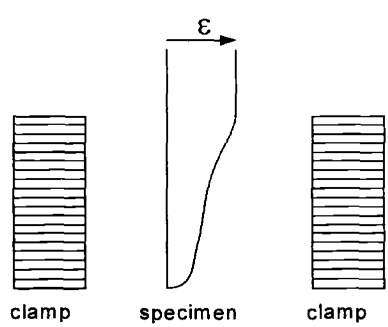


Figure 9 – *ideal strain distribution vs specimen length of clamped material close to rupture (brush-type)*

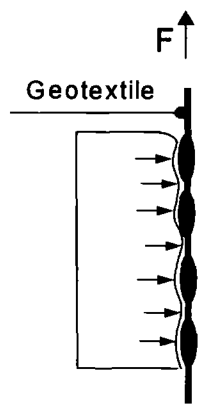


Figure 10 – *uniform lateral stress*

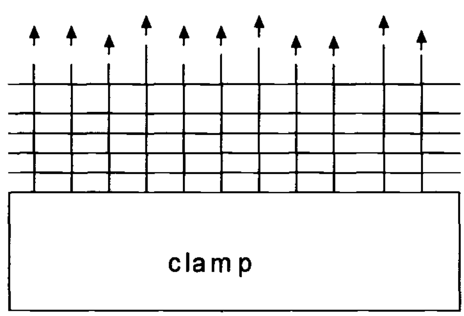


Figure 11 – *uniform longitudinal stress/strain*

Testing Experience

Short time tests

For short time tests, hydraulic grips with two actuators worked well with PET-wovens and PET-grids up to 30 kN in the wide width test (≈150 kN/m) without any cushioning of the clamp face such as interlayers on plain steel or single elastomeric surface (2mm Vulcolan) (see figure 12). The hydraulic clamping pressure had to be adjusted to the material after screening tests. For single or multiple strands of higher strength and lower ultimate deformation capstan clamps were introduced (see figure 13, 14).

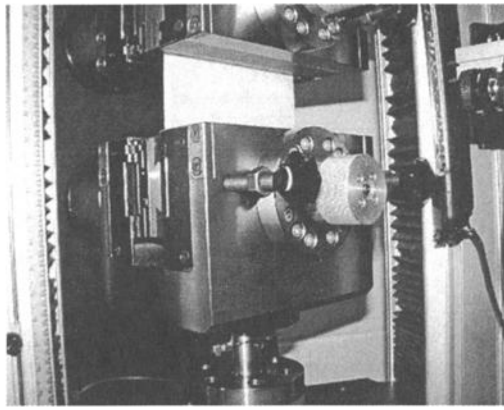


Figure 12 – *hydraulic grids /two actuators*

Figure 13 – *capstan clamps of different roller diameters*

Longterm tests

Plain steel hydraulic grips lead to failure in creep rupture tests at stress levels down to 80 %. The capstan grips were optimized by grinding and polishing the entrance of the clamp, sometimes lubricating the entrance to allow deformation with reduced friction. By increasing the diameter of the capstan clamps the stress level could be increased to c. 90 % of short time strength.

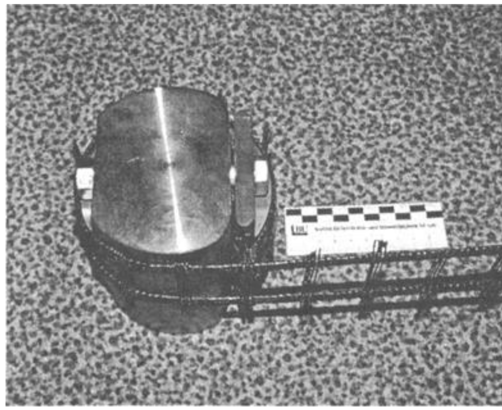


Figure 14 – *optimized capstan clamp*

Comparison of results with existing equipment

Different clamping methods lead to different results for the identical product.

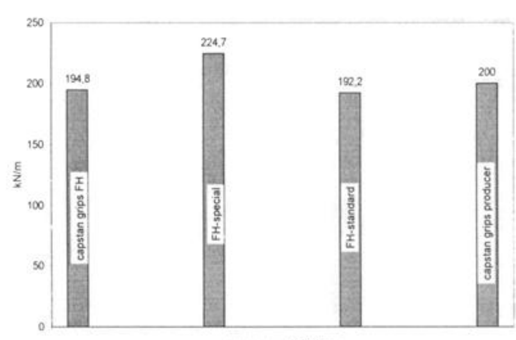


Figure 15 – *Comparison of test results for identical products /1/ PET-grid with nominal Force Fm of 200 kN/m*

Capstan grips FH	roller grips as suggested by test methods ISO 10319 and ASTM D4595
FH Special	customized, capstan grips for minimum friction
FH Standard	typical form of flat face clamps
Capstan producer	similar roller grips meeting test method criteria

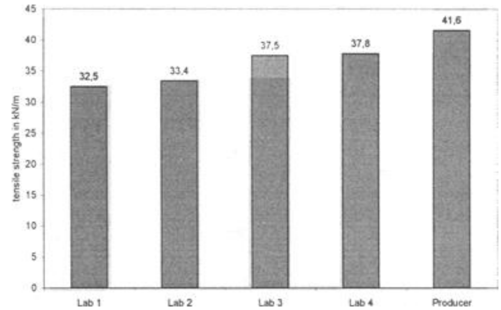


Figure 16 – *Comparison of test results for identical product and different laboratories Polyestergrid with nominal Force Fm of 40 kN/m*

Conclusions

An approach to ideal clamping according to section 3 is the increase of clamping pressure at hydraulic grips during the test. Beginning with a fixation, the final pressure is applied after loading the specimen to some 10...20%. Thus a certain deformation in the clamps is possible allowing a load transfer on a longer length than for a clamp pressed before the test on the final grip pressure.

For each product the final pressure must be determined by preliminary tests.

Plain steel surfaces in hydraulic grips work better with coated grids than serrated or roughened grips. For capstan clamps the bigger the diameter, the better the load transfer.

Allowing a certain low friction movement at the grip's entrance gives a higher transfer length and higher transferred forces.

Summary and vision

Plane fabrics can be clamped satisfyingly by plane hydraulic clamps, sometime interlayers of rubber or PELD may help.

Woven grids give valid results without problems in capstan clamps of sufficient diameter (≥ 100 mm).

Extruded and stretched grids may be clamped by form clamps.

Existing clamping systems can be optimized by tooling and handling modifications, i.e. allowing some longitudinal deformation along the grip length.

Ideal clamping, i.e., testing the true strength of the geosynthetic product, needs some innovative development, which could be test force-controlled grip pressure, "brush" surfaces for the grip surfaces or interlayers with defined deformability.

Reference

[1] Müller-Rochholz, J.: Anwendungen aktueller CEN-Normenentwürfe bei der Untersuchung von hochzugfesten Geweben, Vortrag bei der FS KGEO, München, 3/97

Ajit D. Kelkar,[1] Peter E. Stevenson,[2] Todd R. Skochdopole,[3] and Sergey N. Yarmolenko[4]

Effect of Gage Length and Test Speed on the Measured Tensile Properties of Geosynthetic Reinforcements

Reference: Kelkar, A. D., Stevenson, P. E., Skochdopole, T. R., and Yarmolenko, S. N., **"Effect of Gage Length and Test Speed on the Measured Tensile Properties of Geosynthetic Reinforcements,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: This research will specifically address the tensile testing of textile products employing high tenacity industrial quality multifilament twill textile yarns. The research reported in this paper is directed toward developing a repeatable and reproducible test method for textile reinforcements. The paper will present a new testing technique, which uses pressure clamping system as opposed to conventional roller grip systems. The pressure clamping system incorporates a technique used in other disciplines for very strong materials. This technique is the application of sacrificial tabs to the clamping area of the specimen, thus permitting very high jaw pressures without specimen damage. The specific concerns about testing of reinforcing products expressed in the literature are: (1) the effect of sample gage (length) on reported values including tensile strength, extension and modulus, (2) the effect of test speed, i.e. strain rate on reported values: one specific issue is the difference between ASTM at 10% and ISO at 20% per minute, (3) the effect of jaw or grip types on reported values, (4) the control of sample slippage in grips, (5) the amount of tolerable slippage in clamping devices, (6) the accuracy of various extension measurement systems, (7) the effect of the extension measurement system on the reported values, (8) the effect of sample width on reported values, (9) the definition, measurement and reporting of modulus, (10) which modulus is important and (11) what portion of the sample does a reported modulus represent. The paper will focus on four of the concerns. The issues addressed are sample length and sample gage (area of extension measurement), method of extension measurement, test speed and modulus measurements.

Keywords: mechanical properties, tensile strength, modulus, testing, woven fabrics, specifications

[1] Professor, North Carolina A&T State University, Greensboro, NC 27411
[2] 226 Sitton Road, Easley, SC 29642
[3] Manager, Research and Development, The Tensar Corporation, 6100 Lake Forest Drive, Atlanta, Georgia 30328
[4] Research Scientist, North Carolina A&T State University, Greensboro, NC 27411

Introduction

Much research has been conducted on the type of wide-width testing represented by "Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method" (ASTM D 4595) in hopes of establishing a relationship between laboratory testing and the plane strain conditions a geosynthetic experiences in use. Fifty-three references in the literature explore wide width testing. Less than 10 address reinforcements and 5 of the 10 report serious concerns about current methodology and the results of its application to high strength materials [*1-6*]. In the period from 1977 through the present, 11 issues of concern have been identified with the testing of reinforcements with many of these concerns yet unresolved. The research reported here focuses specifically on the testing of textile products employing twill weave high tenacity industrial quality multifilament textile yarns.

The specific concerns about testing of reinforcing products expressed in the literature are: (1) the effect of sample gage (length) on reported values including tensile strength, extension and modulus, (2) the effect of test speed, i.e. strain rate on reported values: one specific issue is the difference between ASTM at 10% and ISO at 20% per minute, (3) the effect of jaw or grip types on reported values, (4) the control of sample slippage in grips, (5) the amount of tolerable slippage in clamping devices, (6) the accuracy of various extension measurement systems, (7) the effect of the extension measurement system on the reported values, (8) the effect of sample width on reported values, (9) the definition, measurement and reporting of modulus, (10) which modulus is important and (11) what portion of the sample does a reported modulus represent.

The research reported in this paper is directed toward developing a repeatable and reproducible test method for textile reinforcements. This paper focuses on 4 of the major concerns. The issues addressed are sample length, the effect of test speed, method of extension measurement, and modulus. Reference is made but specific research is not reported for jaw types, slippage, sample width, and yarn to fabric relationship. The investigation was carried out using a pressure clamping systems. The pressure clamping system incorporates a technique used in other disciplines for very strong materials. This technique is the application of sacrificial tabs to the clamping area of the specimen, thus permitting very high jaw pressures without specimen damage and possible slippage.

Material System and Test Parameters

For this study all the specimens were fabricated from high tenacity polyester fiber with twill weave architecture. For all the specimens the width was kept constant at 0.0508 m. To study the effects of gage length, five different gage lengths: 0.102 m, 0.203 m, 0.305 m, 0.406 m, and 0.508 m were included in the test matrix. To study the effects of strain rate, four different strain rates: 2%, 5%, 10%, and 20% were included in the test matrix.

Jaws, Grips, and Other Devices

Great difficulty is experienced in gripping samples of strong reinforcement geosynthetics. Experienced researchers [*1-5*] cite grip failure as a key concern. The principal test methods, ASTM, ISO, and BSI, recognize the issue of the difficulty of sample gripping and permit the utilization of roller or capstan grips. Roller grips typically require sample lengths of 1.829 m, width up to 0.203 m and typical spacing between rollers of 0.508 m. Because the sample geometry used in rollers is larger than most extension measurement tools, it seems obvious that displacement could be a critical measure of sample strains. Unfortunately, the large amount of slippage that occurs in roller grips throughout the test negates the application of these techniques for low strain values in roller testing, although displacement can be quite accurate in recording ultimate strain. Equally problematic is the application of other devices. Typical optical devices observe a pencil line wide strip 0.203 m high, and mechanical/electronic devices also observe a very narrow, 0.101 m long section of a specimen with the result that when applied to roller tested specimens, these extension measurement systems represent the area observed and not the specimen's performance.

Roller grips have several other awkward characteristics beside large sample geometry including the need to permit a sample to seat itself. The process of seating, also described as the application of preload, involves a certain extension of the sample. Another issue of difficulty caused by large sample geometry of 1.829 m length, 0.508 m grip separation and sample widths up to 0.203 m is incompatibility with the general definition of wide width sample geometry: 100 mm gage length by 200 mm width. In terms of strain measurement, this definition results in the apparent observation of, and reporting on a 0.101 m section of a 0.508 m or longer sample. It has been reported [*4,5*] that different areas of a fabric were seen to extend at different rates and that any 100 mm by 200 mm section of a large sample would not be representative of the sample, or the product. The phenomenon that extension is not uniform over a large sample is also documented elsewhere in textile literature [*7*].

Sample widths vary according to the test device load capability, but in every case an equal number of yarn ends should be tested in each specimen of a sample or a testing program. In our work extension was obtained by measuring the crosshead displacement. The jaw used in the sacrificial tab system employed in our work is a hydraulic clamp with a wide pressure range. For current strong twill fabrics, grip pressures exceeded 20.7 MPa, insuring control of slippage in the grips. The typical specimen lengths were long enough to include mounting of 0.0508-m sacrificial tabs on each end of the specimen.

Some practitioners have expressed concern about the accuracy of displacement measurement. The conventional testing machine does experience deformation in the conduct of a tensile test. Error introduced by this deformation is corrected by subtracting machine displacement from the data. To demonstrate accuracy we tested a calibrated aluminum bar. The specified modulus of the specimen was 68.95 GPa. Strain gages recorded a modulus of 68.1 GPa. Crosshead displacement recorded a modulus of 54.0 GPa. Displacement values corrected for machine deformation were 68.4 GPa, essentially zero error. Tests conducted on fabrics with loads at 30 kN and extension of 12 to 16% experienced machine deformation of less than 0.1%. Failure to correct for this deformation results in test error of less than 0.5% leading to the conclusion that crosshead displacement provided an accurate measurement for our tests.

Sample Preparation

Sacrificial tabs of light metal are adhesive bonded on both sides of specimens destined for pressure clamps. Adhesives are selected to have minimal influence on samples. Care is taken in mounting samples in grips to avoid skew. For many light load fabrics, under 130 kN/m, protective tabs are unnecessary [*8*].

The sample preparation technique attempts to achieve yarn (and filament) alignment. The sacrificial tab permits very high pressures across the clamped face of the specimen, which prevents the specimen from slipping out of the clamp. Simultaneously, the soft adhesive that binds the tab to the sample permits some relative slippage within the specimen permitting the maximum degree of uniform alignment and engagement of a high proportion of the filaments in the specimen. Slippage is observed in the two procedures at different times. Slippage is first observed on rollers in the early stages of the test, continues through much of the procedure, and reduces to nil when approaching ultimate. Slippage is observed in pressure clamps at the end of the test. This small distortion develops late in the test and allows the continued loading of the filaments in the specimen.

Test Method

The literature review clearly indicates that there is always confusion in obtaining the test initiation point (Figure 1). In order to avoid this confusion a new technique was established. In this new technique, the test sample was initially attached in the jaws in a manner such that there existed a slack in the sample. As the test initiated, a data acquisition system was activated. The data acquisition system recorded displacements but not loads up to a point when all the slack in the sample disappeared and then at that point

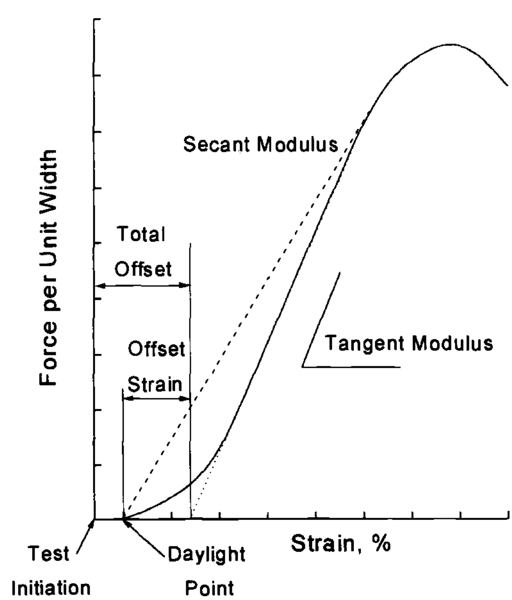


Figure 1 – *Stress-Strain Curve with Complete Test Results*

the data acquisition system recorded both load and displacement values. This collection of raw initial slack data is very important, as it can be used later on to determine the accurate test initiation point. The details of this procedure are explained in the following sections.

Test Data

Figure 2a shows the load vs. strain data for five samples. These samples had five different gage lengths: 0.102 m, 0.203 m, 0.305 m, 0.406 m, and 0.508 m. For all five gage lengths the test speed was kept constant at 0.02 L/min, where L denotes the gage length of the specimen. As mentioned earlier, all of the specimens were 0.0508 m wide. The test speed of 0.02L/min essentially produced 2% elongation per minute. The same procedure was repeated for three different test speeds – 0.05 L/min or 5% elongation per minute, 0.1 L/min, or 10% elongation per minute (ASTM specification), and 0.2 L/min or 20 % elongation per minute (ISO specification). Figures 2b, 2c, 2d respectively. As can be clearly seen from the graphs the beginning of the curves are flat, which represents the collection of data during the initial test period when the test sample had slack in it. Obviously the strain values recorded on the x-axis need to be adjusted to the correct values by removing the artificial strains recorded during the slack test period. The detailed procedure is explained in the following section.

Analysis of Test Data

It is always difficult to pinpoint the test initiation, and interpret the load-strain data. We propose a new technique which will aid researchers in the load-strain data interpretation. This new technique not only helps to interpret the test data, but also suggests a new method about interpreting and reporting the values of various moduli.

The details of the technique are as follows. Conventional ASTM specimens, which are tested under some preload, can miss some important information about the initial portion of load–strain behavior. This initial load-strain data can provide some valuable information in determining the precise amount of tensile preload that can be applied to a particular fabric before the test can begin.

Once all the raw data from the load-strain test are obtained, they are analyzed. The analysis includes determining the values of slope at each data point, and plotting the slope (modulus) values on the y-axis and corresponding strain values on the x-axis. For example, Figures 3a-3d show the modulus vs. strain curves obtained using the data in Figures 2a-2d. These slope (modulus) curves provide valuable information. For example all these curves start with a flat portion till the slope starts rising consistently. This point can be called the test initiation point. After reaching this point the curve slowly rises to a peak value. This behavior is consistent for all gage lengths and test speeds. This peak point will be referred to as first slope or **First Modulus (M1)**.

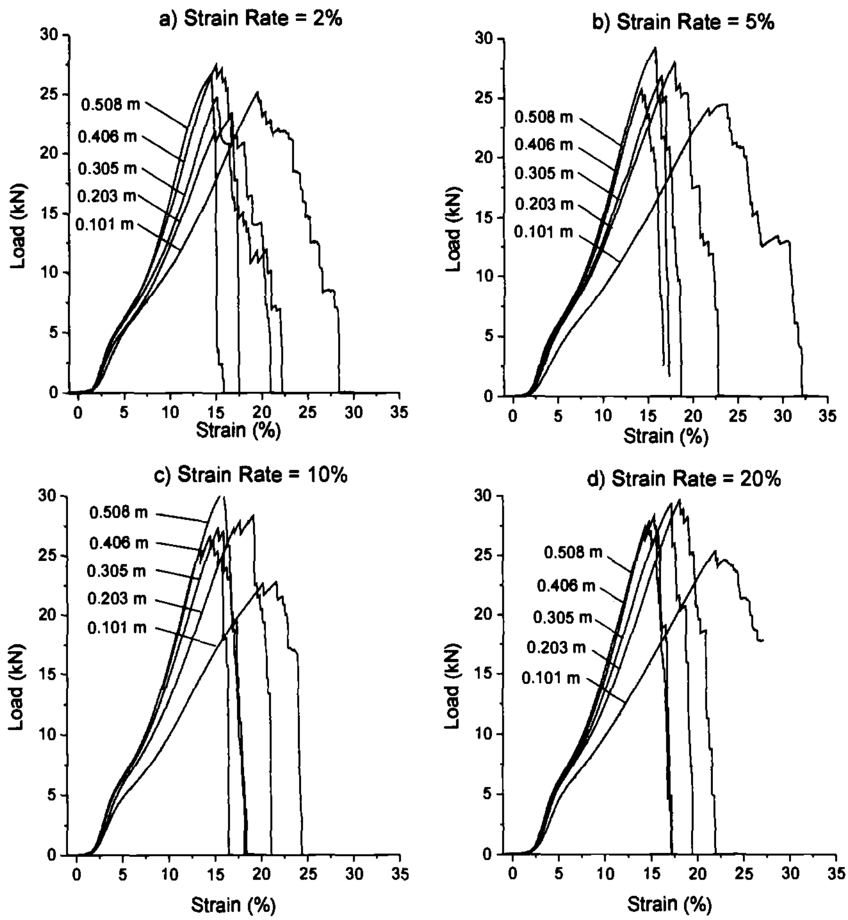


Figure 2 – *Load vs. Strain Behavior for Different Test Speeds and Sample Lengths*

After the peak values were reached it was observed that the modulus dropped, reached a low value, and again increased gradually reaching a second peak value. In some cases this second peak value was smaller than the first peak value, whereas in other cases the second peak value was higher than the first peak value. This behavior was consistent for all the samples and was independent of variations in test speeds. This slope vs. strain information can be used to interpret the load-strain experimental data and to characterize the geosynthetic woven fibers.

These curves also indicate that there are no areas of constant slope, and hence the conventional definition of tangent modulus may not be accurate. This can result in a variety of values of tangent modulus depending upon which portion of the load strain curve was used in the analysis.

Discussion of the Test Results

Due to poor agreement between sources, the definitions of modulus can be problematic for the authors of specifications and test reports on reinforcing geosynthetics. The problem is the selection of the portions of the curve to include in the calculations. ASTM D 4595 defines initial tensile modulus as "the ratio of change in tensile force per unit width to a change in strain (slope) of the initial portion of the force per unit width strain curve." ASTM also defines offset modulus and secant modulus in similar terms

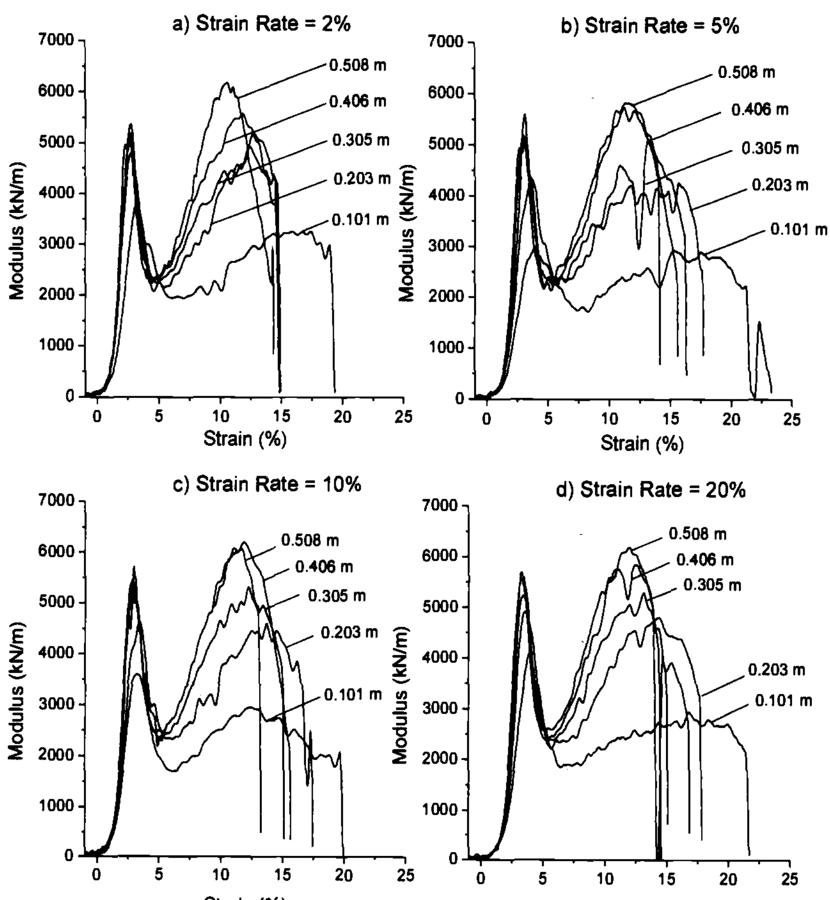


Figure 3 – *Modulus vs. Strain Behavior for Different Test Speeds and Sample Lengths*

with the clear intent that all of these concepts are related to segments of the stress strain curve. The ISO and BSI definitions are compatible with ASTM in language; however, the ISO and BSI curves, with the reporting of extension from test initiation, clearly include data that ASTM excludes, and are thus superior in this respect. The point is that the reporting of a value at 2% or 5% strain on a secant calculated from a body of data that omits part of the specimen extension data may be of little value to the designer of a critical structure.

One of the principle concerns of the research community in its review of wide-width testing on reinforcements was the effect of sample gage. The authors conclude that the 100 mm sample gage has proven to be inadequate for reinforcements. [*6,9,10*] all cited standard testing protocols for strong fabrics as the textile strip method in which sample length was typically 2 to 4 times the width. Recognition that the strip concept of sample configuration is most appropriate for strong tensile specimens is recognized repeatedly throughout the literature. A strip test, is representative of the standard method for testing strong textiles and employs long thin specimens. The Netherlands Organization for Geotextiles [*11*] provides discussion of the mechanisms of testing and

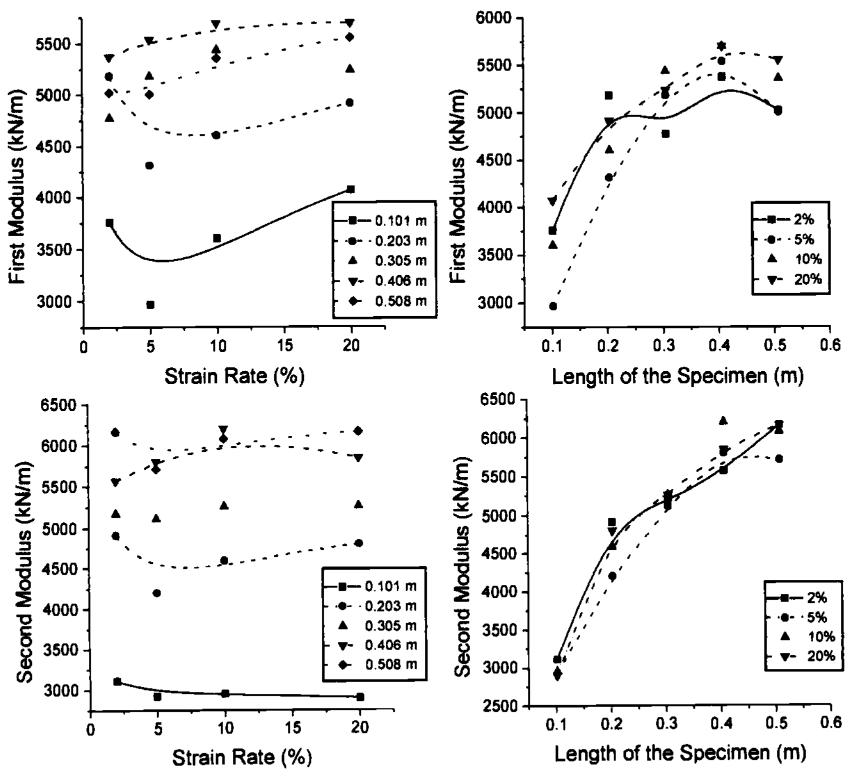


Figure 4 – *Variation of First and Second Modulus vs. Test Speed and Sample Length*

effects of gage, width, and structure. The concept of long sample lengths is common to the textile industry, reflecting the producers understanding that short sample lengths inflate strength and extension while deflating modulus. [*12*] showed that a small variation in the length of textile reinforcements had a large effect on results.

During the execution of a test, data for the entire load-strain curve can be recorded. With the salient data available for analysis, information concerning any, and every, segment of the load elongation curve can be observed. As discussed earlier, the plot of modulus vs. strain clearly indicates that the modulus continuously rises up to a certain point where it becomes maximum. It is recommended that this maximum value should be reported as the **First Modulus** (M1). The modulus decreases and rises again to a second peak value. This second peak value should be reported as a **Second Modulus** (M2).

Figure 4 shows the variation of M1 and M2 values vs. gage length and test speed. As gage length increases the M1 value also increases and for gage lengths of 0.406 m and above, the value remains constant. Shorter gage lengths exhibit variation in the value of M1 as a function of strain rate or test speed, while longer lengths show very little variation in the values. Similar observations were made in the case of M2. Shorter specimens have lower M1 and M2 values compared to longer specimens. For the high tenacity polyester fiber with twill weave architecture this variation was observed up to two times in M1 value. Similar observations were made in the case of M2. Experimental data indicates that a small variation in length of textile reinforcements has a large effect on results. For high tenacity twill woven textile fibers both the effects of sample length and of variations in test speed are greatly reduced by using long specimens.

Conclusions

- For textiles with uniaxial orientation of strength members (yarns), sample length influences test results. Shorter lengths have lower First and Second Modulus. To insure comparable results, we recommend employing sample lengths in pressure grips that are comparable to roller grip separation distances.
- Increased test speed increases modulus; however, longer samples reduce the effect.
- Slippage is also part of the system when testing strong materials and is in fact desirable in order to achieve consistent and meaningful results.
- Tolerable slippage is observed and recorded by developing correlation between extension measurement systems.
- Extension measurement techniques must be reported in detail to avoid undue masking of results.
- Modulus is the contentious issue in testing of reinforcements.

References

[1] Haliburton, T. A., Anglin C.C. and Lawmaster, J. D. "Testing of Geotechnical Fabric for Use as Reinforcement", *Geotechnical Testing Journal*, 1978, Vol. 1, No. 4, pp. 203-212.

[2] Myles, B. and Carswell, I.G., "Tensile Testing of Geotextiles", *Proceedings of the Third International Conference on Geotextiles*, Vol. 3, Vienna, Austria, April 1986, pp. 713-718.

[3] Rowe, R.K. and Ho, S. K., "Determination of Geotextile Stress-Strain Characteristics Using a Wide Strip Test" *Proceedings of the Third International Conference on Geotextiles*, Vol. 3, Vienna, Austria, April 1986, pp. 885-890.

[4] Leschinsky, D. and Fowler, J., "Laboratory Measurement of Load Elongation Relationship of High-Strength Geotextiles", *Geotextiles and Geomembranes*, 1990, Vol. 9, No. 2, pp. 145-164.

[5] Brand, E.W. and Pang, P. L. R., "Durability of Geotextiles to Outdoor Exposure in Hong Kong", *Journal of Geotechnical Engineering*, 1991, Vol. 117, No. 7, pp. 979-1000.

[6] Finnigan, J. A., "The Creep Behavior of High Tenacity Yarns and Fabrics Used in Civil Engineering Applications", Proceedings of the International Conference on the Use of Fabrics in Geotechnics, *L'Ecole Nationale Des Ponts et Chaussees*, Vol. 2, Paris, France, April, 1977, pp. 305-309.

[7] Bais-Singh, Smita and Goswami, Bhuvanesh, C., "Deformation Behavior of Spun-Bonded Nonwovens: Measurement" Proceedings of INDA-TEC 96, *International Nonwovens Conference*, Hyatt Regency Crystal City, Crystal City, VA., 1996, pp. 29.1-29.19.

[8] Stevenson, P. E., Skochdopole, T.R., and Kelkar, A. D., "The Testing of Geosynthetic Reinforcements", *Proceedings of the Sixth International Conference on Geosynthetics*, Atlanta, March 1998, Paper No. 901059.

[9] Sissons, C.R., 1977, "Strength Testing of Fabrics for Use in Civil Engineering", *Proceedings of the International Conference on the Use of Fabrics in Geotechnics, L'Ecole Nationale Des Ponts et Chaussees*, Vol. 2, Paris, France, April, 1977, pp. 287-292.

[10] Van Leeuwen, J.H., "New Methods of Determining the Stress-Strain Behavior of Woven and Non Woven Fabrics in the Laboratory and in Practice", *Proceedings of the International Conference on the Use of Fabrics in Geotechnics, L'Ecole Nationale Des Ponts et Chaussees*, Vol. 2, Paris, France, April, 1977, pp. 299-304.

[11] *A. A. Balkema Publishers*, Old Post Road, Brookfield, VT 05036-9704, USA Fax 1 802 276 3837 ISBN 90 6191 624 0

[12] Pan, N, Chen, H. C., Thompson, J., Inglesby, M. K., Khatua, S., Zhang, X.S., and Zeroinian, S.H., "Fiber Initial Modulus as a Function of Fiber Length", The Fiber Society, *General Technical Conference*, Hotel Viking, Newport, Rhode Island, October 14-17, 1996.

J. Scott Thornton,[1] Sam R. Allen,[2] and Shawn L. Arnett[3]

Effect of Gripping Technique on Tensile, Tensile Creep and Tensile Creep-Rupture Results for a High Tenacity Polyester Yarn

Reference: Thornton, J. S., Allen, S. R., and Arnett, S. L., **"Effect of Gripping Technique on Tensile, Tensile Creep and Tensile Creep-Rupture Results for a High Tenacity Polyester Yarn,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: In order to facilitate a discussion of gripping technology, the effect of three types of grips on the results of rapid loading as well as long-term creep loading tension tests is assessed. As background, a review of combined stresses and friction effects is presented. Monitoring the effective gage length of the specimen under test shows how movement of the specimen in the grips can influence the apparent stress-strain behavior, and how initial use of some extensometry may serve to establish active gage lengths for repetitive testing. Creep-rupture results are affected by both stress concentrations and excessive specimen movement in the grips. There is evidence that a stick-slip resonance phenomenon in the grip can influence creep strain and creep rupture results, particularly data scatter. If the grips used to produce the creep-rupture results are not the same as the grips used to establish the ultimate tensile strength (UTS) then it may be invalid to express the creep-rupture results as a percentage of UTS. In this case, there are three distortions that can arise with two of them leading to overly optimistic estimates of the long term creep-rupture strength.

Keywords: tension testing, creep testing, creep-rupture testing, effective gage length, horn grips, capstan grips, pneumatic clamps, coefficient of friction, polyester, yarn, time-temperature superposition, stepped isothermal method

Introduction and Background

We performed a series of tests on a high tenacity 1000 denier polyester yarn using three different types of grips to assess the effect of the grips on the apparent tensile, tensile creep and tensile creep-rupture properties of the yarn.

[1]Principal Scientist and President, Texas Research International, Inc., Austin, TX 78733.
[2]Vice President and Division Manager, Geosynthetics Technology Division, TRI/Environmental, Inc., Austin, TX 78733.
[3]Research Engineer/Scientist, TRI/Environmental, Inc., Austin, TX 78733.

The tensile grips used are illustrated in Figure 1. Figure 1(a) shows pneumatic plate grips with rubber face pads which we call the air grips; Figure 1(b) circular sectioned single roll capstan grips with helical grooves which we call the spool grips; and Figure 1(c) pneumatic plate clamps which act in conjunction with contoured surfaces which we call the horn grips (after the guide horns, not shown, which ease the loading procedure). The horn grips combine both clamping friction and contour friction gripping features and therefore represent a hybrid of the air grips and the spool grips.

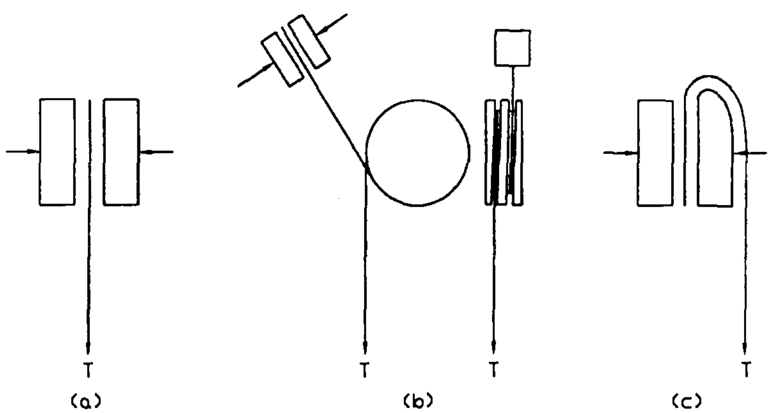


Figure 1 – *Three grip types: (a) clamp (air), (b) roller or capstan (spool), and (c) clamp/contour (horn)*

Clamping Grips

Clamping type grips work by applying an external normal pressure to the specimen. The longitudinal tensile force developed in the test section of the specimen is transferred into or out of the specimen by shear stresses. These stresses must be less than the frictional stresses developed by the product of the normal stress and the coefficient of friction between the grip faces and the specimen to prevent the specimen from slipping in the clamps. If the length of specimen within the clamps is large enough then the shear transfer stresses can be small and specimen slippage is not a problem. Figure 2 illustrates the states of stress in the vicinity of clamp grips. The combined stress formulae for the maximum normal stress (S_n) max and the maximum shear stress (S_s) max are [1]:

$$(S_n)_{max} = \frac{S_x + S_y}{2} + \sqrt{\left(\frac{S_x - S_y}{2}\right)^2 + (S_{xy})^2} \qquad (1)$$

and

$$(S_s)_{max} = \sqrt{\left(\frac{S_x - S_y}{2}\right)^2 + (S_{xy})^2} \quad (2)$$

where S_x is the tensile stress in the specimen, S_y is the clamping stress applied to the ends of the specimen, and S_{xy} is the shear stress developed in the specimen adjacent to the clamp. In the test section of the specimen away from the clamp (see Figure 2) the maximum normal stress is simply the tensile stress in the specimen and the maximum shear stress is one half S_x because S_y and S_{xy} are *0*. Just within the entrance to the clamp at (b) in Figure 2, if we assume that S_{xy} is not large, which is consistent with a long clamping distance, then the maximum normal stress is still nearly the tensile stress in the specimen, but the maximum shear stress is increased by $\frac{|S_y|}{2}$. This is illustrated by Mohr's circle in Figure 3. Slippage due to yielding of the specimen in clamping type grips is a problem that is largely overcome by use of pneumatic action to maintain a constant clamping force. However, in the absence of work hardening in the specimen, premature yielding in the grips can lead to premature tensile failure at the grips.

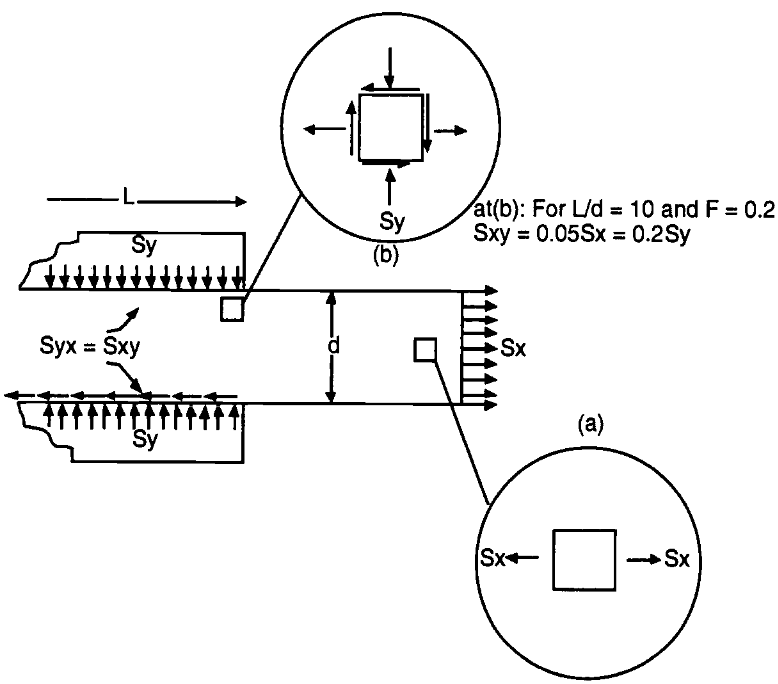


Figure 2 – *Combined stresses in two regions for a test specimen: (a) in the test section, and (b) near the grip entrance*

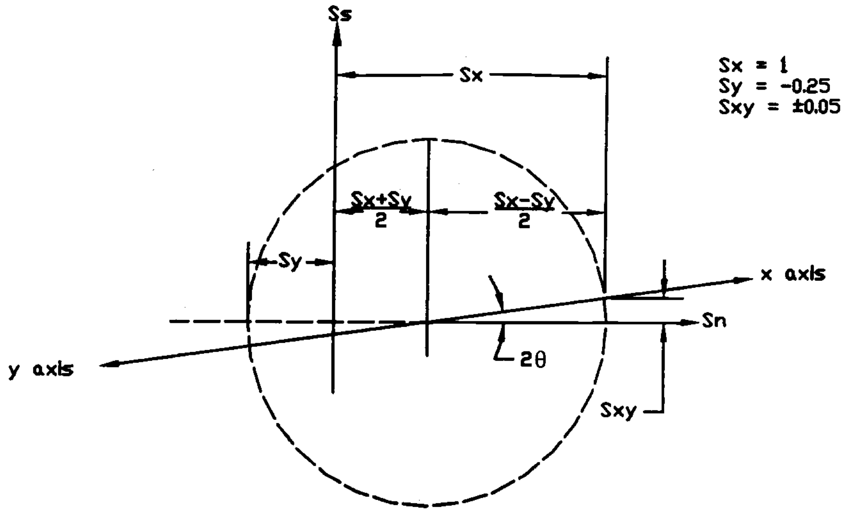


Figure 3 – *Mohrs circle for combined stresses indicative of the state of stress at Figure 2(b) showing that Sxy can be neglected for the values of stress shown*

While the maximum normal stress does not increase appreciably in clamping grips (again assuming S_{xy} is not large) the maximum normal strain does. The maximum normal strain, $(\in_n)$ max, would be given by

$$(\in_n)_{max} = \frac{(S_n)_{max}}{E} \tag{3}$$

where E is Young's modulus. The maximum strain theory of failure simply states that failure will occur when the maximum normal strain reaches a critical value. Obviously, for the pure clamping type grips, this condition will be met in the grips before it is met within the test section of the specimen.

Roller Grips

The roller type grips work by utilizing the tension in the specimen to impart a radial (normal) stress at the contact surface between the specimen and the contoured grip. The tension in the specimen is reduced as tangential stresses transfer load into (or from) the grips. The reduction in tension, T_r, is a function of the original tension, T, the angle of contact, ρ and the coefficient of friction, f, as follows:

$$T_r = T \exp(-f\rho) \tag{4}$$

where ρ is in radians. A brief table of tension reduction factors is given in Table 1 below.

Table 1 - *Tension Reduction Factors*

	Coefficient of Friction		
Angle	0.1	0.2	0.3
30°	0.95	0.90	0.85
90°	0.85	0.73	0.62
180°	0.73	0.53	0.39
270°	0.62	0.39	0.24
360°	0.53	0.28	0.15

Note that even a small contact angle (30°) and a low coefficient of friction (0.1) can lead to a 5% reduction of the tension in a specimen. The effective normal force equals the friction force, which is the tension reduction, T-T_r, divided by the coefficient of friction, f. The small contact angle example of the 5% tension reduction results in a normal force 50% of T. However, this normal force is spread over a relatively large area as is seen in the following. The free body diagram in Figure 4 shows a segment of a yarn specimen under tension, which is in contact with a curved frictional surface with radius of curvature r. The contact arc length is s and the contact angle is ρ. Since the angle is assumed to be small, then $s = r\rho$. The yarn specimen thickness is d and it has unit width.

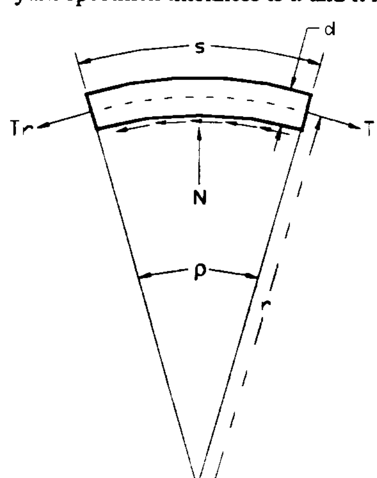


Figure 4 – *Free body diagram of a section of specimen in frictional contact with a contoured surface*

For small values of ρ, equation (4) can be written

$$T_r = T\,(1\text{-}f\rho) \tag{5}$$

As previously noted the normal force is

$$N = -\frac{T - T_r}{f} \tag{6}$$

Combining (5) and (6) yields

$$N = \text{-}T\rho \tag{7}$$

The compressive stress in the yarn specimens (for unit width) is

$$S_y = -\frac{N}{s} = -\frac{T}{r} \tag{8}$$

The tensile stress (for unit width) is

$$S_x = \frac{T}{d} \tag{9}$$

The maximum normal and shear stresses (again neglecting S_{xy}) are

$$(S_n)_{\max} = \frac{T}{d},\ and\ (S_s)_{\max} = \left(\frac{T}{d} + \frac{T}{r}\right)/2 \tag{10}$$

and the maximum normal strain is

$$(\epsilon_n)_{\max} = \frac{1}{E}\left(\frac{T}{d} + \gamma\frac{T}{r}\right) \tag{11}$$

These results are similar to what we obtained for the clamping type grips except that it is easy to arrange the dimensions of roll grips to obtain $r >> d$ which will make $S_y << S_x$ and the increases in the maximum shear stress and maximum normal strain at the grip entrance arbitrarily small. This demonstrates why roll grips are often used when very large tensile stresses need to be reduced as a function of specimen gripping.

Experimental Program

The experimental program was designed to determine the effect of three types of grips on the rapid loading tensile (RLT) properties and the tensile creep and creep-rupture properties of a PET yarn that is used in geosynthetic reinforcement products. The stepped isothermal and conventional methods for time-temperature superposition

(TTS) were employed to accelerate the acquisition of creep data. Of particular interest in these experiments was the effect of using one type of grip for generating the RLT results and another to generate the creep-rupture results. Our laboratory is asked occasionally to express our SIM results as a percentage of the rapid loading ultimate tensile strength (UTS) of the same lot of material but determined by another laboratory. SIM stands for Stepped Isothermal Method, which utilizes time temperature superposition to generate accelerated creep results rapidly [3]. What will be demonstrated in this paper is that use of % of UTS only makes sense if the same type of grips are used to perform both types of test. The RLT tests were conducted on yarn specimens at 20°C to establish the ultimate strength and elongation as well as the variation in stress vs strain properties as determined by the three grip types. The grip separations for the clamp, spool and horn grips were 10 inches in each case.

To establish the actual effective gage length (EGL) of each grip type, at least one RLT test was conducted for each grip type using an extensometer with a 2" gage length. The EGL is defined by the ratio of crosshead displacement to the extensometer strain measurement [2] as follows:

$$EGL = \frac{Crosshead\ displacement}{Extensometer\ strain} \tag{12}$$

When comparing the EGL to the grip separation one can infer the degree of specimen movement that occurs in the grips. The EGL is a useful tool when used to determine the crosshead displacement rate needed to achieve a strain rate objective, such as 10% per minute. When limited to testing at a constant crosshead displacement rate, measurement of EGL may assist in identifying potential strain rate bias at specific events during the tensile test.

A total of thirty (30) creep-rupture tests were performed using SIM. Twelve (12) of these were in the horn grips, ten (10) in the air grips and eight (8) in the spool grips. The tests were performed in an Instron load frame within an Instron environmental chamber. Starting from the reference temperature of 20°C temperature steps of 14°C and time dwells of 10,000 s were applied until specimen rupture or runout at > 10^6h of accelerated time was achieved. Extensometer measurements were made on one SIM test (at 65% of UTS) for each grip type to enable EGL estimates to be made.

Results and Discussion

RLT Results

Effective Gage Length (EGL) - The results of the RLT tests which employed the extensometer to estimate the EGLs are given in Figure 5. Stress vs strain curves for each grip type are close to one another, within the spread of results of any simple grip type and typical of a high tenacity PET yarn. The EGL curves show that the horn and air grips behave generally the same, but the spool grips behave differently. The EGL for the horn and air grips is on the order of 12 for most of the strain range displayed while that for the spool grips ranges between 22 and 28 for the same range. The actual no-load "stringline" distances between the clamping plates compared to the EGLs at 2% and 8% strain are given in Table 2. It is interesting to see that there must be considerable specimen deformation in, and in the vicinity of, the clamps of the air grips to achieve the EGL values shown at 2% and 8% strain. It is also interesting to note that the horn grips have a larger stringline distance than the air grips yet a smaller difference between its stringline distance and its 2% and 8% EGL numbers. Friction along the contour surface of the horn grips appears to reduce the yarn tension to the extent that there is less deformation at the clamps than for the air grips. Obviously the EGL of the spool grip specimen is variable enough that an average EGL divided into the crosshead displacement could not be used as an accurate estimator of strain. With these spool grips, use of an extensometer is strongly advised. Since the ratio of the 8% EGL value to the 2% EGL value for the horn grips is only 1.017, there would be less than ± 1% error in true gage length by using the average value 12. The air grips may represent a border line situation.

Table 2 - *Effective Gage Lengths for Three Grip Types*

Grip Type	No-Load Stringline Distances	EGL at strains of 2%	EGL at strains of 8%
air	10.0	11.4	12.4
spool	39.7	21.5	27.7
horn	11.2	11.9	12.1

There was some concern that the location of the extensometer within the gage length was affecting the yarn EGL. To investigate this possibility, three additional RLT tests were conducted using the air grips. In these additional tests the extensometer was placed near the upper and lower grips, and again in the middle of the specimen gage length. The results of the original and the three additional tests are shown together in Figure 6. The stress vs strain curves are tightly grouped as before. The original EGL curve is the lowest one at 2% strain and is labeled M. The new middle placement result is also labeled M and is the highest curve; so the lower and upper extensometer placement results fall between the replicated M results. From the limited data presented in Figure 6, there does not appear to be a systematic extensometer placement problem. However, of remaining concern is the range of EGL results at 2% strain, although less so at 8% strain.

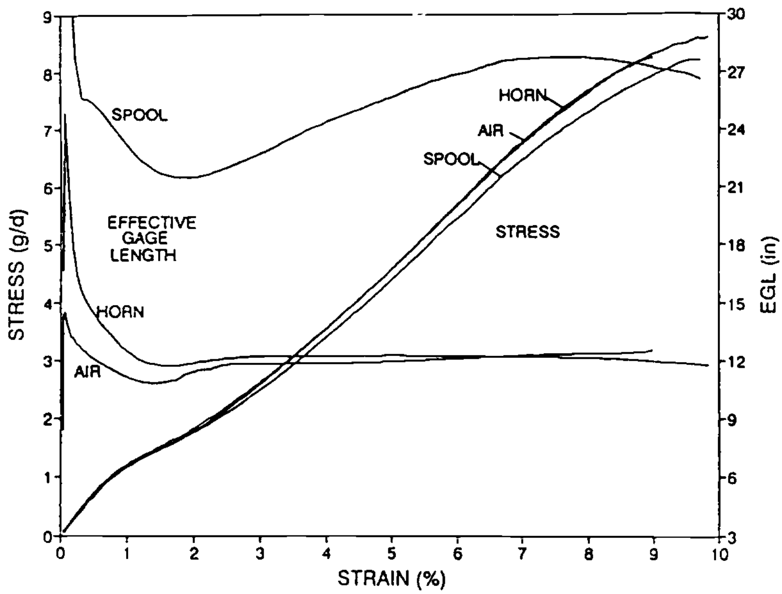


Figure 5 – *RLT stress and EGL vs strain curves for the three grip types: air, spool and horn*

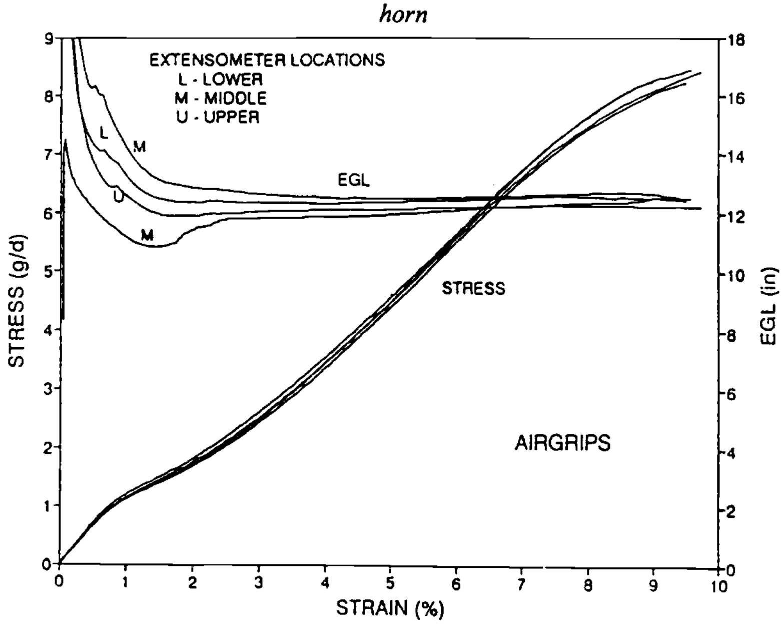


Figure 6 – *RLT stress and EGL vs strain curves for the air grips as a function of extensometer placement in the gage length*

Table 3 lists the EGL results at 2% and 8% strain as well as the ratios of the higher to the lower for each extensometer placement and the highest to lowest EGL at each of the two strain levels. The ratio of highest to lowest EGL at 2% strain is 1.132. Should the 2% modulus be an issue, then clearly use of an average EGL, whether a grand average of the Table 3 results (12.3) or an average of the 2% results of Table 3 (12.15), could return a result easily off by 5%.

Table 3 - *EGL results for four extensometer placements*

	M_2	L	U	M_1	ratio
2%	12.9	12.4	11.9	11.4	1.132
8%	12.7	12.6	12.3	12.4	1.024
ratio	1.016	1.016	1.034	1.088	

Stress and Modulus vs Strain Results

Stress and secant modulus vs strain results for yarn specimens tested with the air grips are shown in Figure 7. All but one set of strain and modulus results were for crosshead displacement using an EGL of 11.4 to estimate strain (see M1 from Table 3). The exception was for the extensometer results. Note the good match of extensometer results with the crosshead/EGL results at strain levels below about 3%. Figure 8 displays similar sets of data, but using an EGL of 12.4 (also M1 from Table 3). Here, the strain and modulus at maximum load are accurately matched, but the deviations between extensometer and crosshead/EGL below about 7% strain are significant. Initial modulus as well as 2% and 5% modulus are significantly over estimated using 12.4. Use of M1 results to illustrate this potential problem with using a constant single value for EGL may exaggerate the problem since the 2% and 8% EGLs for M1 are the most disparate in Table 3.

Results for stress and modulus vs strain for the spool grips are given in Figure 9. Extensometer results as well as crosshead/EGL results with an EGL of 28 are shown. The extensometer results are quite different from the crosshead/EGL results except at maximum strain. The elongations at maximum stress are less and more variable than we saw previously for the air grips and will see below for the horn grips.

Stress and modulus plots for the horn grips are shown in Figure 10. Use of an EGL of 12 places the crosshead/EGL results in reasonable agreement with the extensometer results except for the initial modulus.

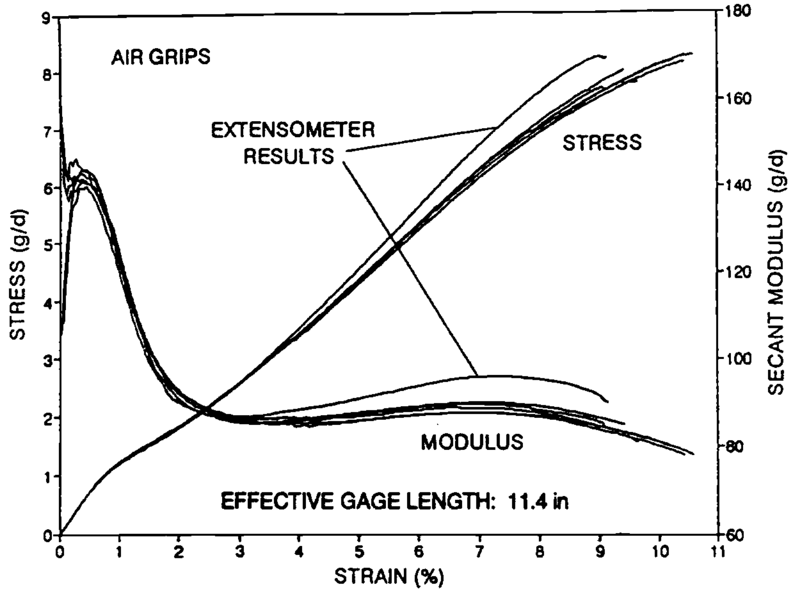


Figure 7 – *RLT stress and secant modulus vs strain results obtained using the air grips and an 11.4 in. gage length*

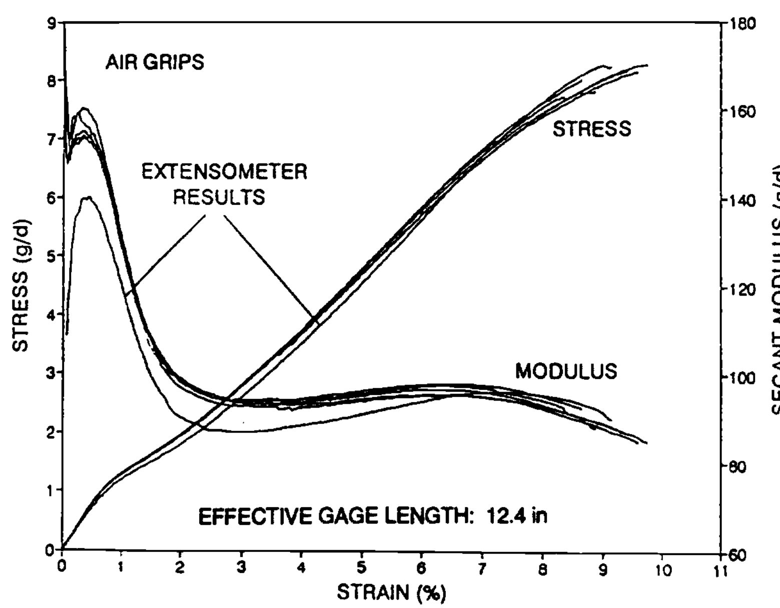


Figure 8 – *RLT stress and secant modulus vs strain results obtained using the air grips and a 12.4 in. gage length*

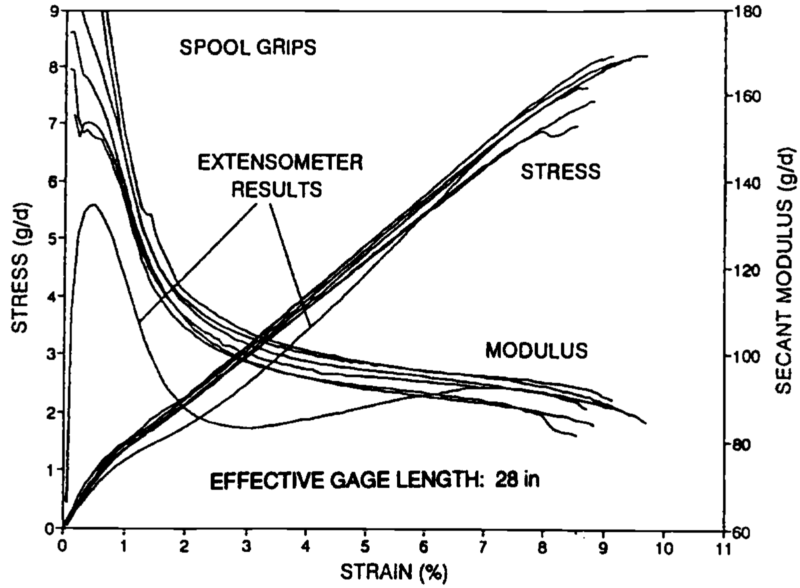


Figure 9 – *RLT stress and secant modulus vs strain results obtained using the spool grips and a 27.7 in. gage length*

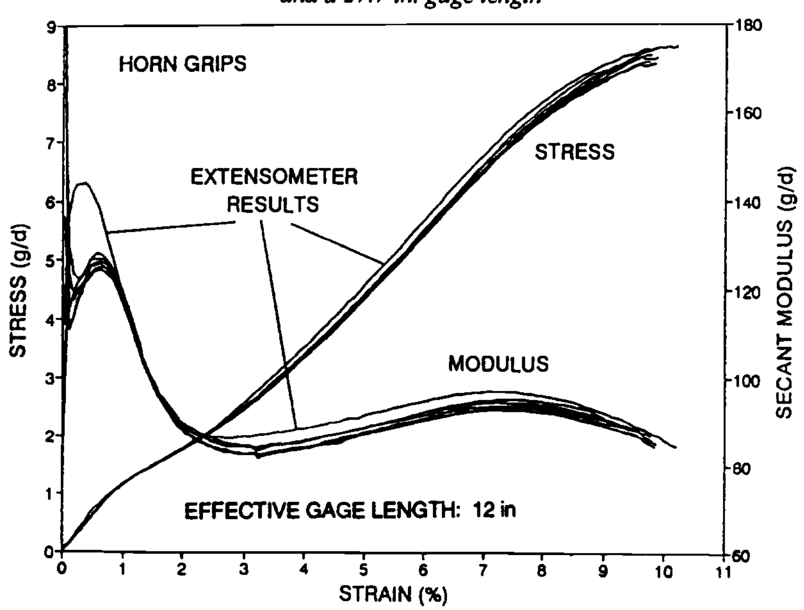


Figure 10 – *RLT stress and secant modulus vs strain results obtained using the horn grips and a 12 in. gage length*

Creep Results

Effective Gage Length

Simultaneous crosshead and strain measurements with time for a yarn specimen in air grips, loaded to 66% of UTS and subjected to SIM are presented in Figure 11. The quotient of these measurements is the EGL, which is cross-plotted along with the crosshead measurements against strain in Figure 12. The EGL varies from about 12.3 to 13 with strain increasing from 6.5% (which is about the peak of the loading ramp) to 8.4% (which is near the final runout strain).

Similar results for a spool grip SIM test are given in Figures 13 and 14. Note that the shapes of the creep steps in Figure 13 differ between the strain and crosshead renditions. In Figure 14 we see that the EGL oscillates between 28 and 29 as the strain goes from 6 to about 9.6%.

Figures 15 and 16 report the EGL results for the horn grips. The EGL vs strain results in Figure 16 are similar to those in Figure 12 for the air grips.

Creep strain vs Log Time

Creep curves for the three grip types generated using the SIM are shown in Figures 17 and 19. Note that the ramp-up portions of the creep response curves are included in the record. Starting the clock at the beginning rather than the peak of the ramp has negligible effect on the shape of the creep curves at times greater than about 10^{-1} hr. The appearances of the curves for the air grips (Figure 17) and those for the horn grips (Figure 19) are similar. EGLs of 12.0 were used in both presentations. The spool grip curves are decidedly different. Instead of smooth master creep curves, the curves are bumpy, suggesting a stick-slip type of response behavior over the spools. To compare the strain responses in the early portions of the creep tests as well as the strains at rupture or runout, Figure 20 was prepared. This graph is of the sets of stress, strain pairs at 120 s (log time -1.477 in hours) and at rupture for each grip type. The two minute data form three lines for the three grip types on the left side of the graph. These lines slope upward and to the right from about 5.6 g/d stress, 6.5% strain to about 7.4 g/d stress, 8.5% strain. The rupture data form three additional lines on the right side of the graph that follow vertical (albeit jagged) paths centering on about 10% strain. We believe that this presentation shows generally that the three types of grips give nearly equivalent performance during the early part of the creep response, but provide different responses by the termination of the creep curves. The spool grips produce generally lower strains at rupture for the same stress levels and the strain variation is the greatest of the three. The rupture strains for the air grips and horn grips both fall mostly within a band between about 9.5% and 11%, but the air grip strain variation is somewhat greater than that for the horn grips.

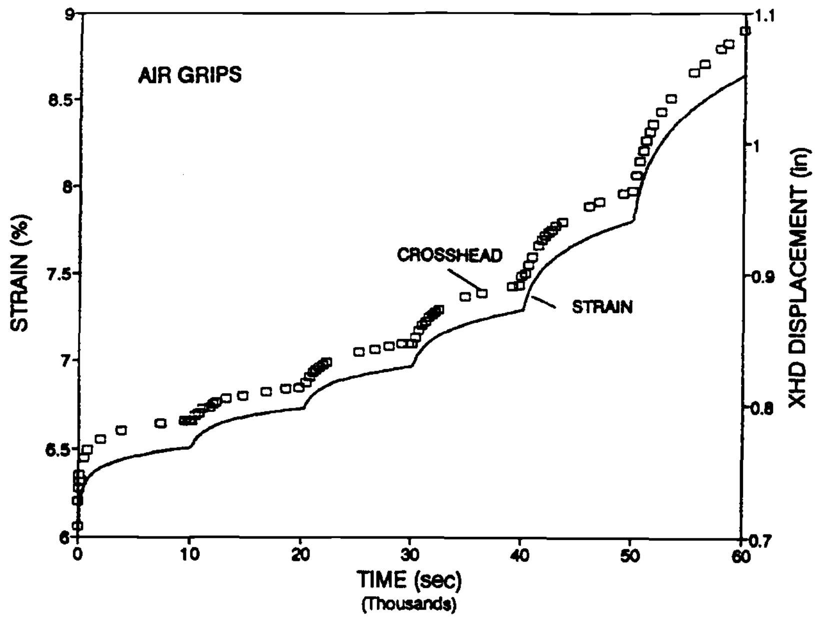


Figure 11 – *Strain and crosshead displacement as a function of time for a SIM test employing air grips*

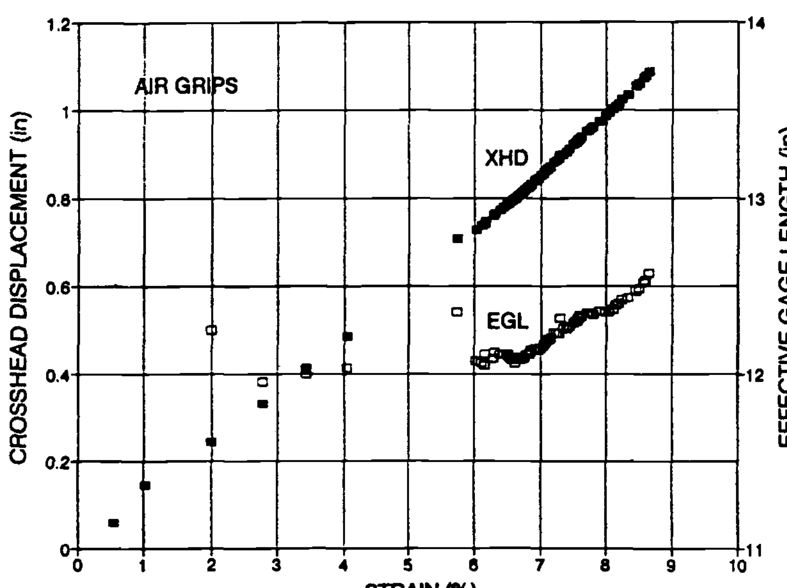


Figure 12 – *Crosshead displacement and EGL vs strain using air grips*

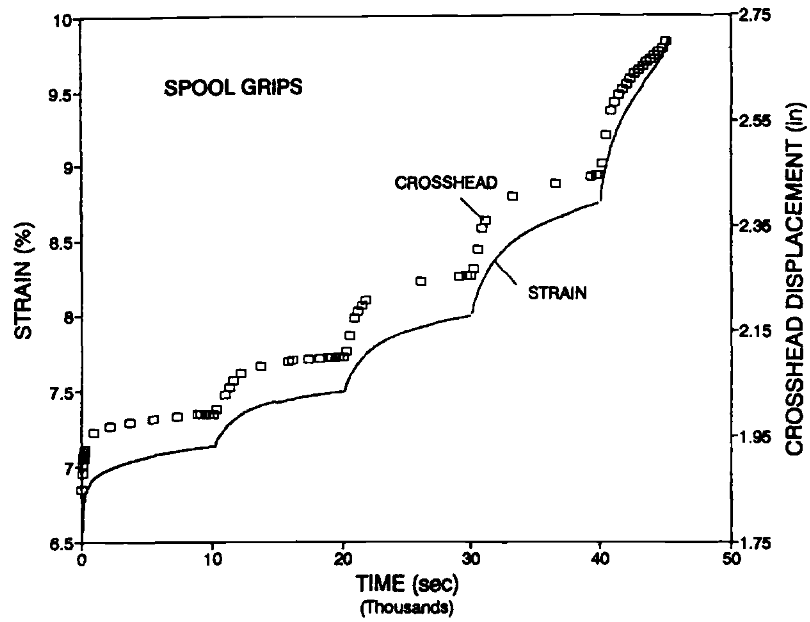


Figure 13 – *Strain and crosshead displacement as a function of time for a SIM test employing spool grips*

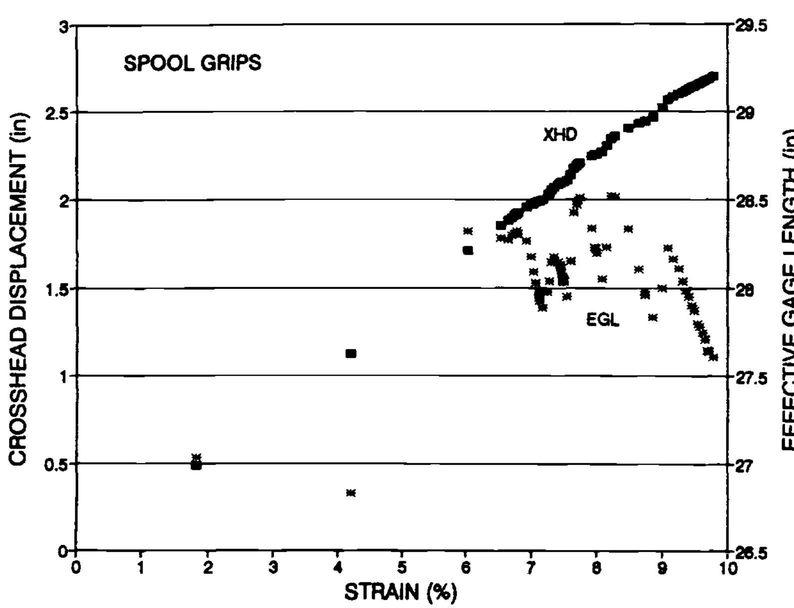


Figure 14 – *Crosshead displacement and EGL vs strain using spool grips*

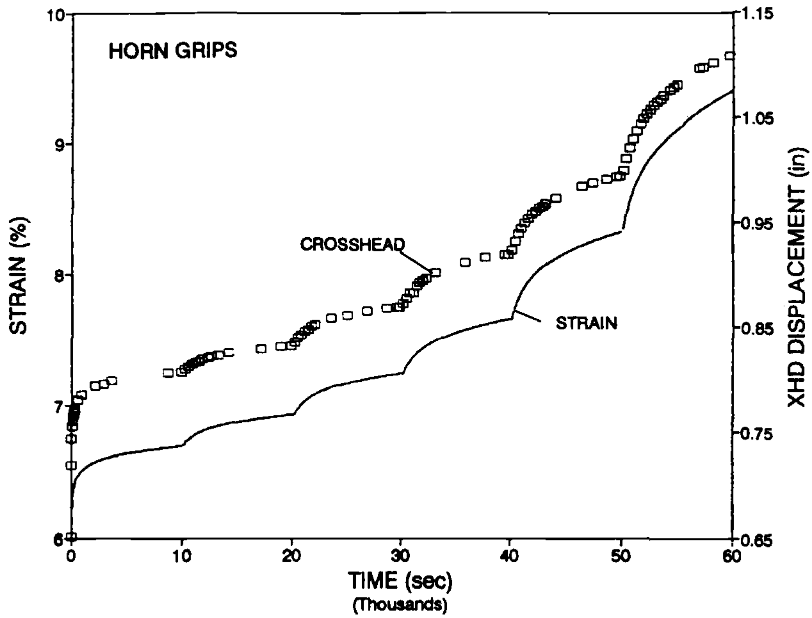


Figure 15 – *Strain and crosshead displacement as a function of time for a SIM test employing horn grips*

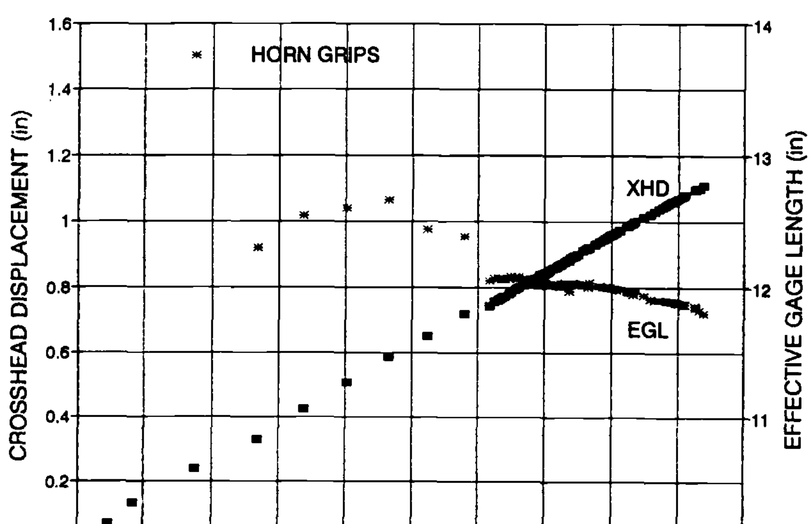


Figure 16 – *Crosshead displacement and EGL vs strain using air grips*

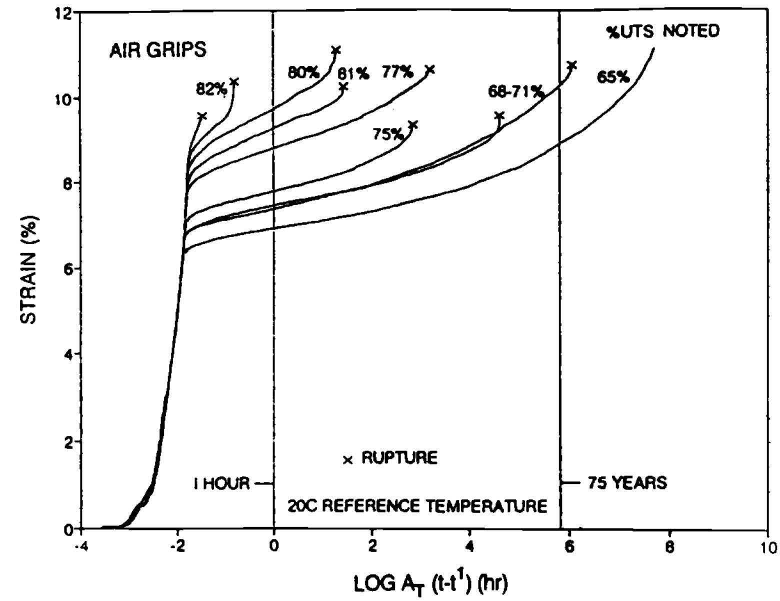


Figure 17 – *Master creep strain curves for air grips*

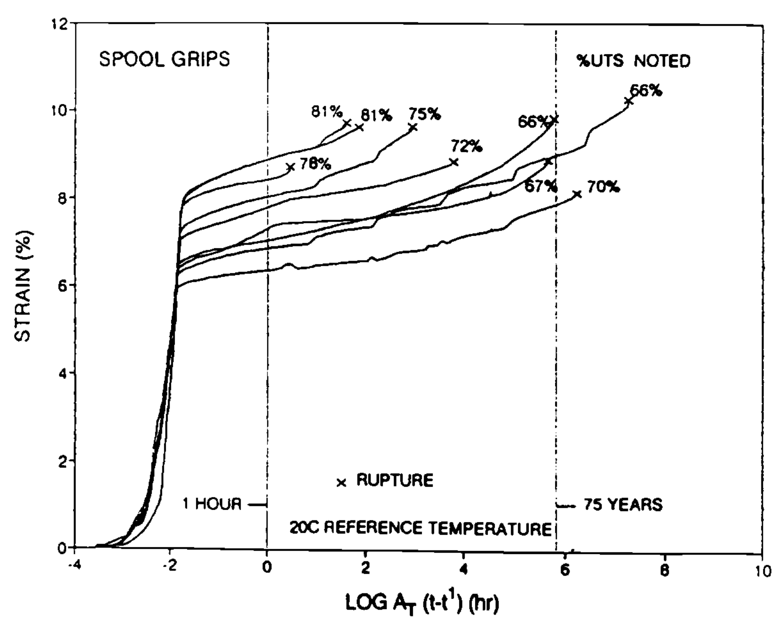


Figure 18 – *Master creep strain curves for spool grips*

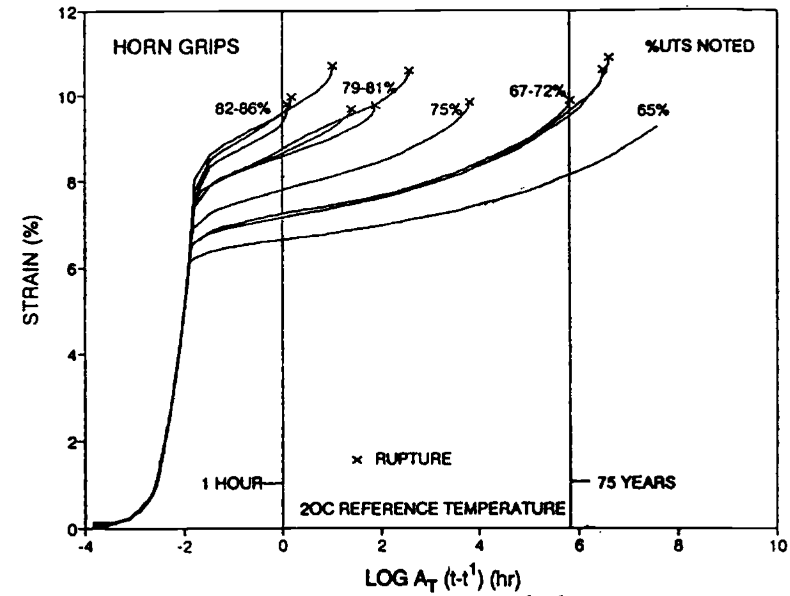


Figure 19 – *Master creep strain curves for horn grips*

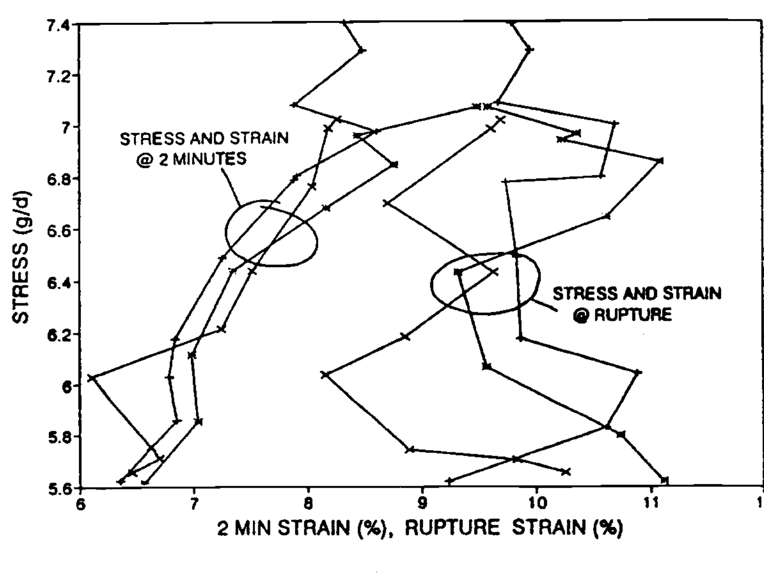


Figure 20 – *Stress-strain pairs at 2 minutes and at rupture for 30 creep rupture tests: 10 that used air grips, 8 that used spool and 12 that used horn grips*

Creep Rupture Results

Figure 21 shows the creep rupture results plotted against log time in hours for each of the three grip types. The rupture strengths are given as a percent of the UTS as determined by the horn grips. Linear regression analysis was used to construct the lines representing the three data sets. As expected, the horn grips provide the highest creep rupture results for all values of time shown. The results for the spool grips and the air grips show small reductions in short term rupture strength of about 10% and 3%, respectively. However, the long term rupture strength determined by the air grips approaches that for the horn grips, implying that the adverse effect of the combined stresses in the grips is reduced when the S_x component is reduced. The spool grips end up at the long term end showing about a 20% reduction in strength over both the horn grips and the air grips. This is thought to be a result of the stick-slip deformation process in the spool grips.

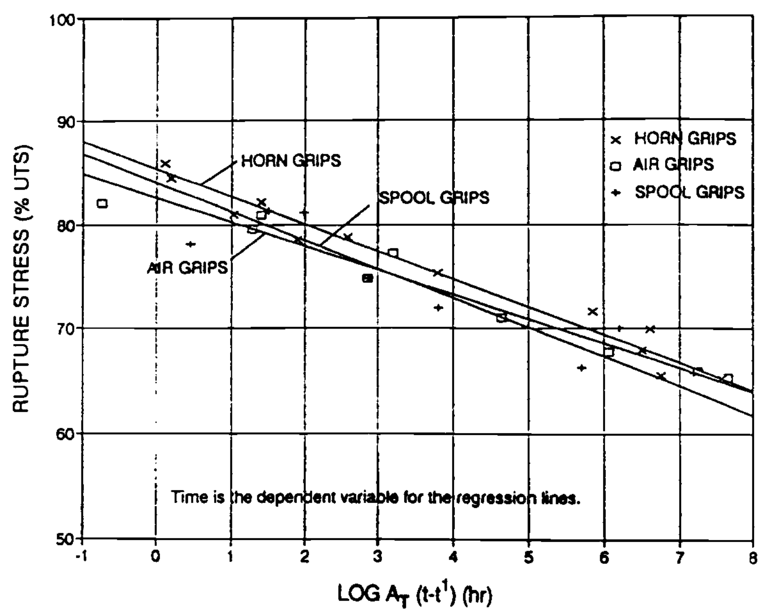


Figure 21 – *Creep rupture results obtained using air, spool and horn grips*

Figure 22 shows regression lines only for the results of four combinations of horn and air grips used to establish the UTS by means of RLT testing and the creep-rupture regression lines by SIM testing. Lines 1 and 2 are repeats for comparison purposes of the lines given in Figure 21 for UTS established using horn grips (1) and air grips (2). To these can be added the regression lines for UTS established by air grips with subsequent creep rupture results established using horn grips (3) and air grips (4). As would be expected, the largest distortion is caused by combination 3 where it appears that a high percentage of the UTS is retained after a fraction of an hour of sustained load, and the improvement at the long term end is significant as well, but not quite as noticeable. With combination 4 the distortion at the short term end might not be noticed in rupture data out to 1000 hours.

The distortion caused by combination 2 where "superior" grips are used for RLT testing and "inferior" grips are used for creep-rupture testing may be the most prevalent in the industry. In a creep-rupture program, usually many test stands are needed and cost constraints may limit the grip selection options.

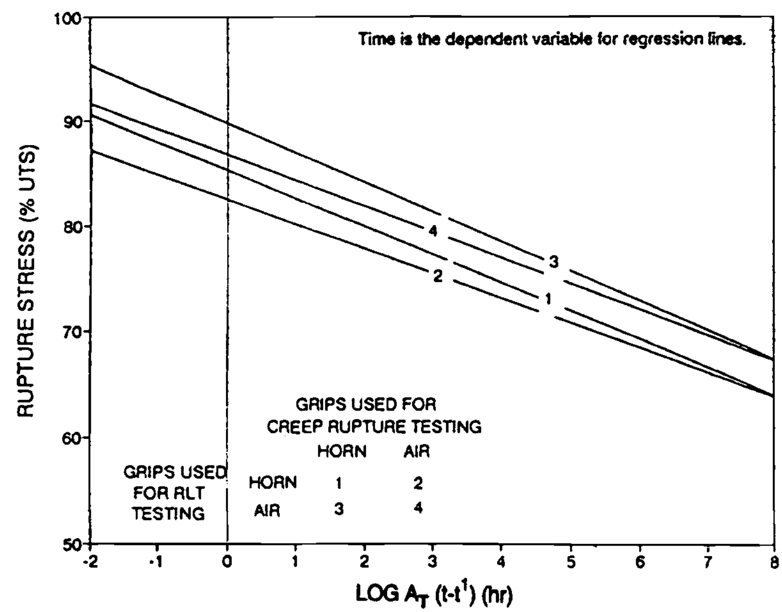


Figure 22 – *Hypothetical creep-rupture results showing the effect of the grip choices for establishing UTS and performing the creep-rupture tests*

Conclusions and Recommendations

Conclusions

The following conclusions apply to the testing of high tenacity polyester yarn using the grip types described above.

1. The effective gage length is a useful measure of specimen movement in the grips used to perform rapid loading tensile and long term tensile creep tests.

2. At least some movement occurs in all three grip types. The horn grips have the least movement and the spool grips the most. Short- and long-term tensile results are adversely affected by the movement.
3. Extensometers should be used for accurate tensile and tensile creep measurements, because the effective gage length tends to be somewhat variable.
4. The spool grips examined here are not suitable for yarn testing because of periodic variations in the effective gage length that seem to be related to a frictional "stick-slip" phenomenon which appears to influence the breaking strength of test specimens.
5. Despite some common features with the spool grips, the horn grips do not appear to adversely influence the test results.
6. The air grips could be used to successfully obtain creep results at stresses below about 70% of UTS.
7. The horn grips provide the highest tensile and tensile creep rupture results, with the lowest variability.

Recommendations for Future Work

1. Investigate alternative ways to provide controllable clamping pressure gradients in new grip designs.
2. Measure clamping pressure and coefficient of friction as necessary to estimate maximum normal and shear stresses of rupture. Such estimates could be useful to evaluate grip efficiency.
3. Grip efficiency might be a useful area to pursue in the quest for better grips.

Acknowledgment: The authors acknowledge with appreciation the financial support of Texas Research International, Inc.

References

[1] Williams, J.G., *Stress Analysis of Polymers*, 2nd Edition, John Wiley and Sons, New York, 1980.

[2] Instron Corporation, *Guide to Advanced Materials Testing*, CAT-8701, Canton, MA, 1987, p. 138.

[3] Thornton, J.S., Allen, S.R., and Thomas, R.W. "The Stepped Isothermal Method for Time-temperature Superposition and Its Application to Creep Data on Polyester Yarn," Sixth International Conference on Geosysnthesis, Atlanta, 1998, pp. 699-706.

Todd R. Skochdopole,[1] L. Cassady,[2] Dennis Pihs,[3] and Peter E. Stevenson[4]

Comparative Study of Roller and Wedge Grips for Tensile Testing of High Strength Fabrics with Laser Extensometry: Comparisons to LVDT and Crosshead Extension

---

Reference: Skochdopole, T. R., Cassady, L., Pihs, D., and Stevenson, P. E., **"Comparative Study of Roller and Wedge Grips for Tensile Testing of High Strength Fabrics with Laser Extensometry: Comparisons to LVDT and Crosshead Extension,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Measurement of the tensile properties of high strength woven and knit geotextiles and geogrids traditionally make use of roller grip-type clamping systems, which are designed to allow a sample to be pulled in tension without applying an excessive crimping or compressive force on the specimen, thus avoiding premature failure. Roller grips also have the advantage of allowing the specimen to align itself with the applied force and therefore loading the specimen uniformly across the width. However, since the specimen tightens itself around the grip during testing, crosshead travel cannot be used to measure specimen strain, making determination of low strain properties difficult. Two issues that must be addressed in obtaining low strain properties are how to measure sample strain and how to get an accurate and repeatable starting point for the test. This paper will explore alternate methods of gripping systems, strain measurement and data analysis with the objective of accurately measuring and reporting low strain properties of woven and knit geotextiles and geogrids.

Keywords: tensile testing, reinforcements, preload, pretension, low strain, modulus, geotextiles

[1] Manager, Research and Development, Atlantech International, Inc., Atlanta, GA 30260.
[2] Research and Development Technician, Atlantech International, Inc., Atlanta, GA 30260.
[3] Quality Control Technician, Atlantech International, Inc., Atlanta, GA 30260.
[4] Manager of Applications Development, Atlantech International, Inc., Atlanta, GA. 30328.

Introduction

The history of the evolution of the wide width test methods, ASTM D4595 and its ISO counterpart 10319, include many references to the difficulty in adapting the test method to the broad range of products and properties that can be found in the geosynthetics arena [*1,2*]. In particular is the problem of measuring tensile properties of high strength geotextiles and geogrids, those products exhibiting tensile between 100 kN/m and 1000 kN/m, over the entire range of the load-elongation curve. Rather than cite a multiple page bibliography, it should suffice to reference the ASTM Standard Test Method for Tensile Properties of Geosynthetic Textiles by the Wide Strip Method D 4595 – 86 (Reapproved 1994) and the note on precision and bias, note 9, which reports difficulty in determining the origin point of the test. This difficulty is particularly onerous in testing reinforcements. This paper will explore alternate methods of gripping systems, strain measurement and data analysis with the objective of accurately measuring and reporting low strain properties of woven and knit geotextiles and geogrids.

Sample Preparation and Testing Parameters

Tensile testing was performed on both woven geotextiles and woven or knit, coated geogrids, using both roller grips and wedge grips, with a 500 mm (20 inch) separation between grips in each case. These required sample lengths of 1.8 meters (72 inches) and 600 mm (24 inches), respectively. Sample width was generally 50 mm (2 inches) for the results discussed here, but testing of wider samples was not found to affect the results. Interestingly, products certified by independent labs using D4595 typically exceed the data developed internally. In addition to recording crosshead extension, an external extensometer, either LVDT or laser type, with a 100 mm (4 inch) gage was used. All tests were run with a 10 mm/minute crosshead speed, to give a strain rate of 10% per minute. The amount of preload was varied throughout our experiments and is noted for each particular test.

When using the wedge grips, a protective metal tab, 50 mm x 75 mm in size, was placed between the specimen and the jaw face to help prevent jaw breaks. Jaw breaks occur when the clamping device cuts the specimen truncating the results. The metal tabs were soft flexible steel, 7.5 mil +- 1 mil with smooth faces. These tabs also allowed higher clamping forces to prevent slippage without damaging the specimen. The use of epoxy in the form of wedges and other geometry's was first reported by Myles [3] and is in wide use by many geosynthetic laboratories today to resolve a variety of gripping issues. We found that minimal slippage occurred when these protective tabs were attached to the specimen with an epoxy glue. However, double sided tape also was found to work nearly as well, and was much quicker and easier to prepare. For the higher strength fabrics, however, the use of an epoxy glue is recommended.

The laser extensometer measures specimen extension by tracking the distance between two pieces of reflective tape attached to the specimen. The width of the laser is approximately 1 mm, which allows the tape markers to be placed in any location along the sample width or length. In the work reported here, the center portion of the specimen was always used for measuring strain. The extensometer we employed has the capability of measuring a maximum separation of 280 mm (11 inches). Compared to the use of an LVDT, the laser extensometer has several advantages. The minimal weight and method of attachment of the reflective tape allow the markers to be attached to the specimen in the untensioned state. Since they do not need to penetrate the specimen, the markers do not influence the performance of the specimen during the tensile test. Of even greater importance to the student of reinforcement behavior is the opportunity afforded by the optical device to observe and compare various gauge lengths quite easily with a single device. It is well known that strain is not uniform throughout a specimen, and, in fact, strain varies greatly depending on the area of a specimen that is observed [4,5]. The ability to observe various areas, and to adjust gauge, allows the development of a larger understanding of the behavior of reinforcements.

Comparison of Grip and Strain Measurement Techniques

Roller grips have found widespread use in the testing of geosynthetics, due to their ability to hold specimens during tensile loading without causing premature failure. During testing, rather than being rigidly clamped in place, the specimen is wound around a drum at each end. During the tensile test, not only is the specimen elongated, but it also winds tighter around the drums (this later action we will refer to hereafter as seating). The total crosshead movement during a test is therefore a combination of seating and specimen elongation and is thus not at all related to the actual strain. To ensure that seating is not inaccurately recorded as strain, systems have been developed which monitor only a small portion of the sample located between the roller grips. In fact, paragraphs 10.6 and 10.6.1 of ASTM Method D4595 encourage the measurement of elongation to three significant figures and refer to various devices such as LVDT's for measuring strain in the specimen in the small area between the roller grips. A comparison of the tensile curves obtained using crosshead movement and an LVDT in the center portion of the specimen clearly shows the large amount of seating that occurs when using roller grips (Table 1). Clearly if crosshead movement is used to calculate strain, the only property that can be accurately measured is ultimate strength; low strain properties and ultimate elongation are grossly inaccurate. Unfortunately the method prescribed by ASTM D4595 does not teach a remedy to the phenomenon that when using an LVDT, the slack must be removed from the specimen to allow the device to be attached. If the slack is not removed, the weight of the device will cause excessive sagging in the specimen as well as making it extremely difficult to zero the device. ASTM D4595, therefore, allows a preload of up to 1.25% of the expected ultimate load to compensate for the slack, and it's ISO counterpart ISO 10319 also allows the specimen to be loaded to 1% of the expected ultimate load.

Table 1. *Comparison of Tensile Properties Using Crosshead Extension and an LVDT to Measure Strain with Roller Grips*

STRAIN (%)	LOAD (kN) Crosshead Extension (500 mm gauge)	LOAD (kN) LVDT Extension (100 mm gauge)
2	0.3	6.0
5	1.0	14.5
10	5.2	30.8
29.3	33.4 (ultimate)	-
10.2	-	31.7 (ultimate)

With roller grips, the method prescribed by ASTM D4595 for monitoring a portion of the specimen between the grips works well for measuring ultimate properties, since the roller grips allow uniform loading and specimen breaks between the grips. Further, ultimate elongation can be determined since the amount of extension experienced by the specimen during preloading is small compared to the ultimate extension. However, the application of a preload, while making reproducibility better, masks the true material behavior at the very beginning of the test, thus inflating the values of the measured low strain properties.

In order to overcome these concerns, a method for rigidly clamping specimens using hydraulic wedge grips was investigated. The hydraulic clamps were specially engineered 8 inch wide flat face plates manufactured by the testing machine manufacturer, MTS, to match the capabilities of the test frame's 65,000 lb. load cell. In order to be able to grip the specimen well enough to prevent slippage and yet not cause failure at the grips, a protective metal tab is placed between the specimen and the grip face. A specimen of woven high strength geotextile was tested using this method, with strain measured both by crosshead displacement and a laser extensometer. Comparison of the resultant tensile properties recorded using these two strain measurement systems demonstrates the relatively small amount of slippage that occurs with this system. (Figure 1). In fact, simply using the crosshead movement to measure low strain properties is possible, since the two curves are basically identical up to 2% strain. This limit of comparable performance in measurement to 2% strain is important. It allows confirmation of accurate data at low strain by parallel measurement and recording. The data compares well despite the fact that the two measurement systems use different gage lengths and therefore, different strain rates.

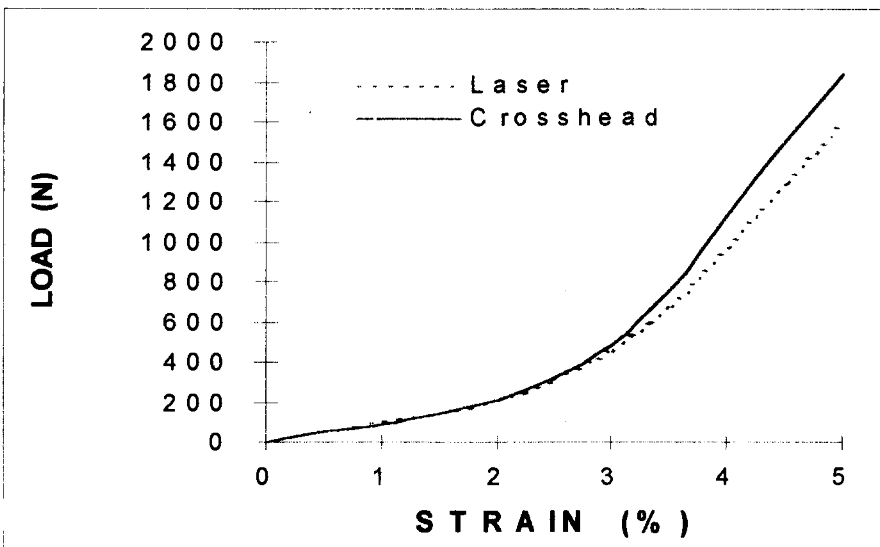


Figure 1. *Effect of Extensometer on Tensile Properties*

Using the wedge grip technique, we are able to reasonably duplicate the test results obtained when using roller grips and an LVDT. This is demonstrated for a high strength geotextile, in which each test was run with an equivalent preload, 100 mm gauge length and 10%/minute strain rate (Figure 2). Note, however, that the ultimate strength measured with the wedge grip system is generally lower than that using roller grips. For very strong products,100 kN/m to 1000 kN/m, the clamping mechanism of the wedge grips was unable to prevent slippage in the grip as the test approached the ultimate value.

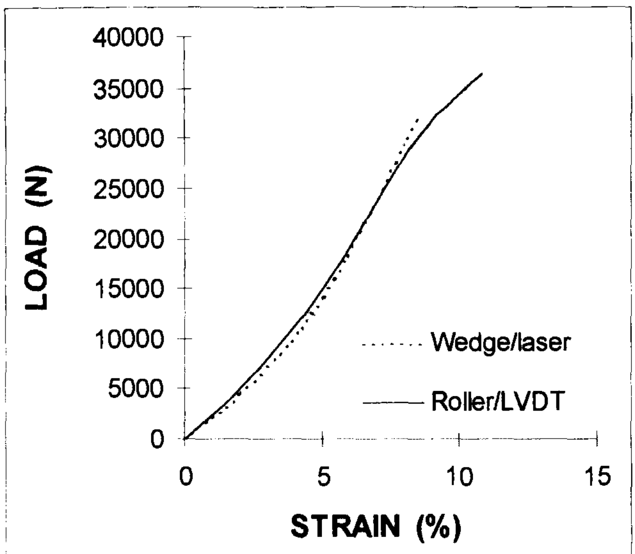


Figure 2. *Comparison of Grip and Extensometer on Tensile Properties*

Measuring Low Strain Properties Using Wedge Grips and Laser Extensometry

In order to obtain accurate and repeatable results for low strain properties it is critical that a reproducible test start point is used. In fact, ASTM D 4595 reports that the results of interlaboratory testing indicated that a major problem was the definition of the origin (zero position) point on the force-elongation curve. In D4595, the convention adopted to achieve a definition of origin is to subject the sample to a small load, referred to as pretension force in ASTM D 4595. We have adopted the term preload in this paper. ASTM D4595 allows 1.25 % of the expected breaking force, up to a maximum of 222 N (50 pounds). The ISO counterpart ,10319, allows 1% of the ultimate with no upper limit on preload. Once the preload is applied, the load and extension are zeroed, and the test is run. In other words, the zero point or origin is defined with the specimen in the preloaded state. While this method can generate reproducible results, it masks, in fact eliminates, the initial portion of the stress-strain curve. Such masking makes it difficult to report stress at the increasingly requested strains of 2 and 5 percent.

An alternate method would be to start the test with slack in the sample, and record force-elongation behavior starting at this point, in other words to eliminate the preload. One problem with this approach is that it is difficult to attach an LVDT to a specimen with no pretension force. While attachment of markers may also present a problem when using a laser or other optical method for measuring strain, it is much easier to overcome. However, a greater problem is that the non-rigid nature of geotextiles and geogrids will not allow repeated specimens to be mounted with a reproducible amount of slack or tension, and any amount of slack will be inaccurately be recorded as specimen elongation and inaccurate low strain properties. The key is to have no tension, and no slack, something which is nearly impossible difficult to achieve. To demonstrate this point, two specimens of a woven fabric were mounted, using wedge grips and a laser extensometer, with varying degrees of slack on purpose, as presented in Figure 3. One specimen was left loose, with some obvious drape, and the other was held with a small amount of hand tension while the bottom clamp was closed. Low strain properties as calculated from these two curves are vastly different if the zero point of the test is taken to be the start of the test.

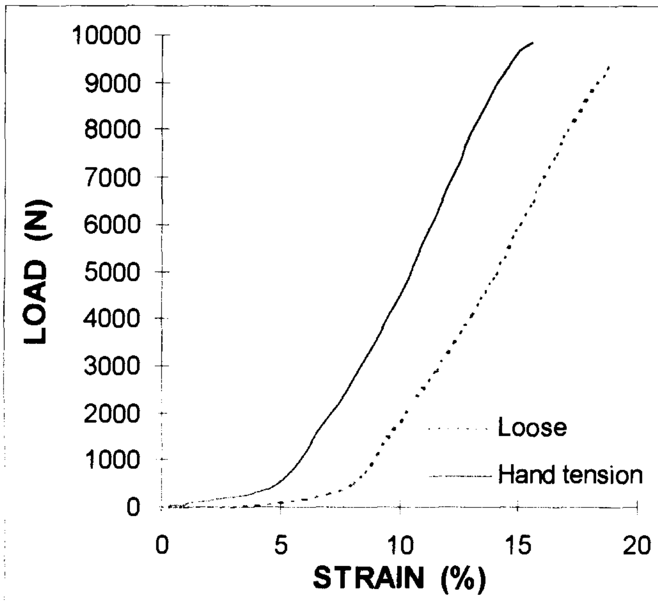


Figure 3. *Effect of Slack in Sample Mounting on Tensile Properties*

It is clear that some means of dealing with this dilemma of requiring a preload to obtain reproducible results and the masking of low strain data with the preload is needed in the testing of the very strong materials typical of geosynthetic reinforcements. Fortunately, there are several techniques to overcome the problem of lost or hidden data resulting from the application of preloads.

One solution is to use the standard ASTM D4595 method with a very small preload, for instance less than 22 N (5 pounds). This method reduces the amount of masking of the low strain behavior, and in theory would be a good solution. However, the repeatable application of such as small preload in practice is difficult.

An alternate approach to solving this problem is the subject of another paper presented at this symposium by Kelkar, etal [*6*]. That method makes use of the wedge grips and crosshead extension to record the load-elongation curve without using a preload. A mathematical technique is presented for determining modulus data based on evaluating the slope of the load-strain curve along its entire length.

A preferred solution is to run the tensile test with the specimen in the untensioned state, thereby allowing the full force-elongation behavior to be recorded. The problem remains as to how to eliminate the slack from being included in the low strain behavior measurement. There are calculations that allow for the slack in a sample to be mathematically eliminated, and are thus known as slack compensation corrections. For example, with the MTS TestWorks software, there are two general types of slack compensation calculations. Both types mathematically adjust the zero point of the test, and recalculate stress-strain values based on this new origin.

In the slope method the origin is defined as the point at which a tangent to a portion of the curve intersects the elongation axis. The portion of the curve to be used to draw the tangent may be defined many different ways (i.e., the minimum slope between two particular load levels or the slope between two predetermined strain points). Selection of a portion, or segment, of the curve is similar to the selection of a segment for the calculation of a segment modulus. The determination of the portion of the curve to be used to draw the tangent can be subjective and dependent on the actual shape of the force-elongation curve. Geotextiles with varying strengths, weave patterns, etc. will have corresponding different force-elongation curves, particularly at low strains. Describing a portion of the curve to use for the zero point determination cannot easily be universally defined. While quite satisfactory for independent research, the slope method for slack compensation is not well suited for a test methodology, which needs to be repeatable and reproducible for a wide range of products.

In the preload method, the origin or zero point is defined as the first location that a line drawn perpendicular to the force axis at a predetermined force intersects the force-elongation curve. This calculation is essentially the same as applying the preloading step after running the test. While the choice of the preload level to use is subjective, it can be defined independent of the resultant curve. Therefore, the test initiation point can be determined, yielding reproducible low strain properties to be calculated, while allowing the entire force-elongation curve to be recorded. The preload method is compatible with both ASTM D4595 and ISO 10319 as it allows the selection of the prescribed values in either method. We have done most of our work using the preload method.

Using the preload method for slack compensation calculation, the specimens shown in Figure 6 were reanalyzed for three different preload levels, 45 N, 107 N and 122 N, the last level corresponding to the maximum of 1.25% of ultimate strength allowed by ASTM D4595 (Table 2). Comparison of low strain properties, at each of the preload levels, show good agreement between the two specimens despite that fact they were mounted with a large difference in the amount of slack prior to test initiation. This is particularly true at strain values of 2% and less. Also important is the relatively large difference in low strain values calculated for preloads of 45 N and 122 N; for example the specimen which was loaded loosely, the values for load at 1% strain are 19 N and 44 N, respectively. This matches the known inflation of low strain properties with increasing amount of applied preload. The use of the preload calculation technique has several important results: (1) the recording of the entire force elongation curve is routine, (2) the entire force elongation curve can be reported in both graphic and tabular form, (3) the data reported is comparable to previously established data bases because the selected preload levels are consistent with historical test methodology and (4) calculation of properties at low strain is possible for preload levels that are very difficult to apply reproducibly in practice.

Table 2
Preload Method Slack Compensation Calculations

Loads Calculated using 45 N Preload			
Strain (%)	Load (N)	Load (N)	
	Loose	Hand tension	
0.5	12	17	
1	19	25	
2	33	42	
3	51	62	
5	202	214	

Loads Calculated using 107 N Preload			
Strain (%)	Load (N)	Load (N)	Actual 107 N
	Loose	Hand tension	Preload
0.5	32	32	12
1	38	36	21
2	63	60	48
3	122	95	109
5	426	368	415

Loads Calculated using 122 N Preload (1.25% of Ultimate)			
Strain (%)	Load (N)	Load (N)	
	Loose	Hand tension	
0.5	34	34	
1	44	43	
2	74	65	
3	149	117	
5	462	424	

Table 2 and Figure 4 present information to demonstrate the consistency of calculated preloads to historical data measured using ASTM D4595 procedures. In the center tabulation of Table 1, the calculated loads at various strains for specimen with no preload are compared with the values recorded for a specimen of the same type fabric preloaded with 107 N prior to test initiation. The data for these three conditions are also shown in graphical form (Figure 4). A decent correlation is achieved between the preloaded specimen and the two calculated curves. In this case, the curves shifted using slack compensation have higher loads at corresponding strain. This may be due to the fact that some relaxation occurs between the application of the preload and the start of the test to mount the extensometer. In fact when using an LVDT, the amount of time between preload application and test initiation may be substantial.

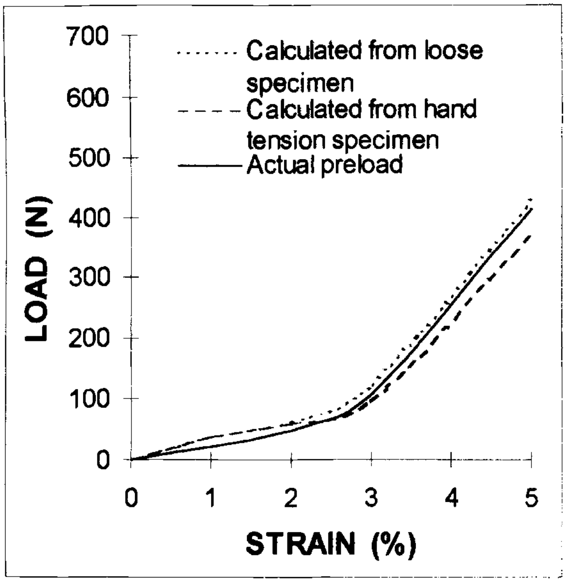


Figure 4. *Comparison of Curves Generated Applying Preload and Shifted Using Slack Compensation*

To demonstrate the viability of the slack compensation method, another set of experiments were run using a warp knit PVC coated textile grid, this time using roller grips and the laser extensometer. Comparison of the curves from specimens with no preload and specimens with 107 N preload once again demonstrate the inflation of low strain properties measured when a preload is applied (Figure 5). Note that there is better agreement between these curves than those of the more flexible woven geogrid (Figure 4). The load at several levels of strain were calculated the specimen run with no preload, at a preload level of 107 N. These values are shown in Figure 6, demonstrating the good agreement with curve of the preloaded specimen. The calculated preload method can therefore be used when using different product types and both roller grips and wedge grips. Note, however, that the use of a laser extensometer is required; we have not attempted to run these experiments using an LVDT because of the attachment issues.

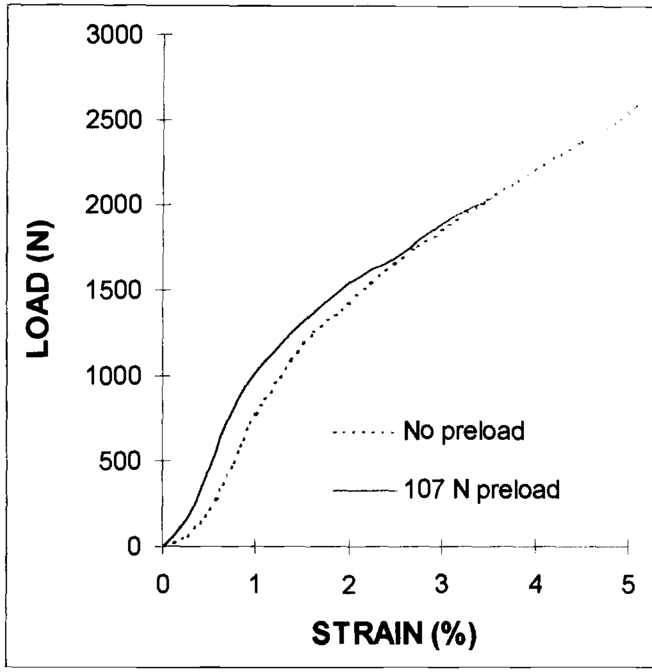


Figure 5. *Effect of Preload on Tensile Properties*

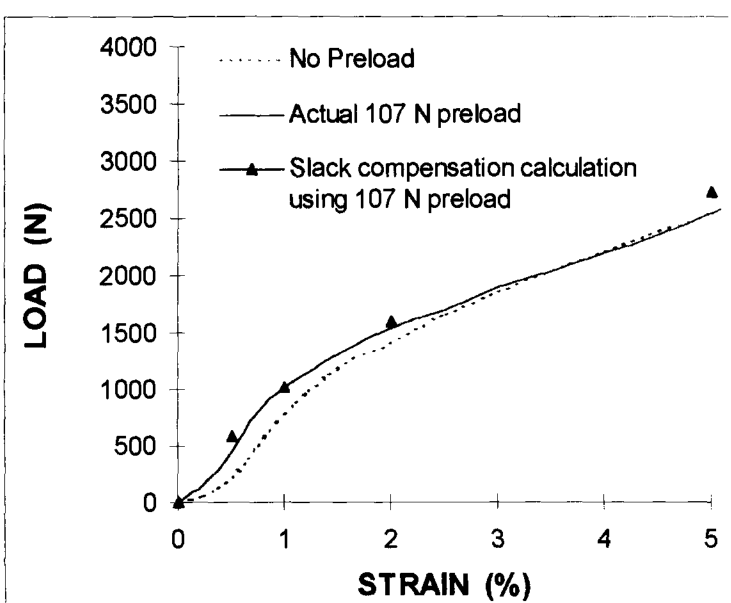


Figure 6. *Comparison of Actual and Calculated Tensile Properties*

Conclusions

Measurement of the low strain properties of high strength geotextiles is difficult, and in fact the current standard, ASTM D4595, points out the problems of reproducibility. The ASTM D4595 preload procedure to make the test more reproducible causes the initial portion of the load-elongation curve to be lost. However, alternate methods are available. The use of wedge grips allows accurate, repeatable and reproducible measurement of low strain properties, even without an external extensometer. The wedge grip system also reduces sample size (length) requirements and the time required to mount specimens compared to roller grips. However, roller grips remain the best system for measuring ultimate properties of high strength geotextiles.

In order to record the complete force-elongation curve, no preload is applied to the specimen, regardless of the grip type employed. The lack of a preload creates the problem of mounting samples with reproducible slack. However, the use of preload slack compensation calculations allows the complete force-elongation curve to be measured and reported, independent of the initial slack. This method allows the use of either wedge or roller grips, but requires the use of laser or other optical extensometers due to their ability to be applied to specimens that have not been preloaded. In addition, the preload slack compensation method allows low strain properties to be calculated for any preload level, which is particularly useful for low preload levels that in practice are extremely difficult to achieve. In fact these low preload levels are preferred in order to best estimate the true geotextile performance. The preload slack compensation method does not exactly replicate ASTM D4595 testing, but should not be expected to because of the difficulty in applying an exact preload in practice, and in the relaxation that occurs between the time a specimen is preloaded and test initiation.

References

[1] Stevenson, P.E. Skochdopole, T.R., Kelkar, A.D., "The Testing of Geosynthetic Reinforcements," *Proceedings of the Sixth International Conference on Geosynthetics*, Atlanta, GA, USA, 1998, pp. 529-537.

[2] Koerner; G.R., "Geosynthetic Proficiency Testing," *Proceedings of the Sixth International Conference on Geosynthetics*, Atlanta, GA, USA,1998, pp. 399-402.

[3] Myles, B. Carswell, I.G., "Tensile Testing of Geotextiles," *Proceedings of the Third International Conference on Geotextiles*, Vienna, Austria, 1986, pp. 713-718.

[4] Bais-Singh, S. Goswami, B.C., "Deformation Behavior of Spun-Bonded Nonwovens:Measurement," *Proceedings of INDA-TEC 96, International Nonwovens Conference*, Crystal City, VA, USA, 1996, pp. 29.1-29.19.

[5] Brand, E.W. and Pang, P.L.R., "Durability of Geotextiles to Outdoor Exposure in Hong Kong," *Journal of Geotechnical Engineering*, Vol. 117, No. 7, pp. 979-1000.

[6] Kelkar, A.D., Stevenson, P.E., Skochdopole, T.R., and Yarmolenko, S.N., "Effects of Gage Length and Test Speed on the Tensile Properties of Geosynthetic Reinforcements," *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379*, P. E. Stevenson and S.R. Allen, Eds., American Society for Testing and Materials, 1999.

Strain Measurement

David Jones[1]

Wide-Width Geotextile Testing with Video Extensometry

Reference: Jones, D., "**Wide-Width Geotextile Testing with Video Extensometry,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: This paper demonstrates the difference between the results of using a conventional direct contact LVDT extensometer versus a non-contacting Video Extensometer where load at specific strains, ultimate load and elongation were measured. Previously, video extensometry has not been used for geotextile testing. Comparisons are made determining their measurement capability and ease of use. Direct contact systems displace yarns and rupture filaments in the fabric sample, which alter both the elongation and ultimate load of the sample. By measuring strain without placing a load on the yarns perpendicular to the loading direction, yarn slippage is eliminated. This principle allows for maximum tensile strength without pseudo failures due to yarn damage. Comparisons are also determined for length of time to calibrate, sample preparation before data acquisition, marking techniques and general observations made from using both systems.

Keywords: direct contact LVDT, video extensometry, rate of strain, MARV, statistically capable.

Introduction

The use of direct contact LVDT units, which contain pins to hold the extensometer between the geotextiles perpendicular yarns, lead to premature rupture of the sample, which affects the ultimate load and elongation of the sample. (Figure 1). In addition, direct contact extensometers have multiple parts and are mechanically limited due to their design. Frequently, there is a certain amount of looseness or 'play' in the LVDT device when attaching it to the geotextile, which directly affects its strain measurement capabilities. This 'play' also creates an inability to have a consistent starting point and continually changes where strain measurement begins, which must be manually set by the operator. This setting of the starting point must be repeated for each sample and, depending on the type of method, can vary between operators and within a set of tests. The Video Extensometer measures strain by tracking two contrasting lines placed on the sample. (Figures 2 & 3). It is set up and calibrated for a specific optical field of view, depending on lens selection. The calibration and internal reference point do not change unless the camera is physically moved or the lens is changed. The use of video also allows the user to average strain measurement data across the width of the sample being measured and takes into consideration any possible skew present in the sample during the test. Conversely, direct contact systems, rely on the perpendicular yarns to hold itself in place and assume zero slippage in its strain measurement calculations.

[1]Technical Manager, Technical Department, Synthetic Industries, Inc., 2100A Atlanta Hwy, Gainesville, GA 30504, ®David Jones, November 1998.

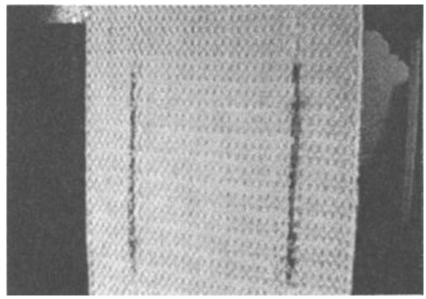


Figure 1. *Premature rupture on the machine direction yarns due to filament damage where the direct contact pins were placed into the sample.*

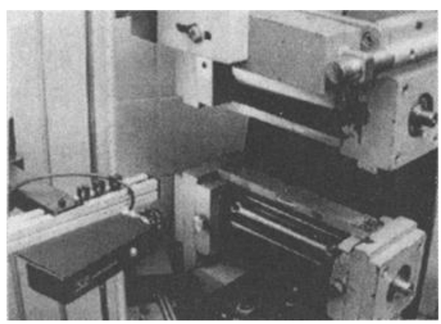


Figure 2. *Video camera mounted at 30° angle from side of tensile tester, shown with 8' wide roller grips.*

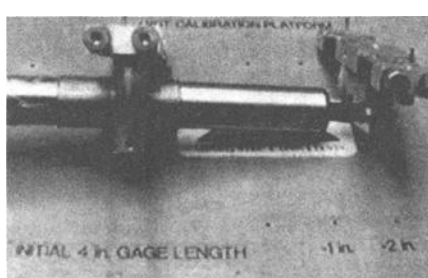


Figure 3. *Conventional direct contact extensometer with screw pins facing upward. LVDT calibration platform is shown in background.*

Calibration

Calibration of the Video Extensometer is performed automatically via computer software using a precision calibration bar placed on the same plane as the material being tested. The calibration constants are stored in a file and are valid for calculations based on optical measurements until the system is moved or another lens is selected. Before the test begins, the distance between the marks is measured using the software. This distance is then used as the gauge length in determining strain for the Test. Accurate positioning of the marks on the sample, therefore, is not required. The direct contact LVDT unit is typically calibrated on an LVDT platform, which was originally fabricated to specifications via caliper. It is then placed onto the geotextile and balanced to zero at a reference point where each sample begins testing. Calibration of the LVDT is performed a minimum of every shift and is required so often due to high-energy release when the sample ruptures. Each rupture on a direct contact LVDT places stress on its displacement rods, which changes its linearity and therefore it must be calibrated frequently. From this standpoint, it is believed that video extensometry would be easier to maintain, calibration and operate.

Methodology

A comprehensive study was performed over a six-month period of time to determine if data measurements could be acquired without a direct contact extensometer mounted on the sample. Load and strain measurements were observed for accuracy with the video system compared to the direct contact LVDT and vice versa. Three different geotextiles were tested in the machine and cross machine direction with a conventional direct contact extensometer and a Video Extensometer. (Data Comparison Tables 1 – 3). This information demonstrates a comparison of the capability of each system to measure load and elongation.

Table 1. Polypropylene reinforcement fabric with 400 lb/in MARV warp and fill direction.

	Avg. Video	**Avg. Direct**	**Std. Dev. Video**	**Std. Dev. Direct**
Ld @ 2% (W x F)	89, 124	83, 129	16.6, 15.0	8.8, 12.4
Ld @ 5% (W x F)	192, 261	180, 258	26.3, 15.1	10.2, 16.5
Ld @ 10% (W x F)	341, 424	328, 443	29.8, 21.1	15.5, 25.9
Max E% (W X F)	14.8, 11.2	15.4, 11	2.9, 1.0	1.4, .7
Max Ld (W x F)	476, 460	435, 468	24.0, 17.4	32.9, 24.8

2

[2] Ferguson, Brint, personal communication, 1998.

Table 2. Polyester reinforcement fabric with 400 x 600 lb/in MARV warp and fill direction.

	Avg. Video	Avg. Direct	Std. Dev. Video	Std. Dev. Direct
Ld @ 2% (W x F)	55, 164	54, 149	5.9, 17.6	5.7, 17.5
Ld @ 5% (W x F)	136, 331	135, 318	13.4, 27.6	9.0, 25.5
Ld @ 10% (W x F)	277, 570	274, 595	21.0, 29.6	14.9, 27.7
Max E% (W X F)	18.3, 12.6	18.7, 12.6	1.4, 1.4	1.1, 1.1
Max Ld (W x F)	452, 661	459, 692	25.6, 21.6	22.4, 34.7

Table 3. Polyester reinforcement fabric with 1200 x 1200 lb/in MARV warp and fill direction.

	Avg. Video	Avg. Direct	Std. Dev. Video	Std. Dev. Direct
Ld @ 2% (W x F)	246, 279	201, 329	18.1, 30.9	57.1, 51.3
Ld @ 5% (W x F)	520, 645	544, 658	42.0, 43.4	111.6, 111.1
Ld @ 10% (W x F)	1331, xxx	1250, 1143	39.6, 84.2	88.7, 156.7
Max E% (W X F)	9.4, 14.1	11.0, 11.6	.4, 1.2	1.8, 2.2
Max Ld (W x F)	1363, 1256	1341, 1295	44.3, 27.1	43.0, 68.1

xxx = Average Elongation did not exceed 10%.

[3]Marking Techniques

It is important to recognize that video extensometers require the operator to draw contrasting lines on the samples being tested. (Figure 4). During the study numerous different marking techniques were attempted in order to optimize the contrast between the sample and the mark that the camera detects. When testing white geotextiles in the warp direction, a black felt tip marker was used to make two lines 1/8" thick four inches apart. The marks were centered on the sample and were made at half the width of the each sample being tested. When testing white fabrics in the filling direction, white

[3] Tench, Marcus, Synthetic Industries, Inc., Gainesville, GA, personal communication, 1998.

corrective tape was placed on the fabric, a 1/8" black line was then drawn over the white tape in the same manner as the warp direction. When testing black geotextiles, a white or silver reflective paint pen was used to make two distinctive marks four inches apart.

Direct Contract LVDT units do not require distinctive marks on the sample since they penetrate the fabric and allow the yarns to hold itself in place as it records strain. However, when testing in the fill direction, it is frequently necessary to place a small dot of hot glue between the pin and filling yarn to hold the LVDT into place. During the study it was common to find the weight of the LVDT itself causing fluctuations in strain measurements because of its natural tendency to pull itself downward. This is especially noticed under the higher load levels with loose constructions geotextile fabrics.

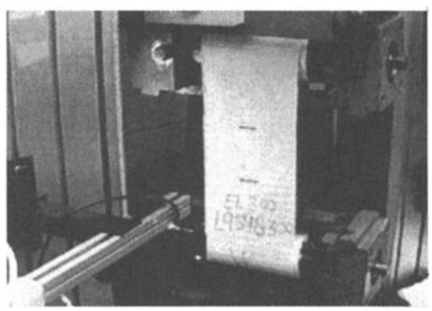


Figure 4. *White geotextile sample with black marks created with 4" template to maintain accurate starting gauge lengths.*

Conclusion

The paper has presented data from a 6-month use of direct contact and video extensometry on like fabrics that indicate both systems to be statistically capable. Calibration of the video system, performed by software, is more accurate than calibration of direct contact units. (Figure 5). Set up time using the video system requires less time and less physical effort than direct measurement systems.

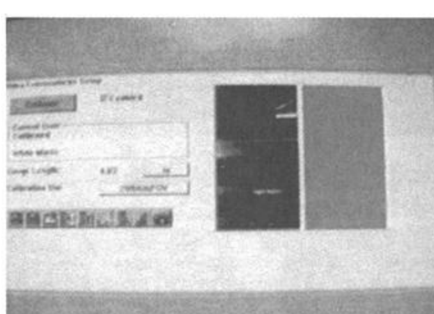


Figure 5. *Display of software calibration screen. Image depicts reference points between each measured mark, which is stored and used in future calculations.*

Finally, the video system demonstrated a greater ease of use, flexibility and increased number of capabilities due to its software calculations and graphics functions. A brief summary is provided to differentiate the two systems. (Table 4).

Table 4. Summary to differentiate the two systems.

	Direct System	**Video System**
Set Up Time	Status Quo	Saved 6' per sample
Calibration	Required at least every shift @ 5' each	Required at lens change @ 10' each
Marking	N/A	Use tape or marker @ <1'
Std. Dev. of 2%, 5% & 10% Strains	Comparable to Video	Comparable to Direct
Std. Dev. of Ultimate Strain	Comparable to Video	Comparable to Direct

__Note:__ The above data are averages over the entire range of fabrics tested. Set up time is the time to place the LVDT onto the geotextile. Comparable is defined by not statistically different in 30 data points.

Each average number represents 30 data points, where each data point is an average of 5 individual tests in both the warp and fill direction.

REFERENCES

Fluet, Joseph E. (1987) "Geotextile Testing and the Design Engineer" American Society For Testing and Materials, pp.163-166.
Joseph Marjory L. (1977) "Textile Science"
Holt, Rinehart and Winston, USA, pp. 161-162.
Morton W. E., Hearle J. W. (1975) "Physical Properties of Textile Fibres" The Textile Institute Manchester, pp. 322-340.

Khalid Farrag and Mark Morvant [1]

Effect of Clamping Mechanism on Pullout and Confined Extension Tests

Reference: Farrag, K. and Morvant, M., "**Effect of Clamping Mechanism on Pullout and Confined Extension Test,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Two different clamping mechanisms are commonly used in pullout and confined extension tests of geosynthetics. The first method consists of extending the clamps inside the soil to a sufficient length that ensures the confinement of the whole specimen length during testing. The frictional resistance of the part of clamping plates inside the soil is subtracted from the results to obtain the resistance of the geosynthetic specimen. The second method consists of clamping the geosynthetic specimen outside the soil. In this method, displacement measurements are taken in the confined part of the specimen in the soil and, hence, the readings are not influenced by the possible slippage of the specimen between the clamps.

A comparison of test results using both installation techniques is presented and the boundary effects associated with both mechanisms are evaluated. In the tests where the clamps were extended inside the soil, earth pressure near the front facing was measured in order to evaluate the frictional resistance of the clamping plates. Soil pressure measurements were taken after applying the confining pressure and during the test to monitor the development of vertical stresses at the vicinity of the clamping plates. The measurements showed an apparent increase of vertical pressure above the clamps. The results were corrected for the increase of the vertical pressure due to frictional resistance of the clamping plates.

When the clamping plates were connected to the specimens outside the box, displacements were measured along the specimen length. These measurements were extrapolated to determine the front displacement of the specimen at the pullout load application point. The use of the extrapolated front displacement resulted in a more reasonable load-displacement relationship for the geosynthetic specimen.

Keywords: geosynthetics, pullout test, confined extension test, clamping plates, earth pressure

[1]Research Coordinator and Geophysical Research Manager, respectively, Louisiana Transportation Research Center, 4101 Gourrier Avenue, Baton Rouge, LA 70808.

Introduction

Geosynthetic specimens in pullout and confined extension tests are usually connected to the loading system using two metal clamping plates having the same width of the specimen with a series of bolts holding the specimen in between [*1, 2*]. For geotextiles, bonding materials like epoxy can be applied on the part of the specimen between the clamps to insure even distribution of the load without slippage. The clamping plates may extend through metal sleeves inside the soil to insure that the specimen remains confined in the soil during the test. Figure 1 shows a schematic diagram of the connection mechanism with the clamping plates extending inside the soil. The frictional resistance of the confined part of the clamps is subtracted from the measured loads to obtain the resistance of the geosynthetic specimen. The frictional resistance of the clamping plates is obtained by running pullout tests on the plates at various confining pressures without the geosynthetic specimen [*1*]. This paper evaluates the effect of the boundary conditions that result from extending the clamping plates inside the soil. Measurements of earth pressure cells near the plates are used in establishing the load-displacement relationship of the specimen.

Another clamping arrangement used in the tests consists of connecting the geosynthetic specimen to the plates outside the soil (Figure 2). In order to exclude the elongation of the unconfined part of the geosynthetic specimen, displacement measurements are taken inside the soil using tell-tail wires attached to points along the specimen length. These wires are connected to elongation measuring devices, as linear variable differential transformers (LVDTs). The measured displacement at the first node (node 1 in Figure 2) inside the specimen is typically assumed to correspond to the measured pullout load. This assumption is evaluated in this paper by establishing the shape of the displacement curve along the specimen. A procedure is presented to estimate a more realistic value of displacement at the location of load application point.

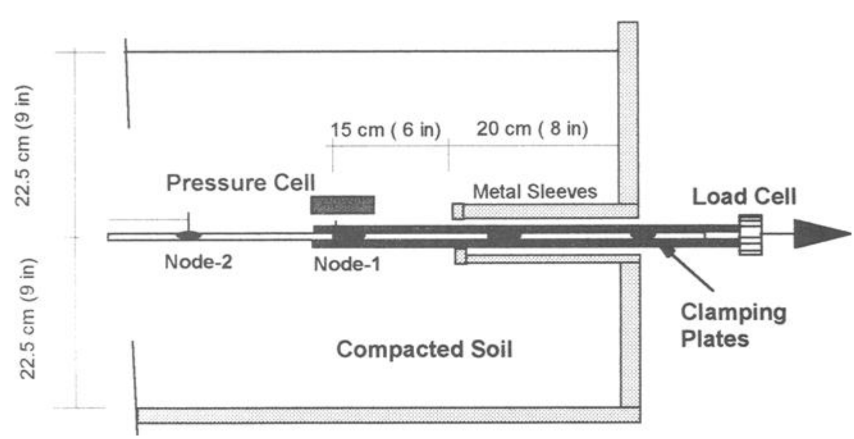


Figure 1- Clamping Plates Extend Inside the Pullout Box

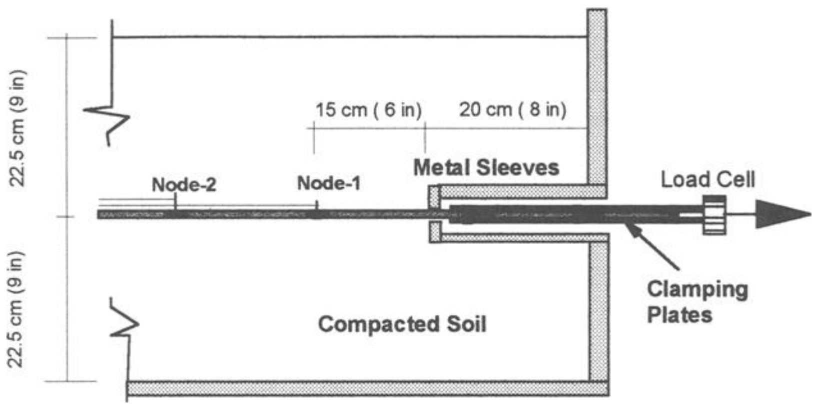


Figure 2- *Geosynthetic Specimen Clamped Outside the Box*

Pullout Tests with the Clamps In-Soil

An advantage of extending the clamping plates inside the soil is to insure that the confined length of geosynthetic specimen remains constant during testing. Such procedure necessitates subtracting the resistance of the confined part of the clamping plates from the measured pullout/extension loads. The resistance of the confined part of the clamping plates is obtained from pullout tests conducted on the clamping plates without the geosynthetic specimens. Pullout tests on the plates are conducted at identical confining pressures and testing conditions as those with the geosynthetics.

Measurements of vertical pressure developed on top of the geosynthetic specimen and the clamping plates show an increase in the apparent pressure during testing. Figure 3 shows measurements of the vertical pressures versus the front displacement of the geosynthetic specimen during pullout tests. These tests were conducted on HDPE geogrids in silty clay soil of dry density 1.5 kg/m^3 (95 pcf), soil moisture contents of 18% and 22%, and at a confining pressure of 49 kPa (7 psi). Earth pressure cells of 5 cm (2 in) diameter were placed on top of the clamping plated near the geosynthetic-soil interface as shown in Figure 1. The results in Figure 3 show that the vertical pressure increased to more than twice the pressure applied at the beginning of the test.

Previous work [*3*, *4*] has also shown that normal pressure at the soil-geosynthetics interface can be 1.5 to 3 times higher than the applied overburden pressure. This increase is mainly due to the displacement of soil at the interface during pullout. As soil is restrained at the rigid front facing of the box, soil displacement results in an increase in the active soil pressure near the facing. Moreover, soil shear strains during pullout result in dilation of the compacted soil near the specimen and the clamping plates interface. The restrained soil dilation also leads to an increase in soil vertical pressure.

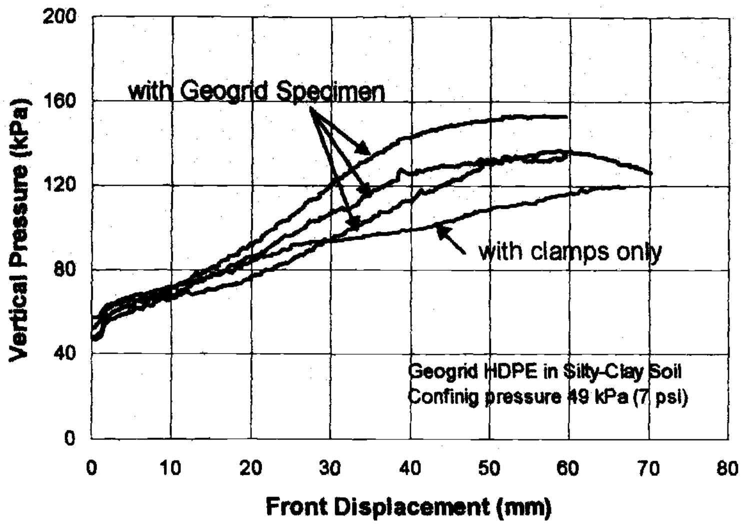


Figure 3- *Measurements of Vertical Pressure at Clamping Plates During Pullout*

It becomes necessary to investigate if the increase in vertical pressure also exists when testing the clamping plates alone. For this purpose, earth pressure was measured on clamping plates tested without the geosynthetic. The results in Figure 3 show comparable increase in the vertical pressure at displacement up to about 30 mm where pullout resistance is fully mobilized. At larger displacement, vertical pressure was slightly higher when testing with the geogrid. This increase is mainly due to the increase in soil dilation on top and bottom of the plates caused by the displacement of the geogrid specimen.

It can be concluded that the difference in the pressures at high displacement is not problematic and that boundary conditions related to the development of vertical pressures are approximately comparable with and without the specimen. Accordingly, geosynthetics load-displacement relationship can be obtained after direct subtraction of the resistance of the clamping plates. Figure 4 shows typical pullout results before and after subtracting the resistance of the clamping plates.

Pullout Test With the Clamps Outside the Soil

When the geosynthetic specimen is connected to the clamping plates outside the soil, the task of subtracting the resistance of the clamping plates from the measured pullout loads is eliminated. However, the portion of the specimen outside the box is subjected to an unconfined extension. As a result, front displacement is measured inside the soil rather than at the load application point.

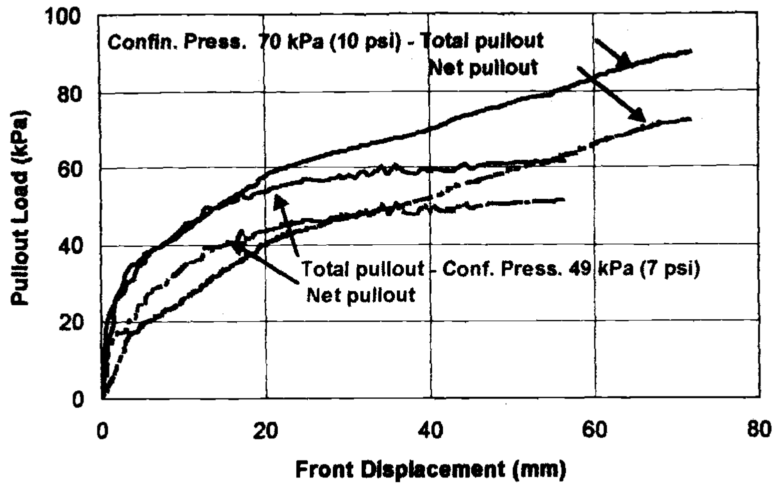


Figure 4- *Calibration for Clamping Plates in Pullout Tests*

A schematic diagram of the displacement measurements along the geosynthetic specimen is shown in Figure 5. The distribution of displacement along the specimen length can be approximated as shown in the figure. Accordingly, the load-displacement relationship is established by plotting the measured load versus the displacement at the front portion of the specimen; i.e. at node 1.

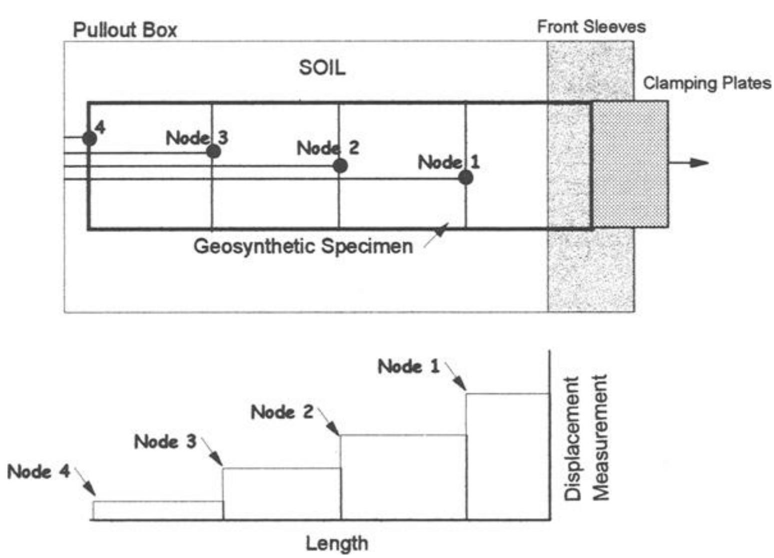


Figure 5- *Displacement Measurements along the Geosynthetic Specimen*

Displacement measurements along geosynthetics specimens show that the elongation curve is steep near the facing with maximum elongation near the load application point [5, 6]. Figure 6 shows the displacement measurements during a pullout test with the clamping plates outside the soil. This test was conducted on HDPE geogrid in silty soil of dry density 1.6 kg/m^3 (100 pcf), soil moisture contents of 15% and at a confining pressure of 49 kPa (7 psi).

When the clamping plates were placed outside the soil, node 1 displacement was measured at a distance of 15 cm (6 in) from the soil facing to ensure that it remained confined during pullout testing. Curve fitting was used to calculate the displacement at the soil facing for each loading level. The procedure consisted of establishing the equation of the displacement curve at selected load levels and the increase in displacement from node-1 to the facing was extrapolated (Figure 6). The figure shows that the displacement at node 1 underestimates the actual mobilized facing displacement and an estimation of the displacement at the facing is necessary in order to establish a more realistic pullout load-displacement curve.

The extrapolated increase in facing displacement is shown in Figure 7 against loading levels. This curve was used to obtain the displacement at the facing at any load. Pullout load versus the calculated displacement at the facing is plotted in Figure 8 along with the curve of pullout load versus the measured displacement at node-1. The first curve would present a more realistic load-displacement relationship for the geosynthetic specimen.

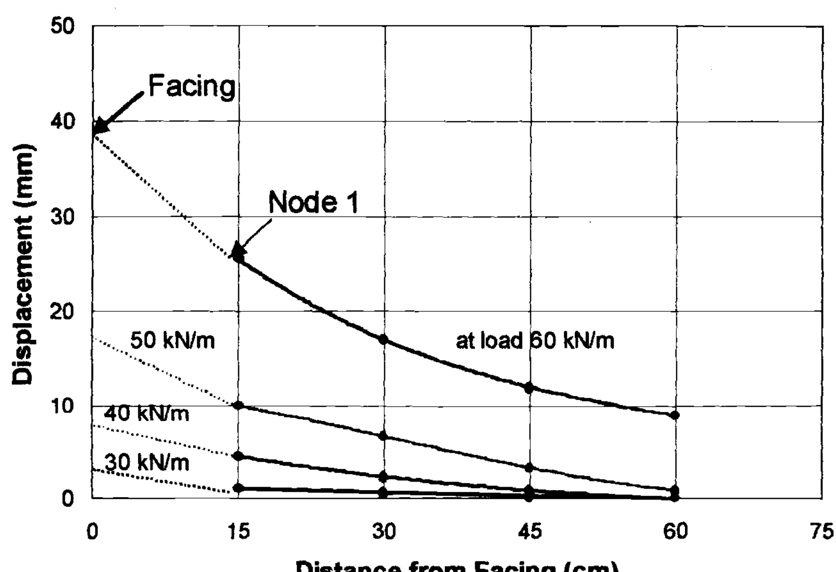


Figure 6- *Displacement Distribution Along the Specimen in Pullout Test*

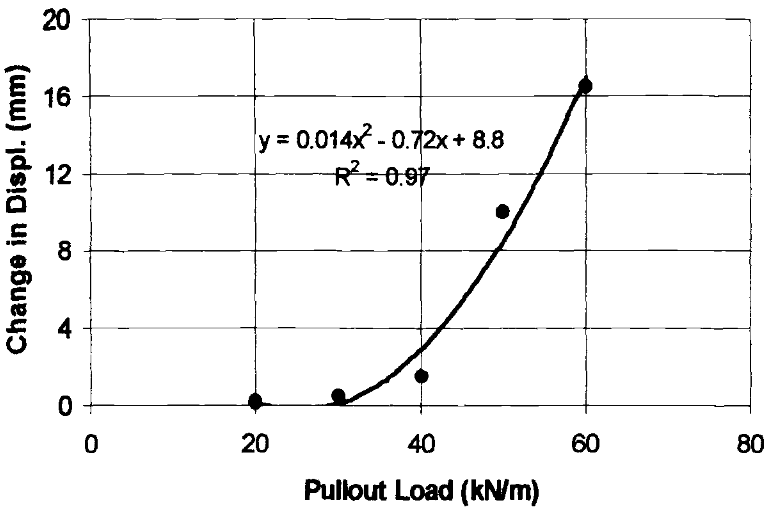


Figure 7- *Increase in Displacement from Node 1 to the Facing with Load*

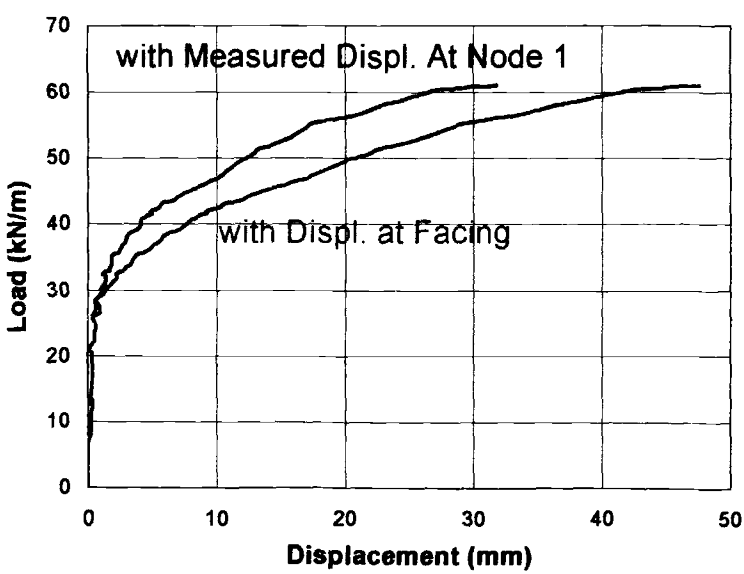


Figure 8- *Pullout Load versus Facing Displacement and Node 1 Displacement*

Conclusion

The two common techniques for clamping the geosynthetic specimens in pullout and confined extension tests were investigated. Extending the clamping plates inside the soil has the advantages of having a constant confined specimen length during the test and of measuring the displacement at the load application point. Test results showed that vertical soil pressure above the clamps increased during pullout tests. Consequently, calibration tests to obtain the frictional resistance of the clamping plates were conducted at the same confining pressures and soil testing parameters as those with the geosynthetic specimen. Results of pullout tests on clamping plates showed that the vertical stresses above the plates were comparable with those tested with geogrid specimens. Accordingly, direct subtraction of the plate's frictional resistance was performed to obtain the geosynthetic resistance.

The use of clamping plates outside the soil has the advantage that displacements are not affected by the slippage between the specimen and the clamps. However, the first nodal displacement inside the soil is less than the actual facing displacement that the specimen undergoes during testing. An extrapolation procedure was presented to estimate the displacement at the facing in order to generate an appropriate load-displacement relationship.

References

[1] Farrag, K., Acar, Y., and Juran, I., "Pullout Resistance of Geogrid Reinforcement," *Geotextiles and Geomembranes*, Vol. 12, No. 2., 1993, pp. 133-159.

[2] Elias, V., Yuan, Z., Swan, R., and Bachus, R., "Development of Protocols for Confined Extension/Creep Testing of Geosynthetics for Highway Application," Federal Highway Administration Report No. FHWA-RD-97-143, 1997.

[3] Juran, I., Knochenmus, G., Acar, Y., and Arman, A., " Pull-out Response of Geotextiles and Geogrids (Synthesis of Available Experimental Data)," *Geosynthetics For Soil Improvement, Geotechnical Special Publication No. 18*, ASCE, 1988, pp. 92-111.

[4] Farrag, K. and Griffin, P., "Pull-out Testing of Geogrids in Cohesive Soils," *Geosynthetic Soil Reinforcement Testing Procedures, ASTM STP 1190*, American Society for Testing and Materials, 1993, pp. 76-89.

[5] Tzong, W.H. and Cheng-Kuang, S., "Soil-Geotextile Interaction Mechanism in Pullout Test," *Proceedings, Geosynthetics'87 Conference*, Industrial Fabrics Association International, New Orleans, USA, 1987, pp. 250-259.

[6] Bonczkiewcz, C., Christopher, B. R., and Atmatzidis, D.K., "Evaluation of Soil-Reinforcement Interaction by Large-Scale Pull-Out Tests," *Transportation Research Record 1188*, Transportation Research Board, 1988, pp. 1-18.

S.H. Chew,[1] W.K. Wong,[2] C.C. Ng,[2] S.A. Tan,[3] and G.P. Karunaratne[3]

Strain Gauging Geotextiles Using External Gauge Attachment Method

---

Reference: Chew, S. H., Wong, W. K., Ng, C. C., Tan, S. A., and Karunaratne, G. P., "**Strain Gauging Geotextiles Using External Gauge Attachment Method,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Measurement of geotextile deformation allows an in-depth understanding of the behaviour of geotextiles. However, attaching strain gauges to geotextiles poses a challenge as geotextiles are soft and have a fibrous surface. A properly installed strain gauge must not only adhere firmly to the geotextile, but also the method of strain gauge attachment must not change the surface properties of the geotextile significantly. Two common methods of geotextile strain measurement are attaching strain gauges directly to the geotextile with an adhesive agent and mounting electronic sensors by means of two end plates fixed to the geotextiles. The first method will inherently stiffen the localized area of the geotextile due to the introduction of the adhesive agent. In the second method, the electronic sensors are generally large, bulky and expensive. Therefore, a new strain gauging method is proposed which is intended to minimize or eliminate the limitations of the present strain measurement methods. This new method makes use of the idea of attaching gauges "externally" to a thin plastic strip whose ends are connected to the geotextile via two end plates. Hence, the geotextile region where the strain is measured remains virtually unaffected. Because of the relatively low modulus of the plastic strip, its strain is nearly the same as that of the geotextile. The results show that the proposed method is able to measure the true global strain developed in the geotextile with a correction factor of about 1.1. This method allows registration of strains up to about 10% and has very little stiffening effect on the geotextile.

Keywords: strain gauge, geotextile, external gauge attachment, strain measurement

Introduction

Continuous strain measurement in geotextiles permits a better understanding of their behaviour in civil engineering applications. However, the present methods of strain measurement have several significant limitations. The most common problem associated

---

[1]Asst. Professor, [2]Research Scholar and [3]Assoc. Professor, Department of Civil Engineering, National University of Singapore, 10 Kent Ridge Crescent, Singapore 119260.

with strain gauge measurement is the local stiffening effect of the geotextile due to the use of adhesives leading to the inability to maintain the flexibility of the geotextile. Hence a new method of attaching strain gauges "externally" is proposed. The preliminary results indicate that the proposed method can produce reliable and repeatable measurement of strains that are comparable to directly measured strains between two end plates via potentiometers.

Stiffening Effect of Adhesive on Geotextile

Specific problems have to be overcome if large strains on the order of around 10 % are to be measured in geotextiles. Among them are the choice of a suitable strain gauge, the choice of a suitable adhesive for gluing the strain gauges to geotextiles, and the interpretation of the signal. As the response of the strain gauge mainly depends on the stiffness ratio of the geotextile to the strain gauge system, a correction factor has to be determined experimentally for each type of geotextile [*1*]. The feasibility test conducted by Sluimer and Risseeuw [*1*] shows that the measured strain by the strain gauge (EP-08-40) directly glued onto the geotextile by silicon gel (Terostat-33) deviates from the actual deformation of the geotextile due to the shear and tensile deformation of the glue and the interaction between geotextile and gauge. The soft elastic silicon adhesive was used because it has a low modulus which minimizes the adverse effects on the geotextile behaviour. However, its cementation may be insufficient to prevent relative movement between the elongating geotextile and the adhered strain gauge. Hence, a laboratory test was conducted to obtain a calibration factor [*2, 3*].

A comparison was made between the strains measured by strain gauges and a tell-tale system during pullout tests of geotextile in sand in the National University of Singapore laboratory by Ho [*4*]. The strain gauges (PL-60-11, manufactured by TML) with maximum strain range of 3% were glued onto the surface of the composite geotextile (PEC 75/25) directly using P-2 adhesive (manufactured by TML). This installation method apparently stiffened and hardened the geotextile. Figures 1 and 2 show the strain readings measured by strain gauges and the tell-tale system during two different pullout tests of geotextiles in sand. The results show that the strain readings recorded by the strain gauges were about 5 to 8 times smaller than those of the tell-tale system in areas of high strain. Therefore, the stiffening effect of the adhesive on the flexible polyester base geotextile is a significant limitation in using strain gauges to monitor strain development in geotextiles.

Electronic Sensors Mounted on Two End Plates

In view of the stiffening effect of adhesives, an innovative type of strain measurement system was developed by Perkins and Lapeyre [*5*]. Four types of electronic sensors, mounted on two end plates, were glued onto the geotextiles permanently. The four sensors used were vibrating wire displacement gauges, vibrating wire strain gauges, linear variable differential transducers and bonded resistance foil strain gauges.

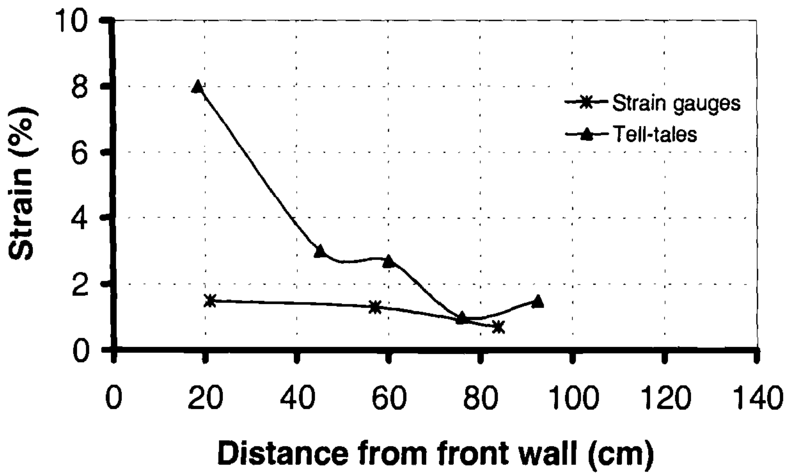


Figure 1 - *Pullout Test 1 in Sand (after Ho, [4])*

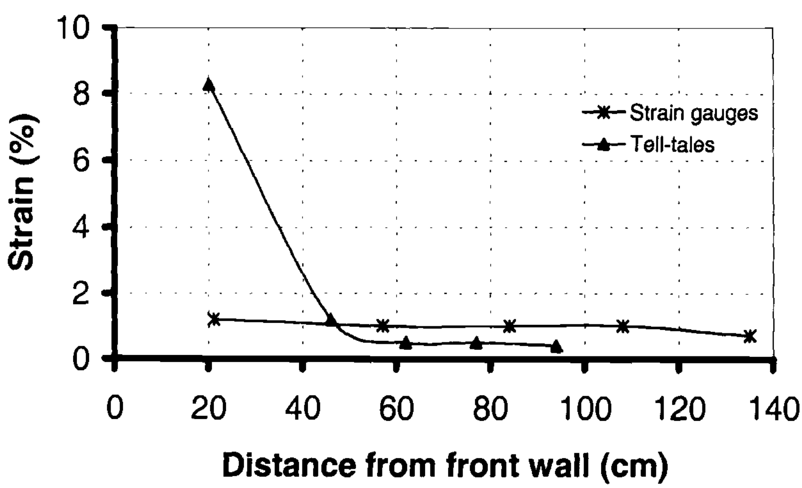


Figure 2 - *Pullout Test 2 in Sand (after Ho, [4])*

Perkins and Lapeyre [5] stated that the measured strain is lower than the global strain at a particular load level. A correction factor, which accounts for the portion of the geotextile specimen in the unclamped region between the mounting plates, has to be used to calibrate the measured strain. This factor depends on the arrangement of the mounting plates, the geotextile type, and the direction of the load applied.

There are a few limitations of this method. Firstly, the sensors are expensive for practical use. Secondly, they are too bulky for use in field installation as they may not survive through the construction process. Thirdly, the sensors' rigidity restricts the free deformation of the geotextiles.

External Strain Gauge Installation Method

In view of the above limitations, a new strain gauging method is proposed. This method minimises the stiffening effect of the geotextile as no adhesive agent is used. The simplicity, durability, and sensitivity of the new method are taken into consideration in the development. Figure 3 shows the proposed method, where the strain gauge is attached "externally" without coming into contact with the geotextile directly.

The new strain gauging method makes use of the idea of attaching gauges "externally," where two ends of a thin plastic strip (glued with strain gauges) are connected to the geotextile via two aluminium end plates. It is to be noted that the strain gauge is not glued onto the geotextile directly but spans on the backing of the plastic strip across two aluminium end plates that are attached to the geotextile. Hence, no adhesive is used to stiffen the geotextile region where the strain is to be measured. When the plastic strip strains between the two end plates, the strain is measured by the strain gauge. The end plates may be of a much stiffer material than the geotextile. The length and width of the end plate are 45 mm and 15 mm respectively. The stiffening effect of the geotextile caused by the plastic strip is minimised and can be controlled by varying the width of the two end plates on which it is attached. The same method may be used for geotextiles of different stiffness with proper choice of the dimensions of the end plates. As long as the stiffness of the plastic base material is significantly less than that of the geotextile, the plastic base material will not affect the strain measurement by external strain gauges. This new method also allows the strain gauge to follow the flexibility of the geotextile. The strain gauge and its relevant components of this method can also be protected to ensure that they survive the harsh installation and construction activities.

The installation procedure is described as follows: An I-shape plastic base material is cut from a transparent acetate film used for overhead projector to the desired size. The strain gauge is fixed using CN glue (Cynoacrylate adhesive by TML, Japan) onto the plastic base, which is used as a backing material for the strain gauge. Super glue (Cyanoacrylate adhesive by Yamayo, Japan) is used to mount the plastic base onto the end plates. The end plates are then attached to the geotextiles using Araldite (High performance epoxy adhesive by Performance Polymers, UK). Finally, the whole arrangement is protected from damage due to vibration and moisture by applying a coat of silicone gel (RTV75). An important factor to note is that the two ends of the strain gauge must extend beyond the inner edges of the end plates. If a portion of the plastic surface between the end plates is not covered by the strain gauge, the strain gauge system will fail to register strain above 0.9% due to the yielding of this gap of the plastic base in between the end plates (Figure 4).

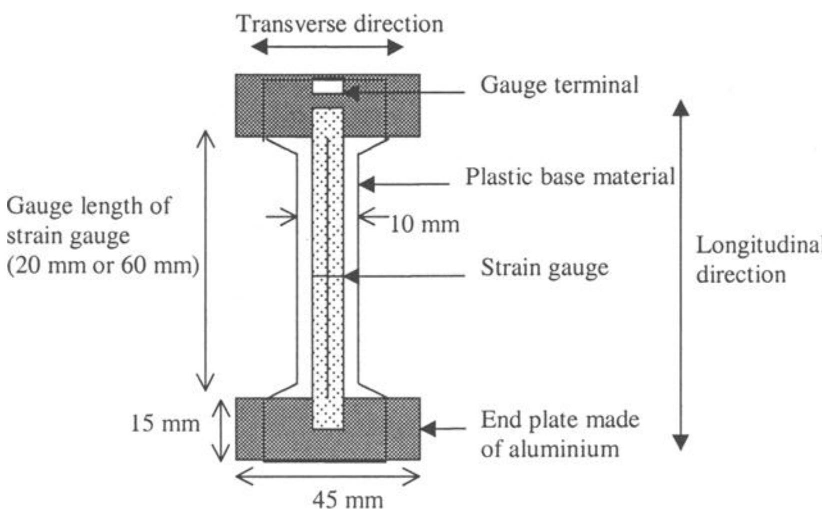


Figure 3 - *Schematic View of the Strain Gauge and Components*

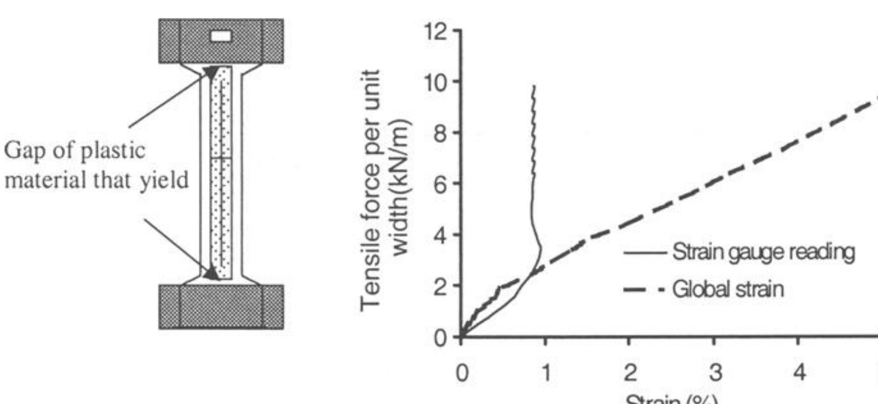


Figure 4 - *Yielding of Uncovered Gap of the Plastic Surface Material*

Testing Procedure

The effectiveness of this method was examined by conducting a series of wide width tensile tests on geotextiles with external strain gauges attached to them. A high yield strain gauge manufactured by Tokyo Sokki Kenkyujo Co., Ltd. (TML), YL series, was used as it has a maximum strain range of 20%. Two strain gauges of the same specifications except for different gauge length, namely YL-20 and YL-60, were used in order to check whether the new strain gauging method is independent of the gauge length. The details of the test program are summarized in Table 1. The geotextile was 200 mm in width and 100 mm in gauge length, with an aspect ratio of 2. The wide width tensile test was conducted using an improvised triaxial testing machine. The machine produced a constant displacement rate of 6 mm per minute during these tests. The specimen was clamped in place by roller grips to minimize slippage and localised concentration of transferred force [6]. During the tests, the actual elongation of the specimens was monitored by two potentiometers attached to the end of the specimen via the end plate.

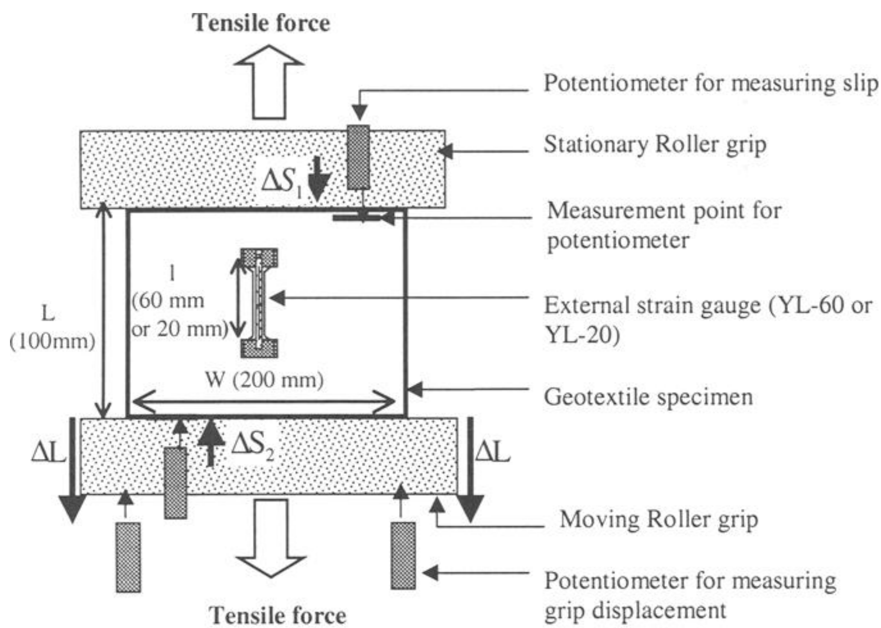
Care was exercised to eliminate the amount of slip at both ends of the geotextile specimen at the roller grips. The absolute displacement between the two end points of the specimen was determined and hence the global strain developed as shown in Figure 5.

Table 1 - *Test Program*

Test No.	1	2	3	4	5
Strain gauge	No gauge	YL-60	YL-60	YL-20	YL-20
Gauge length	-	60 mm	60 mm	20 mm	20 mm
Protection	-	-	Silicon Gel	-	Silicon gel
Displacement rate	6 mm/min	6 mm/min	6 mm/min	6 mm/min	6 mm/min
End plate dimension	45 mm by 15 mm	45 mm by 15 mm	45 mm by 15 mm	45 mm by 15 mm	45 mm by 15 mm

Results and Discussion

Figure 6 shows the tensile force against global strain curves for the two specimens, one with a strain gauge and one without. The global strain of the two specimens, measured using machine displacement and potentiometer readings, shows almost the same trend, which means that the stiffening effect was insignificant. The low modulus of the 10 mm plastic strip compared to the high modulus of the geotextile partly explains this phenomenon. The modulus of the plastic strip with the strain gauge was approximately 3.4 kN per unit strain. However, the modulus of the 200 mm wide geotextile is approximately 100 kN per unit strain. Hence, the load transferred to the strain gauge system from geotextile was only about 3% of the total tensile load. Therefore, the stiffening effect was found to be relatively minor.



Global strain,

$$\varepsilon = \frac{\Delta L - (\Delta S_1 + \Delta S_2)}{L} \times 100\%$$

Where	ΔS_1, ΔS_2	= Geotextile slip from grip
	ΔL	= Grip displacement
	L	= Gauge length of geotextile
	ε	= Global strain

Figure 5 - *Schematic Diagram for Wide Width Tensile Test*

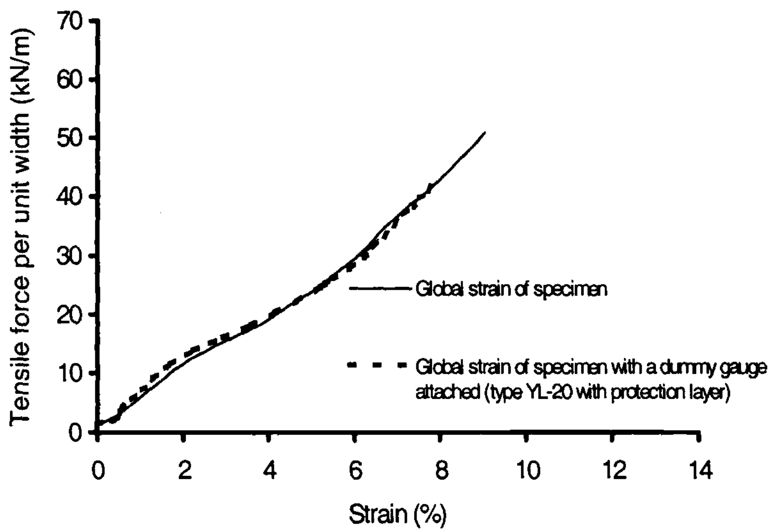


Figure 6 - *Global Strain Measured with Potentiometers*

The local strain recorded by the strain gauges in all the tests was compared with global strain calculated from potentiometer readings to study the effectiveness of the strain gauge system in measuring strain. Figure 7 shows the local strain measured by the strain gauge and global strain calculated from potentiometer readings for the specimen installed with strain gauge type YL-60 not protected by silicon gel. Figure 8 shows the same information for YL-60 protected by silicon gel. In both graphs, the strain measured by the strain gauges shows trends that were quite similar to the global strain and they recorded strain up to about 10%. The results clearly show that the concept of external strain gauging works effectively. The results also suggest that the stiffening effect of the silicone protection layer on the strain gauging system and the geotextile is insignificant. Hence, this strain gauge system can be used to monitor the true strain developed in the geotextile for in-air and in-soil tensile test. Figures 9 and 10 similarly show the comparisons between the measured local strains via strain gauges and global strain calculated from potentiometer readings for the specimens installed with strain gauge type YL-20 with and without protection by silicon gel.

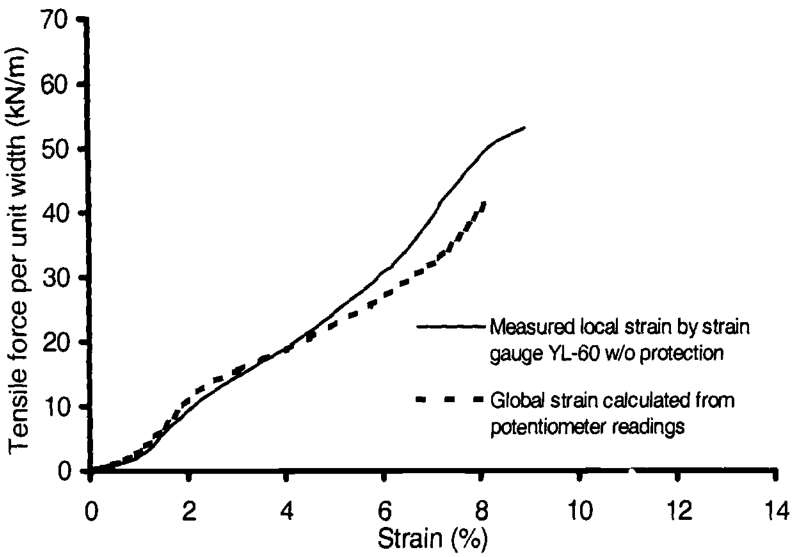


Figure 7 - *Tensile Force versus Strain for Geotextiles Installed with Strain Gauge YL-60 without Protection*

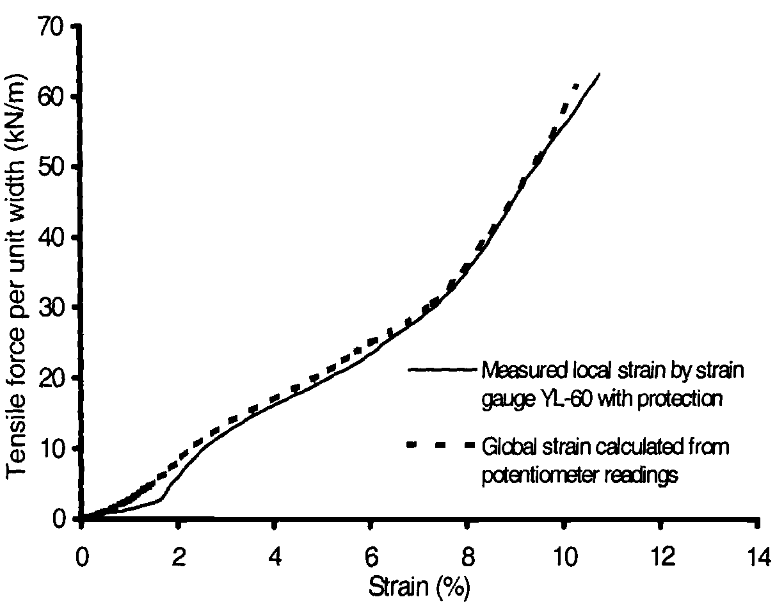


Figure 8 - *Tensile Force versus Strain for Geotextiles Installed with Strain Gauge YL-60 with Protection*

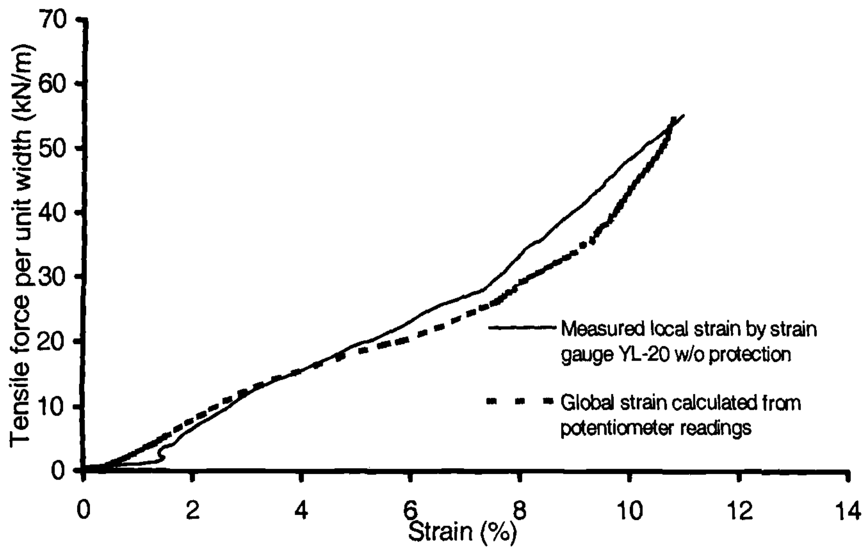


Figure 9 - *Tensile Force versus Strain for Geotextiles Installed with Strain Gauge YL-20 without Protection*

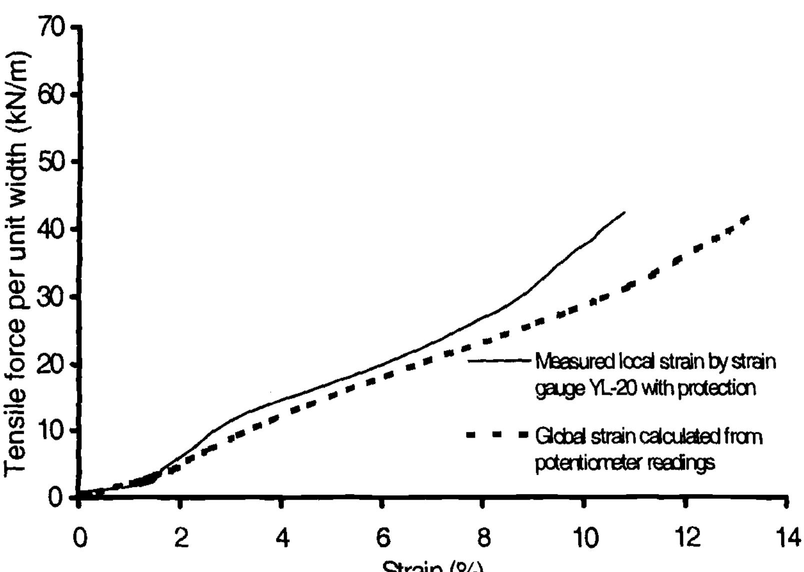


Figure 10 – *Tensile Force versus Strain for Geotextiles Installed with Strain Gauge YL-20 with Protection*

Figures 11 and 12 show the linear relationships between the local strain measured by strain gauge types YL-20 and YL-60 respectively against global strain calculated. Hence, M, the ratio of measured local strain by the external strain gauge to the global strain measured by potentiometers, can be established from the plots. This ratio, M, defined as a correction factor for strain gauge YL-20 and YL-60 is summarized in Table 2.

Table 2 - *Calibration Factors of the Strain Gauges*

Strain gauge	YL-20	YL-20	YL-60	YL-60
Gauge length of strain gauge	20 mm	20 mm	60 mm	60 mm
Protection	yes	no	yes	no
Maximum range of strain	20%	20%	20%	20%
Correction factor, M[1]	1.22	1.14	1.00	1.17

[1] Correction factor M is defined as ratio of measured local strain to global strain.

Figure 13 shows the spread of the correction factor, M, with respect to the gauge length of the strain gauges for the limited available data. The correction factors, M for all the external strain gauge system are between 1.00 and 1.22, with an average correction factor of 1.1. The results show that the strain measured by external strain gauge is always higher than the global strain as the gauge length of geotextile between the end plates is shorter than the specimen length. It should be noted that other published results [*1-3*, *5*, *7*] show the under-estimation of local strain as compared to global strain. The under-registration of strain by the strain measurement systems such as strain gauges glued directly onto the geotextile by silicon adhesive and electronic sensors mounted on two end plates is probably due to the stiffening effect of the geotextile by adhesive agents and the inherent stiffness of the electronic sensors.

The error in using a correction factor of 1.1 to determine the global strain from the measured local strain would not be too high and is quite tolerable for practical applications as long as the strain expected is in the region of around 10%. Investigations are in progress to study the trend in the variation of factor M.

This "external" strain gauging method was used recently for monitoring the static strain developed in the reinforcement of geotextile-reinforced wall models during a field trial in Singapore. Most of the strain gauges survived through the construction activities and registered the corresponding static strain of the geotextile.

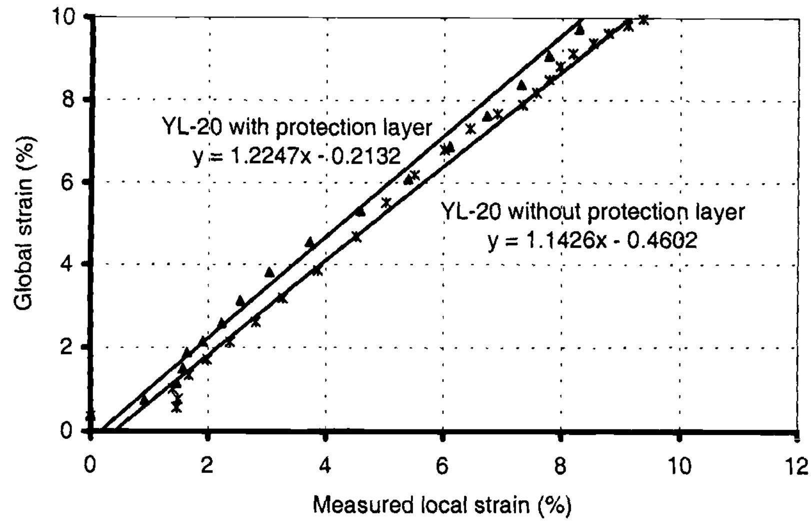


Figure 11 - *Global Strain versus Local Strain for Geotextiles Installed with Strain Gauge YL-20 with Protection*

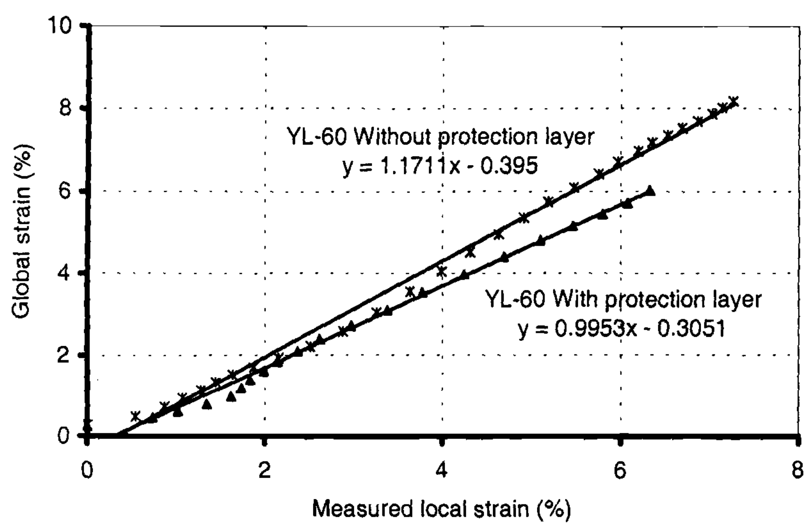


Figure 12 - *Global Strain versus Local Strain for Geotextiles Installed with Strain Gauge YL-60 with Protection*

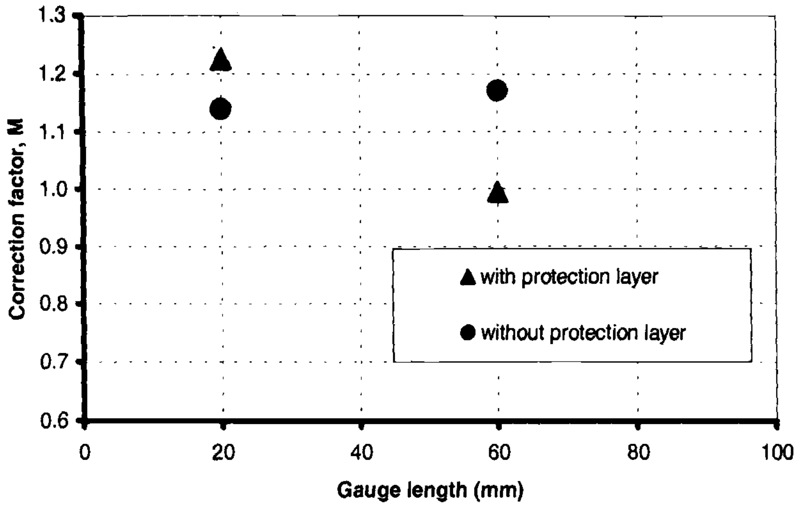


Figure 13 - *Effect of Gauge Length of Strain Gauge on the Calibration Factor, M*

Conclusions

The proposed "external" strain gauging method is able to measure the true global strain developed in the geotextiles within an error of 10%. This method allows registration of strains up to about 10% and has little stiffening effect on the geotextiles. Furthermore, the installation process is simple, fast and inexpensive as the strain gauge, aluminium end plates, plastic strip, CN glue and Araldite are relatively low-cost materials. Hence, this method can be useful in field monitoring of strain and deformation of geotextile reinforced structure.

References

[1] Sluimer, G., and Risseeuw, P., "A Strain-Gauge Technique for Measuring Deformations in Geotextiles," *Proceedings of Second International Conference on Geotextiles*, Vol. 3, Las Vegas, U.S.A., 1982, pp. 835-838.

[2] Leshchinsky, D., and Fowler, J., "Laboratory Measurement of Load-Elongation Relationship of High-Strength Geotextiles," *Geotextiles and Geomembranes* , Vol. 9, 1990, pp. 145-164 .

[3] Fowler, J., and Leshchinsky, D., "Field Installation of Strain-Gaged Geotextiles," *Serviceability and Durability of Construction Materials*, Vol. 1, 1990, pp. 360-369.

[4] Ho, C.T., *Pullout response of geotextiles*, M(Eng.) Thesis, National University of Singapore, 1998.

[5] Perkins, S. W., and Lapeyre, J. A., "In-Isolation Strain Measurement of Geosynthetics in Wide-Width Strip Tension Test," *Geosynthetics International*, Vol. 4, No. 1, 1997, pp. 11-32.

[6] Myles, B., "A Review of Existing Geotextile Tension Testing Methods," *ASTM STP 952*, American Society for Testing and Materials, Philadelphia, Geotextile Testing and the Design Engineer, 1987, pp. 57-68.

[7] Lee, S. H., and Ruei, E., and Tonus, S., "The Monitoring of Non-woven geotextiles by Strain Gages," *Proceedings of Fourth International Conference on Geotextiles, Geomembranes and Related Products*, Balkema, the Hague, Netherlands, Vol. 1, 1990, pp. 97-99.

Gripping and Strain Measurement in Geotechnical Tests

Christopher Elvidge[1] and Gerald Raymond[2]

Wide-Width Strength Test for Nonwoven Geotextiles Without Using Grips

---

Reference: Elvidge, C. and Raymond, G., "**Wide-Width Strength Test for Nonwoven Geotextiles Without Using Grips,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Development of a simple method of testing nonwoven geotextiles in wide-width testing without using complex grips is presented. The technique has been used mainly on 200-mm-wide samples and has been checked using light 500-mm-wide samples (due to machine testing load limitations on the 500 mm samples). It may be used on any width of geotextile if a testing machine of sufficient capacity is available. The proposed method uses a loop of geotextile that is pulled apart by two bars inserted through the loop. The loop joint is made using heavy duty glue applied by a heat gun. By replacing the glue joint with a seam the method is applicable to testing seams. In order to gauge the accuracy of the method a number of variables were tested. These included two types of polymers, the length of the specimen, the rate of extension, and the direction of extension versus the machine or cross-manufactured direction of the geotextile. The test is quick and the testing technique simple. In the one case where manufacturer's published minimum strength results were available every comparative test obtained exceeded those published results. This shows that the modified methodology has given expected results.

Keywords: elongation, geotextile, laboratory tests, material tests, mechanical properties, nonwoven, tensile strength, testing

---

[1]Graduate Student, Department of Civil Engineering, Queen's University, Kingston, ON, K7L-3N6, Canada.
[2]Professor Emeritus, Department of Civil Engineering, Queen's University, Kingston, ON, K7L-3N6, Canada.

Introduction

Geotextiles are thin, flexible, permeable sheets of synthetic material that are used to enhance the performance of geotechnical and civil engineering works. The concept of using fabrics in earth structures is not new. Cotton duck fabric, comparable to modern denim, was used to stabilize roads in Holland over sixty years ago. Similar material was also used, about the same time, to repair North Sea dikes. In the 1960's, however, modern synthetic geotextiles began their growth into extensive geotechnical and civil engineering practice.

Geotextiles may be subdivided by manufacturing process. The three main categories are woven, nonwoven, and knitted. Although the technique being developed in this study could possibly be used to test all three subdivision types, testing has so far been restricted to the nonwoven manufactured type.

Geotextiles have a wide range of applications in the field of geotechnical and civil engineering. The main identified applications for nonwoven geotextiles are filtration, erosion control, drainage, separation, and soil reinforcement. In all these applications it is common for a nonwoven geotextile to be subject to considerable extension that may in some cases be close to rupture. In unfavorable conditions, and if strength characteristics have not been correctly assessed, rupture may result. Clearly the strength characteristics of nonwoven geotextiles are of major concern. It is therefore essential for designs where strength is a critical factor that a two-dimensional strength test, commonly known as a wide-width strength test, be used to establish the strain-strength characteristics of the selected geotextile. The present (1999) North American method for wide-width testing of Geotextiles is outlined in (ASTM D4595-86), Standard Test Method for Tensile Properties of Geotextiles by the Wide-width Strip Method. The method uses clamps that are, at best, difficult to attach so as to ensure a uniform width of test sample. The jaws do not permit lateral movement at the grip ends and necking causes stress concentrations. This is indirectly identified within the specification which states:

> "10.5.2 ....any break occurring within 5% (1/4 in.) of the jaws which results in a value below 20% of the average of all breaks shall be discarded. No other breaks shall be discarded unless known to be faulty."

Herein is presented the development of a simple method of testing nonwoven geotextiles in wide-width testing. The method uses a loop of geotextile, pulled apart by two bars inserted through the loop. The method is used to investigate a number of nonwoven geotextile characteristic variables. One set of results permitted comparison with manufacturer's published minimum strength results. A good comparison was obtained. The test, like all tests, is approximations of true answers requiring appropriate factors of safety in their application to construction projects.

Brief Review of Previous Wide-Wide Development

It is well known that the stress-strain behavior of a geotextile in a simple tensile test is significantly influenced by details of the test procedure [*1, 2*]. Such test details have been stated to include the method of gripping the geotextile, rate-of-strain, sample size/aspect ratio, initial preload, and geotextile conditioning [*3*]. Conventional tensile testing, such as specified by ASTM D4595-86, assume a positive gripping mechanism that provides secure load transfer and defines rate-of-strain, sample size/aspect ratio, initial preload and geotextile conditioning. The most comprehensive study of gripping methods is reported by Myles [*4*] who identifies the three main gripping methods as using a mechanical wedge, encapsulation in epoxy or low melting point metal, and roller or capstan grips.

In the testing of nonwoven geotextiles considerable necking occurs over the gage test length. Attempts have been made to reduce this necking. Typical of such an attempt involved the installation of light wooden brackets set with pins [*5*]. Stevenson et al., [*6*] lists 14 concerns related to the testing of geosynthetics for use in reinforcement applications. Most of these concerns also relate to nonwoven geotextiles. Properties measured on nonwoven geotextiles tested in tension are numerous and a small number of examples are listed here [*7-19*]. None of these examples use the loop test presented herein.

Geotextiles Used

While testing was not limited to any specific nonwoven geotextile most of the extensive testing was conducted using two main geotextiles types, commonly available in Ontario and elsewhere in North America. The first of these was the Texel family of polyester nonwoven geotextiles, known as Product "A" under the trade names "7605," "7607," "7609," "7612," and "7618." The second was the Terrafix family of polypropylene nonwoven geotextiles, known as Product "B" under the trade names "270R," "370R," "400R," "800R," "1200R," and "1600R." The appropriate manufacturer's published geotextile characteristics are given respectfully in Tables 1 and 2.

Tensile Testing Apparatus and Geotextile Preparation

The developed method allows for any suitable tensile testing machine to be used that is rated above the final failure load and has a variable speed motor required for appropriate standard specifications. ASTM D4595-86 specifies a testing rate of 10 ± 3% per minute. Initially data was obtained manually so a rate of 0.83% per minute was selected to allow recording and plotting of collected data as the test proceeded.

The tension test equipment available for the project was a Unite-O-Matic unit which is a compression-extension machine whose head cross-beam moves through worm gears at a constant rate and contains a central load cell. The cross-beam motion may be set over a wide range of constant rates of movement. Attached to the load cell was a universal swivel joint that allowed any attachment to rotate in any direction.

Table 1. Product "A" published data [20].

Trade name	7605	7607	7609	7612	7618
Strength (kN/m) ASTM D4595 (200 mm)	6.3	7.6	8.7	14	19
Strength (N) ASTM D4632	355	450	530	755	1200
Elongation at Break (%) ASTM D4632	55-85	55-85	55-85	55-85	55-85
Tear Propagation (N) ASTM D4533	190	240	260	360	540
Bursting (Mullen) (kPa) ASTM D3786	1100	1300	1500	2250	3500
Permeability (x 10^{-1} cm/s) ASTM D4491	3.1	3.1	3.1	2.8	2.4
Equivalent Opening Size (μm) ASTM D4751	75-125	75-125	75-125	75-125	60-100
Thickness (mm) ASTM D5199	1.2	1.4	1.6	2	2.8
Mass (g/m^2) ASTM D5261	-	240	280	375	600

The designed testing technique involved the extension of a loop of geotextile that is pulled apart by two rounded bars inserted through the loop. Each round bar was attached to a square bar making up a bar unit. Figures 1 and 2 show, respectively, the machine shop diagrams of a typical bar set unit for the testing of a 200 mm and 500 mm wide-width nonwoven geotextile sample. The square bar of the upper set was attached to the swivel joint. The square bar of the second set was attached to the fixed bottom platform of the tensile testing machine. The bolts of the rounded bar holding the geotextile were screwed finger tight and then backed-off one quarter of one turn. This allowed the round bars to rotate during extension testing.

When manual readings were taken a dial gauge checked the deformations. Later, after automation, a linear variable differential transducer (LVDT) was used to check the rate of movement of the cross-beam. Figure 3 shows the test setup using a 500 mm wide-width nonwoven geotextile sample and Figure 4 shows the test setup for a 200 mm wide-width nonwoven geotextile.

Table 2. Product "B" published data [*21*].

Trade name	270R	300R	400R	800R	1200R
Strength (N) ASTM D4632	690	840	1090	2000	2250
Elongation at Break (%) ASTM D4632	70-100	70-100	70-100	70-100	70-100
Tear Propagation (N) ASTM D4533	330	405	580	800	900
Bursting (Mullen) (kPa) ASTM D3786	1900	2100	2750	5000	6000
Permeability (x 10^{-1} cm/s) ASTM D4491	2	2.6	2.8	2.3	1.5
Equivalent Opening Size (μm) ASTM D4751	75-150	50-150	50-150	50-150	50-150
Mass (g/m^2) ASTM D5261	180	230	295	470	560

Scissors were used to cut the geotextile samples into the desired rectangle sample size. The majority of tests were performed as 200 mm wide-width samples and had a cut length of 350 mm. The source geotextiles used were manufactured in optional length rolls about 3.7 m wide. The 350 mm sample length was orientated either parallel to (machine direction) or perpendicular to (cross direction) the long axis of the geotextile role. All of the samples were numbered according to the type of geotextile (e.g. 270R) and direction of testing (e.g. machine direction) plus sample number (e.g. #1).

The cut rectangular nonwoven geotextile samples were first prepared into a loop suitable for testing. The two ends of the lighter mass per unit area geotextile samples were glued together using a lap joint of 25 mm length. Heavier mass per unit area geotextiles were joined with a butt joint using two 50 mm lengths of similar geotextile so as to cover both ends on both sides of the geotextile over a length of 25 mm per geotextile end. In both cases the geotextile length was strengthened (test length shortened) by 50 mm. The joints in both cases were made using a glue gun with a control to allow dual tip heat. The two tip heats were 121° C and 136° C. In general only the hotter control was used in conjunction with a high strength heavy duty glue stick. Multiple strips of glue were placed, one single (fat) strip at a time across the 200 mm or 500 mm geotextile end widths and then quickly pushed together to force the hot glue into the geotextile's open porous structure. The pressure was maintained for several minutes

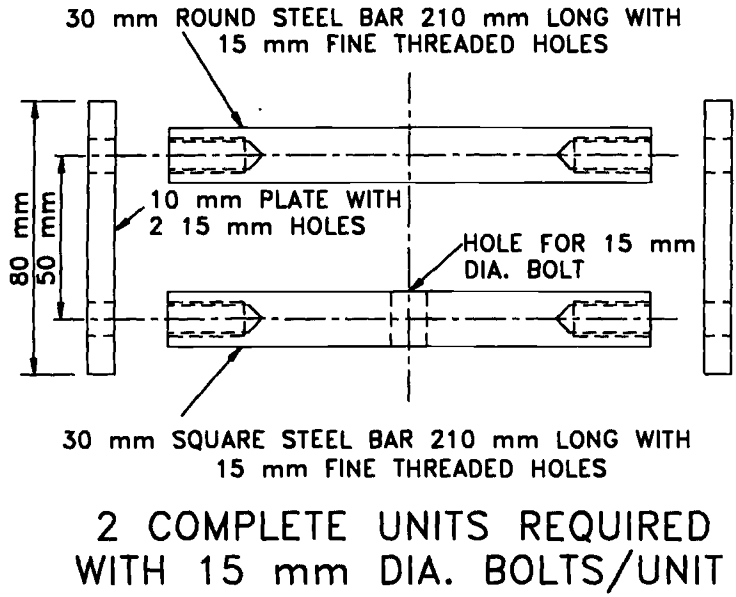


Figure 1. Geotextile holder for 200 mm wide width test.

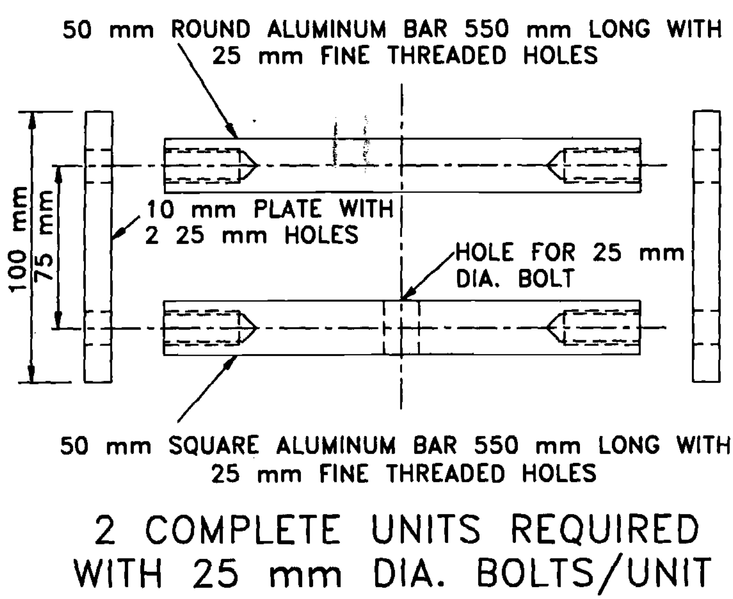


Figure 2. Geotextile holder for 500 mm wide width test.

until the glue had cooled. It was found important to place the multiple glue strips in single thick fat strips. The glue strip process was repeated two or three times until the full 25 mm end of geotextile was jointed. A lap joint needed only one jointing while four joints were needed for a butt joint. Note that by replacing the glue joint with a seam the method is applicable to testing seams.

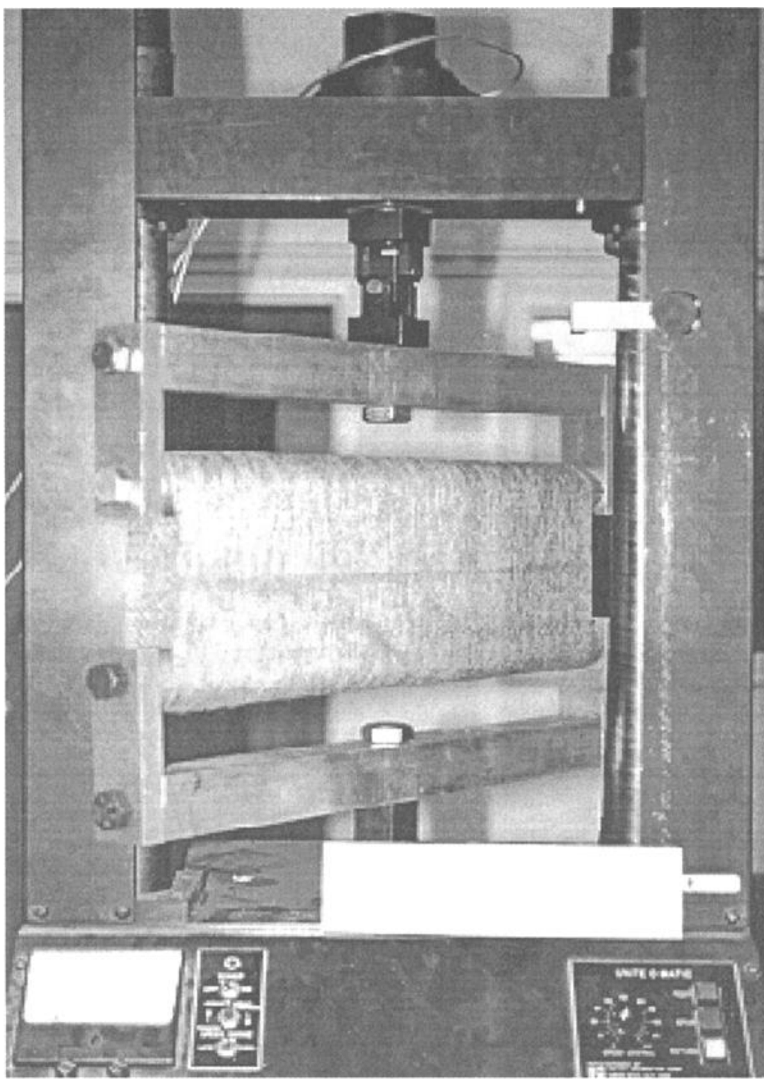


Figure 3. Testing apparatus with a 500 mm wide-width nonwoven geotextile sample.

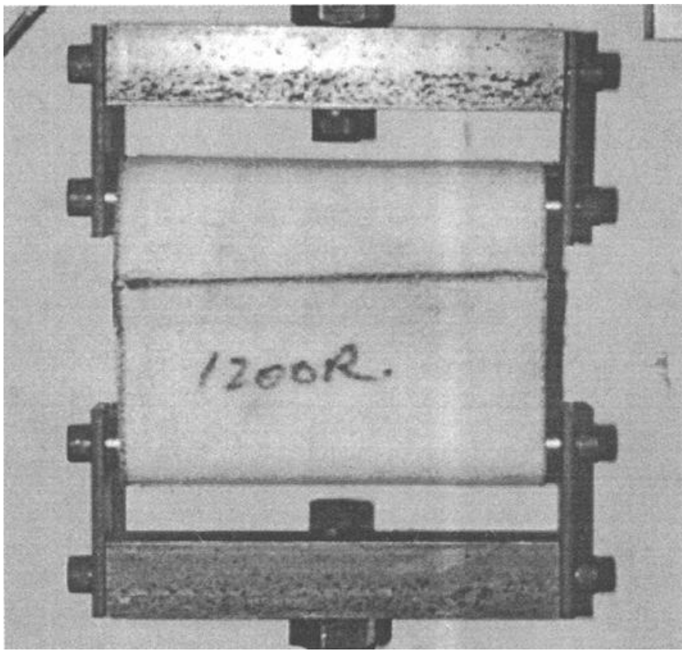


Figure 4. Apparatus with a 200 mm wide-width nonwoven geotextile sample.

The jointing process was completed in about 15 minutes for a lap joint. The 350 mm length of sample was assumed to have a test loop length of 300 mm. The value of using fat glue strips is important. Fat strips retain heat, and thus softness, longer that thin strips. This allows better glue penetration into the geotextile during jointing. Correctly jointed samples rarely failed on the joint side due to the stiffening effect of the joint resulting in less necking on that side.

The glue was a general purpose, high strength, hot gun glue available from most local hardware stores. The cost of the glue was nominal, and was less than $10 for 25 sticks. Each stick lasted for three to four lap joints. The glue gun cost about $30. Thus the cost of jointing was associated with the labor costs involved in jointing rather than the material costs.

Figure 5 show a number of typical looped 200 mm wide-width samples originally cut to 350 mm long. A piece of different colored paper has been placed behind the failure break of the failed samples so as to show the damage. Some necking is evident on the failed samples. One improvement would be a flexible membrane covering greased rollers so as to reduce friction that caused some necking of the tested geotextiles. The glued joint can be seen beyond the paper's edges and may be seen to have experienced minimal elongation. For this reason the effective circumference length used in the analysis was the cut length minus 50 mm. Shown are both samples prior to (and ready to be placed into the testing apparatus) and after failure. These include samples that were lap jointed and butt jointed. Other tests were done with circumferences of 225 and 250 mm; however, only results for 300 mm circumference length samples are reported herein.

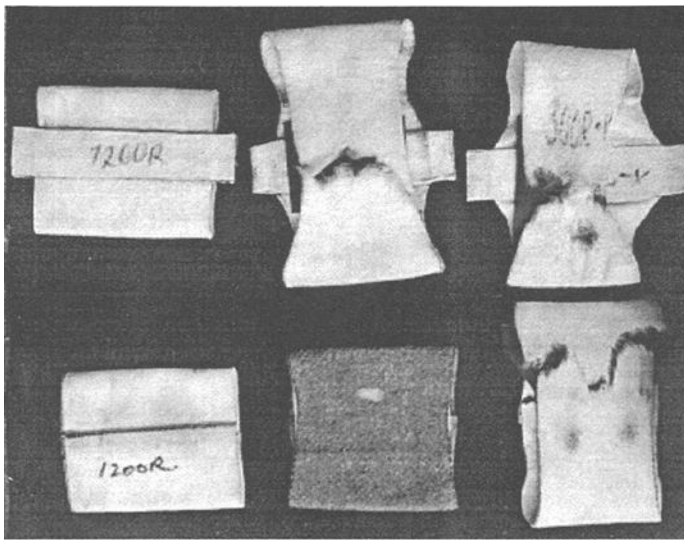


Figure 5. Typical untested and failed 200 mm geotextile loop samples.

Once the data acquisition was automated the test data were recorded digitally into a micro-computer using a Notebook (NB) software program. The program was set up to record the load and extension every 1 or 10 seconds, depending on testing rate, and to plot the data as recorded. The load cell of the tensile equipment sent millivolts to both a HP 3465A Digital Multimeter (also used during manual recording) and to a Slimpack Amplifier. The latter amplified the reading to values acceptable to the computer. The LVDT output was read directly into the computer. The manual data were typed into the computer. The source data were manipulated using a FORTRAN software program written by the second author. This program interrelated the test data to a uniform strain x-axis. This allowed multiple tests to be compared using spread-sheet software.

Tensile Strength Testing

Once the designed testing apparatus had been manufactured, assembled, and debugged so as to give what appeared to be satisfactory test results the second phase of the study was to test the tensile strength of the undamaged geotextiles. A loop geotextile sample was placed between the two steel bars with the glued seam at mid-height. The tensile equipment was then allowed to extend the geotextile until a tensile force of 20 N (0.1 kN/m) was recorded by the multimeter, after which it was stopped. This force represented about 1 % of the failure load of the weakest sample tested and 0.12 % of the strongest sample tested. The digital data recorder was turned on and the tensile equipment, after setting to the test selected speed, was restarted. Once the geotextile failed the tensile equipment and data acquisition system were stopped and the cross-beam was returned to its original position. The geotextile was removed and its extended length measured. This measurement was used as a rough check to the accuracy of the recorded test results. Failure occurred on the non-glued side except when jointing was performed with insufficiently thick (thin) glue strips. This was particularly evident for the heaviest butt jointed geotextiles (7618 and 1200R). With insufficient glue penetration the geotextiles pulled apart at the joint through their thickness. Only non-glued side failures were used herein, although the results where failure occurred on the glued side gave comparable results unless it was obvious that the glue joint had pulled apart. Joint failure was associated with using thin glue strips during jointing. Correctly jointed samples rarely failed on the joint side due to the stiffening effect of the joint that reduced necking on the jointed side.

Data Recovery and Analysis

The manually recorded data were manually placed into a computer, while the automated data collection was recorded digitally. The data were then manipulated using

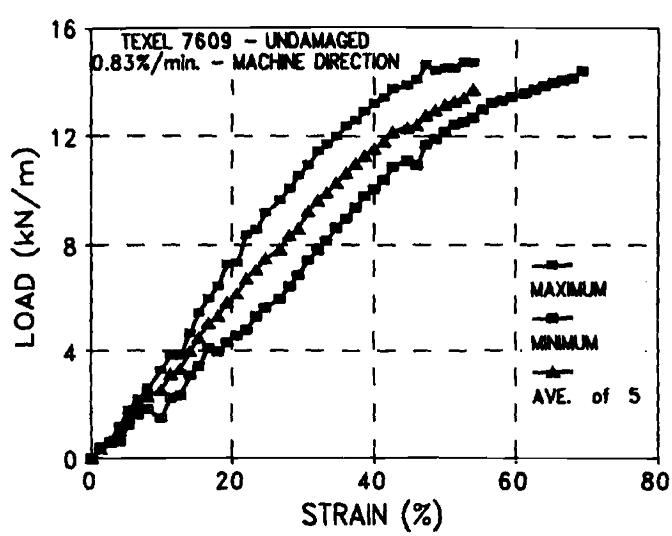


Figure 6. Typical load per unit length versus strain results.

the process discussed above, ending in the computer as spread-sheet data ready for final analysis and graphical presentation. Most nonwovens fail between 50% and 100% elongation. Figure 6 shows selected results (maximum, minimum and average of 5 tests to failure of geotextile failing at least strain) of load per unit length versus strain data obtained on one type of the geotextiles tested. Five tests were used in accordance with ASTM D4595-86 minimum requirement. Clearly there is some scatter in the results. Multiple tests should, therefore, be use in any assessment for a critical design or, if only a single sample is tested, a suitable factor of safety should be applied. Based on observations related to selecting test samples it became evident that the greatest variation occurred if test samples were cut from different axes in relation to the machine and cross direction. This observation was to be expected based on reported data by Novais-Ferreira and Quaresma [10]. Clearly if field extension of the geotextile is to occur in a know direction then testing should occur in that direction.

Verification of Procedure

Figure 7 shows a comparison of minimum average roll value (MARV) tensile strengths obtained using the ASTM wide-width strip method of testing published by the manufacturer of Product "A" with tests obtained in this investigation. The MARV is the average value minus two standard deviations (or the value that will be exceeded by 97%) of all test values from any manufactured roll. Within any one roll the results may be

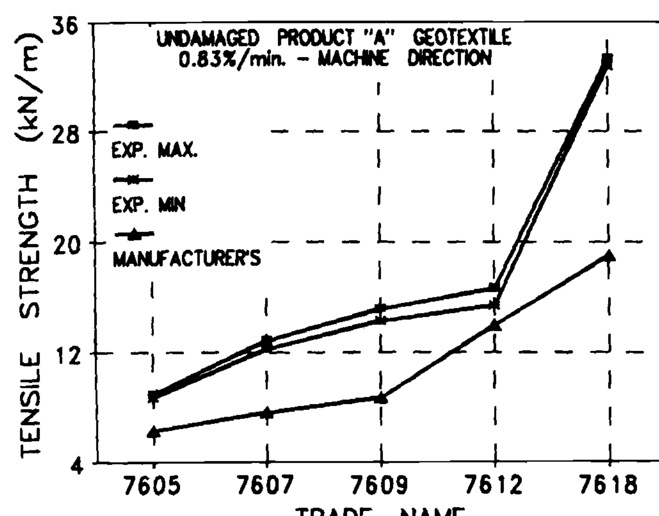


Figure 7. Comparison of failure strength of Product "A" geotextiles tested at 0.83% strain per minute with manufacturer's data.

expected to be reasonably uniform. This uniformity is seen from the closeness of the experimental minimum and maximum obtained not only from the same roll, but even more so from a short distance of one roll per geotextile type tested. This gives confidence that the wide-width strip procedure developed here is a valid test method. Figure 8 shows a plot of the recorded maximum and minimum strains at failure obtained from testing multiple samples of the same geotextile. No comparable results were available. The two figures show (via Table 1) that both the failure strength and failure strains increase as the mass per unit area of the nonwoven Product "A" increased.

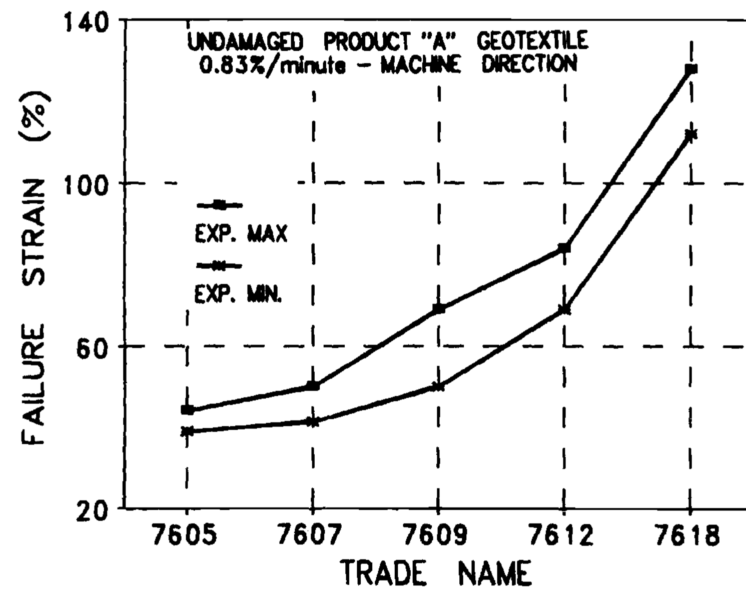


Figure 8. Failure strains of Product "A" geotextiles tested at 0.83% strain per minute.

Directional Test Results

The tests so far presented were performed on a nonwoven polyester geotextile. Similar tests were performed on a set of nonwoven polypropylene geotextiles. Figure 9 shows a summary of the failure strengths obtained on this set of geotextiles. Four sets of data are plotted. Two sets were obtained at a strain rate of 0.83% per minute and two sets with a strain rate of 10% per minute. Of the tests done at any one strain rate one was tested in the machine or roll direction and the other in the cross or width direction. Geosynthetics in general and polypropylene in particular exhibit highly viscous or time dependent phenomena [*1, 8, 11, 15*]. Despite this fact the results obtained from samples cut in the same direction but tested at different rates of strain showed remarkably similar failure strengths. In contrast the failure strengths of samples tested in the machine

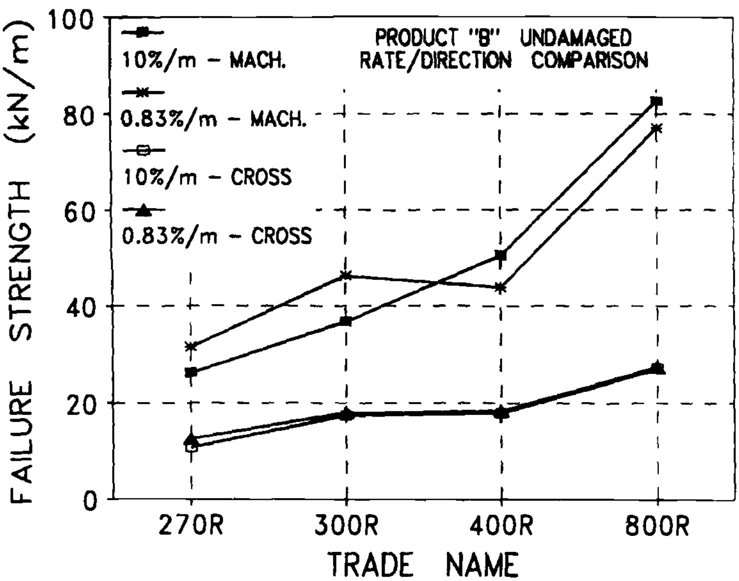


Figure 9. Failure strengths of Product "B" geotextiles tested at 0.83% strain per minute.

direction were greater that the failure strengths of the samples tested in the cross direction.

Figure 10 shows a plot of manufactured grab strength data and the machine direction wide-width failure strength. A case could be made for a relationship, however more data are needed.

Conclusions

A simple method of testing nonwoven geotextiles in wide-width tension without using complex grips has been developed and the details are presented herein. The proposed method uses a loop of geotextile that is pulled apart by two bars inserted through the loop. The loop joint is made using heavy duty glue applied by a heat gun. By replacing the glue joint with a seam the method is applicable to testing seams. While the method may be used on any wide-width sample its validity was verified for 200 mm and checked on some 500 mm wide-width nonwoven geotextiles. The developed test produces results, like all results, that are approximations of true answers and thus require appropriate factors of safety in their application to construction projects. One improvement to the test procedure as presented would be to grease the rollers and cover them with a membrane so as to reduce the roller friction that caused some necking of the tested geotextiles.

Geotextiles made from two different polymers were tested at two rates of strain and cut from both the machine and cross direction of manufacture. The samples cut from the

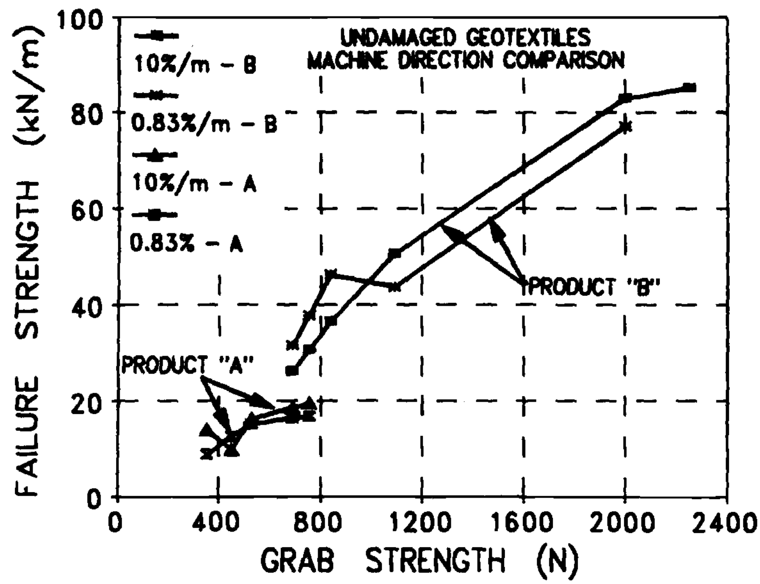


Figure 10. Comparison of machine direction failure wide-width results with the manufacturers' grab test failure results.

same geotextile and from the same direction exhibited similar failure strengths. In contrast, the samples cut from the same geotextile and from different directions exhibited dramatically different failure strengths/strains. The samples tested by extension in the machine direction exhibited greater strengths than those extended in the cross direction.

Acknowledgments

Gratefully acknowledged is the financial support provided by the Natural Scientific and Engineering Research Council of Canada (NSERC) as a grant awarded to Professor G. P. Raymond, and the geotextiles supplied by the manufacturers.

References

[1] Sissons, S. S. "Strength Testing of Fabrics for use in Civil Engineering", *Proceedings International Conference on the use of Fabrics in Geotechnics*, 1977, Vol. 2, pp. 287-292.

[2] Halibuton, T. A., Anglin, C. C. and Lawmaster, J.D. "Testing of Geotechnical

Fabric for use as Reinforcement", *Geotechnical Testing Journal*, 1978, Vol. 1, pp.

[3] Richardson, G. N. and Bove, J. A. "Testing and Monitoring of High Strength Geosynthetics", *Geotextiles and Geomembranes,* Vol. 6, pp. 157-172.

[4] Myles B. "A Review of Existing Geotextile Tension Testing Methods", *Geotextile testing and the Design Engineer, ASTM STP 952,* J. E. Fluet, Jr., Ed., American Society for Testing Materials, 1987, pp. 57-68.

[5] Shrestha, S. C. and Bell, J. R. "A Wide Strip Tensile Test of Geotextiles", *Proceedings 2'nd International Conference on Geotextiles*, 1982, Vol. 3, pp. 739-744.

[6] Steward, J. and Mohney, J. "Trial Use Results and Experience Using Geotextiles for Low-Volume Forest Roads", *Proceedings 2'nd International Conference on Geotextiles*, 1982, Vol. 1, pp. 336-340.

[7] Cazzufi, D. and Venesia, S. "The Mechanical Properties of Geotextiles: Italian Standard and Interlaboratory Test Comparison", *Proceedings 3'rd International Conference on Geotextiles*, 1986, Vol. 3, pp. 695-700.

[8] Myles, B. and Carswell, I. G. "Tensile Testing of Geotextiles", *Proceedings 3'rd International Conference on Geotextiles*, 1986, Vol. 3, pp. 713-718.

[9] Murray, R.T., McGown, A, Andrawes, K.Z. and Swan, D. "Testing Joints in Geotextiles and Geogrids", *Proceedings 3'rd International Conference on Geotextiles*, 1986, Vol. 3, pp. 731-736.

[10] Novais-Ferreira, H. and Quaresma, M. G. "Anisotropy of Mechanical Properties of Geotextiles", *Proceedings 3'rd International Conference on Geotextiles,* 1986, Vol. 3, pp. 719-724.

[11] Rowe, R. K. and Quaresma, M. G. "Determination of Geotextile Stress-Strain Characteristics using a Wide Strip Test", *Proceedings 3'rd International Conference on Geotextiles*, 1986, Vol. 3, pp. 885-890.

[12] Frobel, R. K. and Montalvo, J. R. "A Comparison of Three Commonly Specified Axisymetric Stress Tests for Geosynthetics", *Proceedings Geosynthetics '93*, 1993, Vol. 2, pp. 561-570.

[13] Wayne, M. H., Montalvo, J. R. and Boatwright, M. "Relationship Between Wide-Width Strip Tensile and Modified Strip Tensile Tests when Testing Nonwoven Geotextiles", *Proceedings Geosynthetics '93*, 1993, Vol. 2, pp. 571-577.

[14] Paulson, J. N., "High Strength Geotextile Testing and Material Property Evaluation," *Geotextile Testing and the Design Engineer, ASTM STP 952,* S. C. J. Cheng, Ed., American Society for Testing and Materials, 1993, pp. 111–118.

[15] Rankilor, P. R. and Heiremans, F. "Properties of sewn and adhesive bonded joints between geosynthetic sheets", *Geosynthetics: Applications, Design and Construction, M. B. De Groot, G. Den Hoedt and R. J. Termaat (eds.)*, Balkema, 1996, pp. 261-269.

[16] Boyle, S. R., Gallagher, M. and Holtz, R. D. "Influence of Strain Rate, Specimen Length and Confinement on Measured Geotextile Properties", *Geosynthetics International*, 1996, Vol. 3, pp. 205-225.

[17] Ashmawy, A. K. and Bourdeau, P. L. "Response of a Woven and a Nonwoven Geotextile to Monotonic and Cyclic Simple Tension", *Geosynthetics International*, 1996, Vol. 3, pp. 493-515.

[18] Perkins, S. W. and Lapeyre, J. A. "In-Isolation Strain Measurement in Wide-Width Strip Tension Test", *Geosynthetics International*, 1997, Vol. 4, pp. 11-32.

[19] Koerner, G. R. "Geosynthetic Proficiency Testing", *Proceedings 6'th International Conference on Geosynthetics*, 1998, Vol. 1, pp. 399-403.

[20] Terrafix Geosynthetics, Company Flyer, Terrafix Geosynthetics Inc., 425 Attwell Drive, Rexdale, Ontario, Canada, 1991.

[21] Texel Geosynthetics, Company Flyer, Texel Inc., 485 Des Erables, St-Elzear, Beauce-North, Quebec, Canada, 1991.

Dave Ta-Teh Chang, Fang-Ching Chang, Gang-Shun Yang, and Cheng-Yang Yan

The Influence Factors Study for Geogrid Pullout Test

Reference: Chang, D. T. T., Chang, F. C., Yang, G. S., and Yan, C. Y., "**The Influence Factors Study for Geogrid Pullout Test,**" *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: The interaction coefficient of pullout (μ) between the interface of soil and geosynthetic is known the major parameter for designing the details of the reinforced soil. To obtain this coefficient (μ), it is suggested to perform the pullout test. Some researchers followed GRI or the like to guide the procedures for running this test. However, details of the test have not been clearly identified. In this study, factors that could affect the pullout resistance are subject to further evaluation. One type of thick HDPE, stiff geogrid was used with confinement of sand soil in the confining box. Factors focused in this study include the pullout rates, sleeve lengths, frictional effect of the box wall, and specimen widths. Findings indicated that the optimum pullout rate is 1.0 mm/min for fully mobilizing the pullout resistance and is used for the entire program. Sleeve length of 15 cm is ideal for eliminating the effect of the front wall of the box. With a specimen width of 20 cm, the boundary effect can be reduced to a minimum. Moreover, the results of pullout behavior as in the case of wall with low friction angle (3.7°) is not much different from that of wall with high friction angle (24.7°).

Keywords: Pullout Test, Geogrid, Pullout Rate, Sleeve Length, Specimen Width, Boundary Effect, Frictional Effect, Coefficient of Pullout

Background

In the full-scaled test on the "Denver Walls," Wu [*1,2*] used very thin membrane and special grease to minimize the friction of the side walls. The failure loads predicted by most of the attended researchers were much lowered than the actual "failure" surcharge pressure. What makes most attended researchers believe in their own prediction values, which turned out very different from the full-scaled test results? It seems that conventional test methods might have some deficiencies, which await further review. Yet, the efficiency of the transmission of normal load needs to be to re-examination. In particular, the range of influence due to boundary effect and the actual transmission of normal load will be scrutinized. Pullout test is one of the most ideal tests for the simulation of the failure of a reinforced wall by normal load. Also, the testing conditions and mode of loading are rather similar to that used by the "Denver Walls" full-scaled test. On the other hand, standard testing device and comprehensive specification for governing the testing procedures do not exist. It is therefore a primary objective of the present study to identify factors influencing pullout resistance. With this in mind, material of low friction angle was determined using direct shear test. The material was used to reduce the frictional effect of the side wall of the confining box on pullout test. Proper sleeve length was selected to reduce the boundary effect of the front wall. In addition, the tests were repeated using different pullout rates so that the optimal pullout rate can be determined. The pullout tests were again repeated using geogrid of different specimen widths to investigate the range of boundary effect, so that an appropriate specimen size can be determined.

Factors Influencing Pullout Resistance

According to Farrag and Griffin [*3*], the following are major factors that could affect the pullout resistance, namely, 1) testing device, 2) boundary effect, 3) pullout rate, 4) type of reinforcement, 5) soil compaction process, 6) soil properties, and 7) confining pressure. Fannin [*4*] has grouped these factors into three attributes: 1) testing device related, 2) soils related, and 3) reinforcement related. These factors are tabulated in Table 1 below.

Table 1 - *Factors Influencing Pullout Resistance*

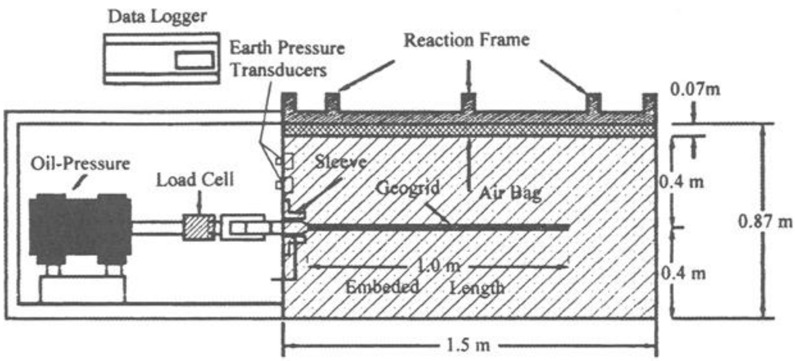
Testing Device Related	Soils Related	Reinforcement Related
1. lift thickness 2. front wall effect 3. side wall effect 4. pullout rate 5.confining pressure and its distribution	1. soil type 2.soil characters (e.g. shear strength, grain size distribution, density, water content, degree of compaction)	1. specimen type 2. specimen width 3. size of opening

In this study, emphasis is placed on the testing device related factors. Hence, only one type of soil and one type of geogrid were used in the study this time, to avoid dealing with the soils related and reinforcement related factors. While carrying the pullout test, recommendation by Farrag et al [*5*] was followed for the thickness of the upper and lower lifts inside the confining box, i.e., each lift has a thickness of at least 30 cm. Pullout rate, front wall effect, side wall effect, normal pressure applied and its distribution, as well as specimen width are all subject to re-assessment in this study.

Test Program

First, basic properties of the sandy soil and the geogrid to be used in subsequent tests of this study program were tested. Thereafter, pullout rate was evaluated and selected for controlling the entire testing program.

In this study program, the confining box has a dimension of 0.8 m (H) × 0.9 m (W) × 1.5 m (L). Hydraulic piston was used for the application of pullout force. Similar to the "Denver Walls" test, paper air bag was also used in this study to apply the normal load. Figure 1 may be referred to for the side view and over view of the pullout testing device.



(a) *Side View*

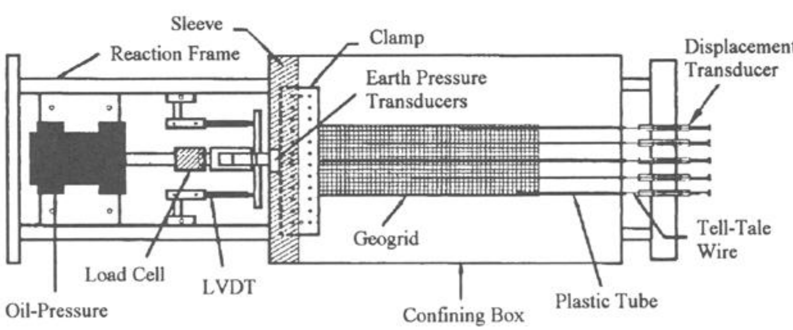


Figure 1 - *Diagram of the Pullout Testing Device*
(a) Side View (b) Over View

Test Materials

Backfill material used in this study was clean river sand from Tatu river of Central Taiwan. Following applicable ASTM, physical and mechanical properties of the sand was detected and indicated in Table 2. During subsequent tests, the density of the sand backfill was controlled at Dr = 80%.

Table 2 - *Basic Properties of Sand Backfill*

Gs	2.71
γ_{dmax} (g/cm^3)	1.72
γ_{dmin} (g/cm^3)	1.42
D_{60} (mm)	0.43
D_{50} (mm)	0.35
D_{30} (mm)	0.27
D_{10} (mm)	0.17
Cu	2.5
Grain Shape	Sub-Angular
USCS Classification	SP
Friction Angle ϕ (°)	42.3

Stiff geogrid (120 kN/m) of high density polyethylene (HDPE) was used in this study program, with the intention to amplify the boundary effect. Following GRI Test Methods GG1 and GG2 [*6,7*], rib strength and junction strength of the geogrid were obtained and tabulated in Table 3.

Table 3 - *Basic Properties of the Geogrid*

Material	HDPE
Initial Modulus (kN/m)	2200
Longitudinal Rib Thickness (mm)	2.3
Transverse Rib Thickness (mm)	5.7
Longitudinal Rib Strength (kN/m)	119.2
Elongation at Peak Strength (%)	8.3
Tensile Strength at 2% of Elongation (kN/m)	37.3
Tensile Strength at 5% of Elongation (kN/m)	78.5
Single Junction Strength (kgf)	261.1

To select the wall materials for the proposed study, direct shear tests were performed at backfill sand compacted to Dr = 80%, to evaluate the frictional properties of five types of inter-surface materials. These include plate wood, aluminum foil, Teflon, ceramic coating (OTT1), and lubricated layer (silicon grease with thin membrane). The direct shear test results were shown in Table 4 and Figure 2.

Table 4 - *Direct Shear Test Results from Inter-surface Materials with Soil*

Material	c (kPa)	ϕ (°)
plate wood	3.0	24.7
aluminum foil	3.0	24.2
Teflon	3.0	17.7
ceramic coating (OTT1)	3.0	26.5
lubricated layer (silicon grease + thin membrane)	4.0	3.7

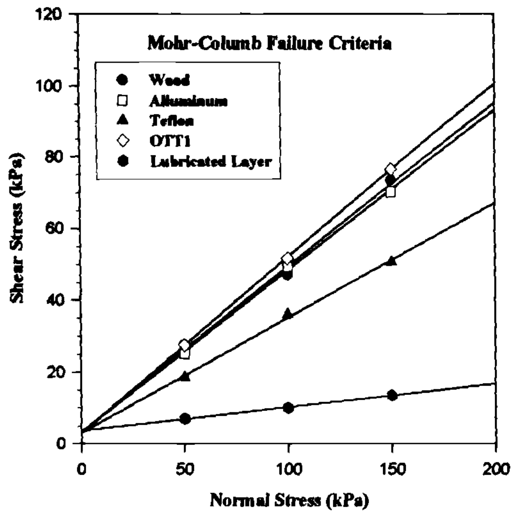


Figure 2 - *Direct Shear Test Results from Inter-Surface Materials with Soil*

It is apparent from Table 4 that the adhesion (c) between these materials and the dry sand is almost the same, i.e., around 3.0 kPa, a rather low adhesion which can be neglected in most cases. The lubricated layer has a friction angle of 3.7 °, which is the lowest among these materials. This lubricated layer was therefore selected to form the interior surface of the confining box.

Pullout Rates

The testing device as used in this study is of strain controlled type. To study the effect of pullout rates on pullout resistance, stiff geogrid (120 kN/m) of specimen size 100 cm (L) × 20 cm (W) was used. The sleeve length was fixed at 15 cm, the soil density was fixed at Dr = 80%, and a fixed normal load of 50 kPa was applied to the test system. The tests were repeated for five times at five different pullout rates, 1.0 mm/min, 5.0 mm/min, 10 mm/min, 20 mm/min, and 50 mm/min. The results were summarized in Figure 3.

As is evident from Figure 3, when the pullout rate increased from 1.0 mm/min to 10 mm/min, the ultimate pullout load dropped from 68.67 kN/m to 59.32 kN/m, which meant a drop by 16%. However, when the pullout rate is further increased to 20 mm/min or even 50 mm/min, the ultimate pullout load remained more or less the same as that at the pullout rate of 1.0 mm/min. As can also be seen in Figure 3, the effect of pullout rates on pullout behavior is of particular significance during the initial stage. System pulled out at a lower pullout rate experienced a moderate increase of pullout resistance. On the contrary, system pulled out at a higher pullout rate experienced an abrupt increase of pullout resistance. Reason for this is that with such a high pullout rate, the transverse ribs of the geogrid will push the front wall, in that the lateral earth pressure will increase in a great extent, which in turn will increase the normal load locally.

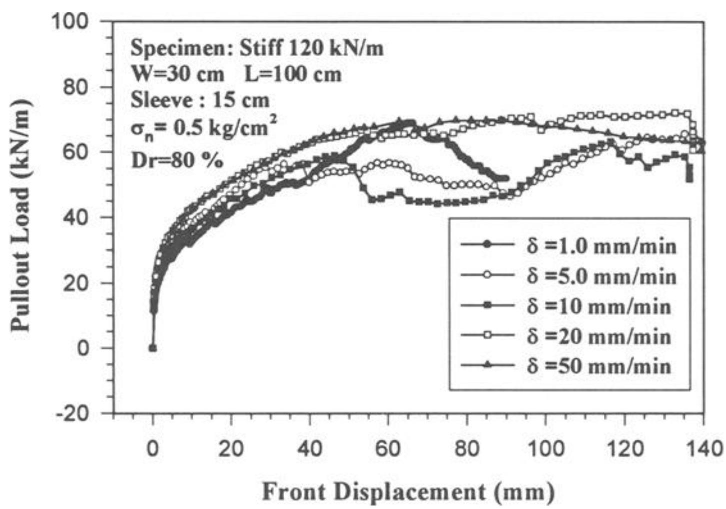


Figure 3 - *Pullout Rate Effect on Pullout Behavior*

In subsequent tests, the pullout rate was fixed at 1.0 mm/min. This also accords with that recommended by GRI [*8*].

Sleeve Lengths

In this study program, four different sleeve lengths were used to conduct the tests. They are 0 cm, 7.5 cm, 15 cm, and 20 cm respectively. Pullout test without the use of sleeve was performed for reference purpose. Similar testing conditions were applied. In particular, a fixed normal load of 50 kPa was applied, and the pullout rate was fixed at 1.0 mm/min.

To study the variation in the lateral earth pressure, two earth pressure meters (cell A and cell B) were installed on a vertical side wall of the confining box. They were positioned at 26 cm and 17.5 cm from the front edge of the geogrid specimen. The results were illustrated in Figures 4 to 6. From Figure 4, it can be concluded that the shorter the sleeve, the greater the pullout resistance. However, for a testing device with a sleeve length of 15 cm and 20 cm, their difference in pullout loads is negligible. This phenomenon is again confirmed by the readings of cells A and B as indicated in Figure 5 and Figure 6.

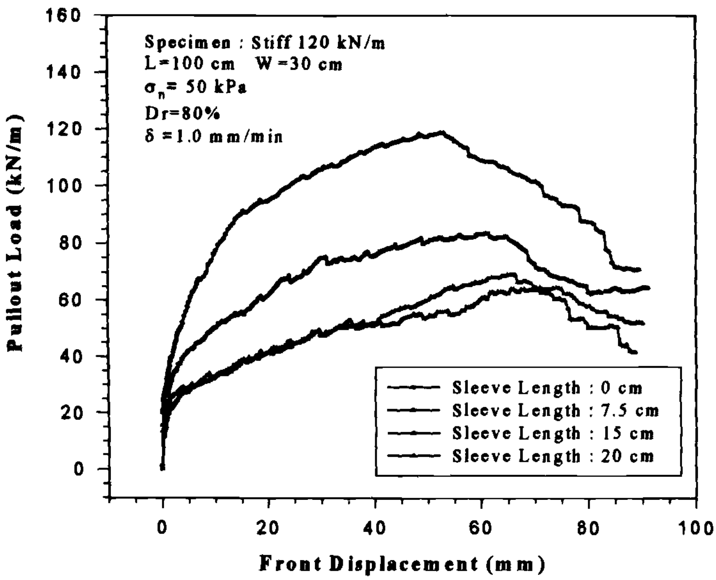


Figure 4 - *Sleeve Length Effect on Pullout Behavior*

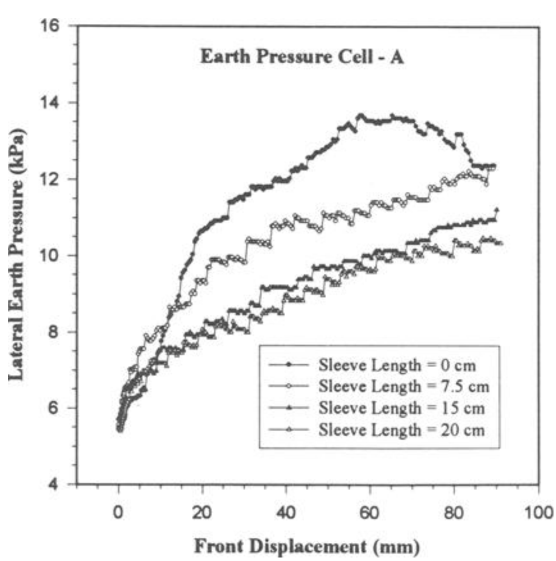


Figure 5 - *Earth Pressure Reading from Cell - A*

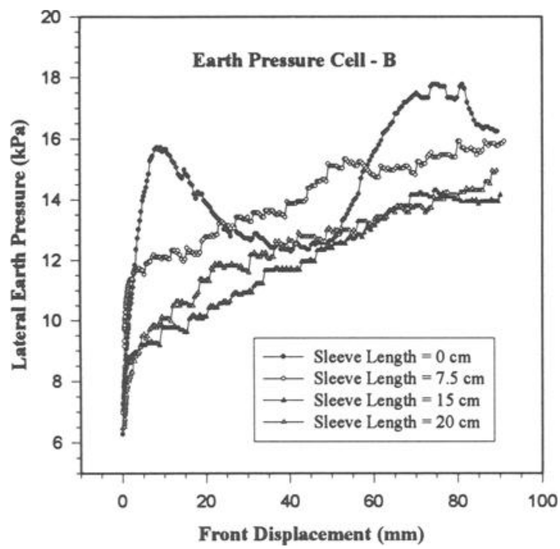


Figure 6 - *Earth Pressure Reading from Cell – B*

Specimen Widths and Frictional Resistance on the Side Wall

In Chang et al's earlier studies [9],same geogrids of different specimen widths but lower strength (100 kN/m) were used in performing similar pullout tests of geogrid with sand confinement. Test results (see Figure 7) showed that the pullout load versus displacement curves are nearly consistent for specimen widths of 22.2 cm and 31.1 cm. Yet, for specimen of widths over 40 cm, the average pullout resistance shows a falling trend. It was therefore inferred that for specimen widths ranging between 20 to 30 cm, the normal loads can still be regarded as being homogeneously distributed over the entire width of the geogrid. For specimen widths over 40 cm, the normal loads may not be effectively transferred to the geogrid, and therefore, the pullout resistance per unit width is lower than that with specimen widths between 20 to 30 cm. Heretofore, this phenomenon is generally interpreted as side friction effect. In Chang et al's earlier studies [9], plate wood was used, which has a friction angle of 24.7°.

In this study program, material of very low friction angle (3.7°) was placed on the side wall. The relative density of the sand was still kept at Dr = 80%; stiff geogrid of 120 kN/m, normal load of 50 kPa, and pullout rate of 1.0 mm/min were still adopted for this test. The tests were conducted using geogrids with length of 100 cm, but seven different widths, 10 cm, 20 cm, 25 cm, 30 cm, 40 cm, 50 cm and 60 cm. The results were illustrated in Figure 8.

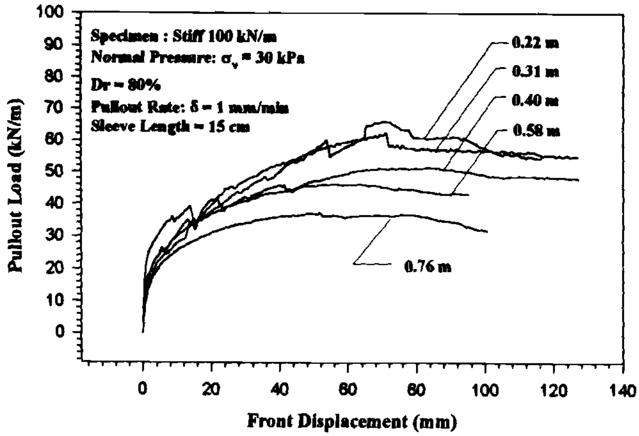


Figure 7 - *Results of Pullout Test with Plate Wood on Side Wall*

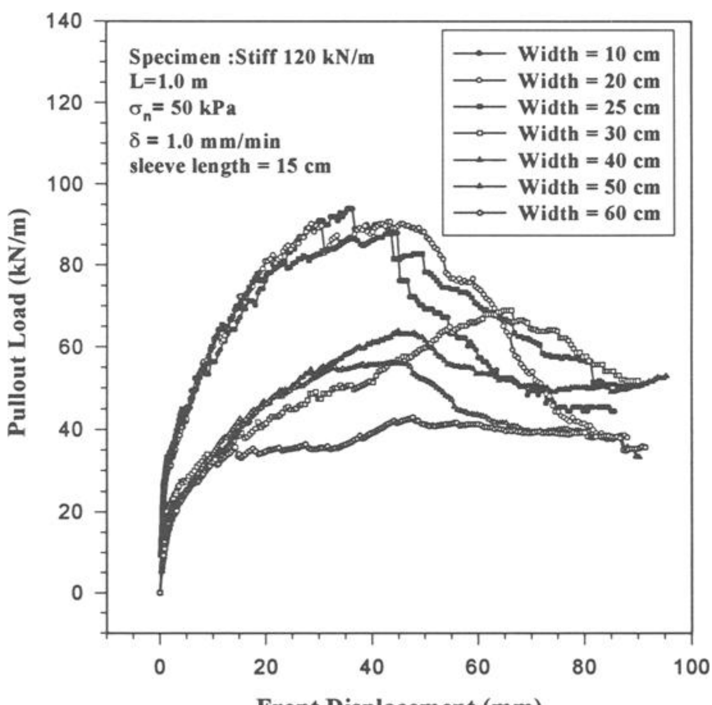


Figure 8 - *Results of Pullout Test with Lubricated Layer on Side Wall*

It can be seen from Figure 8 that for specimen widths of 10 cm, 20 cm and 25 cm, the pullout loads versus front displacement curves also overlapped themselves. This meant that the pullout resistance per unit width of these cases are almost consistent. For specimen widths over 40 cm, however, the pullout resistance per unit width drops substantially because the normal load exerted thereupon failed to transfer to the entire width of the geogrid. The results in Figure 8 led to a same conclusion as that shown in Figure 7. Apparently, minimizing side wall friction can neither avoid the specimen width effect nor the side effect for normal load transmission.

Conclusions

There are numerous factors that could affect the results of pullout tests of geogrids. Following are some recommendations for the standardization of pullout tests:

Front Wall Effects

1. During the pullout process, it does exist that the ribs will push the soil towards the front wall. Using a sleeve length of 15 cm, such a front wall effect can be reduced to a reasonable level.

Side Wall Effects

1. To reduce the side wall frictional effect on the transmission of stress, it is required to reduce side wall friction and to aptly control the distance between the specimen and the side wall of the confining box.
2. To reduce the side wall friction, lubricated surface (silicon grease with thin membrane) was used in this study, which has a friction angle of 3.7°.
3. To ensure that the normal load can be fully and effectively transferred to the geogrid, it is necessary to restrict the specimen width within 30 cm, or to keep a distance of around 30 cm between the specimen and the side wall of the confining box.

References

[1] Wu , Jonathan T.H., "Predicting performance of the Denver walls," General Report, Denver, USA.,1992.
[2] Wu, Jonathan T.H., Qi, X., Chou, N., Ksouri, I., Helwany, M.B. and Huang, C.C. "Comparisons of predictions for the Denver walls". General Report, Denver, USA.,1992.
[3] Farrag, K., and Griffin, P., "Pull-Out Testing of Geogrids in Cohesive Soils," *Geosynthetic Soil Reinforcement Testing Procedures, ASTM STP 1190*, Cheng, Jonathan S.C., Ed., American Society for Testing and Materials, Philadelphia, 1993, pp.76-89.
[4] Fannin, R.J. ,D.M. Raju, "Large-Scale Pull-Out Test Results on Geosynthetics," *Proceedings of Geosynthetics Conference*, Vancouver, British Columbia, Canada, 1993, pp.633-643.
[5] Farrag, K., Acar, Y. B., and Juran, I., "Pull-Out Resistance of Geogrid Reinforcements," *Journal of Geotextiles and Geomembranes*, Volume 12, 1993, pp. 133-159.

[6] GRI Test Method GG1 "Geogrid Rib Tensile Strength," Geosynthetic Research Institute, Drexel University, Philadelphia, PA.,1991.

[7] GRI Test Method GG2 "Geogrid Junction Strength," Geosynthetic Research Institute, Drexel University, Philadelphia, PA., 1991.

[8] GRI Test Method GG5 "Test Method for Geogrid Pull-Out," Geosynthetic Research Institute, Drexel University, Philadelphia, PA., 1991.

[9] Chang, T.T., Sun T.S., and Hung, F.Y., "Pullout Mechanism of Geogrids Under Confinement by Sandy and Clayer Soils," *TRB Transportation Research Record*, No.1474, 1995, pp.64-72.

[10] Chang, T.T., Fu, Y.C., and Chang, F.C. "Large-Scale Pullout Test of Geogrid with Sand Confinement", Journal of the Chinese Institute of Civil and Hydraulic Engineering, (in Chinese), Vol.10, No.1, 1998, pp.39-46.

地工織物試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	其它試驗法	費用
材質			燃燒法 或 AATTC20	500
單位重	12915	D5261		350
厚度	12915	D1777		350
定水頭透水係數		D4491		2700
織物表觀開孔徑 AOS		D4751		4500
條式抗拉強度	5610	D751		2400
抓握式抗拉強度	13483	D4632		2400
梯形撕裂強度	13299	D4533		2400
寬幅抗拉強度	13000	D4595		4800
瑕疵	5618			350
起始模數		D1682		750
抗穿刺強度		D4833		2700
抗磨損強度				3600
水力坡降比 GR 試驗		D5101		20000
紫外線耐候試驗		D4355		18000
平面透水		D4716		6000
縱向透水量		D4716		12000
纖維型態			目視法	500
織法			目視法	350
織物孔徑分佈		D4751		6000
抗崩裂強度		D3786		2700
地工格網試驗項目				
試驗項目	ASTM 規範編號	GRI 規範編號	其它試驗法	費用
材質			燃燒法	500
單位重		GG1		500
網目尺寸			測微尺	350
肋條強度	D1682	GG1		6000
結點強度		GG2		3000
延伸率	D1682	GG1		0
起始模數		GG1		750
拉出試驗		GG5		35000
垂直排水帶試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	其它試驗法	費用
材質			燃燒法	500
尺寸		D1777		350
濾層定水頭透水係數		D4491		2700

整體縱向透水量		D4716		12000
濾層抓式抗拉強度		D4632		2400
帶心抓式抗拉強度		D4632		2400
帶心斷裂點延伸率		D4632		0
帶心降伏點延伸率		D4632		0
整體抗拉強度		D4595		3000
平面抗壓				3000
排水片試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	其它試驗法	費用
整體抗壓		D1621		3000
材質			燃燒法	500
開孔率			測微尺	750
排水管試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	其它試驗法	費用
管心開孔率			游標尺	750
管心材質			燃燒法	500
管心抗壓強度			壓縮速率 50mm/min	3000
內徑			測微尺	350
比重		D792		500
抗拉		D638		4000
最大開孔徑			測微尺	350
路工材料試驗項目				
試驗項目	AASHTO 規範編號	ASTM 規範編號	其它試驗法	費用
防炫版材質			燃燒法	500
防炫版密度		D792	DIN53479	500
防炫版軟化點溫度		D1822	DIN53460	3500
防炫版抗拉強度		D638	DIN53455	4000
防炫版延伸率		D638		0
防炫版起始模數		D638		750
金屬組件鍍鋅量	T65			1500
熔點			DSC	3500
衝擊強度		D1922		4000
土壤試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	AASHTO 規範編號	費用
標準夯實試驗及 OMC		D1557-A		15000
修正夯實試驗及 OMC	T-180	D1557		25000
透水係數		D2434		5000

阿太堡限度	5087, A3086	D423		8000
粒徑分析	152H			6000
回彈模數			T274-82	30000
地工止水膜試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	GRI 規範編號	費用
基重		D792&D1505		500
厚度	3552	D5199&D5994		350
單位面積重		D1910		500
吸水率	3276			1800
抗拉張強度(啞鈴式)	4396			4000
抗拉強度（切條式）		D751		4000
抗拉強度（寬幅）		D4885		4000
接縫抗拉強度（剪式及撕式）	12494(剪式)	D4437(HDPE) D413(PVC)		4000
直剪摩擦阻抗試驗		D5321		15000
撕裂強度（梯型）		D2263		4000
撕裂強度（B 型試片）	3559			4000
抗穿刺試驗		D5494		2700
應力破裂（彎曲）	12494	D1693		4000
應力破裂（恆荷重）		D5397-95		4000
應力破裂（單點）		D5397		4000
抗紫外線試驗		G268&D4355		18000
高密度聚乙烯止水膜試驗項目				
試驗項目	CNS 規範編號	ASTM 規範編號	GRI 規範編號	費用
厚度	4174			500
比重	2940			500
抗拉及延伸率	4396			4000
撕裂強度	3559			4000
掩埋試驗	4396			5000
吸水率	3276			1800
接縫強度	12494			4000
耐熱尺度變化率	3143			2000
環境彎曲應力龜裂	12494			3000

John H. Greenwood[1] and John M. Palmer[2]

Good Laboratory Practice in the Creep Testing of Geosynthetics

Reference: Greenwood, J. H. and Palmer, J. M., **"Good Laboratory Practice in the Creep Testing of Geosynthetics,"** *Grips, Clamps, Clamping Techniques, and Strain Measurement for Testing of Geosynthetics, ASTM STP 1379,* P. E. Stevenson, Ed., American Society for Testing and Materials, West Conshohocken, PA, 2000.

Abstract: Ten years ago the coefficient of variation of creep test measurements in our laboratory was reported as being 8.6% to 12%. Now it is between 1.0 and 1.6%. This paper reports on the changes which have brought about this large improvement in accuracy.

Keywords: creep, strain measurement, laboratory practice, repeatability

Introduction

In 1990 we published a paper [*1*] in which we stated that the repeatability of creep tests was between 8.6 and 12%. This was a coefficient of variation based on tests performed in 1987-1989 on woven polyester and polypropylene and polyester strip. The standard deviations of the data ranged between 0.42% strain for the polyester weave and 0.78% strain for a light polypropylene weave, the strains being typically around 5%. Most of the variation was believed to have occurred during initial loading, and additional short-term tests were performed to provide a more reliable average value for the creep strain at 1 h. A recent publication [*2*] gives extended data for some of those tests which have continued for ten years, but comments again on the poor repeatability. BS 6906 Part 5, "Methods of test for geotextiles. Part 5: Creep", issued in 1991, quotes a coefficient of variation of 5% to 14% for the reproducibility (including material variation, in-house repeatability and reproducibility between laboratories) based on interlaboratory trials carried out by four British laboratories and coordinated by ERA Technology Ltd.

Note that for five specimens the 90% (two-sided) confidence limits will lie at $\pm 2.0 \times$ the coefficient of variation. Thus if the coefficient of variation is 1%, the results of nine out of ten creep tests should lie within a range of $\pm$ 2% (total 4%) of the

[1]Technical Executive, Materials Testing Department, ERA Technology Ltd., Cleeve Road, Leatherhead, Surrey, KT22 7SA, United Kingdom.
[2]Technical Officer, Materials Testing Department, ERA Technology Ltd., Cleeve Road, Leatherhead, Surrey, KT22 7SA, United Kingdom.

mean, if it is 5%, the range will be ± 10%. These ranges narrow as the number of specimens increases: for a large number of specimens they become ± 1.6% and ± 8%, respectively.

Another recent publication [3] reproduces some of the results of creep tests on two polyester geogrids tested at ERA. Tests on the first set, coded Product A, were started during 1993-1994. The coefficient of variation of six tests at approximately 56% of tensile strength at 60°C was 1.3%. This is taken from the creep modulus (load divided by instantaneous strain) after 1 h (t_{sec} = 3600 s; log t_{sec} = 3.56) for tests on five products in the same range, the load on each expressed as a percentage of that product's tensile strength. At 40 °C the coefficient of variation was 3.4% and at 20 °C it was 10.1%. Strains were in the range 7.5 to 11%. At the loads of 21% and 31% of tensile strength illustrated in [3], with strain levels from 4.5 to 7.5%, the creep modulus is reduced because of an inflexion in the stress-strain curve, and no duplicate measurements were made to give a value for repeatability.

Product B in [3] was a polyester geogrid tested for creep and creep-rupture over the period 1996-1997 at three temperatures and at strains typically in the range 13-15%. The coefficient of variation of the tests at 60 °C, calculated from the creep modulus in the same way from between 8 and 12 tests at each temperature, was 1.1%. At 40 °C it was 1.0% and at 20°C it was 1.6%. All specimens were taken from the same sample of material.

Creep tests have also been performed between 1994 and the present on specimens taken from a sample of polyethylene sheathed polyester strip. The coefficient of variation of creep modulus at between 70% and 80% of tensile strength, taken from 10 tests after 1 h at 20 °C, was also ± 1.6%. After 1000 h it was ± 1.5%.

A reduction in variation from a maximum value of 12% to 1.6% represents a great improvement in accuracy. This paper describes the measures we have taken to achieve it.

Testing Ten Years Ago

ERA has been testing the creep of geosynthetics since 1980. Early tests on yarns and extruded grids were set up in its main creep laboratory which was designed for testing the creep of steel in enclosed furnaces. The ambient air is maintained at a normal working temperature and there is no need to control humidity.

In 1987 a special laboratory was set aside for the testing of geosynthetics. This was located in the basement of a new building which was free of mechanical vibration, naturally stable in temperature and where the tests were isolated from other activities. Since the loads on the specimens can be as high as 5 tonnes, it was necessary to use lever loaded testing machines. Linear variable differential transformers (LVDTs) have been used from the start to measure strain; each calibrated through its own conditioning module against a secondary standard micrometer, traceable to the UK National Physical Laboratory. The steel weights and the ratios of the lever arms were also calibrated against traceable standards.

Environmental Conditioning

The normal 20/65 environment for testing textiles is (20 ± 2) °C, (65 ± 5)% relative humidity (ISO 554. "Standard atmospheres for conditioning and/or testing - Specifications"). BS 6906 Part 5 states (20 ± 2) °C, (65 ± 2)%, but a ± 2% tolerance on humidity cannot be achieved in practice unless the temperature is maintained within ± 1°C. Although the temperature of the laboratory has always varied little, thanks to its underground location, with the issue of BS 6906 Part 5 in 1991 it was decided to introduce full environmental conditioning. A portable air conditioner is held in reserve to cover for breakdown of the environmental unit in any of ERA's environmentally conditioned laboratories.

Long-Term Drift

A constant temperature leads to increased stability not only in the material but also in the instrumentation. An LVDT has been left attached to a piece of unstressed carbon fibre reinforced plastic of very low coefficient of thermal expansion within the geotextiles laboratory with only one interruption, to fit a new conditioner, in 1991. Over the ten years from the start of readings in March 1988 up to March 1998 there has been a small but steady drift totalling +0.05 V which, given a calibrated sensitivity of 1.05 mm/V, amounts to an apparent movement (not a real movement) of 0.05 mm. For a gauge length of 100 mm this is equivalent to a systematic error of 0.05% strain over ten years.

Full Digital Recording

Initial recording was by chart recorder during the initial loading followed by manual recording of strain after set intervals. These results were plotted by hand on to conventional graph paper, although those from long-term tests were digitised some years later to form a continuous record. The use of a data logger with full digital recording has eliminated errors arising from manual recording and in the calculation of elapsed hours from dates and times. Using standard spreadsheet procedures it is possible to manipulate and plot the data in tables and graphs according to the standards without risk of error in calculation and plotting. Errors should not occur, but in the copying, transcription and plotting of large volumes of data by hand they do.

Digital Calibration

For a LVDT the relation between distance travelled and electrical output (mm/V) is slightly nonlinear, and for the type used was specified to be < ±1% of the movement of any point over the range of the transducer. The points were plotted and a best straight line was fitted. The gradient of this line is used for all subsequent calculations. The procedure is now fully automated, eliminating the potential errors introduced by manual recording and line fitting.

Grips

A range of grips has been constructed which are easy to assemble and use:

a) For geotextiles, 230 mm wide roller grips to accommodate 200 mm wide specimens. The end of the specimen is secured by a bar inset into the roller and the geotextile is subsequently wound around the roller several times such that most of the load is transferred by friction. Once the specimen is mounted the roller is prevented from turning by two high strength steel pins. The roller is attached coxially to a frame which moves to allow the textile to align itself with the load axis.
b) For serrated geogrids and polyester strips a similar arrangement is used. The surface of the roller is patterned to increase the friction. Nonwoven material can be used as padding between successive overwound layers to prevent damage.
c) For extruded geogrids flat plates are used with a profile matching the thick nodes. At loads close to the tensile strength flat plates with serrated surfaces clamped under pressure are found to perform better.
d) Nonwovens can be gripped in any of the above ways but flat plate grips with a choice of facing materials are found to be sufficient.

Loading Procedure

Loading at a steady, uniform rate appears to be critical for polyester. A preload had been introduced in BS 6906 Part 5 to eliminate the difficulty in defining zero strain for nonwovens and other materials where any strain introduced during handling and loading is irretrievable. Care is needed so as not to stress a textile excessively during handling and, in particular, insertion in the grips. There appears to be a more fundamental problem, probably associated with polyester fibres themselves, that makes the strain on loading sensitive to the manner in which that load is applied [*1*, *3*]. It was not the purpose of this work to explain the reason for this sensitivity, only how to control it.

Loading is now performed by assembling the required steel weights first, without loading the specimen, and then applying the load to the specimen gradually by means of a worm gear. The worm gear is already in place as the means of adjusting the height of the weights and keeping the lever within its calibrated range. This procedure is much smoother. It is limited only by the available travel on the worm gear and the extension of the material during loading. A hydraulic jack can be used with similar effect.

In-House Procedures

The methods described are documented in easily understood in-house procedures which are audited by the United Kingdom national accreditation service UKAS. J M Palmer has been responsible for loading most of the tests since 1990.

Variability Today

This paper shows that good laboratory practice can lead to a repeatability with a coefficient of variation of 1.6% or less. This is based on measurements on geogrids and strips tested at higher loads 1 h after loading, which is when most of the variability is believed to originate. Data from very long-term tests reveal loading problems that were not recognised at the time. They have since been solved, and the resulting recommendations have been introduced into the proposed international standard for measurement of creep in geosynthetics, EN ISO 13431, "Geotextiles and geotextile-related products - determination of tensile creep and creep-rupture behaviour".

Materials, too, have improved. A coefficient of variation of ± 1.6% can only be achieved if the material properties are themselves this uniform.

Because of the low creep gradient, even this level of variability will present a problem with the time-temperature superposition of polyester, the problem being elegantly avoided by the Stepped Isothermal Method (SIM) of applying temperature steps to a single specimen [*3*]. While the SIM provides a short cut to demonstrating that a new material follows the pattern set by an old one, its validity rests on comparison with real long-term creep tests. Long-term tests will continue to be specified by national approvals authorities. This paper shows that the results of such creep tests can be relied on with greater confidence than before.

Acknowledgements

We thank Nicolon Mirafi, Polyfelt Ges. m. b. H., Strata Systems Inc., and Terram Ltd. for permission to use calculations derived from results on their materials, and the directors of ERA Technology Ltd. for permission to publish.

References

[1] Greenwood, J. H., "The creep of geotextiles", *Proceedings of the 4th International Conference on Geotextiles, Geomembranes and Related Products*, G.den Hoedt ed., Balkema, Rotterdam, Netherlands, 1990, pp. 645-650.

[2] Watts, G. R. A., Brady, K. C., and Greene, M. J., "The creep of geotextiles", *TRL Report 319*, Transport Research Laboratory, Crowthorne, United Kingdom, 1998.

[3] Thornton, J. S., Paulson, J. N., and Sandri, D., "Conventional and stepped isothermal methods for characterising long term creep strength of polyester geogrids", *6th International Conference on Geosynthetics*, Industrial Fabrics Association International, Roseville, MN, U. S. A., pp. 691-698.

ISBN 0-8031-2854-1