Geotextiles and Geomembranes 42 (2014) 201–213

Contents lists available at ScienceDirect

Geotextiles and Geomembranes

journal homepage: www.elsevier.com/locate/geotexmem

Micro-scale tensile properties of single geotextile polypropylene filaments at elevated temperatures

Tanay Karademir[a,*], J. David Frost[b,1]

[a] Department of Civil Engineering, Istanbul Bilgi University, Istanbul 34060, Turkey
[b] School of Civil & Environmental Engineering, Georgia Institute of Technology, Atlanta, GA 30332, USA

ARTICLE INFO

Article history:
Received 29 July 2013
Received in revised form
10 February 2014
Accepted 25 March 2014
Available online 17 April 2014

Keywords:
NPNW geotextiles
Temperature effects
Single geotextile filaments
Dynamic mechanical analyzer
Micro-scale tensile testing
Statistical analysis

ABSTRACT

Geotextiles are porous and fibrous materials that consist of randomly oriented and isotropically distributed long filaments which vary in terms of spatial distribution, curvature, orientation, size, and mass density. The heterogeneous internal structure of geotextiles constituted from individual/discrete fibers and having different micro-structure and macro-structure properties are prone to exhibit dissimilar tensile stress–strain behavior (i.e. progressive versus reactionary) as well as showing favorable versus adverse response to varied experimental conditions such as temperature and strain rate change when tested at macro scale as opposed to micro-scale level. To this end, in order to evaluate thermo-tensile strength properties as well as to characterize tensile extension behavior of single geotextile filaments at micro-scale level, micro-mechanical tensile tests were performed at different temperatures using a Dynamic Thermo-Mechanical Analyzer (DMA) on single filaments extracted from polypropylene needle punched nonwoven geotextile. Various test temperatures between 21 °C and 50 °C were chosen to represent and simulate the wide range of temperatures encountered in the field for geotechnical applications such as landfill base liners. The paper also presents a statistical analysis of the results of the test program to provide a basis for comparison of inherent filament variability.

1. Introduction

The tensile strength properties of geotextiles made from polymeric materials is an important issue in geotechnical engineering design. For example, geotextiles originally produced from several different polymer resins are widely used under tensile load conditions in landfills, retaining walls, slopes, foundations and road subgrades in which they are subjected to tensile stresses as well as ambient temperature variations throughout their service life (Koerner, 2005; Andrejack and Wartman, 2010; Rawal and Sayeed, 2013). Temperature has a significant effect on the physical and mechanical engineering properties of the polymeric, fibrous geotextiles such as tensile strength, modulus and toughness (Henry and Durell, 2007). Additionally, the field deterioration of geotextiles over time fundamentally results from damaging thermal effects and mechanical stresses (Li and Hsuan, 2004). Fibers in geotextile fabrics lose their tensile strength due to thermally induced relaxation effects at higher temperatures resulting from inherent physico-chemical properties of the material (Tisinger et al., 1990). In particular, when employed in a multi-layered composite systems such as a landfill liner, the field deterioration of the geotextiles at macro level as well as at micro scale result primarily from detrimental and damaging external thermal effects due to increases in ambient temperatures as well as mechanical stresses (i.e. tensile, shear) imposed on these materials (Southen and Rowe, 2011; Azad et al., 2011). In this context, the influence of temperature variations on the tensile strength properties of polymeric geotextiles is especially crucial for long-term engineering design (Bueno et al., 2005). To this end, the endurance properties of the geotextiles must be properly evaluated at the “macro-scale” as well as at the “micro-scale” so that the appropriate factor of safety (FS) can be incorporated into the long-term design of structural systems as originally emphasized by Nielsen (1974).

2. Background to study and relevant literature

The tensile force – displacement test is one of the common mechanical test types extensively used for polymers, and thus, to evaluate the engineering properties of geotextiles. This is attributed

* Corresponding author. Tel.: +90 533 311 3598.
E-mail addresses: tanay.karademir@bilgi.edu.tr (T. Karademir), david.frost@ce.gatech.edu (J.D. Frost).
[1] Tel.: +1 404 894 2280; fax: +1 404 894 2281.

http://dx.doi.org/10.1016/j.geotexmem.2014.03.001

to the fact that many geotextiles are designed to complement the relatively low tensile capacity of soils (Mitchell et al., 1990; Koerner, 2005). On the other hand, geotextiles can exhibit different tensile stress–strain behavior (Rawal et al., 2011) as well as show favorable versus adverse response to varied test conditions such as temperature and strain rate variations when tested at the "macro-scale" level versus when tested at the "micro-scale" level. This is due to the heterogeneous internal structural formation of the fibrous geotextiles. Therefore, it is possible to observe a contradictory response of the geotextile when tested at the "micro-scale" level as opposed to the response inferred from tests at the "macro-scale" level resulting from the geotextiles having different "micro-structure" and "macro-structure" properties. At micro-scale, the tensile failure takes place due to breakage of filaments; while, at macro scale, the slippage between filaments and the structural deformation due to fiber realignment and inherent internal geotextile void space governed by geotextile manufacturing and fiber processing type, dominates.

Needle-punched nonwoven (NPNW) geotextiles are inherently comprised of a fibrous inner structure formation that is highly compressible and loosely structured (Koerner, 2005; Koerner and Koerner, 2010). The tensile strength of NPNW geotextiles manufactured using randomly distributed fibers is primarily governed by the fibers' inherent tensile strength, the fiber aspect ratio, crimping and fiber interweaving (Bueno et al., 2005). Therefore, the macro-scale response of a geotextile is a complex phenomenon and strongly depends upon the geotextile's dimensional and structural properties (Rawal et al., 2013; Rawal and Sayeed, 2013). That is to say, the total deformation under extension or contraction loading in a NPNW geotextile is the summation of elastic elongations, inelastic (plastic) deformations in the filaments as well as is the cumulative result of the deformations due to inherent internal structural rearrangement of the geotextile including void space for which the initial elasto-plastic type deformation is strongly temperature and strain rate dependent, while the long-term rearrangement type deformation is not. As such, deformations due to the rearrangement of the internal structure are not sensitive to temperature and strain rate change, whereas, the elasto-plastic deformations of the polymeric geotextile filaments under stress are sensitive to temperature (Andrawes et al., 1984). On the other hand, the woven geotextiles with aligned filaments have virtually no structural deformation component; therefore, it is the filament polymer which controls the total deformation. Hence, the woven geotextile is significantly influenced by temperature and strain rate changes (Kongkitkul et al., 2012), whereas, the filament polymer effect in needle-punched nonwoven (NPNW) geotextiles is small compared to that of the structural changes, with the result that its deformation is almost independent of the temperature and strain rate *only* at "macro-scale" level (Andrawes et al., 1984). However, as far as the tensile testing of the geotextile at "micro-scale" level is concerned, the effects of the rearrangement of internal structure of the geotextile on the test results attained are avoided since only a single filament is being tested and the tensile behavior developed as well as the tensile strength parameters obtained are strongly dependent on the single geotextile filament polymeric properties. Therefore, temperature has a significant and crucial influence on tensile test results attained when the observation of tensile strength behavior of the geotextiles at different temperatures is being considered at the "micro-scale" level. Consequently, the temperature effect on tensile strength behavior/properties of the fibrous geotextile at "micro-scale" is more pronounced in the tests and vital to the results than that at "macro-scale" levels. To this end, single geotextile filament tensile tests at micro-state must be performed to evaluate micro-tensile strength properties of single geotextile filaments at different temperature conditions.

3. Characterization of micro-tensile properties of single geotextile filaments

3.1. *Experimental device: Dynamic Thermo-Mechanical Analyzer (DMA)*

A Dynamic Thermo-Mechanical Analyzer (DMA) (Fig. 1) was used to measure micro-tensile strength properties of single geotextile filaments at different temperatures. The Gas Heating/Cooling Accessory (Fig. 1a) extends the operating range of the DMA from −150 °C up to 600 °C. Cold nitrogen gas is used for rapid heating/cooling capability of the system which is generated from controlled heating of liquid nitrogen. The clamping system installed on the DMA is a tension smooth clamp fixture with flat jaws (Fig. 1b) used for gripping the filament specimens and designed to minimize slippage in the clamps during the tests.

3.2. *Test method*

The controlled constant Force or Strain Rate mode of operation of the DMA was used to measure tensile properties and to observe the development of tensile force versus strain relationships of

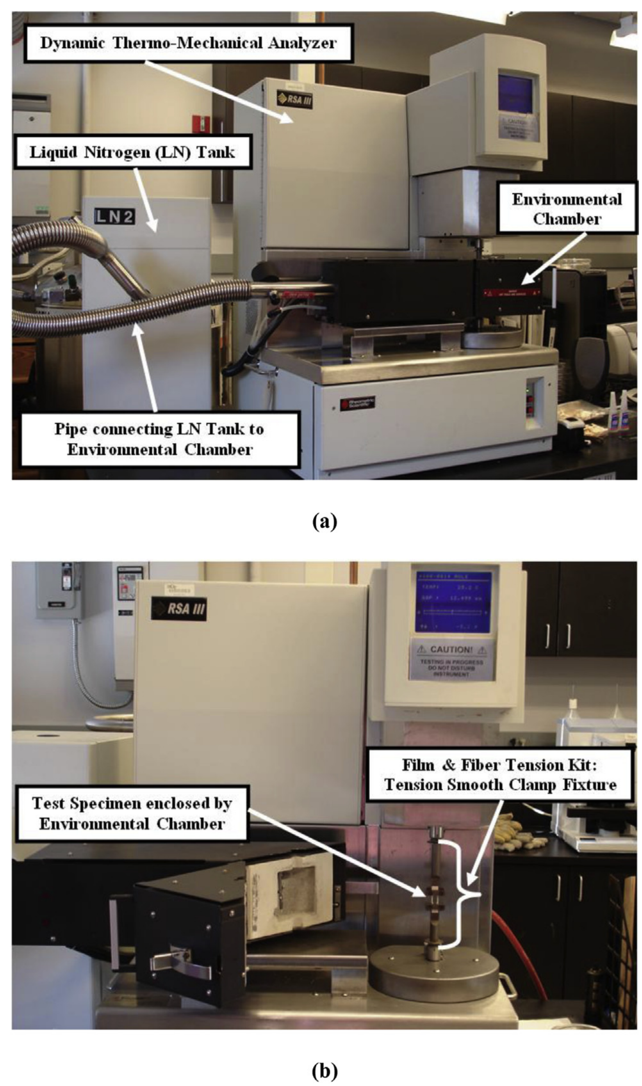

Fig. 1. Dynamic Thermo-Mechanical Analyzer – DMA: (a) Entire system; (b) Close-up view.