Materials Letters 183 (2016) 77–80

Contents lists available at ScienceDirect

Materials Letters

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

Needle-punched thermally-bonded eco-friendly nonwoven geotextiles: Functional properties

Jia-Hsun Li [a], Jing-Chzi Hsieh [b], Ching-Wen Lou [c], Chien-Teng Hsieh [d], Yi-Jun Pan [e], Wen-Hao Hsing [f], Jia-Horng Lin [g,h,i,j,*]

[a] Department of Ph.D. Program in Civil and Hydraulic Engineering, Feng Chia University, Taichung City 40724, Taiwan
[b] Department of Land Management, Feng Chia University, Taichung City 40724, Taiwan
[c] Institute of Biomedical Engineering and Materials Science, Central Taiwan University of Science and Technology, Taichung 40601, Taiwan
[d] Department of Fashion Design and Merchandising, Shih Chien University Kaohsiung Campus, Kaohsiung 845, Taiwan
[e] Department of Material and Fiber, Oriental Institute of Technology, New Taipei 22061, Taiwan
[f] Department of Textile Engineering, Chinese Culture University, Taipei 11114, Taiwan
[g] School of Textiles, Tianjin Polytechnic University, Tianjin 300387, China
[h] Laboratory of Fiber Application and Manufacturing, Department of Fiber and Composite Materials, Feng Chia University, Taichung City 40724, Taiwan
[i] School of Chinese Medicine, China Medical University, Taichung City 40402, Taiwan
[j] Department of Fashion Design, Asia University, Taichung City 41354, Taiwan

ARTICLE INFO

Article history:
Received 11 April 2016
Received in revised form
5 July 2016
Accepted 16 July 2016
Available online 18 July 2016

Keywords:
Nonwoven geotextile
Recycle Kevlar
Shear resistance
Functional
Thermal properties

ABSTRACT

As a replacement for mineral materials, geotextiles have been pervasively used in civil engineering so as to provide separation and filtration. This study aims to recycle Kevlar selvages for the preparation of nonwoven geotextiles. The effects of fiber types and manufacturing processing are examined in terms of pore size, water permeability, and shear resistance (bursting strength, and puncture strength). The test results and statistical analyses indicate that a combination of 20 wt% Kevlar fibers, 60 wt% three-dimensional crimped polyester (PET) fibers, and 20 wt% low-melting-point PET (LMPET) fibers creates geotextiles that have a small pore size, good water permeability, and good shear resistance. These geotextiles prevent soil loss, and have greater water permeability and a higher resistance to sharp objects.

1. Introduction

Geotextiles are planar products which are made from polymers, and are commonly composed of woven fabrics or nonwoven fabrics [1]. Nonwoven geotextiles have a unique three-dimensional fiber structure, which results in a high porosity, variation in pore size, and water permeability [2], and thus have been commonly used for civil engineering in terms of filtration and drainage [3,4]. Nevertheless, nonwoven fabrics are not as mechanically strong as woven fabrics. Many studies examine how the addition of high modulus fibers improves the ability of composite nonwoven fabrics [5,6], and glass fibers, aramide fibers, and carbon fibers are primarily used as reinforcing materials. Kevlar fibers are one type of aramide fiber, and have an increasingly broad range of applications. The amount of Kevlar selvages also increases with the production of Kevlar related products; thus directly using Kevlar selvages for the preparation of geotextiles can provide mechanical reinforcement at a low production cost [5,7], and is also environmentally protective.

There are a great number of geotextiles, which are produced using different polymer types, fiber types and manufacturing processes, the latter of which has a significant influence on the pore size and water permeability of the geotextiles [8]. Moreover, the environment that geotextiles are used in is abundant in sharp objects, such as stones or wood; therefore, the shear resistance of geotextiles is also an important evaluation [9].

In sum, this study aims to recycle Kevlar selvages that are applied to the preparation of geotextiles. Moreover, three-dimensional and crimped PET fibers are the primary constituent, and LMPET fibers are also added for the purpose of thermal bonding. The three fibers are made into Kevlar/PET/LMPET nonwoven geotextiles via a nonwoven manufacturing process, mechanical bonding and thermal bonding in order to stabilize the loose webs. Therefore, this study examines the influence of fiber ratios, needle punching depths, and the application of thermal treatment on the pore size, water permeability, bursting strength, and puncture strength. Moreover, one-way ANOVA and post-hoc Scheffe's tests

* Corresponding author at: Laboratory of Fiber Application and Manufacturing, Department of Fiber and Composite Materials, Feng Chia University, Taichung City 40724, Taiwan

E-mail address: jhlin@fcu.edu.tw (J.-H. Lin).

http://dx.doi.org/10.1016/j.matlet.2016.07.074
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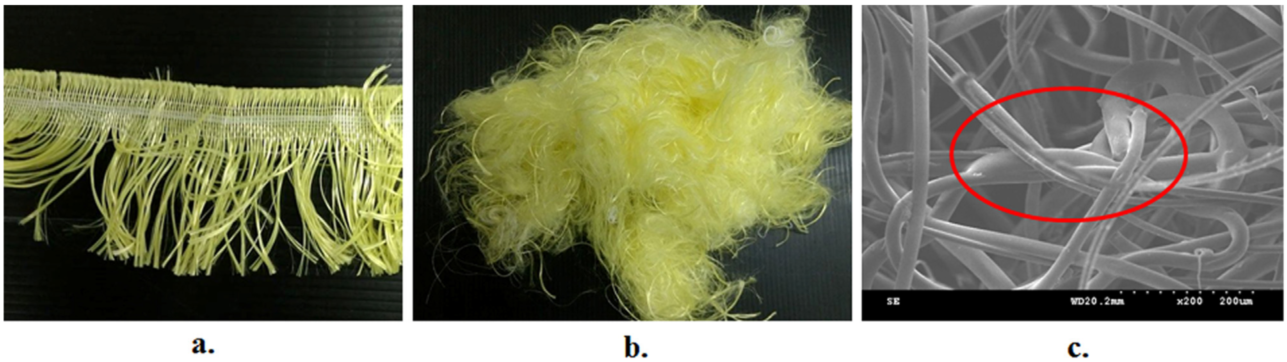

Fig. 1. Images of a) Kevlar selvages, b) recycled Kevlar fibers, and c) thermal bonding points.

of SPSS statistics software (version 20.0) are used for statistical analyses.

2. Experimental

2.1. Materials

Kevlar uni-directional selvages (Dupont, U.S.) include K29, K49 and K129 multi-filaments. The recycled Kevlar fibers have a fineness of 1.5–2 Denier (D) and a length of between 50 and 60 mm. The three-dimensional crimped PET fibers (Far Eastern New Century, Taiwan, ROC) have a fineness of 7 D and a length of 64 mm. LMPET fibers (Far Eastern New Century, Taiwan, ROC) have a fineness of 4 D and a length of 51 mm. LMPET fibers have a sheath-core structure. The glass transition temperature of the sheath is 60 °C, while its melting point is 110 °C.

2.2. Sample preparation

Recycled Kevlar selvages (Fig. 1a) are processed via opening so as to form Kevlar staple fibers (Fig. 1b). At different ratios of 0/80/20, 5/75/20, 10/70/20, 15/65/20, and 20/60/20, PET fibers and LMPET fibers are blended, and then undergo opening, blending, carding, lapping, and needle-punching in order to form Kevlar/PET/LMPET nonwoven geotextiles with a basis weight of 200 ± 10 g/m^2. These nonwoven fabrics are needle punched at different depths (15, 17, or 19 mm), and then thermally treated at 120 °C. The thermal bonding points are formed as a result of the thermal treatment, and are photographed using a scanning electron microscope (JSM-6360LA, JEOL Ltd.) in Fig. 1(c). As shown in Fig. 2(a) and (b), samples are denoted by their NT/T series and Kevlar content (0, 5, 10, 15, 20 wt%) or needle punching depth (15, 17, 19 mm). "NT" series refer to non-thermally treated samples, while "T" series refer to thermally treated samples. "K" refers to Kevlar content and "P" refers needle punching depth. For example, "NTK10" means non-thermally treated samples containing 10 wt% Kevlar fiber, and "TP17" means thermally treated samples that are needle punched at 17 mm.

2.3. Tests

2.3.1. Apparent opening size (AOS)

AOS is commonly used to evaluate the pore size of geotextiles using the ASTM D4751 standard test method. In dry sieving, glass bead fragments of different sizes are sieved through a geotextile to determine the diameter of the pores, where 95% by weight of the beads is retained on the geotextile, expressed as O_{95}.

2.3.2. Water permeability

This test is performed as specified in test standard ASTM D4491-99a. Eq. (1) is used for the computation of water permeability.

$$K_{20} = \frac{W}{A\Delta ht} \cdot \eta \tag{1}$$

where W is quantity of flow (cm^3), A is cross-sectional area of the test area of a specimen (cm^2), Δh is head of water on the specimen (cm), t is time for flow (s), and η is the temperature correction factor.

2.3.3. Bursting strength and puncture strength

An Instron 5566 Universal Tester (Instron, USA) is used for both tests as specified in test standard ASTM F1342-05. The probe for the bursting strength test has a diameter of 25 mm, while the probe for the puncture strength test has a diameter of 2 mm. The specimen support assembly consists of two flat metal specimen support plates with a centered hole that is 45 mm in diameter for

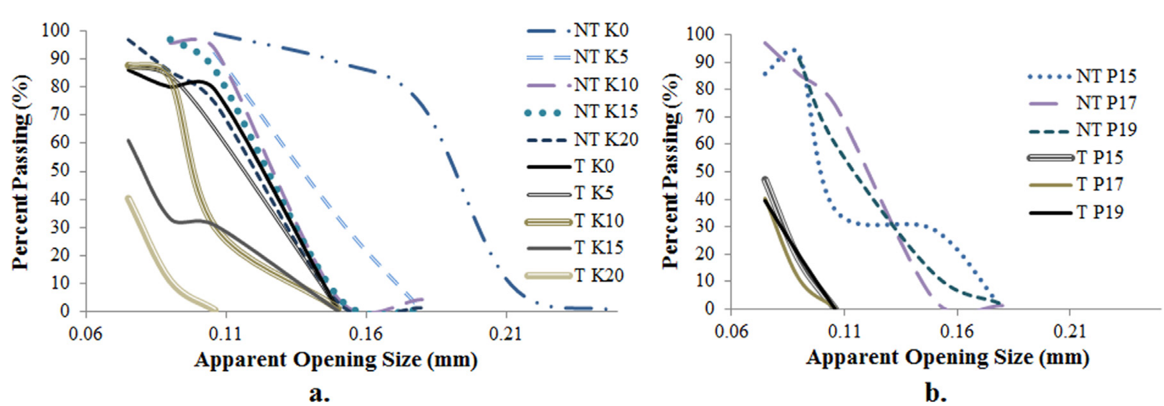

Fig. 2. Pore size of Kevlar/PET/LMPET nonwoven geotextiles in relation to a) Kevlar fiber contents and b) needle punching depths.