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Feasibility Assessments of the Use of Recycled Fibers in Nonwoven Fabrics

Jia-Horng Lin [1,2,3,4,5], Yan-Lan Hsing [2], Wen-Hao Hsing [6], Yi-Jun Pan [7], Chien-Teng Hsieh [8] and Ching-Wen Lou [1,9,*]

1 Department of Chemistry and Chemical Engineering, Minjiang University, Fuzhou 350108, China; jhlin@fcu.edu.tw
2 Laboratory of Fiber Application and Manufacturing, Department of Fiber and Composite Materials, Feng Chia University, Taichung 40724, Taiwan; yalanhsing@gmail.com
3 School of Chinese Medicine, China Medical University, Taichung 40402, Taiwan
4 Department of Fashion Design, Asia University, Taichung 41354, Taiwan
5 Innovation Platform of Intelligent and Energy-Saving Textiles, School of Textiles, Tianjin Polytechnic University, Tianjin 300387, China
6 The Department of Textile Engineering, Chinese Culture University, Taipei 11114, Taiwan; hsing@staff.pccu.edu.tw
7 Department of Materials and Textiles, Oriental Institute of Technology, New Taipei 22061, Taiwan; fc003@mail.oit.edu.tw
8 Department of Fashion Design and Merchandising, Shih Chien University Kaohsiung Campus, Kaohsiung 84550, Taiwan; edo@mail.kh.usc.edu.tw
9 Graduate Institute of Biotechnology and Biomedical Engineering, Central Taiwan University of Science and Technology, Taichung 40601, Taiwan
* Correspondence: cwlou@ctust.edu.tw; Tel.: +886-2239-1647 (ext. 6806)

Academic Editor: Kerry Kirwan
Received: 20 October 2016; Accepted: 23 December 2016; Published: 5 January 2017

Abstract: Environmental protection has become an increasing concern, which makes recycling and reclaiming highly important. In addition to governmental campaigns and promotion, enterprises should examine each perspective thoroughly in order to prevent excessive resource consumption. In this study, recycled materials, including recycled far-infrared polyester (FPET) fiber, three-dimensional crimped hollow flame-retarding (TPET) fiber, and low-melting-point polyester (LPET) fiber, are used to form nonwoven fabrics. The influence of different amounts of FPET fiber, 0–80 wt %, on the properties of nonwoven fabrics was examined. The sheath of LPET fibers can be melted as a result of hot pressing, which provides cohesion between fibers that mechanically improves the nonwoven fabrics. The tensile strength, tearing strength, air permeability, and far infrared (FIR) emissivity of the nonwoven fabrics were examined, thereby determining the optimal parameters. The test results show that the thermally treated nonwoven fabrics have better mechanical properties and FIR emissivity, compared to those of non-thermally treated nonwoven fabrics. Moreover, more FPET fibers cause the mechanical properties along the cross machine direction (CD) to decrease by 9% and that along the machine direction (MD) to decrease by 5%. In particular, all the thermally treated samples exhibit a FIR emissivity of 0.8, which is health-promoting.

Keywords: environmental protection; recycled fiber; far infrared (FIR) emissivity

1. Introduction

In the textile industry, solid waste causes severe environmental problems. As a result, there has been a considerable amount of research into recycling and reclaiming textile waste. With the increasing awareness of the importance of environmental protection, enterprises have a social duty to help to protect the environment. The best solution is to have materials that cause zero pollution. For example, selvages can be recycled for the production for geotextiles [1], penetration resistant planks, or far infrared emissive or electromagnetic interference shielding (EMI SE) functional fiber composites [2–8].

Using recycled FIR fiber conforms to eco-friendly concepts, and FIR rays activate water molecules, which increases body temperature and attains the added value of thermal insulation. FIR rays boost the circulation and metabolism rates for the human body and provide substantial health-care effects [9–11].

Low-melting-point polyester (LPET) fiber has different components, structure, and functions from those of common fibers. LPET fiber has a sheath-core structure that is composed of common polyester and modified polyester multi-filaments. Unlike common PET fibers, the sheath of LPET fiber can be melted at a lower temperature, as its melting point is 110 °C. It can serve as an adhesive to bond fibers, and thus replace the commonly used glues. Therefore, LPET fiber is suitable for use in nonwoven fabrics, which meets economical and environmentally protective requirements [12,13].

For this study, recycled far infrared polyester (FPET) fiber that accounts for the majority of industrial waste was collected from textile waste. They have the function of emitting FIR rays. Moreover, three-dimensional crimped, hollow, flame-retarding (TPET) fiber and LPET fiber were added during the production of nonwoven fabrics in order to evaluate the influence of these materials on the properties of the nonwoven. The properties of nonwoven fabrics were evaluated and compared, examining the influence of hot pressing.

2. Experimental

2.1. Materials

Three-dimensional crimped, hollow flame-retarding (TPET) fiber (Far Eastern New Century Corporation, Taipei, Taiwan) has a fineness of 7D, a length of 51 mm, and a melting point of 259–269 °C [14,15]. Low melting point polyethylene terephthalate (LPET) fiber (Far Eastern New Century Corporation) has a fineness of 4D, and a length of 51 mm. The sheath of LPET fiber has a melting temperature of 110 °C [16]. Recycled far infrared (FPET) fiber (True Young Co., Ltd., Tainan, Taiwan) has a fineness of 6D, 2% far infrared powder, and a length of 64 mm.

2.2. Preparation of Nonwoven Fabrics

FPET, TPET, and LPET fibers are respectively scattered via an opening process using a porcupine in order to make them loose and fluffy, which facilitates their mixture. The fibers at ratios of 0/80/20, 20/60/20, 40/40/20, 60/20/20, and 80/0/20 are processed with mixing and carding. The webs are folded and needle punched in order to form nonwoven matrices. These matrices are then processed with a roller-type hot pressing with a gauge distance of 1 mm, allowing the LPET fibers to create bonding points that toughen the connection between fibers. These samples are evaluated using different tests, examining the influence of the fiber blending ratios.

3. Tests

3.1. Air Permeability Test

A TEXTEST FX3300 (GO-IN International Co., Ltd., Munich, Germany) was used to measure the air permeability of samples, as specified in ASTM D737. Nonwoven fabrics were composed of five different fiber blending ratios, and 20 samples for each specification were taken for the test. Air permeability is defined as the air volume (cm^3) that passes through per 1 cm^2 of a sample, and is represented as $cm^3/(s \cdot cm^2)$.

3.2. Stereomicroscopic Observation

A stereomicroscope (SMZ-10A, Nikon Instruments Inc., Shinagawa, Japan) was used to observe the surface of the samples. Afterwards, Motic Images Plus 2.0 software (Motic Group Co., Ltd., Barcelona, Spain, 2012) was used to analyze the photographs.

3.3. Tensile Test

Samples are trimmed along the cross machine direction (CD) and the machine direction (MD) into 2.54 cm × 18 cm strips. The distance between clamps was 7.5 cm and the tensile rate was 300 mm/min.

3.4. Tear Strength Test

Tear strength along the CD and MD of nonwoven fabrics was measured as specified in CNS 12915. Ten samples were taken along the CD and MD for each specification. The sample size was 7.6 cm × 20.3 cm. The test rate was 300 mm/min.

3.5. Far Infrared Emissivity Test

A far infrared emissivity (TSS-5X, Desunnano Co., Ltd., Tokyo, Japan) test measures the far infrared emissivity of 10 spots of nonwoven fabrics as specified in FTTS-FA-010. The fabrics release heat radiation when being measured with far infrared emissivity.

4. Results and Discussion

4.1. The Effect of Content of Recycled Fiber on Air Permeability of Nonwoven Fabrics

The data in Figure 1a show that air permeability decreases as a result of increasing the amount of FPET fiber. FPET fiber and TPET fiber account for 80 wt % of the nonwoven fabrics, while LPET fiber was used at a specified amount of 20 wt %. TPET fiber is three-dimensional, crimped, hollow, and fire-retardant, which enables it to hold more air. Moreover, the sheath of LPET fiber melts during hot pressing, which creates a compact structure between fibers. That is, a lower amount of pores is presented in the nonwoven fabrics, as indicated in Figure 1c, and the nonwoven fabrics have a smaller thickness. The air permeability of hot pressed nonwoven fabrics is higher by 20 cm^3 (cm^2/s) than that of non-hot-pressed nonwoven fabrics.

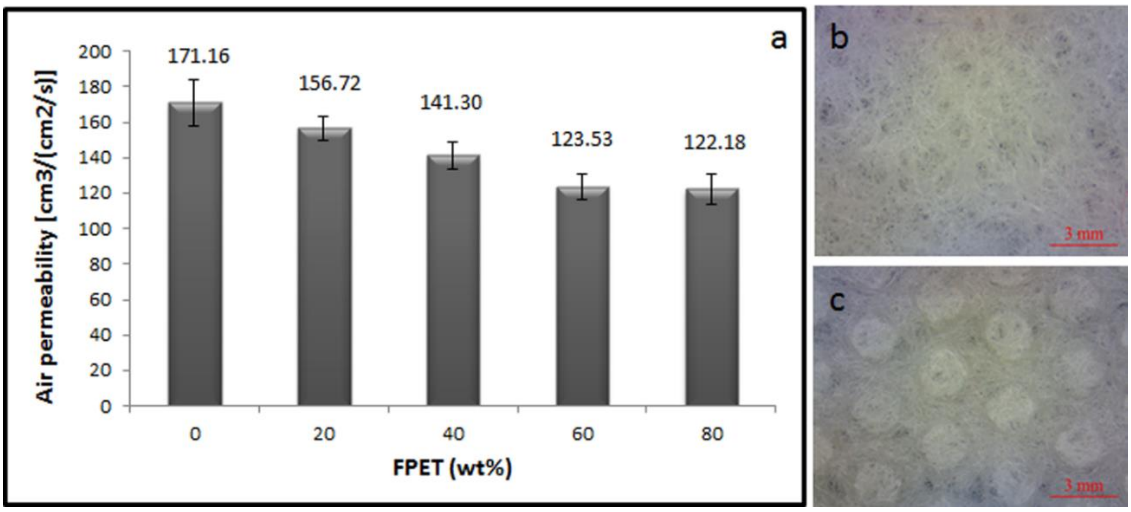

Figure 1. (**a**) Air permeability of nonwoven fabrics in relation to far-infrared polyester (FPET) content; (**b**) Stereomicroscopic images (6.7×) of the non-thermally treated and (**c**) thermally treated nonwoven fabrics.

4.2. The Effect of Content of Recycled Fibers on the Tensile Strength of Nonwoven Fabrics

Figure 2a shows that more FPET fiber causes the tensile strength of nonwoven fabrics to decrease. The needle punching process results in the entanglement and cohesion of fibers. As the barbed needles repeatedly pierce the fabric, they pull the fiber from the bottom through to the upper surface. The repetitive needle punch provides nonwoven fabrics with a higher density, which is conducive for tensile strength. However, recycled fibers often have a poor strength. When recycled fibers are repeatedly needle-punched, they exhibit fiber breakage. Therefore, the tensile strength of nonwoven fabrics is in inversely proportional to the amount of recycled fiber. Moreover, the tensile strength along the CD is higher than that along the MD. This result is ascribed to the carding process, which laminates the webs along the CD, as illustrated in Figure 2b and good arrangement of the fiber wed in Figure 1b. Therefore, nonwoven fabrics exhibit a higher tensile strength along the CD.

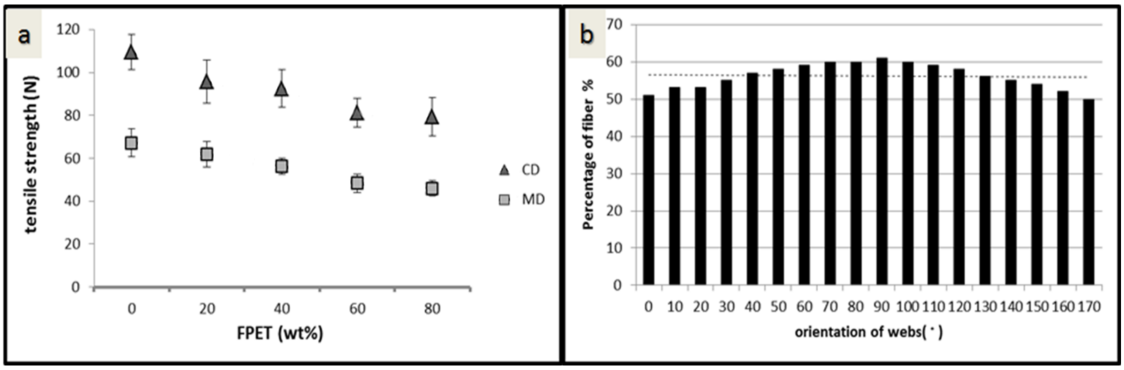

Figure 2. (**a**) Tensile strength of nonwoven fabrics in relation to FPET content; (**b**) Schematic illustration of the orientation of webs.

4.3. Effect of Content of Recycled Fibers on the Tear Strength of Nonwoven Fabrics

That the nonwoven fabrics exhibit lower tear strength when they contain more FPET fiber, is illustrated by the data presented in Figure 3, the trend observed for tensile strength. This result indicates that the recycled fibers have a decreased physical properties as a result of being recycled. In the recycling process, the recycled fibers are processed via melting, granulating, or spinning. In addition, the presence of the LPET fiber can mechanically improve the compact structure of nonwoven fabrics due to the fusion swing presence of hot pressing. The tear strength of nonwoven fabrics is assumed to be primarily due to the three-dimensional crimped, hollow, flame-retardant TPET fiber. The end user can thus adjust the tear strength according to their requirements.

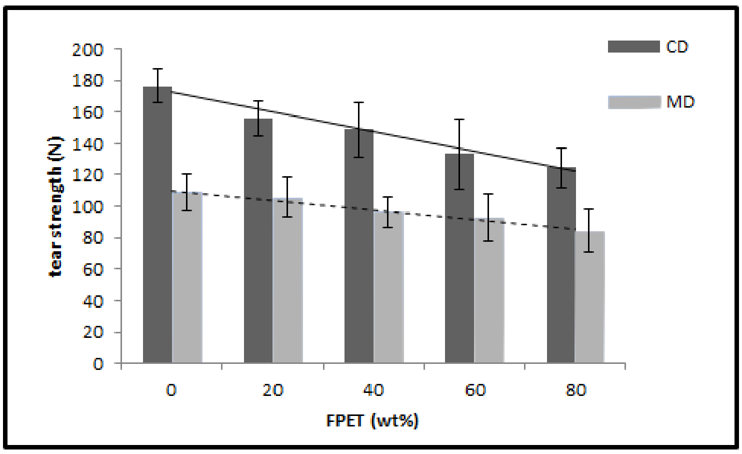

Figure 3. Tear strength of nonwoven fabrics in relation to the content of FPET.

4.4. Effect of Content of Recycle Fibers on the Far Infrared Emissivity of Nonwoven Fabrics

Using more FPET fiber stabilizes the slightly increased far infrared emissivity of nonwoven fabrics, as shown in Figure 4. All thermally treated nonwoven fabrics exhibit far infrared emissivity of above 0.8, which is qualified for health care and is 8% greater than the non-thermally treated samples. The recycled FPET fiber contains 2% far infrared powder. It is difficult for these powders to be evenly dispersed in fluffy nonwoven fabrics. In performing the far infrared emissivity test, there is a high potential for black body to detect the air inside the fabrics. Moreover, the test is highly influenced by external environment conditions in terms of humidity, temperature, or people's interference and creates a high variation coefficient. In contrast, the thermally treated fabrics not only have a smaller thickness, but also allow the powder to be evenly dispersed, which leads to an efficient far infrared emissivity. In particular, using 40 wt % FPET fiber helps to yield a stabilized far infrared emissivity, indicating that this specified amount of FPET fiber is suitable for applications relating to far infrared emissivity for health care.

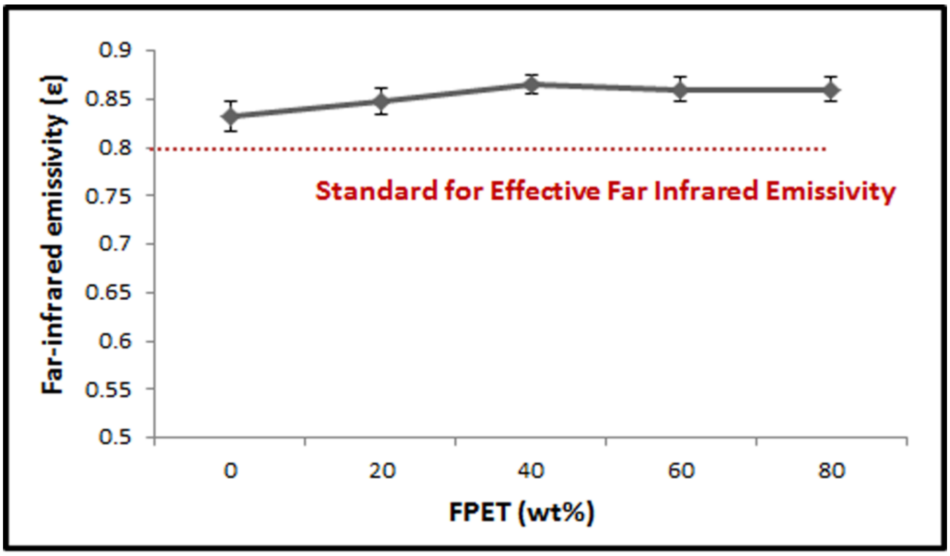

Figure 4. Far infrared emissivity of nonwoven fabrics in relation to FPET content.

5. Conclusions

In this study, the influence of FPET fiber on the properties of nonwoven fabrics was examined in terms of air permeability, tensile strength, tear strength, and far infrared emissivity of FPET/TPET/LPET nonwoven fabrics. The air permeability increases by 6% when the TPET fiber is increased from 40 to 60 wt % and from 60 to 80 wt %. When the content of FPET fiber is increased by 20 wt %, the mechanical properties along the CD of nonwoven fabrics decrease by 9%, while those along the MD decrease by 5%. The recycled far infrared fiber can be adjusted in view of the application field. For thermally treated FPET/TPET/LPET nonwoven fabrics, the far infrared emissivity shows an increasing trend when the content of the FPET fiber is increased from 0 to 40 wt %, and it is then stabilized at 0.85ε when the content of the FPET fiber is increased from 60 to 80 wt %.

Acknowledgments: The authors would especially like to thank the Ministry of Science and Technology of Taiwan for financially supporting this research under Contract MOST 105-2622-E-034-001-CC2.

Author Contributions: In this study, the concepts and designs for the experiment, all required materials, and the processing and assessment instruments were provided by Jia-Horng Lin, and Ching-Wen Lou. Data were analyzed and experimental results were examined by Wen-Hao Hsing, Chien-Teng Hsieh, and Yi-Jun Pan. Experiment were conducted and tests were carried out by Yan-Lan Hsing.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

The following abbreviations are used in this manuscript:

PET	polyester
FPET	far-infrared polyester
TPET	three-dimensional crimped hollow flame-retarding polyester
LPET	low-melting-point polyester
FIR	far infrared
CD	cross machine direction
MD	machine direction

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