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Chemical ageingaging of a polyester nonwoven membrane used in aerosol and drainage filter

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ABSTRACT

The filter media in polyester is one of the most geotextile materials used in aerosol and drainage filtration, particularly for soil reinforcement in civil engineering due to its appropriate properties and its low cost. However, the current understanding of the durability and stability of this material in real service conditions, especially under severe long-term conditions are completely limited. This work presents an investigation of the chemical aging of a commercial nonwoven polyester membrane under different temperatures and pH environments in relation to its morphology, mechanical properties and molar mass. The results showed a significant reduction of mechanical properties in term of tensile strength, puncture resistance and tearing forces of the membrane after aging process due to the chemical degradation. The molar mass and mechanical properties changes with temperature and pH showed a complex dependence of material properties on environmental conditions. Based on the obtained results, the lifetime of the material at different temperatures was determined by the use of the Arrhenius model. These results provide useful information to a better understanding of phenomena occurring during chemical aging of the polyester nonwoven membranes and may help to predict the service lifetime of this material in conditions of use encounteredin service.

1. Introduction

In the last decades, filter media, especially non-woven fabrics, have found extensive use in various commercial applications both domestic and industrial. This multidisciplinary research field combines several sciences such as chemistry, mechanics and physics including numerical simulation of materials.

Filter media have been used extensively since the 70s and still widely employed with an annual growth in the rate of use of 9%. For emerging countries such as China and India, this growth rate may reach 15% [1]. Today, global consumption of filter media is about 2.5 billion US dollars and will climb to $ 3.5 US billion in 2015 [2]. These materials are used both for daily domestic use (filtering water for swimming pool) as well as for high-tech applications (automotive and aerospace industries and civil Engineering). There are two types of filter media: woven and non-woven that are made from natural or synthetic fibers according to desired application. Sometimes nanotechnology may be involved in manufacturing filter media based on nano-fiber technology.

With the higher requirements for safety standards for specific applications, technologies and manufacturing processes of filter media are constantly developing to improve filtration efficiency, and to reduce the pressure drop or durability. Obtaining the optimal efficiency of filter media for various applications requires perfect control of their behavior under different service conditions. In the case of geotextiles reinforced for building soils for example, filters can undergo many kinds of mechanical damages likes compression, tearing or perforation. The problem becomes more complex with the presence of acid or alkaline medium that may occur in underground water, depending on soil type. Seasonal changes in soil temperature may have also a significant effect on the degradation of geotextile materials. These environmental factors must be taken into account in the design and application of filter media [3].

The degradation of filter media can be directly initiated by etching due to acid or alkaline media or indirectly by radioactive waste in the environment. Depending on the operating environment, the performance of the polymer can be degraded by oxidation, chain scission, crosslinking, swelling or dissolution, volatilization or extraction of additives, or even modification of the degree of crystallinity of the polymer.

Several studies that conducted on the chemical resistance of polymers used in manufacturing geotextiles are found. Andre L.

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Rollin compared the influence of main environment factors affecting the durability of various geotextile membranes including polyethylene terephthalate (PET), polypropylene (PP), polyethylene (PE) and polyamide (PA) [4]. Horz [5] and Cassidy [6] studied the chemical resistance of a various geo-synthetics. Halse [7,8] studied the effects of high levels of alkalinity on the flow and tensile behavior of several geotextiles. Accelerated aging in a chemical environment has also been studied in order to predict the lifetime of geotextile PET (polyester) and PP (polypropylene). Cassidy [9] and Koerner [10] suggested the use of the Arrhenius model to predict the lifetime of geosynthetic material. Mashiur used an empirical equation and the Arrhenius model for preventing of life time of polymer material. Author indicated that obtained results are well fitted to used equations [11].

Mathur et al [12]. reported the results of several studies on aging of polyester geotextiles at 25 °C and at a higher temperature (95 °C) over six months, at different pH using solutions of pH = 3, pH = 8 and pH = 10. Different techniques have been used to improve the understanding of the durability of polyester. The results indicated that there was a significant decrease of tensile strength during the aging process. The degradation of polyester can be attributed to polymer hydrolysis under acidic or alkaline conditions at temperatures above the glass transition temperature. The Arrhenius model was successfully applied to extrapolate short-term results to determine the lifetime of long-term geotextile polyester.

Laetitia et al. [13] conducted a study on the durability of polyester geotextiles in moderately alkaline medium (pH = 9 and 11) and at temperatures below 75 °C for aging periods ranging from 22 days to 2 years. They observed a decrease in the mechanical strength of 60% at high temperature after two years of aging at pH = 11. They found a relationship between the decrease of average molar mass and fiber diameters. An investigation of chemical resistance of eight types of non-woven geotextile in polyester (recycled or new ones) and polypropylene (PP) in different pH solutions of pH = 3, 8 and 12 was conducted by Han Yong et al. [14] and submerged conditions were varied between 30 and 180 days at different temperatures ranging from 25 °C to 80 °C. The chemical resistance of these nonwoven geotextiles was estimated by measuring the tensile strength before and after aging. The authors concluded that the transmissibility of geotextiles for drainage is slightly decreased in solutions with pH = 3 and 8, while a significant decrease was observed for the alkaline solution of pH 12.

This report presents the results of a study on chemical aging of a new polyester nonwoven filter media under different environmental conditions. The main goal was to improve our understanding of the degradation mechanism, modification of morphology, mechanical and thermal properties of this membrane under drastic conditions and provide a model that would help to predict the lifetime of the material under actual long-term use.

2. Methodology and experimental

2.1. Materials

The filter media used in this work consists of needled nonwoven polyester fibers. This material is a commercial product namely TXC-10 that is kindly provided by the company Soleno Textiles (Quebec, Canada).

2.2. Chemical treatments

Chemical aging attempts to simulate major environmental parameters that might influence the durability of filter media. This chemical treatment is carried out in various solutions: pH = 2 (pH 2), pH = 7 (pH 7) and pH = 12 (pH 12) and at different temperatures (25 °C, 55 °C and 80 °C). Filter media strips are periodically removed, washed and then dried at 25 °C before characterizing their properties.

2.3. Mechanical properties measurements

2.3.1. Tensile strength

Tensile tests were performed on rectangular samples of 15 × 100 mm with a tensile testing machine Universal Alliance 2000 (MTS), operated at a crosshead speed of 300 mm/min according to the ASTM D4632-13 standards [15].

2.3.2. Tearing strength

The tearing resistance of membrane material was measured according to the trapezoidal method with a notched specimen using the modified ASTM D 5587 standard method [16]. The sample dimensions were slightly reduced to adapt to the MTS machine in our university (Fig. 1). An isosceles trapezoid was drawn on rectangular samples of 50.8 mm × 101.6 to mark the position of the jaws and a cut of 1 cm was made in the smaller side. The upper jaw was moving at a speed of 200 mm/min until the sample was completely torn. The tearing strength was determined from the maximum force value. Four replicates for each condition were measured to obtain the average value.

2.3.3. Puncture resistance

Puncture tests are conducted on the tensile testing machine Universal Alliance 2000(MTS) operated at a speed of 300 mm/min according to ASTM D 4833 using the round puncture die of 8 mm [17].

2.3.4. Scanning electron microscopy (SEM)

The morphological changes induced by chemical aging were determined by using a scanning electron microscope model Hitachi S570. The samples were coated with a thin gold layer of several nanometers, using a pulverized gold under high vacuum. This equipment allows deposing a controlled uniform layer on the entire sample surface. An acceleration voltage of 10 kV was applied. A working distance of 5 mm was maintained in most observations.

2.3.5. Intrinsic viscosity

Intrinsic viscosity was used to determinate the molar mass changes of the polymer after the aging process. Viscosity measurements were performed by using a viscometer type Ubbelohde at 25 °C. The polymer samples were dissolved in m-cresol solvent at 60 °C in accordance to ISO 1628-5 standard [18] and the calculus of intrinsic viscosity were done according to ASTM D2857 standard [19]. The average molar masses of the polymer chains were then calculated from these measurements of viscosity data based on the Mark–Houwink equation as described in the literature [20].

2.3.6. Thermogravimetric analysis (TGA)

Thermal analyses of polyester sample were performed using a Perkin Elmer TGA. The measurements were carried out in an inert

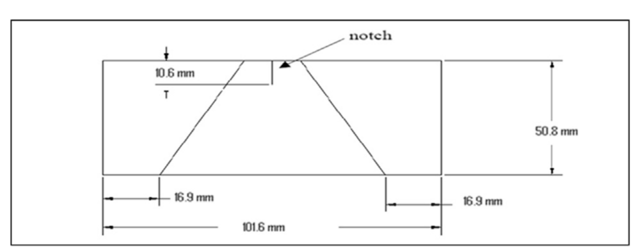

Fig. 1. Geometry of tearing testing sample.