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Prediction of outdoor weathering performance of polypropylene filaments by accelerated weathering tests

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Abstract

The effects of both accelerated and outdoor weathering tests on polypropylene filaments are studied to seek the possible relationship between weathering performance of the material under the two weathering conditions. Three intensities of Ultraviolet (UV) irradiation were provided in accelerated weathering tests to study the influences of UV irradiation intensity on photo-oxidation of the filaments. These are 81.58, 162.58 and 325.25 W/m^2 using 2, 4 and 8 UV fluorescent lamps, respectively. One year of outdoor weathering tests was also conducted. The tensile strength of the filament samples under different weathering conditions was then measured. Also, the intrinsic viscosity of the corresponding samples was measured to examine molecular weight reduction of the filaments in various stages of the arranged weathering conditions. In addition, Fourier transform infrared spectrometry was used to analyze the samples. Formation of carbonyl group of "chain end" carboxylic acids has observed from the samples under both outdoor weathering test and accelerated one with the lower intensities of UV irradiation (81.58 and 162.58 W/m^2), indicating a decomposition reaction of hydroperoxides. However, carbonyl group of esters and some lower molecular weight acids have been observed from the samples by the accelerated weathering test with the higher intensity of UV irradiation (325.25 W/m^2), indicating different degradation mechanism of the samples from the outdoor test. The study shows that the lower intensities of UV irradiation in accelerated weathering tests could offer a compatible condition with the outdoor ones for photo-oxidation of the material, and consequently, provide a possible way to predict weathering performance of polypropylene filaments used outdoors.

Keywords: Polypropylene; Photo-oxidation; Accelerated weathering; Outdoor weathering

1. Introduction

Because of good resistance to microbiologic degradation, chemical degradation and hydrolysis, the use of polypropylene geotextiles has expanded to such an extent that nowadays they are almost certain to be included in any construction work. However, polypropylene has poor resistance to photo-oxidation (e.g. Ahmed, 1982; Leflaive, 1988; Den, 1989; Heinrich, 1989; Koerner et al., 1993). Ultraviolet (UV) irradiation will cause a serious degradation of the material and consequently weaken its strength when it is exposed directly under sunlight. Many attempts have been made to investigate the results of photo-oxidation of the material in order to provide a good estimation to its long-term service performances.

Two methods have commonly been used for the purpose. One is the outdoor weathering test (e.g. Leflaive, 1988; Suits and Hsuan, 2003), which is more reliable but time consuming. The other is the accelerated weathering test (e.g. Suits and Hsuan, 2003; Li and Hsuan, 2004), which is more efficient by intensifying UV irradiation but difficult in interpreting the results with respect to the actual performances of the material in outdoor applications. Various studies have been conducted trying to investigate weathering performances of polymers. Langshaw (1960) proposed an empirical equation to illustrate the effects of weathering variables, such as heat, light, oxygen, oxidants, water, etc., in the wethering performance of plastics. By measurements of exposure variables and the resulting changes in properties at short intervals, the equation can be established. Langshaw's

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model is typical of other longevity functions which represent empirical correlations between changes in plastic properties and weathering variables. Probably because of complexities in calculation and measurements, Langshaw did not attempt to test the applicability of the proposed equation. By introducing the combined effects of both kinetic parameters and exposure variables, Kamal (1966) proposed an "exposure parameter technique" to study weathering performance of plastics. On the basis of an extensive program relating to the changes of 13 different properties of 10 plastic materials, he was able to establish a correlation between the weathering performances and the defined exposure parameters. The contribution of the study is to provide a possible way to study weathering performance of plastics by examining the process of decomposition kinetics. Since then, a number of models have been developed trying to correlate the results of accelerated weathering tests to outdoor ones. In examining the long-term weathering performances of polypropylene, nonwoven geotextiles, Thomas and Baker (1997) conducted experiments by exposing samples in both xenon-arc test apparatus and outdoors at South Florida. By comparison the strength retention of samples from both of the exposure tests, they suggested that the results from accelerated weathering test with xenon-arc could be used to estimate outdoor performance of the material at South Florida once UV radiant level was compatible under the two exposure conditions. However, Jean-Louis et al. (1999) showed that by changing the intensity of UV irradiation would induce notable changes to the decomposition kinetics of hydroperoxides during photo-oxidation of polypropylene. In their study to understand the mechanisms of formation of the final products and to characterize the decomposition of the intermediates by using infrared spectroscopic analysis, they were able to demonstrate that different kinetic laws were followed during weathering tests with the intensity UV irradiation. In other words, different weathering performances of the material should be expected even if the cumulative energy of UV irradiation was identical. Controversial conclusions mentioned above lead to the present study.

It was quite certain that the intensity of UV irradiation would play an important role in influencing the photo-oxidation process of polypropylene geotextiles. Therefore, different intensities of UV irradiation were selected in the present study to conduct accelerated weathering tests, together with outdoor tests. The objective of the present study is to examine the possibility of using the results from the accelerated weathering tests to predict actual degradation process of polypropylene under outdoor weathering conditions.

2. Experimental

2.1. Materials

To concentrate the study on the degradation of polypropylene due to UV irradiation and to avoid system errors introduced by textile processing and specimen sampling, instead of polypropylene fabrics, polypropylene filament yarns, the same material used to manufacture the geotextile to be investigated, were chosen in the experiments. The specifications of the filament yarns are shown in Table 1.

2.2. Outdoor weathering test

The polypropylene filaments were exposed to atmospheric conditions for an incremental period of time up to 12 months in Shanghai from April 1, 2002, following the standard ASTM D5970-96. The filaments were attached to a number of cardboards, which were fixed to metal frames, facing south at an angle 45° to horizontal. The filaments were sampled at intervals of 2, 6, 7, 8, 10, 11, and 12 months.

During the outdoor weathering test, a UV irradiation tester (Model SUR-1 by Shanghai Meteorological Research Institute) was used in the exposure field to record the amount of UV irradiation. In addition, the average temperature and amount of rainfall during the period of outdoor test were provided by the Shanghai Weather Center, a local weather service, and listed in Table 2.

Our previous study (Yang et al., 2002) has demonstrated that neither the ambient temperature nor the amount of rainfall in Shanghai area would give a noticeable change to weathering performance of polypropylene geotextiles under outdoor weathering conditions. The present study is therefore concentrated on the influence of UV irradiation on the photo-oxidation of the material.

2.3. Accelerated weathering test

In parallel to the outdoor weathering test, following the standard ASTM G154-00, an accelerated weathering apparatus (Model UV-II by Changzhou Puke Co., China) with fluorescent UVA-351 lamps was operated to conduct accelerated weathering test. Fig. 1 shows the relative spectral energy distribution of the light in the wavelength between 300 and 400 nm from both the lamps and the sunlight (at 12 o'clock on July 1, 2002) in Shanghai.

Table 1
Specifications of polypropylene filaments

Tensile strength (N)	Fineness (denier)	Melting point at peak[a] (°C)	Crystallinity[a] (wt%)	Viscosity average molecular weight[b]
81.90	1000	169.50	46.64	118,500

[a]Measured in a Seiko DSC220C at 10 °C/min, from 30 to 200 °C.
[b]Measured at 135 °C in Deca-hydro-naphthalene (98%) stabilized by Irganox 1010, using an Umstatter viscometer.