Polymer Degradation and Stability 112 (2015) 145–159

Contents lists available at ScienceDirect

Polymer Degradation and Stability

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

Outdoor and accelerated laboratory weathering of polypropylene: A comparison and correlation study

Yadong Lv, Yajiang Huang*, Junlong Yang, Miqiu Kong, Heng Yang, Jincan Zhao, Guangxian Li*

College of Polymer Science and Engineering, State Key Laboratory of Polymer Material Engineering of China, Sichuan University, Chengdu 610065, China

ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form
22 December 2014
Accepted 24 December 2014
Available online 6 January 2015

Keywords:
Outdoor
Accelerated laboratory
Weathering
Polypropylene
Correlation

ABSTRACT

The degradation behaviors under outdoor and accelerated laboratory weathering conditions of isotactic polypropylene (iPP) were compared, aiming to establish a correlation between both weathering types. Outdoor weathering experiments were performed at six national standard natural exposure stations which represent six typical climate types in China. The evolutions in the chemical/molecular structure, surface morphologies, mechanical and crystalline properties were compared and the results suggested that the accelerated weathering experiment is substantially capable to mimic the main outdoor weathering behaviors. The degradation mechanism for all weathering conditions is consistent according to the similarity in the species and proportions of the carbonyl products. An improved Arrhenius equation, which considered the multiple effects of temperature, irradiation and oxygen pressure, was proposed to correlate the outdoor weathering behavior of iPP with that of accelerated laboratory weathering. The predictions for the outdoor weathering behavior of iPP based on this approach were satisfactory compared with the experimental results. Depending on the outdoor exposure locations, the acceleration of laboratory weathering was found to range from 8 to 30 times in comparison to outdoor weathering.

1. Introduction

Polymeric materials are susceptible to degradation during long-term service, suffering photo-chemical, oxidative and even hydrolytic degradation individually or simultaneously [1–4]. Such degradation processes would induce significantly changes in physical and chemical structure, which finally lead to the failure of materials. Therefore, an accurate assessment of the degradation behavior of polymeric materials is obviously crucial concerning both the safety and economic aspects.

However, the real outdoor exposure experiments are usually laborious, expensive and particularly time-consuming which might last for many years. By exposing the materials to artificially intensive weathering conditions, the degradation processes of polymeric materials could be accelerated, allowing a fast evaluation of the service durability of materials in a rationally short period of time. A critical point involved in the lifetime prediction of polymeric materials is the establishment of the linkage between the outdoor and laboratory accelerated weathering behaviors using various mathematic models [3,5–10]. At present, the well-known Arrhenius equation and its modified versions are still the main bases for the lifetime prediction of polymeric materials [3,5–11]. For example, Bauer [5] has developed generic models combining the effects of temperature, wavelength distribution and irradiance of UV light and humidity, and effectively predicted the relative rate of weathering processes for automotive coating. Recently, Gu et al. [10] also linked the laboratory and outdoor exposure results for a model epoxy coatings system with a cumulative damage model, which considered simultaneously the multiple factors of temperature, relative humidity, wavelength and the light intensity. Polymeric materials in service are usually subjected to the impacts of multiple weathering factors (such as light, heat, oxygen etc.). A satisfactory correlation for the outdoor and accelerated laboratory weathering behavior of polymer materials under the impacts of multiple weathering factors is still a challenging target at present.

Isotactic polypropylene (iPP) has been widely used in numerous fields such as household goods and packaging due to its versatile properties and relative low price. However, iPP is sensitive to various external aging environment such as physical or chemical factors, due

* Corresponding authors. Tel.: +86 02885401841; fax: +86 28 85405402.
E-mail addresses: hyj@scu.edu.cn (Y. Huang), guangxianli@scu.edu.cn (G. Li).

http://dx.doi.org/10.1016/j.polymdegradstab.2014.12.023
0141-3910/

to the present of the tertiary hydrogen atoms present in iPP chains which are susceptible to attack by oxygen. The common feature of the oxidation of iPP is an attack of free radicals initiated by light or heat on the molecular chains, and followed by the reaction of alkyl radicals with oxygen. This would lead to the buildup of oxidation products [12,13] as well as the molecular chain scission [14], which could deteriorate the materials properties. Although the main reactions occurring during oxidation degradation of iPP have been elaborated by many studies in the last decades [15,16], the prediction of the outdoor weathering behavior of iPP materials considering simultaneous multiple factors, especially oxygen, are still limited.

Hence, the main objective of this work is to study the outdoor and accelerated laboratory aging behavior of iPP, to compare their degradation mechanism, and further to make a linkage between them under multiple weathering factors. For this purpose, six national standard natural exposure stations in China, representing different typical climate types of China (including warm damp, warm dry, cold temperate and warm temperate) classified according to the IEC 721-2-1 [17], were selected to perform outdoor weathering experiments. Then, the microstructure evolutions and degradation mechanisms in different outdoor weathering stations were studied and compared to that under accelerated laboratory condition. Subsequently, an improved Arrhenius model, which considered the simultaneous effects of temperature, irradiation and especially oxygen pressure was proposed, in order to establish a correlation between the outdoor and accelerated laboratory aging behavior. The prediction capacity of the model for the outdoor degradation was verified by corresponding experimental results.

2. Experimental

2.1. Materials and sample preparation

A commercial grade isotactic polypropylene (T30s, Dushanzi Petrochemical chemical Corp.) was used as the raw material. The material has a melt flow rate (MFR) of 2.9 g/10 min (2.16 kg, 230 °C, ISO 1133). Standard dumb-bell tensile samples (110 mm gauge length, 4 × 10 mm^2 cross-section) of iPP were injection-molded on a PS40E5ASE precise injection-molding machine (Nissan, Japan), with a temperature profile of 170, 200, 200, and 195 °C from the feeding zone to the nozzle. Before injection molding, iPP pellets were dried in a vacuum oven at 60 °C for 24 h respectively.

2.2. Weathering experiments

Outdoor weathering experiments of iPP samples were carried out in six national standard natural exposure stations in China with various climate types, including Qionghai (QH, in Hainan island, a warm damp climate type), Guangzhou (GZ, a warm damp climate type), Ruoqiang (RQ, in Taklimakan desert, a warm dry climate type), Lhasa (LS, capital of Tibet, a cold temperate climate type), Qingdao (QD, at seaside, a warm temperate climate type) and Hailar (HLR, in the inner Mongolia and northeast China, a cold temperate climate type). The climate types were classified according to the IEC 721-2-1 [17] and these weathering sites were established and managed cooperatively with the local weather bureau. The specific locations as well as climate types of the six national standard natural exposure stations are shown in Fig. 1. The weather data were logged daily and reported monthly to us. The annual average weather data at each location are calculated based on the monthly average values and are shown in Table 1. During outdoor weathering, specimens were clamped at both ends by aluminum plates, put on out rack in a horizon position and tilted at 45° facing south for exposure. The outdoor exposure tests took place from September 2011 to September 2013 lasting for two years. Samples were collected after different time intervals (30, 90, 180, 360, 540 and 720 days). For each batch of samples collected from corresponding exposure site, six replicates were used to ensure the repeatability.

Fig. 1. Locations and climate types of six national standard natural exposure stations in China considered in this study.