

Methodology of accelerated weathering test through physicochemical analysis for polymeric materials in building construction

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Physicochemical analysis in the microscopic sense is a critical assessment of monitoring the polymeric materials under a weathering test, and it links the accelerated laboratory test with the outdoor performance results for a long-term durability. Here, by taking an experimented example for vinyl siding after an outdoor weathering test in Okinawa, Japan for 17 years and a QUV accelerated weathering test for 2880 hours, it was observed that there were entirely different results on the functional groups and the surface image with the atom concentration measured by the attenuated total reflectance Fourier transform infrared and scanning electron microscopy with energy dispersive spectroscopy, respectively. Furthermore, the optimal conditions of a specified accelerated weathering test based on a replication of the natural weathering characteristics are deliberated, thus correcting the deterioration factors configuration in consideration for the physicochemical degradation of a specific material. The aim of this study places an emphasis on the crucial points for improving the accelerated weathering test through a physicochemical analysis.

Keywords: Accelerated weathering, Polymeric material, Physicochemical analysis, Durability, Degradation

Introduction

In civil engineering, the long-term service life of buildings as environmental measures is one of the important performances being comparable with the structure and fire safety, and it is demanded to improve the durability of the materials in building construction. This improvement of the material durability is highly associated with the lifetime of a building so as not to reach the limit state of the building components. It is imperative to determine a specific means and method in order to identify the deteriorating effect of the surrounding environment on the building components and materials, as well as predicting the process of the degradation phenomena and the limit state of the buildings. As a part of the building materials, the polymeric materials become widespread in civil engineering because they taking advantage of the excellent properties, such as lightweight, high corrosion resistance and good formability. However, the life cycle cost should be considered in order to have an effective application of this material, hence it is necessary to understand the life cycle of such a material. In weathering, the outdoor weathering test is the surest way to clarify

exactly how a material, component or products degrade by environmental stresses in an acceptable timeframe, but it usually takes a few years to decades to obtain a useful or referable result. Meanwhile, the accelerated weathering test methods have been proposed as a method to obtain the results in a short period of time than the outdoor weathering test. However, the method for estimating a material's durability in the actual environment from these obtained data has not yet been established.

In this section, attention would be paid to a comparison of the results from the outdoor and the accelerated weathering tests. Then, the need for investigating the weatherability of the polymeric materials through a physicochemical analysis is emphasized to improve the relevance and the precision of durability under the field and the laboratory weathering tests. Lastly, we introduce the design of the accelerated weathering method based on the natural weathering characteristics.

Weatherability of the polymeric material Definition of durability and reliability

First of all, it is important to clarify the difference between durability and reliability before estimating the properties of a material. Both the terms are usually being confused and misplaced alternately even if indicating different functions of property changes. Durability is the ability of a product, which is designed to perform the

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functions within a specified time. In weatherability, durability is a measure of the retention of the initial condition and the function of a material under a specified set of conditions. It is concerned with measuring the changes in the physical, chemical, appearance properties, mechanical property, loss of performance, time to unacceptable change etc.,¹ which generally come under the category of macroscopic events. Reliability is an engineering discipline that should be applied throughout all the stages of development and the maintenance of the product in its life service. This category is using the probability statistics to measure the failure rates, the components of the lifetimes and an estimation of the product lifetimes. Since the reliability of a system is a function of the durability from various materials and components, a decline in the durability of some critical levels contributes to a loss reliability.¹

Weathering durability

Weathering durability is a specialized discipline including the larger context of the background. It is defined as the specific ability of a material, component or product to resist degradation caused by stresses from the service environment. There are a variety of environmental stresses in the outdoor environment, and the primary causes of failure for the polymeric materials are light (solar radiation), temperature (thermal change) and water (rain, dew). These factors cause the polymeric materials to produce hydroperoxide (-OOH), which is an unacceptable functional group (such as carbonyl groups) to generate a sequence of propagation.² Furthermore, chain scission and crosslinks, the main degraded processes, react to determine the property of a single polymeric material.

Physicochemical analysis and the accelerated weathering test principle

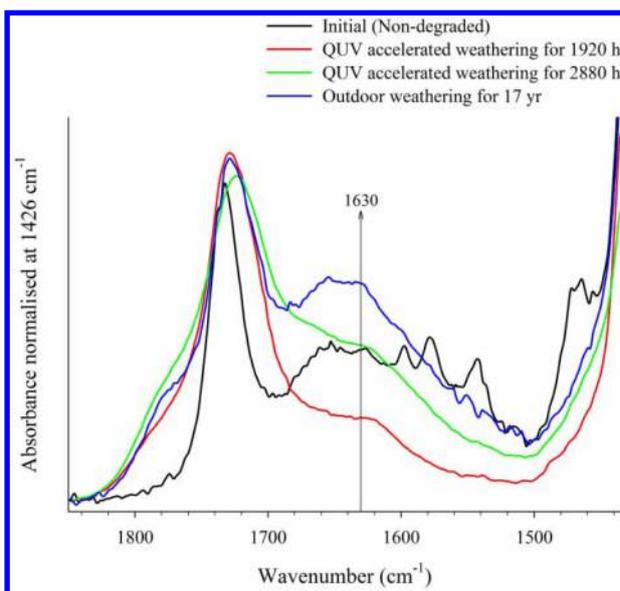
Physicochemical analysis

Physicochemical analysis is imperative for investigating weatherability of the polymeric materials, especially which is used on the exterior of buildings, because the environmental stresses cause the physicochemical reactions to cause a low performance of the polymeric materials. Unfortunately, only very few researchers in civil engineering have been researching on the macroscopic size (colour, mechanical property etc.) of the polymeric materials but barely discussing their microscopic size (physicochemical production). So far, many typical analytical methods, such as Fourier transform infrared (FTIR), GPC and DSC, have been used to clarify the degradation mechanism and the desired characteristics from the microscopic to the macroscopic should be measured by the appropriate instruments, respectively. However, the issue is that not all the materials are suitable for detecting the properties under the same conditions of the weathering test, that is, the weathering device designed for a specific material may not be suitable for the other materials.

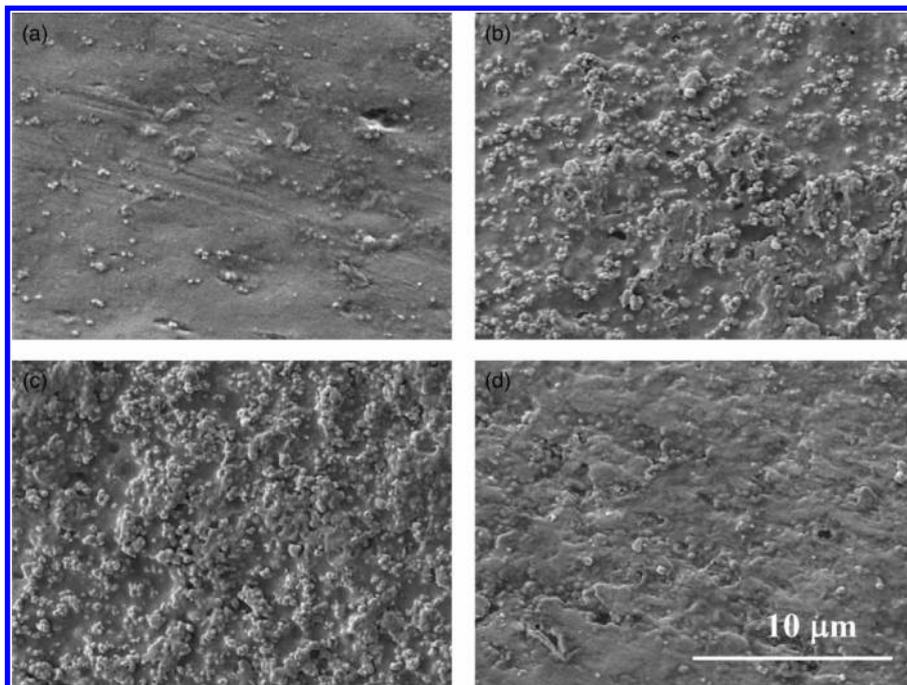
Take vinyl siding, for example, a widely used material for the exterior wall of building construction in North America, to demonstrate the importance of a physicochemical analysis.³ Vinyl siding is manufactured primarily from around 80% poly(vinyl chloride) resin, with 20% being the ingredients. Comparison among the

functional groups and the surface images with the atom concentration of vinyl siding degraded under the QUV accelerated weathering test for 2880 hours and the outdoor weathering test at Okinawa in Japan for 17 years. Figure 1 shows the FTIR-attenuated total reflectance spectra of vinyl siding elapsed in the accelerated and the outdoor weathering tests for the 1435–1900 cm^{-1} absorption range. It was found that polyene at 1630 cm^{-1} was extremely high after the outdoor weathering test for 17 years compared with the QUV accelerated weathering test. Polyene easily absorbs UV to generate free radicals and causes changes in the length of polyene, the generation of the carbonyl groups by the binding of oxygen and a low molecular weight by chain scission. Therefore, the material under the accelerated weathering test was attacked by consecutive UV irradiation over a long period of time, therefore the variation of these reactions was intense on the material surface. These results indicated that it is necessary to investigate the appropriate condition of UV irradiation.

Figure 2 shows the surface image of the material subjected to the outdoor and the accelerated weathering tests from a scanning electron microscope. In the material surface degraded after the accelerated ageing tests for 1920 and 2880 hours we markedly found the appearance of titanium dioxide (TiO_2) particles owing to a washout of the degraded PVC from condensation (Fig. 2*b,c*). Contrarily, this result was not observed on the surface of the material during the outdoor weathering test (Fig. 2*d*). It is believed that the TiO_2 particles had been washed away and the smoothness was lost by the erosion of the reinforcing agent. Furthermore, the changes in the atom concentration of the material degraded by each test from the energy dispersive spectroscopy are shown in Table 1. The changes of the elements on carbon (C), chlorine (Cl), oxygen (O) under the QUV accelerated weathering test for 1920 hours were similar with the outdoor weathering test for 17 years. Meanwhile, the relatively less atom



1 Fourier transform infrared spectroscopy-attenuated total reflectance spectra of vinyl siding after accelerated weathering for 0 h (initial), 1920 and 2880 hours and outdoor weathering for 17 years



2 Surface image of vinyl siding. a Initial; b QUV accelerated weathering for 1920 hours; c QUV accelerated weathering for 2880 hours; d outdoor weathering for 17 years

Table 1 Energy dispersive spectroscopy concentration of the atoms on the vinyl siding surface after the weathering test

Atom	Initial	QUV accelerated weathering		Outdoor weathering 17 years
		1920 hours	2880 hours	
C	73.5	58.1	56.0	63.4
Cl	18.5	17.1	16.2	16.2
O	7.0	21.9	24.5	18.6
Ti	1.0	2.9	3.3	1.9

concentration of titanium (Ti) and the surface image (Fig. 2d) verified that the appearance of the TiO₂ particles was minor on the material surface under the outdoor weathering test for 17 years. On the basis of these results, it is important to decide the technique and the period time of water.

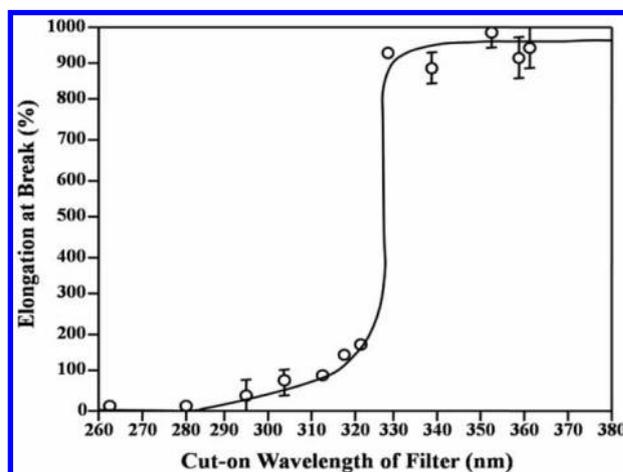
The other key point here is that these effect factors are not all absorbed by the material to transform the degradation phenomena. For example, considering only the UV attack, it should be concerned with the wavelength sensitivity of the polymeric materials whose range of wavelength largely damages the properties. For instance, the wavelength-dependent photochemical changes, which are the absolute values of a selected property, are obtained as a function of the cut-on wavelength of the filter.⁴ Figure 3 shows a spectral wavelength dependence of the elongation at break of an ethylene copolymer film exposed to a filtered xenon source for 219 hours at 60°C.⁴ The cut-on filter technique is used to separate the UV spectra by a glass filter to degrade the materials, thus detecting the absorbance of UV to calculate the increment of the radiation (equation 1) and the total effective dosage (equation 2), defined as the radiation is incident upon and absorbed by the specimens.^{4,5} The model can be used as the link between chemical degradation in

the outdoor and the accelerated conditions. The model of the increment of the radiation and the total effective dosage can be demonstrated as follows:

$$R(\lambda) = H(\lambda)[T_i(\lambda) - T_{i+1}(\lambda)] \quad (1)$$

$$D_{total}(t) = \int_0^t \int_{\lambda_{min}}^{\lambda_{max}} E_0(\lambda, t)(1 - e^{-A(\lambda, t)})\phi(\lambda)d\lambda dt \quad (2)$$

where $R(\lambda)$ is the increment of the radiation; $H(\lambda)$ is the spectral irradiance distribution; $T(\lambda)$ is the increment of the spectral band of the radiation transmitted by the filter; $D_{total}(t)$ is the total effective dosage at the time t ; λ_{min} and λ_{max} are the minimum and the maximum photochemically effective wavelengths; $E_0(\lambda, t)$ is the spectral UV irradiance of the light source at the time t ; $A(\lambda, t)$ is the



3 A cumulative spectral sensitivity curve for the elongation at break of the copolymer sheets (ethylene-carbon monoxide 1%)⁴

spectral absorption of the specimen at the wavelength and the time t and $\phi(\lambda)$ is a spectral quantum efficiency, respectively. This is used with the UV-Vis spectra to detect the UV sensitivity of the material and is appropriate for the thin specimens, which is negative for the effect of the depth, such as sheet and coating.^{4,5} For the bulk specimens, this is a consideration of the depth profiling with the surface strip sectioning (or skiving), such as automotive coating.⁶

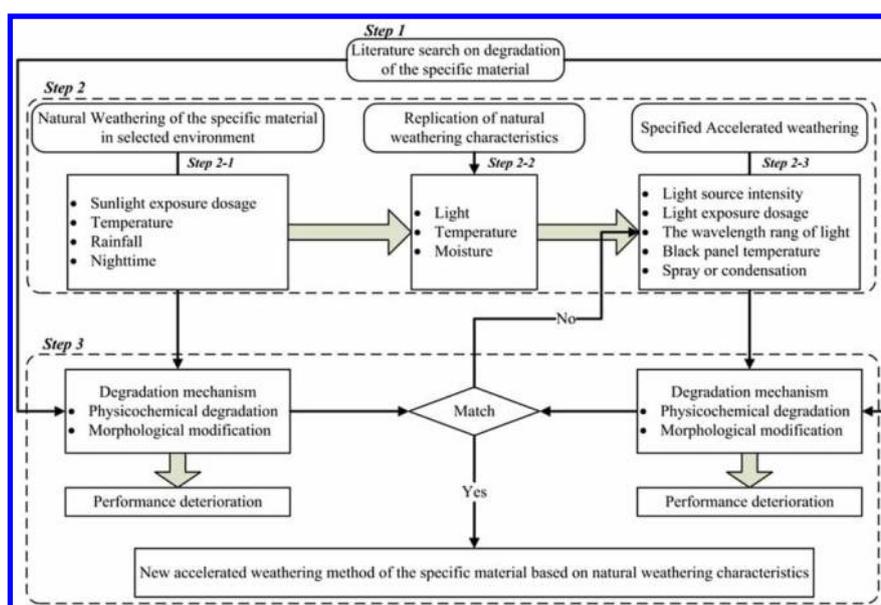
Proposal for the accelerated weathering test

It is well-known that on using the accelerated weathering test, which is a typical set of environmental cycles, the performance results of the various materials obtained will be obviously different when compared with the outdoor weathering test. Therefore, it is required to set appropriate environmental cycle for a specific material. It can be obtained in a short time to gain a higher reliability by the improvement of this setting. For example, a long-term prediction programme was conducted by Honda R and D Americans Inc. to explore the setting of the accelerated weathering test close to the selected local environmental test.⁷ In other words, the target was to change the setting of the degradation factor to improve the repeatability of the results under the accelerated weathering test. In addition, Gu *et al.*⁸ used the reliability-based methodology as a linkage between the accelerated and the outdoor exposure results for an epoxy coating based on chemical degradation through a total effective dosage model. The concept of the accelerated weathering test modified from these researches⁴⁻⁸ is shown in Fig. 4.³ There are three steps to explain this method. *Step 1*: Estimation of the degradation scheme and a clarification of the degradation mechanism of a specific material from the literature. In this step, it would be investigating a wide range of degradation mechanisms and the degradation scheme of the used material from the literature, and then examining the research of interest to clarify the cause of the degradation, the analysis of the degradation mechanisms and the changes in the primary, the secondary, the higher-

order and the composite structure of the material exposed to the type of the accelerated weathering test or the field environment. *Step 2*: Assembling or choosing an accelerated weathering device and setting the degradation factors. It would be setting the optimal conditions of a specified accelerated weathering test based on a replication of the natural weathering characteristics, correcting the deterioration factors configuration in consideration for the physicochemical degradation of a specific material. *Step 3*: Setting the degradation factors of the accelerated weathering test by a comparison of the physicochemical degradation. The comparison of the physicochemical analysis of a material that had passed through the accelerated weathering test under certain conditions and the location environment of the outdoor weathering test, examining the phenomena and the effect of the degradation factor. That made the setting of the degradation factor highly repeatable as the condition of the accelerated weathering test of a specific material is based on the location environment. It should be noted that the applicable range of this method shall be narrowed down to a specific material. Furthermore, for enhancing the higher repeatability and correlation, it is required to record, measure and analyse every degraded condition, in addition to having the knowledge and the skills of all the related fields and the long-term studies.

Conclusion

Physicochemical analysis is of the utmost importance to not only link the properties between the microscopic and the macroscopic events but also for a correlation between the results from the accelerated and the outdoor weathering tests. However, the accelerated weathering test is the only way to obtain an early and a detailed understanding of how a specific material will perform degradation during its lifetime. However, the acceleration, the repeatability and the precision determine the quality of the accelerated weathering test. Therefore, in terms of the degraded factors, it would be very different owing to the variation of the materials, the product design, the



4 New accelerated weathering method of the specific material based on the natural weathering characteristics

manufacturing quality and the degradation mechanisms. Hence, it is important to improve on a test programme, which is appropriate for the materials, the performance requirement and the application, to raise the reliability.

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