# Monitoring the UV Degradation of PVC Window Frames by Microhardness Analysis

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## Synopsis

While well-known methods of bulk analysis of thermal degradation of PVC become standard industrial tools, techniques for the study of surface damage produced by weathering are not generally considered. In this paper we present a new test, based on microhardness measurements, which can be used as a complementary technique for the study of this phenomenon. Comparison of this method with color changes and specific elongation at break measurement has been established for PVC window frames.

## INTRODUCTION

Poly(vinyl chloride) (PVC) is a polymer which is very sensitive to the weathering action and this restricts its outdoor applications. This occurs mainly because of changes in mechanical properties and color. Under UV irradiation, and in the presence of oxygen and moisture, it undergoes a very fast dehydrochlorination and peroxidation process with the formation of polyenes and subsequent scission and/or crosslinking of the chains.[1]

In order to improve the stability of the product and to study systematically the influence of weathering on the engineering properties, several physicochemical measurements have been assessed. In general, the industrial methods for monitoring the degradation evolution of rigid PVC are based on the measurement of color change and mechanical properties, standard tools for the study of thermal degradation, but only the color test, in our opinion, is valuable in the study of the evolution of the photodegradation processes, because the absorption of visible-UV radiation in this polymer is a surface phenomenon (to a depth of about 2 $\mu$m) whereas the classic mechanical tests, such as modulus and tensile strength, specific elongation, or impact techniques are essentially bulk measurements.

In the search for possible tests which may be used as criteria for the evaluation of the surface resistance to weathering, we propose a method of indentation measurement (microhardness), a well-known and reliable test, which has been previously used in our laboratory for the study of the thermal degradation of rigid PVC[2,3] and other physical measurements.[4]

In the present paper, we present a comparative study of the UV photodegradation of PVC window frame samples examined using microhardness measurements, coloring tests, and specific elongation at break values; this last one is the mechanical property most easily translated into product performance.

Journal of Applied Polymer Science, Vol. 38, 1879–1882 (1989)
 CCC 0021-8995/89/101879-04$04.00

## EXPERIMENTAL

### Samples

We have investigated samples of 2 mm thickness cut from white window profiles of a commercial PVC, supplied by Rio Rodano S.A./Spain.

Tensile specimens were prepared from extruded profiles according to standard ASTM 0882 requirements. Samples of $3 \times 3$ cm$^2$ were employed for the microhardness and color measurements.

### Apparatus

Vickers microhardness values were obtained at room temperature using a square-based diamond pyramid of face angle 136° pressed on the sample surface. The apparatus and procedures were basically the same as those published elsewhere.[2-4] It is very important to choose an optimum applied load, in order that the indentation be located in the optically injured area. A deeper indentation than the optimal one could provide a misleading value corresponding to the average between the degraded and nondegraded zones.

Elongation at break was evaluated by means of an Instron testing machine (Model 1122) using an elongation rate of 10 mm/min ($F = 5.000$ N), at 20°C, according to ASTM D638 standard. Data points plotted generally represent average values from five measurements.

The color development in the PVC sheets was measured as a yellowing index, using a Hunterlab colorimeter type (ASTM standard 1925-70).

Artificial irradiation conditions were created in a specially constructed chamber, equipped with a cylindrical distribution of eight fluorescent UV lamps and with controlled temperature and humidity. The lamps (Philips TLD 36/07) emitted between 300 and 420 nm a continuous Gaussian shaped spectrum with a maximum at 365 nm; the intensity of radiation at the samples was 0.265 J min$^{-1}$ cm$^{-2}$. Despite the fact that this UV illumination range constitutes only a part of the total solar radiation energy corresponding to natural weathering, there are many practical examples of its overwhelming dominance in the photodegradation of PVC materials. Prepared samples were positioned in removable panels in a drum which turned at 5 rph around the cylindrical distribution of lamps. The distance between both cylinders is 50 mm. In this configuration only one face of the samples was exposed to

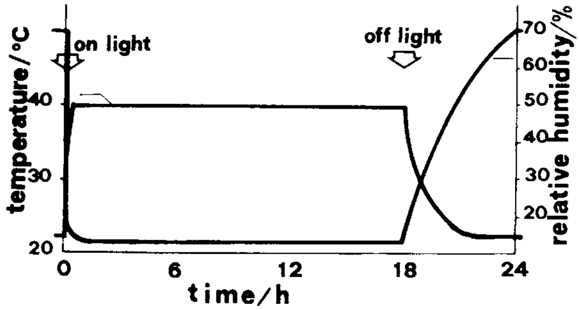


Fig. 1. Exposure conditions of artificial weathering.

alternate cycles of light and darkness, for a different number of hours, according to the light, temperature, and humidity programs shown in Figure 1. The other face was in the dark during the experimental period.

As far as the microhardness measurement is concerned, we assumed that thermal and optical degradation are accumulative processes and so the data reported in this work correspond to the difference between the values measured in both the illuminated and nonilluminated face of the samples. Values obtained by the other techniques manifest the addition of both degradation effects.

## RESULTS AND DISCUSSION

The results obtained in our experiments are summarized in Figure 2. Evaluation of the color changes showed an adequate stability of the samples. We can observe that a weak bleaching effect takes place during the first 1000 h of illumination, probably associated with an oxidative process on the polymer chains. It is known that when oxygen is present, during a UV

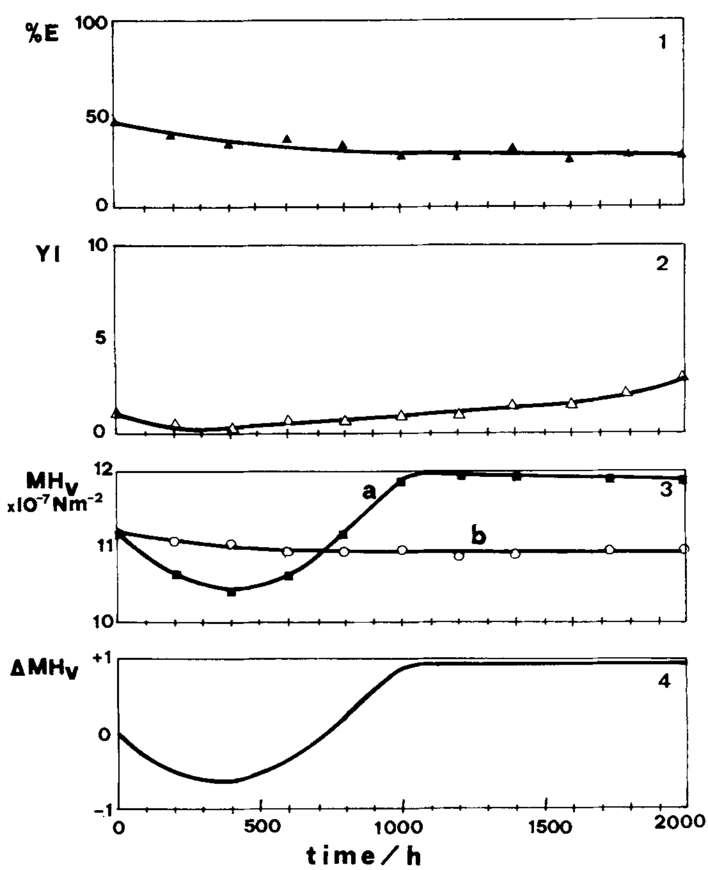


Fig. 2. Changes in the elongation to break ($E$) as a function of the illumination time. (2) Color development measured as yellowness index (YI). (3) Variation of Vickers microhardness (MHv) with weathering in illuminated (a) and nonilluminated (b) faces. Optimal load: 1.5 ponds; indentation time: 30 s. (4) Microhardness difference between both faces.

exposure the long chain conjugate double bonds are destroyed, giving a shorter sequences of polyenes which do not absorb in the visible region.[5]

The elongation at break values indicate that the weathering has embrittled the material, normal behavior in this polymer as a consequence of the scission and crosslinking processes.[6] A significant decrease from 50% to 30% occurs in the first 1000 h approximately and after that the elongation at break reaches a constant value.

The most important qualitative and quantitative variations were registered on the microhardness experiments. The shape of the curve obtained shows the same behavior to that earlier reported by ùs for the thermal degradation of this polymer.[3] During the first period of irradiation a decrease in the microhardness of the material occurs, which can be related to the scission of structural elements and incorporation of stabilized groups to the PVC chains. After 500 h of irradiation the MHv reaches a minimum and then increases. In this second period crosslinking reactions are predominant and a concomitant increase of the MHv is estimated. At about 1000 h the MHv values reach a plateau at a moment that approximately coincides with the 1000 h reported above for the yellowing of the sheets and with the constant values in the elongation measurements.

In conclusion we present a microhardness test, complementary technique which can be used as a useful tool for research, development, or quality control in the assessment of the weathering effect on rigid PVC.

Financial support by the Dirección General de Investigación Cientifica y Técnica (PA86-0198) is gratefully acknowledged.

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Received December 15, 1988
Accepted January 6, 1989