JOURNAL OF APPLIED POLYMER SCIENCE VOL. 14, PP. 1473–1475 (1970)

A Method of Estimating Resistance to Abrasion

JAN BAREŠ, *Institute of Macromolecular Chemistry, Czechoslovak Academy of Sciences, Prague, Czechoslovakia*

INTRODUCTION

As the optical degradation of the loss in transparency or "shiny" appearance is greater than the accompanying weight loss, optical methods are widely used for measurement of abrasion resistance.[1,2] The amount of abrasion is expressed in terms of the increase of the optical haze and/or in terms of the decrease in specular surface reflectance. Only two measurements of optical quality, before and after the abrasion, are usually made. Therefore the abrasion resistance of two samples may only be compared if their optical properties and quality of surfaces before the abrasion are almost the same for all samples.

The method described here utilizes the time dependence of the reflectance change.

EXPERIMENTAL

The investigated samples were abraded in a shaker machine by carborundum sand and steel balls $^1/_8$ in. in diameter. This treatment is equivalent to the "falling carborundum method," but according to our opinion is more efficient. The reflectivity of the samples was measured by a simple automatic goniophotometer.[3]

The abraded surface causes an incident light beam to be reflected not only according to the law of reflection but also in all other directions. To characterize the time dependence of abrasion, the value

$$P(t) = \frac{I_a}{I_d} \tag{1}$$

has been introduced, where I_a is the intensity of light reflected by nondamaged parts of the surface and I_d is the intensity of diffusion light, i.e., intensity of light scattered by the parts of surface scratched by carborundum. To estimate the time dependence of $P = P(t)$, it is assumed that (1) the dimensions of every scratch are large in comparison to the wavelength of goniophotometer light and (2) the following scratches are randomly distributed over the luster surface and the previous scratches.

Generally, we may write

$$I_a = I \cdot p_a \cdot k_a, \tag{2}$$

where I is the intensity of light incident on the sample, p_a is the fraction of nonabraded surface, and k_a is a constant depending on specimen properties and the goniophotometric apparatus. For I_d similarly

$$I_d = I \cdot p_d \cdot k_d, \tag{3}$$

where p_d is the fraction of the scratched surface and k_d is the constant. Assuming conditions (1) and (2), the increase of the scratched surface during the interval dt is

$$dp_d = p_a \alpha dt, \tag{4}$$

where α is a constant characterizing the abrasion resistance of the material. This constant, of course, depends on the abrasion method, which could easily be kept the same in all cases. If condition (2) does not apply, i.e., if there is no simple proportionality between dp_d and p_a, we should replace eq. (4) by more general relation

$$dp_d = f(p_d)\alpha dt$$

where the function $f(p_d)$ must be known. Because

$$p_a + p_d = p = \text{constant}, \tag{5}$$

we use the variable p_d as well. The solution in this general case then has the form

$$p_d = p\varphi(\alpha t) \tag{6}$$

as the obvious proportionality between p_d and p can be anticipated. The boundary conditions are apparently $\varphi(0) = 0$, $\lim_{t \to \infty} \varphi(\alpha t) = 1$. From eqs. (1), (2), (3), (5), and (6), we obtain

$$P(t) = \frac{k_a}{k_d} \frac{1 - \varphi(\alpha t)}{\varphi(\alpha t)} \tag{7}$$

and

$$\lim_{t \to 0^+} P(t) = +\infty, \lim_{t \to +\infty} P(t) = 0$$

In the simplest case when the condition (2) apply, solving eq. (4) with the condition $p_d = 0$ for $t = 0$, we obtain from eq. (7), because $f(p_d) = p_a$ and consequently $\varphi(\alpha t) = 1 - e^{-\alpha t}$,

$$P(t) = \frac{\mathrm{e}^{-\alpha t}}{1 - \mathrm{e}^{-\alpha t}} \frac{k_a}{k_d}.$$

Then

$$\alpha t = -2 < 2,303 < 3 \log \frac{P(t)}{P(t) + (k_a/k_d)} = 2 < 2,303 < 3 \log X. \tag{8}$$

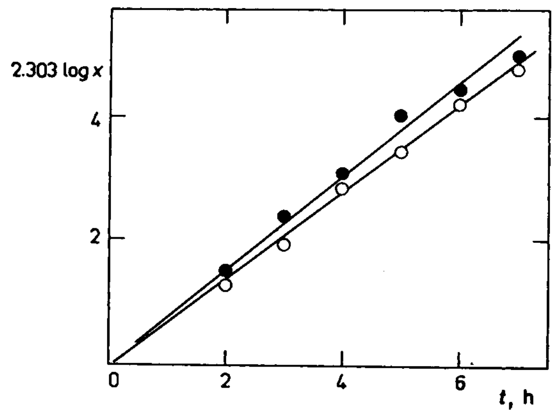

Fig. 1. Plot of 2 < 2.303 < 3 log X vs. time t: (O) sample with α = 0.69 and k_a/k_d = 50, (●) sample with α = 0.75 and k_a/k_d = 35.

As the left-hand side of eq. (8) is a linear function of t, the unknown constant k_a/k_d has to be chosen in order to obtain a linear plot of $\log\{P(t)/[P(t) + k_a/k_d]\}$ versus time t.

The above calculation shows that by utilizing the time dependence $P(t)$ we succeeded in eliminating the influence of the "initial conditions," the optical constants of the investigated specimens, and the properties of the goniophotometer, which are all involved in the constant k_a/k_d. The resistance to abrasion is characterized by the constant α. In order to have a sufficient precision in the estimation of I_a, I_d, and $P(t)$ from goniophotometric measurements, the abrasion time should be maintained within reasonable limits where the condition $0 < P(t) \ll + \infty$ holds.

Figure 1 shows the measurements on two samples of poly(methyl methacrylate), with slightly different qualities of surface at the beginning of the abrasion treatment and also with slightly different conditions of photometric measurements. Because the material of both samples is the same, the constants α should be the same. In fact, we obtained α = 0.69 hour^{-1} and 0.75 hour^{-1}, respectively. The eliminated constants are apparently different, i.e., k_a/k_d is 50 and 35, respectively. In the evaluation of photometric diagrams, the intensities I_a and I_d were approximatively represented by the height of the acute peak (specular reflection) and the broad peak (corresponding to diffusively reflected light), respectively.[3]

References

1. J. J. Gouza, in *Testing of Polymers*, Vol. 2, V. V. Schmitz Ed., Interscience, New York, 1966.

2. ASTM D 1044-56, Standard Method of Test for Resistance to Abrasion of Plastic Materials, in Part 27 Plastics—General Methods of Testing, Nomenclature, American Society for Testing and Materials, Philadelphia, Pennsylvania, 1967.

3. J. Bareš, Report H-6/68-IMC, Prague, 1968.

Received October 2, 1969.
Revised February 15, 1970