JOURNAL OF APPLIED POLYMER SCIENCE VOL. 15 (1971)

NOTE

Absorption Coefficient of Unpigmented Poly(methyl Methacrylate), Polystyrene, Polycarbonate, and Poly(4-methylpentene-1) Sheets

INTRODUCTION

The absorption of electromagnetic radiation in a polymeric medium is an extremely complicated phenomena that is not completely understood. However, this process is of direct practical importance in the radiant heating portion of a forming process. Two plastic sheets of the same thickness but of different polymers can exhibit remarkably different heating patterns. In an analysis presented by Lunka,[1] this difference was solely attributed to the difference in the thermal diffusivities of the two materials. However, in a recent analysis by Progelhof, Quintiere, and Throne,[2] it was shown that the distribution of absorbed energy, $q(x)$, within the sheet, which is a function of the temperature of the primary radiating source and absorption coefficient α of the polymeric material, is of equal importance. Experimental data of the absorption coefficient for many unpigmented or colorless polymers are not available to the plastic engineer. In this paper, we present these data for unpigmented poly(methyl methacrylate), polystyrene, polycarbonate, and poly(4-methylpentene-1) sheets.

THEORETICAL ANALYSIS

From an engineering viewpoint, the attenuation of a beam of monochromatic electromagnetic radiation propagating in the direction is assumed to obey Beer's law:

$$dI(\lambda) = -\alpha(\lambda,T)I(\lambda)d\lambda \tag{1}$$

where α is the absorption coefficient (cm^{-1}) and I is the energy flux of the beam. Using a one-dimensional, or "two flux" model,[3,4,5] and assuming uniform properties, the radiation characteristics of an absorbing and scattering sheet irradiated on one side were determined by Klein.[3] Based on this analysis, Klein proposed a method for experimentally evaluating both the absorption and scattering coefficients by measuring the total hemispherical transmission of diffuse radiation through two identical flat plate specimens D and $2D$ thick. Since the polymers under consideration are nonscattering, the internal and external interfacial reflectivities, ρ_i and ρ_0 respectively, are equal, and the scattering coefficient is zero. Thus, the reflectance r, transmittance τ, and absorptance α of an absorbing nonscattering sheet are as follows:

$$r(\lambda) = \frac{2\rho[\rho \sinh \alpha D + (1 - \rho) \cosh \alpha D]}{(1 + \rho^2) \sinh \alpha D + (1 - \rho^2) \cosh \alpha D} \tag{2}$$

$$\tau(\lambda) = \frac{(1 - \rho)^2}{(1 + \rho^2) \sinh \alpha D + (1 - \rho^2) \cosh \alpha D} \tag{3}$$

$$\alpha(\lambda) = \frac{(1 - \rho) [(1 + \rho) \sinh \alpha D + (1 - \rho) (\cosh \alpha D - 1)]}{(1 + \rho^2) \sinh \alpha D + (1 - \rho^2) \cosh \alpha D}. \tag{4}$$

Progelhof and Throne[6] have shown that the radiation properties predicted by this one-dimensional model, eqs. (2) to (4), are in good agreement with the results obtained from a more sophisticated three-dimensional model.

The monochromatic absorption coefficient for a nonscattering medium can be obtained from one transmission measurement of either collimated or diffuse incident radiation. For the test results presented in this work, a collimated source with normal incidence to the surface was used. For these conditions the interfacial normal reflectivity, ρ_n, was obtained by Frensel's law:

$$\rho_n = \left(\frac{n-1}{n+1}\right)^2. \tag{5}$$

For the range of index of refractions of the materials tested, it can be assumed that

$$e^{\alpha D} \gg \rho^2 e^{-\alpha D} \tag{6}$$

which enables eq. (3) to be solved directly for the absorption coefficient:

$$\alpha(\lambda) = -\frac{1}{D} \ln \left[\frac{\left(1 - \left(\frac{n-1}{n+1}\right)^2\right)^2}{\tau(\lambda)} \right].$$

It is important to note that the actual path length the beam travels within the sheet and the interfacial reflectivity are both relatively insensitive to small deviations from normal incidence. Thus, it was not necessary to make angular corrections in the reduction of each set of data.

TEST RESULTS

The absorption coefficient for natural poly(methyl methacrylate), polystyrene, polycarbonate, and poly(4-methylpentene-1) sheets as experimentally measured by the authors as well as data obtained from other sources are presented in Figures 1 through 4, respectively.

Beer's law states the absorption coefficient α is independent of sheet thickness D. The data for three cast polycarbonate sheets (D = 0.0825 in., 0.102 in., and 0.228 in.) and a set of data for a 40-μ film supplied by the General Electric Company were analyzed.

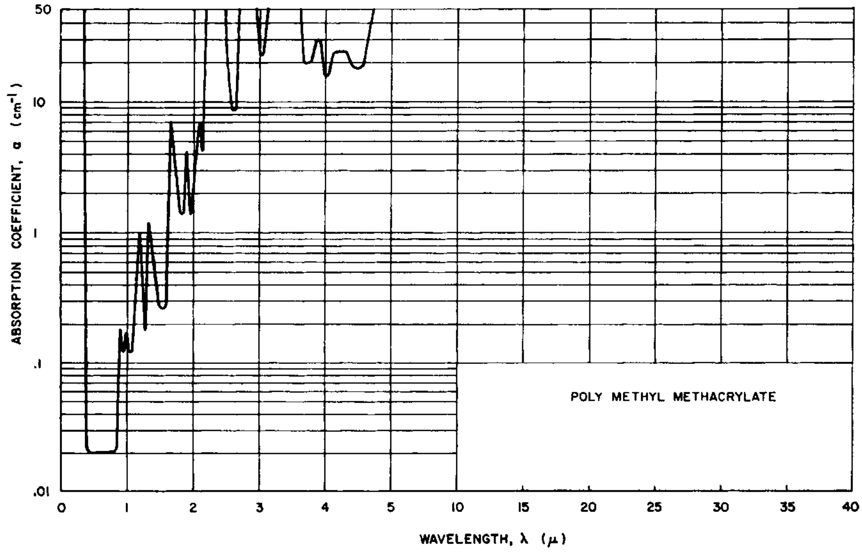

Fig. 1. Absorption coefficient for poly(methyl methacrylate).

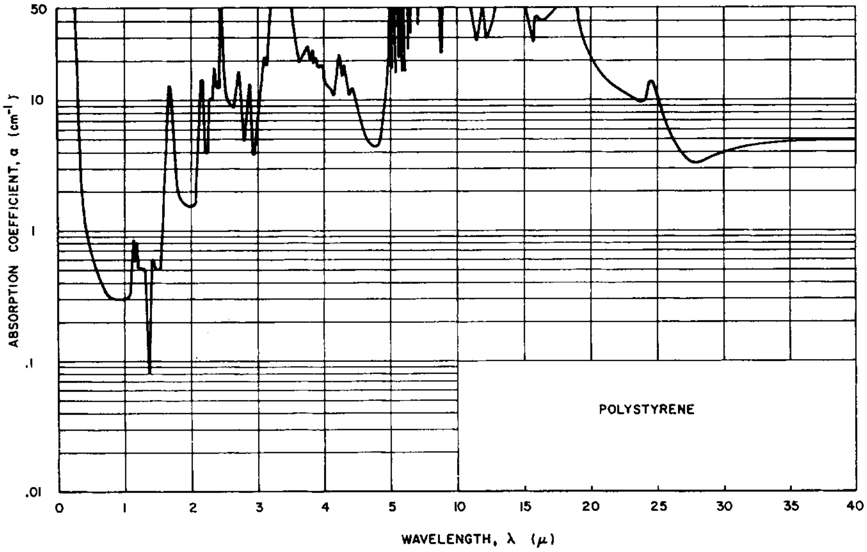

Fig. 2. Absorption coefficient for polystyrene.

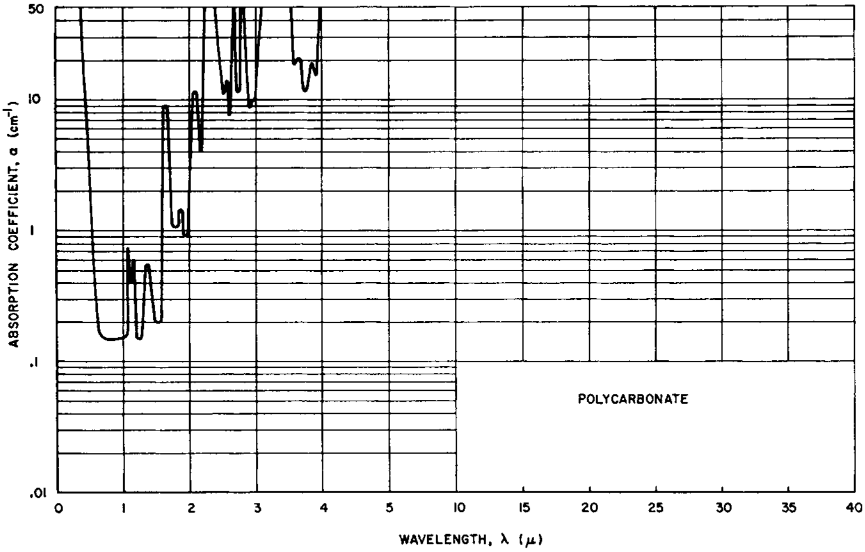

Fig. 3. Absorption coefficient for polycarbonate.

Shown in Figure 5 is a comparison of the monochromatic absorption coefficient for the cast sheets as a function of specimen thickness for several wavelengths. It will be noted that, for all wavelengths, the absorption coefficient is independent of the sheet thickness, thus verifying the application of Beer's law to the absorption of electromagnetic radiation in cast polycarbonate sheets. However, a comparison of the transmittance through a thin film to that through a cast sheet, Figure 6, shows that the proportionality of trans-

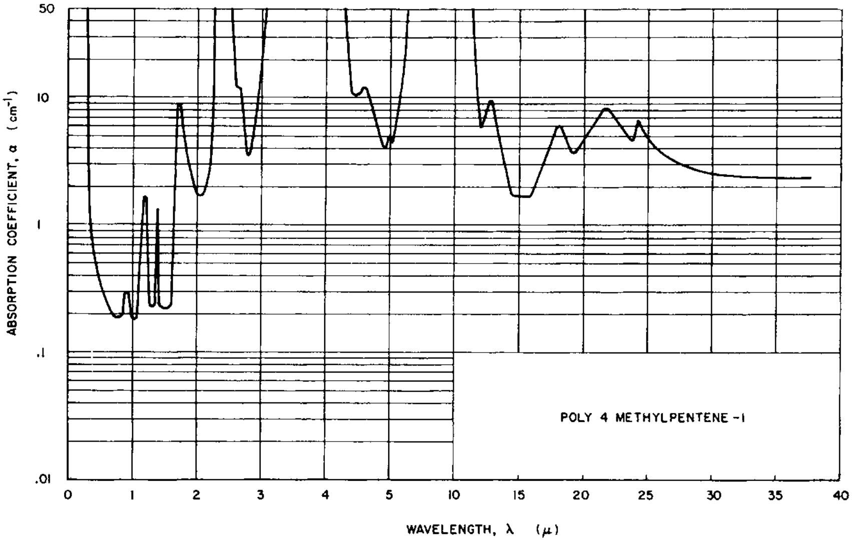

Fig. 4. Absorption coefficient for poly(4-methylpentene-1).

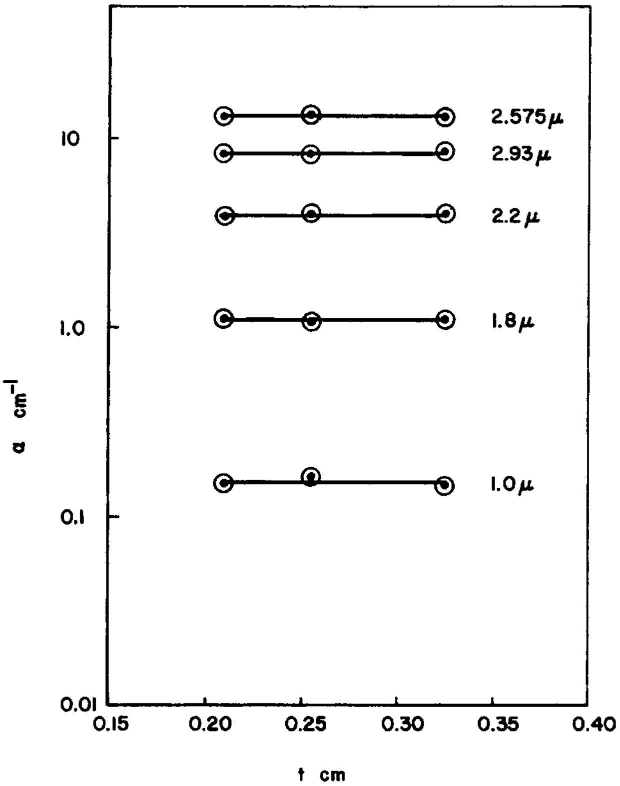

Fig. 5. Effect of polycarbonate sheet thickness on absorption coefficient.

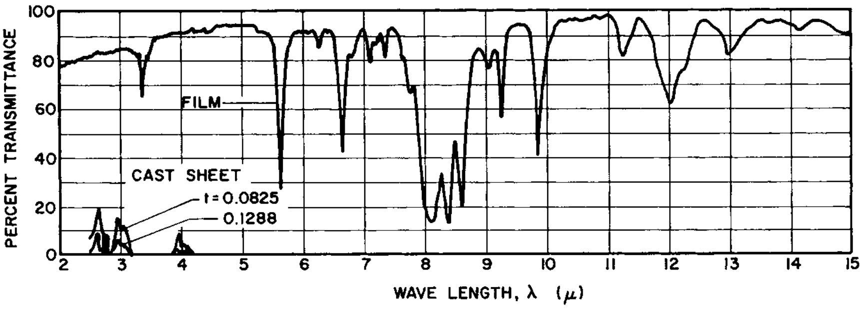

Fig. 6. Transmittance of a polycarbonate film and cast sheet.

mittance with sheet thickness as is predicted by Beer's law does not exist. The reason for this failure is not clear. Two possible explanations of this discrepancy are: firstly, when the wavelength of the incident radiation is a significant fraction of the sheet thickness, the continuum model described by Beer's Law fails; or, secondly, the molecular orientation of the film is different than that of the cast sheet, thus having different overall characteristics. This phenomenon is presently being investigated by the authors.

Nomenclature

D	sheet thickness
I	energy flux
n	index refraction
q	energy generation per unit volume
T	temperature
x	absorption coefficient
λ	wavelength
ρ	reflectivity

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R. C. Progelhof
J. Franey
T. W. Haas

Department of Mechanical Engineering
Newark College of Engineering
Newark, New Jersey 07102

Received March 10, 1971