

Preparation of Poly(vinyl alcohol) Films with Promising Physical Properties in Comparison with Commercial Polyethylene Film

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ABSTRACT: Poly(vinyl alcohol) (PVA) films with different thicknesses (0.08, 0.2, 0.23, 0.42 mm) were prepared by a casting technique. The transmission and the absorption of the PVA films were measured as functions of the wavelengths. PVA film with a thickness of 0.42 mm showed zero transmission in the wavelength range of 190–350 nm. The transmission spectrum of a commercial polyethylene film with a thickness of 0.21 mm was compared to the transmission spectrum of PVA film with a thickness of 0.42 mm. A correlation was found between the two transmission spectra in the region 190–350 nm and a 20% increase in the transmission of the PVA film in comparison with the transmission of commercial polyethylene in the region 350–1500 nm. The near-infrared region of the transmission of commercial polyethylene was increased by 15% with respect to the transmission of the PVA film. The stress–strain measurements were done for PVA and commercial polyethylene films. The

Young's modulus and the strength at break for PVA films are higher by two orders of magnitude than those for commercial polyethylene film. The strain at break for commercial polyethylene is 17% lower than that for PVA film. Radiation effects on the optical properties of PVA and commercial polyethylene films were investigated. The PVA and commercial polyethylene films were irradiated with a xenon arc lamp at 3.5–5 W/cm². The optical properties for PVA and commercial polyethylene films were studied after irradiation. The obtained results showed that PVA film with a thickness of 0.42 mm gave promising properties which could be used in technological applications. © 2002 Wiley Periodicals, Inc. *J Appl Polym Sci* 86: 1219–1226, 2002

Key words: FT-IR, polyethylene (PE), radiation, mechanical properties

INTRODUCTION

Attention has been focused on poly(vinyl alcohol) (PVA) for more than 40 years because of its unique chemical and physical properties as well as its industrial applications.^{1–9} The optical uses of PVA are concerned with the retardation, polarization, and filtration of light and with photography and related imaging fields.

Harmful solar radiation could be screened via the addition of light stabilizers, mainly UV absorbers (UVA) and radical scavengers (HALS)¹⁰ to the polymeric material or a highly resistant coating capable of effectively screening harmful solar radiation. Some light filters based on PVA cut out ultraviolet and infrared radiation and transmit the visible part of the spectrum.¹¹ These filters contain a polyindamine in PVA, formed by the oxidation of aniline and various aniline derivatives. Abd El-Kader et al.¹² described a cutout filter for UV radiation from PVA via UV radiation and thermal annealing. Hoffman¹³ described a filter of this type, which is green, ab-

sorbs between 750 and 1000 nm and below 400 nm, and transmits 30% of 500-nm light. A similar filter¹⁴ based on PVA containing cupric chloride absorbs below 430 nm and from 760 to 1300 nm and transmits 80% of 550-nm light.

Many problems appeared due to the use of additives which may evaporate during molding and extrusion processes and also migrate from plastics during storage. UV-cured coatings are considered to have poor resistance to weathering and to be ill-suited for outdoor applications because they contain some residual photoinitiators and the incomplete polymerization at the coating/substrate interface leads usually to poor adhesion.

To avoid all these problems, this article was devoted to prepare PVA films without any additives or UV-cured coatings to screen harmful solar radiation. A comparison between the optical and mechanical properties of the prepared PVA films and the commercial polyethylene which are used in greenhouses is presented. This will be of great value to technology.

EXPERIMENTAL

PVA of molecular weight 5000 gm/mol (BDH England) was used as a basic polymeric material in this work. PVA films were prepared using a casting tech-

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TABLE I
Sample Characterizations and Irradiation Conditions of PVA and Commercial Polyethylene Films

Sample code	Polymer	Thickness (mm)	UV treatment
a	PVA	0.08	—
b	PVA	0.2	—
c	PVA	0.23	—
d	PVA	0.42	—
d1	PVA	0.42	3.5 W/cm ²
d2	PVA	0.42	5 W/cm ²
f	Commercial polyethylene	0.21	—
f1	Commercial polyethylene	0.21	3.5 W/cm ²
f2	Commercial polyethylene	0.21	5 W/cm ²

nique.¹⁵ A PVA solution was prepared by dissolving PVA in distilled water and then was maintained for 24 h at room temperature to swell. The mixture was then warmed to 60°C and stirred, using a magnetic stirrer, thoroughly for 4 h until the polymer became

completely soluble. The solution was then poured into flat glass plate dishes. Homogeneous films were obtained after drying in an air oven for 48 h at 40°C. Table I shows the samples' characteristics. The optical absorption and transmission measurements for all the samples were measured using a JASSCO V-570 spectrophotometer in the range from 190 to 2500 nm. Infrared spectra of samples a–d were recorded using a JASSCO FTIR 420 spectrophotometer in the wavenumber range from 400 to 4000 cm⁻¹ with a scan resolution of 4 cm⁻¹.

The stress–strain measurements were performed using a mechanical test machine (AMETEK), in which a force gauge (Hunter Spring Accu Force II, 0.01 N resolution) was attached. The readings were automatically recorded through a microprocessor as a function of time. A locally designed motor with a microswitch system was attached to the test machine to control the strain rate. The strain rate throughout the experiment was 0.04 cm/s. The samples used in the mechanical measurements were strips of dimensions 20 × 2 mm. The thickness of films d and f were 0.42 and 0.21 mm, respectively.

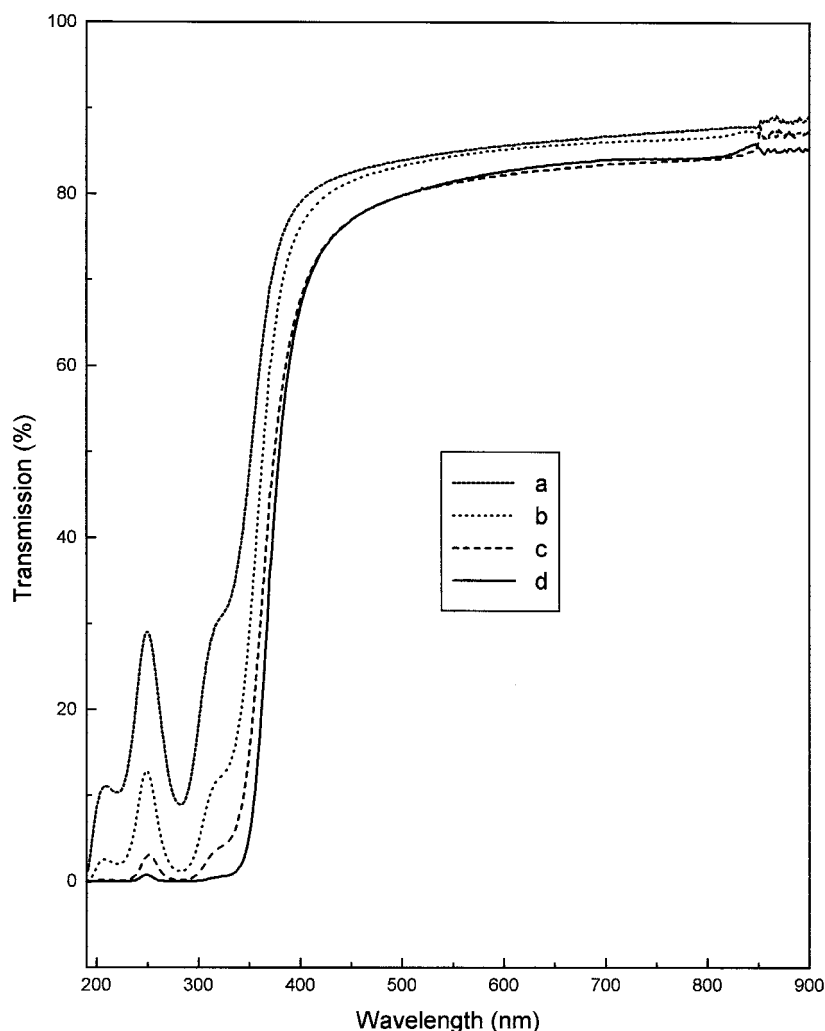


Figure 1 Transmission spectra of PVA samples a–d.

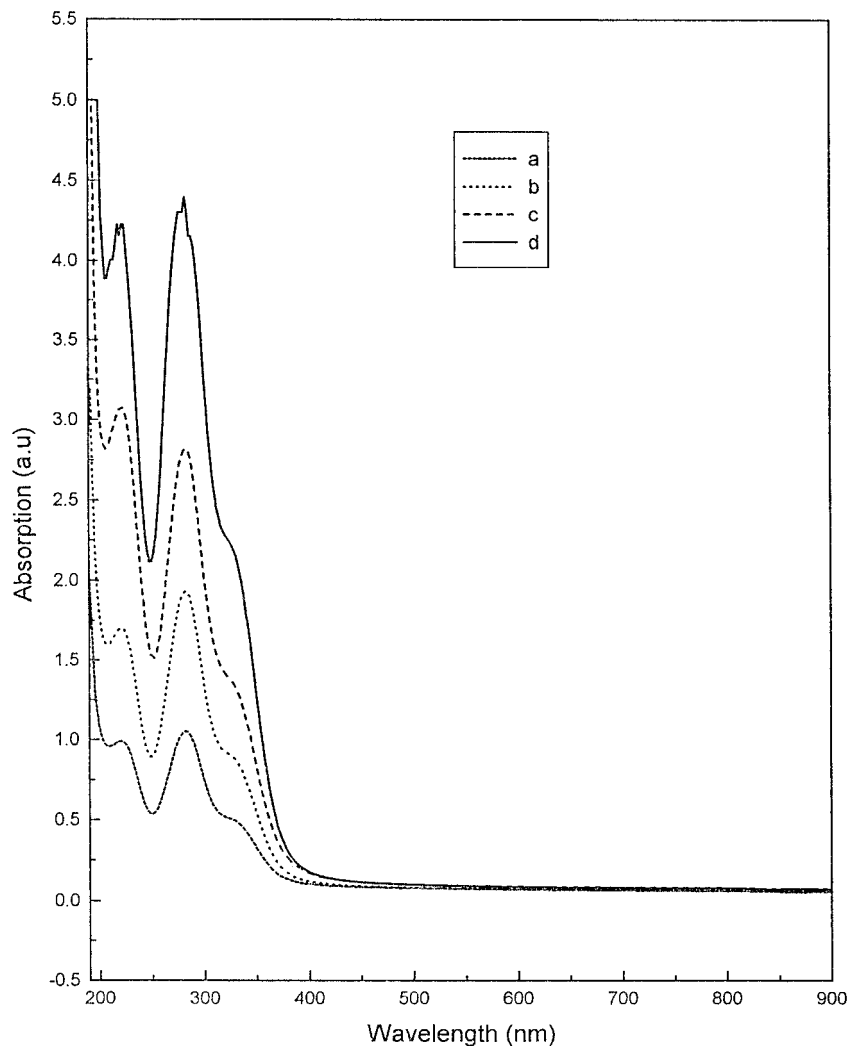


Figure 2 Absorption spectra of PVA samples a-d.

Three commercial polyethylene film films (f, f1, f2) with the same thickness of 0.21 mm were used in the photodegradation experiment. An xenon arc lamp with a wavelength 320 nm was used to irradiate the samples for 5 min. The irradiance was measured using an iL1400A radiometer/photometer.

RESULTS AND DISCUSSION

UV-visible transmission spectra

Figure 1 shows optical transmission spectra of PVA samples a-d in the region 190-900 nm. For sample d, one can observe a nearly zero transmission intensity in the wavelength range of 190-350 nm, a sharp increase in the transmission reaching 75% in the region 350-420 nm, and then a transmission intensity that is approximately constant at 80% in the region 430-900 nm. For samples a-c, the same trend is observed. The transmission intensity is minimum at a wavelength of 250 nm for sample d and then increases gradually as the thickness decreases.

Optical absorption

Figure 2 shows absorption spectra of samples a-d in the range of 190-900 nm, which is the conventional

TABLE II
Analyzed Data of UV Absorption Spectra for PVA Samples a-d

Significant samples	Bands (nm)	Absorption (au)	Assignment
a	223 (s)	0.96	$n \rightarrow \pi^*$
	282 (w)	1.05	$\pi \rightarrow \pi^*$
	327 (w)	0.49	$\pi \rightarrow \pi^*$
c	223 (s)	1.7	$n \rightarrow \pi^*$
	282 (w)	1.93	$\pi \rightarrow \pi^*$
	327 (w)	0.89	$\pi \rightarrow \pi^*$
c	223 (s)	3.1	$n \rightarrow \pi^*$
	282 (w)	2.79	$\pi \rightarrow \pi^*$
	327 (w)	1.35	$\pi \rightarrow \pi^*$
d	223 (s)	4.19	$n \rightarrow \pi^*$
	282 (s)	4.4	$\pi \rightarrow \pi^*$
	327 (sh)	2.2	$\pi \rightarrow \pi^*$

s: strong; sh: shoulder; w: weak.

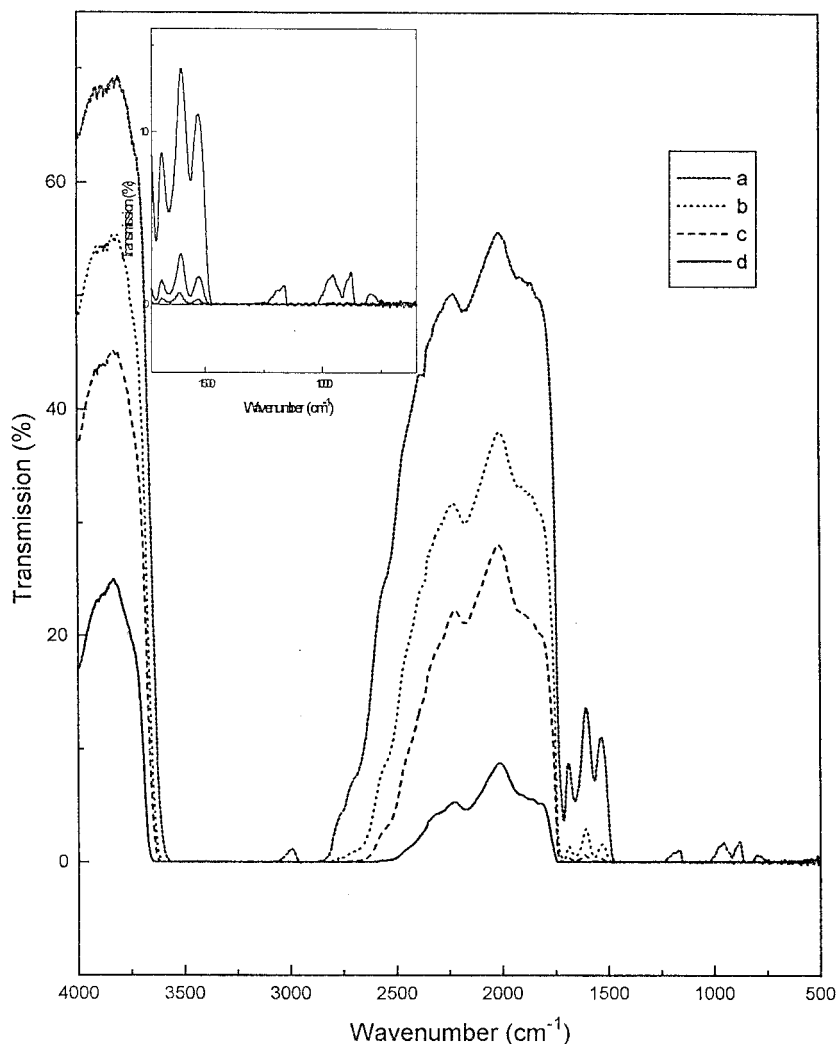


Figure 3 FTIR spectra of PVA samples a-d.

spectral region, and Table II contains analyses of the spectra. In the UV region, all the samples showed three absorption bands at the same positions (223, 282, and 327 nm), which are related to high-energy absorption at the UV region. The band at 223 nm, a strong one for all the samples, may be assigned to an $n \rightarrow \pi^*$ transition due to the presence of the C=O group; meanwhile, the bands which appeared at 282 and 327 nm with different absorption intensities may be assigned to $\pi \rightarrow \pi^*$, which come from unsaturated bonds, mainly C=O and/or C=C, which are present in the tail-head of the polymer. When the thickness increases, the concentration of the C=O and C=C increases and so the absorption increases because the absorption is proportional to the number of absorbing molecules according to Beer's law.

Infrared spectra

Figure 3 depicts the IR transmission spectra of PVA films. The PVAs' most notable characterizing frequencies, observed in the present spectra, were assigned

and are listed in Table III. The observed features can be summarized as follows:

All the compounds gave a broad and strong band centered at 3400 cm^{-1} which could be assigned to the stretching vibration of the hydroxyl group ($\nu_{\text{O-H}}$) with strong hydrogen bonding as an intra and/or inter type.¹⁶⁻¹⁹

The carbon-hydrogen stretching vibration which occurs at the high-frequency end of the spectrum is

TABLE III
Significant IR Data for PVA samples a-d

Significant samples	$\nu_{\text{O-H}}$ (cm^{-1})	$\nu_{\text{C=O}}$ (cm^{-1})	$\nu_{\text{C=C}}$ (cm^{-1})
a	3600 (broad, s)	1605 (m)	1529 (m)
b	3600 (broad, m)	1605 (m)	1529 (m)
c	3600 (broad, s)	1605 (m)	1529 (m)
d	3600 (broad, m)	1605 (s)	1529 (m)

s: strong; m: medium.

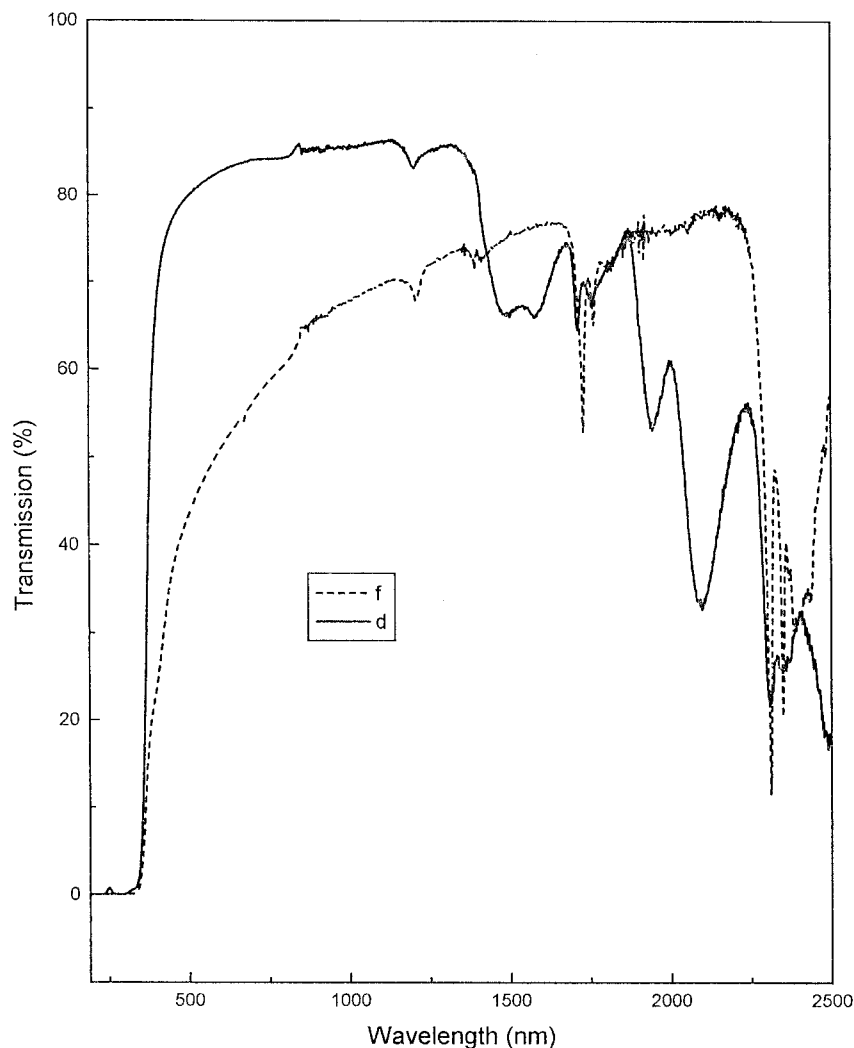


Figure 4 Transmission spectra of sample d of PVA and sample f of commercial polyethylene.

characteristic of the hybridization of the carbon holding the hydrogen: at $2800\text{--}3000\text{ cm}^{-1}$ for tetrahedral carbon and at $3000\text{--}3100\text{ cm}^{-1}$ for trigonal carbon (alkenes). That they are not observed here may be due to the strong hydrogen bond which gave a very broad band that may be contain the carbon-hydrogen stretching.²⁰

The stretching vibration bands of $\text{C}=\text{O}$ and $\text{C}=\text{C}$ appeared at 1610 and 1570 cm^{-1} for all the samples under investigation. The values of $\nu_{\text{C}=\text{O}}$ and/or $\nu_{\text{C}=\text{C}}$ indicating that these samples have the same resonating structure from alkene \leftrightarrow alkane and $\text{C}=\text{O} \leftrightarrow \text{C}-\text{O}^-$ and/or the presence of a hydrogen bond with oxygen of the $\text{C}=\text{O}$ group.¹⁷

The IR spectra of the synthesized polymer under investigation have the same band positions, with some extent of variation in the absorption intensity with the variation in the thickness. Figure 3 indicates that all the compounds, which have different thicknesses, have nearly the same chemical structure with the same functional groups.

Comparison between optical and mechanical properties of the prepared PVA and commercial polyethylene films

In Figure 4, the transmission spectra of PVA film (sample d in Table I) is compared with that of commercial polyethylene film (sample f in Table I). The results demonstrated that there is a correlation between the two transmission spectra in the region $190\text{--}350\text{ nm}$. There is a 20% increase in the transmission of sample d over the transmission of sample f in the region $350\text{--}1500\text{ nm}$, and in the near-infrared region, the transmission of sample f is 15% higher than is the transmission of sample d.

The stress-strain behaviors of samples d and f are shown in Figure 5. Table IV summarizes the mechanical properties of the Young's modulus Y , strength σ , and strain at break ϵ_b for the two samples. The Young's modulus and the strength at break for sample d is higher by two orders of magnitude than is the Young's modulus and the strength at break for sample

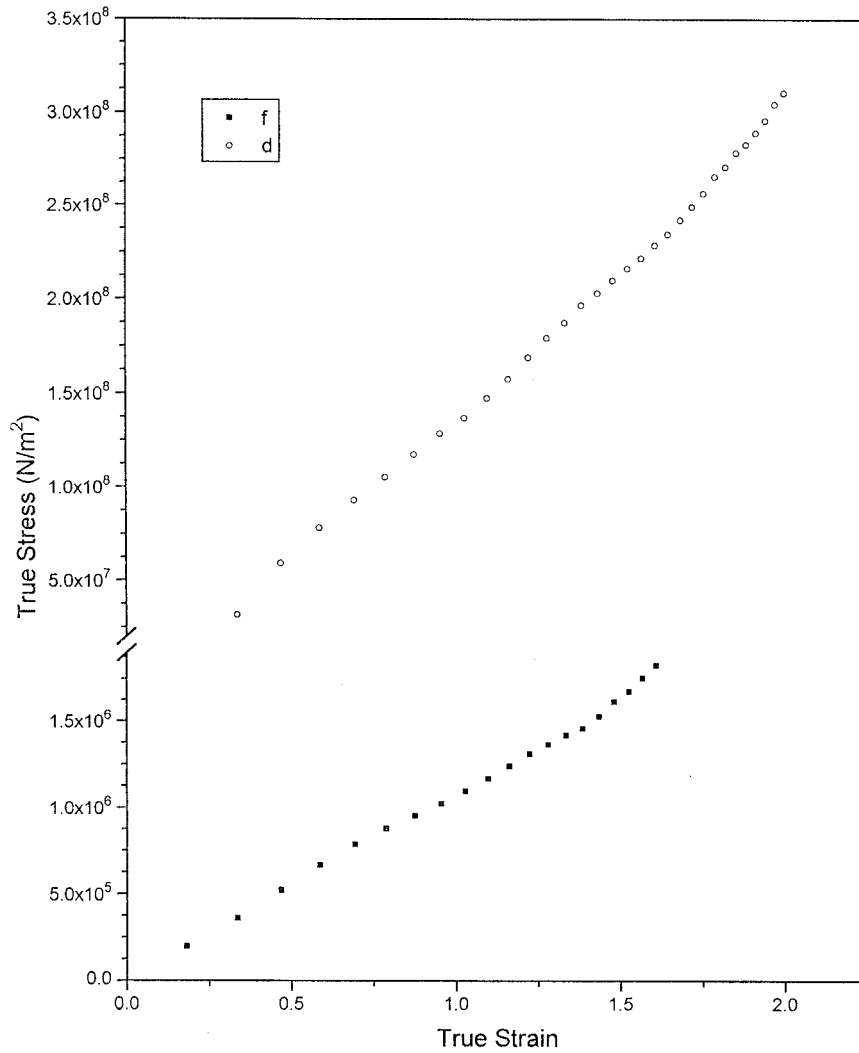


Figure 5 Stress-strain behavior of sample d of PVA and sample f of commercial polyethylene.

f. The strain at the break for sample f is 17% lower than is the strain at break for sample d.

Effect of UV irradiation on the optical properties of the prepared PVA and commercial polyethylene films

Radiation effects on the optical properties of PVA and commercial polyethylene films were investigated. Figures 6 and 7 illustrate the recorded transmission spectra of samples d, d1, and d2 and f, f1, and f2, respectively.

The transmission intensity for samples d1 and d2 increased with respect to the transmission intensity of sample d in the wavelength range of 220–320 nm.

TABLE IV

Mechanical Properties of PVA and Polyethylene Samples

Samples	Y (N/m ²)	σ (N/m ²)	ϵ_b
d	1.4×10^8	3.1×10^8	2
f	1×10^6	1.52×10^6	1.65

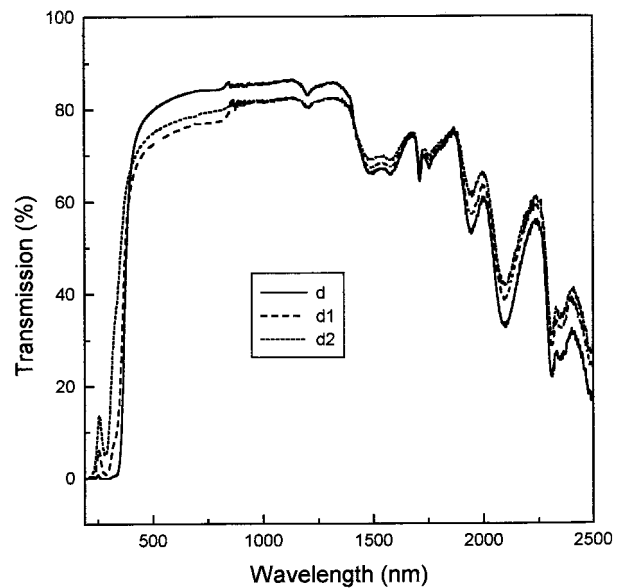


Figure 6 Transmission spectra of samples d, d1, and d2 of PVA after irradiation.

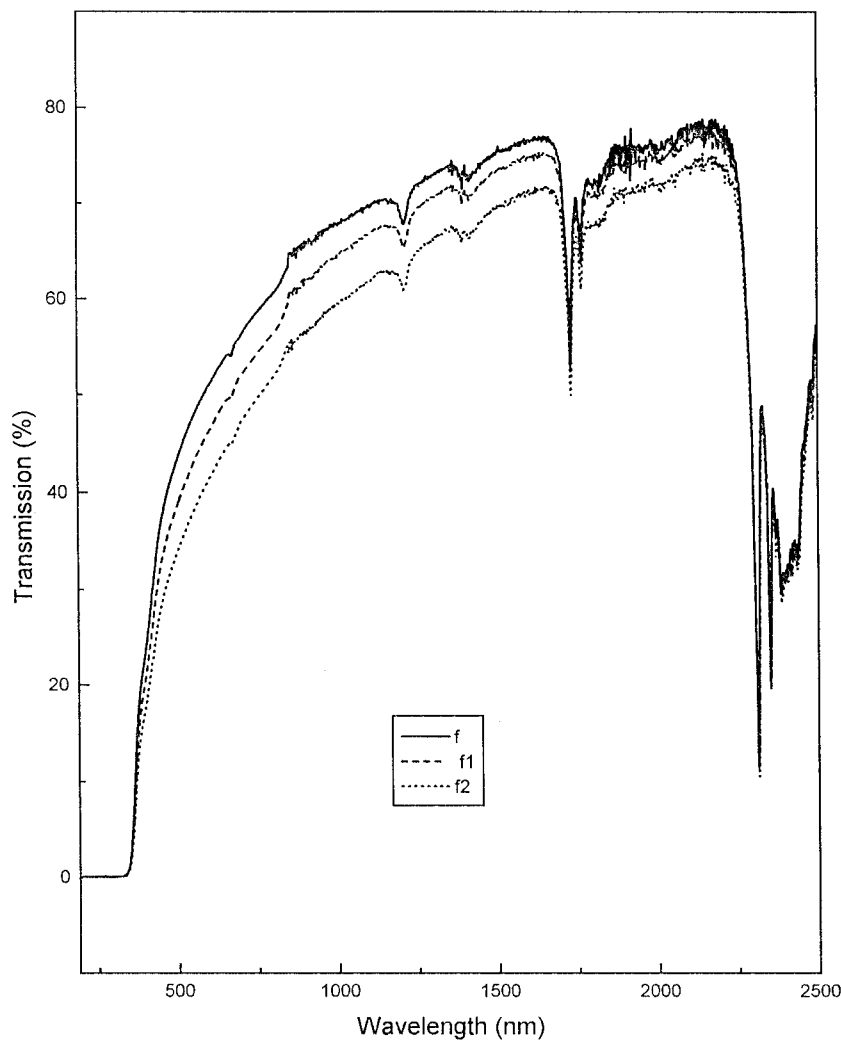


Figure 7 Transmission spectra of samples f, f1, and f2 of commercial polyethylene after irradiation.

With an increasing incident energy density, the transmission intensity for samples d1, d2, f1, and f2 in the wavelength region of 350–900 nm was decreased because the UV radiation-induced chemical reactions of vinyl polymers include, in general, crosslinking, chain scission, small molecular elimination, and internal or terminal double-bond formation.²¹

CONCLUSIONS

PVA films with different thicknesses were prepared by a casting technique. It was found that the optimum thickness to cut out UV radiation is 0.42 nm. The optical and mechanical properties of PVA films with a thickness of 0.42 nm and commercial polyethylene films were compared. The results showed that there is a relationship between the two transmission spectra in the region 190–350 nm and a 20% increase in the transmission of PVA film in comparison with the transmission of commercial polyethylene in the region 350–1500 nm. The near-infrared region of the trans-

mission of commercial polyethylene was increased by 15% with respect to the transmission of the PVA film.

With respect to the mechanical properties of the PVA film, the Young's modulus and the strength at break are two orders of magnitude higher than are those for commercial polyethylene film. The strain at break for commercial polyethylene is 17% lower than the strain at break for PVA film.

Radiation effects on the optical properties of PVA and commercial polyethylene films were investigated. The PVA and commercial polyethylene films were irradiated with an xeon arc lamp at 3.5–5 W/cm² for 5 min. The obtained results showed that the PVA film with a thickness of 0.42 mm gave pronounced properties which could be used in technological applications.

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