JOURNAL OF APPLIED POLYMER SCIENCE VOL. V, ISSUE NO. 13, PAGES 48–52 (1961)

Clarity Measurement of Polymer Films

ZIGMOND W. WILCHINSKY

Esso Research and Engineering Company, Linden, New Jersey

INTRODUCTION

The term "clarity" of a sample signifies how well objects are seen when viewed through the sample. Clarity is therefore related to optical resolution. By simple visual tests, such as viewing a Snellen chart through a sample,[1] a measure of clarity can be obtained. However, such methods depend on individual judgment which may vary from observer to observer. This disadvantage has been eliminated in instrumental methods involving quantitative light measurements. One such method relates clarity to scattering from particles within a transparent material.[2] In plastic films, however, considerable loss of clarity can occur by refraction from surface irregularities. A second method relates clarity to transmittance measured for a fine beam of light at zero scattering angle.[3,4] Ratings of clarity obtained by this method are affected by absorption within the sample and by the width of the light beam used. Under certain conditions, however, the results are essentially equivalent to the method discussed in the present paper. This method is essentially free of the aforementioned limitations. In this method the degree to which the presence of a polymer film affects the resolution of optical images is taken as a measure of clarity. This is evaluated by scattering of light at angles generally less than 1°.

RELATIONSHIP OF LIGHT SCATTERING TO SHARPNESS OF OPTICAL IMAGES

The loss of clarity, in terms of resolution, can be analyzed in terms of some simple concepts of image formation. Consider a beam of light emerging from a narrow slit S having a uniform intensity throughout its cross section. Let the slit of width W be viewed through a film F at a distance D as indicated in Figure 1. Also, let the ratio W/D be small enough so that the rays from the slit can be considered parallel. After traversing the sample, all the rays are no longer parallel, because of scattering, refraction, etc., by the sample. One such ray R in Figure 1, is deviated through an angle ψ. It will appear to come from the direction OS′ which makes an angle, also ψ, with the original direction, OS. Similarly, other rays will appear to come from other directions. Thus by considering all the rays, it follows that the light appears to be coming from a virtual source (broken curve in Fig. 1) having the same angular intensity distribution as the scattered light. Consequently, when the slit is viewed through the film, the image perceived is that of the virtual source, and the slit will tend to appear diffuse.

If the images of two such slits when viewed through the film are well resolved, they will have intensity distributions as indicated in Figure 2*A*. As the angular separation between the centers of the slits decreases, the images eventually overlap as in Figure 2*B*, but are still resolved. On further decrease of the angular separation, a critical angular separation α, indicated in Figure 2*C*, is reached at which the slits cease to be resolved. This angle, α, is the *minimum angle of resolution*. At any significantly smaller angle of separation, such as indicated in Figure 2*D*, the two images will definitely appear as one.

The minimum angle of resolution can be conveniently defined in terms of the intensity distribution of the resultant image at the critical condition indicated in Figure 2*C*. Let ψ be the viewing

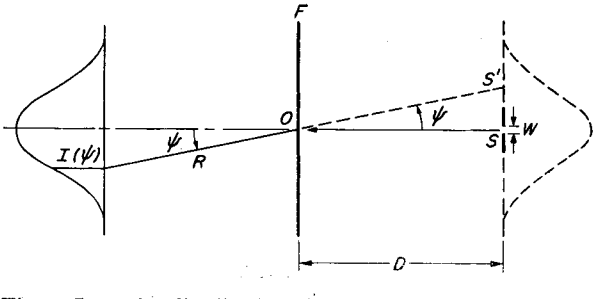

Fig. 1. Intensity distribution of scattered light and of virtual source.

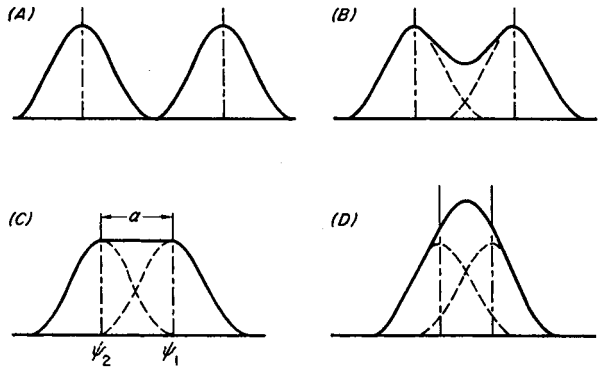

Fig. 2. Superposition of images of two identical slits: (*A*) and (*B*), images resolved; (*C*) critical condition for minimum angle of resolution, α; (*D*) images not resolved.

angle measured from the midpoint between the slits. At any angle ψ the intensity $I(\psi)$ will be the sum of the contribution from the first and second slits, i.e., $I(\psi) = I_1(\psi) + I_2(\psi)$. The condition obtaining at the minimum angle of resolution is that the intensity at $\psi = 0$ equals that at the centers of the first slit ψ_1, and second slit ψ_2. One may then write:

$$\begin{aligned} I(0) &= I(\psi_1) = I(\psi_2) \\ &= I_1(\psi_1) + I_2(\psi_1) \\ &= I_1(\psi_2) + I_2(\psi_2) \end{aligned} \qquad (1)$$

The angle subtended by the centers of the slits is then the minimum angle of resolution given by

$$\alpha = \psi_1 - \psi_2 = 2\psi_1 \qquad (2)$$

In general $I_2(\psi_1)$ and $I_1(\psi_2)$ are small compared with $I_1(\psi_1)$ and $I_2(\psi_2)$, hence one may approximate α by

$$\alpha \approx B \qquad (3)$$

where B is the width of the distribution curve at half the maximum intensity for the image of one of the slits.

If the intensity distribution across the image of a narrow slit considered by itself is represented by a Gaussian curve of the form

$$I_1(\psi) = \exp\left\{-c(\psi - \psi_1)^2/B^2\right\} \qquad (4)$$

then it can be shown that when condition (1) holds for a pair of such slits,

$$\alpha = 0.95B \qquad \text{(Gaussian, narrow slits)} \qquad (5)$$

In eq. (2), c is a constant making $I(\psi) = 1/2$ for $\psi - \psi_1 = B/2$; the value of c is approximately 2.76.

As the slit width increases, the value of α increases, i.e., resolution becomes poorer. If the intensity distribution of the image for each element of each slit is Gaussian and given by an equation of the form of eq. (4), then the intensity $I(\psi)$ is simply the summation of the contributions from all the elements of both slits. For a slit width W equal to one-half the separation between the slit centers a, the condition (1) leads to

$$\alpha = 0.995\,B \quad (W = a/2) \qquad (6)$$

Thus, within comfortable limits, the slit width is not very critical.

From the foregoing discussion the following conclusions are drawn which are used here as a basis for clarity measurement: (*1*) Clarity of a film can be rated by α, the minimum angle of resolution; a small α corresponds to high clarity. (*2*) The value of α can be conveniently approximated by the width B of the scattering curve of a narrow slit beam of light measured at half the maximum intensity.

METHODS OF MEASUREMENT

A. Light Scattering Method

Experimental scattering curves were obtained with a commercial version (Model III Scattermaster, manufactured by Engineering and Equipment Corp., Hatboro, Pa.) of an instrument described by Aughey and Baum.[5] Although ideally a more desirable instrument would be one permitting exposure of a larger area of film surface with a parallel beam (rather than a convergent beam), the instrument used was adequate for the purpose.

With no sample in the path of the beam, a scattering curve of width B_0 is obtained. For measurements of high clarity films, a correction for the effect of the instrument was made according to the eq. (7):

$$B = (B_m^2 - B_0^2)^{1/2} \qquad (7)$$

where B_m is the width of the measured scattering curve due to the sample plus instrument. This equation holds rigorously for Gaussian distributions; it is derived in the same manner as Warren's correction for the width of x-ray lines in crystal size determinations.[6]

For the instrument used, B_0 was 2.0 minutes of arc. The intensity distribution for B_0 was found to be nearly Gaussian. For cases where the correction to B_m was significant, it was found that the

scattering curves approximated Gaussian's distributions closely enough so that eq. (7) could be applied. For relatively broad curves the departure from a Gaussian shape was more pronounced. However, for these cases the correction in eq. (7) was not too important.

Films that showed striations showed greater scattering when the slit source was parallel to the striations than when transverse to them. For cases where the striations were coarse, the intensity tended to vary erratically with scattering angle. For such cases it was found convenient to determine the (uncorrected) curve width for the parallel position from measurements with the film in the transverse position and 45° position according to the relationship

$$B_{m,||} = (2B_{m,45}^2 - B_{m,\perp}^2)^{1/2} \qquad (8)$$

where the subscripts refer to the parallel (||), 45° and transverse (⊥) positions. This equation is discussed in the Appendix.

B. Visual Method

The corrected angular widths B of the scattering curves at half the maximum intensity were correlated with values of α determined visually by the simple arrangement shown in Figure 3. A pair of slits for which the slit width was one-half the separation between slit centers, was illuminated uniformly from behind and viewed through the film. Since the eye, as a viewing instrument, has a minimum angle of resolution of about 2 minutes of arc, its ability to measure values of α close to 2 minutes is therefore seriously limited. This limitation was eliminated by using a laboratory telescope. Its minimum angle of resolution, about 0.2 minute of arc, was adequate for the measurements involved.

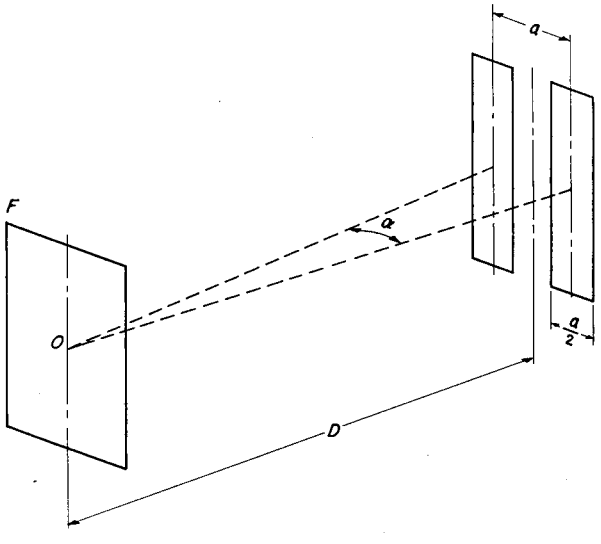

Fig. 3. Schematic arrangement for visual determination of the minimum angle of resolution.

By varying the viewing distance, the critical condition at which the slits were just resolved was obtained. The angular separation of the center of the slits subtended at the film was taken as α.

It was found convenient to have several pairs of slits of various sizes to measure α in different ranges conveniently.

CORRELATION OF LIGHT SCATTERING WITH VISUAL METHOD

Clarity was measured of several polymer samples in the form of film or sheet. Results obtained by the two methods are summarized in Table I.

TABLE I

Clarity Measurements of Polymer Film and Sheet. Direction of Striations, Die Marks, etc., with Respect to Light Slits Is Indicated. Values of α were Determined Visually; Values of B Were Determined by Light Scattering Measurements

	B		α	
Sample	Parallel	Transverse	Parallel	Transverse
Polypropylene				
Film A	4.1	1.2	5	1.5
Film B	7	0.9	10	0.9
Film C	15	1.2	18	0.9
Film D	13	3.9	18	3.4
Film E	18	2.8	23	2.1
Film F	0.6[a]	—	0.3[a]	—
Sheet	1.9[a]	—	2.4[a]	—
Polyethylene				
Film G	62	33	78	26
Film H	2.4[a]	—	2.3[a]	—
Film I	1.7[a]	—	2.8[a]	—
Polystyrene film	4.1	0.5	3.8	0.19

[a] Sample showed no directional effect.

It can be noted that most of the samples showed directional properties. As these samples were rotated in their own plane, it was found that the positions for maximum and minimum scattering were at right angles to each other. Values of B for these two extremes were measured where the difference was significant.

A plot of B versus α is shown in Figure 4. The expected straight-line correlation was obtained, within experimental accuracy, down to about one

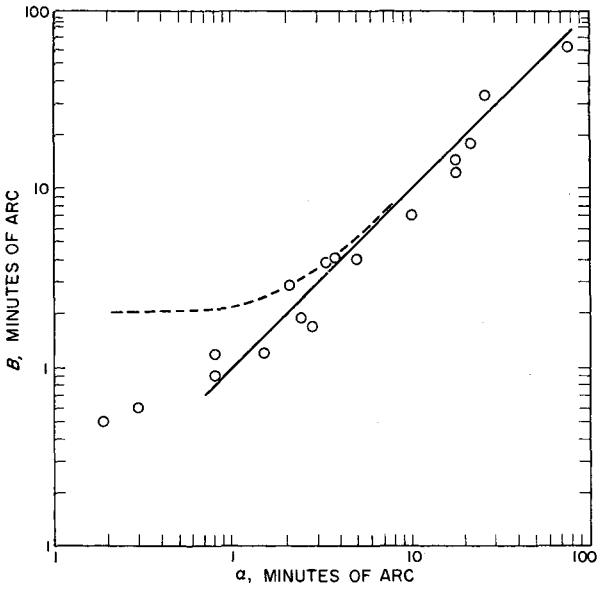

Fig. 4. Correlation of scattering curve width B with visual determination of minimum angle of resolution, α. Broken curve is obtained if resolution correction for the instrument is not applied.

minute of arc. If the correction for the resolution of the instrument is not applied, the curve flattens out at low values of α as indicated by the broken line in Figure 4, and approaches the value B_0 of the instrument. This indicates the importance of the correction when measuring polymer films of relatively high clarity.

DISCUSSION

The ratings of film clarity were carried out in a manner analogous in principle to that generally used in rating image-forming characteristics of optical instruments. In the simple method described, it was possible to avoid use of arbitrary units so that the clarity measurements of the films are not dependent on the characteristics of the instrument used. With the available commercial equipment, clarity measurements can be conveniently carried out on films to be used in packaging and other applications where extreme clarity is not required.

Appendix

USE OF OBLIQUE MEASUREMENTS

For samples giving highly erratic light scattering curves for one principal position of the sample, the value of $B_{||}$ (for that position) can be conveniently estimated from measurements in the transverse and 45° positions.

On rotating an anisotropic sample in its own plane, it was observed that the intensity I_0 at zero scattering angle had a distribution with respect to the angle of rotation which was approximately elliptical. The equation of the ellipse can be represented by

$$(x/I_{0,\perp})^2 + (y/I_{0,||})^2 = 1 \qquad (9)$$

where $I_{0,\perp}$ and $I_{0,||}$ are the semimajor and semiminor axes, respectively.

At 45° to the coordinate axes, the intensity $I_{0,45}$ is given by

$$x^2 + y^2 = I_{0,45}{}^2 = 2x^2 = 2y^2 \qquad (10)$$

since $x = y$. Substituting these values for x and y into eq. (9), one obtains

$$(1/I_{0,\perp})^2 + (1/I_{0,||})^2 = 2/I_{0.45}{}^2 \qquad (11)$$

Since the absorption within this film is negligible, the area under the scattering curve, for any position of the sample, is a constant. Assuming that the scattering curves are of the same general type, e.g., Gaussian, then it follows that I_0 is inversely proportional to B_m. Therefore, in terms of the curve widths, eq. (11) can be written

$$B_{m,\perp}{}^2 + B_{m,||}{}^2 = 2B_{m,45}{}^2 \qquad (12)$$

which is equivalent to eq. (8).

References

1. U. S. Department of Commerce, "Recommended Commercial Standard for Polypropylene Film," Report TS-5438, January 20, 1959.
2. Billmeyer, F. W., *J. Opt. Soc. Am.*, **49**, 368 (1959).
3. Pinsky, J., *Modern Packaging*, **30**, 230 (1957).
4. Weber, A. C., *J. Opt. Soc. Am.*, **47**, 785 (1957).
5. Aughey, W. H., and F. J. Baum, *J. Opt. Soc. Am.*, **44**, 833 (1954).
6. Warren, B. E., *J. Am. Ceram. Soc.*, **21**, 49 (1938).

Synopsis

The component of clarity of polymer films, dependent on optical resolution, was conveniently and objectively determined from light-scattering measurements at low angles (i.e., below 1°). The width of the scattering curve at half the maximum intensity was used as an index of clarity. This quantity is essentially equivalent to the minimum angle of resolution obtained when viewing a test object through the film. By applying a correction for the resolution of the instrument, the range of the instrument was extended in the direction of high clarity, and within the precision of the measurements the clarity ratings are independent of instrument characteristics.

Résumé

La clarté de films polymériques qui dépend de la résolution optique, a été déterminée d'une manière adéquate et objective au départ de mesures de diffusion lumineuse pour des angles faibles (p.e. au dessous de 1°). La largeur de la courbe de diffusion correspondant à l'intensité demimaximale a été utilisée comme indice de clarté. Cette quantité est essentiellement équivalente à l'angle minimum de résolution obtenu lorsqu'on observe un objet test au travers du film. En appliquant une correction pour le pouvoir de résolution de l'appareil, le domaine d'application de celui-ci a été étendu aux clartés élevées, et dans les limites de précision des mesures les expressions de clarté sont indépendantes des caractéristiques instrumentales.

Zusammenfassung

Die von der optischen Auflösung abhängige Komponente der Klarheit von Polymerfilmen wurde bequem und objektiv durch Lichtstreuungsmessungen bei kleinen Winkeln (d.h. unterhalb 1°) bestimmt. Die Breite der Streukurve bei halber Maximalintensität wurde als Klarheitsindex benützt. Diese Gröss ist im wesentlichen dem kleinsten Auflösungswinkel äquivalent, der bei der Betrachtung eines Testobjektes durch den Film erhalten wird. Durch Anwendung einer Korrektur für die Auflösung des Instruments wurde der Bereich des Instruments in Richtung auf hohe Klarheit vergrössert; innerhalb der Messgenauigkeit sind die Klarheitswerte unabhängig vom Messinstrument.

Received June 27, 1960