

Mechanical Properties of CdS-Binder Resin Electrophotographic Plates

INTRODUCTION

Films consisting of CdS powder and binder resin are commercially in use as electrophotographic plates.^{1,2} In determining the composition of the film for practical use, it is important to pay attention not only to the electrical properties, but also to the mechanical properties of films. Both properties depend on the sort and the volumetric content of the binder resin. We have published the experimental results concerning the dependence of electrical properties of CdS-binder resin films on the sort of binder resins.³ The purpose of this note is to discuss briefly the experimental results of the mechanical properties of these films.

EXPERIMENTAL

CdS powder (Dainippon Teryo M1109) having a mean diameter of about 2 μm and a particle density of 4.43 g/cm³ as determined by a pycnometer was used. Poly(vinylbutyral) (PVB) (Sekisui Kagaku S-LEC BM2, density approximately 1.13) was used as polymer matrix. After dissolving a proper quantity of PVB in *n*-butanol, CdS powder was added to the solution. The resulting paste was mixed by stirring for 5 hr. Immediately after degassing the paste at 30 mm Hg for 5 min, a Mylar film, clinging to a glass plate, was coated with this paste using a flat blade to a dry thickness of 100 \pm 10 μm .

After stripping the Mylar film, the densities of CdS-binder resin films were determined by measuring their weights and thicknesses. These films were cut into rectangular specimens (8 mm \times 50 mm). Their mechanical properties were measured using a tensile tester (Toyo Baldwin TENSILON/UTM-II-20, 30 mm gauge length) at a constant displacement rate of 2 mm/min.

RESULTS AND DISCUSSION

Density and Void Content of Film

The densities of films shown in Figure 1 were plotted against the volumetric concentrations C_n of PVB, which are defined as

$$C_n = \frac{C_w/1.13}{C_w/1.13 + (100 - C_w)/4.43}$$

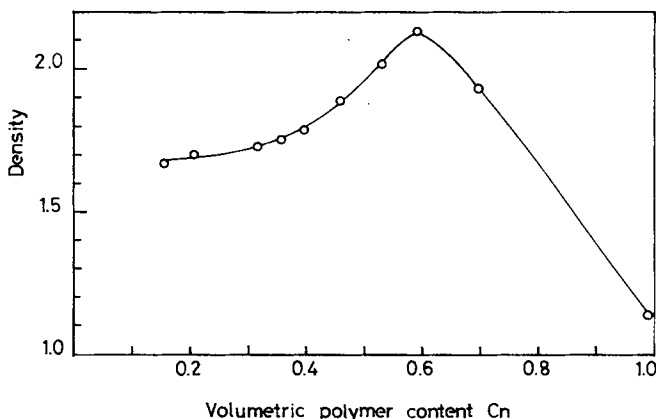


Fig. 1. Density of the film vs. volumetric polymer content C_n .

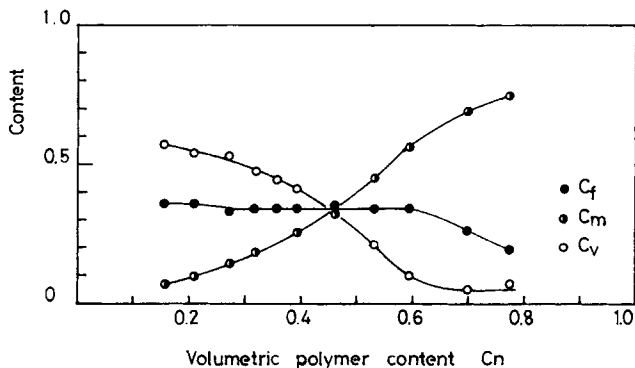


Fig. 2. Volumetric CdS, binder resin, and void contents vs. volumetric polymer content C_n .

where C_w is the weight per cent of PVB. If the film consisted of two solid phases, the density of the film should decrease monotonically with increasing binder resin content. However, Figure 1 shows a maximum at about $C_n = 0.6$. This fact can be attributed to the presence of voids in the films. Assuming that the film is a three-phase composite consisting of CdS filler, polymer matrix, and void, the void content is obtainable from particle densities of the two solid phases and the density of the film. In Figure 2, void contents C_v thus obtained are plotted against C_n together with volumetric CdS contents C_f and PVB contents in the three-phase composite C_m , where $C_v + C_f + C_m = 1.00$. It is seen that at smaller C_n values, more than 50% of the volume is occupied by voids. It is also seen that below $C_n = 0.6$, C_f is almost constant and C_v decreases with increasing C_n . These results can be ascertained by microphotographs taken by a scanning electron microscope as shown in Figure 3. These photographs are the SEM images of the fracture surfaces of the films. Figures 3a and 3b are the images of films with $C_n = 0.16$ and 0.46, respectively. A comparison of the two images reveals that an increase in binder resin content results in a decrease in void content.

Mechanical Properties of Films

Stress-strain curves obtained for the films could be classified into three groups: films with C_n between 0.16 and 0.46 belong to group a and were broken before they got to the yield point; films with C_n 0.53 and 0.60, group b, were broken just after they reached the yield point; and for films

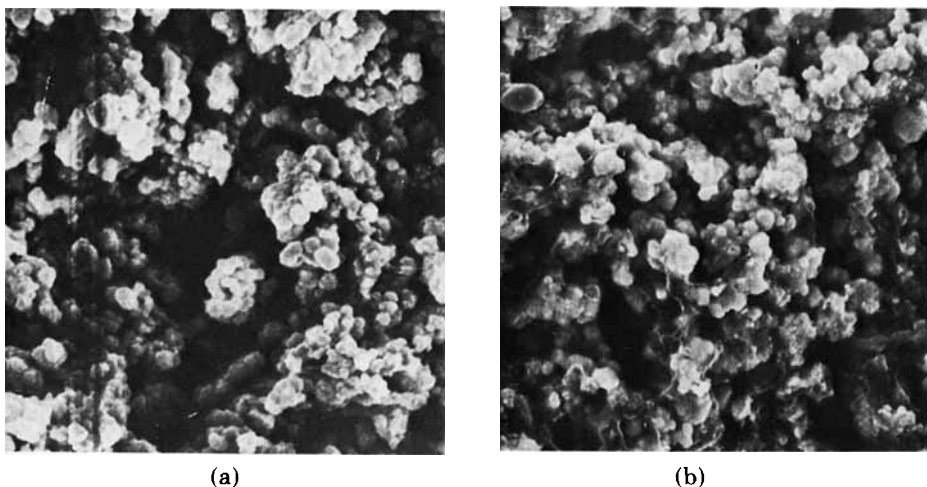


Fig. 3. SEM images of the fracture surfaces of the films ($\times 1600$): (a) $C_n = 0.16$; (b) $C_n = 0.46$.

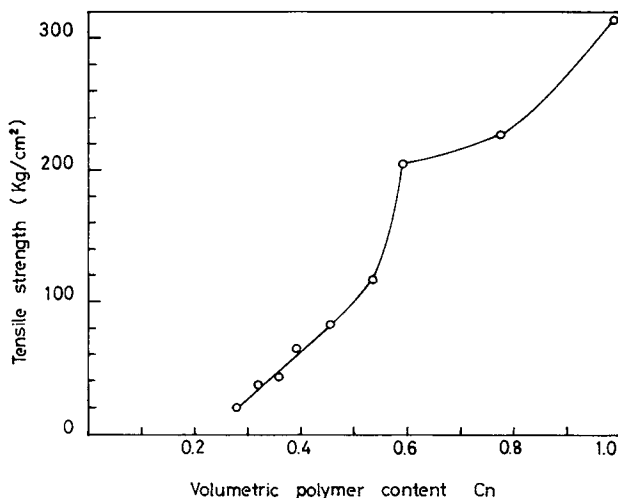


Fig. 4. Tensile strength vs. C_n .

with C_n larger than 0.60, group c, a considerable elongation was observed after they got to the yield point.

The tensile strengths are plotted against C_n in Figure 4, where they are defined as those at break for group a and as the yield stresses for groups b and c. In Figure 5, the elongations at break are shown. The stress-strain behavior can be qualitatively interpreted by taking notice of the presence of voids. In the case of films with C_n less than 0.60, C_f is nearly constant, and an increase in binder resin content results in filling voids. Thus, the tensile strength is a monotonically increasing function as C_n increases from 0.28 to 0.60. For films with C_n larger than 0.60, voids are practically filled with binder resin, and mechanical properties are thought to be determined mainly by the nature of the binder resin. A sudden increase in elongation at $C_n = 0.60$ in Figure 5 shows that the transition point is at $C_n = 0.60$.

The modulus of the idealized model system of a two-phase particulate composite containing a cubic filler embedded within a cubic matrix, whose boundaries are subjected to uniform displacement, is given as follows⁴:

$$E_c = E_m \left(1 + \frac{C_f}{\frac{M}{M-1} - C_f^{1/3}} \right) \quad (1)$$

where E_m is the modulus of the voidless matrix, M is the modular ratio of filler to matrix, and C_f is the volumetric filler content. Cohen and Ishai⁴ extended this simple model to a three-phase composite consisting of a cubic matrix with modulus E_{c_v} and void content C_v^0 , in which a cubic inclusion with modulus E_f and volumetric filler content C_f is embedded. They obtained the following expression for the modulus of the three-phase composite when it is assumed that the modular ratio of filler to matrix is sufficiently large:

$$\varphi_3 = (1 - C_v^{0\ 2/3}) \left(1 + \frac{C_f}{1 - C_f^{1/3}} \right) \quad (2)$$

where φ_3 is the modular ratio of the three-phase composite to the matrix.

In Figure 6, the experimental and calculated Young modular ratios against the corresponding C_n . Young's modulus of the film made only from binder resin was 1.15×10^{10} dynes/cm². The modular ratio of the film increases with increasing binder resin content i.e., with decreasing void content, and it reaches a maximum at $C_n = 0.60$ and then decreases toward the modulus of the binder resin. These results can be interpreted as follows: films with C_n smaller than 0.60 are three-phase composites, and those with C_n larger than 0.60 are practically voidless, two-phase composites as shown in Figure 2. The modular ratio of the film, therefore, increases with increasing binder resin content, i.e., with decreasing void content below $C_n = 0.60$. A further in-

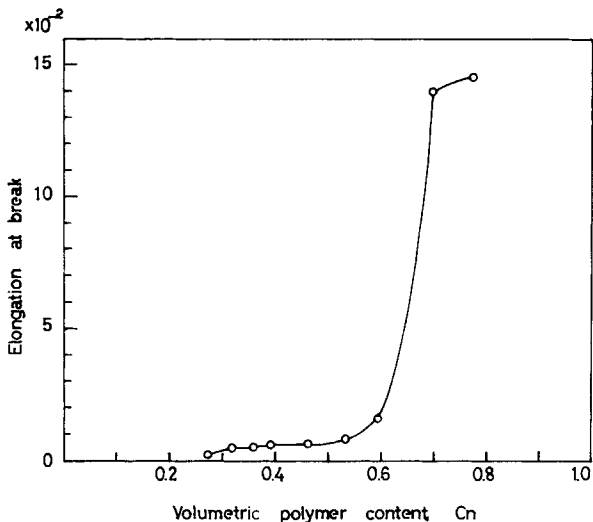


Fig. 5. Elongation at break vs. C_n .

crease in binder resin content results in a two-phase composite, and the modular ratio decreases with increasing polymer content above $C_n = 0.60$.

When we compare the theoretical results with the experimental ones for Young's modular ratios, an interesting characteristic is seen. Both results show a similar dependence of the modular ratio on the volumetric concentration of binder resin qualitatively, though eq. (2) was derived assuming a highly idealized model. In this model, several important factors such as particle size, adhesion strength between the different phases, and the amount of particle agglomerations were not taken into account. The most suitable composition of the films, from the mechanical point of view, can be roughly estimated without tensile tests if the densities of the two solid phases are known and the densities of the films are measured.

CONCLUSIONS

In the films made from paste consisting of CdS powder, binder resin, and solvent, the void content amounted to more than 50% when the volumetric binder resin content was less than 0.30. The void content played a predominant role in the variations in the tensile strength, elongation at break, and Young's modulus with the volumetric binder resin content. It was found that

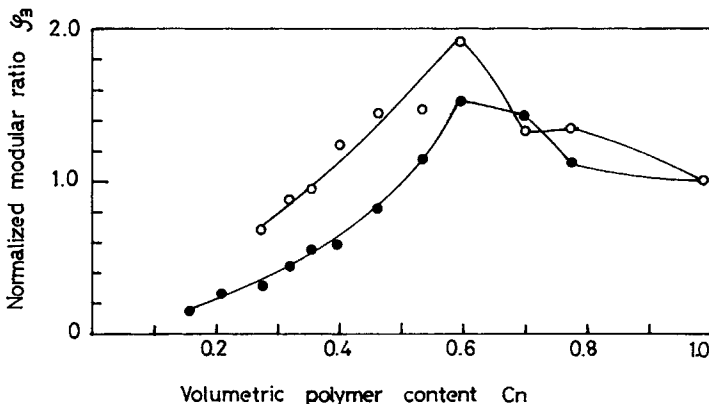


Fig. 6. Plots of (O) experimental and (●) theoretical normalized modular ratio vs. C_n .

Young's modulus could be roughly estimated by measuring only the density of the film. Consequently, the most suitable composition of the films, from the mechanical point of view, could be estimated without tensile tests.

References

1. K. Nakamura, *IEEE Trans. Electron Devices*, **ED-19**, 405 (1972).
2. M. J. Mitsui, *IEEE Trans. Electron Devices*, **ED-19**, 396 (1972).
3. H. Kusakawa, T. Masumi, and H. Ogata, *Mitsubishi Denki Giho*, **48**, 937 (1974).
4. L. J. Cohen and O. Ishai, *J. Composite Mat.*, **1**, 390 (1967).

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