MECHANICAL PROPERTIES OF COPPER-POWDER-FILLED POLYETHYLENE COMPOSITES

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Mechanical properties such as tensile strength, elongation at break, modulus of elasticity of copper powder filled high density polyethylene composites are investigated in the filler concentration range 0-18% by volume. A brief literature survey is made on mechanical properties of particle filled composites. Tensile test results are analyzed using various theoretical predictive models for two-phase composites to understand the composite structure.Tensile strength and elongation at break decreased with increasing Cu content, which is attributed to the introduction of discontinuity in the structure.

INTRODUCTION

Metal-filled polymers composites are emerging as a new group of engineering materials especially with the rapid proliferation of electronic equipment which has created an increasing need for adequate electromagnetic radiation shielding. Metal-filled polymers are used widely for electromagnetic interference shields , they have the advantages of being less costly and of lighter weight than the metals. Metal-filled polymers find outlets in other specific applications such as discharging static electricity,heat conduction, electrical heating, converting mechanical to electrical signals.

To make an adequate use of filled polymers the variation of physical properties with the kind and percentage of filler materials must be known.

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THEORY

In a two-phase composite made up of a continuous matrix and particle fillers, the type, the concentration, the size, the shape and the orientation of the filler particles are important factors in determining the mechanical and physical properties. Among several other factors that can greatly affect the mechanical behavior of filled systems, the strength of the adhesive bond between the different phases,the type of dispersion and the amount of particle agglomeration are especially important.Unfortunately,these factors are often difficult to separate and to evaluate in a quantitative manner.

Although there is no good general theory about the stress-strain behavior of filled systems , it is known from observations that generally fillers cause a large decrease in elongation to break and also fillers often decrease the tensile strength of a material. The simple model developed by Nielsen (1) explains in a semiquantitative manner many of the stress-strain properties of filled systems. For the case of perfect adhesion, and for any kind of a stress-strain curve, the model predicts that the elongation to break of a system filled with particles (ϵ_c) of approximately spherical shape is:

$$\epsilon_c/\epsilon_p = 1 - \phi^{1/3} \qquad (1)$$

where, ϕ is the volume fraction of filler, and ϵ_p elongation at break of unfilled polymer.

The tensile strength of the composite (σ_c) may be predicted by one of the following equations (2):

$$\sigma_c/\sigma_p = (1 - \phi)S \qquad (2)$$

$$\sigma_c/\sigma_p = (1 - \phi^{2/3})S' \qquad (3)$$

where, σ_p is the tensile strength of the matrix polymer These expressions represent no-adhesion type of composite structure and are derived on the basis of the relationship of area fraction to volume fraction of the inclusion. The parameters S or S' describe weakness in the structure generated through discontinuity in stress transfer or formation of stress concentration points at the inclusion-matrix interface. Unity for the value of S ar S' represents no stress concentration effects; the lower the value of S or S' from unity the greater the stress concentration effect.

Many equations have been developed for the elastic modulus of a material filled with spherical particles. The theories generally assume perfect adhesion between the filler and the polymer matrix, as well as perfect dispersion of individual filler particles. The simplest theoretical equation is the Einstein's equation which is valid only at low concentrations of filler:

$$E_c = E_p(1 + 2.5\ \phi) \qquad (4)$$

An extension of Einstein's theory for the increase in modulus due to rigid spherical filler is due to Guth(3) and Smallwood (4) and is valid for both low and high filler concentrations:

$$E_c = E_p(1 + 2.5\ \phi + 14.1\ \phi^2) \qquad (5)$$

EXPERIMENTAL

Sample Preparation

The matrix material is commercial high density polyethylene in powder form, density= 0.968 g/cm^3, melt index=5.8 g/10min. The metallic filler is copper,in the form of fine powder with particle size in the range of 10-20 microns , and density 8.92 g/cm^3. HDPE and Cu powders were mixed at various volumetric concentrations by tumbling till a homogeneous mixture was obtained.The calculation of volumetric concentrations was based on solid densities of the constituents. Then, the mixed powder was placed in a die and melted at 185°C under 4MPa pressure with a heating residence time of 10 min. After cooling by air blowing and solidification under pressure, the standard specimens of 2mm thick were obtained. Homogeneity of the specimens was examined using a light microscope, copper particles were found to be uniformly distributed in HDPE matrix with no voids in the structure.

Results and Discussion

Tensile tests were performed at room temperature (20°C) with an Instron Universal Testing Machine (Model 1114), the strain rate being 1mm/min, initial crosshead separation 4 cm. At least four specimens were tested in each case, and the average value reported. From stress-strain curves, tensile strength, modulus of elasticity and elongation at break were determined and are presented in figures 2 through 4 as function of volume

fraction of Cu powder. Figure 1 compares the stress-strain curves for pure HDPE with 8%Cu and 18%Cu powder filler. Results of tensile strength versus volume fraction of Cu are given in figure 2. From this figure, it may be noticed that there is a gradual decrease in the relative tensile strength (σ_c/σ_p), as the volume fraction of filler increases; for 18% of copper filler the tensile strength is 75% of the pure HDPE value. Solid curve in figure 2 represents predicted tensile strength behavior according to equation (2),with S=0.96 which implies that the stress concentration effect is not very important.

Results of elongation at break versus volume fraction of Cu are given in figure 3 and the experimental values are compared with the model developed by Nielsen. It may be noticed from this figure that elongation at break decreases more rapidely than may be predicted from the Nielsen model.Intermetallic contacts are playing a vital role in ductility and other mechanical properties of these composites; with the onset of metallic contact formation the composites show enhanced brittleness. From figure 4, it may be noticed that the theory of Guth (3) and Smallwood (4) predicts quite well the increase in the modulus of elasticity with the increase in filler concentration.

SYMBOLS USED

ϕ = volume fraction of filler material (%)

σ_p = tensile strength of the matrix polymer (N/mm^2)

σ_c = tensile strength of the composite (N/mm^2)

E_p = Modulus of elasticity of the matrix polymer(N/mm^2)

E_c = Modulus of elasticity of the composite (N/mm^2)

REFERENCES

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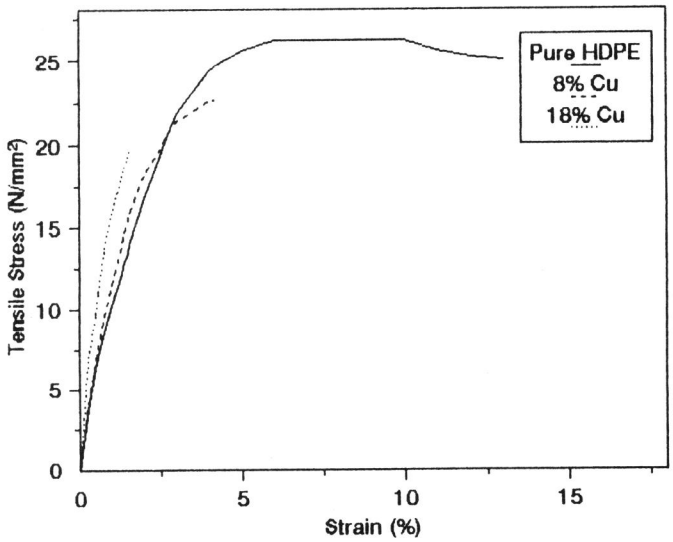

Figure 1. Stress-strain curves of pure HDPE and HDPE-Cu composites with 8% and 18% of Cu concentrations.

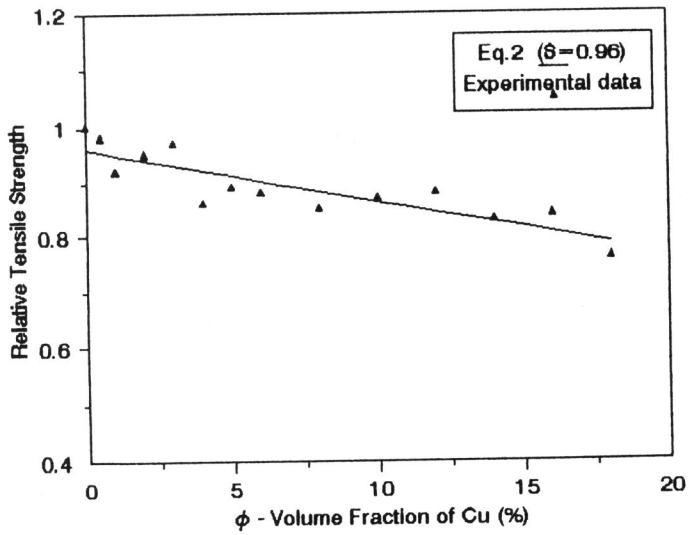

Figure 2. Relative tensile strength of HDPE-Cu composite plotted against volume fraction of Cu

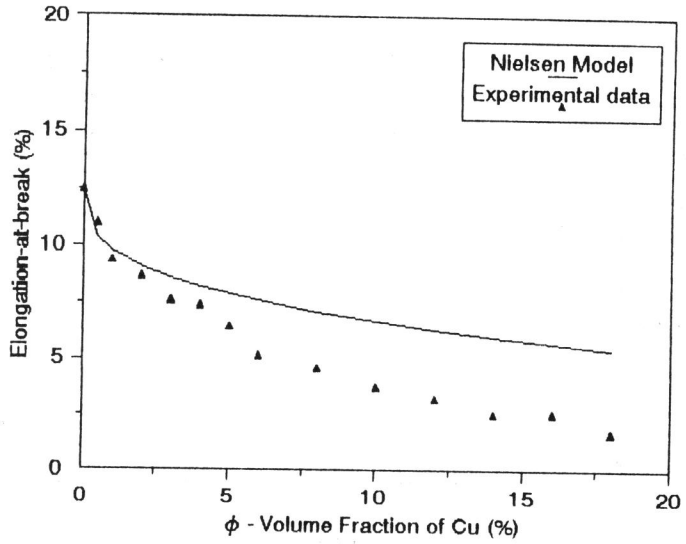

Figure 3. Elongation at break of HDPE-Cu composite as a function of volume fraction of Cu.

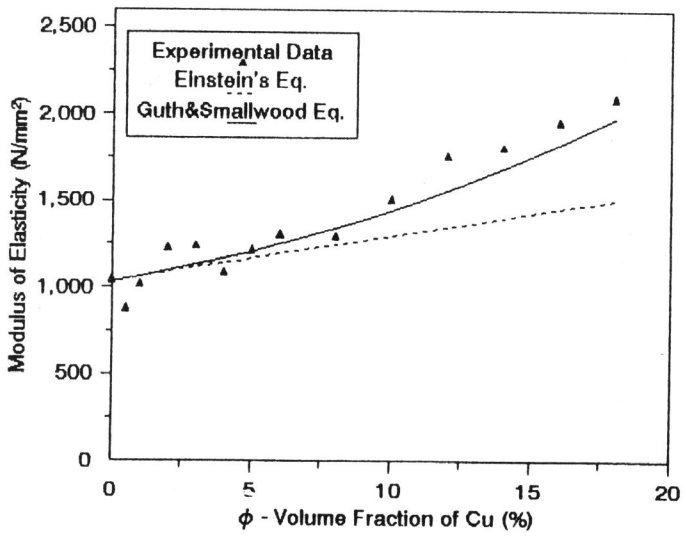

Figure 4. Modulus of elasticity of HDPE-Cu composite as a function of volume fraction of Cu.