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DYNAMIC MECHANICAL PROPERTIES OF A SPHERICAL INCLUSION-POLYMER COMPOSITE: A SELF-CONSISTENT APPROACHE BASED ON THE MORPHOLOGY

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The developments of micromechanical models based on spherical composite inclusions, are now extensively used in predictions the mechanical response of such as heterogeneous materials. In order to study the elastic behaviour of two phases matrix-inclusion composites, Mackensie[1], Christensen and Lo[2] and Hervé and Zaoui[3] have proposed *Self-Consistent Schemes* from the micro to macro scale. From that, we can consider the spherical inclusion is surrounded by a matrix shell which in turn is surrounded by the effective equivalent medium. Here we attempt to resolve several of the differences between theory and experimental by carrying out measurements of the dynamic mechanical properties of a crosslinked polymer reinforced with spherical glass using a low frequency torsion pendulum working in forces oscillations. In this work we have chosen the *n-layered inclusion model* of the Hervé and Zaoui and we have solved the problem for n=2 by modifying it with repeating the self-consistent model. Hervé and Zaoui(1993) generalised the solution of Christensen and Lo(1979) and they determined the effective shear and bulk modulus of the composites. This analysis consists of the single composite sphere (Fig. 1) embedded in the infinite medium of unknown effective properties. This model required that the effective homogeneous medium has the same average conditions of stress and strain as does the spherical model of figure 1. The procedure here will be applied to the case of the shear property. In the case of simple shear deformation the final equation for shear moduli of composite (G^*_c) is given[4] by the following second order equation:

$$X\left(\frac{G^*_c}{G^*_m}\right)^2 + Y\left(\frac{G^*_c}{G^*_m}\right) + Z = 0$$

where X, Y and Z are the constants and G^*_m is the complex shear moduli of matrix. Using the above quadratic equation, the solution for the equivalent shear modulus of the spherical model can be determined. Numerical results by giving the (n+1)phases model of Hervé and Zaoui (for n=2) were carried out by developing a program in complex numbers computed with *Mathcad-Plus* package. It occurs that the calculated results obtained for high volumic fraction of the spherical inclusions (above 20%) show a difference which can be very important with experimental data. There is two reasons for explaining this difference. (i) the first is the dependence on temperature of two matrix properties[5]: Poisson's ratio and shear modulus. For glassy polymers such as epoxy, Poisson's ratio does not equal 0.5 but only 0.32, while above *Tg* it increase towards 0.5 (rubbery behaviour). The magnitude of the ratio G'_f/G'_m increases slowly with temperature in the transition region since the temperature dependence of G'_f and G'_m are not equal, and the ratio increases markedly in the region of the main mechanical relaxation, (ii) the second is the material morphology or phase arrangement or the heterogeneity in the inclusions dispersion at the mesoscopic scale[6]. The microscopic photos show that we spheres i.e. the agglomeration of the inclusions. For fitting the calculated results with the experimental data, two parameters have to be considered: (i) the Poisson's coefficient is not constant from glassy to rubbery state[7], (ii) the morphology of the material is important and it must be considered also. So we have considered the model of Figure 1 which corresponds to polymeric matrix reinforced by spherical inclusions being themselves composite with a volume fraction of glass spheres higher than the global one, thus we have made the analysis in two steps: In the first step, we have calculated the dynamic mechanical properties of the *highly reinforced zones* and, in the second step, we have calculated again the self-consistent model with three phases whose the inclusion is the highly reinforced composite. Thus we have chosen the *highly reinforced zones(hrz)* as a composite with higher volume fraction of glass beads($\phi_{hrz} > \phi_f$), and we have solved the problem in two steps by repeating the self-consistent model. In the first step the dynamic mechanical properties of the highly reinforced composite with three phases: (i) the glass bead spherical inclusion with a volume fraction higher than the global value, (ii) a shell of matrix polymeric material, and, (iii) an outer region of equivalent homogeneous material, was calculated and in the second step we have calculated the properties of the equivalent homogeneous media or actual composite that the three phases are: (i) the highly reinforced composite embedded as spherical inclusion (a new inclusion phase) having the properties calculated in the first step, (ii) a shell of matrix, and, (iii) the outer region of equivalent homogeneous material of unlimited extent. The figure 2 shows the calculated results, if we consider that the Poisson's coefficient of the matrix is variable between 0.32 and 0.49, and by given the real morphology of the composite. The value of ϕ_{hrz} is important and it must be considered correctly by measuring the volume fraction of glass beads in the highly reinforced composite. The final calculated results for a composite 30%, by giving ϕ_{hrz}=51% are shown in the figure 2, thus the theoretical curves satisfactorily fit experimental data. An examination of the Kerner's solution[8] reveals it to be brief and sketchy and usually serves as a lower bound. The present results are compared with the results from other related models such as Kerner's model. The calculated results shows that we can not to have satisfying results by using the Kerner's model, in the transition domain and in the rubbery state of the composite.

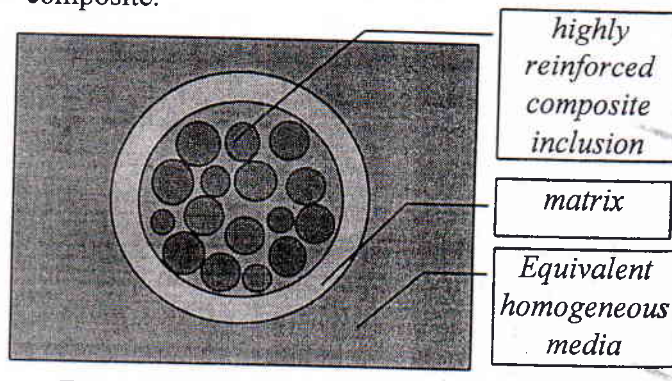

Figure 1: Three phases model of solution by two steps calculation

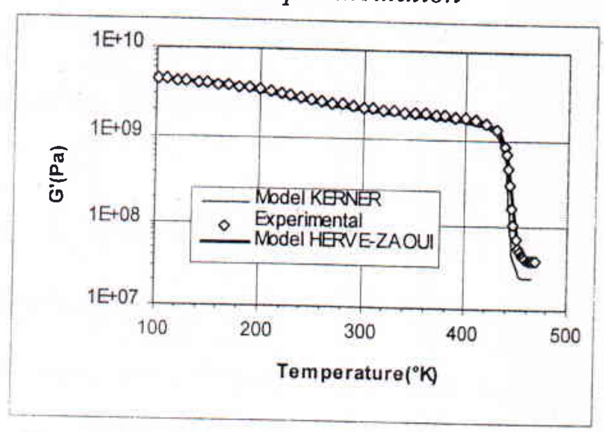

Figure 2: The calculated results(2 steps, ν=variable and ϕ_{hrz}=51%) in comparison with experimental data for the composite 30%.

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