ICCE/8

EIGHTH ANNUAL INTERNATIONAL CONFERENCE ON COMPOSITES ENGINEERING

Edited by
David Hui

International Community for Composites Engineering · ICCE ·

August 5-11, 2001
Tenerife, Canary Islands, Spain

sponsored and Organized by
International Community for Composites Engineering and College of Engineering, University of New Orleans

ZONES UNDER HIGH STRESSES: BASIS OF MODELING THE PLASTIC STRAIN BEHAVIOUR OF FILLED POLYMERS

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Extended Abstract: Particulate composite are generally used as model systems (1) for studying the mechanical behavior of composites in which the filler has a more complex geometry. The developments of micro mechanical 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 behavior of two phases matrix-inclusion composites, Christensen-Lo, Hervé-Zaoui and Shaterzadeh have proposed *Generalized Self-Consistent Schemes* (*GSCS*) from the micro to macro scale (2- 6).

Analysis and modeling of the plastic behaviour of the composites: ***Going from the viscoelasticity to plasticity (Incremental law):*** The self-consistent models have presented are valuable for prediction of the composite dynamic moduli in the viscoelastic region (linear deformation) (2-6), but they are not sufficient for describing the plastic strain behaviour. In this work, we try to develop a method to model the plastic behaviour of the particulate composites based on a polymer matrix by using the self-consistent model. The incremental method for calculation allows us to describe the way to go from viscoelastic to plastic behaviour.

Methodology for calculation: This method consists in:

i) Dividing the compression curve of the matrix by *"n"* increment *(Figure 1)*, that in each increment, we suppose the part of the compression curve is linear and the tangent gives an apparent modulus of material (E).

ii) In calculating the composite modulus by using the self-consistent model (3) in each increment by equation 1:

where A, B, and C are constants and E_m is the Young modulus of matrix.

iii) In calculating the composite strain in each increment:

$$\sigma_{cj} = E_{cj}(\varepsilon_j - \varepsilon_{j-1}) \qquad \textit{(Equation 2)}$$

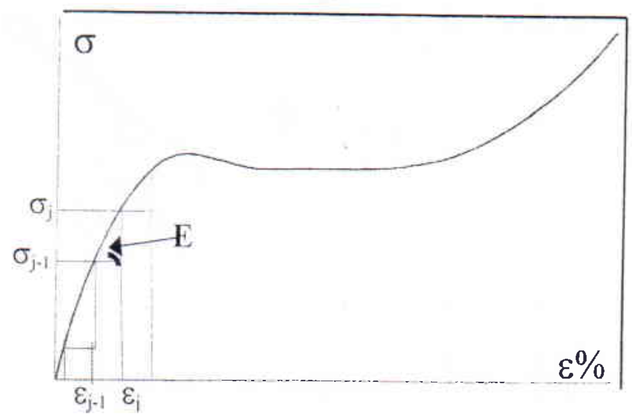

Figure 1 : *Incremental law*

iv) Making the theoretical stress-strain curve of the composite by using the sum of the stress in each point $\sum_{1}^{j}\sigma_{cj}$, *(Figure 2)*.

$$\sigma_{cj} = \sigma_{c1} + \sigma_{c2} + \sigma_{c3} + \dots + \sigma_{cj} \qquad \textit{(Equation 3)}$$

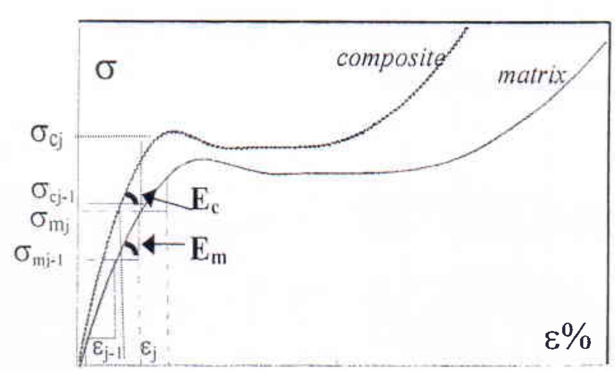

Figure 2 : *Composite curve scheme*

Using the self-consistent model by considering

i) Spherical inclusion,
ii) Matrix,
iii) Equivalent homogeneous media.

As it can be noticed in *Figure 3*, the calculated results do not agree with the experimental data.

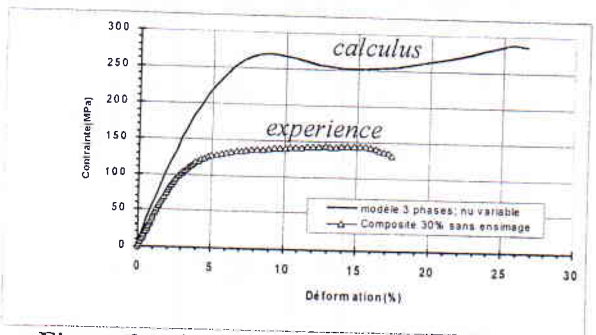

Figure 3: *Three phases model comparison*

Existence of highly stressed zones of matrix: For understanding the reasons of the disagreement between experimental and calculated data, we observed by optical transmission microscopy under polarized light, that the plastic deformation of the composites is more homogeneous than the matrix alone. So we considered the zones where the stress concentration (or higher deformation) can be very important parameter to describe plastic strain behaviour. As consequence, we considered an additional *phase* i.e. zone with a higher stress more than the average value. The composite behaviour was calculated by using a self-consistent model with four phases (instead of three phases):

- First phase: *spherical inclusion,*
- Second phase: *high stress zone of matrix,*
- Third phase: *normal matrix,*
- Forth phase: *equivalent homogeneous media.*

Here we need to know two parameters in the second phase:

i) what is the stress concentration ratio, k, i.e. the ratio between the average stress and the real stress in confined zones?

ii) what is the volume of this additional phase?

The response of the first question concerns the stress concentration around an inclusion in a heterogeneous material *(Figure 4)*.

The local stress around the spherical inclusion was calculated by using the Eshelby's method (7). The stress concentration ratio (k) depends on the distance between the inclusions (or volume fraction of particles):

$$i = d\left(\frac{\pi}{6\phi_p}\right)^{1/3} \qquad \textit{(Equation 4)}$$

with:

i: distance inter-particle (center to center)

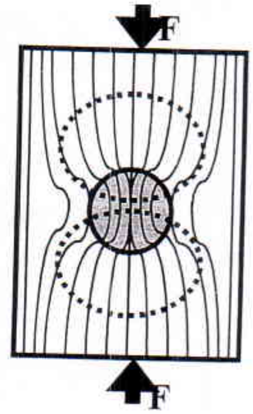

Figure 4: *Local stress around the inclusion*

By using the Eshelby's equation, the values of "*k*" (stress concentration ratio) for different volume fraction of particles are:

Volume fraction (%)	*k*
10%	*1.8*
20%	*2.1*
30%	*2.6*
50%	*3.3*

The results of the calculation for each type of composite were in a very good agreement with experimental stress-strain curve *(Figure 5)*.

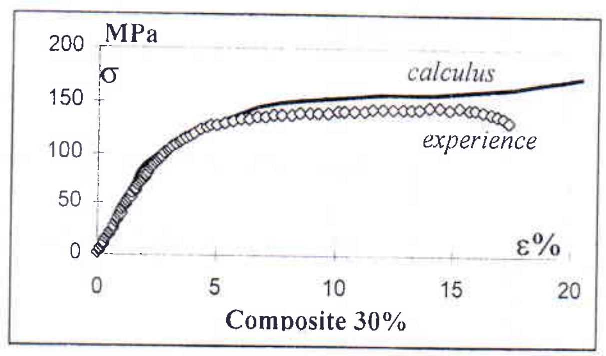

Figure 5: *Four phases model comparison*

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