Stochastic Modelling of Progressive Damage in Polymer Concrete Composites

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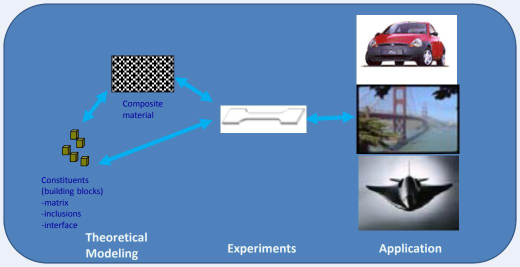
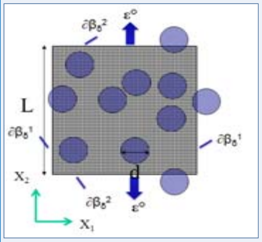
Multiscale Modelling

Fracture and effective stress-strain graphs in two-dimensional random composites subjected to a uni-axial in-plane uniform strain are characterized. The inclusions are arranged randomly in the matrix. Both inclusions and matrix are isotropic and elastic-brittle. We conduct this analysis numerically using a very fine two-dimensional triangular spring network and simulate the crack initiation and propagation by sequentially removing of the bonds, which exceed a local fracture criterion. We consider several "windows of observation" (scales) and study crack patterns, types of constitutive responses, and statistics of the corresponding scale dependent effective elastic stiffness and strength of such composites.

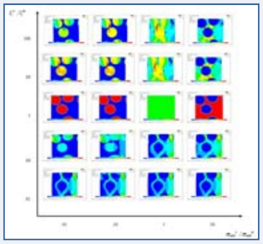
Problem:



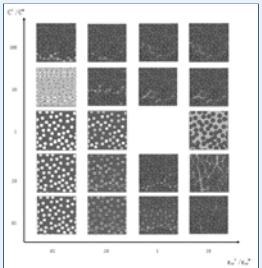
Approach:



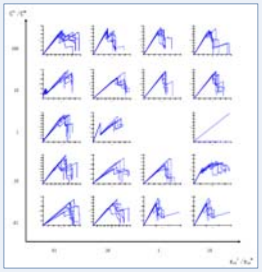
δ=L/d



Stress Contours for δ=2.5



Damage map for case of δ=10



Effective of Stress-Strain for multiple realization using δ=2.5

Fracture Simulation

Input :

1.Modulus Of Inclusions C^i

2.Modulus Of Matrix C^m

3.Strength of Inclusions ε^i

4.Strength of Matrix ε^m

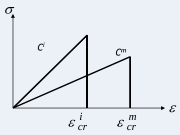
5. Diameter of Inclusions

6. Minimum Separation Distance

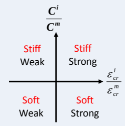
7.Mesh size

8. Volume Fractions

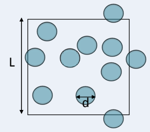
9.Interface Condition.



Linear Elastic Brittle Materials



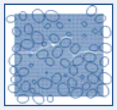
Contrast: Strength,& Stiffness



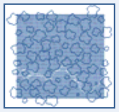
Window Scale δ=L/d

Output :

1. Randomness



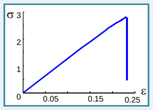
N_t=3



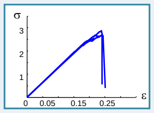
N_t=9

where N_t is the number of terms used in the Fourier series that approximate R(ϕ).

2. Stress Strain Diagram



Stress Strain Curve For a Single Geometry



Stress Strain Curves For Different Geometries

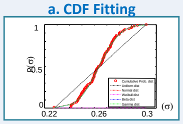
3. Crack Path

Crack Initiation

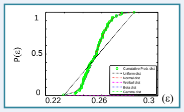
Crack Propagation

4.Statistics

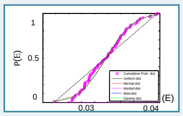
a. CDF Fitting



Max. Stress CDF

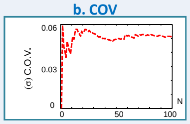


Max. Strain CDF

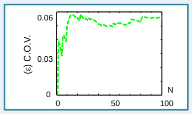


Max. Energy CDF

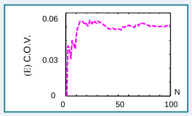
b. COV



Stress COV



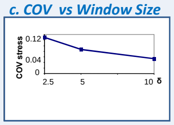
Strain COV



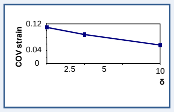
Energy COV

N: number of realization

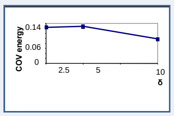
c. COV vs Window Size



Stress COV versus Size



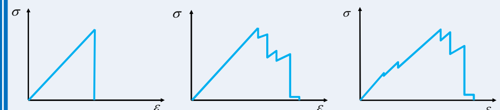
Strain COV versus Size



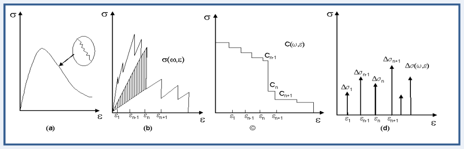
Energy COV versus size

Stochastic Modelling

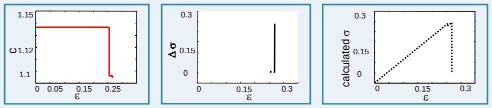
Stochastic Modeling: Stress Strain Response



Linear Elastic *Post Peak* *Pre- Peak*



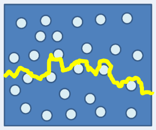
(a) Effective response in a macroscopic, deterministic continuum limit with local magnification showing an infinitesimal zigzag; (b) general zigzag realization of random process;(c) a corresponding realization the random process; and (d) a corresponding realization of the random process . Note that ε plays the role of a controllable, time-like parameter of stochastic processes.



$C(\omega,\varepsilon)$ $\Delta\sigma(\omega,\varepsilon)$ $\sigma(\omega,\varepsilon)$

Stochastic Modeling: Predicting Stress Strain Diagram

Stochastic Model : Predicting Crack Path



mean (ρ)		C^i/C^m 0.10	1.0	10.0
$\varepsilon^i/\varepsilon^m$	0.10	N.A.	0.004	0.001
	1.0	0.001	N.A.	0.334
	10.0	0.011	0.334	0.306

Specimen with a specific realization of fracture path

$$\rho(\gamma_{avg}) = \frac{1}{A}\exp[-\lambda_1.\gamma_{avg} - \lambda_2.\gamma_{avg}^2]$$

Conclusions:

- In this study, periodic boundary conditions were applied, and different window sizes were simulated for a range of elastic and strength parameters to study the joint effect of material, spatial disorder and size on strength and mode of failure of random composites.
- Spring network modeling of elastic brittle linear composites, is an effective rapid method that can be used to get composite stiffness, maximum stress, maximum strain, and stored elastic energy for range of properties and parameters. Such method, is effective to predict the material response according to geometry variation with less effort and less time. Using this approach there is no need for remeshing which is needed in any finite element method.
- statistical calculations took place on all stiffness and strength contrasts, for different window sizes, and different number of realizations.
- Normal distribution fitting was observed to be the best model to fit the entire range of parameters studied in this paper.

Acknowledgment

The authors wish to acknowledge the partial support for this research from U.S. Air Force Grant # F08637-03-C-6006 with a subcontract # S-29000.23 from Applied Research Associates Inc.