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Title: Joint DoD/DOE Munitions Program (JMP)
New results in Mesoscale Explosive Modeling

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Joint DoD/DOE Munitions Program (JMP)

New Results in Mesoscale Explosive Modeling

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Overview

- One considers the case of composite explosives: a random distribution of HMX grains of various sizes in a viscoelastic matrix (binder).
- The analysis is focused at the mesoscale level (RVE).
- A new procedure for pressure calculation in the case of explosives and propellants with examples.
- A Viscoelastic Damage Model and Failure Analysis (explicit cracks) for heterogeneous viscoelastic materials with application to DoD explosives and propellants.
- A new Two-Scale Finite Element Method (FEM) formulation for heterogeneous materials with applications to composite explosives.
- Future Work

Clements-Mas Homogenized Viscoelastic Model ("Dirty Binder"-DB Model)

•Clements and Mas (2004) proposed a homogenized model for heterogeneous viscoelastic composites.

$$\sigma(t)=\int_0^t K^*(t-\tau)\dot{\varepsilon}_V(\tau)d\tau+\int_0^t 2\mu^*(t-\tau)\dot{\varepsilon}_S(\tau)d\tau$$

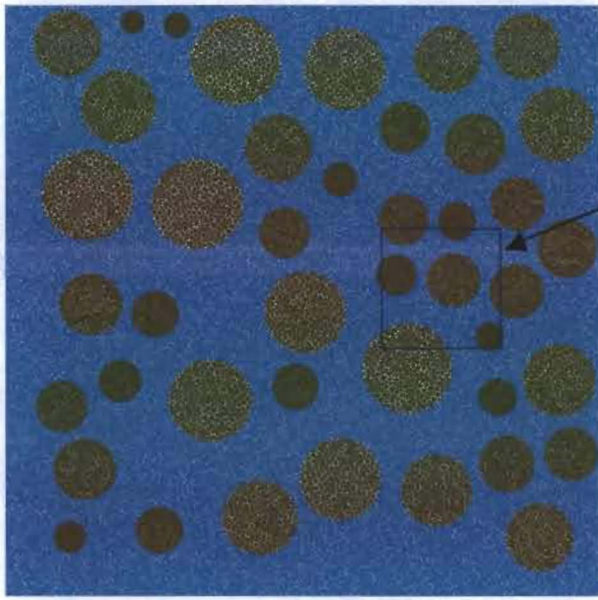
$$K^*(t)=K_0^*+\sum_{m=1}^{M}K_m^*e^{-t/\tau_m} \qquad \mu^*(t)=\mu_0^*+\sum_{m=1}^{M}\mu_m^*e^{-t/\tau_m}$$

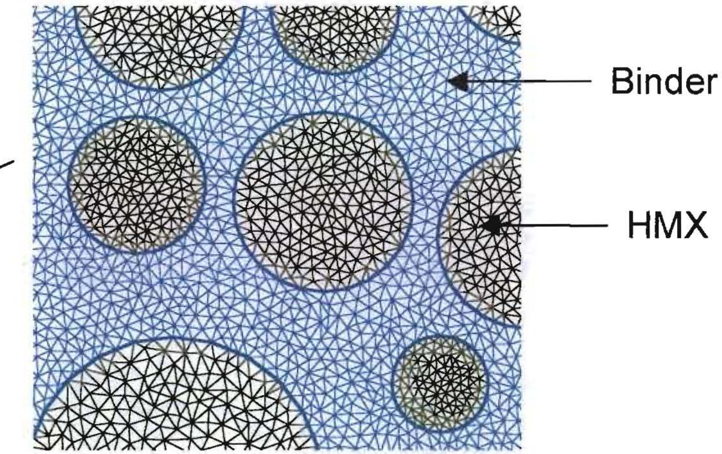
$$K_m^*=\begin{cases}\dfrac{K_BK_{HMX}}{c_{HMX}K_B+c_BK_{HMX}}, & m=0\\ \dfrac{4c_{HMX}c_B\left(K_{HMX}-K\right)^2}{3\left(c_{HMX}K_B+c_BK_{HMX}\right)^2}\mu_0^m(t), & m\neq 0\end{cases} \qquad \mu_m^*=\begin{cases}0, & m=0\\ \left(1+2.5\dfrac{c_{HMX}}{1-fc_{HMX}}\right)\mu_0^m & m\neq 0\end{cases}$$

•In using FEM a special attention needs to be taken in evaluating the pressure term.

Pressure calculation for the binder in a FEM Analysis

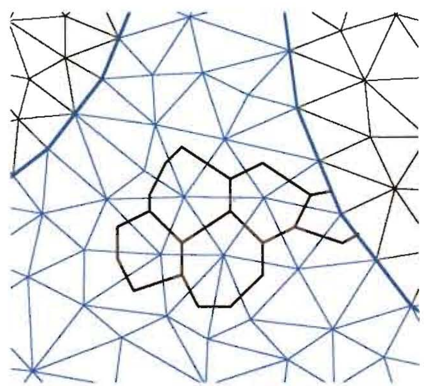
RVE=40% HMX+60% Binder





$$p^E = K\varepsilon_v^E$$

$$\varepsilon_v^E = \frac{V_t^E - V_0^E}{V_0^E}$$



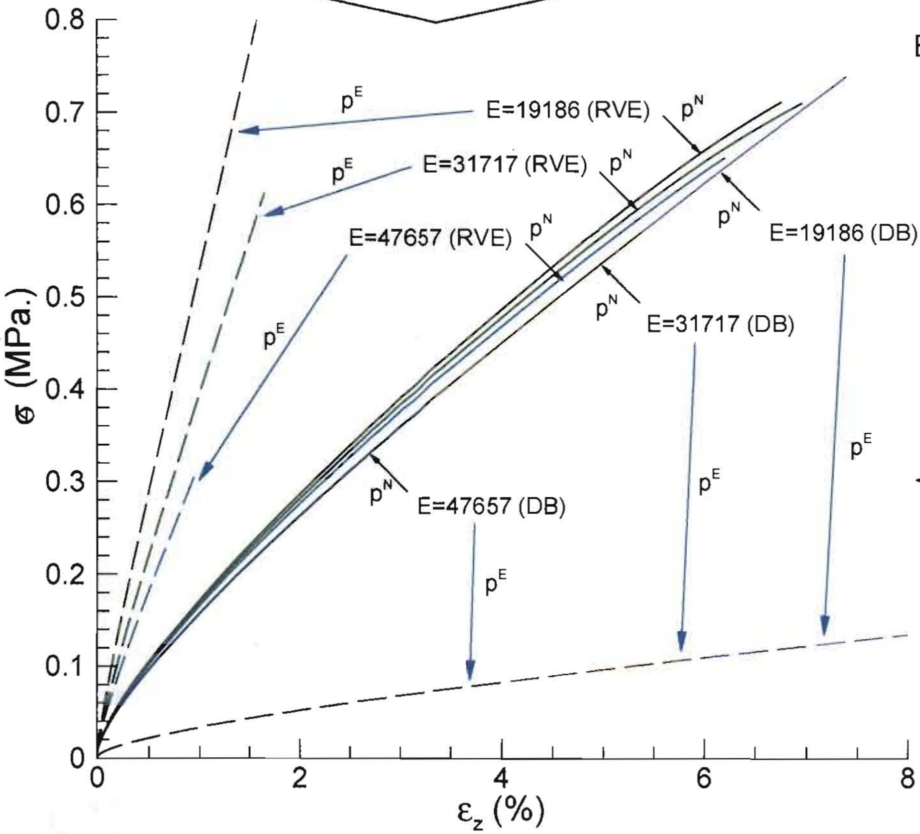
$$p^E = \sum_i \phi_i p^{N_i}$$

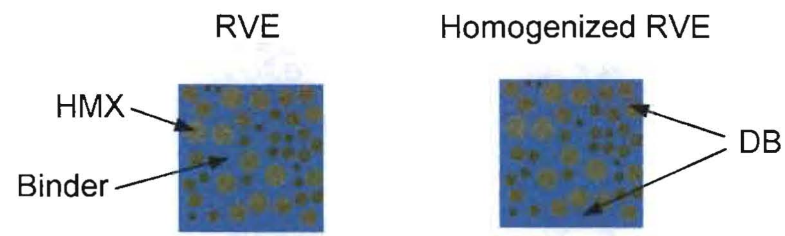
$$p^N = K\varepsilon_v^N$$

$$\varepsilon_v^N = \frac{V_t^N - V_0^N}{V_0^N}$$

Validation of the DB Clements-Mas model. Stress vs. strain in the loading direction.

Results for RVE (40%HMX+60%Binder) using two methods for calculating pressure: p^E and p^N





In the homogenized RVE for all elements was assigned the same material: a DB viscoelastic material with $c_{HMX}=0.4$, $c_B=0.6$ and $f=1$

Results for the homogenized RVE using two methods for calculating pressure: p^E and p^N

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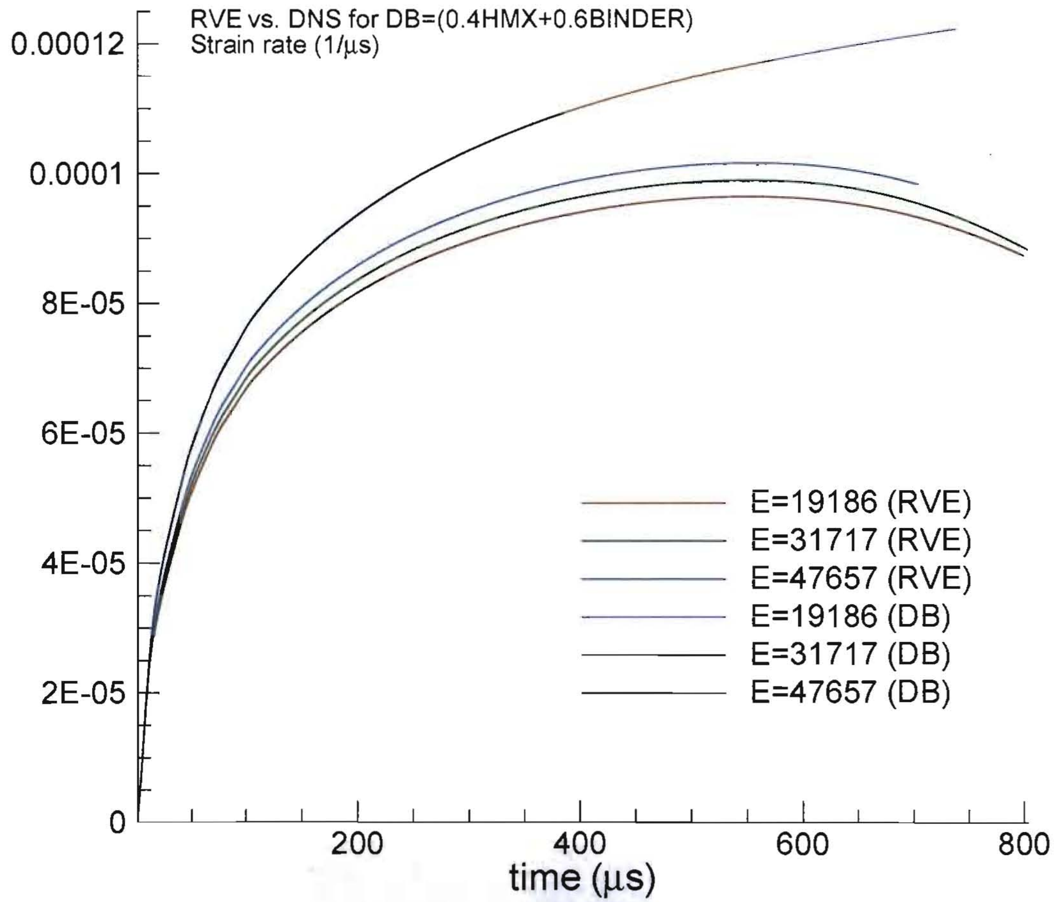
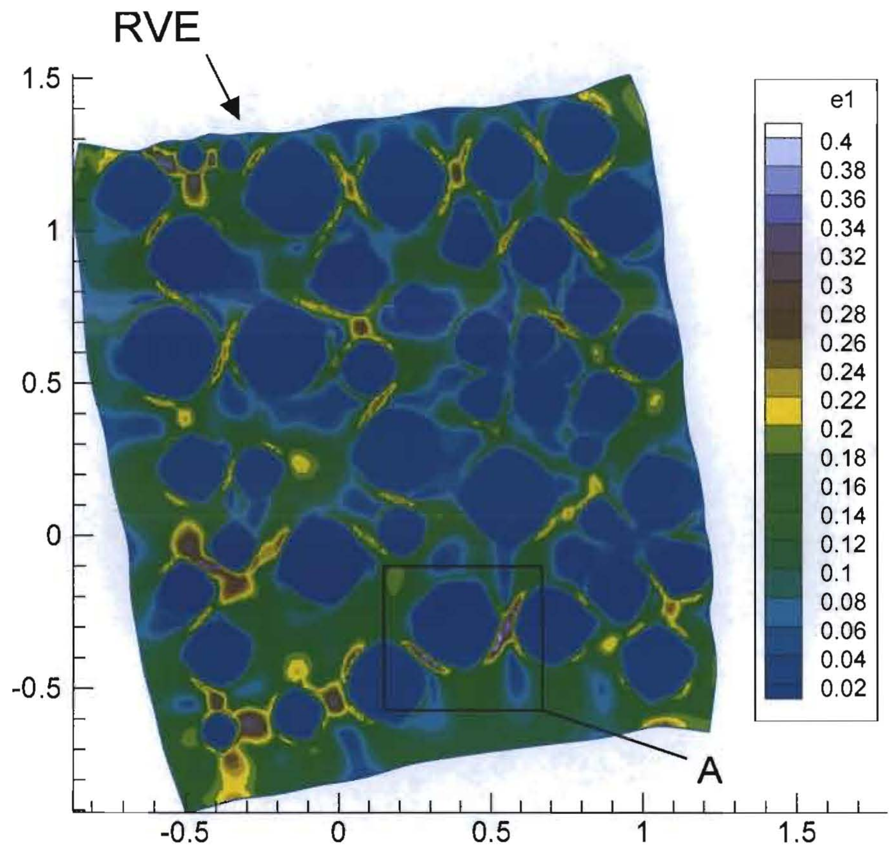
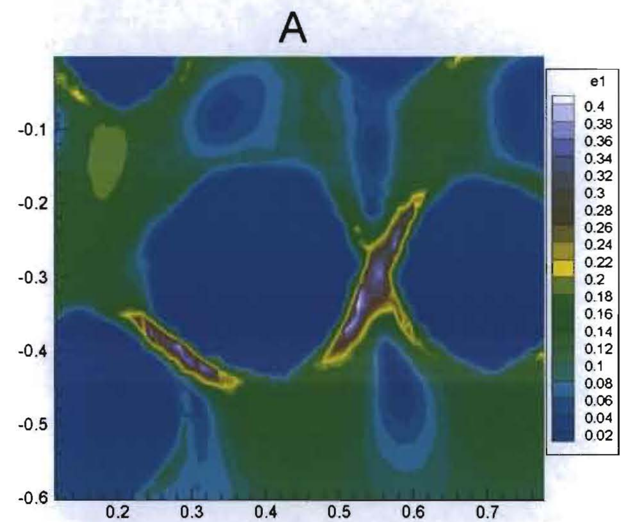
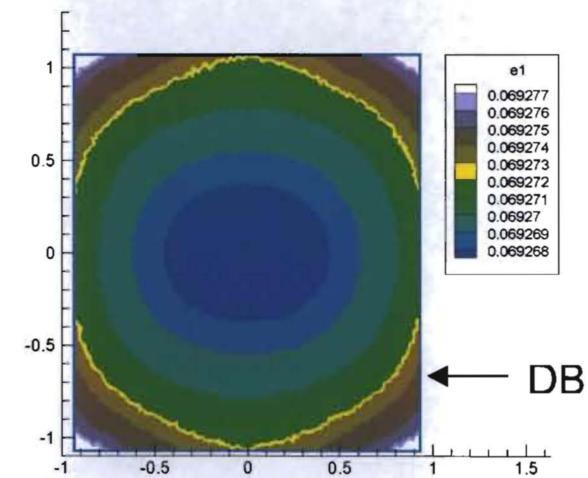
Validation of the DB Clements-Mas model. Strain rate vs. time.



Validation of the DB Clements-Mas model. Maximum Principal Strain.



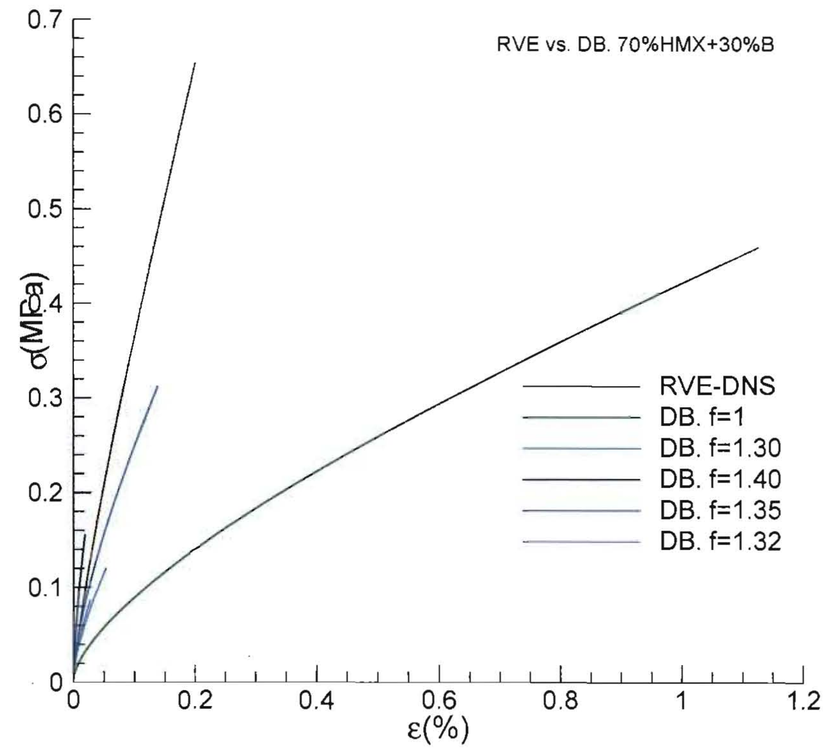




Validation of the Clements-Mas model.
Stress vs. strain in the loading direction for different values of *f*.

RVE=70%HMX+30%Binder

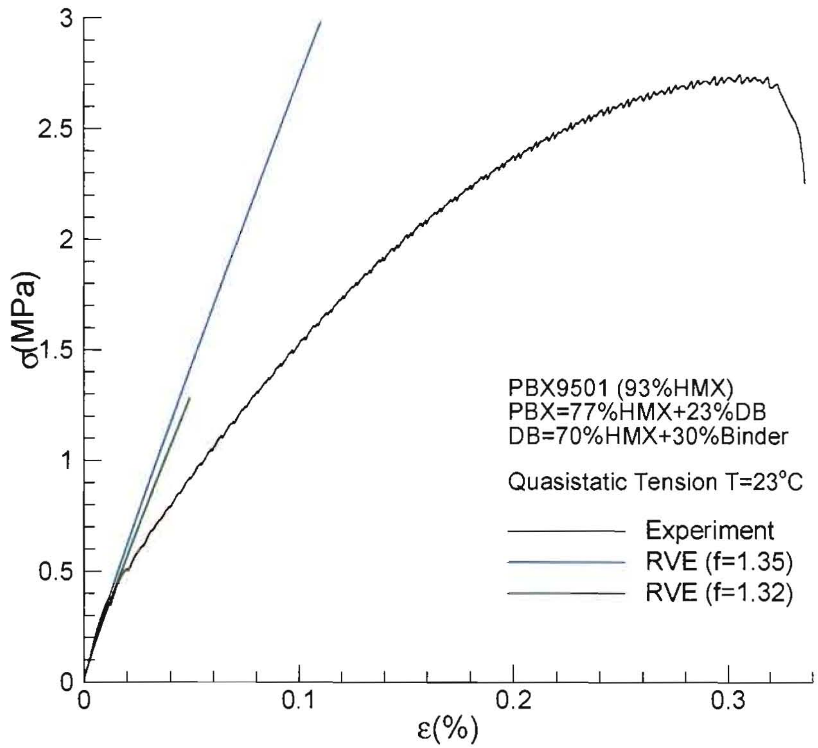
N=18288, E=35870



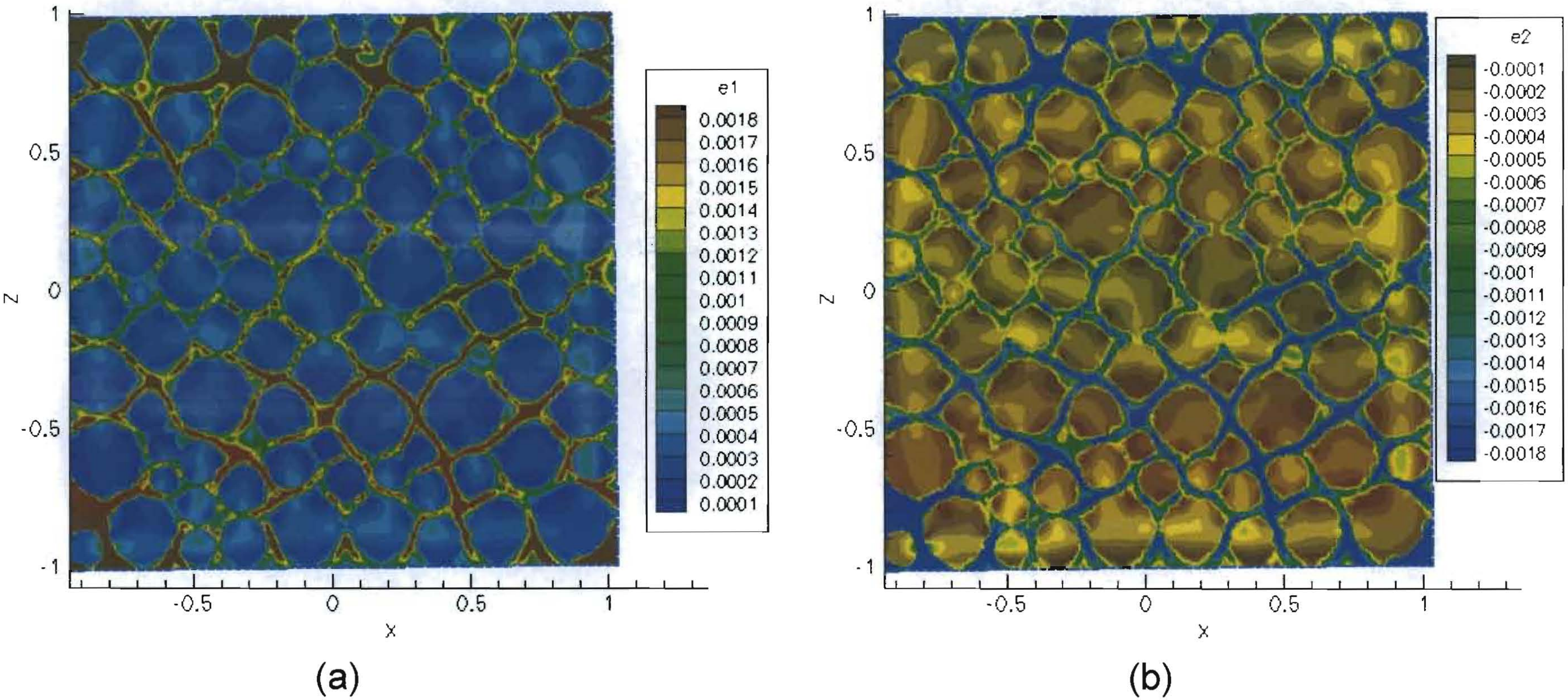
Application to PBX9501.
Stress vs. strain in the loading direction.

RVE for PBX9501 (77%HMX+23%DB)

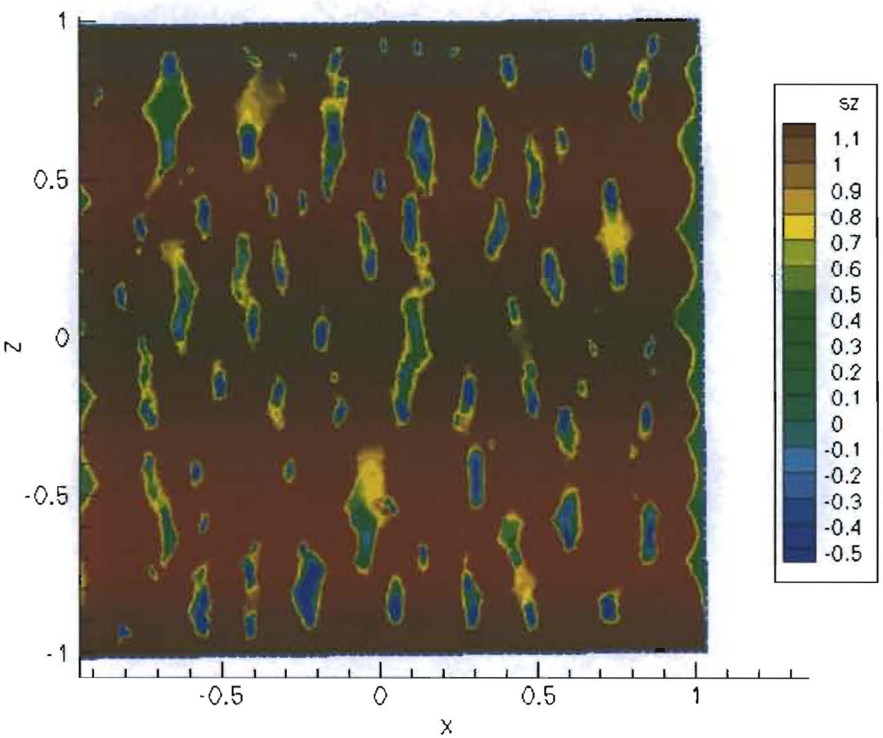
N=17223, E=34006 DB HMX



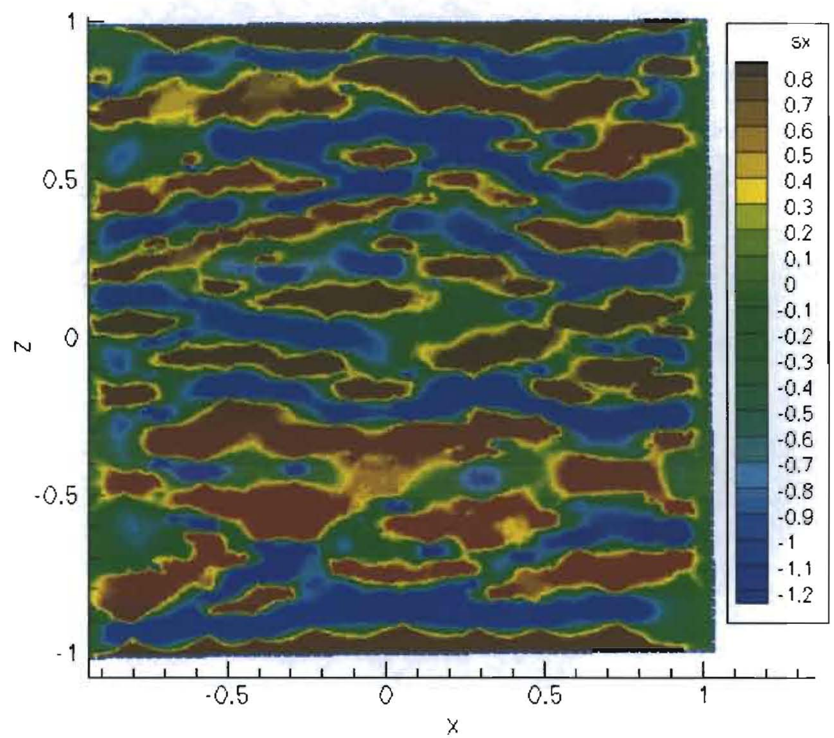
Application to PBX9501. Maximum (a) and minimum (b) principal strain.



Application to PBX9501.
Stresses (MPa) in the loading (a) and normal to the loading direction (b).

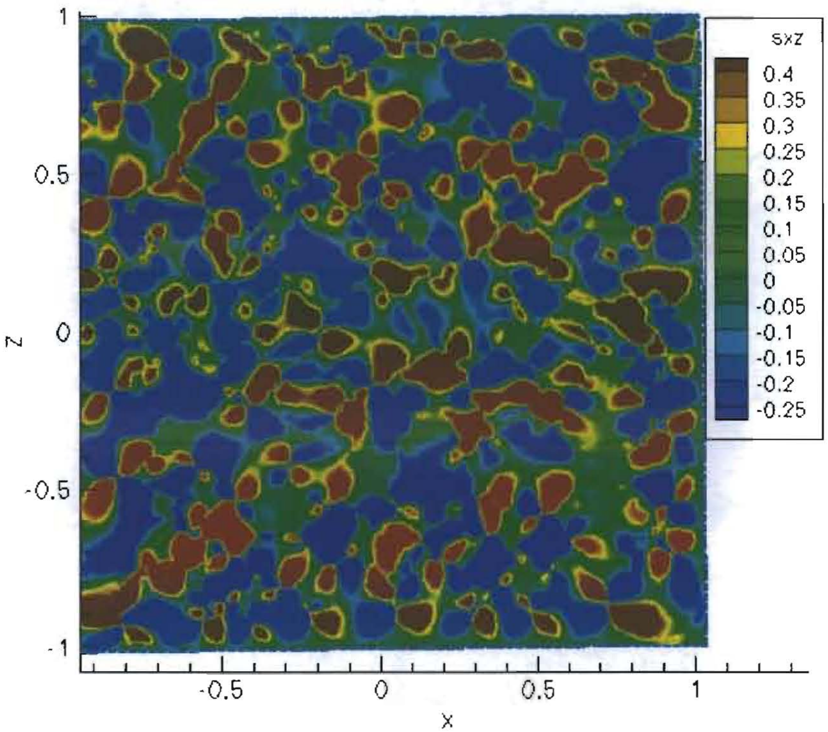


(a)

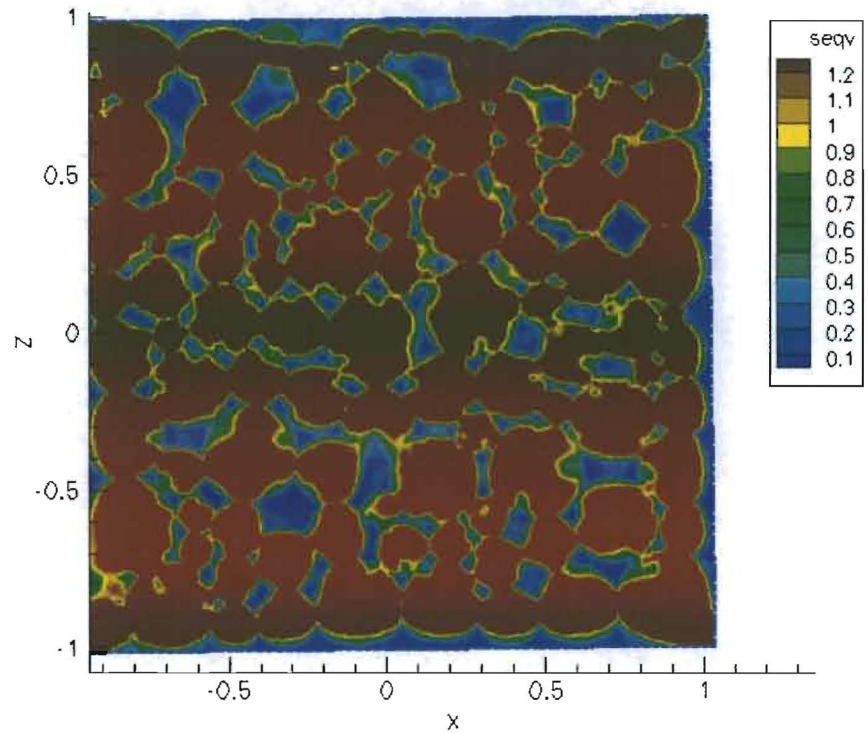


(b)

Application to PBX9501. Shear (a) and Von-Mises (b) stresses (MPa).



(a)



(b)

A Viscoelastic Damage Model with Failure for Explosives and Propellants

•We propose the extension of the Clements-Mas homogenized model with a viscoelastic damage model.

$$\sigma(t) = P_V(\omega_V)\int_0^t K^*(t-\tau)\frac{\partial}{\partial\tau}\left[P_V(\omega_V)\varepsilon_V(\tau)\right]d\tau + P_S(\omega_S)\int_0^t 2\mu^*(t-\tau)\frac{\partial}{\partial\tau}\left[P_S(\omega_S)\varepsilon_S(\tau)\right]d\tau$$

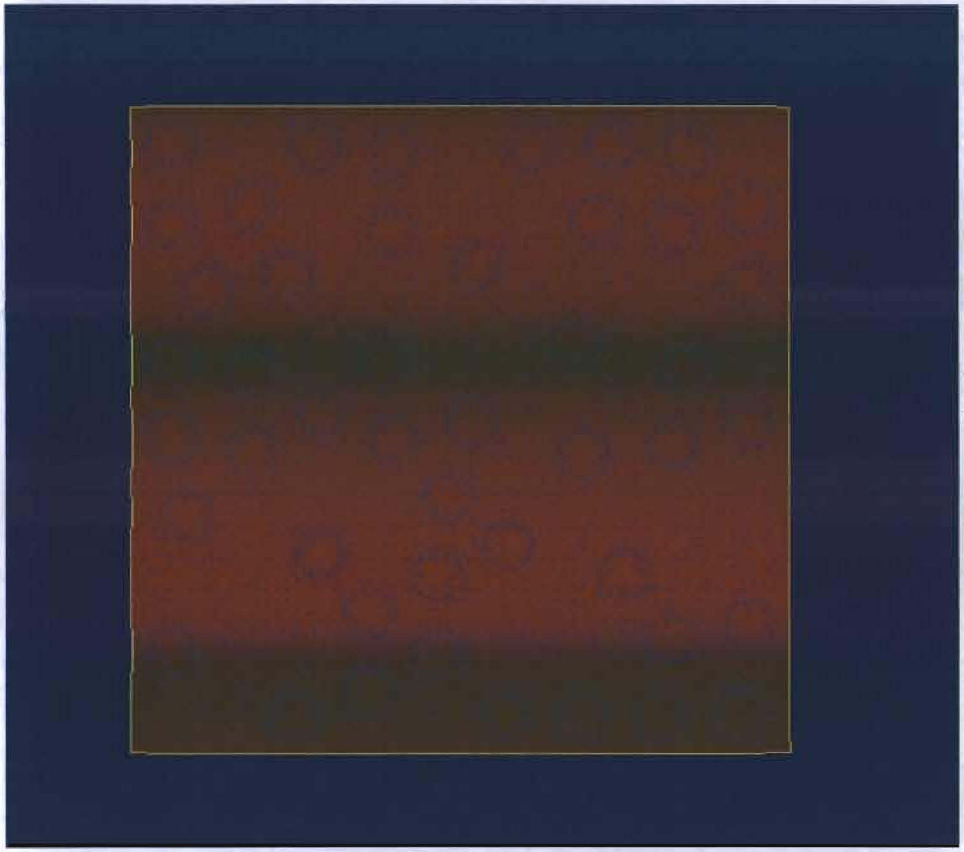
ω_V and ω_S are the volumetric and shear damage and $P_V(\omega_V)$ and $P_S(\omega_S)$ are the volumetric and shear damage tensors.

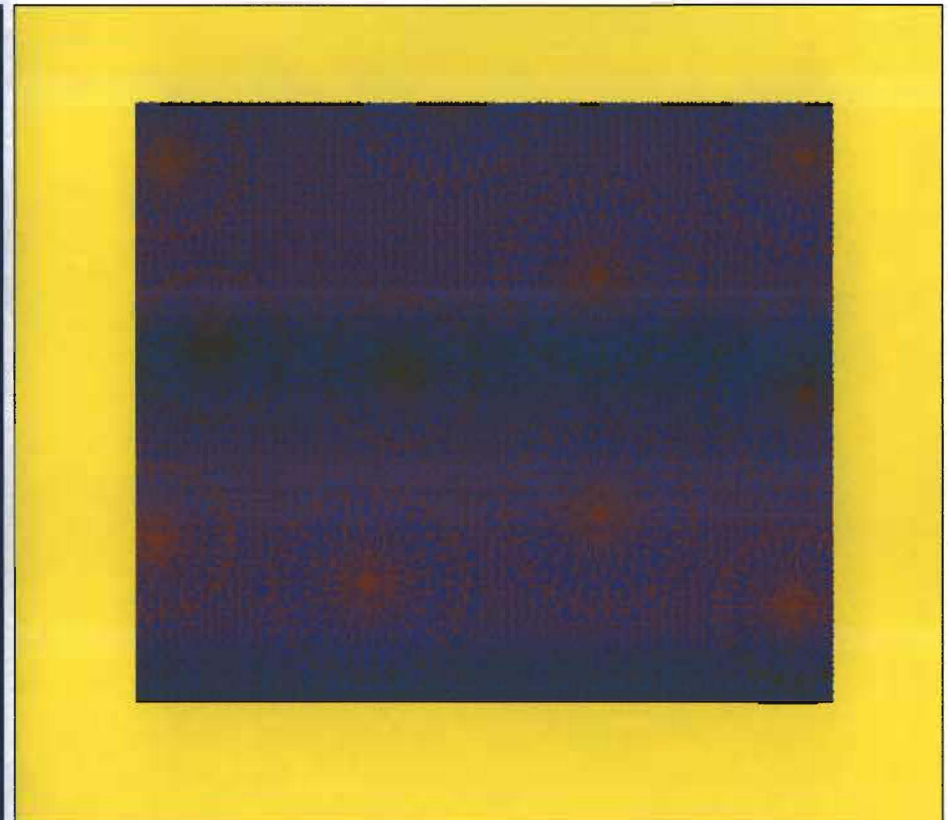
•The damage evolution is given by a damage evolution law

$$\dot{\omega}_V = \dot{\omega}_V(t,\omega_V,\ldots), \qquad \dot{\omega}_S = \dot{\omega}_S(t,\omega_S,\ldots)$$

•Introducing a local failure criterion together with damage evolution laws at the mesoscale level (RVE) and studying the global RVE response through various numerical simulations one can determine damage evolution laws at the engineering level.

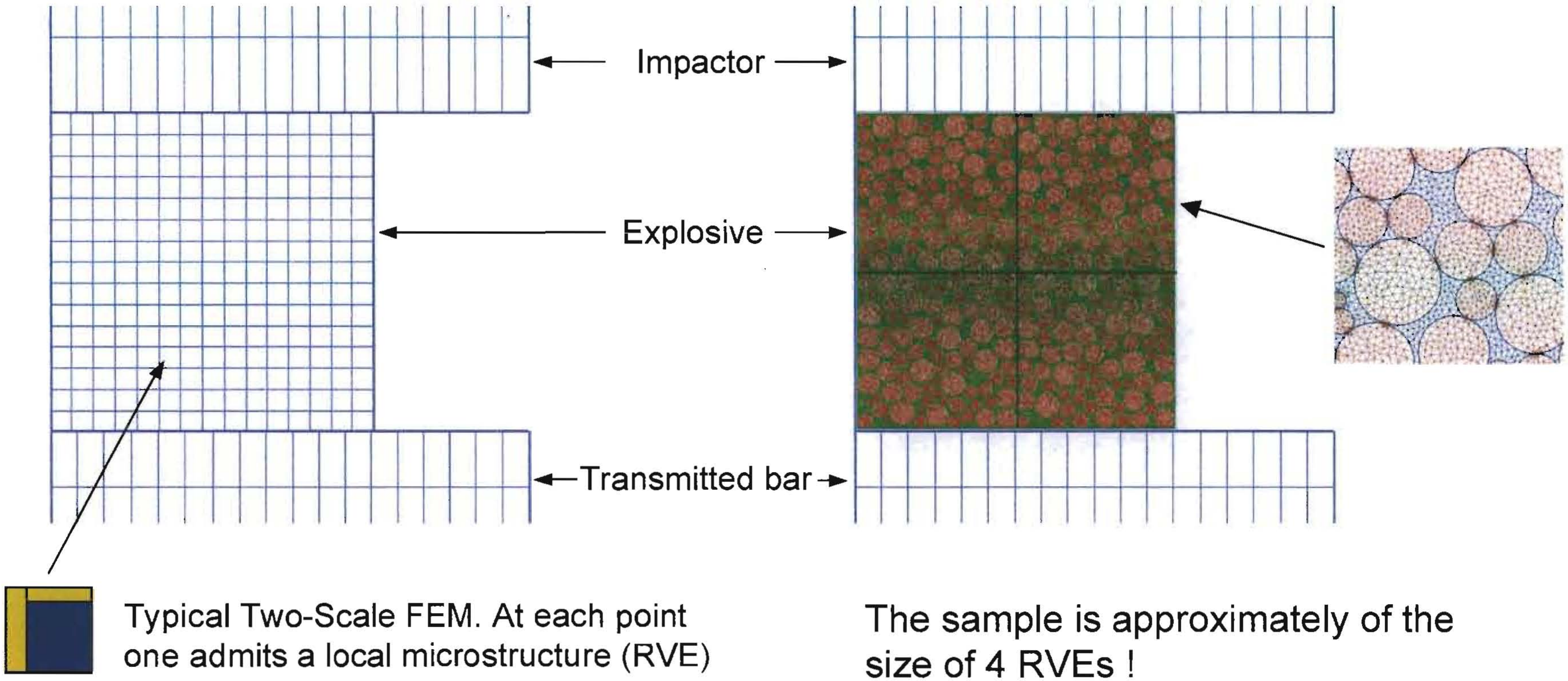
Example of a RVE analysis with failure. Explicit cracks formation.





Two-Scale FEM formulation for the Dynamic Analysis of Heterogeneous Materials (Composites explosives)

Example: Explosive sample in a Hopkinson-bar impact test.



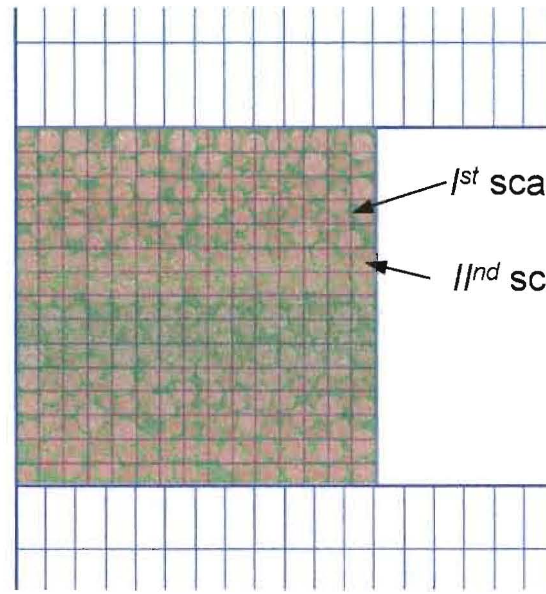
RVE

Typical Two-Scale FEM. At each point one admits a local microstructure (RVE) thus implying RVE << finite element

The sample is approximately of the size of 4 RVEs !

Two-Scale FEM formulation for the Dynamic Analysis of Heterogeneous Materials (Composites explosives)

- In the new Two scale FEM one employs two meshes: a “coarse” mesh (I^{st}-scale) and a “fine” mesh (II^{nd}-scale) for each element of the ”coarse” mesh.



- In this approach the dynamics is solved at I^{st}-scale while the II^{nd}-scale is used to determine the material response.

- The governing equations for the fluctuating field $\tilde{v}$

$$\mathrm{div}\left(\Lambda^{T} C \Lambda \nabla^{s} \tilde{v}\right) = -\mathrm{div}\left(\Lambda^{T} C \Lambda \nabla^{s} V\right) + \mathrm{div}\left(\Lambda^{T} C \dot{\varepsilon}^{a}\right)$$

with the constraint $\langle \rho \tilde{v} \rangle = 0$

- Currently the new Two-Scale FEM is implemented in EPIC.

Future Work

- Extension of Clements-Mas homogenized model with a viscoelastic damage model.
- Simulations of composite explosives with damage and failure (explicit cracks) at mesoscale (RVE) in order to identify a damage evolution law at the macro-scale.
- Application of the new Two-Scale FEM for composite explosives at engineering level.
- Application of all above to DoD explosives (PBXN-9) and propellants.
- Input for other models (for example Williams STFA model).