

# REPORT DOCUMENTATION PAGE

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# **Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.**



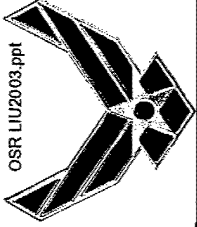
**AFOSR Program Review**

**8 Sept. 2003**

**C. T. Liu**

**AFRL/PRSM**

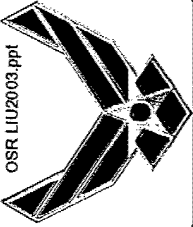
**Edwards AFB CA.**



# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



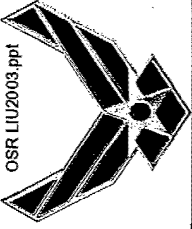
- **Objectives:**
  - Obtain a fundamental understanding of the tensile and fracture behavior of nano composite materials.
  - Develop a microstructure and statistical based technology to evaluate the inherent material quality.
- **State of the Art:**
  - Uniaxial tensile and combustion characteristics tests were conducted.
  - Fracture behavior not studied.
- **Approaches:**
  - Multi-scale experimental, analytical, and numerical modeling analyses
  - Damage mechanics, experimental mechanics, fracture mechanics, and statistical mechanics
- **Applications:**
  - Strategic and tactical missile systems.



# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



- **Past Year Accomplishments:**
  - Conducted strain measurements on two matrix materials (Solithane 113 and TPEG) and a composite material ( TPEG and 10% by weight of 6 micron AL particles).
  - Investigated the failure mechanisms in the three materials.
  - Investigated microstructural change and damage mechanisms in a solid propellant under incremental strain conditions.
  - Conducted computer simulation of damage initiation and evolution processes in a solid propellant.
- **Research Payoff:**
  - Provide a fundamental understanding of the role of nano size particles on the deformation and damage processes as well as crack growth behavior.
  - Provide guidance for developing high strength nano composite materials.
- **Related Research Program:**
  - SERDP Green Missile Program (P.I. Dr. T. Hawkins; AFRL/PRSP)



# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



## Uniqueness of Research:

- **Unique Material (dual function and highly filled multi-size particles material).**
- **Account for microstructural effect on tensile and crack growth behavior.**
- **Account for local time-dependent behavior in crack growth simulation.**
- **Multi-scale microstructure controlling factors for damage and crack growth.**
- **Bridge the gap between meso and macro analyses.**

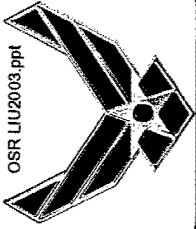


# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



## Success Story:

- There is no success story yet, because this four-year program just started in FY 03.

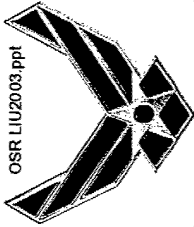


# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



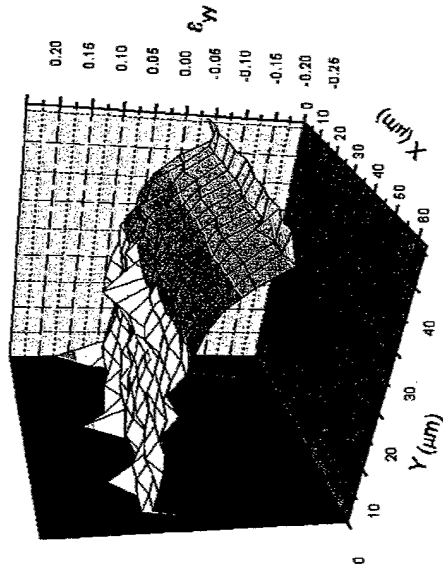
## Applications:

- The developed techniques can be used to formulating high performance solid propellants for future strategic and tactical missile systems.

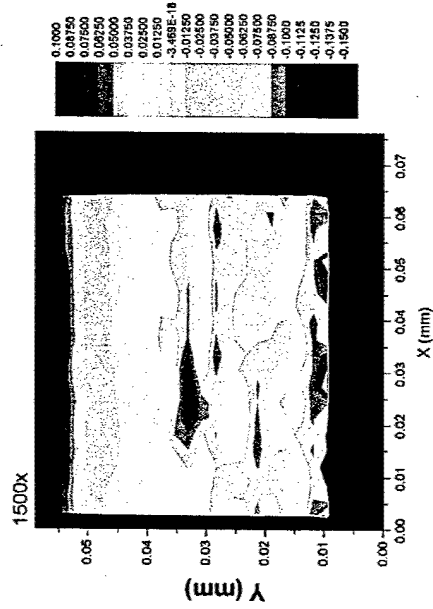


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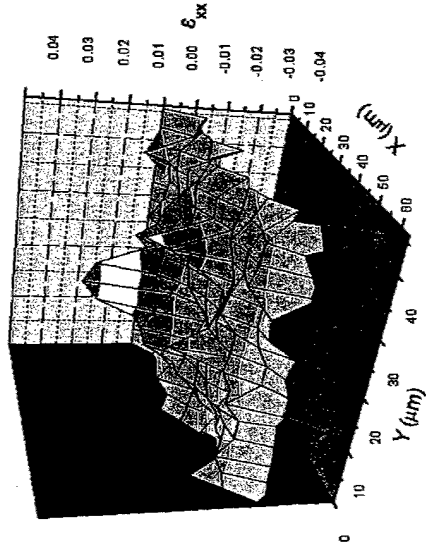
# Strain Distributions at 1500X (Solthane 113)



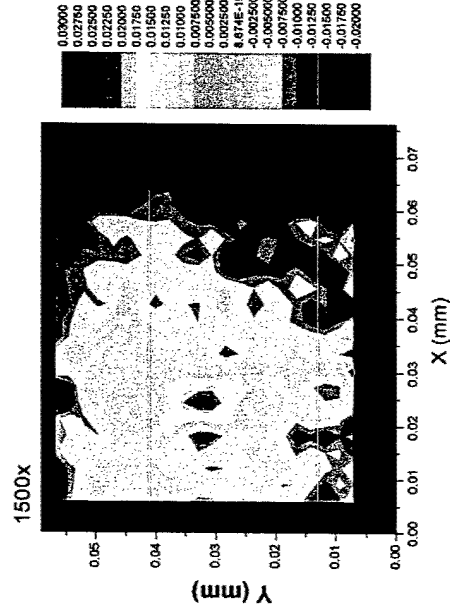
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$\epsilon_{yy}$  2-D



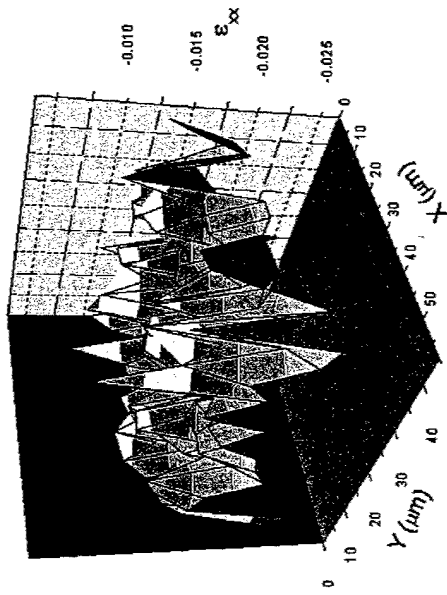
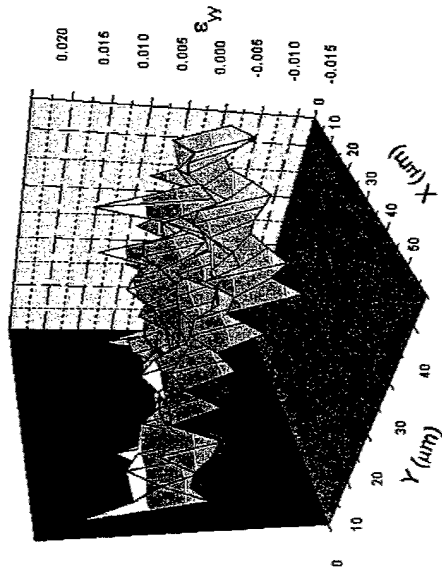
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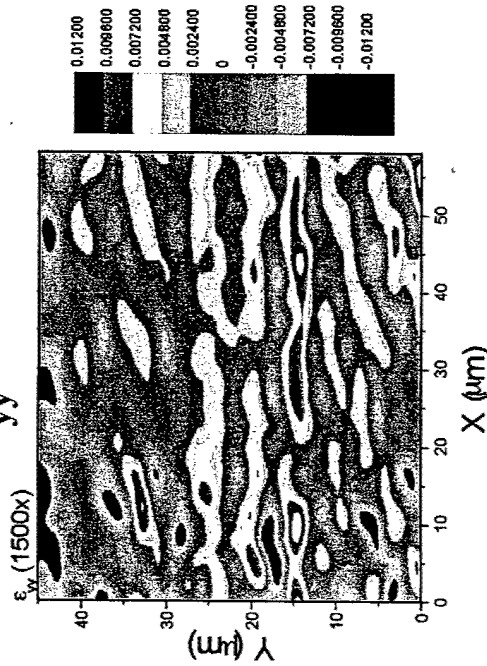
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# Strain Distributions at 1500X (TPEG)

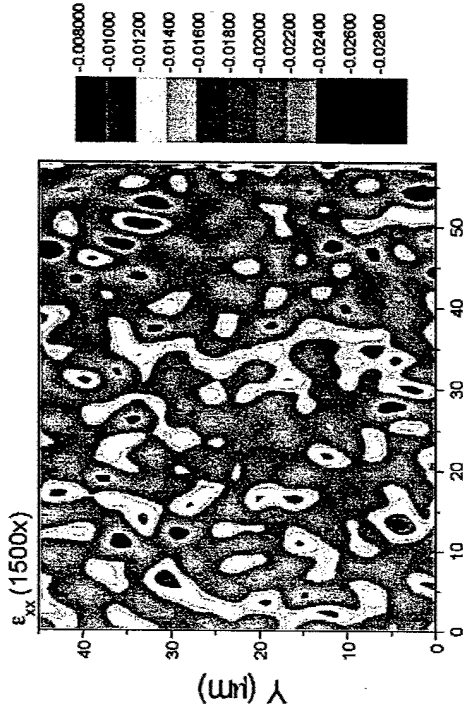


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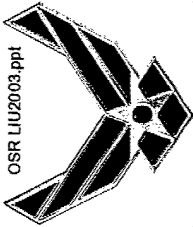


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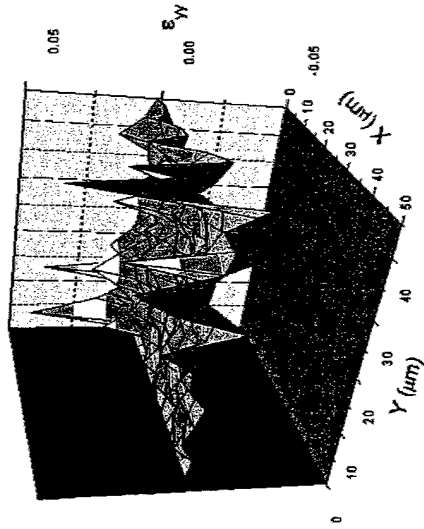
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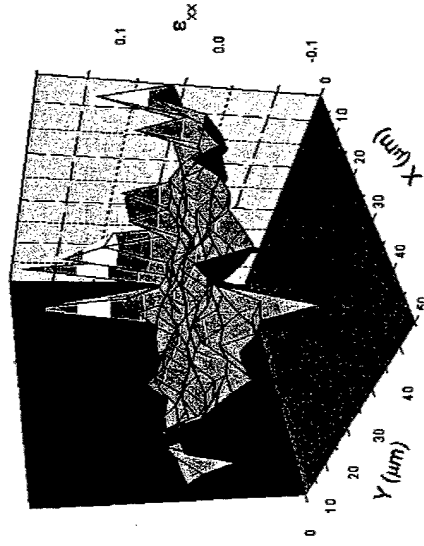
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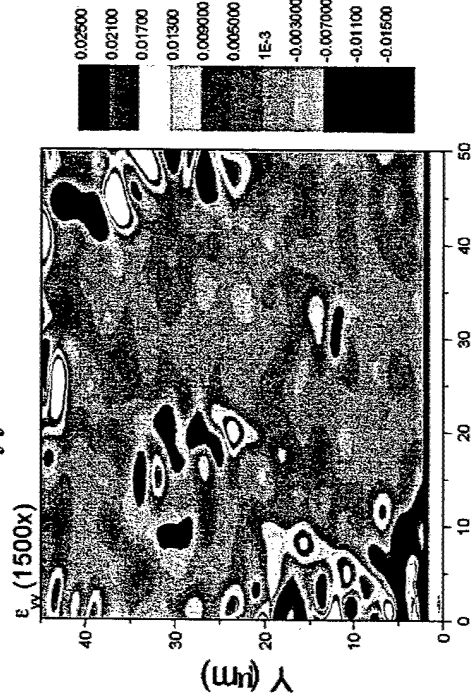
# Strain Distributions at 1500X (Composite Material)



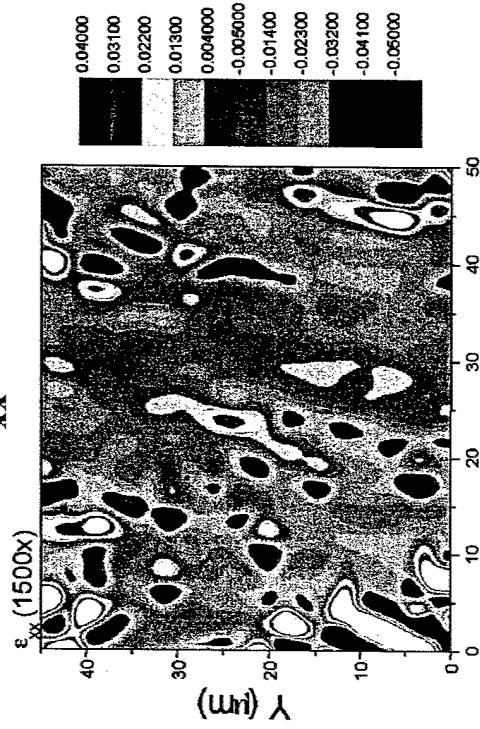
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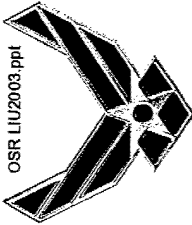
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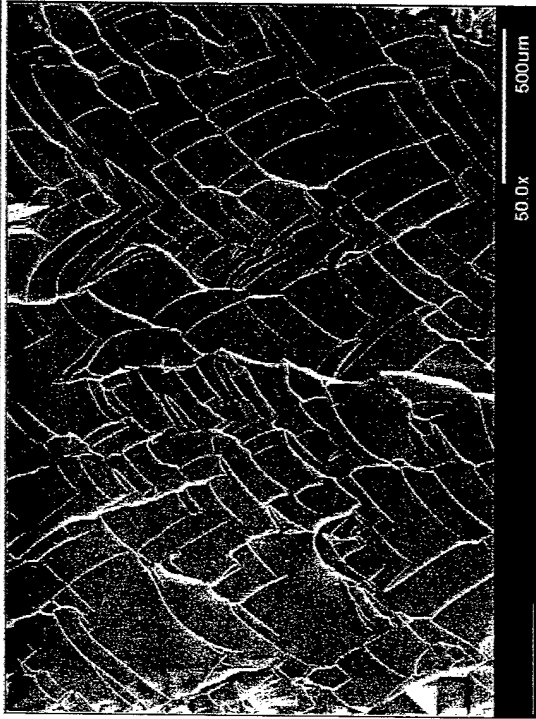


$\epsilon_{xx}$  2-D



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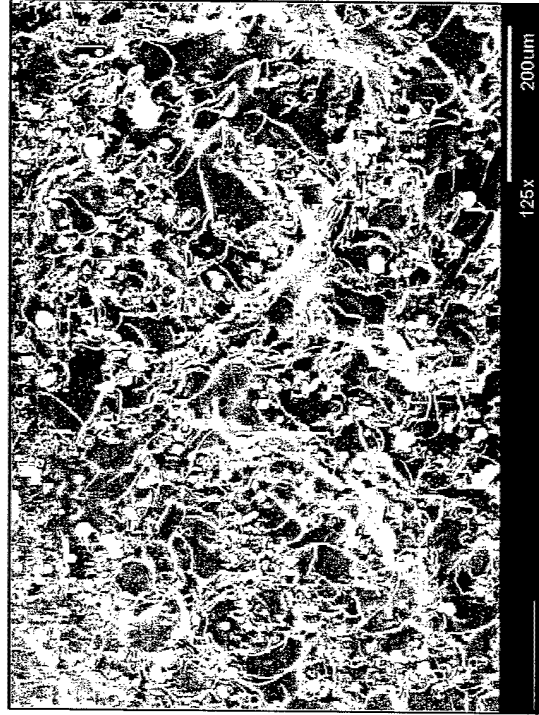
# Fracture Surfaces



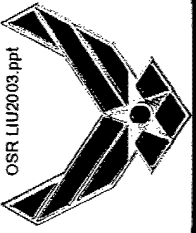
(Solithane 113)



(TPEG)

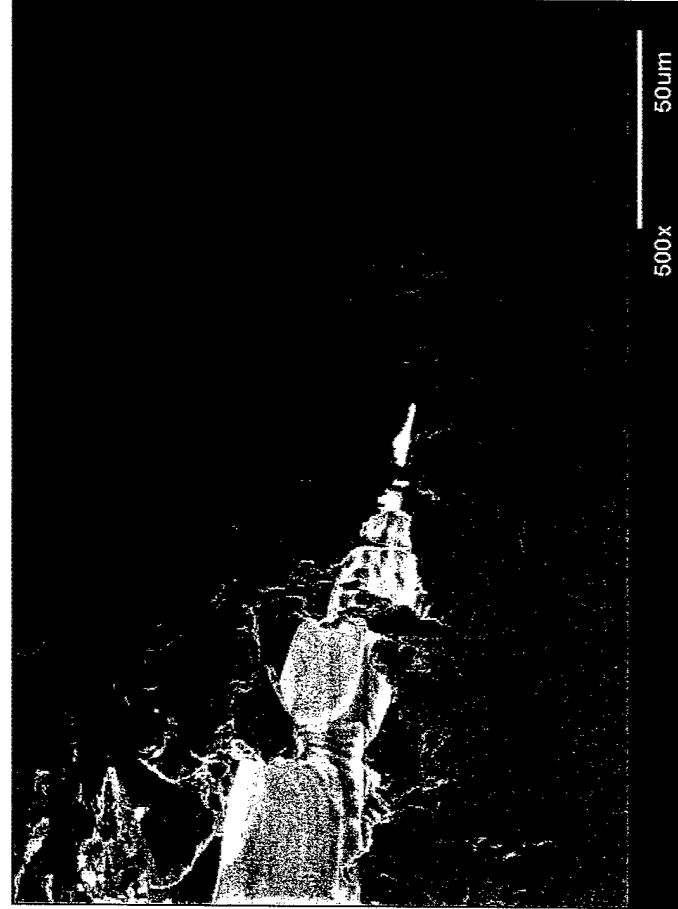
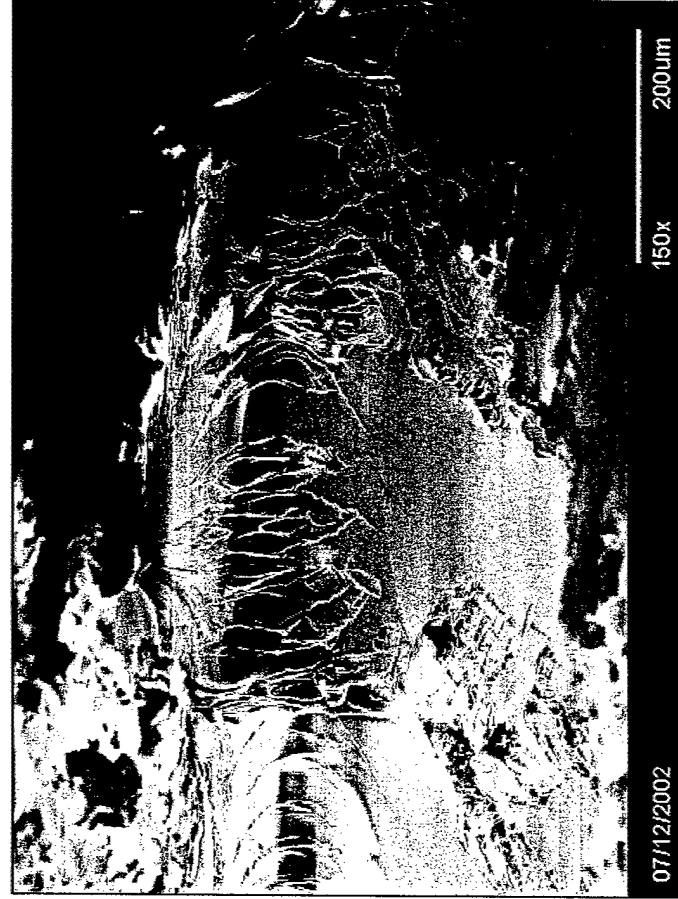


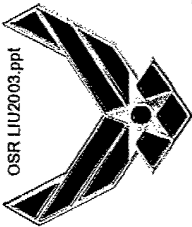
(Composite Material)



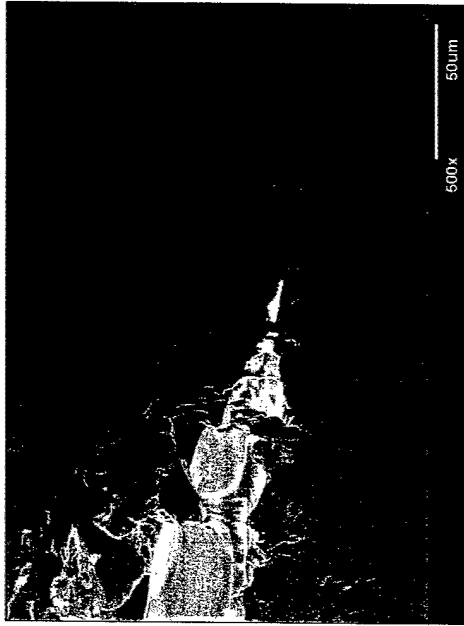
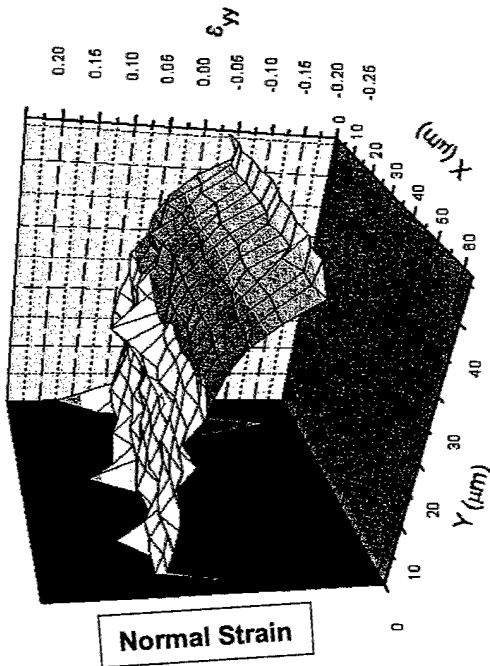
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# Local Deformation and Failure Mechanisms (Solithane 113)



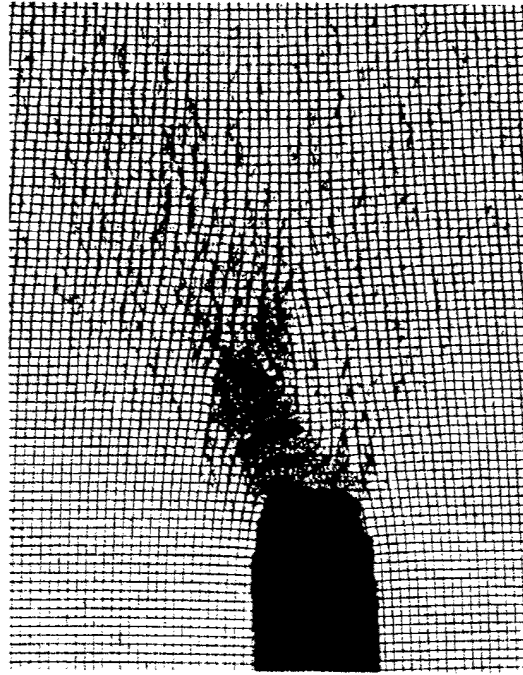
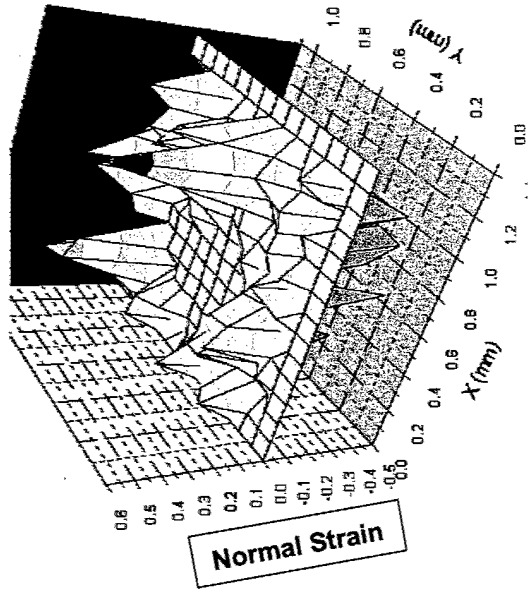


# Mechanisms and Strain Distribution (Solithane 113 and a Solid Propellant)



Solithane 113

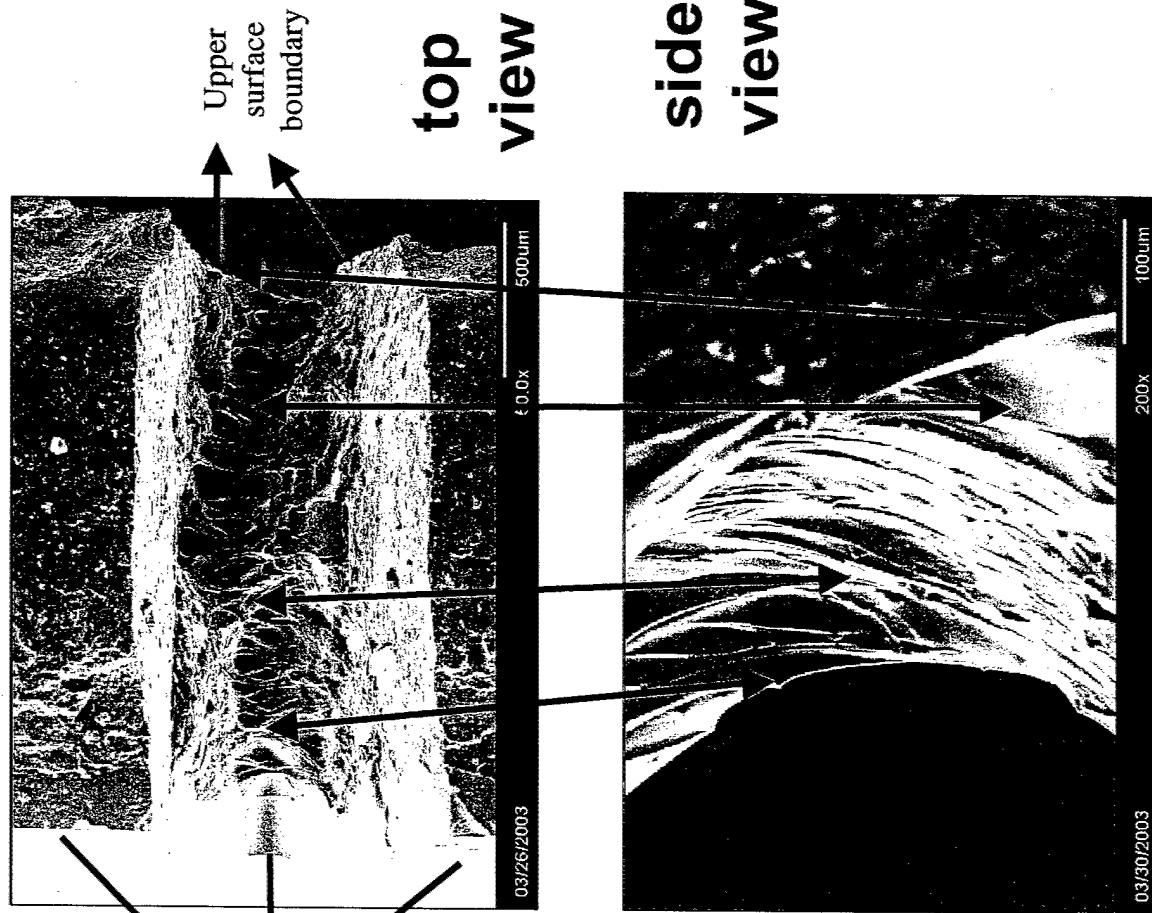
Solithane 113

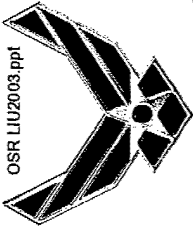


Solid Propellant

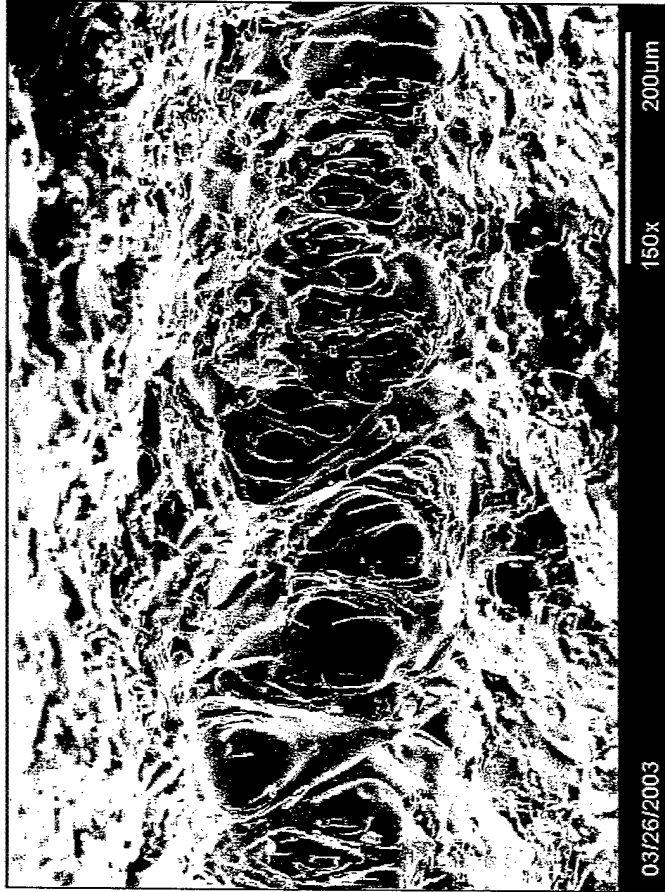
Solid Propellant

# Local Deformation and Failure Mechanisms at Crack Tip (TPEG)



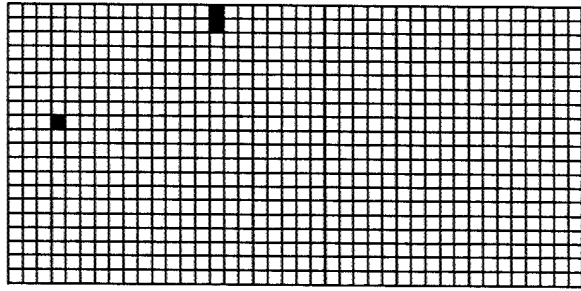


# Local Deformation and Failure Mechanisms at Crack Tip (Composite Material)

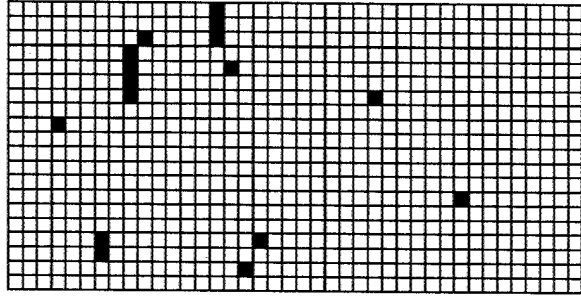




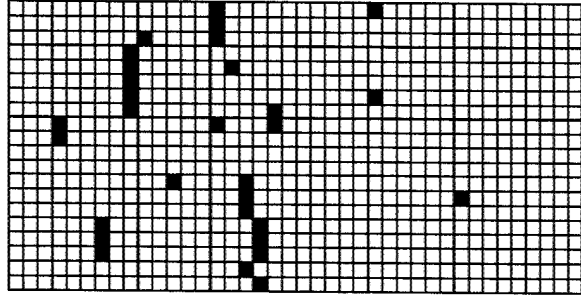
# Numerical Simulation on Damage Initiation and Evolution



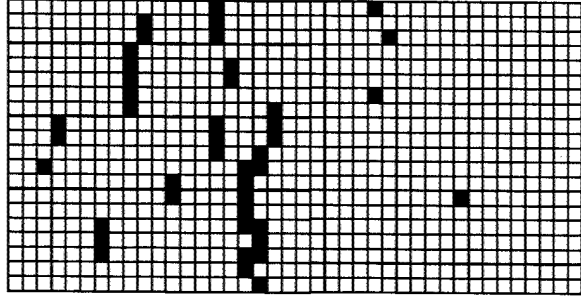
applied strain level  
0.109 [m/m]



applied strain level  
0.121 [m/m]



applied strain level  
0.128 [m/m]



applied strain level  
0.134 [m/m]

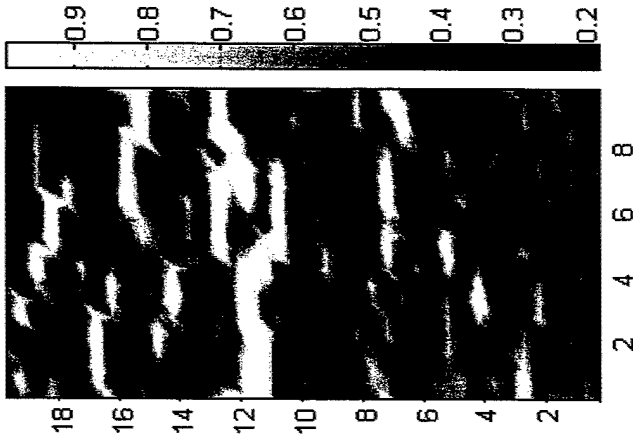
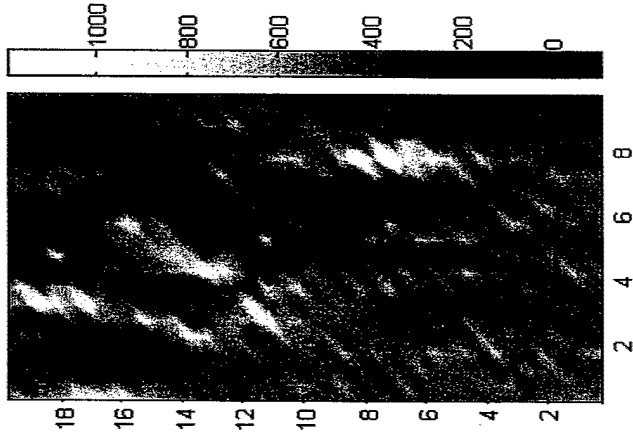
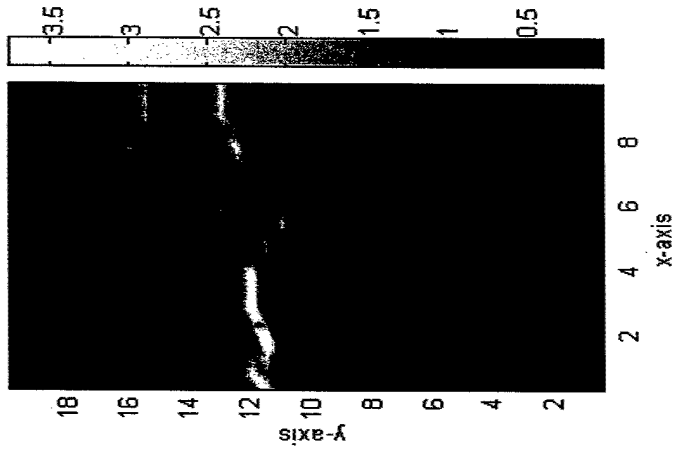
- Based on meso-macromechanical multi-level analyses, the simulated damage processes under a constant strain rate condition compares well with experimental observation.
- The coalescence of neighboring non-propagating crack results in breakage of the specimen.

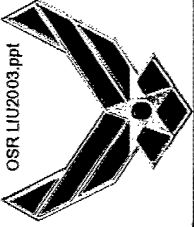




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# Distributions of Damage, Macro-Normal Strain and Macro-Normal Stress Prior to Specimen Fracture





# Multi-Scale Approach to Investigate the Tensile and Fracture Behavior of Nano Composite Materials.



## Conclusions:

- **Microstructure has a significant effect on the strain fields on the meso scale.**
- **The local deformation mechanisms (large displacement and ligament formation) near the crack tip for the three material studied are similar but the damage mechanisms are different.**
- **Base on the multi-scale analysis, the damage initiation and evolution processes compare well with experimental observation.**
- **Based on the multi-scale analysis, the damage distribution prior to specimen fracture is similar (different) to the macro strain distribution (macro stress distribution).**
- **The developed multi-scale analysis technique is a promising technique to model and simulate the microstructural effect on damage initiation and evolution processes in a solid propellant.**