DOE - Enhanced Geothermal Systems

Program Review

Experimental and Analytical Research on Fracture Processes in Rock

Herbert H. Einstein
Massachusetts Institute of Technology
Phone: 617-253-3598 Fax:617-253-6044

einstein@mit.edu

Project Objectives

Addresses GTP areas of interest

No. 3: Fracture Formation and Growth

and

No. 4: Fracture Evaluation

through

Laboratory experimental and analytical work to

- Understand fracture propagation and interaction
- Create basis for methods allowing one to indirectly infer fracture mechanisms in the field.

EGS Problem

Importance: Fracture processes are central to much of geothermal energy extraction

Technical issues: Propagation and coalescence of fractures are only partially understood, both under ambient temperature and under elevated (up to 150° C) temperature.

Addresses EGS Technical Challenge:

High-temperature rock usually is not extensively fractured.
Effective geothermal energy extraction requires fractured rocks.
The process of fracturing needs to be understood
(effect of lithology, stress conditions, temperature, etc.)

Project - Approach
Tasks

Task 1. Testing of different rock types and fracture geometries under different, mostly biaxial stress fields under ambient temperatures.

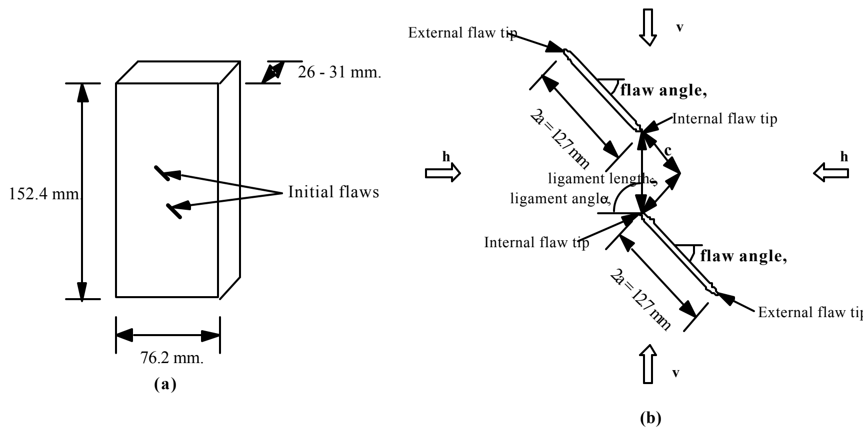
Task 2. Conducting experiments like Task 1 but at elevated temperatures.

Task 3. Extension of crack (fracture) initiation-, propagation- and coalescence criterion and incorporation in numerical models.

Task 4. Initial steps toward modelling larger/smaller scale fractures.

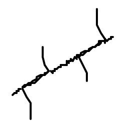
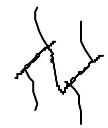
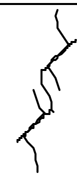
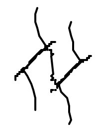
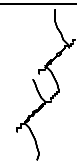
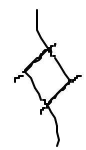
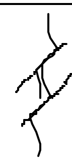
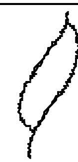
Task 5. Reporting and suggestions for further research.

Experimental Work



Geometries of (Model) Rock Specimens. (a) Overall View. (b) Detail

Experimental Work - Summary of Past Results

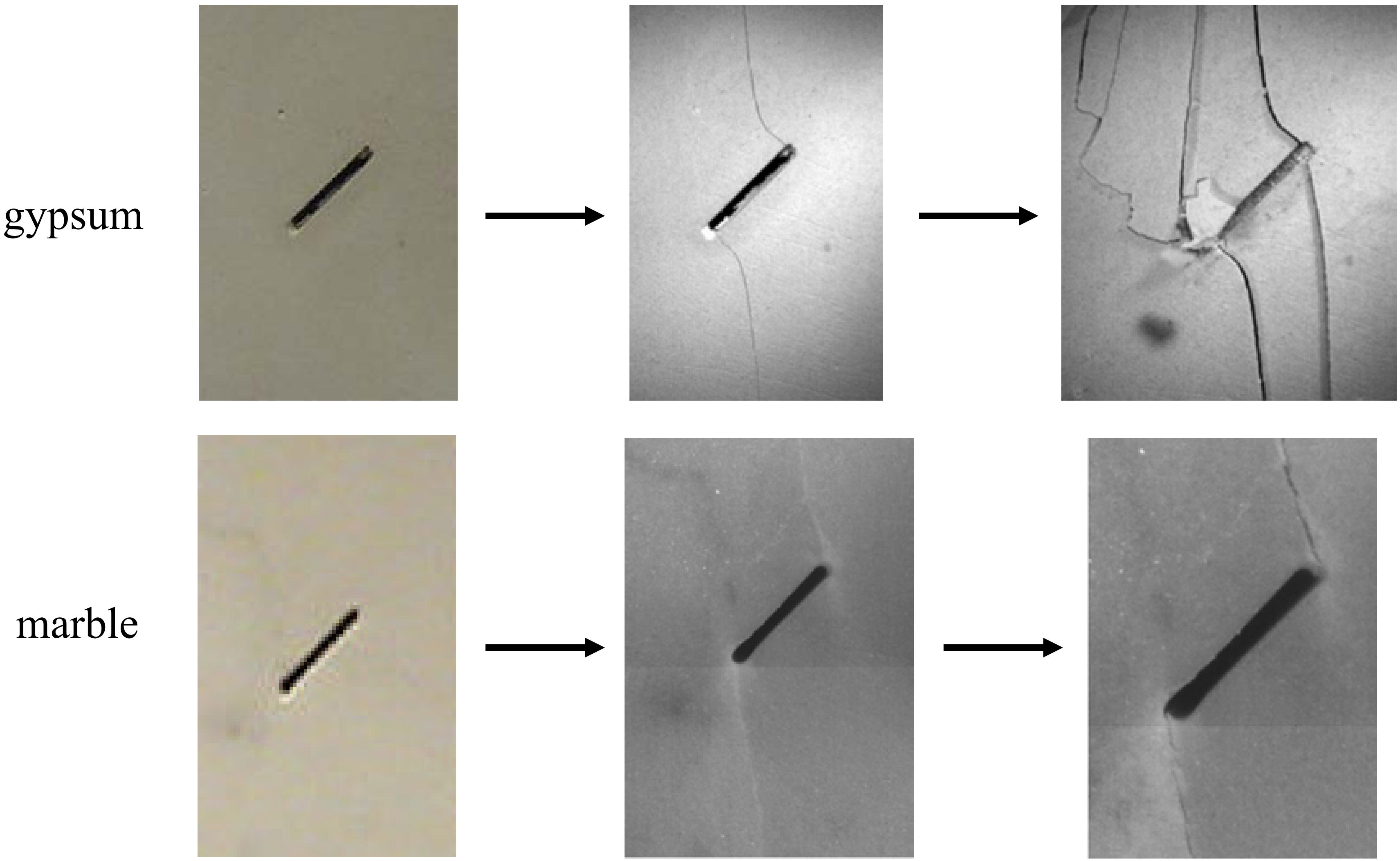
Type	Schematic path of Coalescence	Mode of Coalescence	Type	Schematic path of Coalescence	Mode of Coalescence
I		Shearing	V		Shearing + tension
II		Shearing + tension	VI		Shearing + tension
III		Shearing + tension	VII		Shearing + tension
IV		Tension	VIII		Shearing

Types of Coalescence Patterns in Uniaxial Compression

Based on Past Work

Experimental Work – Recent Results

Single Flaw

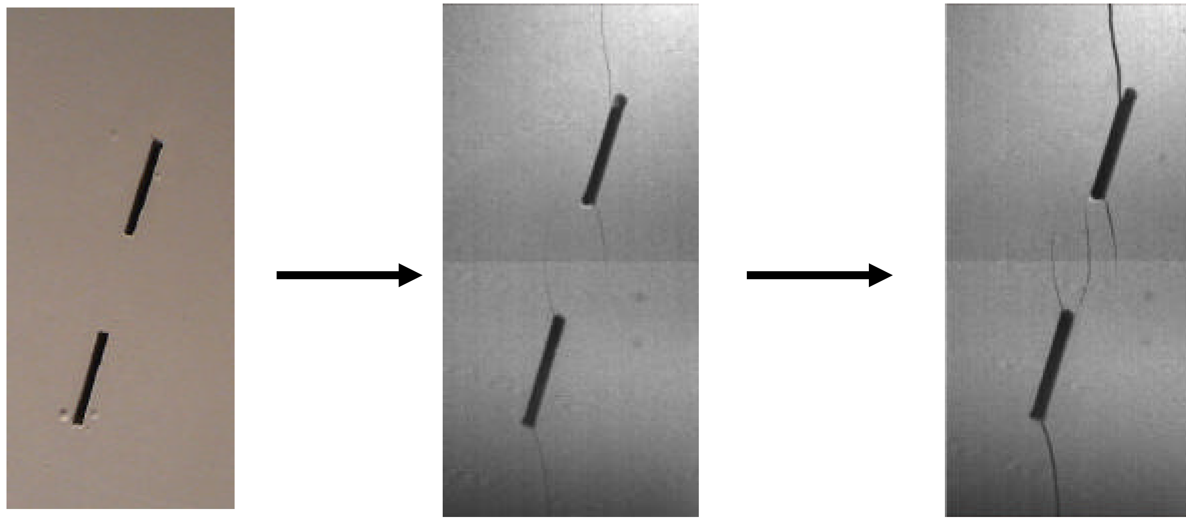


Flaw Inclination = 45^{o}

Experimental Work – Recent Results
Double Flaws

Gypsum – Coplanar

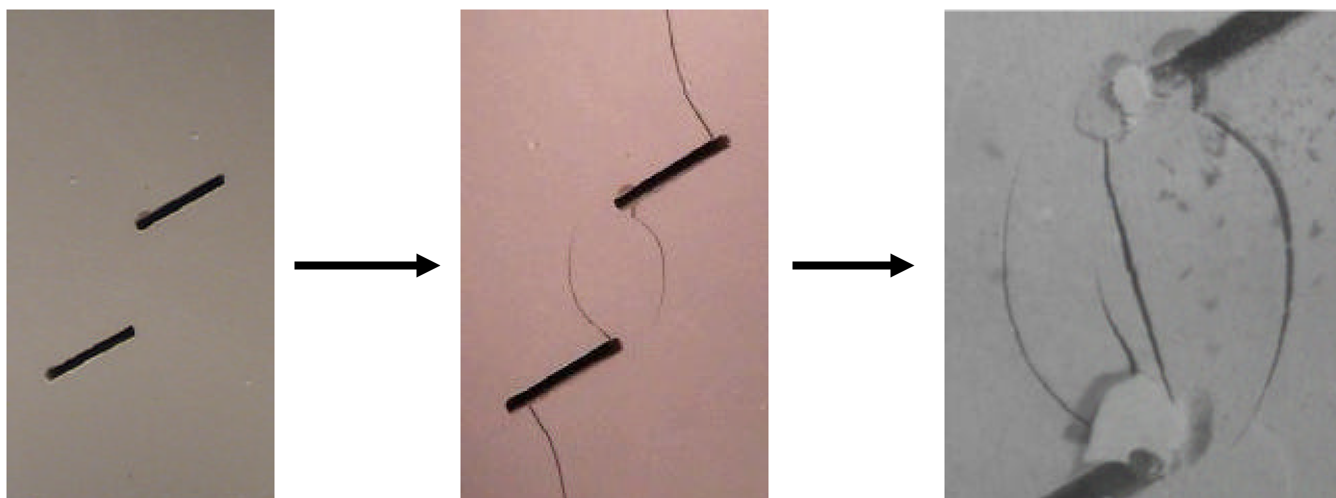
Flaw Inclination = 75^o



Gypsum – Stepped

Flaw Inclination = 30^o

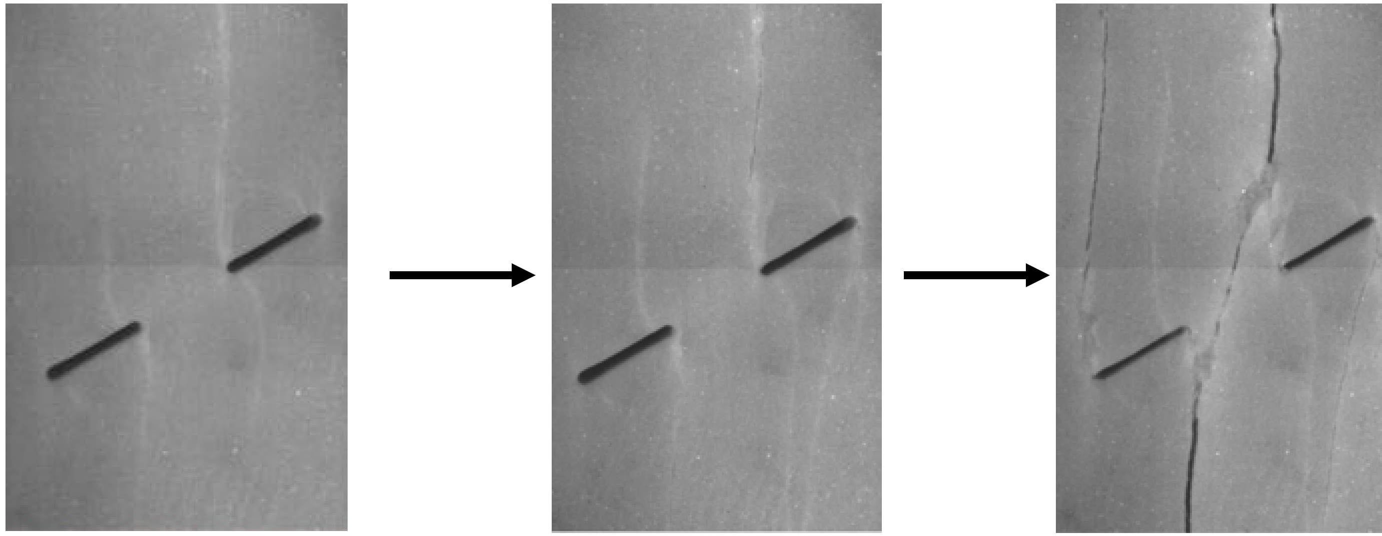
Bridging Angle = 60^o



Experimental Work – Recent Results
Double Flaws

Marble – Coplanar

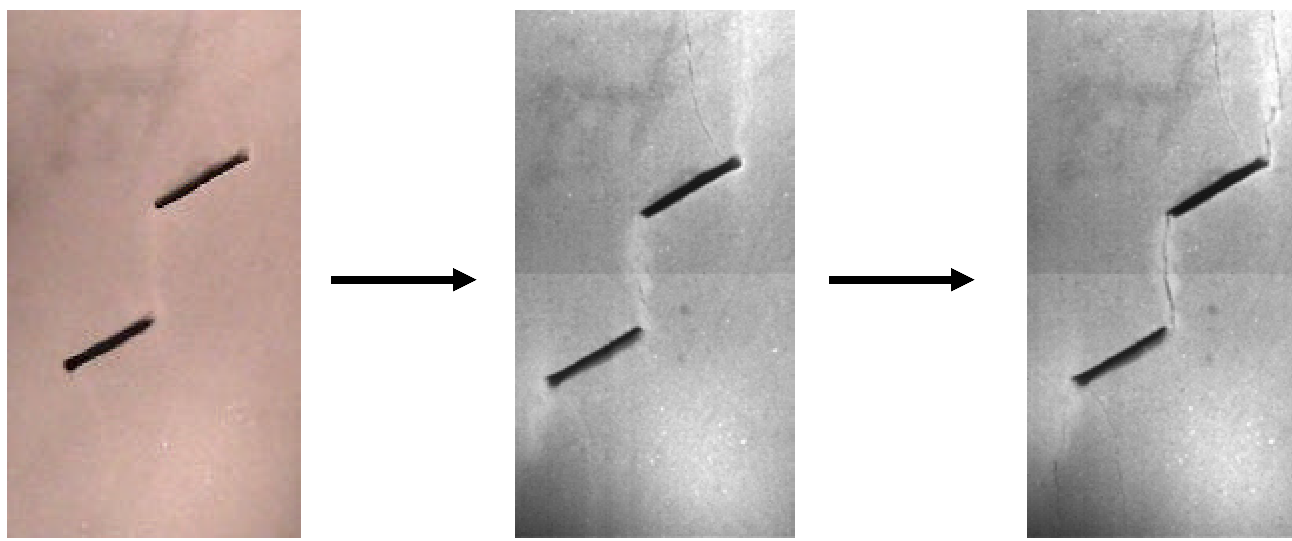
Flaw Inclination = 30°



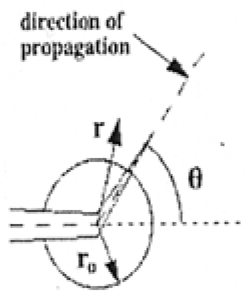
Marble – Stepped

Flaw Inclination = 30°

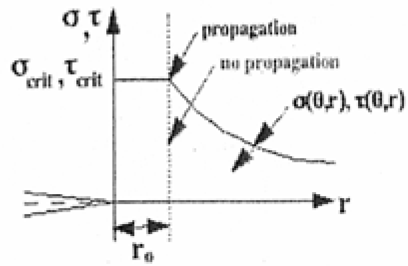
Bridging Angle = 60°



Analytical Work - Crack Initiation and Propagation Criterion



Core Region

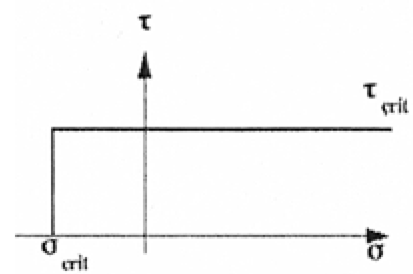


Propagation Criteria

propagation criterion

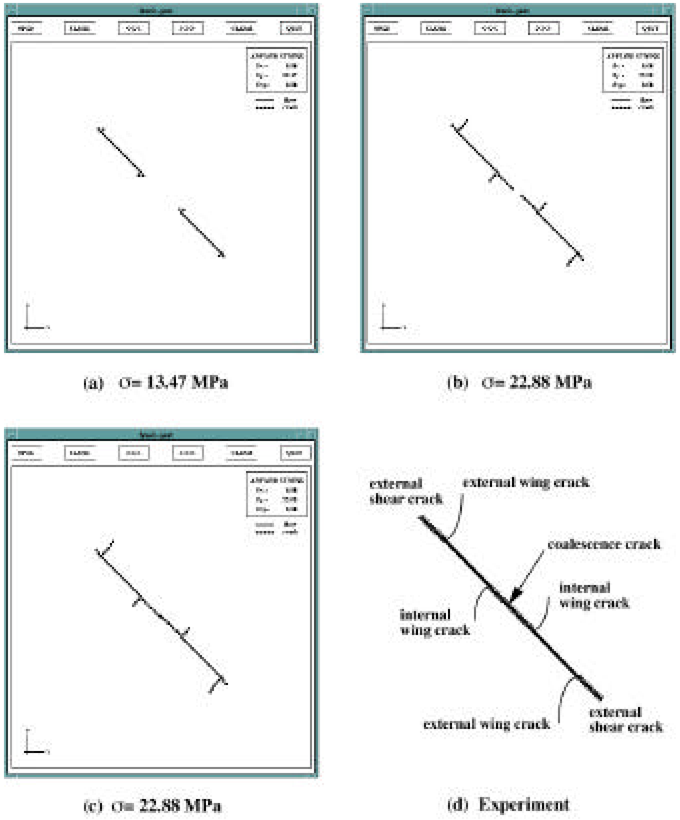
tensile	shear
$\left.\frac{\delta \sigma_\theta}{\delta \theta}\right\vert_{r=r_0} = 0$ $\left.\frac{\delta^2 \sigma_\theta}{\delta \theta^2}\right\vert_{r=r_0} > 0$	$\left.\frac{\delta \tau}{\delta \theta}\right\vert_{r=r_0} = 0$ $\left.\frac{\delta^2 \lvert\tau\rvert}{\delta \theta^2}\right\vert_{r=r_0} < 0$
$\sigma_\theta = \sigma_{crit}$	$\tau = \tau_{crit}$

Mathematical Formulation



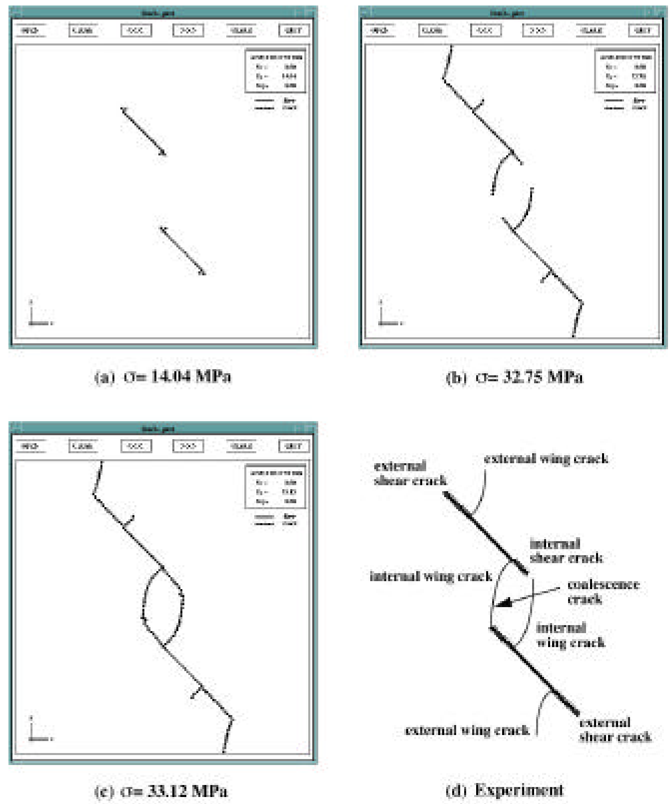
Failure Envelope

Analytical Work - Comparison of Simulation and Experiment



Comparison between Numerical Prediction and Experiment for Coplaner-Open Flaw Geometry, Uniaxial Compression

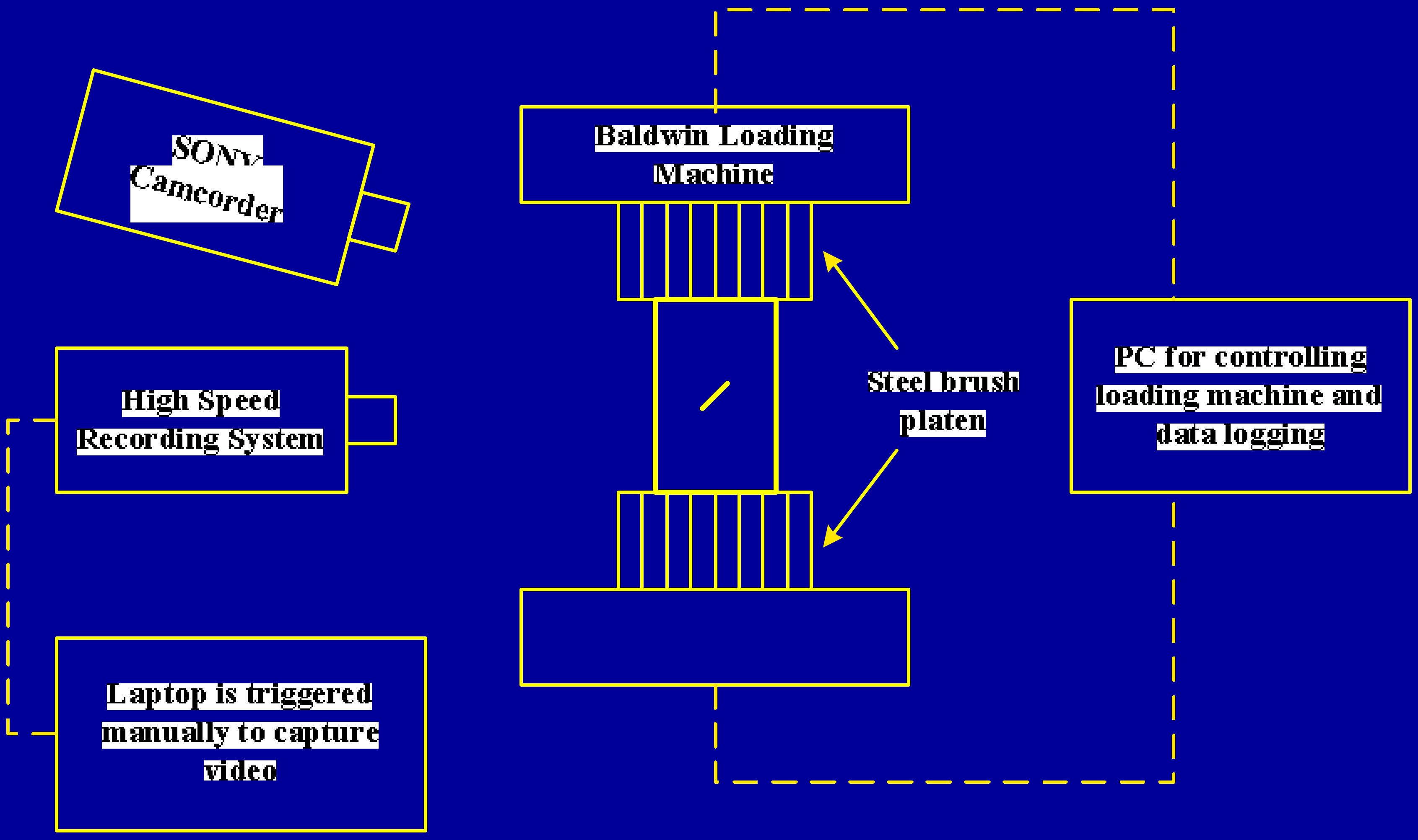
Analytical Work - Comparison of Simulation and Experiment



Comparison between Numerical Prediction and Experiment for for Stepped, Non-Overlapping Open Flaws

Uniaxial Compression

Experimental Schematic



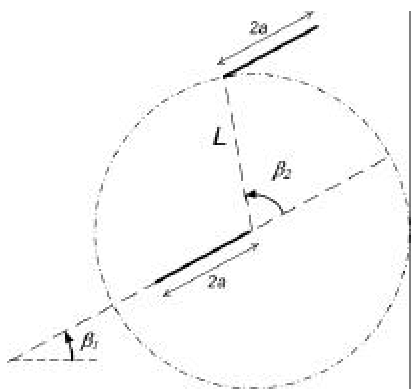
Experimental Equipment

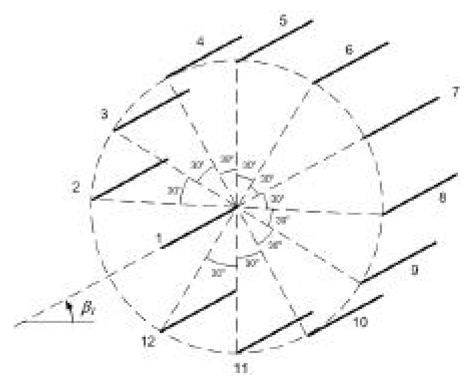
Experimental Equipment

Proposed Experimental Work

Parameters to be Varied

- Rock Type
- Flaw Length (12.7, 25.4, 6.35 mm
- Flaw Aperture (0.1 to 1 mm)
- Flaw Geometry





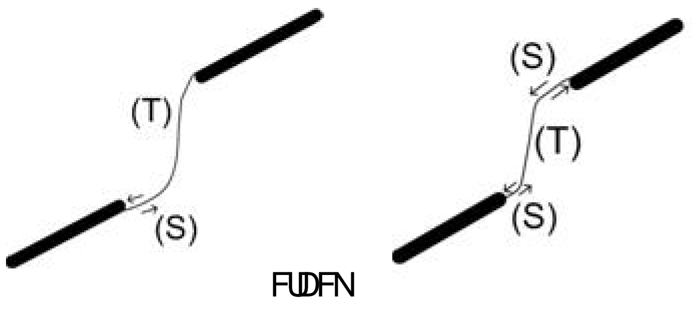
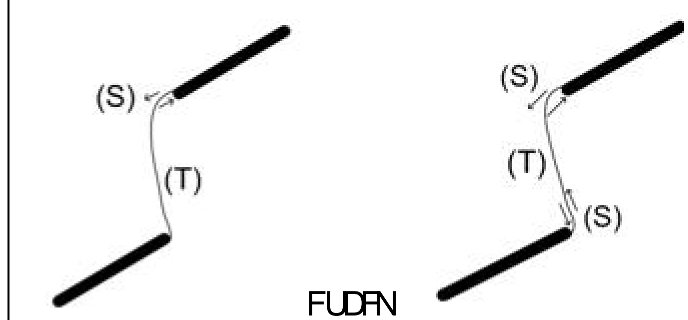
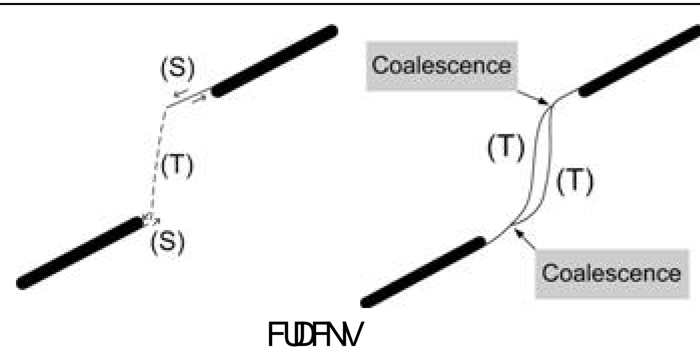
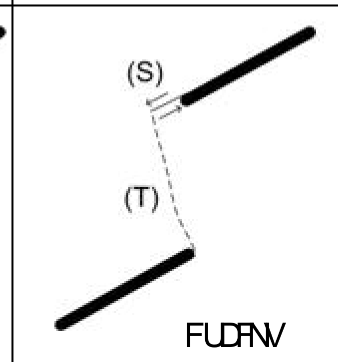
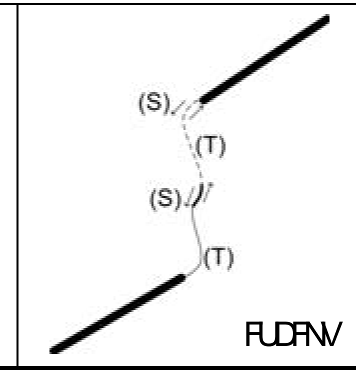
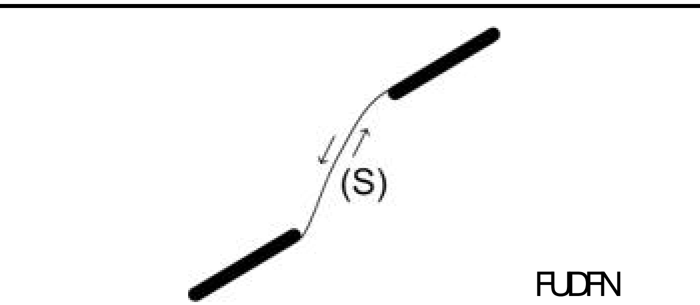
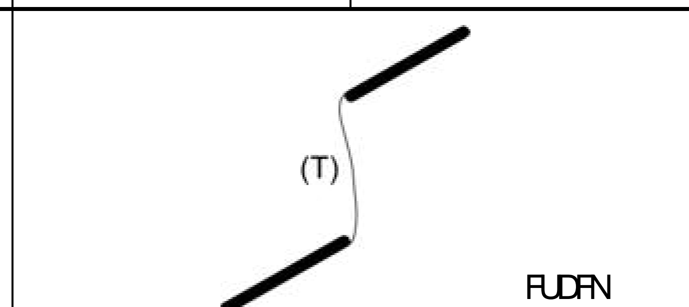
Key
β_1 _ flaw inclination angle
β_2 – bridging angle
L – ligament length
a – half flaw length

- Stress States (Uniaxial, Biaxial, Different Magnitudes)

Other Aspects of Proposed Research

- Measure Sonic Wave Velocity
- Analysis - New propagation/coalescence criteria?
- Details of Fracture Process
- Scaling
  - Lab
  - Field - Seismic
  - Field - Rockbursts

flaw inclination angle *30°*; positive bridging angles *30°*, *60°*

α / PDWHULDO	R	R
J\SVXP		
		 
PDUEOH		

Expected Accomplishments of Proposed Research

- More complete picture of fracturing based on lab experiments including different scales

- New analytical propagation/coalescence criteria if necessary

- Some idea on relation to field

Conclusions

- GTP related objectives - better knowledge of fracture formation and growth and fracture evolution will be achieved

- Will provide analytical tools for modeling fracturing process.

- Will provide ideas on how fractures in the field are created