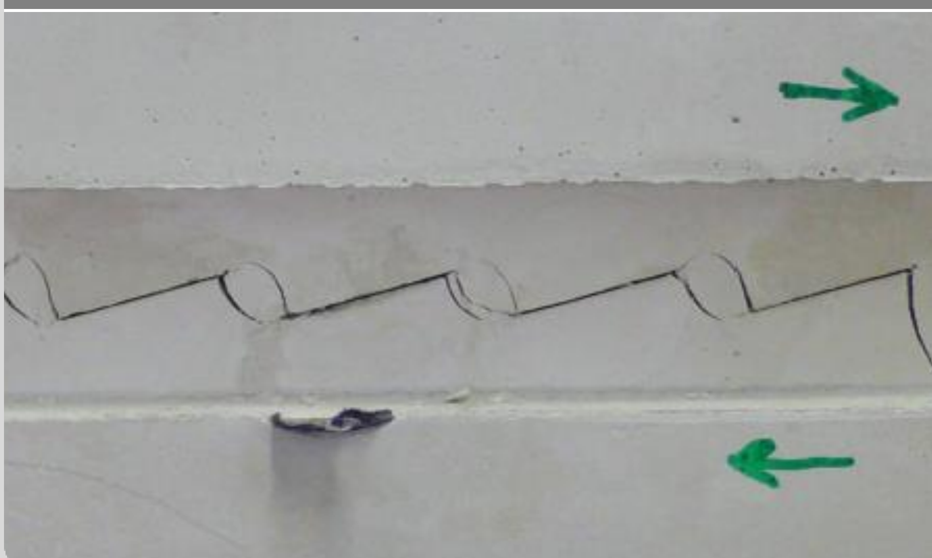
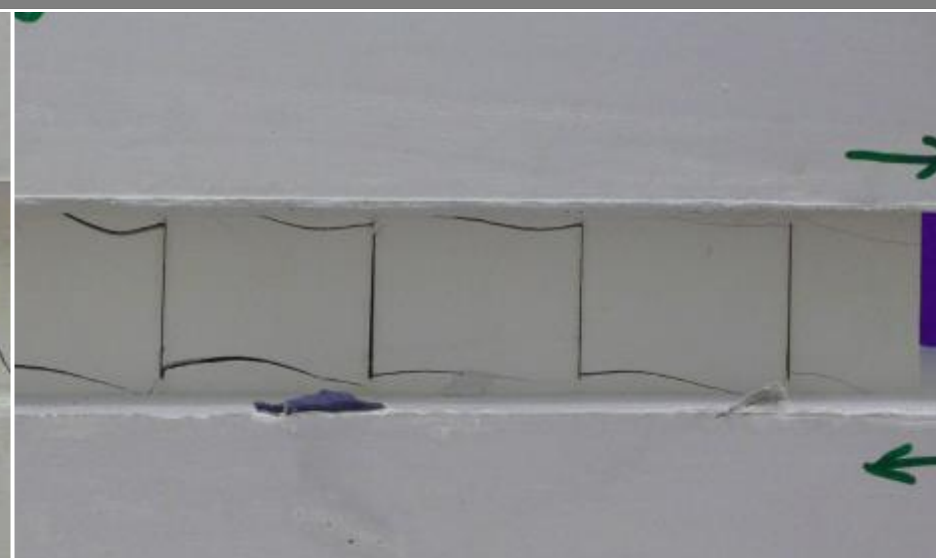
Karlsruhe Institute of Technology

# Experimental Investigation of the Shear Strength of Rock Mass with Intermittent Joints

**E. Gerolymatou, M. Vergara and Th. Triantafyllidis**

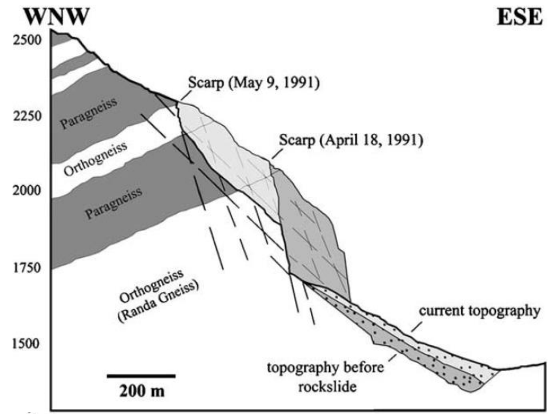
Institute of Soil Mechanics and Rock Mechanics (IBF)





# Intermittent Joint Occurrence

Karlsruhe Institute of Technology



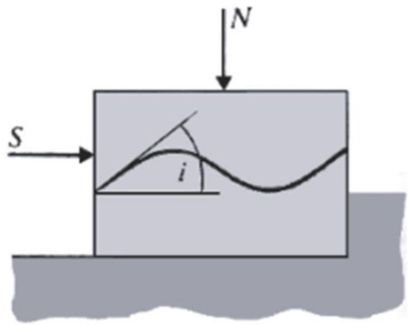

Stead et al. (2006)
The 1991 Rana rockslide


Larsen and Gudmundsson (2010)
Limestone and shale formations in Kilve

- Relevant when the spacing is comparable to the bridge length
- Decisive for the strength of the rock mass
- Potentially interesting for the permeability

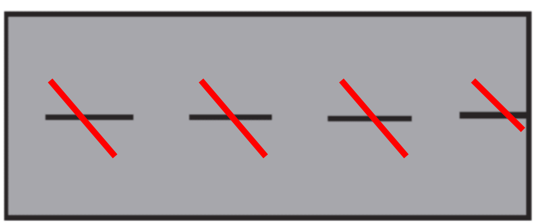
# Strength of Continuous and Discontinuous Joints

- Continuous Joints:




$$\tau = \tan(\phi + i)\sigma + c$$

- Discontinuous Joints:



Averaging:

e.g. Saeb and Amadei (1992)

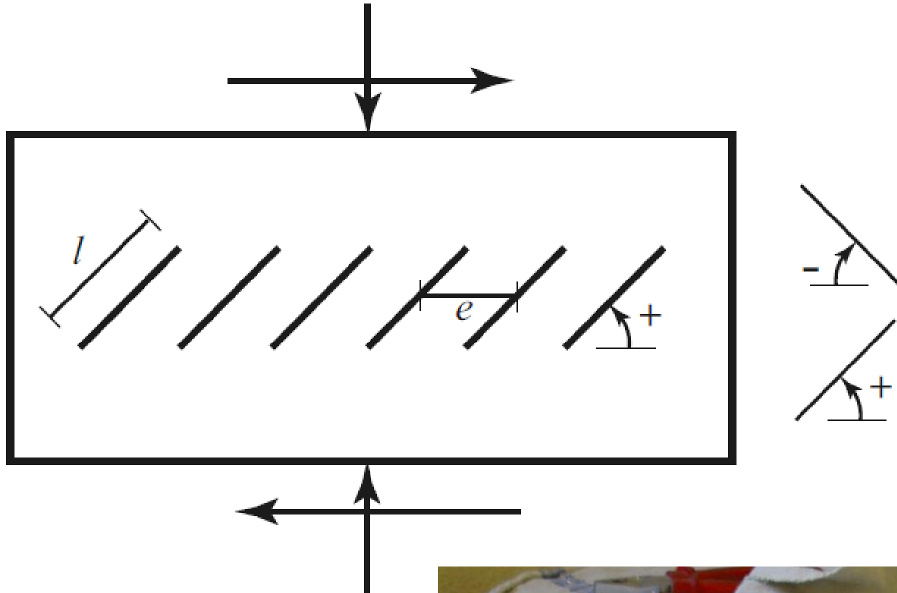
$$\tau = \tan(\phi_j + i)\sigma(1 - a_s) + a_s\tau_s$$

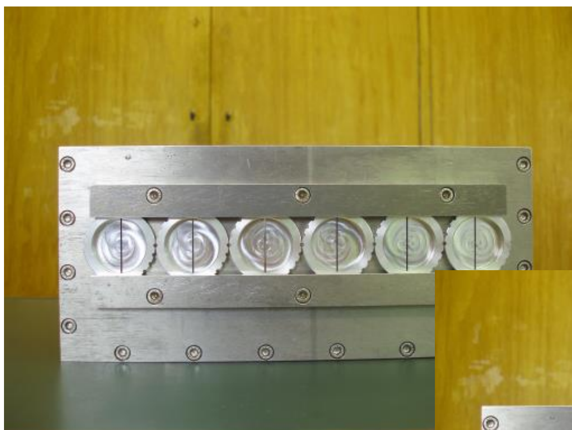
Fracture mechanics:

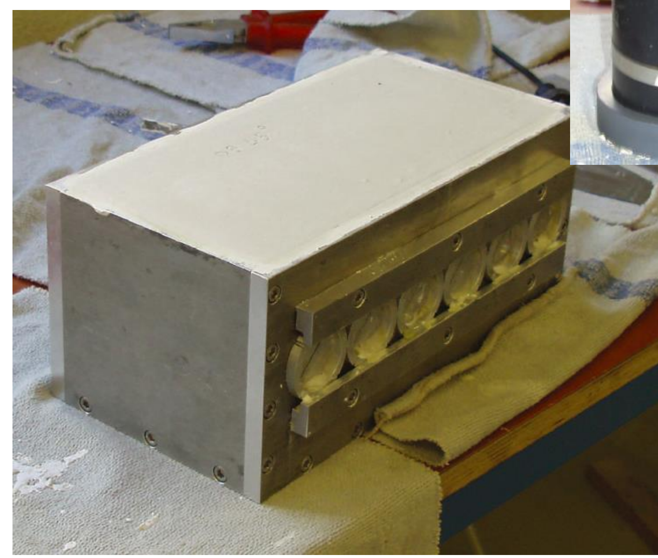
e.g. Griffith criterion

$$\frac{K_i^2}{K_{ic}^2} + \frac{K_{ii}^2}{K_{iic}^2} = 1$$

# Test Setup



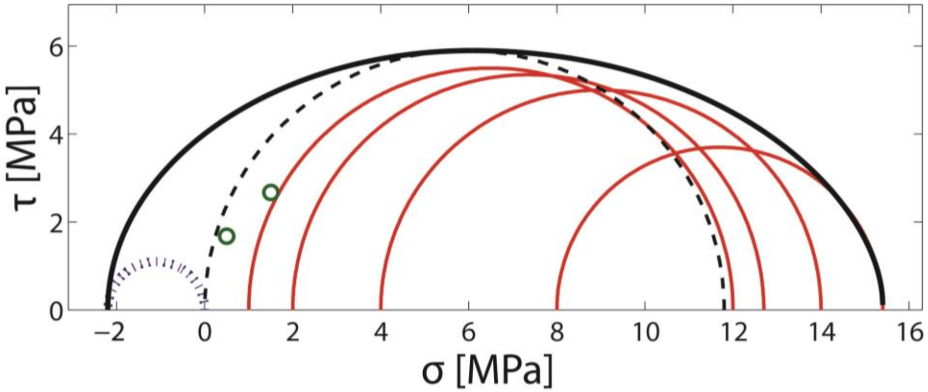





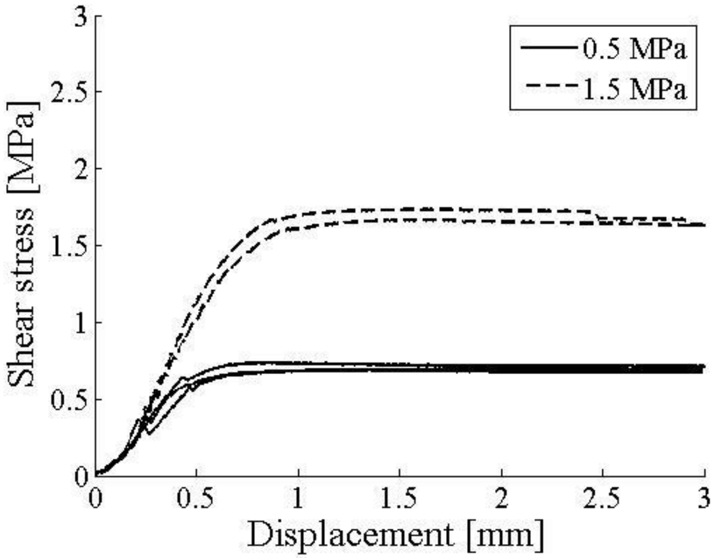
Gerolymatou and Triantafyllidis (2016)

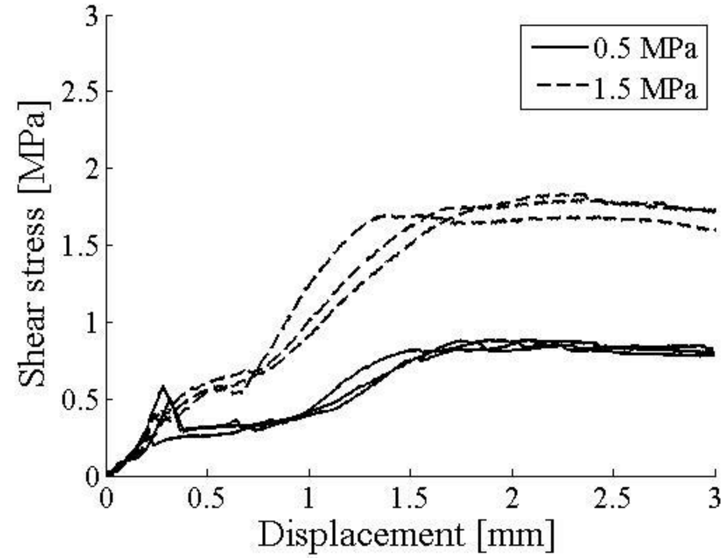
# Tests performed

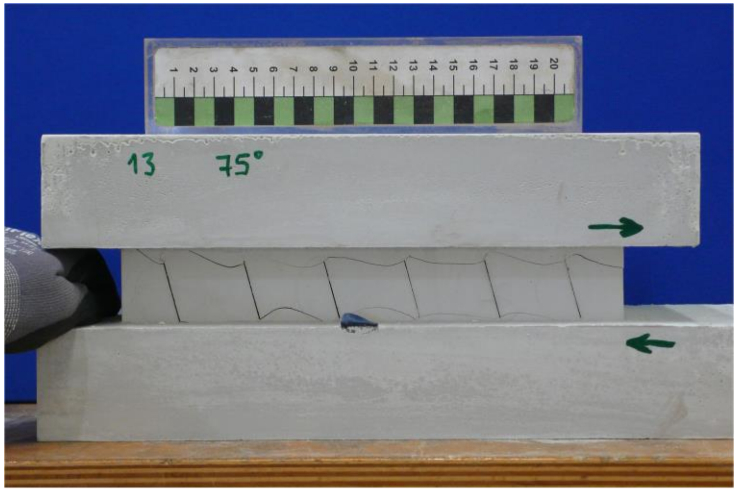
- Material characterization
  - Uniaxial
  - Simple shear
  - Brazilian
  - Triaxial
- Shear at 0.5 MPa
- Shear at 1.5 MPa
- Large shear displacement

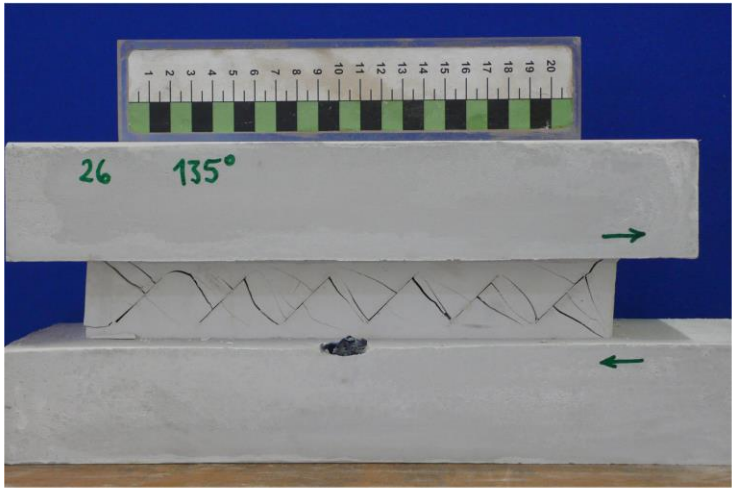


# Stress - displacement responses

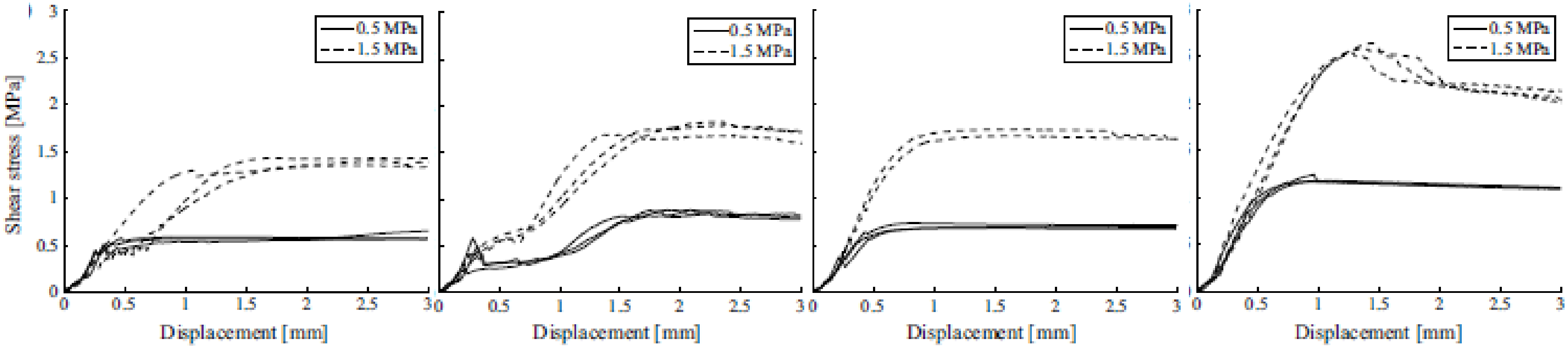


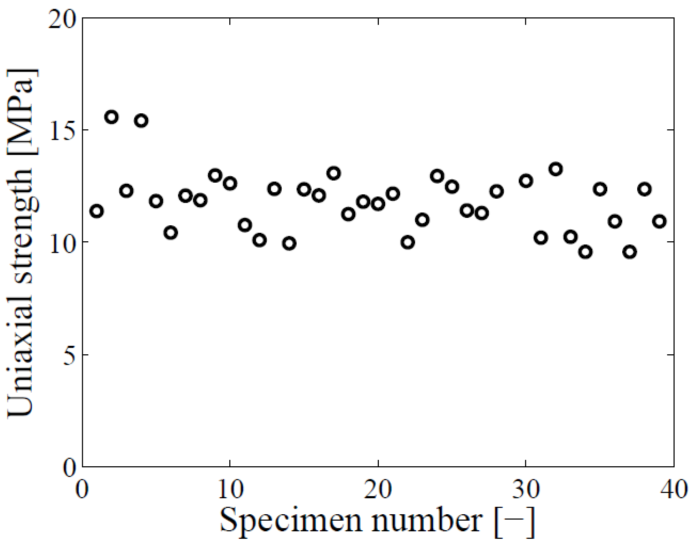



# Repeatability – Material and Structure

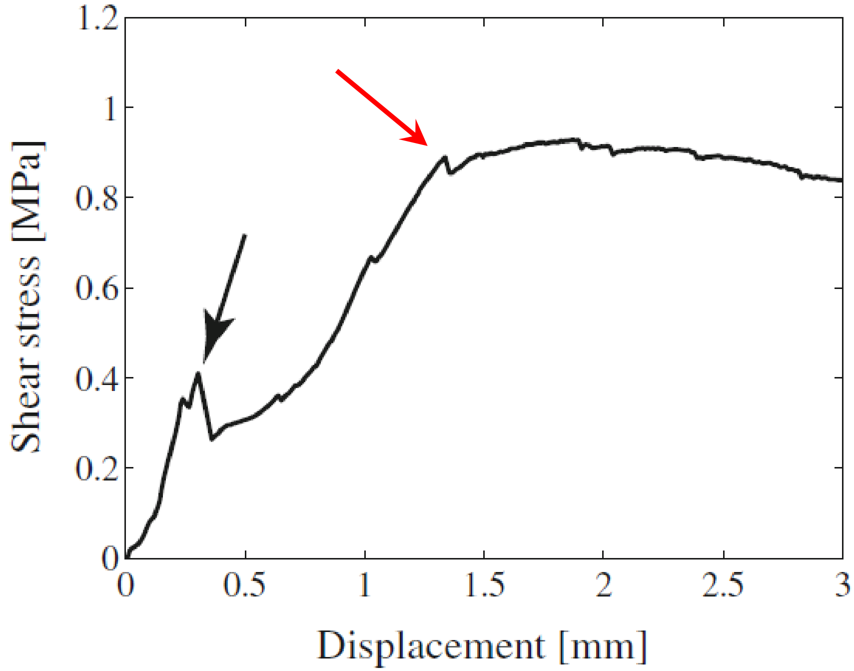


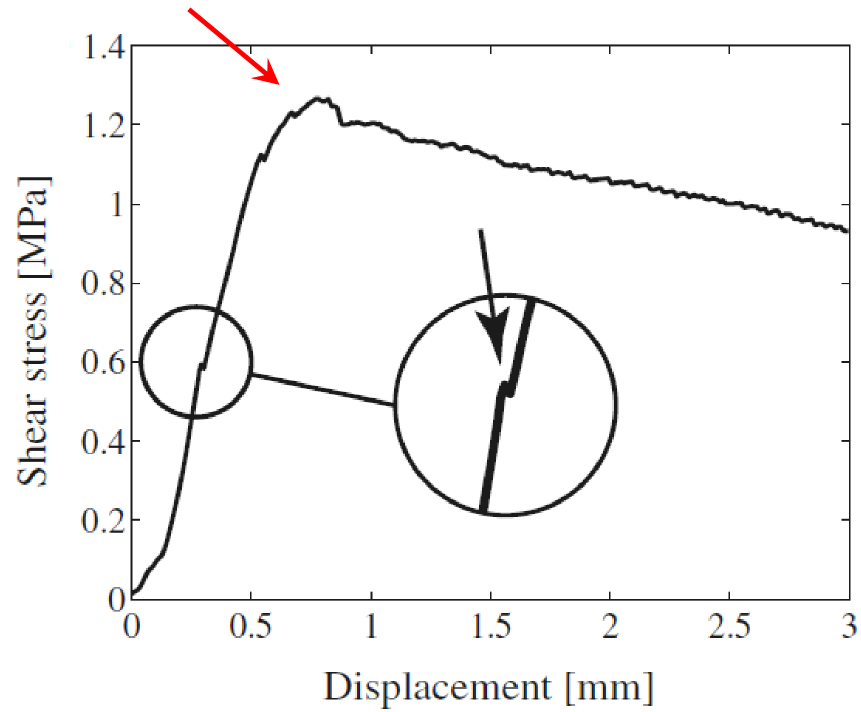

Structure

Material

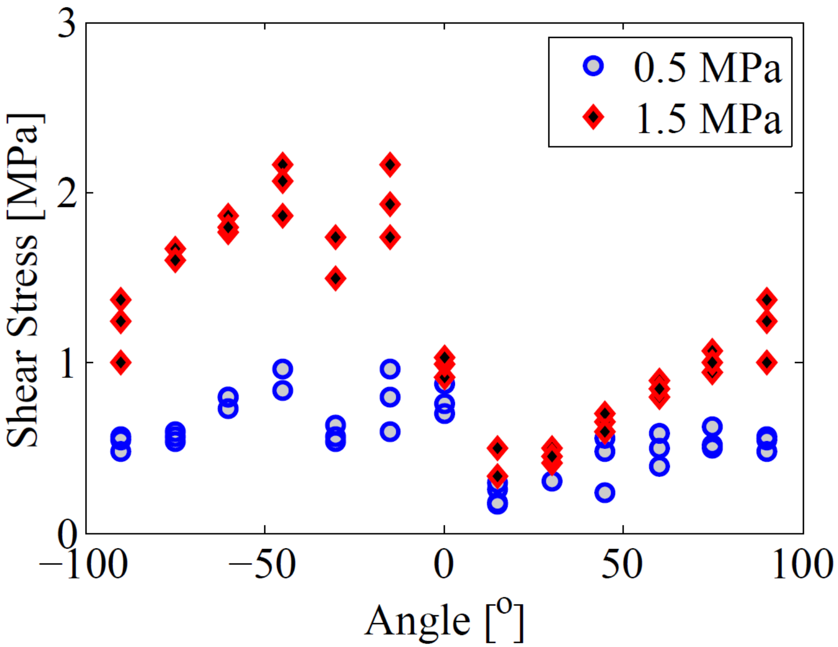


# Strength vs. Coalescence

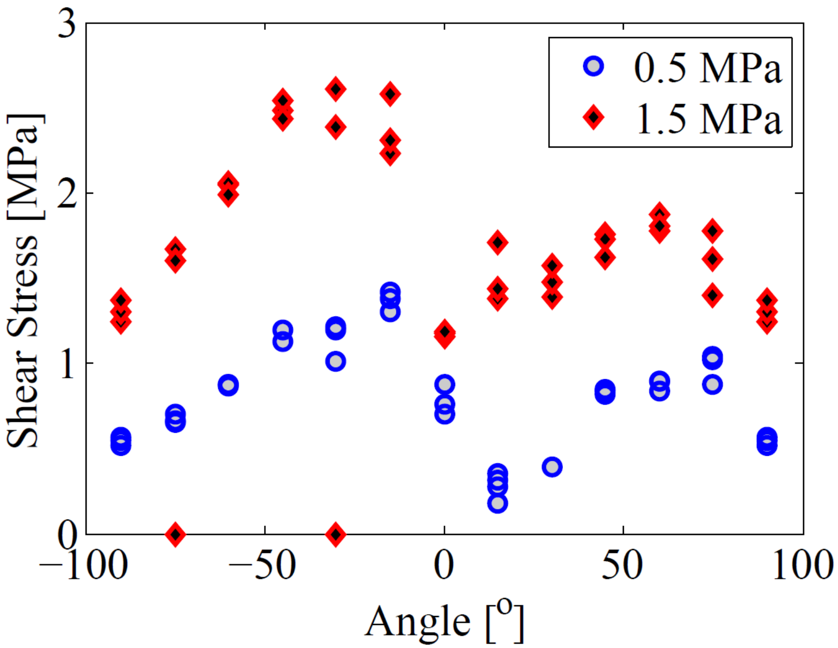


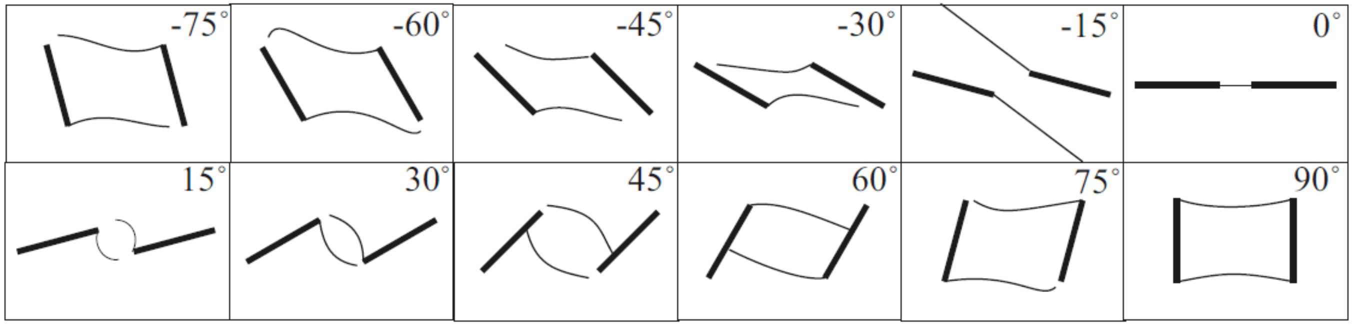
# Cumulative results – small displacement



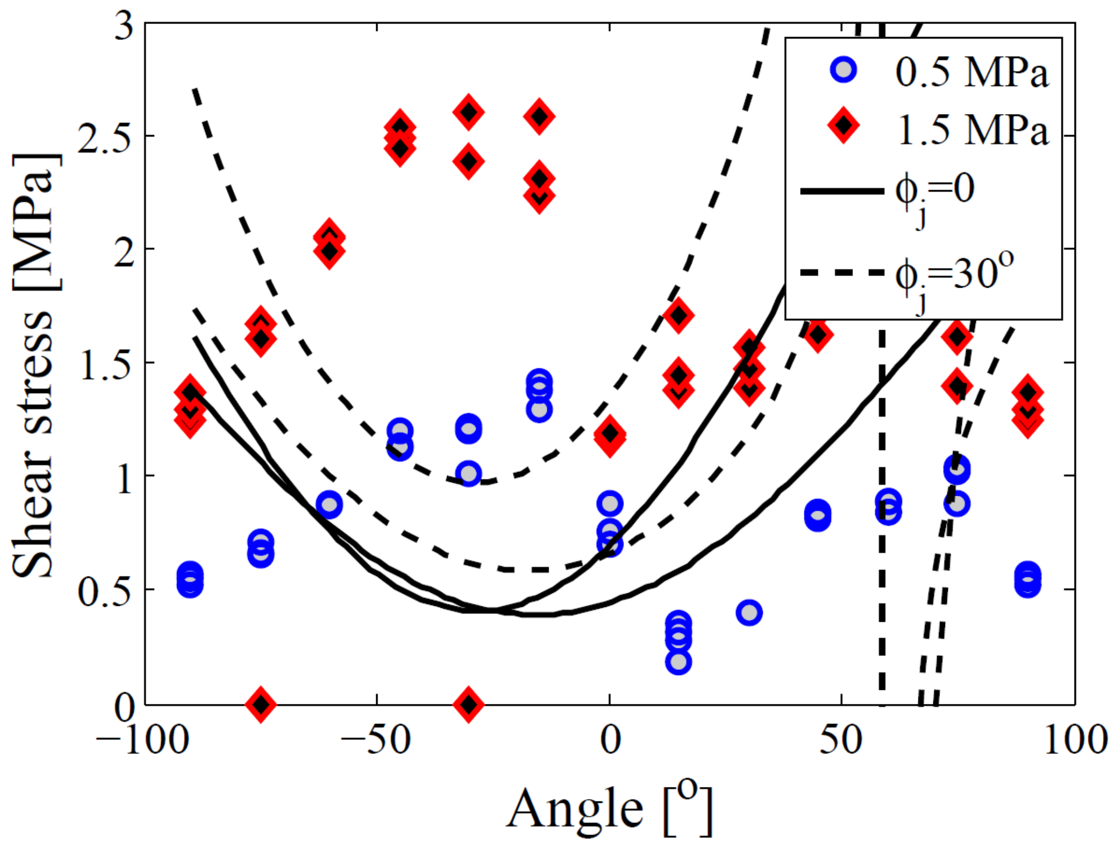

Coalescence

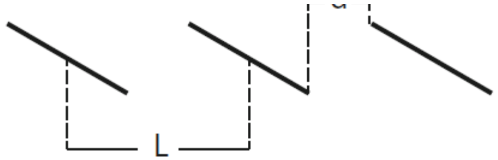



Maximum



# Small displacement– Maximum shear stress




$a_s = \frac{d}{L}$

$$\tau = \tan(\phi_j + i)\sigma(1 - a_s) + a_s\tau_s$$

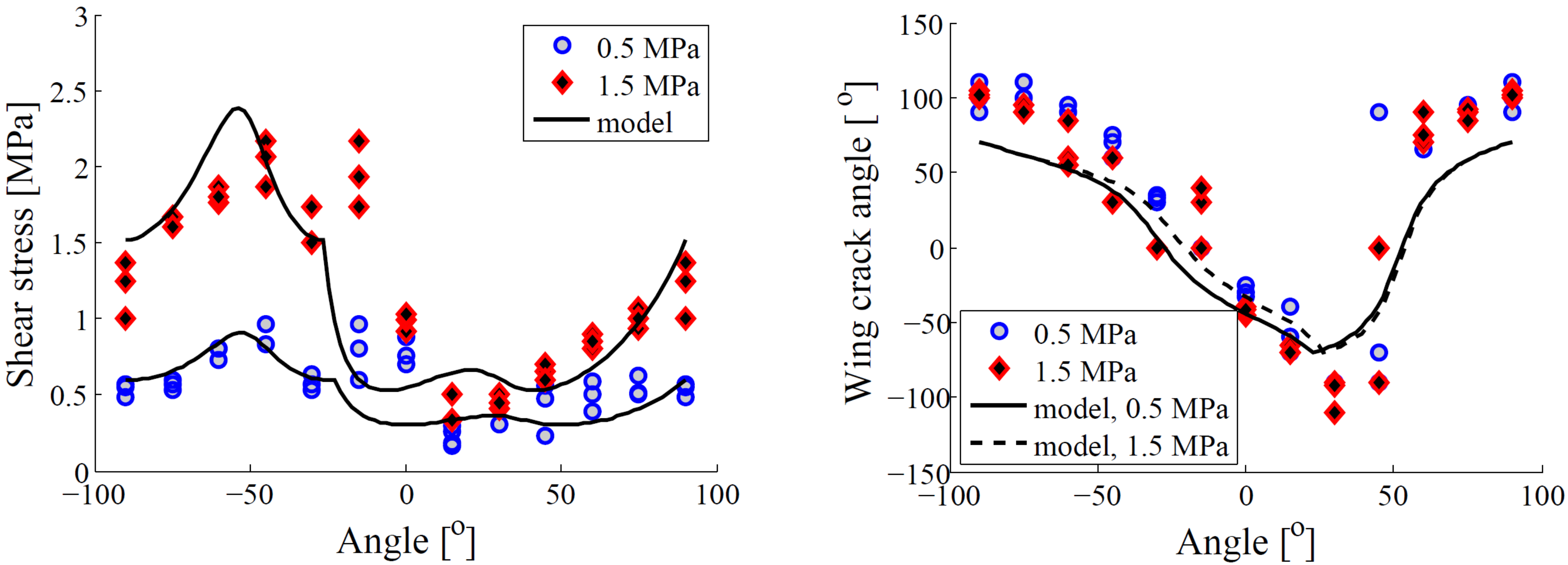
Saeb and Amadei (1992)

# Small displacement– Shear stress at coalescence

$$K_I\left(3\cos\frac{\phi_0}{2}+\cos\frac{3\phi_0}{2}\right)-K_{II}\left(3\sin\frac{\phi_0}{2}+3\sin\frac{3\phi_0}{2}\right)=4K_{IC}$$

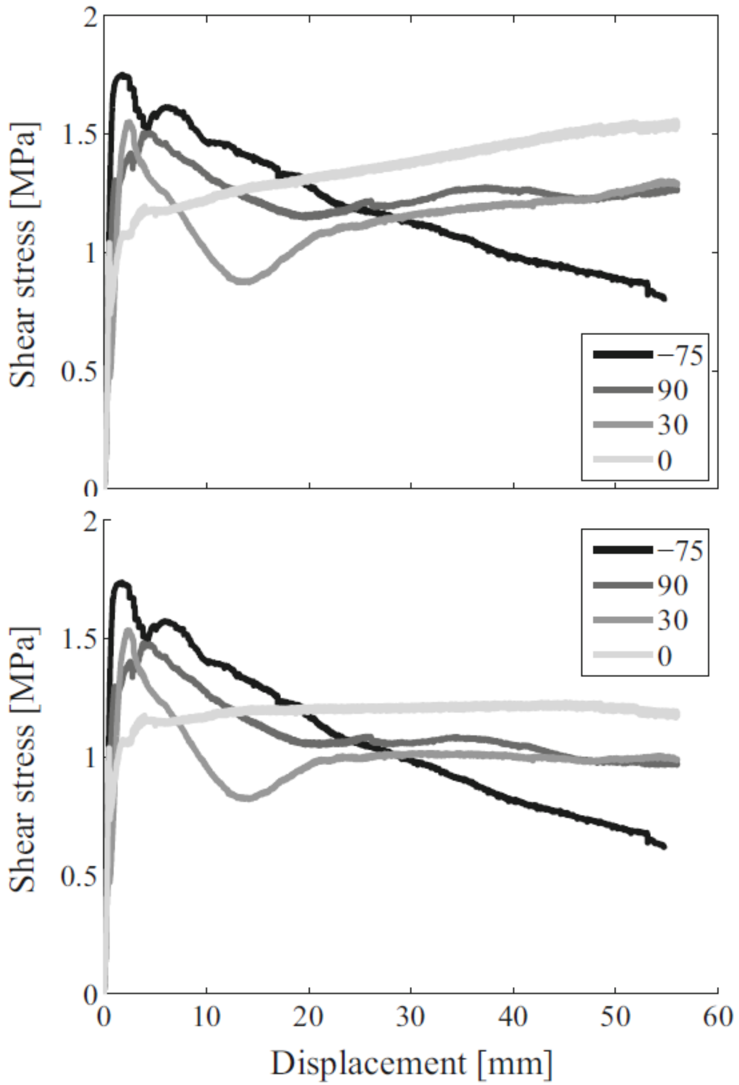
$$K_I\sin\phi_0+K_{II}\left(3\cos\phi_0-1\right)=0$$

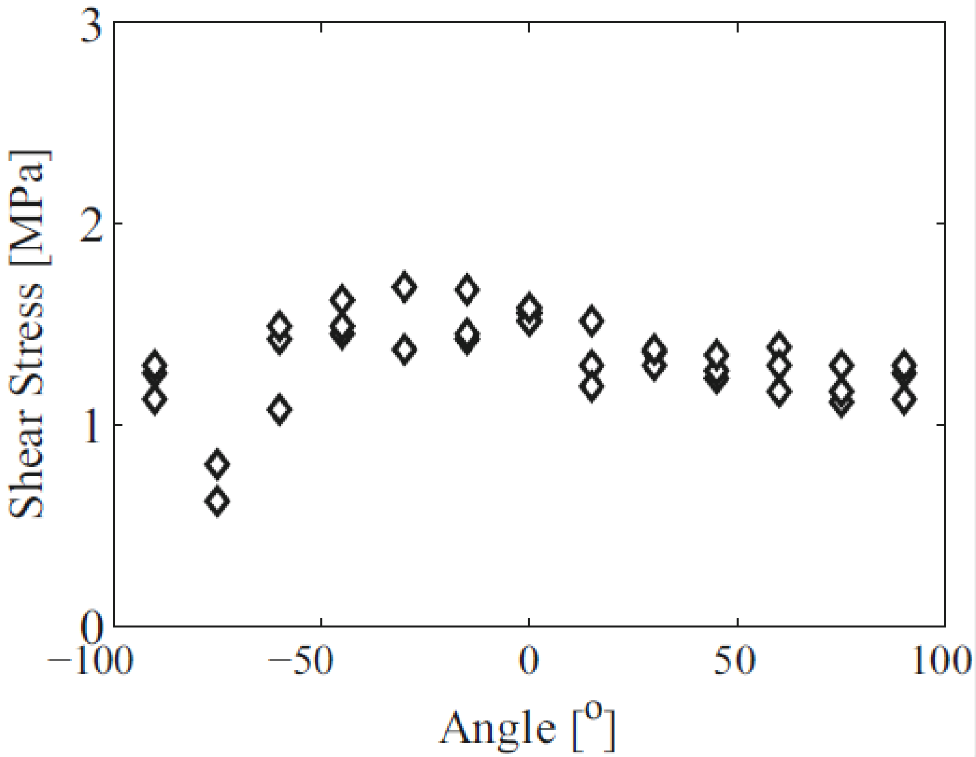
Erdogan and Sih (1963)



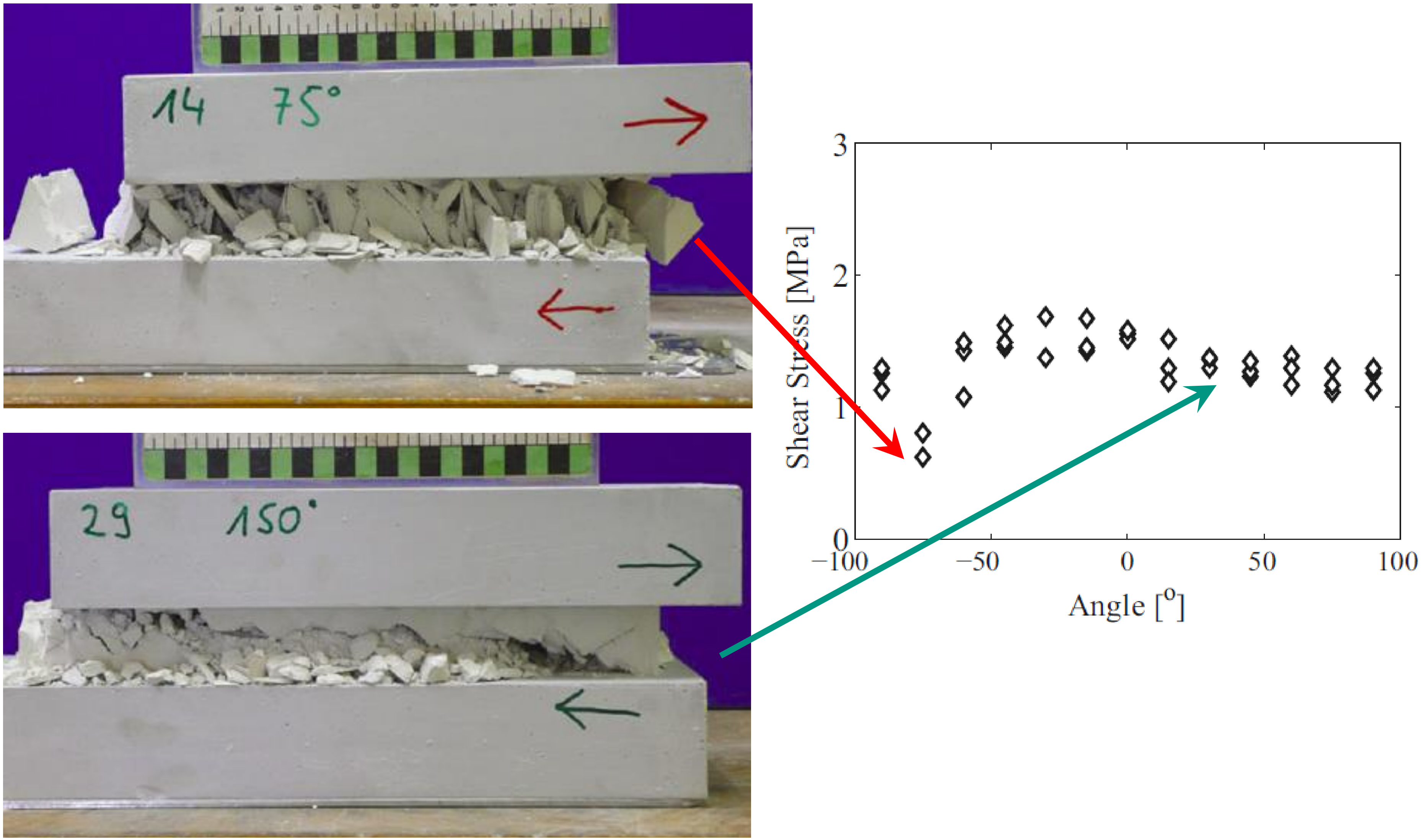

| Type | Without interaction | |
|---|---|---|
| $\sigma$ (MPa) | 0.5 | 1.5 |
| $K_{Ic}$ (MPa$\sqrt{m}$) | 0.15 | 0.38 |

# Cumulative results – large displacement

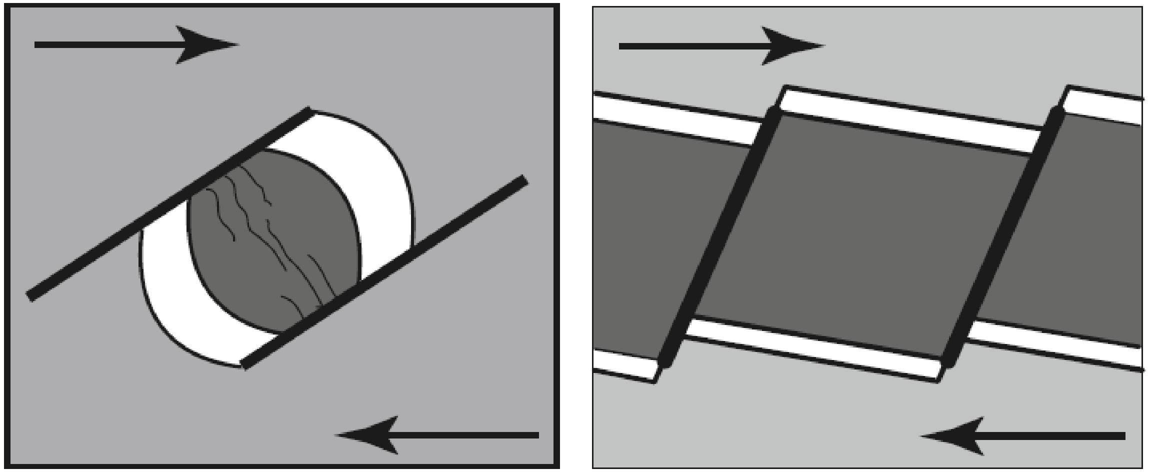


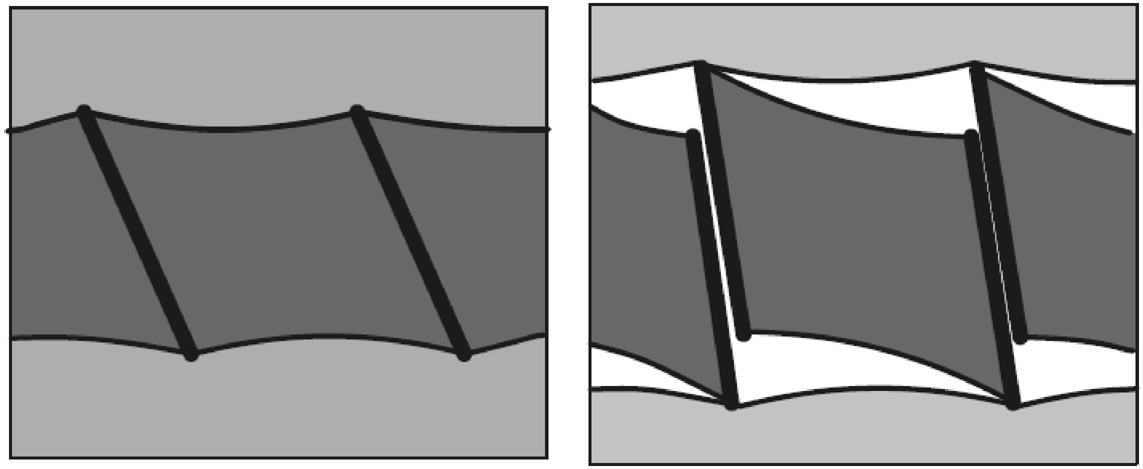
# Large displacement– failure image



# Large displacement– Rolling and Sliding

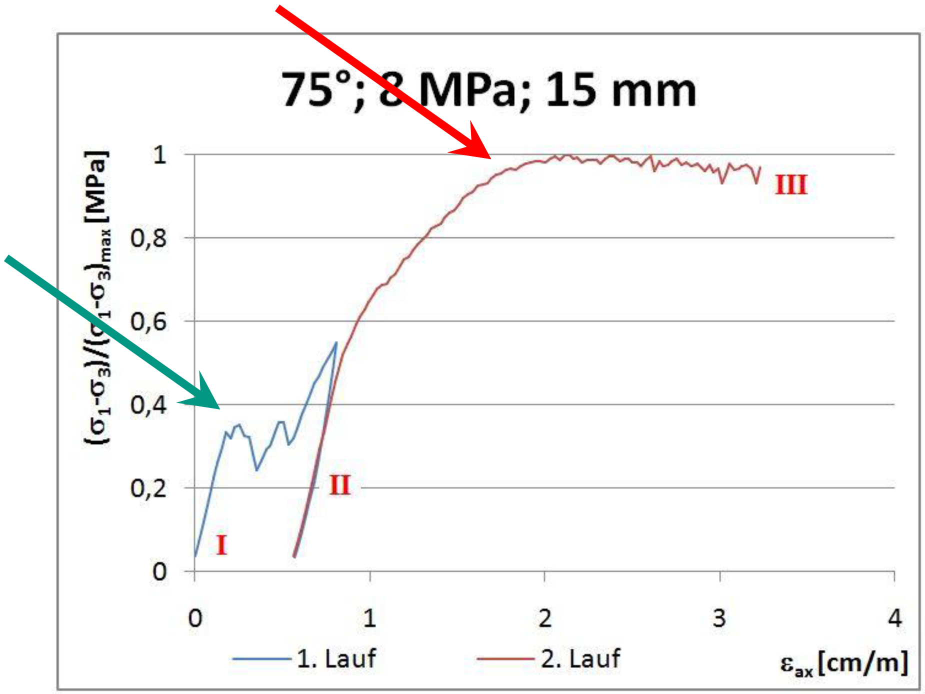


Sliding mechanism



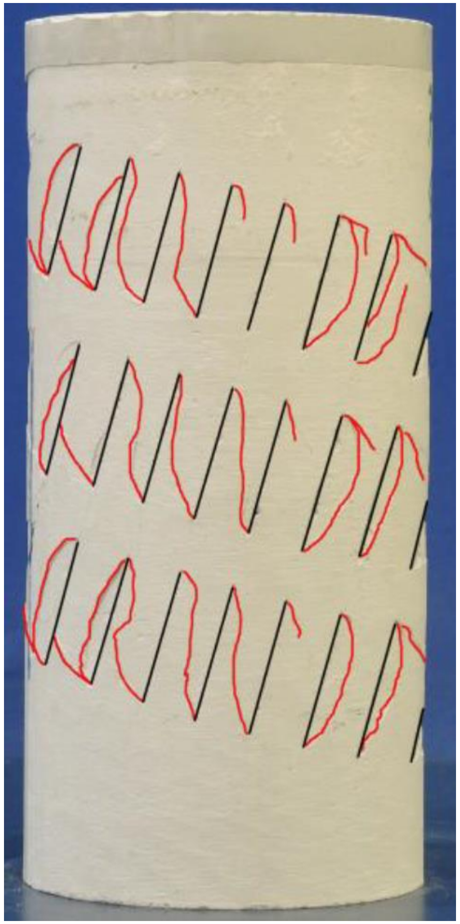
Rolling mechanism

# Triaxial tests and strength



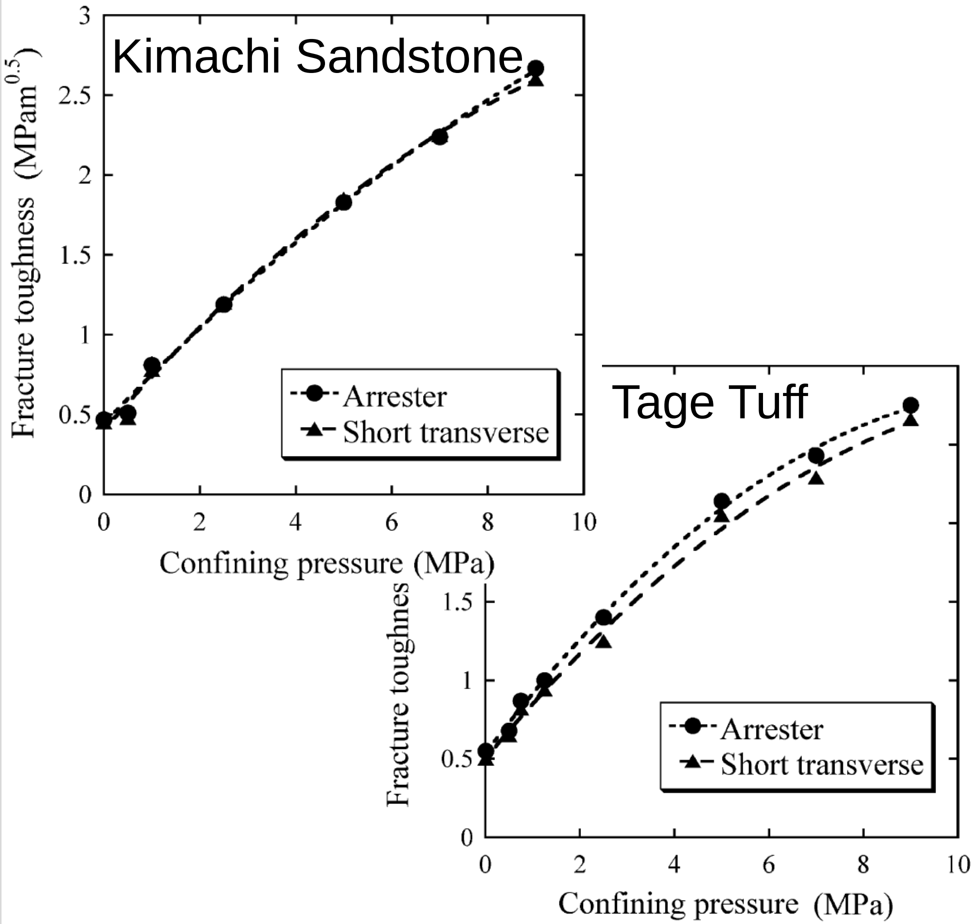

$$\alpha = 75^o, \quad d = 15 \ \ mm$$

# Triaxial tests and strength

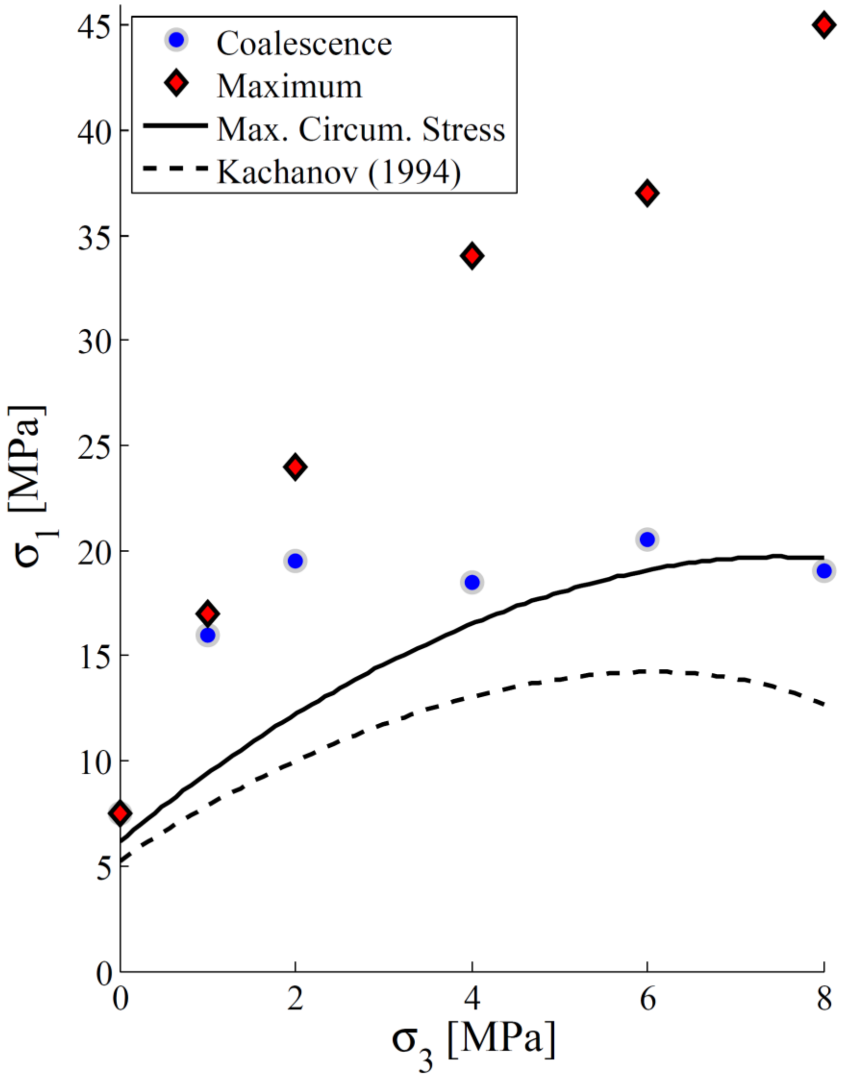


$\alpha = 75^o, \quad d = 15 \;\; mm$

# Triaxial tests and strength

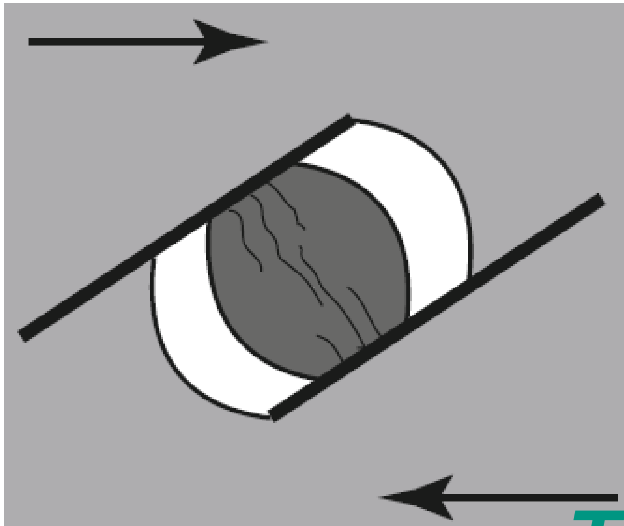


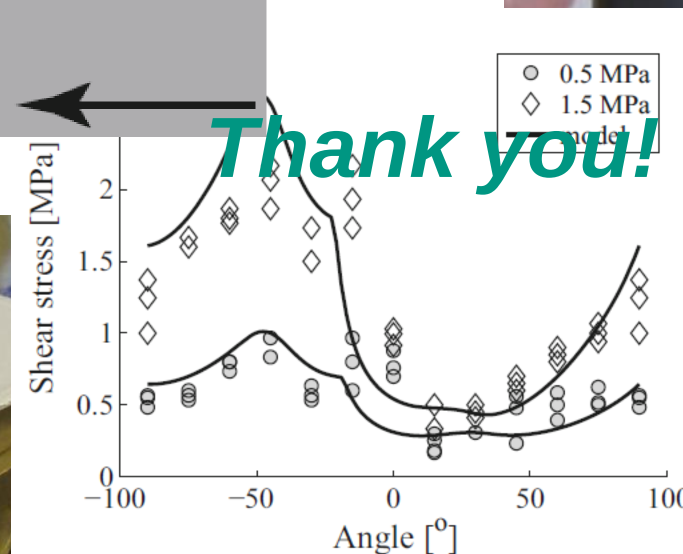

Funatsu et al. (2004)



# Conclusions and Outlook

- Available semi-analytical methods are not sufficient to describe the strength of rock mass with intermittent joints
- The same is true of fracture mechanics approaches
- Fracture mechanics work well for fracture coalescence, predicting both load and wing crack angle
- For large shear displacements shear resistances may be observed that are significantly lower  that the residual shear resistance of the material
- Such occurrences depend on the initial geometry of the intermittent joints




0.5 MPa
1.5 MPa
model
Shear stress [MPa]
0
0.5
1
1.5
2
−100
−50
0
50
100
Angle [o]

# Thank you!