Damage Simulation of Fracture Asperity in Geothermal Systems

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INTRODUCTION: Fracture as a major factor which greatly affects the fluid flow, heat recovery in subsurface. Natural fractures are usually maintained by self-propping asperity .The in-situ stress loading on fractures are balanced by contacting asperity pairs. In geothermal systems, cold water is pumped into deep formation and has heat exchange with hot asperity[1]. Significant temperature difference between water and rock would induce considerable thermal strain and possibly damage asperity. In this study, isotropic damage model is implemented in Weak Form PDE interface to simulate the damage evolution of asperity under different invading water temperature.

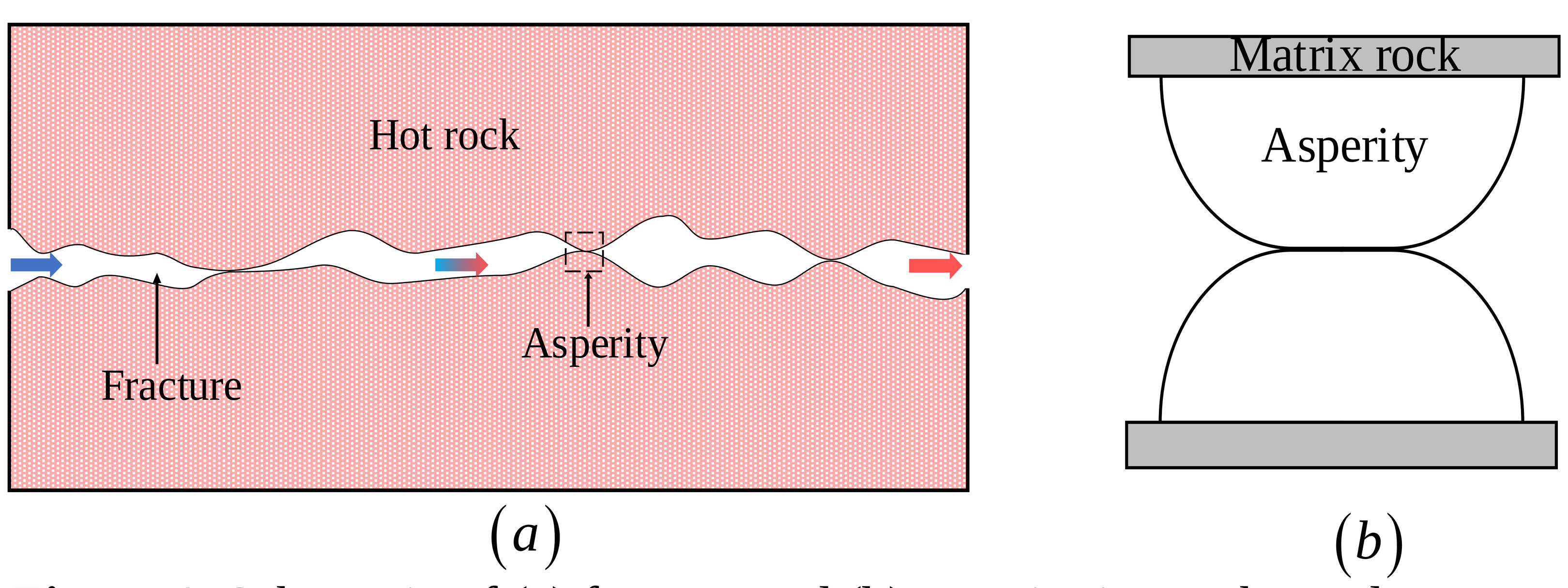

Figure 1. Schematic of (a) fracture and (b) asperity in geothermal systems

COMPUTATIONAL METHODS: Isotropic damage model [2] is implemented in Weak Form PDE interface to analyze the potential damage of asperity.

$$\nabla \cdot \boldsymbol{\sigma} + \boldsymbol{F}_v = 0$$

$$\boldsymbol{\varepsilon} = \frac{1}{2}\left(\nabla \boldsymbol{u} + \nabla \boldsymbol{u}^T\right)$$

$$\boldsymbol{\sigma} = (1 - D)\mathbf{C} : (\boldsymbol{\varepsilon} - \boldsymbol{\varepsilon}_{th})$$

$$f(\boldsymbol{\varepsilon}, k) = \tilde{\varepsilon}(\boldsymbol{\varepsilon}) - k$$

Heat conduction equation is solved to obtain temperature distribution in geometry and then calculate thermal strain.

$$\alpha_{th} \nabla^2 T = 0$$

From numerical consideration, three sequences are involved in this process: a) displacement loading of asperity, b) stress loading of asperity, b) thermal cooling coupled with damage model.

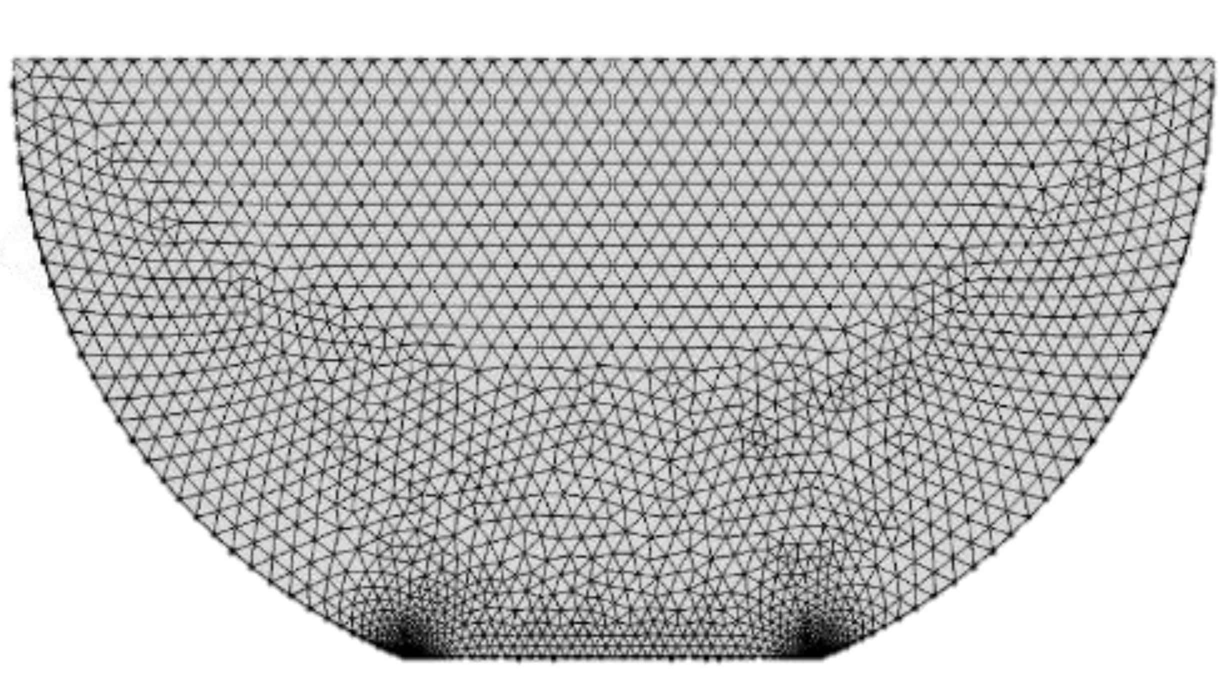

Figure 2. Meshed fracture asperity model

RESULTS: Displacement loading and thermal cooling steps are presented to illustrate the degradation of asperity and failure evolution.

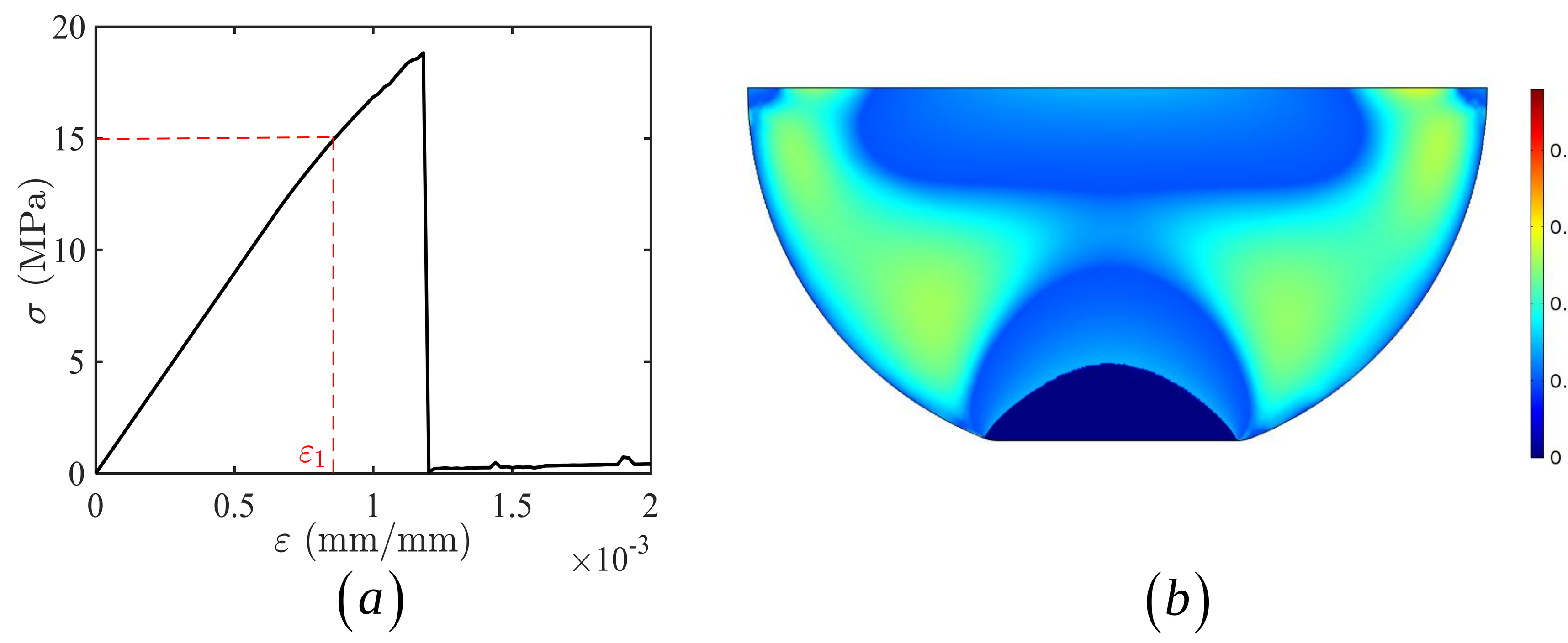

Figure 3. Mechanical analysis of asperity: (a) stress-strain curve and (b) damage contour at initial stage, $\varepsilon_1 = 0.86 \times 10^{-3}$.

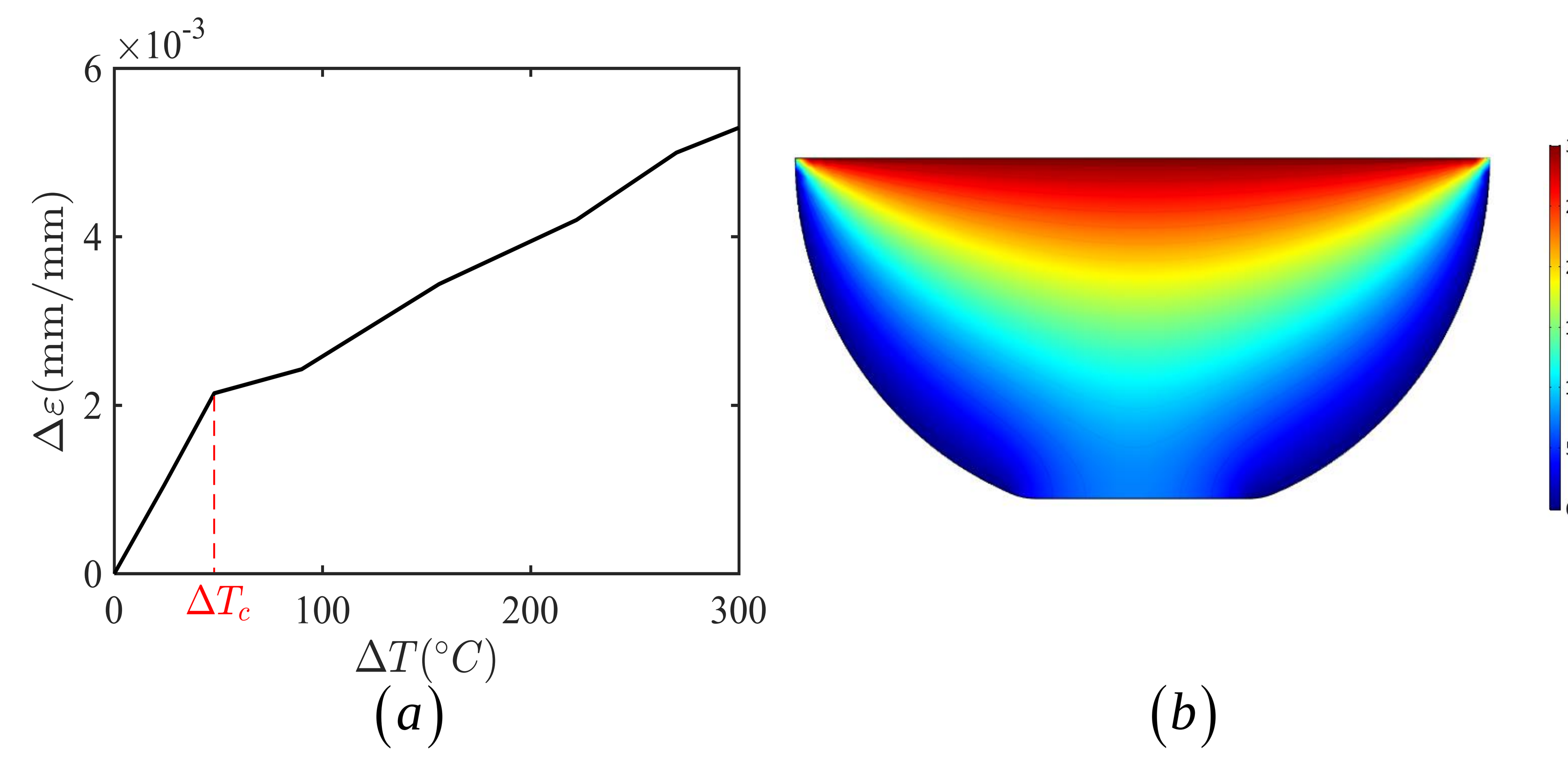

Figure 4. Thermal-mechanical analysis of asperity: (a) compaction with response to different temperature difference and (b) temperature distribution after cooling at $\Delta T = 300$°C.

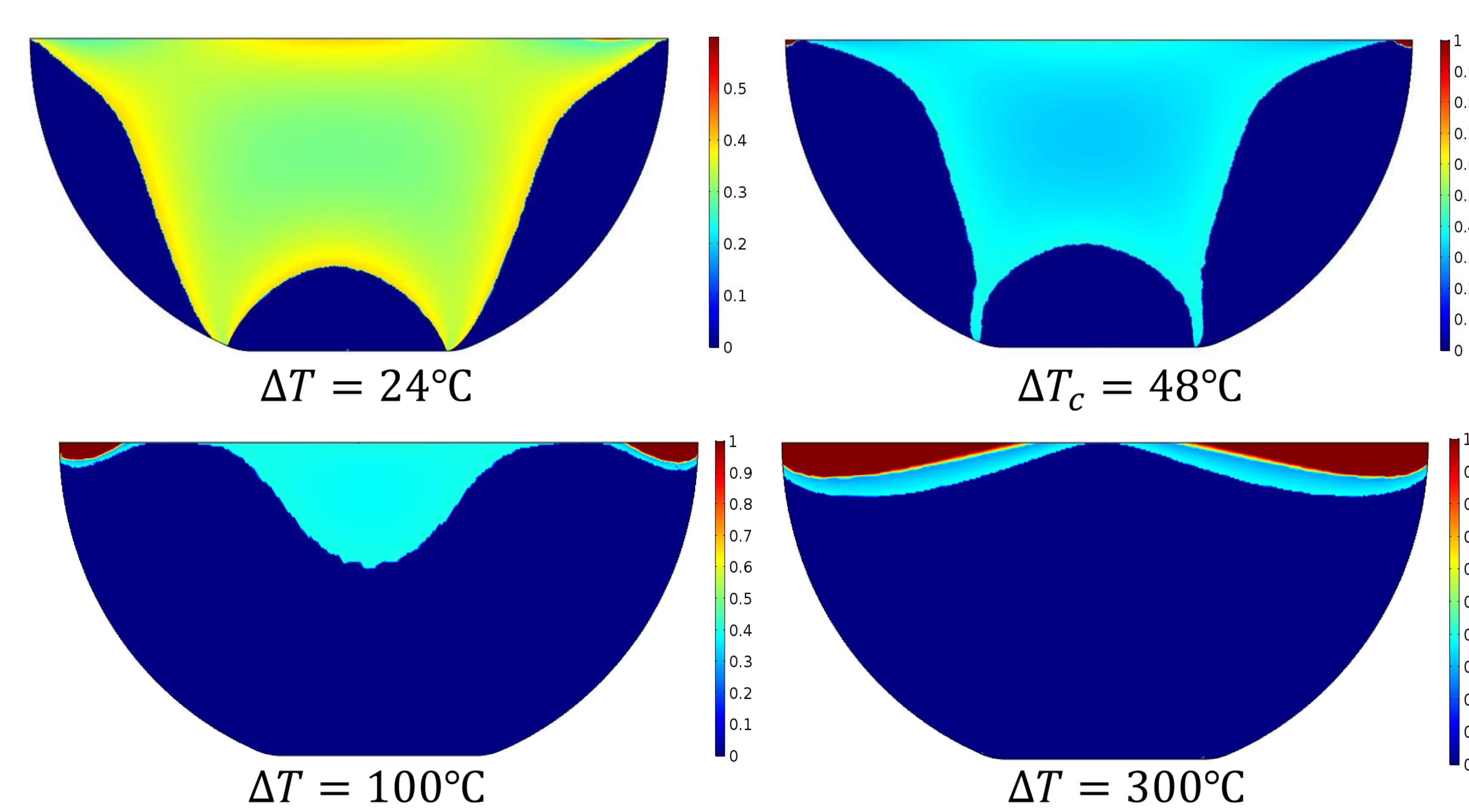

Figure 5. Thermal-mechanical analysis of asperity: (a) compaction with response to different temperature difference and (b) temperature distribution after cooling at $\Delta T = 300$°C.

CONCLUSIONS: Two stages of damage take place with increasing temperature difference (Fig. 4a):

1. the first stage is degradation of stiffness in the center region of asperity (Fig. 5a&5b);
2. the second stages correspond to damage of element towards radial direction (Fig. 5c&5d).

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2. J Mazars, G Pijaudier-Cabot, Continuum Damage Theory – Application to Concrete, J. Eng. Mech., 115, 345-65 (1989)