Project 10046 Final Report

The Effect of Strain-Rate on the Generation of Off-Fault Damage In the Process Zone of an Earthquake

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It is generally accepted that there is an intimate relation between fault zone structure and earthquake mechanics. Stress concentration at the tip of an earthquake rupture has been shown to be capable of fracturing rock to distances of 10s of meters. The abundance of "pulverized rock" adjacent to the fault plane of major faults provides field evidence for the plausibility of this phenomenon. It has also been demonstrated experimentally that the presence of pulverized rock adjacent to a fault plane can have a strong effect on the rupture velocity. Further, the propagation of a rupture along one edge of a highly-fractured fault zone can produce a strong asymmetry in the propagation direction – even to the point of producing unidirectional propagation.

There have been many recent attempts to numerically model rupture propagation in the presence of off fault fracture damage. The question is: how does one best represent the damage? Three approaches have been pursued: Coulomb plasticity, continuum damage mechanics, and micromechanical damage mechanics. Our group has pursued the latter approach by building the Ashby and Sammis (1990) micromechanical damage mechanics into the ABAQUS dynamic finite element code. The Ashby/Sammis damage mechanics models the nucleation, growth, and interaction of fractures that form by frictional sliding on preexisting flaws (fractures and grain boundaries). It has the advantage that it incorporates enough fracture mechanics to naturally accounts for the size and density of these preexisting flaws.

A problem with the Ashby/Sammis micromechanics is that it is quasistatic; it always assumes that the evolving damage is in equilibrium with the instantaneous stress field. While this is a good assumption when modeling triaxial laboratory experiments which are typically performed at relatively low stressing rates, it is a poor assumption for the high stress-rates near the rupture tip of an earthquake rupture traveling at several kilometers per second (as well as for other phenomena of geophysical interest such as the non-linear source regime of underground nuclear explosions and meteorite impacts).

In collaboration with Professor Ares Rosakis at Caltech (with support from the Southern California Earthquake Center), we have introduced dynamic fracture mechanics into the Ashby/Sammis micromechanics. In the new model, both the nucleation and growth of fractures depends on the loading rate in a way that is consistent with recent experimental and theoretical investigations. A manuscript describing this work is currently being prepared for publication in Mechanics of Materials. Rather than reproduce the manuscript here, I show below the key figure.

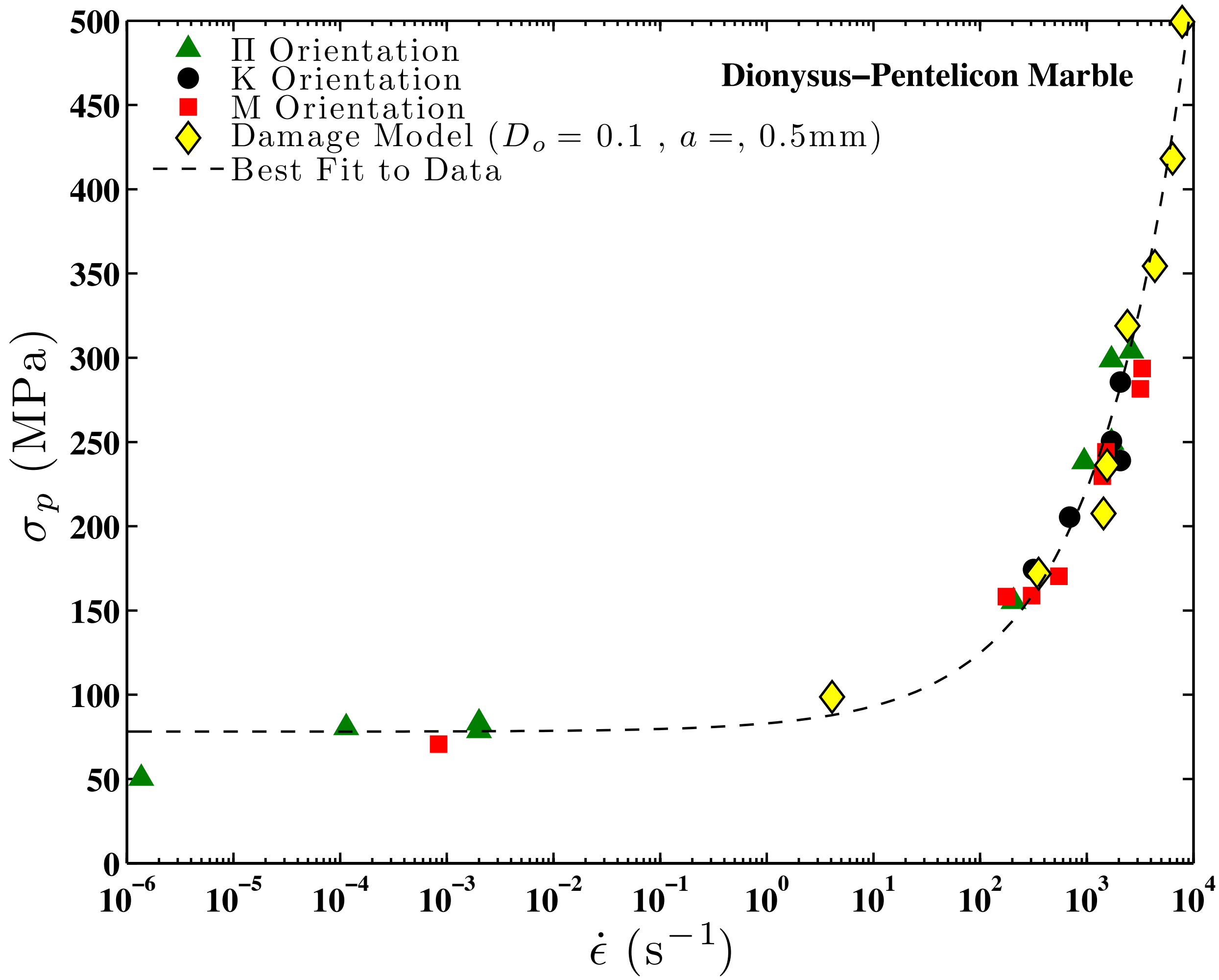

Figure 1. Comparison between experimental measurements of the strength of Pentelicon marble as a funtion of loading rate and the predictions of our dynamic damage mechanics model (Bhat, Rosakis, and Sammis, 2011, in preparation)

In Fig. 1 we have used our model to calculate the strength of Pentelicon marble (from the Parthenon in Greece) over a range of 10 orders of magnitude in loading rate. It should be noted that the rate dependence comes out of the physics of rupture nucleation and growth at high loading rates – the only parameters in the model are the size and density of the initial flaws.

Having validated our approach at high loading rates, the next step is to simulate earthquakes in order to explore the relation between fault zone structure and earthquake mechanics – particularly the case of multiple earthquakes on a large fault.