Fractal particle size distribution of pulverized fault rocks and dynamic fragmentation of rocks

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Earthquake is a catastrophic phenomenon caused by the rapid slip on fault. Development of high-speed rotary shear apparatus enables us to conduct friction experiments of various rocks at seismic slip rates to investigate dynamic fault behaviors [1]. The nominal strain rate at the seismic slip reaches 100 /s under the slip rate of 1 m/s occurring across the 1 cm width of the slip zone. On the other hand, the field observations along large-scale strike-slip faults reported the peculiar fault rocks with in-situ shattered microstructures [2]. The rocks are called pulverized fault rocks and characterized by a lack of shear deformation and intense fragmentation. These intensive damage zones have been suggested to form dynamically during earthquake rupture propagation. Theoretical calculation of the rupture propagation predicts much higher strain-rate deformation exceeding 10000 /s near the rupture tip [3]. However, because such high strain rate can be achieved only along the very close to the tip, several models have also been proposed to explain the wide distribution (~ 100 m from the fault core) of the pulverized rocks along the fault [2,4,5]. From the microstructural analysis of pulverized rocks, we reported the measurements of size distributions of fractured particles [6]. Fragments in those rocks in both fault zones show a fractal size (power-law) distribution down to the micron scale. Fractal dimensions of fragments, dependent on mineral types, reaches 2.92 near the fault cores. The value exceeds a theoretical upper fractal limit of confined comminution (~2.58 [7]) and experimentally created gouges by high-speed friction experiment (~2.6 [8]). Fractal dimensions close to 3.0 have been reported in high-speed impact loading experiments. The observed fractal properties imply that pulverization is likely to have occurred by a dynamic stress pulse with instantaneous volumetric expansion, possibly during seismic rupture propagation similar to impact loading. The obtained results from fractal properties of the pulverized rocks are consistent with laboratory experiments for dynamic fragmentation of rocks using Split-Hopkinson Pressure Bar (SHPB or Kolsky Bar) apparatus [5, 9]. SHPB is a loading apparatus that transmits planar elastic compressive waves into a sample under strain rates of 10 ~ 1000/s. Using the apparatus, Doan and Gary [5] clearly showed that the high strain rate exceeds 150 /s is required to cause pulverization of granite. Moreover, from the analysis of grain size distribution of fragments created by SHPB experiments of fine-grained novaculite, Barber and Griffith [9] showed that energy dissipation by fragmentation is not trivial than previously considered (10 % to as much as 40 %). According to dynamic fragmentation model by Hild [10], strength of rocks in multiple fragmentation regime dramatically increases with strain rate. This implies that the significant strain-rate hardening accompanying pulverization may be the responsible for the significant energy sink of the earthquake [9]. In the presentation, we review the dynamic fragmentation phenomena based on field evidence, theoretical models and laboratory experiments using SHPB apparatus to shed light on the dynamic fault behavior.

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