# Paradox in Rupture Propagation Velocity

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According to the Griffith fracture criterion, rupture propagation velocity is determined by the balance between the supplied energy (e.g. elastic strain energy) and the consumed one (e.g. fracture energy). Generally, rupture propagates with the velocity slower than S- wave velocity for Mode 3 and slower than Rayleigh wave velocity for Mode 2 rupture. In Mode 2 case, when the supplied energy is extremely large or the consumed energy is extremely small, the rupture propagates faster than the S wave velocity but still slower than the P wave velocity (termed supershear or intersonic rupture).

Recently, there are some experimental reports that the rupture can propagate faster than the P wave velocity (termed supersonic rupture). Gori et al. (2018) observed supersonic rupture propagation along a polymeric material interface by identifying the shock wave front of P waves with the high speed DIC measurement. Fukuyama et al (2019) found an emergent slow slip (EMS) events that propagates faster than the P wave velocity during the meter-scale biaxial rock friction experiments. The characteristics of the EMS events are as follows: 1) The onset of source time function was gentle compared to the regular stick slip (RGS) events. 2) Elastic waves were emitted at the rupture front of the EMS events. 3) Predominant frequency of the emitted waves was low compared to the RGS events. 4) Amount of stress drop was similar to that of the RGS but total amount of slip was about 1/5 of RGS.

It was reported that supersonic rupture occurred only when the extremely large energy was supplied for the rupture initiation (e.g. Gori et al., 2018). However, Fukuyama et al. (2019)'s data indicated that the supersonic rupture could occur even without large external energy supply. This could be achieved since the onset of the EMS rupture was very gentle and the consumed energy at the rupture front was small. Nevertheless, wave radiation was observed, which could be considered as a sort of shock wave generated at the supersonic rupture front.

If we assume that the EMS events occurred on a zero-thickness boundary between two rock specimens, all materials will behave elastically and all information has to propagate with elastic wave velocity. In this case, the rupture velocity cannot exceed the elastic wave velocity. In contrast, when a thin layer exists on the fault, which sheared during the EMS events, the thin layer could be deformed nonlinearly with high strain rates as Fukuyama et al. (2019) proposed. In this case, the rupture can propagate faster than the elastic wave velocities.

In summary, recent experimental observations raise a paradox with regard to rupture propagation velocity, which seemed difficult to resolve by the classical fracture mechanics theories. Therefore, we need to construct physical models to explain these new phenomena.