A new paradigm to study dynamic shear crack propagation and friction evolution

V. Rubino[1,2*], A. J. Rosakis[2], N. Lapusta[3,4]

[1]Institut de Recherche en Génie Civil et Mécanique, Ecole Centrale de Nantes, 1 rue de la Noë, 44321 Nantes, France, vito.rubino@ec-nantes.fr
[2] Graduate Aerospace Laboratories, California Institute of Technology, Pasadena, CA, USA
[3]Seismological Laboratory, Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA, USA
[5] Division of Engineering and Applied Science, California Institute of Technology, Pasadena, CA, USA

Experimentally measuring the behavior of dynamic cracks is very elusive due to metrological challenges associated with the high speeds of deformation. Yet, physically based models of dynamic cracks require key inputs from experimental measurements. In this work, we present our novel experimental approach to study dynamic shear cracks and friction evolution in real time, using the digital image correlation (DIC) method.

Characterizing dynamic shear cracks and how friction evolves poses several metrological challenges as it is difficult to measure the full-field velocities and stresses close to the interface during sliding. Our approach is based on digital image correlation combined with ultrahigh-speed photography. To capture the highly transient nature of dynamic cracks we employ frame rates of up to 2 million frames/sec and a highly-tailored analysis [1,2]. Our experimental configuration features two quadrilateral plates in contact over an inclined frictional interface, loaded in shear and compression. The plates are made of a polymer, typically either Homalite-100 or PMMA. Dynamic rupture is initiated by the small pressure discharge due to a thin filament of NiCr placed across the interface.

Our measurements allow us to visualize the full-field behavior of spontaneously evolving dynamic shear cracks and to characterize the patterns of sub-Rayleigh and supershear ruptures with a level of accuracy that, until recently, was only possible to achieve with numerical simulations [2,3]. Our detailed measurements also reveal the highly heterogeneous structure of the strain rates, which has profound effects on the rupture behavior due to the strain-rate dependent nature of the tested polymers [4].

Friction plays a central role in rupture propagation along interfaces and it influences a broad class of issues, including rupture nucleation, propagation, and arrest. We find that friction evolution is consistent with the rate-and-state friction laws combined with flash heating weakening mechanism but not with the widely used slip-weakening laws. Our recent experiments along interfaces enriched with granular materials, reveal an even more complex behavior characterized by intermittent rupture propagation [5]. The shear strength of the compressed granular layers initially increases, inhibiting rupture propagation, but later drops promoting rupture re-nucleation. Our observations of the weakening and strengthening behavior of friction in fine granular materials show the pronounced dependence of their rheology on slip velocity and related processes, such as shear heating, and localization and delocalization of shear.

References

[1] A. J. Rosakis, V. Rubino, N. Lapusta, Recent milestones in unraveling the full-field structure of dynamic shear cracks and dault ruptures in real-time: from photoelasticity to ultrahigh-speed digital image correlation, J Appl Mech, 87 (2020), 030801.

[2] V. Rubino, A. J. Rosakis, N. Lapusta, Full-field ultrahigh-speed quantification of dynamic shear ruptures using digital image correlation, Exp Mech, 59 (2019), 551-582.

[3] V. Rubino, A. J. Rosakis, N. Lapusta, Spatiotemporal properties of sub-Rayleigh and supershear ruptures inferred from full-field dynamic imaging laboratory experiments, J Geophys Res, 125 (2020), e2019JB01892.

[4] M. Gori, V. Rubino, A. J. Rosakis, N. Lapusta, Pressure shock fronts formed by ultra-fast shear cracks in viscoelastic materials, Nat Commun, 9 (2018) 4754.

[5] V. Rubino, A. J. Rosakis, N. Lapusta, Intermittent lab earthquake in dynamically weakening fault gouge, Nature, 606 (2022) 922-929.