Nucleation of frictional sliding at non-uniform interfaces

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We study the quasi-static nucleation process of friction along interfaces with non-uniform properties. Our simulations and theoretical models demonstrate the existence of three distinct nucleation regimes and provide a stochastic description of macroscopic frictional strength of interfaces. Our results show that nucleation may occur through coalescence of localized slip patches, and that known solutions from linear stability analysis provide for most cases an accurate description of the critical nucleation length. Finally, we show how the local properties of interface non-uniformity affects the macroscopic strength using a Monte-Carlo model.

Keywords (from 3 to 5 max): frictional rupture fronts, nucleation, instability, linear elastic fracture mechanics

1. Introduction

The onset of frictional motion is mediated by the propagation of rupture fronts, which nucleate quasi-statically in a localized region and slowly increase in size. When a rupture reaches a critical nucleation length it becomes unstable, propagates dynamically and eventually breaks the entire interface, leading to macroscopic sliding. The nucleation process is particularly important because it determines the stress level at which the frictional interface fails, and therefore, the macroscopic friction strength. Here, we study the nucleation process along slip-weakening interfaces with varying local non-uniformities and analyze the link between small-scale defects and the macroscopic stability of the frictional interface.

2. Methods

We apply a combination of numerical simulations and theoretical models to study the nucleation of local slip at interfaces with non-uniform strength profile. For our numerical simulations, we use an open-source implementation [1] of the Spectral Boundary Integral (SBI) method, which is a computationally efficient and precise method for modeling failure of interfaces.
Furthermore, we apply linear stability analysis and stochastic calculus to provide analytical references and establish a relation between small-scale properties of random friction profiles and their macroscopic performance. Finally, we develop and apply a Monte-Carlo model [2] for a statistical description of macroscopic friction strength.

3. Discussion

Our results show that interfaces with small correlation lengths present a non-smooth nucleation process with coalescence of localized slip patches (see Fig. 1) [3]. These subcritical systems are characterized by a relatively high macroscopic strength, which corresponds to the averages interface strength (homogenization limit). Conversely, interfaces with large correlation lengths follow a homogeneous nucleation process, and the macroscopic strength is low as it corresponds to the (global) minimum of the local interface strength profile. Interestingly, there is an intermediate critical regime, where the correlation length is similar to the nucleation length, and coalescence dominates the nucleation process leading to macroscopic strength considerably lower than existing theoretical predictions.

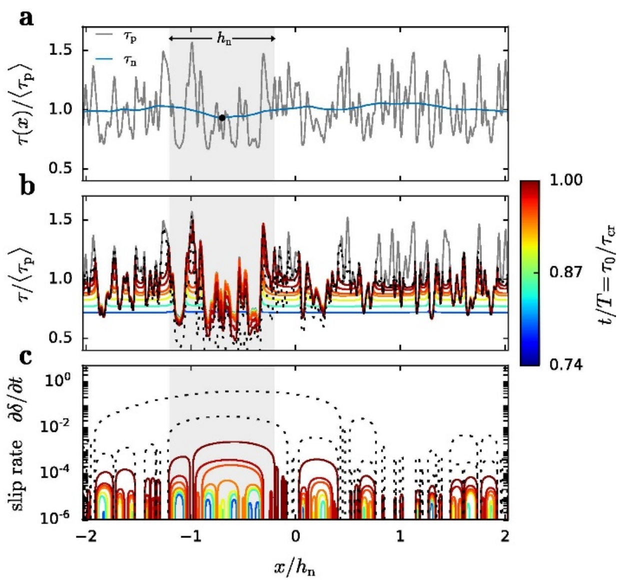

Figure 1: Nucleation of frictional sliding at interface with random strength profile occurs through a combination of continuous growth and coalescence. Figure taken from [3].

4. References

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