Spontaneous Emergence of Static Friction Force and Vanishment of Dynamic Friction Force in Slip Front Propagation

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We show spontaneous emergence of static friction force and vanishment of dynamic friction force in the dynamics of slip front propagation with local friction law nonlinearly depending on the slip velocity, which has no static friction force. We consider a block on a substrate and load one side of the block to slide it against the substrate. We take x axis along the loading direction and the block is assumed to be a semi-infinite isotropic homogeneous medium occupying the region $z>0$. The substrate is a rigid plane at $z=0$. The slip of block at x \to \infty is fixed to be zero and we load the block at x \to -\infty to initiate the slip. We employ the friction law having a quadratic form of the slip velocity, and derive the steady state solution for the motion of the slip front; the friction force tau is given by $-av^2 +2abv$, where v is the slip velocity and a and b are constants. With this friction law, the sliding friction force changes from the velocity-strengthening to the velocity-weakening behaviors with increasing slip velocity. This friction law enables us to treat the problem analytically, because the friction force is a single valued function of the slip velocity.
We can obtain the profiles of the slip and the strain of the steady state of the slip front dynamics, which is found to give the relationship between the strain at x \to -\infty (the loading point) p_{inf} (<0) and the slip front velocity c; $|p_{inf}|=2b/c$. It is also important to note that c must be smaller than the bulk elastic wave velocity v_e for the existence of the steady state. These statements indicate that p_{inf} has the critical value. If $|p_{inf}|<2b/v_e$, the steady propagation cannot be observed and the slip amplitude decays with increasing time. On the other hand, if $|p_{inf}|>2b/v_e$, the steady propagation of slip appears. These behaviors imply spontaneous emergence of the static friction force even though the local friction has no static friction force. Macroscopic static friction force is given by $2bE_1/v_e$, where E_1 is the Young modulus.
The analytical result obtained in the present study also indicates the slip velocity at $x_1(=x-ct)$ \to -\infty is $2b$, which results in that the friction force at the loading point in the steady state vanishes since tau is zero with $v=2b$. The dynamic friction force in the steady state is concluded to vanish spontaneously at x_1 \to -\infty.

Keywords: Static Friction Force, Dynamic Friction Force, Nonlinear Friction Law, Analytical Solution, Slip Front Propagation

