RING epl A LETTERS JOURNAL EXPLO

A crease characterized by strains $\epsilon \sim 1$ within a volume $V \sim (0.3\ \text{micron})^3$ would be a strongly athermal object; in polyacrylamide with shear modulus $G \sim 1$ kPa, its elastic energy would be of order $GV\epsilon^2 \sim 10^4 k_B T$. Here, however, we consider the possibility that compression-induced, non-affine fluctuations can act as an "effective temperature," endowing a micro-crease with an "effective entropy". This viewpoint leads to a novel mechanism for the formation of micro-creases that can be regarded as precursors to macro-creases. Furthermore, the essential features of our proposed micro-creasing mechanism are amenable to simple analytic calculations, by virtue of a domain decomposition that relegates nonlinear elasticity to small, energetically inconsequential regions analogous to vortex cores.

The main content of this letter is a new quasi-particle framework for shear stress focusing in soft solids, assuming planar geometry and neglecting surface tension. We consider the formation of micro-creases from within this framework, finding evidence that i) creasing onset maps to the Kosterlitz-Thouless (KT) transition [26], ii) nonlinear deformations can be decoupled from linear, and iii) compression-induced shear strain fluctuations set the fundamental, microscopic lengthscale in the problem. Our theory makes contact with experimental results on critical strain and crease surface profiles. In particular, we obtain a universal critical compressive strain $\epsilon_c \approx 30\%$ above which creases emerge. Finally, the theory points to a set of minimal physical ingredients for creasing, and suggests a possible unification with ridging (formation of localized surface protrusions) [27], and dimple crystallization [28,29].

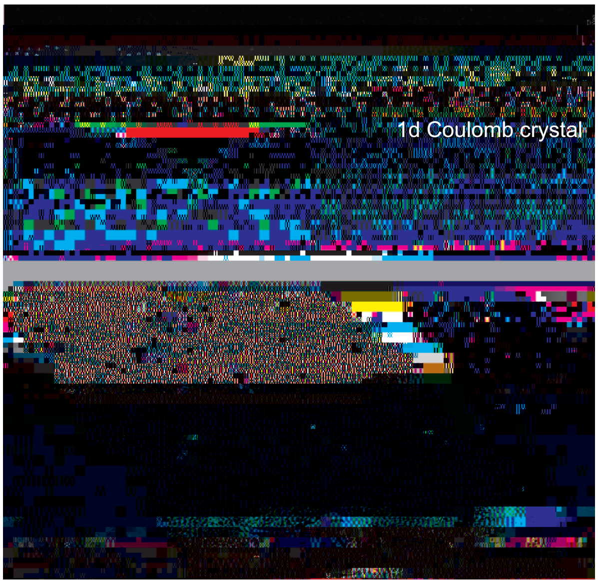
Our point of departure from prior work is to consider a distinct regime of zero-length creases, qualitatively similar to those observed in [6–8], immediately upon nucleation, and those in [16], as the critical point is approached from above. Deformations reminiscent of these zero-length creases also appear in a very different continuum elastic context, namely the shear lag model of composite materials science and engineering [30,31]. In this model, which will become foundational to our theory of micro-creasing, one assumes that shear coupling is supported at the interface between a low-dimensional reinforcing phase (i.e., 1d fibers or 2d slabs) and a surrounding 3d matrix phase. Next, an approximation is made that the transfer of axial loads between the two components is accomplished entirely via tension or compression in the reinforcing phase, and pure shear in the matrix. Axial loads refer to external or internal forces (such as those arising from differential growth of the two components) acting parallel to a long axis of the reinforcing phase. In the case of a fiber-matrix composite, the model predicts that matrix shear stress and strain fall off as $1/r$, where r is the perpendicular distance

$\frac{1}{2}\lambda_d\sqrt{\langle\Box_d^2\rangle}$. This triangular waveform represents an idealized surface roughness profile arising from the non-a□ne displacements. We further assume conservation of the area of the free surface, i.e., as the slab is compressed, the surface concertinas between stress concentrators. (Qualitatively similar roughening behavior has been observed for polycrystalline metal under compressive plane strain [39].) Setting the lattice constant s equal to the largest lengthscale over which shear strain is constant in this model, namely $\lambda_d/2$, , we then find $\Box_c = 1-(1+K_c^{-1})^{-1/2} = 38\%$ (mean-field theory) and = 30% (renormalization group), which bracket 33%.

o .n o n. .on

Two important features of creasing experiments remain to be explained by our quasi-particle theory: i) that only creases and not anticreases appear to be seen, and ii) that zero-length creases smoothly become finite-length creases. In this section we consider i), and in the next section we will consider ii).

The KT transition does not involve (or at least, does not require) self-contact in the core region. Yet self-contact is generically observed [7,8,14,16,22]. We propose that self-contact ensues at strain $\Box_{sc} > \Box_c$, and point out that it can only be available to creases, because a self-contacting anticrease is an unphysical concept. Anticreases shoul(sc1(a)0(s)0.2(6)0.9.9626394(to78454.3303Tm/Tc1-292.5(thc)0.5(c)0.5(r)


1d Coulomb crystal

and vice versa (see, e.g., ref. [47]). In the electrostatic picture, the essential di erence between surface and interfacial creasing is in the behavior of the charge density 2πR tan(θ