Crackling noise in a discrete element model of shrinkage induced cracking

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Shrinkage induced cracking of thin material layers attached to a substrate gives rise to spectacular polygonal crack patterns. Examples range from drying lake beds through paint layers in art and industry to the columnar joints formed in cooling volcanic lava [1]. Laboratory experiments with desiccating layers of dense suspensions like coffee, clay, and calcium carbonate [1, 2] on rigid substrates revealed that the emerging crack patterns have a cellular structure with a high degree of isotropy in the crack orientation. Recent experiments have demonstrated that applying mechanical perturbation, e.g. vibration to a dense paste before desiccation sets on, the structure of the emerging crack pattern becomes anisotropic, and its structural features can be tuned by controlling the perturbation. Due to its technological potential for microelectronic manufacturing, it is important to explore the intermittent dynamics of shrinkage induced cracking in the presence and absence of anisotropy, where realistic computer simulations are indispensable.

To investigate shrinkage induced cracking phenomena, recently we have introduced a discrete element model which captures the essential mechanisms of crack nucleation and growth in the shrinking layer attached to a substrate, furthermore, the model allows for a representation of anisotropic material properties with a controllable degree of anisotropy [3]. In the model the layer is discretized in terms of randomly shaped convex polygons, which are coupled by beam elements representing their cohesive contacts. Shrinking of the layer is modelled by gradually reducing the natural length of beams, while adhesion to the substrate is ensured by springs connecting the polygons to the underlying plane. Based on computer simulations of the model, here we investigate the temporal evolution of the accumulation of damage in the shrinking layer.

In particular, we demonstrate that cracking of the shrinking layer proceeds in bursts which are trails of correlated local breakings. Single bursts are characterized by their size, and duration, which both fluctuate in broad ranges due to the inherent disorder of the layer material. Our simulations revealed that the probability distribution of the burst size and duration exhibit power law behaviour with exponents which have a weak dependence on the degree of anisotropy. The size and duration of bursts are correlated since larger bursts typically grow for a longer time, which is expressed by a power law relation of the two quantities.

Most notably, we show that the average temporal profile of cracking bursts has a nearly symmetric parabolic shape, which indicates that burst start slowly then accelerate and stop gradually. Based on a careful numerical analysis we obtained the scaling structure of profiles of different durations and gave a detailed characterization of the form of the scaling function.

References

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