Triangular fractographic patterns reveal the nature of slip-stick transition in polymeric materials

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Polymeric materials like PMMA are materials with a highly intertwined network of polymeric chains and on the application of external force, exhibit two distinct mechanisms of fracture. At slow crack propagation polymeric chains of PMMA are first stretched and then broken one-by-one. At larger speed the energy supplied at the crack tip is sufficient to directly break the polymeric network without allowing for the prior elongation of the polymeric chains. Interestingly, if the crack is driven at some intermediate range of velocity, then the crack begins to oscillate from one mechanism to the other switching from a fast propagating crack to a slow velocity crack. This phenomenon is referred to as stick-slip instability in crack propagation [1, 2] and is observed in several other systems like during the peeling of a thin film or the sliding of a frictional body although emerging from different competing mechanisms. When a crack is in fast propagation regime (slip phase), the fracture surface is optically smooth while it is rough for crack in the slow propagation regime (stick phase). Interestingly, at the transition between the slip phase and the stick phase, the fracture surface exhibits repetitive triangular features with the triangles starting from smooth and propagating to rough region.

To get more insights on the mechanisms governing the transition from slip to stick fracture, we analyze the fracture surface and find a unique recurring triangular pattern in the transition zone. A closer look at the crack front geometry within this transition regions shows that the crack line is reminiscent of a planar crack pinned by a tough obstacle of constant width [3]. To understand this further, we analyze the problem of a brittle crack front pinned by a triangular obstacle of large toughness. This problem can be solved exactly using Rice's work which provides the distribution of the elastic energy along a perturbed crack front. The deformed shape not only depends on the toughness contrast (C) of the obstacle but also on the ratio ϵ of the growth speed of the obstacle along the crack front direction to a characteristic material velocity that emerges from the rate dependency of the fracture energy. This solution captures well the experimental front shapes observed on the fracture surfaces and interestingly provides us an estimate of the difference in fracture energies inside and outside the triangle. This is an indication that the transition from slip to stick occurs heterogeneously along the front through the nucleation of self-generating tough stick phase and their spreading along the crack front into the slip phase. The value of contrast C and velocity ratio ϵ selected by the material at the stick-slip transition will be finally discussed.

References

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