

# Looking into the science of fracture mechanics: examples of polymeric materials

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### Abstract:

Brittle fracture is conventionally understood to arise from intrinsic (structural) flaws. This brief allows one to characterize material strength by measurement of toughness through the use of the Griffith's law, i.e., the operational definition of critical energy release rate  $G_c$  for fracture. Brittle polymers including thermoplastics and vulcanized rubbers indeed obey the basic scaling for a precut specimen:  $\sigma_c \approx (G_c/E)^{1/2} a^{-1/2}$ , i.e., the critical stress for fracture  $\sigma_c \sim a^{-1/2}$ , where  $a$  is the size of the precut and  $E$  the Young's modulus. However,  $G_c$  being a material constant has mystified the community ever since it was found for a variety of materials including metals, ceramics and polymers that  $G_c$  was orders of magnitude greater than the energy required to create new fracture surface (known as surface fracture energy  $\Gamma$ ). Because  $G_c > \Gamma$ , we cannot rationalize why  $G_c$  is still a constant! Throughout the history, the consensus is to preserve the Griffith energy balance argument by suggesting that there are some other dissipative processes involved in fracture. If the person wishes to make tougher materials, the person looks for more dissipation mechanisms.

After an introduction of nonlinear melt rheology (episode 1) and chain-level mechanics of solid polymers (episode 2) to provide the background and motivation, I will develop episode 3 on fracture mechanics of polymers and discuss how our pursuit based on the second pillar (Westergaard) of linear-elastic fracture mechanics (LEFM) has allowed us to develop a comprehensive description of fracture behavior of polymers. Using polymers as "model materials", we are able to show for the first time why  $G_c$  is a constant, i.e., being material specific, and what parameters determines its magnitude. Specifically, during drawing of a precut specimen to the point of fracture, we apply time-dependent polarized optical microscopy (POM) to measure birefringence and map out the strain/stress field around crack tip for both plastics and elastomers. Being able to achieve spatial resolution (10 microns) required to quantify the near-tip stress field, our POM observations reveal emergent phenomenology in remarkable contrast to the theoretical framework of LEFM. The findings may provide new guidance in understanding and development of tougher polymeric materials and suggest that the criterion for fracture, i.e., spontaneous crack propagation, is the stress at crack tip exceeding the inherent material strength. Observed  $G_c$  is an effect not the cause. In short, the talk will show the unraveling of all aspects mechanical of polymeric materials.

### Bio:



Shi-Qing Wang arrived in US in 1982 through the CUSPEA program. He received PhD in physics from University of Chicago in 1987, working on hydrodynamic theory of dilute polymer solutions under Professor Karl Freed. After two years of postdoctoral research at UCLA, Shi-Qing Wang joined Macromolecular Science and Engineering Department at Case Western Reserve University in fall 1989. He moved to Polymer Science at University of Akron in fall 2000. He is Distinguished Professor and Kumho Professor of Polymer Science. He has published his first book Nonlinear Polymer Rheology in 2018 to show how a new paradigm describes the subject. In the subsequent and current episodes, he focused on chain-level and fracture mechanics of polymers in all forms (i.e., plastic, elastomeric and thermosetting). He plans to write a second book to summarize the emerging knowledge and understanding on all aspects mechanical of solid polymers. He was elected APS fellow in 1997 and AAAS fellow in 2014.

Monday, October 3<sup>rd</sup>, 2022 4:00 – 5:20 p.m.

1310 Yeh Student Center