Anticracks as localized damage with volume loss: overview and new experimental insights

Mathis Hach*[1], Elisa Kühn[1], Sebastian Spitzer[1,2], and Philipp Weißgraeber[1]

[1]Chair of Lightweight Design, University of Rostock – Germany
[2]Institute of Lightweight Engineering and Polymer Technology, TU Dresden – Germany

Abstract

The concept of anticracks is used to describe the localized damage under compression that is associated with negative mode-I stress intensity factors. Such localized damage can only appear and propagate within a material when a volume loss mechanism within the material exists. It has been shown that concepts of classical fracture mechanics can be applied to describe such phenomena.

Anticracks have been used to describe propagating volume loss phenomena in various domains. The concept was first formulated by Fletcher and Pollard (1981) to describe the behavior of localized compaction mechanisms in porous sedimentary rocks. In such cases, a local stress concentration leads to enhanced pressure dissolution and removal of minerals which leads to further localization of the stress fields and to planar extension of the compacted domain and movement of the stress singularity. Additionally, compaction bands in porous sandstones were analyzed and explained by this concept. Anticracks have also been used to describe the propagation of volume loss mechanisms occurring in phase changes of minerals under high hydrostatic pressure, which are associated with deep earthquakes. In snow mechanics, anticracks have been extensively studied in the context of dry-snow slab avalanches. Here, snow covers that contain highly porous weak layer exhibit a propagating collapse that extends below the slab and explains remote triggering of avalanches or the infamous whumpf-sound of instable slopes (Heierli et al., 2008). To analyze anticracks in snow covers extensive theoretical and experimental studies have been conducted, enabling the identification of fracture toughness values of anticracks under pure mode-I and mixed-mode loading conditions (Adam et al., 2024). In technical materials like highly porous foams or additively manufactured cellular structures the formation of anticracks has also been reported for negative mode-I loadings (Heierli et al., 2012; Shenhav and Sherman, 2019).

In contrast to these volume-loss damage mechanisms, the term anticrack has also been used to describe the singular stress field around rigid lamellar inclusions, which also exhibits a square root singularity. This concept has been used in micromechanics of composites with significant elastic contrasts.

In this work, we provide an overview of the concept of anticracks and compare anticrack models across various settings. We discuss the required extent of volume loss mechanisms, the associated time scales and the change of stiffness within the anticrack domain. The different applications of the anticrack concept imply different internal material mechanisms for lateral, planar propagation that are analyzed with respect to their brittle nature and energy

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*Speaker

dissipation mechanisms. The role of negative mode-I stress intensity factors in mixed-mode problems will also be addressed.

We show recent experimental findings on anticrack propagation in brittle highly-porous technical foams. Using microscope imaging and CT analysis we show the microstructural mechanisms associated with stable anticrack propagation in fracture mechanics specimens. Using digital image correlation, we provide insights into the elastic and inelastic strain fields in the vicinity of the anticracks. The results allow for an analysis of the energy dissipation during anticrack propagation.

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