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The effect of geometry on fracture strength measurement using DCDC samples

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ABSTRACT

The fracture behavior of poly(methyl methacrylate) (PMMA) is studied using double cleavage drilled compression (DCDC) experiments. Increasing sample thickness is found to increase the stresses required to propagate long cracks. Crack surface features show a correlation with regimes of crack growth. Decreasing hole size leads to significant inelastic deformation during testing and, after unloading, the formation of new stress-relieving cracks at the central hole. A computational model using the experimental data estimates the critical stress intensity factor of PMMA to be 0.6–0.75 MPa m$^{1/2}$. Photoelastic observations are used to compare experimentally observed and simulated stress distributions.

1. Introduction

The double cleavage drilled compression (DCDC) test is a suitable method for evaluating the fracture properties of brittle materials. Originally applied to glass [6], the test has been successfully applied to other materials [4,5,11,12] and interfaces in bi-material sandwiches [14]. The DCDC test subjects a column of material with rectangular cross-section and central circular hole to uniaxial compression (Fig. 1). The geometry and Poisson's effect create regions of tension at the apex and base of the hole, leading to mode I cracks. As the axial compression is increased, the cracks are driven along the length of the sample, slowly at first and then more quickly, until being arrested by frictionally-constrained end conditions.

Most DCDC experiments published in the literature have been conducted using increments of load to grow the cracks. Plaisted et al. [11] used displacement control for DCDC testing and observed two regimes of crack growth. The importance of sample height, width, and hole size was investigated. A theoretical model was developed combining short and long crack approximations. The model treats a DCDC sample with short cracks as an infinite plate containing a hole, with corrective factors accounting for the finite width. Once the cracks are sufficiently long, the DCDC sample is treated as a structure consisting of four beams bending under axial compression.

The DCDC geometry has been used to quantify healing in re-mendable polymers [12] and polymers containing microvascular networks [3]. There are several aspects of the DCDC configuration that lends itself to studying healing in these materials. Unlike the standard compact tension test, crack growth in DCDC samples is generally stable, and the crack length can be controlled by the applied compression. Since the cracks cease to grow before they reach the ends of the sample, the sample remains in one piece, allowing the crack faces to be brought together after unloading. This maximizes contact

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Nomenclature

E	Young's modulus
G	energy release rate
K_{Ic}	mode I critical stress intensity factor
l	crack length; measured from the edge of the hole to the tip of the crack
L	height of the DCDC sample
R	radius of the central hole in the DCDC geometry
t	thickness of the DCDC sample
U	internal energy
w	half-width of the DCDC sample
ν	Poisson's ratio
σ_a	axial stress applied to the DCDC sample

between the crack faces, which is necessary for effective healing. After the cracks have been healed, the sample can be retested. The new cracks will initiate and grow essentially in the same manner and over the same path as in the original virgin sample.

Healable materials can be difficult to produce and are often available in limited quantities. Repurposing a sample is one way to conserve material, but compromises must be made on the sample geometry to make it suitable for all experiments. Reviewing the DCDC literature, there is limited information on the effect of only some geometric parameters on the observed fracture behavior. In the present work, we investigate the effect of sample thickness and hole size using a readily available polymer: poly(methyl methacrylate) (PMMA). We complement this experimental work with a systematic computational simulation to estimate the critical stress intensity factor from the experimental data.

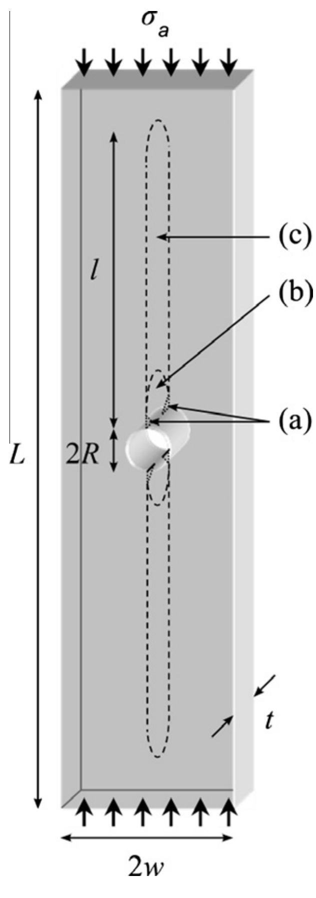

Fig. 1. A DCDC sample. Under compression, pre-cracks (a) grow together to form cracks (b), which grow along the height of the sample (c).