A New Stable Fracture Mechanics Test: Application to PMMA

Investigators: Dinakar Sagapuram[1], Ashlee Watts[2], and Arun Srinivasa[3]

Student Contributors: Harsha K. Narayanaswamy, Dhruvil Hareshkumar Shah, and Shwetabh Yadav

[1]Department of Industrial and Systems Engineering (COE) [2]Department of Large Animal Clinical Sciences (CVMBS) [3]Department of Mechanical Engineering (COE)

T3: TEXAS A&M TRIADS FOR TRANSFORMATION

A President's Excellence Fund Initiative

Abstract

This study aims to address a longstanding problem in experimental fracture mechanics, viz. the ability to produce stable cracks in highly brittle materials. We present a novel wedge fracture test for performing stable fracture mechanics tests in brittle materials and capturing the descending branch of the force-displacement curve. The method does not require sophisticated testing equipment and can be performed using common displacement-driven testing machines. The method is demonstrated with a brittle glassy polymer polymethylmethacrylate (PMMA). Details of the proposed test method and preliminary studies concerning the effect of various test parameters are outlined. Modeling work to quantitatively determine the fracture properties of brittle materials (both engineering and biological) based on the proposed test are under way.

Introduction

The measurement of the fracture properties of brittle or quasi-brittle materials is usually performed using conventional testing geometries such as three-point or four-point bending or by tension of single-edge or double-edge notched specimens. These methods unfortunately do not allow for recording the softening part of the fracture beyond the maximum load needed for determination of fracture mechanics properties such as the specific fracture energy and the strain softening diagram. Sophisticated testing and control devices are usually required to carry out fracture tests under displacement control beyond the maximum load.

The method presented here overcomes these challenges and enables controlled propagation of cracks in a stable manner or the so-called '*stable fracture mechanics*'. The idea is to split a brittle specimen in a controllable (as opposed to catastrophic) manner by controlling the strain energy that is fed into the specimen. This method, which involves driving a stiff wedge between two cleaved parts of the sample and called the 'wedge fracture test', allows us to achieve a quasi-static (stable) fracture since the crack growth is very stable due to the small amount of elastic energy stored.

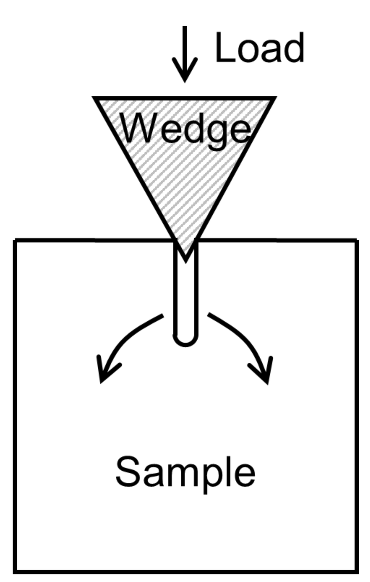


Figure 1. Proposed fracture test

Objectives

- Demonstrate stable crack propagation in brittle materials using a new wedge fracture test.
- Analyze the effects of wedge and sample geometry on crack formation and propagation dynamics.

Support from *T3: Texas A&M Triads for Transformation* Grant is gratefully acknowledged.

References

- MR Ayatollahi, MR Moghaddam, SMJ Razavi, and F Berto. "Geometry effects on fracture trajectory of PMMA samples under pure mode-I loading". *Engineering Fracture Mechanics*, 163:449-461, 2016
- FC Roesler. "Brittle fractures near equilibrium." *Proceedings of the Physical Society (Section B)*, 69:981, 1956.

Materials and Methods

The wedge and sample geometries used in the study are shown in **Figure 2**. PMMA samples tested included a 2 mm wide slot pre-machined into the sample and a sharp initial crack scribed at the tip of the slot.

All the experiments were carried out on a conventional MTS machine at slow speeds. A typical fracture experiment involved driving the wedge into a stationary sample until full separation of the sample or load drop to near-zero.

Two geometries were considered: 'Standard Sample' (3" by 2" by 1/4", slot length: 3/4"), and 'Elongated Sample' (6" by 2" by 1/4", slot length: 1.5").

Other test variables studied included the effect of edge radius at the slit entry, lubrication at the wedge-sample contact and the wedge penetration speed.

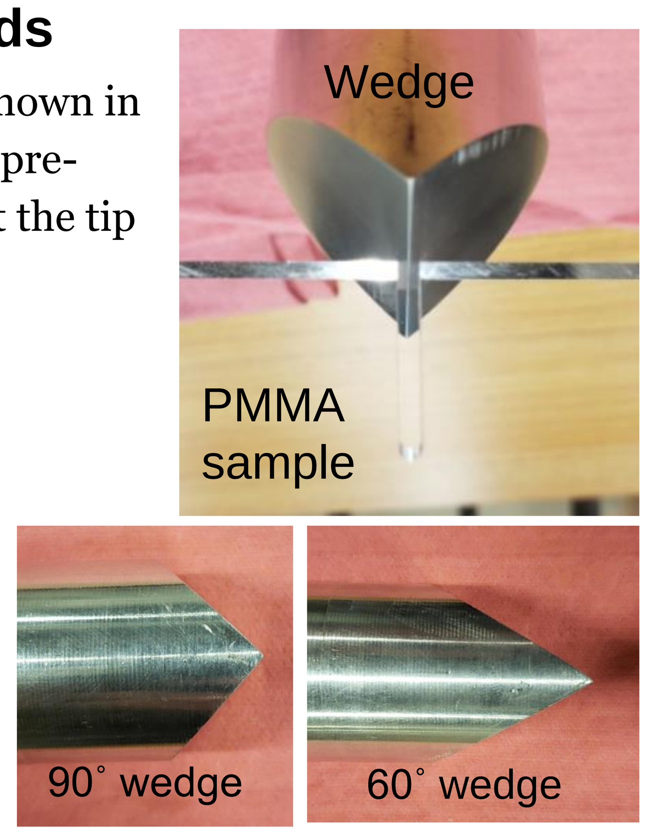


Figure 2. Wedge/sample geometry.

Results and Discussion

60º Wedge (Standard Sample)

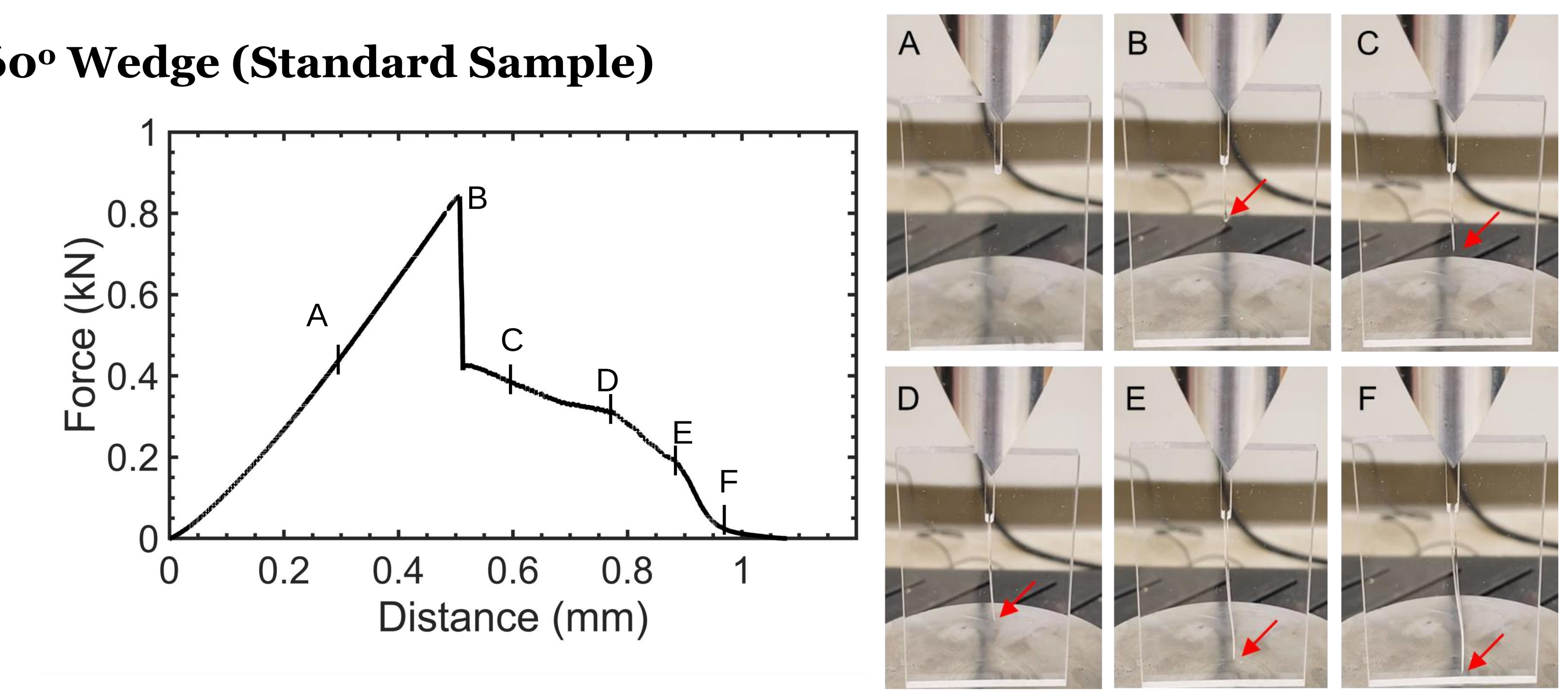


Figure 3. Force-disp. curve and corresponding images showing crack propagation (arrow)

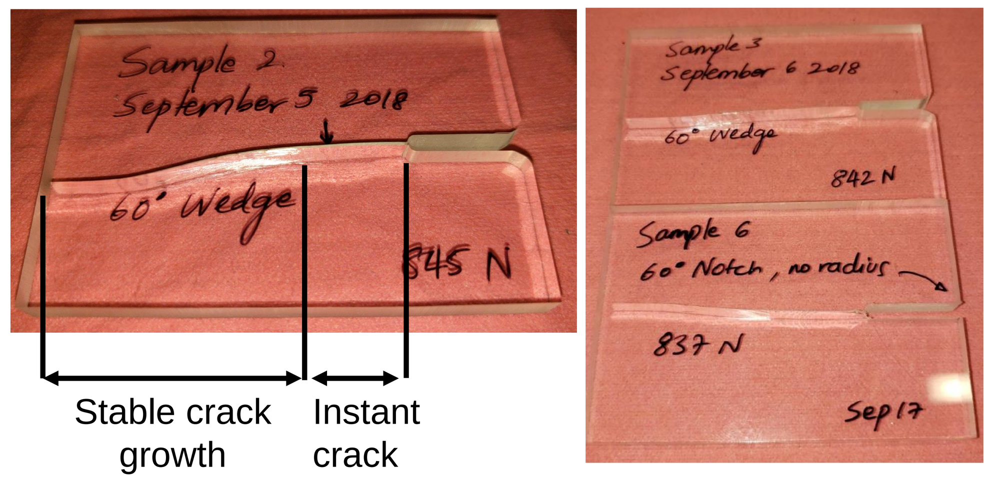


Figure 4. Fractured PMMA samples with 60º wedge.

Fracture behavior with a 60º wedge is characterized by instantaneous formation of a crack at maximum load, followed by stable crack propagation under a dropping load. The critical load at instantaneous crack formation (about 840 N) and subsequent stable crack growth behavior are quite repeatable from test to test.

90º Wedge (Standard Sample)

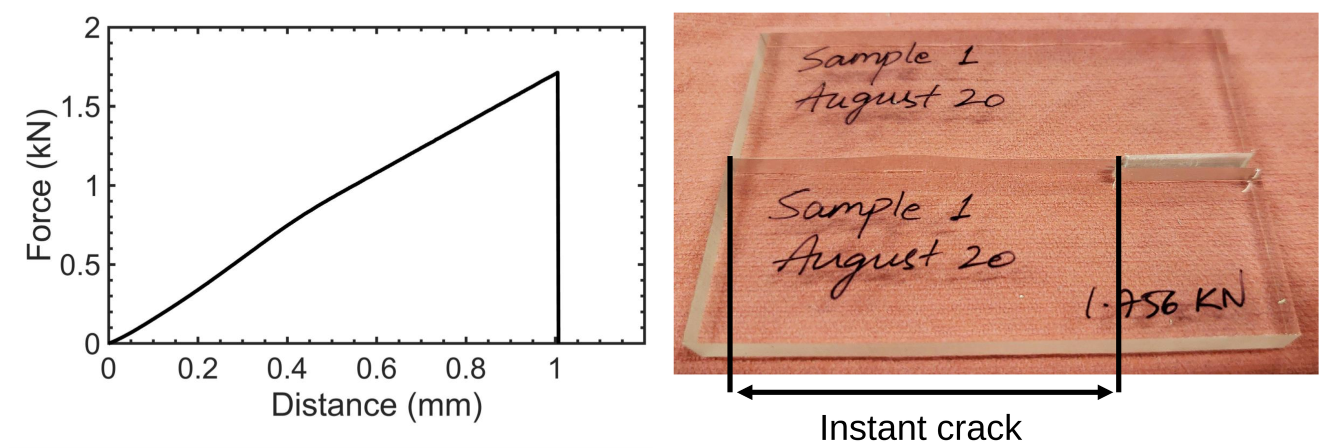


Figure 5. Fracture test with a 90º wedge.

Tests with 90º wedge resulted in instantaneous cleavage of the sample at a critical (maximum) load. No stable crack growth was found, likely due to the higher strain energy in this case. Load at fracture is about twice compared to 60º wedge and showed large scatter from sample to sample.

Results and Discussion

Elongated Sample Geometry

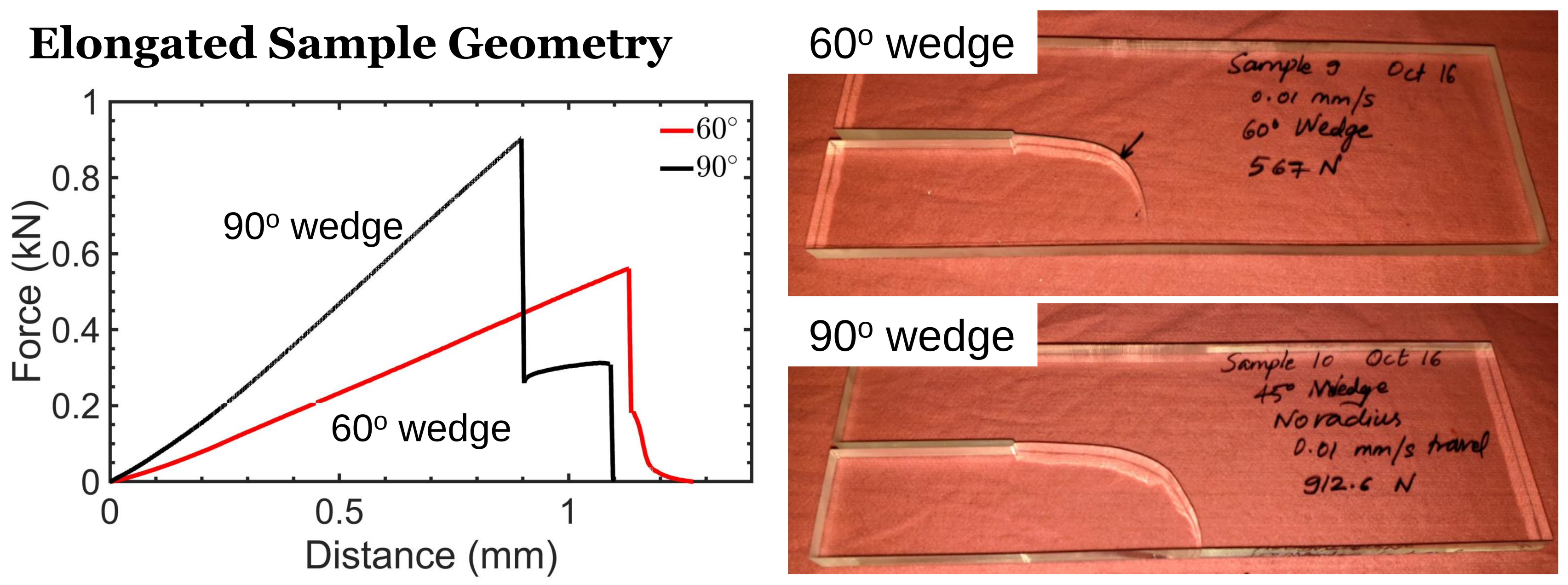
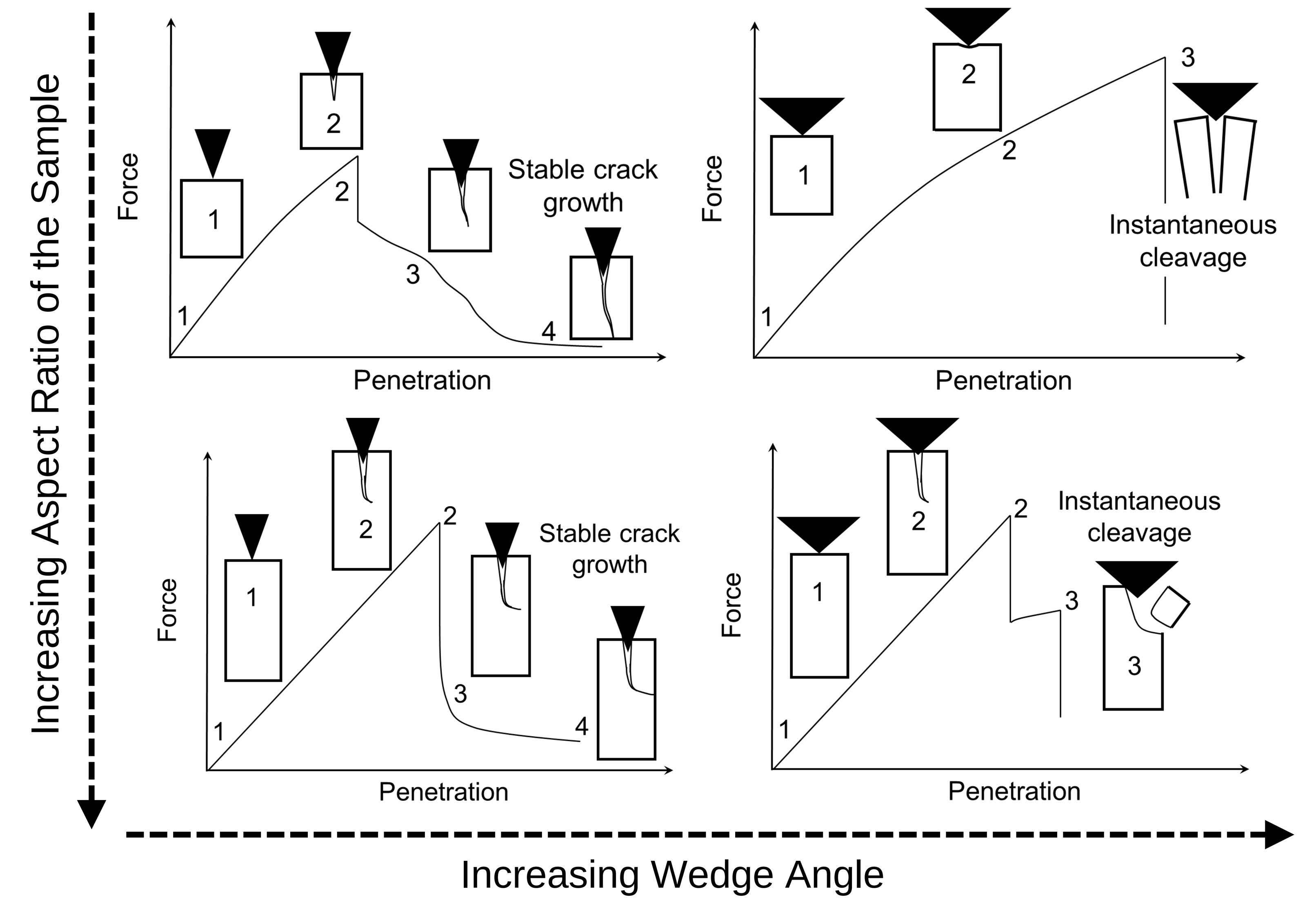


Figure 6. Test results with 'Elongated Samples'. Note the curving of cracks to the side.

Fracture tests with higher aspect ratio samples showed formation of cracks curved towards the side edge of the specimen. Similar to the standard geometry, 60º wedge first resulted in instantaneous crack (at maximum load), followed by stable crack growth towards the side edge. The crack curvature seems to have been established during the instantaneous crack nucleation phase itself.

No stable crack growth was observed with the 90º wedge. Specimen fracture occurred in two distinct stages: instantaneous formation of a curved crack at maximum load, followed by sudden cleavage of the sample after some additional penetration of the wedge.

Summary of Results



Concluding Remarks

Our study has shown that it is possible to produce stable cracks even in highly brittle materials such as PMMA using a simple wedge fracture test under low wedge angles (60º or less). The curved crack trajectory at higher sample aspect ratios is consistent with recent observations of crack curving under pure Mode-I loading of PMMA (Ayatollahi, 2016). The origin of this behavior is however less clear. Other experimental factors such as the slit edge radius and wedge penetration speed have little effect on the qualitative aspects of crack formation and subsequent growth, at least in the investigated range.

Efforts are under way to study the utility of this test method to produce stable cracks in "perfectly" brittle materials such as silica glass; such observations of stable cracks in glass are extremely rare (Roesler, 1956). A concurrent line of research includes coupling experimental results with finite element modeling for quantitative determination of fracture properties.