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Experimental investigation of dynamic crack propagation in PMMA plates

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Abstract

In this paper we present experimental data on dynamic crack propagation in square PMMA plates of two types – 3.5 and 20 mm thick. Samples were loaded dynamically (mode I loading type) and crack tip position was registered using high speed camera. Explosion of a copper wire due to high electrical current was used to load faces of the initially prepared cracks. In order to investigate stress intensity factor (K_I) history, method of caustics was applied. Thick samples demonstrated considerably higher values of final crack travel distance and higher crack velocity values. Additionally, dependence of stress intensity factor on crack velocity was observed.

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Keywords: crack propagation, dynamic fracture, stress intensity, caustic, PMMA

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Nomenclature

V	crack velocity (m/s)
K_I	mode I stress intensity factor ($MPa\sqrt{m}$)
C	condenser capacity (μF)
U	condenser charge voltage (kV)
E	energy stored in condenser (J)
$D(t)$	caustic diameter (m)
z_0	distance from the sample to the shadow zone (m)
c	shadow optical constant
d	sample thickness (m)

1. Introduction

Dynamic crack propagation is one of the most studied areas of dynamic fracture mechanics. This phenomenon has been studied theoretically (Freund 1998, Broberg 1960), experimentally (Ravi-Chandar and Knauss 1984a,b,c, Dally 1979) and numerically (Xu and Needleman 1994, Kazarinov et al. 2014, Bratov and Petrov 2007), however there are still many unsolved problems in this area, such as problem of a limiting crack velocity (Livne 2008, Sharon and Fineberg 1999) and ambiguity in stress intensity factor – crack velocity dependence (Dally et al. 1985).

One should note here, that two main types of experiments on dynamic crack propagation are usually carried out – with dynamic (Ravi-Chandar and Knauss 1984, Kalthoff and Shockey 1977) and quasistatic (Fineberg et al. 1992, Kalthoff 1983) loading. In both cases transient effects should be taken into account, as propagating crack tip generates time-dependent stress-strain state in the sample with multiple travelling waves and corresponding effects (Kalthoff and Shockey 1977). Both experimental approaches are time-consuming, since specimens need to be very thoroughly prepared and registration of a moving crack tip position and stress field, surrounding it, requires special equipment and precise synchronization. Moreover, for the case of dynamic loading custom testing machines are usually designed in order to apply pressure pulses to the samples.

In this work we present experimental results on dynamic crack movement in PMMA square plates specimens of two thicknesses –3.5 and 20 mm. Samples were loaded dynamically with pressure being normally applied to the crack faces and crack tip position was registered throughout the experiment. In addition to this data, dependence of stress intensity factor (K) on time was investigated.

2. Specimens and experimental techniques

Square PMMA plates of 200 mm side and 3.5 and 20 mm thickness were tested. Initial crack was 50 mm long. Tip of the initial crack was sharpened using a razor blade. Mechanical properties of the tested PMMA are listed in table 1.

Table 1. Material properties of the tested PMMA

Young's modulus (GPa)	5.9
Poisson's ratio	0.33
Density (kg/m^3)	1180
Ultimate stress (MPa)	75
Ultimate stress intensity factor (MPa$\sqrt{\text{m}}$)	1.1
Longitudinal wave velocity (m/s)	2720
Transversal wave velocity (m/s)	1370
Rayleigh wave velocity (m/s)	1277