THE INVESTIGATION ON DYNAMIC FRACTURE BEHAVIOUR OF MATERIALS UNDER COMPRESSION-SHEAR COMBINED STRESS WAVES*

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ABSTRACT: In this paper, an improved plate impact experimental technique is presented for studying dynamic fracture mechanism of materials, under the conditions that the impacting loading is provided by a single pulse and the loading time is in the sub-microsecond range. The impacting tests are carried out on the pressure-shear gas gun. The loading rate achieved is \( \frac{dK}{dt} \sim 10^8 \text{ MPa m}^{1/2} \text{s}^{-1} \). With the elimination of influence of the specimen boundary, the plane strain state of a semi-infinite crack in an infinite elastic plate is used to simulate the deformation fields of crack tip. The single pulses are obtained by using the “momentum trap” technique. Therefore, the one-time actions of the single pulse are achieved by eradicating the stress waves reflected from the specimen boundary or diffracted from the crack surfaces. In the current study, some important phenomena have been observed. The special loading of the single pulse can bring about material damage around crack tip, and affect the material behavior, such as kinking and branching of the crack propagation. Failure mode transitions from mode I to mode II crack are observed under asymmetrical impact conditions. The mechanisms of the dynamic crack propagation are consistent with the damage failure model.

KEY WORDS: single pulse, compressive-shear combined stress wave, pressure-shear gas gun

1 INTRODUCTION

There are two kinds of dynamic fracture experiments of materials. One is carried out on conventional installations, such as the Kolsky bar, in order to investigate the dynamic responses of materials near crack tips under the loading conditions of low impacting velocities\(^{[1-9]}\). The loading rates achieved are \( \frac{dK}{dt} \sim 10^{3-6} \text{ MPa m}^{1/2} \text{s}^{-1} \), and the loading duration of stress pulse is in microsecond ranges. At various loading rates, the cracking mechanisms of materials are brittle and/or ductile; the failure modes can be both of crack fracture and of adiabatic shear band; the transitions of failure modes and/or failure mechanisms, sometimes induced by unloading waves, are observed. The dynamic fracture toughness is very different from that under quasi-static loading. The micro-cracks around the crack tip may induce the propagating crack kink and branch. Owing to the limitation
of the present measuring technique and the influence of the boundary, it is impossible to study the mechanisms of the crack initiation and the stress wave diffracted from the crack surfaces in the tests.

However, tests can be conducted with the plate impact experiment carrying out on a pressure-shear gas gun\textsuperscript{[10,11]}. The loading rates are approximately $\frac{dK}{dt} \sim 10^8 \sim 10^9$ MPa m$^2$s$^{-1}$. Because no unloading waves reach the crack tip during the loading, the plane strain state at the crack tip is obtained, which is similar to a semi-infinite crack tip in an infinite elastic plate. Upon impact, the compressive waves, which are reflected from the rear surface of the specimen and subject the crack tip to step tensile pulses inducing the initiation of crack, are generated. The impact speed and ambient temperature affect distinctly the mechanisms of the crack propagation. The time of the crack initiation can be fixed on experimental velocity-time profiles, which will be useful in studying the mechanisms of the crack propagation. But two problems involving the studies are:

1) Before the step tensile pulses arriving, the crack tip has already subjected to a compressive wave. The influence of the compressive wave on the material properties in the vicinity of the crack tip and on the mechanism of the crack initiation is still poorly understood.

2) After the crack initiation, the stress waves are reflected from the specimen boundaries and diffracted from the crack surfaces. It is necessary to study the influence of the phenomena on the mechanism of the crack propagation.

The objective of the present work is to probe into these problems. In Section 2 a description of the plate impact experimental technique is provided, which allows for the study of dynamic fracture processes when the impact loading is a single pulse and the loading time is in the sub-microsecond range. The improved plate impact experimental processes are described in Section 3. The experimental results are analyzed in Section 4. Lastly the conclusions of the present work are drawn.

2 EXPERIMENTAL PRINCIPLES

According to the theory of elastic waves\textsuperscript{[12]} and combining with the experimental schemes of Refs. [2\textsuperscript{−}4] and [10,11] shown in Fig.1 (a) and (b), a plate impact experiment is designed to load a mode II crack by an asymmetrical single pulse, which possesses the sub-microsecond time scales, and impinges at both normal (Fig.1(c)) and oblique incidence (Fig.1(d)). The diffracted wave pattern of the normal impact is shown in Fig.2(a) when the

![Fig.1 Experimental arrangements of Refs.[2\textsuperscript{−}4] (a), [10,11] (b), and the present work (c), (d)]