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Dynamic Fracture of Ductile Materials

High-speed X-ray PCI and XRD during Dynamic fracture

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Abstract

When a crack or a shear band propagates in a ductile material under impact loading, there is a severe stress concentration and/or strain localization near the tip of the discontinuity. It has been understood that the locally severe and fast deformation can lead to phase transformation and heat generation. The adiabatic conditions cause the local temperature to rise. However, it has been a challenge to experimentally measure the microstructural evolution, such as crystal d-spacing, texture evolution and material phase transitions, associated with the dynamic deformation and fracture process of ductile metallic materials. It is also a challenge for optical high-speed imaging techniques to image the details of the advancing crack tip with sufficient spatial resolution. In the dynamic experiments presented in this article, we used Kolsky bars integrated with a simultaneous X-ray phase contrast imaging (PCI) and diffraction (XRD) technique to study the dynamic deformation and fracture processes during high-rate loading. In such a Kolsky bar experiment, high-speed imaging of the specimen deformation and fracture processes and high-speed X-ray diffraction are recorded simultaneously in real time. The experimental setups and results on the dynamic fracture of an aluminum alloy and a bovine tibia bone are presented and discussed.

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Keywords: Dynamic fracture, High-speed X-ray imaging, X-ray diffraction, Kolsky bar

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1. Introduction

Whether under quasi-static loading, such as pressure vessels, or impact loading, such as projectile impact, when a crack initiates in a material, the resultant propagation if often dynamic. In applied mechanics, dynamic fracture behavior has been investigated extensively both analytically [1] and experimentally [2]. At the tip of the running crack, deformation in the material is usually very severe and fast. Local plastic deformation converts the strain energy into heat that does not have sufficient time to dissipate through thermal diffusion. Thus the local temperature will rise [3]. Microstructural evolution under such severe conditions, such as crystal d-spacing, texture evolution and material phase transitions, associated with the dynamic deformation and fracture process in materials is an important aspect to understand but has been lacking effective experimental methods that have sufficient temporal and spatial resolutions. In this presentation, we present Kolsky tension and compression bars, also called a split Hopkinson pressure bars (SHPB), integrated with a high-speed optical camera, an intensified charge-coupled device (ICCD), and a simultaneous X-ray imaging and diffraction technique to study the dynamic ductile deformation and fracture processes during high-rate tensile and flexural loading. In such a Kolsky bar experiment, high-speed imaging of the specimen deformation and fracture processes and high-speed X-ray diffraction are recorded simultaneously in real time [4]. We achieved temporal resolutions of 100 ps and 3.37 ms in capturing the diffraction patterns of interest. These resolutions correspond to single-pulse and 22-pulse X-ray exposures, respectively. Phase contrast imaging was used to capture the deformation and fracture processes in the sample plane as the X-ray penetrated the specimen from the through-thickness direction. Although the concept is straight forward, high-speed x-ray imaging and diffraction have not been reported in the literature as tools to visualize dynamic fracture processes inside materials in real time,

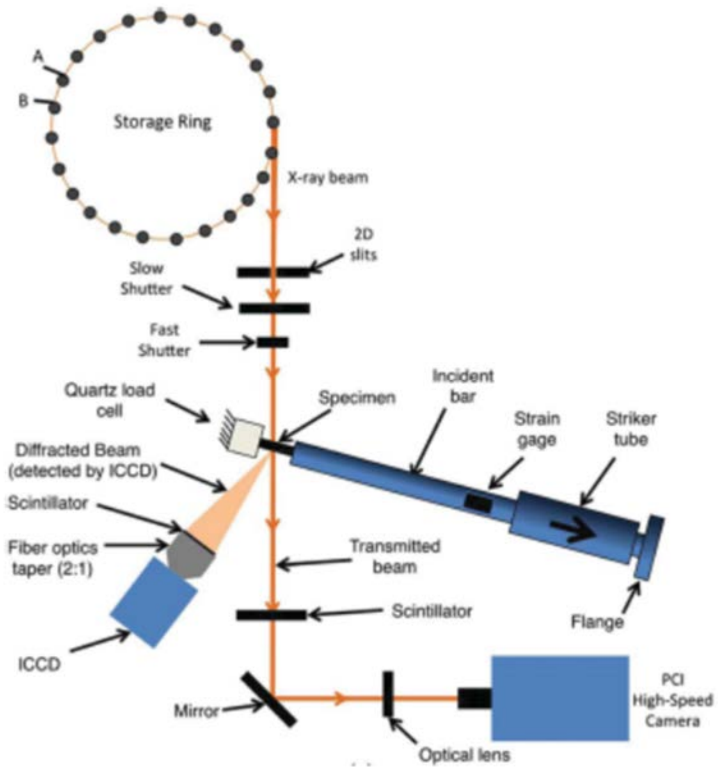

Fig. 1. A schematic of the experimental setup for high-speed X-ray imaging and diffraction under tension.