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Dynamic fracture analysis of crack–defect interaction for mode I running crack using digital dynamic caustics method

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ABSTRACT

The crack–defect interaction mechanism was studied both experimentally and numerically. Experimental results found that the presence of empty hole before crack results in both the velocity and stress intensity factor of crack decrease. More energy accumulated at crack–hole tip before second initiation. Dynamic stress intensity factor is qualitatively in accord with Crack velocity, but it oscillates strongly with hole size increasing. Numerical study shows that the stress concentration would be reduced significantly when the modulus radio between the inclusion and the matrix is more than 0.5. Results may shed lights on the interaction behavior between running crack and inclusion.

1. Introduction

A macro structure consists of material mixed with many inner defects, which in turn control the strength and failure properties of the structure [1]. Crack–defect interaction is of great significance in the study of structural failure mechanism. For example, in mining excavation, earthquake engineering and oil exploration, various defects exist in rock masses, such as joints, fractures and other discontinuities, which have great influence on the propagation of running cracks [2,3]. Among these applications, one of the core issues is how the running crack interacts with adjacent defects, and to what extent the local stress field, as well as the cracks fracture behavior, will be weaken or enhanced with different geometry and stiffness of the defects. Due to the importance of the local stress field to the fracture behavior of an adjacent running crack, the researches of crack–defects interaction have attracted a great deal of attention [4–7]. Most of these studies are concentrating on the fracturing mechanism of crack crossing to the weak joints, using theoretical analysis [8,9], as well as numerical simulations, such as finite element method [10,11] and boundary element method [12]. Some experimental models were also proposed to study the interaction mechanism between the running crack and defects. Milios [13] investigated the process between the interaction of a running crack and a hole lying eccentrically in respect to the crack's axis using caustic method. Using the same experimental technique, Theocaris [14] analyzed the differences of crack arrest modes between crossing a perpendicular crack and crossing a hole. The behavior of a moving crack around a small hole was studied by Ishikawa experimentally using photo-elastic method [15], whose work did not notice the 'size effect' of the hole. Wide range of defect geometry and stiffness have been investigated to give a macroscopic understanding of the interaction between running crack

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Nomenclature

C_p, C_S	the compressive wave speed, and shear wave speed of stress wave propagate in PMMA
E_d, ν	the dynamic elasticity modulus and Poisson's ratio of PMMA
$\lvert C_t \rvert$	the stress optical-constant of the specimen ($\lvert C_t \rvert = 0.85 * 10^{-10}$ m^2/N for PMMA)
x, y	the coordinate system in the specimen plane
x', y'	the coordinate system in the reference plane
d	the thickness of the specimen
Z_0	the distance from the specimen plane to the reference plane
σ_1, σ_2, σ_3	the stress component at a point in the specimen
A_S	the area of caustic spot at crack tip
r_i	the distance between the measured points to the crack tip
V	crack velocity
DSIF	the dynamic stress intensity factor of crack tip

and local defects, and reveal the effects of the size, strength, and distance of weak filled defects on local stress field and crack propagation using theoretical analysis, experimental research and numerical simulation. However, few of the researchers using experimental technology to consider the influence of defects size on the whole fracturing interaction process between running crack and defects. Thus, it is the objective of this paper to take both the size effect and stiffness effect of defects into consideration in the study of the influence of defects on local stress field and crack propagation.

Caustics method has been widely used in both static and dynamic fracture problems for being an effective way to eliminate stress singularity of crack-tips [16,17]. The main advantage of the caustic method, comparing with other methods, is that it concerns only the local stress field of crack-tip, providing a more reliable measurement of crack position, crack propagation velocity and stress intensity factor. Therefore, caustics method is adopted in this study for the interaction mechanism between crack and defect with different size.

This paper is organized as follows. Section 1 reviews the previous studies on the interaction between running cracks and defects and analyzes the existing defects in these studies; Section 2 describes the digital dynamic caustic system, introduces the preparation of the edge crack-inner defected specimens, and then derives the equations for dynamic stress intensity factor at blunted crack-tips; Section 3 shows the experimental and numerical results in detail; Section 4 discusses the relationship between the dynamic stress intensity factor and crack velocity; and finally, a brief conclusion is given in Section 5.

2. Experimental setup and data reduction

2.1. Digital dynamic caustic system

Based on the geometric optical laws, the optical method of caustics is able to transform the stress singularity into an optical singularity. The experimental setup is shown in Fig. 1, including a laser, a beam expander, two convex lenses, a loading device, a high speed camera, and a computer. The light rays from the laser are extended to divergent light through the beam expander, and then transformed into parallel light when penetrating into convex lens I. When the parallel light goes through the transparent specimen, it is deviated from the local region around the crack-tip induced by dynamic loading, and eventually captured by high speed camera, and the caustics images of cracked specimen are obtained. In our tests, the reference plane (namely, the focus plane of the camera) is at a distance of 900 mm from the front surface of the specimen.

The high speed camera (model: Fastcam-SA5, Photron USA, Inc.) mounted with 50 mm f/1.4D focal-length by Nikon was utilized in our tests as image receiving configuration. This camera has a maximum frequency of 1,000,000 frames per second

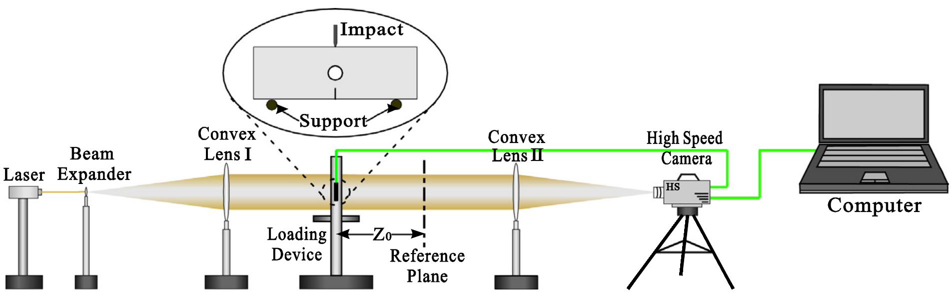

Fig. 1. Digital-leaser dynamic caustics system.