Crack Propagation in Ice under Impact Loading
Study by Digital Image Analysis and X-FEM Simulation

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Abstract:

The study of crack propagation in ice under impact loading are difficult because multiple fracture occurs and the crack propagates quickly even under very low impact. This paper presents a series of impact experiments in which the ice specimen fracture with a main crack starting from a pre-crack, depending on the impact velocity. The experiment is conducted by Split Hopkinson bar with a cold chamber. The processes of experiments are recorded by high speed camera. The crack tip’s position, the crack path and crack propagation velocity are evaluated by image analysis. The eXtended Finite Element Method (X-FEM) is chosen to simulate the crack propagation.

In present, there are two main kinds of experiments on dynamic behavior of ice. One kind is ice impacting on a rigid structure at high velocity and measuring the impact forces on the structure. Combescure (Combescure, 2011) and Tippmann (Tippmann, 2013) concerned experiments on the fracture of ice impacting on a plate at high impact velocity. The other kind of experiment is a rigid structure impact on ice. Usually Split Hopkinson bar is used. Dutta (Dutta, 2004), Kim (Kim, 2007) and Shazly (Shazly, 2009) investigated the dynamic behavior of ice under impact at different strain rates. The ice specimens in these experiments fracture with multiple cracks, it is hard to study the fracture behavior of ice under impact. If we want to study the crack propagation in ice under impact the best way is to start from only one crack propagation. With this purpose this paper presents a series of impact experiments in which the ice specimen fracture with a main crack starting from a pre-crack, depending on the impact velocity.

A Split Hopkinson Pressure Bar (SHPB) is employed to conduct the tests. A cooling chamber with a liquid Nitrogen tank are used to control the temperature. The experimental process is recorded by a high speed camera with a high brightness light (fig.1). In the experiments, the specimens are ordinary ice prepared by running water with few bubbles (fig.2). Three groups of experiments with a main crack are present in fig.3, the experiments without a main crack are abandoned. The impact velocity guaranteed a main crack generation is in the range of 1-5m/s.
A typical experiment is presented in fig. 4. High speed camera focuses on the specimen and records the transformations of the specimen during impact. 9 images display the process of crack propagation in ice. The duration of crack propagation is 216us. The main crack propagates as Mode I along the pre-crack in horizontal direction, the specimen breaks into two main parts.

At 216 us, the crack already propagated to the end of the interesting area. But the crack path is hard to observe by naked-eyes. Therefore, the digital image analysis method is used to evaluate the crack tip’s position and the crack path. It is accomplished through subtracting one image from the previous one, since the image can be seen as a grayscale matrix, if the crack propagates during the interval time of the two images the difference could be obtained and taken as a crack path (fig.5). The crack tip is identified (fig.6). The length of the crack propagation at each 27us is measured thereby crack propagation velocity is evaluated (fig.7). The whole crack path is obtained by subtracting the first image from the last one.
Fig. 4 Crack propagation image from high speed camera

Fig. 5 Crack path evaluated by digital image analysis
The eXtended Finite Element Method (X-FEM) is chosen to simulate the crack propagation. The identification of the fracture parameters is accomplished through fitting the numerical simulations to the experimental results. The equivalent domain integral (EDI) method is used to calculate $J$-integral.

**Mots clefs** : dynamic crack propagation; impact loading; ice; Split Hopkinson bar; digital image analysis; X-FEM

**Références**


