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Application News

No. V29

High-Speed Video Camera

Fracture Observation and Observation of Strain Distribution of Plastic Material with Hole in Impact Compression Test

Understanding the properties of materials is essential in designing products. For this reason, various testing standards have been established, including standards for tensile testing, compression testing, and bend testing. When materials are to be used in transportation equipment, the possibility of impact loads must also be considered. Thus, in order to accurately understand the properties of materials, an understanding of not only their static properties but also their impact properties is necessary. In particular, if an impact load is applied to a material, the material may display stress-strain characteristics different from those under static loading. Impact testing is required in order to understand those characteristics. The Hopkinson bar method is widely used as an impact testing technique. Observation of the fracture behavior in the test is also important for a detailed elucidation of the failure mechanism of the material. However, because high-speed deformation is a characteristic feature of these test methods, it had been difficult to observe material failure during tests, even with conventional high-speed cameras, and recording of images for image measurement had also been limited by the recording speed and resolution of the conventional devices. The Shimadzu HPV™-X2 high-speed video camera used in this study makes it possible to record images with both high speed and high resolution, enabling observation of various high-speed phenomena [(1)].

This article introduces an example of observation of the fracture behavior of an acrylic block having a round hole in its center in an impact compression test using the Hopkinson bar method. In addition, a random pattern was made on the surface of the specimen, and the strain distribution on the surface was visualized by DIC analysis.[*1]

*1 DIC analysis: Digital Image Correlation analysis. A technique for investigating the amount of pattern movement at the surface of an object by comparing a random pattern before/after deformation. Here, the random pattern was drawn with a marker.

Measurement System

The fracture behavior of an acrylic block was observed using an HPV-X2 high-speed video camera. Table 1 shows the recording equipment. Fig. 1 and Fig. 2 show the conditions of recording and the test part, respectively. Illumination was provided by a Cavilux® laser light source (manufactured by Cavitar Ltd.). Use of the Cavilux system with the HPV-X2 can be considered an appropriate combination for high-speed recording, as the Cavilux is capable of outputting pulses as short as 20 ns in response to the shutter signals of the HPV-X2. The test specimen was an acrylic plastic block having a round hole with a diameter of 2 mm in its center. Table 2 shows the recording conditions. In this study, observation from the front face of the hole, observation from the side of the hole, and observation for use in the DIC analysis were carried out.

Table 1 Recording Equipment

High-speed video camera	: HPV-X2
Lens	: 105 mm macro lens Teleconverter
Illumination	: Cavilux
DIC software	: GOM Correlate

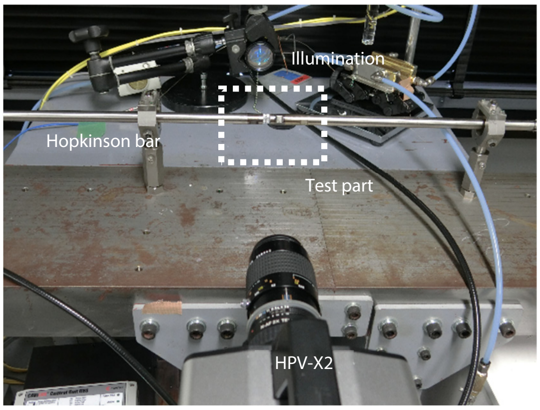

Fig. 1 Condition of Recording

Fig. 2 Condition of Test Part

Table 2 Recording Conditions

Recording No.	Specimen Dimensions	Recording Speed	Observation Direction
1	10 × 10 × 10 mm (round hole, 2 mm)	1 Mfps	Front
2	10 × 10 × 10 mm (round hole, 2 mm)	1 Mfps	Side
3	10 × 10 × 10 mm (round hole, 2 mm)	1 Mfps	Front (DIC)

Measurement Results

Fig. 3 shows the results of fracture observation from the front face of the hole. Deformation of the hole center can be observed from image (1) to image (6). In image (8), cracks initiate from both sides of the hole and grow in the horizontal direction. In image (10), cracks growing diagonally from the hole can also be seen, and in image (11), these cracks have reached final fracture before the horizontal cracks. As the diagonal cracks are considered to be caused by shearing, it is thought that the acrylic plastic specimen finally failed due to shear fracture, with the hole as the point of origin.

Fig. 4 shows the results of fracture observation from the side of the hole. In images (1) to (6), the specimen undergoes compressive deformation, and in image (7), cracks have occurred on the part of right and left sides of the hole. In image (8), these cracks have extended to the entire hole region, and they continue to grow in images (9) and (10). In image (11), cracks different from those in images (7) to (10) can also be observed, and final fracture occurs in image (12). The cracks in images (7) to (10) are thought to be the horizontal cracks in Fig. 3, and the cracks in images (11) and (12) are thought to be the diagonal cracks in Fig. 3.

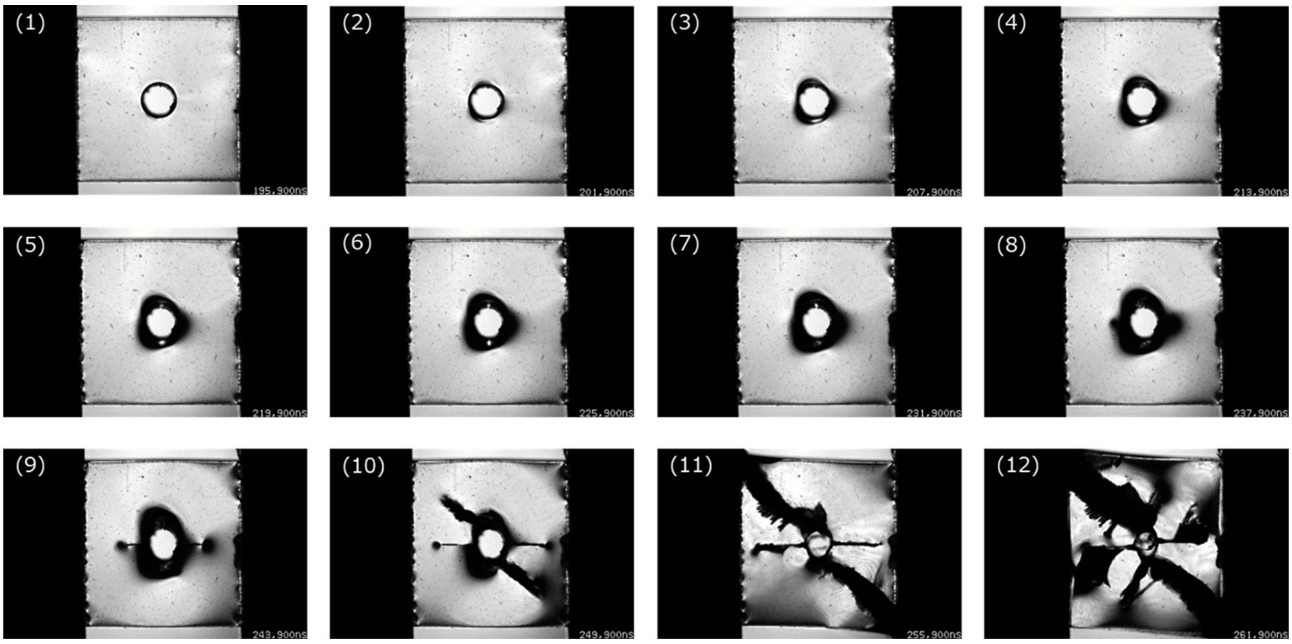

Fig. 3 Observation of Failure from Front of Hole (Time Interval Between Images: 6 µs)

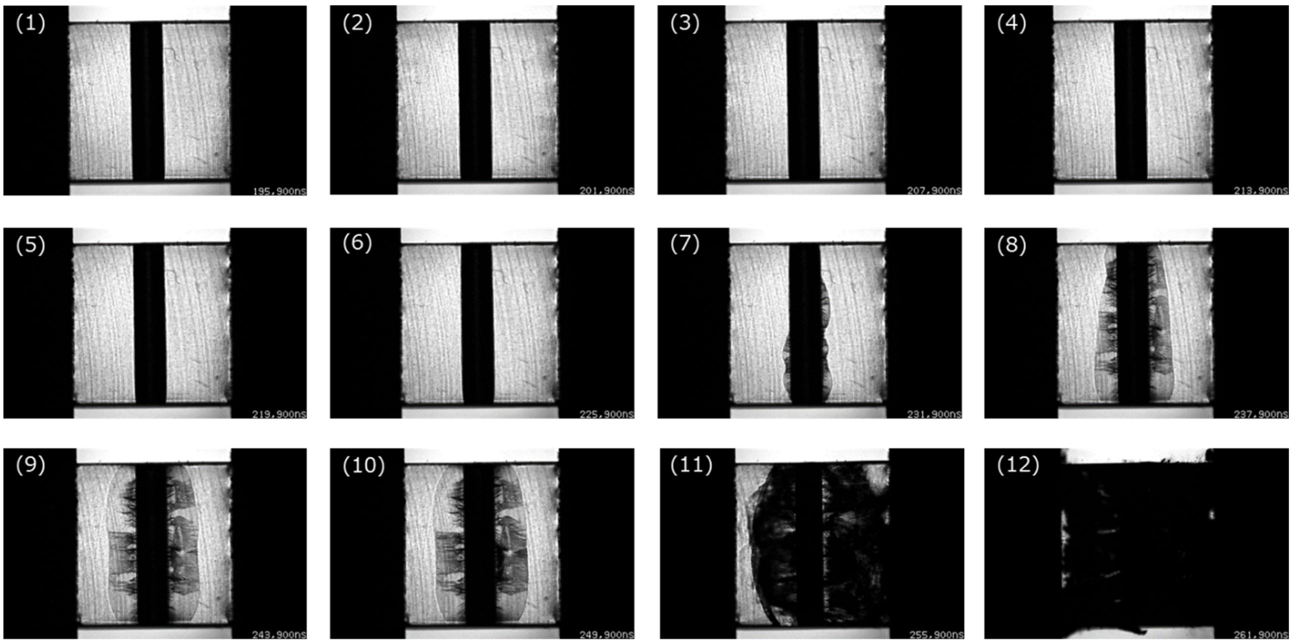

Fig. 4 Observation of Failure from Side of Hole (Time Interval Between Images: 6 µs)

The lengths of the horizontal and diagonal cracks were calculated based on the images in Fig. 3. Fig. 5 shows the relationship between the time from the start of the test and the crack length. Although the horizontal cracks grew at a constant speed until about 60 µs, crack growth slowed after that time. Subsequently, the cracks grew instantaneously at 64 µs, and final fracture occurred. On the other hand, the diagonal cracks initiated at around 50 µs, those cracks then grew at a substantially constant rate, and fracture occurred at 59 µs. When the respective crack growth rates were calculated from Fig. 5, it was found that the growth rate of the horizontal cracks was 130 m/s, while that of the diagonal cracks was 630 m/s, or approximately 5 times faster.

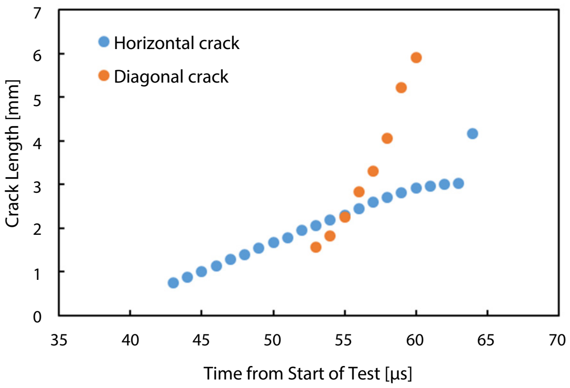

Fig. 5 Relationship of Time from Start of Test and Crack Length

Fig. 6 shows the compressive strain distribution during the test obtained by the DIC analysis. The images from (1) to (3) show the strain distribution before crack initiation. In this figure, green and blue indicate small and large compressive strain, respectively. Thus, as the test progresses, an increase in strain in the compressive direction can be observed. On the other hand, Fig. 7 shows the compressive strain distribution after the specimen fractures. After fracture, the specimen separated largely into two pieces, one at the upper left and the other at the lower right, and a decrease in compressive strain from image (1) to image (3) could be confirmed.

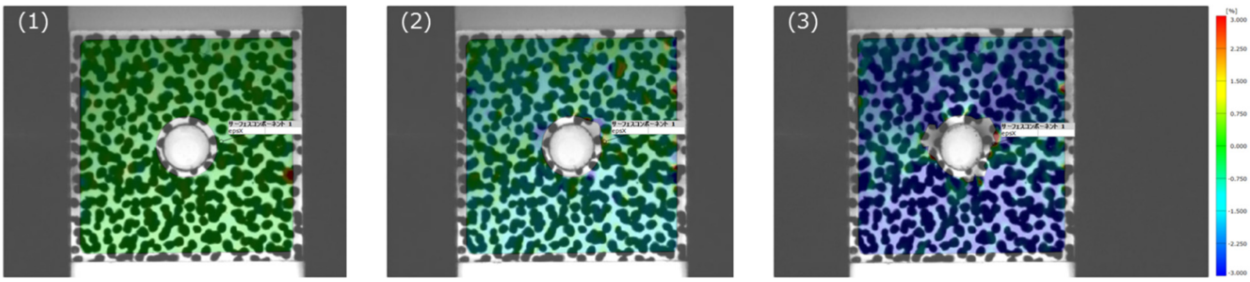

Fig. 6 Strain Distribution in Compressive Direction During Test (Time Interval Between Images: 20 µs)

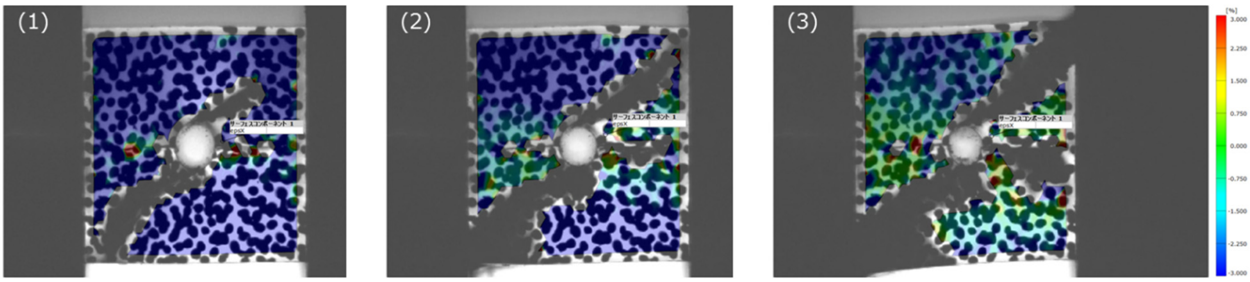

Fig. 7 Strain Distribution in Compressive Direction After Fracture (Time Interval Between Images: 3 µs)

Conclusion

Fracture observation and measurement of the strain distribution of an acrylic plastic specimen with a hole in a compression test by the Hopkinson bar method were carried out using an HPV-X2 high-speed video camera. From the recorded images, it was found that two types of cracks occurred, with the hole as the point of origin, and final fracture occurred as a result of shearing. The condition of the cracks as they propagated at high speed could be recorded clearly. Furthermore, calculation of the crack growth rate and visualization of the strain distribution were also possible, demonstrating that the HPV-X2 has sufficient resolution for these analyses.

In fracture observations in impact tests like that recorded here, both a high recording speed and high resolution are necessary. The HPV-X2 possesses both types of performance, and thus can be considered a suitable high-speed video camera for fracture observation in impact tests.

Cooperation in recording: Research Group of Mechanics and Physics of Materials, Department of Mechanical Engineering, Graduate School of Engineering, Kobe University

Reference
(1) Fumiaki Yano, Nobuyuki Tokuoka, Proceedings of 32nd International Congress on High-speed Imaging and Photonics (2018)

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