Application News

Hyper Vision HPV™-X2 High-Speed Video Camera / HITS™-TX High-Speed Impact Testing Machine

Dynamic Observation of Strain Distribution in High-Speed Tensile Test

Fumiaki Yano, Yuki Nishikawa

User Benefits

- High-speed imaging at a maximum framerate of 10 million fps is possible in high-speed tensile tests.
- High-speed tensile tests of resins at a maximum test speed of 20 m/s is possible.
- DIC analysis enables observation of the strain distribution of the test piece surface.

■ Introduction

Plastic materials are used in various industrial fields and applications from fine gears to automobiles and aircraft because of their thermal characteristics and light weight. In transportation applications, dynamic deformation due to collisions or dropping products is a possibility. Therefore, not only conventional static testing, but also impact testing is necessary to ensure reliability. In particular, it is known that the mechanical properties of polymer materials such as plastics show deformation velocity dependence. Moreover, it is also important to observe the fracture behavior in the test in order to clarify the detailed mechanism of the material. DIC (digital image correlation) analysis can clarify the strain distribution at the material surface, and thus is especially useful for identifying locations where strain concentrations occur in a test.

In this experiment, test specimens in which a round hole or notch was machined in the parallel part of an acrylic test piece were prepared, and the strain distribution in a high-speed tensile test was visualized by DIC analysis. Since Shimadzu Corporation has also conducted evaluations[(1), (2)] and DIC analyses[(3), (4)] in high-speed tensile tests of plastic materials in the past, the reader may also refer to those reports.

■ Measurement System

High-speed imaging was carried out during a high-speed tensile test using a Hyper Vision HPV-X2 high-speed video camera and HITS-TX high-speed impact testing machine. Table 1 shows the test devices, and Fig. 1 shows the measurement set-up.

Table 1 Test Devices

High-speed video camera	: HPV-X2
Lens	: 105 mm macro lens
Lighting	: Strobe
High-speed impact testing machine	: HITS-TX
Grips	: Flat grip (for high-speed tensile test)
DIC software	: VIC-2D

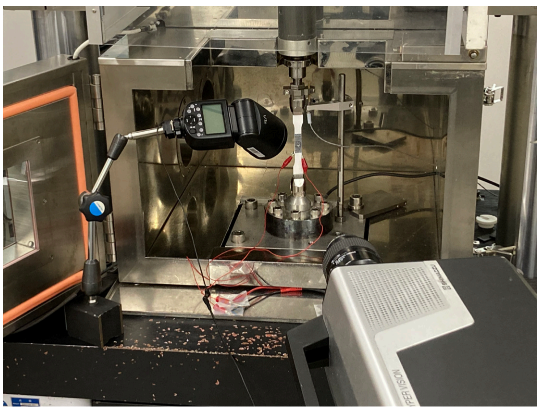

Fig. 1 Measurement Set-up

■ Test Pieces and Measurement Conditions

Three types of test pieces were used, a dumbbell shaped type, a test piece with a round machined hole, and a notched test piece with a machined notch. Fig. 2 shows drawings of the test piece with the hole and the notched test piece. The material of the test pieces was acryl.

The test speed in the high-speed tensile test was set at 10 m/s, and the framerate (frames per second: fps) in a high-speed imaging was changed depending on the type of test piece. Table 2 shows the details of the measurement conditions.

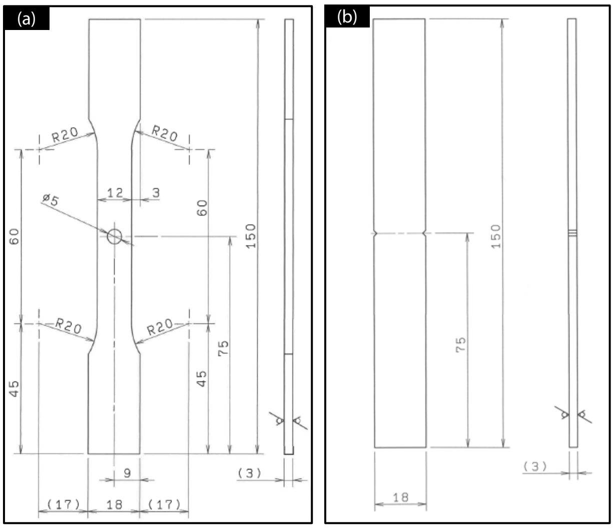

Fig. 2 Details of Test Piece Geometry (Unit: mm)
(a) Test Piece with Hole, (b) Notched Test Piece
*The geometry of the dumbbell test piece was the same as in (a), but without the round hole machined in the center.

Table 2 Measurement Conditions

Test pieces	: Test piece ①: Dumbbell test piece
	Test piece ②: Test piece with hole
	Test piece ③: Notched test piece
Test speed	: 10 m/s
Framerate	: Test piece ①: 250 kfps
	Test piece ②: 1 Mfps, 5 Mfps
	Test piece ③: 1 Mfps, 5 Mfps

■ Measurement Results

The colors in the DIC analysis images in Fig. 3 to Fig. 7 show the strain in the color bar on the right side of the figure, where purple represents the smallest value and red indicates the largest value. The largest values differ depending on the analysis results. Fig. 3 shows the DIC analysis result for dumbbell-type test piece ①. A condition in which the strain increases uniformly in the parallel part of the test piece from Fig. 3 (1) to (9) can be seen. However, from a detailed observation of the DIC video images, it could be confirmed that the strains originating at the R parts at the upper and lower ends of the test piece increase toward the center of the parallel part, and finally, in image (10), the test piece fractures from the areas around the R parts at the upper and lower ends of the test piece.

* For the details of the respective measurement results, please see the video.
https://www.an.shimadzu.co.jp/test/products/video/hpvx/applications.htm

Test piece ② was measured at two different framerates. The entire test was observed in the measurement at 1 million fps, and the detailed fracture behavior was observed in the measurement at 5 million fps. Fig. 4 shows the DIC analysis results of the entire test for test piece ②. Fig. 4 (1) is an image immediately after loading. As the test proceeds from Fig. 4 (1) to (7), the strain on the right and left sides of the round hole increases, but the strain does not increase as significantly at the above and below the hole. In image (8), a stress concentration occurs on the left side of the hole, and in image (9), the test piece fractures on the left side of the hole. As a result of the fracture, the strain decreases on the left side of the hole but increases on the right, and in image (10), a fracture also occurs on the right side and the strain decreases.

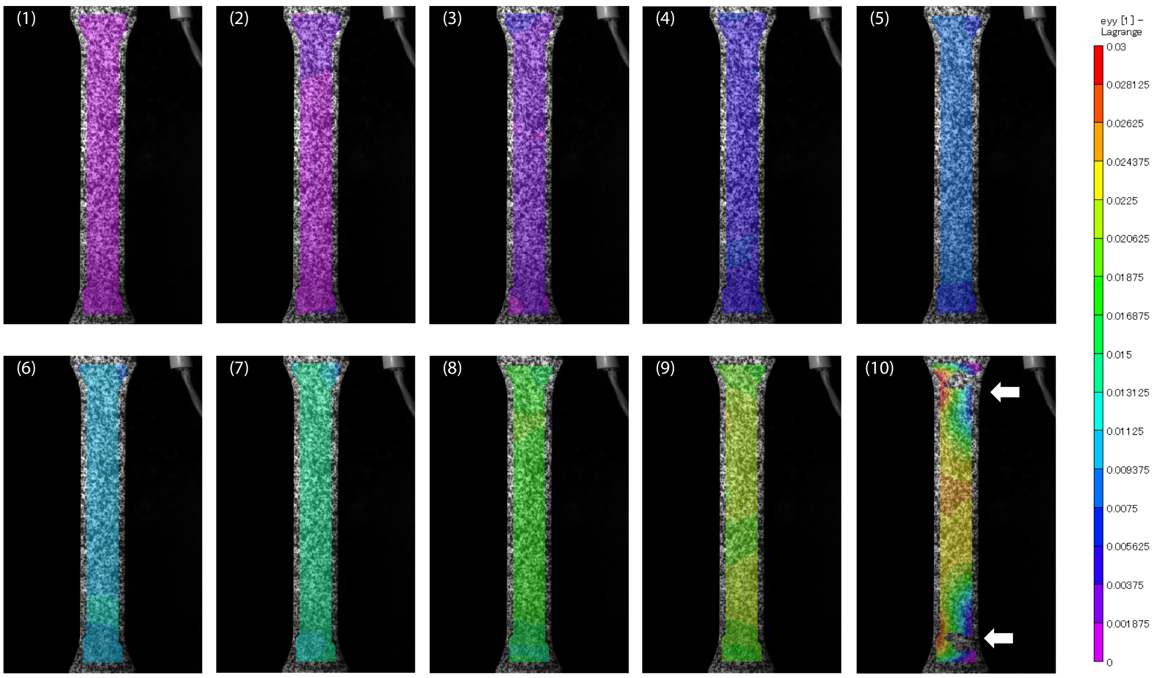

Fig. 3 DIC Analysis Results for Test Piece ① (Strain Distribution in Test Piece Longitudinal Direction)
(Time interval between images: 32 µsec)

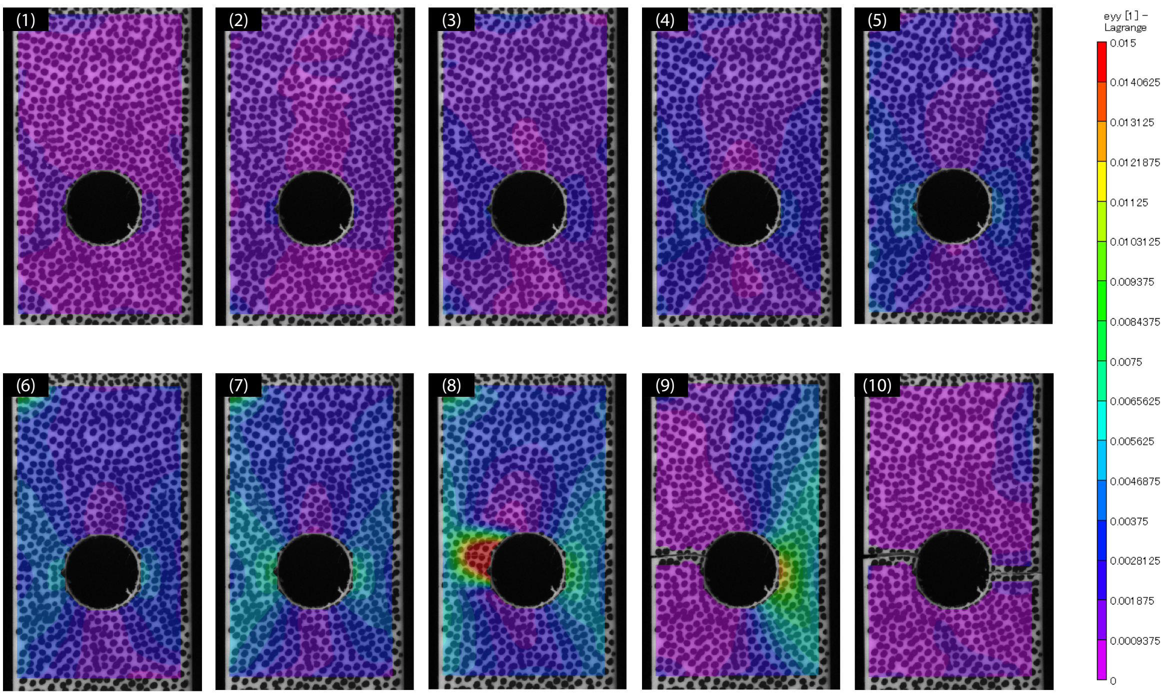

Fig. 4 DIC Analysis Results for Test Piece ② (Strain Distribution in Test Piece Longitudinal Direction)
(Time interval between images: 8 µsec)

Fig. 5 shows the results of observation of the fracture behavior of test piece ②. In image (1), strain concentrates from the left side of the round hole, and fracture also occurs from the left side. Thereafter, in images (2) to (4), the strain gradually decreases above and below the stress concentration region on the left side of the hole, as could be confirmed from the spread of the purple region. In image (5), strain also concentrates on the right side of the hole, and from images (6) to (10), movement of the stress concentration region to the right side could be observed. As on the left side of the hole, a condition in which the strain decreases in the regions above and below the location where the crack occurred could be observed.

As in the case of test piece ②, the notched specimen, test piece ③, was also measured twice, at framerates of 1 million fps and 5 million fps, in order to observe the condition of the entire test and the detailed fracture behavior, respectively. Fig. 6 shows the DIC analysis results of the entire test for test piece ③. Image (1) shows the condition after approximately 40 µsec from the start of the test. In images (1) to (7), the strain of the entire region is substantially uniform, but the purple color gradually changes to light blue, indicating that the strain is increasing. From the video images, the strain initially increases at the notches and then spreads to the entire region. In image (8), large strain is concentrated on the left side of the notch and a crack occurs. In image (9), strain also concentrates at the notch on the right side, and in image (10), the strains on the left and right sides spread to the central part. In addition, a condition in which strain decreases in the regions above and below the crack could also be observed in images (8) to (10), after the crack occurred.

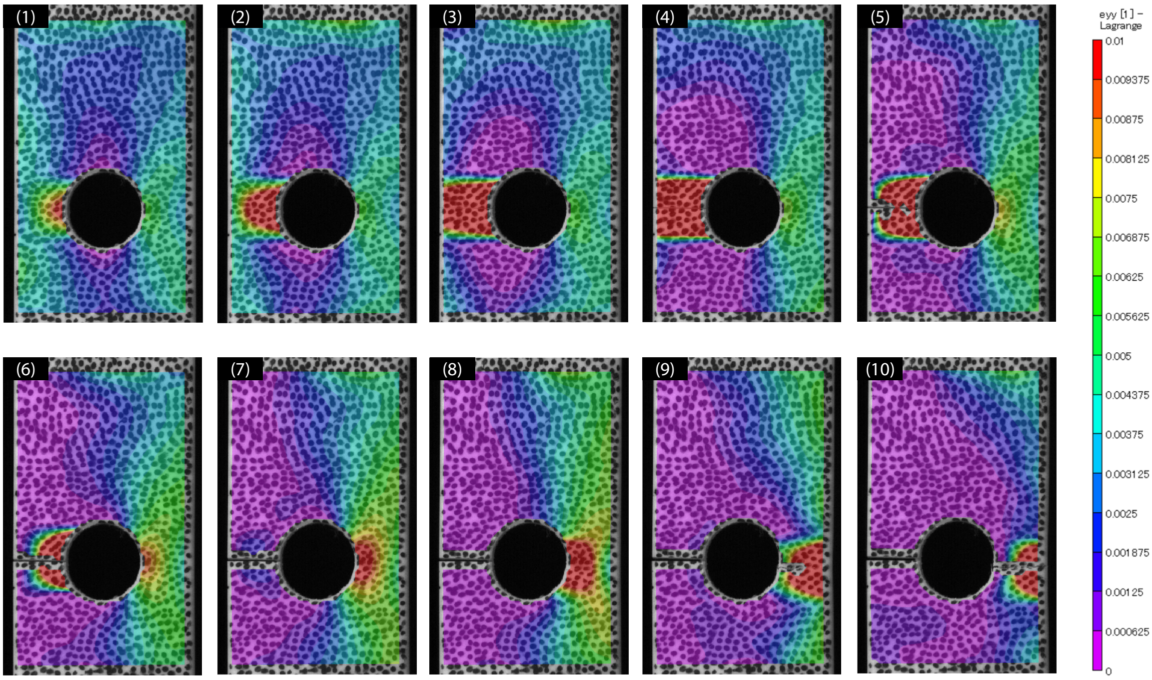

Fig. 5 DIC Analysis Results for Test Piece ② (Strain Distribution in Test Piece Longitudinal Direction)
(Time interval between images: 2.2 µsec)

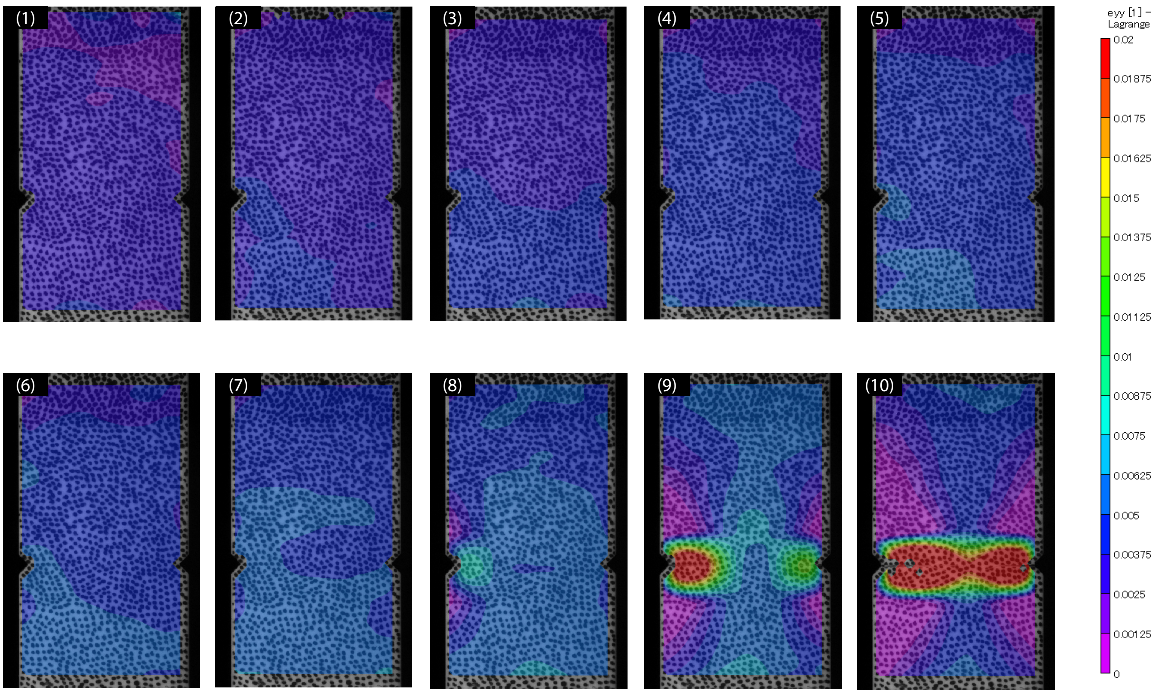

Fig. 6 DIC Analysis Results for Test Piece ③ (Strain Distribution in Test Piece Longitudinal Direction)
(Time interval between images: 4 µsec)

Fig. 7 shows the results of observation of the fracture behavior of test piece ③. Image (1) in Fig. 7 is an image that was captured immediately after the crack occurred at the notch on the left side. From the fact that the crack occurred in image (1), the strain is concentrated at the notch on the left side, and the strain has already decreased in the regions above and below the location where the crack occurred. As observed from images (2) to (10), the location where the strain is concentrated gradually shifts to the right, and the region where the strain decreases as a result of the crack expands to the right with the propagation of the crack.

■ Conclusion

The fracture behavior of resin test pieces with various geometries was observed in a high-speed tensile test using a Hyper Vision HPV-X2 high-speed video camera and HITS-TX high-speed impact testing machine, and the strain distribution of the test piece surfaces was visualized by a DIC analysis of the high-speed images captured in the test. In the test pieces with a round hole or a notch, it was found that strain concentrated at those defects, and fracture progressed from those points. It was also possible to observe the process in which strain decreased after crack initiation.

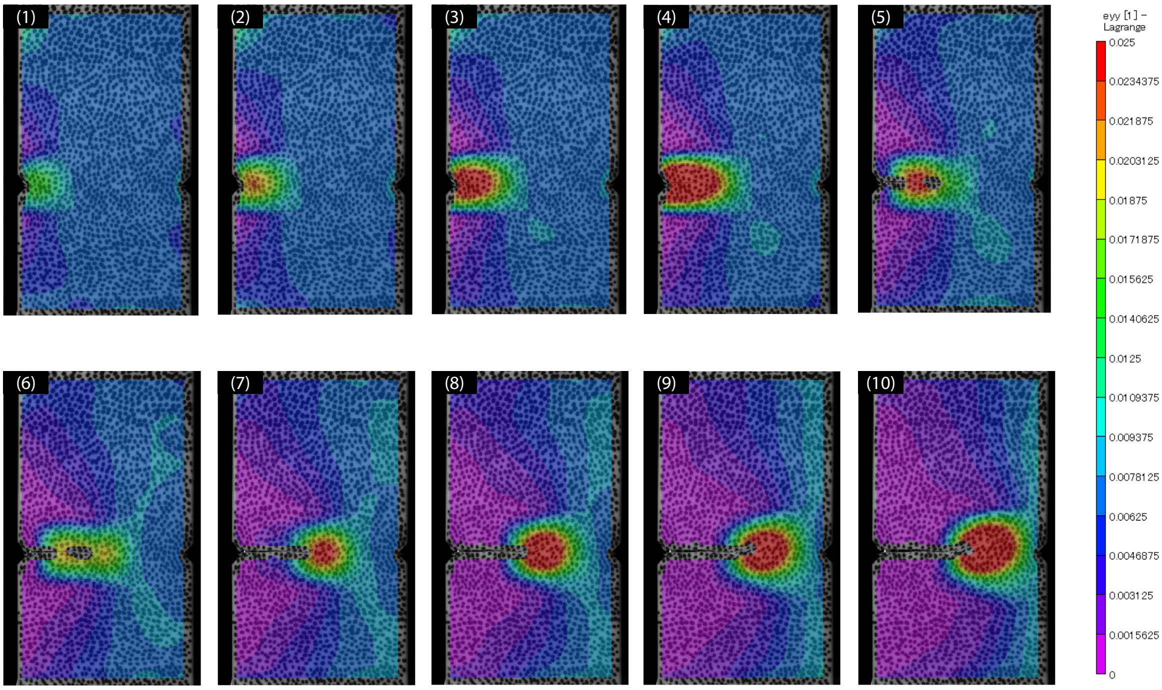

Fig. 7 DIC Analysis Results for Test Piece ③ (Strain Distribution in Test Piece Longitudinal Direction)
(Time interval between images: 1.6 µsec)

<Reference>
(1) Application News No. i266, Evaluation of Mechanical Characteristics and Fracture Surface Observation in Static and High-Speed Tensile Tests of Plastic Materials
(2) Application News No. i275, High-Speed Tensile Test of CNF-Reinforced Plastic
(3) Application News No. V26, Observation of Fracture Behavior of Resin Material from an Impact Compression Test by the Hopkinson Bar Method
(4) Application News No. V29, Fracture Observation and Observation of Strain Distribution of Plastic Material with Hole in Impact Compression Test

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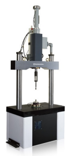

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