# THE EXPERIMENTAL COMPARISION OF THE STRAIN MEASUREMENT TECHNIQUES ON TENSILE TEST

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**Keywords:** High-speed imaging, Digital image correlation, Tensile fracture,

## Abstract

The objective of this study is the high temporally resolution measurement for the tensile fracture behavior of CFRP. To grasp the fracture of CFRP experimentally is very important. However the fracture observation of unidirectional CFRP on tensile test was difficult, because the fracture speed of UD CFRP was quite high. We could get high-speed image of the fracture behavior at tensile test for UD CFRP to use high-speed video camera. We introduced Digital Image Correlation for the results of high-speed images. We suggest it was possible to analyze strain from the high-speed images.

## 1 Introduction

Carbon Fiber Reinforced Plastics (CFRP) is one of the materials, which have higher specific stiffness and strength than the metal material. The use of CFRP is increasing in the aerospace and rapid transit railway industries, sports, leisure and automotive industries. With the soaring of the fuel price, CFRP is attracted attention from the aerospace and the automobile industry as the energy saving material. There are some proposed theories to find out the tensile fracture of CFRP by using numerical calculation. But the tensile fracture mechanism of unidirectional CFRP has not been experimentally made clear because the fracture speed of unidirectional CFRP is quite high.

The objective of this study is to clarify the fracture behavior of unidirectional CFRP under static tensile loading. We selected the intermediate modulus and high strength unidirectional CFRP laminate which is a typical material used in the aerospace field. The fracture process under static tensile loading was captured by a conventional high-speed video camera and a new type high-speed video camera. It was found that the duration of fracture is 200 microseconds or less, then images taken by a conventional camera doesn't have enough temporal-resolution. On the other hand, results obtained by new one have higher quality where the fracture process can be clearly observed.

However the high speed imaging is definition evaluation and is not quantitative evaluation. The strain is one of the important elements in the evaluation of the destruction phenomenon. We introduced Digital Image Correlation (DIC) into high speed imaging of CFRP fracture. We succeeded in the measurement of the in-plane deformation and the analysis of the strain by DIC, and compared DIC analysis results as the simulation for the validity evaluation. These showed very good agreement. We investigate the analysis method to have considered the detection range of the DIC analysis result, and we refer to the influence which the velocity dependence gives the fracture process.

## 2 Specimens and Experimental methods

### *2.1 Specimens*

The material used in this study was T800S/3900-2B (Toray). This material has the characteristics which are reinforced by intermediate modules, high tensile strength carbon fiber and 180 degrees centigrade cure type epoxy resin system (Table 1). The specifications of specimens are shown as Table 2. The evaluation area is painted small random points by white ink. The GFRP tabs glued to prevent from the stress concentration by grasping tools. The overview of specimen was shown in Figure 1.

| | |
|---|---|
| Manufacturer | Toray |
| Carbon fiber | T800SC |
| Matrix | Epoxy 3900-2B |
| Volume functions [%] | 55 |
| Strength [MPa] | 3100 |
| Elastic modulus [GPa] | 153 |
| Poisson's ratio | 0.34 |

**Table 1.** Properties of T800S/3900-2B

| | |
|---|---|
| Material | T800S/3900-2B |
| Number of ply | 2 |
| Lf [mm] | 80 |
| Ls [mm] | 20 |
| W1 [mm] | 6 |
| T1 [mm] | 0.35 |
| Lt [mm] | 30 |

**Table 2.** Specifications of the specimen

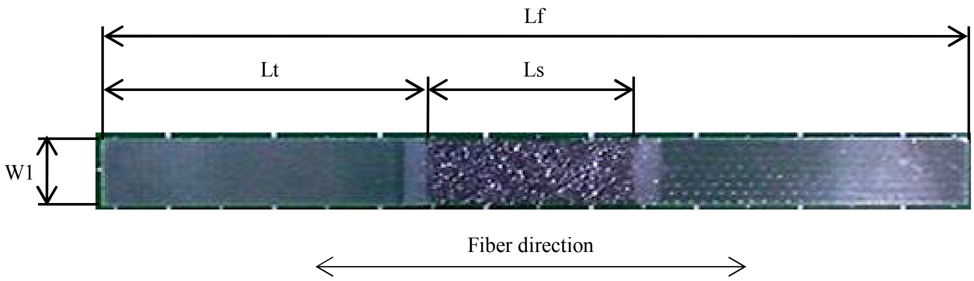



**Figure 1.** Overview of specimen

### *2.2 Experimental methods*

We used precision universal testing machine (Autograph AG-X, Shimadzu Corp.) with a load cell of 50kN capacity on static tensile test. The tensile load was applied to the specimen under displacement control with a crosshead speed of 0.5, 5.0 mm/min. And we used high speed tensile testing machine (Hydroshot HITS-T10, Shimadzu Corp.) with a load cell of 10kN capacity on high speed tensile test. The tensile speeds were set to 0.002, 0.02, 0.2, 2.0, 5.0, 10 m/sec. We used high-speed video camera (HyperVision HPV-1, Shimadzu Corp.) for high resolution measurement. Both testing machines had the functions to quickly make trigger signal for the high-speed video camera.

### *2.3 Image analysis methods*

We used digital image correlation (DIC) method about the images gotten by high speed video camera from high speed tensile test. We selected larger inspection area and the appropriate overlap quantity at image analysis of DIC.

## 3 Results

### *3.1 Tensile test*

The results of static and high speed tensile tests were shown as Table. 3 and Figure 2. Strain rate ε was shown (1). V was tensile speed.

$$\dot{\varepsilon} = \frac{V}{Ls} \tag{1}$$

Figure 2 was shown that the tensile stress became large so that tensile speed became fast. The results of high speed tensile tests were shown as Figure 3. The strength of high speed tensile test was up to 20 % larger than static tensile test.

| | ◆ Static tensile test | | ■ High speed tensile test | | | | | |
|---|---|---|---|---|---|---|---|---|
| Tensile speed | 0.5 mm/min<br>$8.3x10^{-6}$ m/sec | 5 mm/min<br>$8.3x10^{-5}$ m/sec | 0.002 m/sec | 0.02 m/sec | 0.2 m/sec | 2.0 m/sec | 5.0 m/sec | 10 m/sec |
| Strain rate [1/s] | 0.00042 | 0.0042 | 0.1 | 1 | 10 | 100 | 250 | 500 |
| Strength [MPa] | 3030 | 3020 | 3210 | 3351 | 3476 | 3633 | 3640 | 3682 |

**Table 3.** Result of tensile test

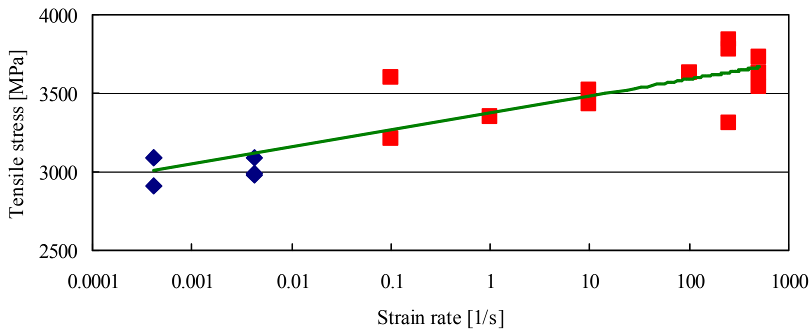
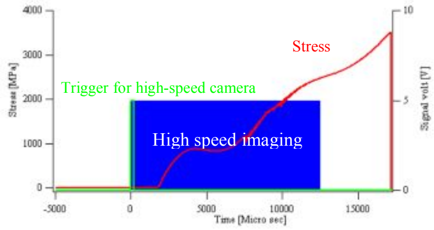


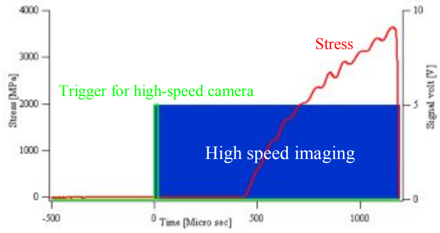

**Figure 2.** Tensile stress – Strain rate curve

### *3.2 High speed imaging*

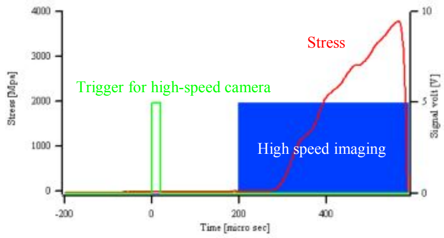
Destructive behaviors of this specimen were recorded by high-speed video camera. Figure 3 showed relation between the recording time and the phenomenon. The images provided by high-speed video camera were shown as Figure 4. We couldn't get fracture behavior on Figure 4 (A). However, we succeeded in the high speed imaging up to 250,000 frames per second within fracture behavior at the other cases. We could observe that the vertical cracks (splitting) occurred to the regular intervals regardless of strain rate (Figure 4-(B), (C), (D)). In 10 m/sec tensile test, we could understand that the image of maximum stress point (640 μsec) was the beginning of fracture. Maximum stress points were the beginning of fracture in 2, 5 m/sec tensile test, too.



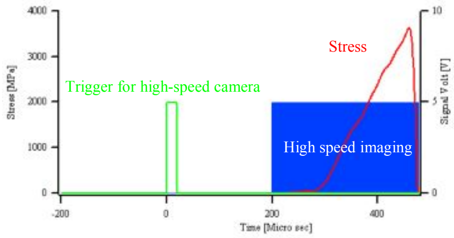

(A) 0.2 m/sec




(B) 2.0 m/sec

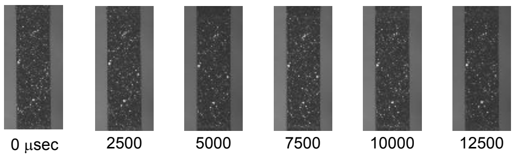



(C) 5.0 m/sec

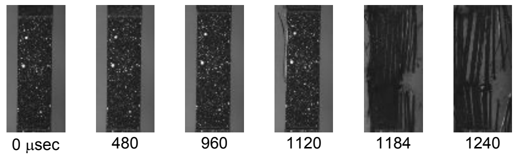



(D) 10 m/sec

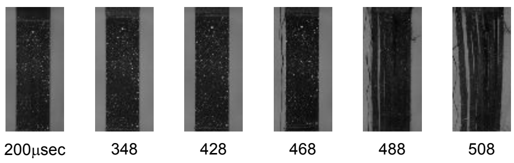
**Figure 3.** Stress-time curve (high speed tensile test)



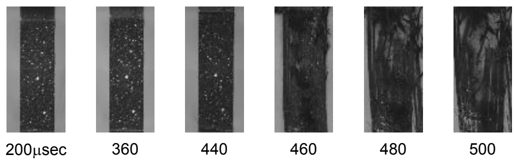

**(A)** 0.2m/sec, 8,000 fps




**(B)** 2m/sec, 32,000 fps




**(C)** 5m/sec, 250,000 fps




**(D)** 10m/sec, 250,000 fps

**Figure 4.** Results of high speed image on high speed tensile test

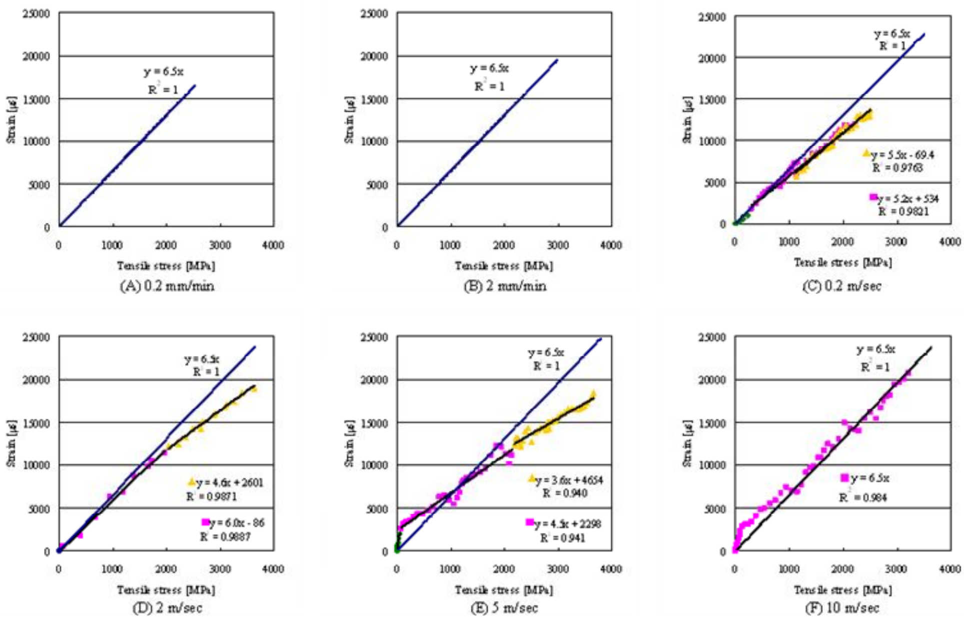



**Figure 5.** Tensile stress – Strain from DIC curve

*3.3 Digital image correlation*

We calculated the average strain using DIC technique from high speed images. Results of DIC were shown as Figure 5. The DIC results of static tensile tests were good agreements with JAXA-ACDB. While, some of DIC results of high speed tensile tests were good agreements with static tensile tests in only low stress area up to 10,000μs. High stress area of some results shifted from DIC result of static tensile tests. However DIC result of 10m/sec tensile test was good agreement with static tensile tests about all area of stress measurement.

## 4 Conclusions

- We could succeed high speed imaging for fractures of static and high speed tensile test. We could observe the fracture process on unidirectional CFRP with high speed video camera.

- In to digital image correlation, we could quantify the high speed image. The temporal resolution of DIC depended on the frame rate of high speed camera. In this high speed tensile test, we could get high speed image, up to 1,000,000 frame per second.

- We suggested that UD CFRP had strain rate dependency of strength. The Strength of high speed tensile test for UD CFRP was up to 20% larger than static tensile test.

- DIC results from static tensile tests and high speed tensile test were good agreements in low strain rate area. However those were not so good agreements on high strain rate area. It was reason that CFRP had two or more elastic modulus from carbon fiber and the resin. Those physical properties didn't agree. The resin has generally strain rate dependency.