NUMERICAL STUDY ON INDENTIFICATION OF ANISOTROPIC MATERIAL PROPERTIES FOR DYNAMIC LOADING

K. Suga[1*], K. Okamoto[2], K. Takagi[2], H. Nakatani[1], S. Ogihara[1], M. Kikuchi[1]

[1]*Department of Mechanical Engineering, Faculty of Science and Technology, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba, 278-8510, Japan*
[2]*Graduate School of Science and Technology, Tokyo University of Science, 2641 Yamazaki, Noda, Chiba, 278-8510, Japan*
**ksuga@rs.noda.tus.ac.jp*

Keywords: Split Hopkinson Pressure Bar, Material Characterization, Numerical Simulation, Carbon Fiber Reinforced Plastic

Abstract

The present study investigates the experimental conditions for composite materials in a tensile loading Split Hopkinson Pressure Bar (SHPB) test using three-dimensional finite element method. The strain distribution on a specimen and stress-strain curves are simulated for several length of specimens in order to investigate the effect of the length on the stress-strain curves.

1 Introduction

Material characterization of composite materials under high strain rate is important in the designing of safe and efficient structures and machines. However, a standardized method for the characterization has not been proposed. The split Hopkinson pressure bar (SHPB) method [1] is one of the most reliable and simple methods because it has been widely used for metal materials. In order to obtain true material character using SHPB method, one dimensional wave theory should be satisfied in the input/output bar and specimen, composite materials, however, are anisotropic materials and its specimens are usually obtained in flat plate because of limitations of its manufacturing process. In addition, The Young's modulus becomes significantly smaller compared with that of input/output bars when the fiver direction is off-axis to loading direction. Because of the above difference from the case of metal material, the effect of the difference on material characterization should be investigated to ensure a reasonable characterization.
The study investigates the experimental conditions for composite materials in a tensile-loading SHPB using the three-dimensional finite element method. The relationship between the duration time of impact loading and the length of specimen is investigated.

2 Split Hopkinson pressure bar

2.1 Theory

Figure 1 shows the overview of the SHPB, the elastic wave propagates from the input bar to output bar through a specimen.

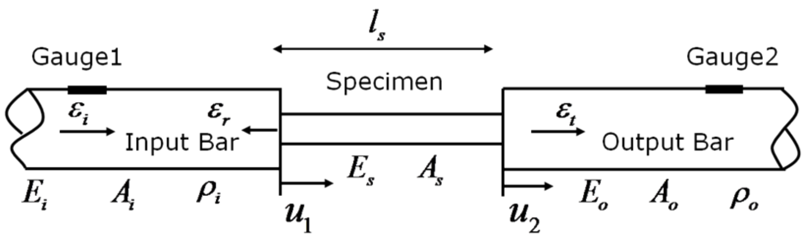

Fig. 1 Split Hopkinson pressure bar

The stress and strain relationship is given by

$$\dot{\varepsilon}_s(t) = \frac{d\varepsilon_s(t)}{dt} = \frac{c_i\left\{\varepsilon_i(t) - \varepsilon_r(t)\right\} - c_o\varepsilon_t(t)}{l_s} \tag{1}$$

$$\varepsilon_s(t) = \frac{1}{l_s}\int_0^t \left[c_i\left\{\varepsilon_i(t') - \varepsilon_r(t')\right\} - c_o\varepsilon_t(t')\right]dt' \tag{2}$$

$$\sigma_s = \frac{E_o A_o}{A_s}\varepsilon_t(t) \tag{3}$$

where, E, c, and A are the elastic modulus, velocity of the longitudinal wave in the medium, and cross-sectional area, respectively. The subscripts i, o, and s denote the input bar, output bar, and specimen, respectively.

2.2 Numerical model

The dimensions of the SHPB are shown in Fig. 2. The input bar is 3000 mm in length and 16 mm in diameter stainless steal. The output bar is 1500 mm in length and 10 mm in diameter aluminum alloy (A5056). E, ν , and ρ denote the Young's modulus, poisson's ratio and mass density of each bar, respectively. For measurement of the strain in Eqs. (1) to (3), strain gauges are installed 1500 mm away from the right end of the input bar and 300 mm away from the left end of the output bar.

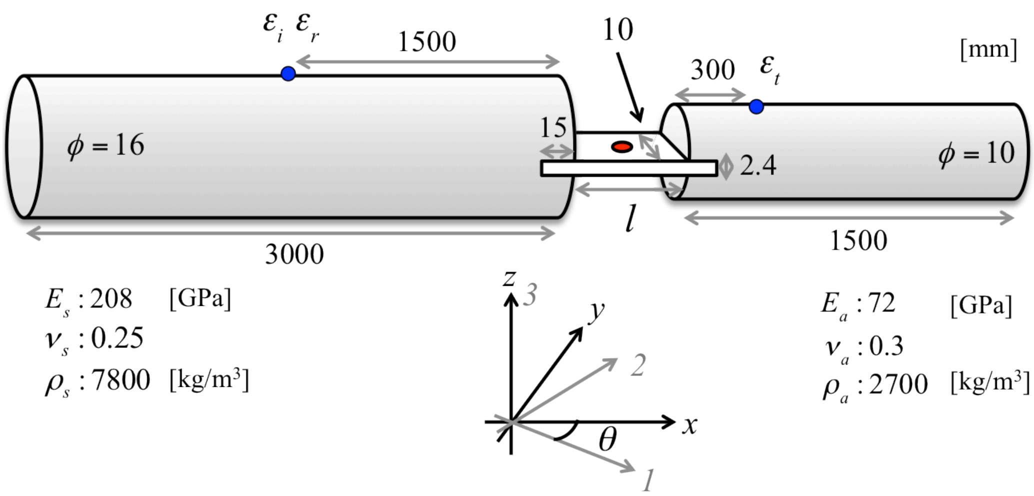

Figure 2. Numerical Model of SHPB

The composite specimen was modeled as an orthotropic elastic material, its material properties are listed in Table 1. The coordinate is shown in Figure 2.

Young's modulus [GPa]	E_1	130.3
	E_2	9.5
	E_3	9.5
Shear modulus [GPa]	G_{12}	4.7
	G_{23}	3.2
	G_{31}	4.7
Poisson's ratio	ν_{12}	0.34
	ν_{23}	0.5
	ν_{31}	0.03
Mass density [kg/m^3]	ρ_s	1800

Table 1. Material properties of specimen

The applied impact loading was assumed based on a practical experiment. Figure 3 shows the applied loading, the red line denotes the experimental data, and the blue denotes the assumed loading. The loading was applied to the left end of the input bar shown in Figure 2.

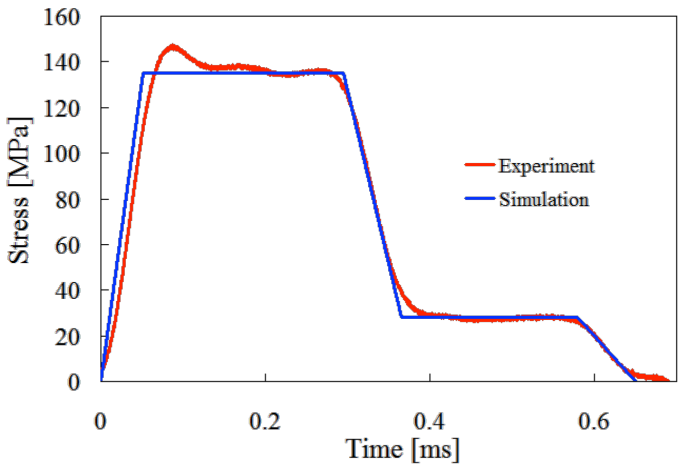

Figure 3. Impact loading

3 Results

3.1 Strain distribution on specimen

In order to evaluate strain distribution in *z*-direction, the time variations of strain along the centerline on a specimen were observed. The results were shown in Figure 4, where the horizontal axis denotes the distance from the right end of input bar, the vertical axis denotes normalized strain by the maximum strain in each time step. The time origin is the time when the strain on the interface between the input bar and a specimen is more than 10^{-7}.

In every case, as increasing the time the distribution became flat. It means the strain distribution became uniform along the centerline of a specimen. The length of specimen becomes larger the length of uniform distribution section becomes larger, on the other hand, the effect of jig joint on strain reduction is larger on shorter length of specimen.

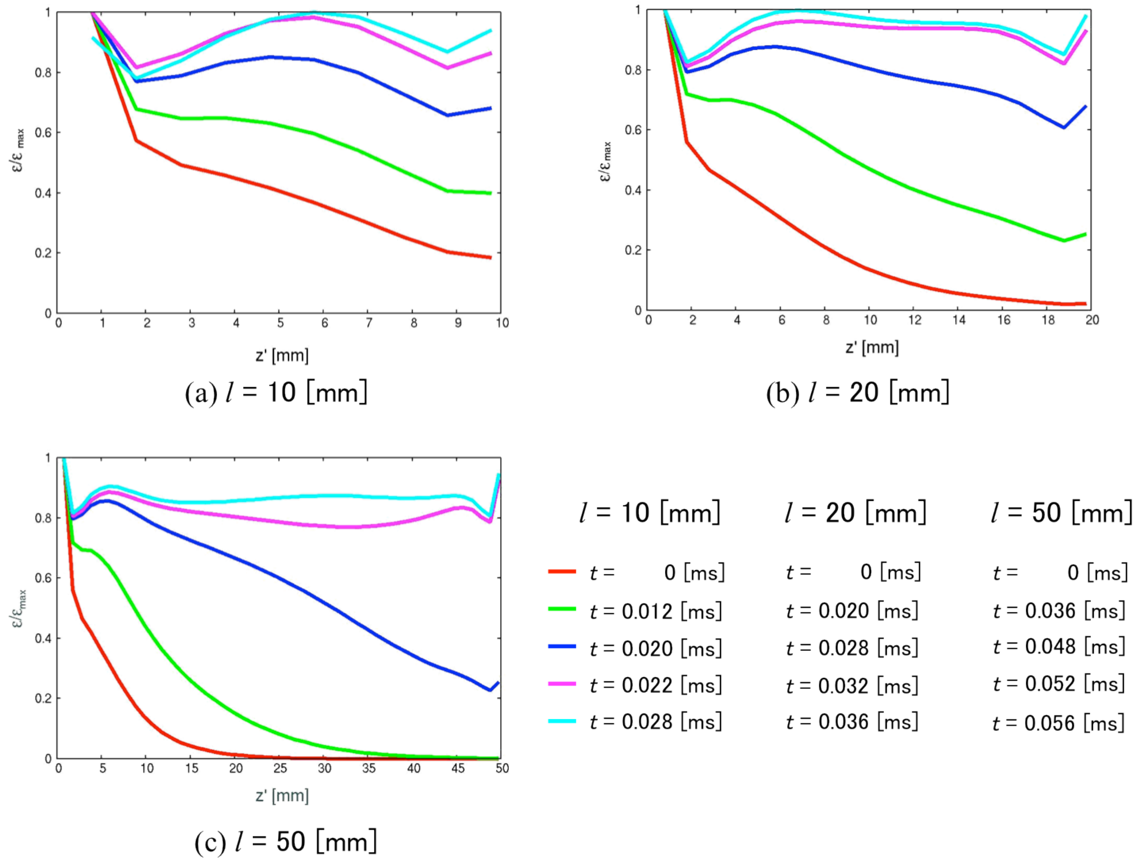

Figure 4. Time variations of strain along the centerline on specimens

3.2 Stress-strain relationship

Figure 5 shows the stress-strain curves for several lengths of specimen. The specimen in the figure indicates that the curve is obtained without constraint effect by the input and output bars (see Figure2). The stress and strain are measured directly on a specimen without using eqs. (1) – (3).This study considers that the curve is ideal stress-strain curve. From the results, when the length of specimen is short, ideal stress-strain curve cannot be obtained, its Young's modulus is evaluated higher than ideal one. As increasing the length, the stress-strain becomes close to the ideal one.

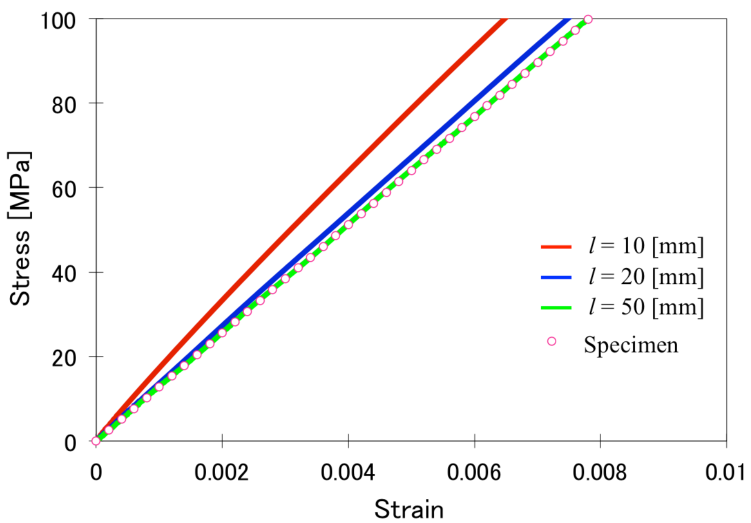

Figure 5. Effect of specimen length

Figure 6 shows the stress-strain curves employing eqs. (1) – (3). In the figure, "Specimen" means the curve is obtained on a specimen directly, on the other hand, "SHPB" means the curve is obtained SHPB theory given by eqs. (1) – (3). If specimen lengths are is 10 mm and 20 mm, the stress-strain curves obtained by SHPB theory are similar to that obtained on specimens directly, however in case the length is 50 mm, the difference of stress-strain curves between "SHPB" and "Specimen" becomes larger than that of other cases. In the case of the specimen length is 20 mm, the stress-strain curve which is close to ideal stress-strain curve can be obtained.

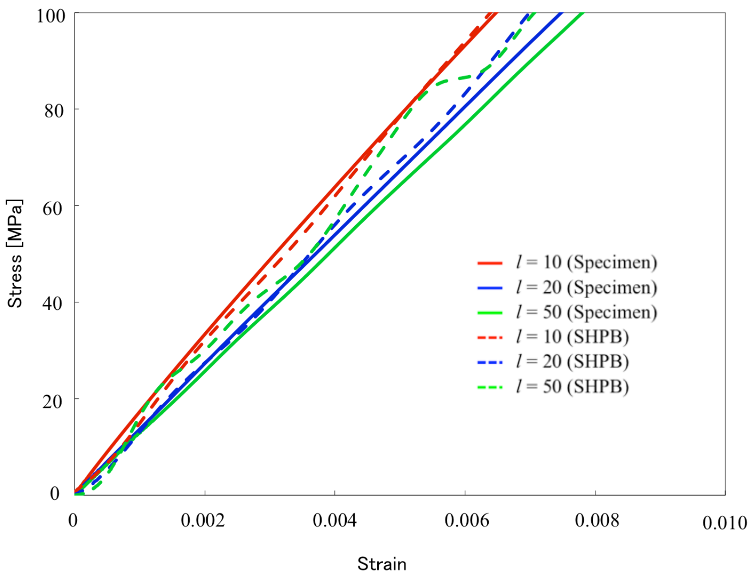

Figure 6. Stress-strain curve obtained SHPB theory

The numerical simulations shows there is optimal length of specimen in order to obtain ideal stress-strain curve by SHPB test for composite material. Also, if general composite material properties listed in Table 1, the optimal length is about 20 mm. The criteria to decide to the specimen length will be given in the future research.

4 Conclusions

The study investigated the experimental conditions for composite materials in a tensile-loading SHPB using the three-dimensional finite element method. The relationship between the duration time of impact loading and the length of specimen was investigated.

The numerical simulations shows there is optimal length of specimen in order to obtain ideal stress-strain curve by SHPB test for composite material. If the length is shorter, the constraint effect of input and output bar are observed, on the other hand, if the length becomes too larger, the stress-strain relationship becomes different from ideal stress-strain curve. The criteria to decide to the specimen length will be given in the future research.

References

[1] U. S. Lindholm, Some Experiments with the Split Hopkinson Pressure Bar. J. Mech. Phys. Solids, **12**, pp. 317-335 (1964).