

NUMERICAL EVALUATION OF HOPKINSON BAR TEST FOR CARBON FIBER REINFORCED PLASTICS

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1 Introduction

Carbon fiber reinforced plastics (CFRP) are widely used as components of structures, vehicles and so forth. Therefore the development of technique to characterize material properties of CFRP for impact force is required. The split Hopkinson bar (SHPB) test is a useful technique to characterize material properties for impact loading for steels, however the effectiveness for CFRP has not been evaluated sufficiently. This paper evaluates the effectiveness of the Hopkinson bar test for CFRP by a dynamic finite element method.

2 Split Hopkinson bar test [1]

2.1 Theory

A time history of strain of a specimen is given by eq. (1),

$$\varepsilon(t) = -\frac{2C_0}{L} \int \{\varepsilon_i(t') - \varepsilon_r(t') - \varepsilon_t(t')\} dt' \quad (1)$$

where t is time, L is the length of a specimen, $\varepsilon_r(t)$ is the strain of a reflection wave, C_0 is the wave velocity calculated from the Young's modulus E and the mass density ρ as the follows,

$$C_0 = \sqrt{\frac{E}{\rho}} \quad (2)$$

Also, the stress is given by

$$\sigma_s(t) = \frac{E_0 A_0}{A_s} \varepsilon_i(t), \quad (3)$$

where E_0, A_0 are respectively the Young's modulus and the area of an output bar.

In order to obtain a stress-strain relation by eqs. (1) and (3), 1dimensional stress-wave theory is satisfied [2].

2.2 Experimental equipment

Figure 1 shows the jigs and test specimen. The specimen is flat plate because it is difficult to create a cylinder specimen from CFRP. The jigs are attached to the input and output bars with screw.

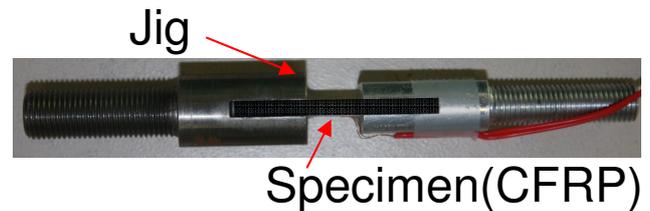


Fig.1 Jig and test specimen

3 Numerical evaluations

The effects of the angle of fiber and length of specimen on wave propagation are evaluated by a dynamic finite element method.

3.1 Governing equation

The governing equation and boundary conditions for the elastic dynamic simulation is given by the following equations [3]:

$$\rho \ddot{u}_i = \mu \nabla^2 u_i + (\lambda + \mu) u_{k,ki} + b_i \quad (4)$$

$$u_i = g_i \quad (5)$$

$$\sigma_{ij} n_j = h_i \quad (6)$$

where, ρ is the mass density, μ, λ are the Lamé's constants, σ is stress tensor, u is the displacement

vector, n is normal unit vector, g and h are the given displacement and force vectors, respectively.

3.2 Model

Figure 2 shows the geometry of a numerical model of SHPB.

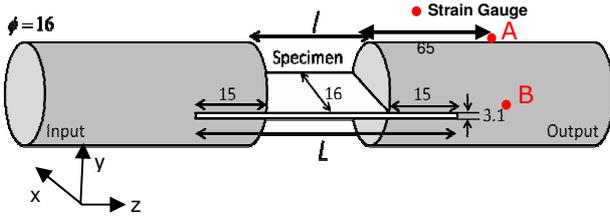


Fig.2 Numerical model of SHPB

The strain of a transparent wave is observed at the position A shown in Fig. 2.

A specimen of CFRP is modeled as an orthotropic material, the angle between fiber and the z-axis is defined by θ as shown in Fig. 3.

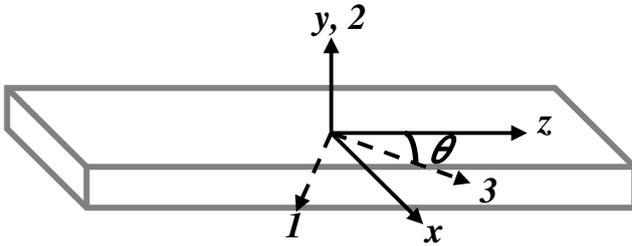


Fig.3 Fiber angle

The material constants of specimen are listed in Table 1. The input and output bars are assumed to be steel.

Table 1 Material constants of specimen

Young's modulus [GPa]	E_1	=	9.5
	E_2	=	9.5
	E_3	=	130.3
Shear modulus [GPa]	G_{32}	=	4.7
	G_{13}	=	4.7
	G_{21}	=	3.1

Poisson's ratio	ν_{32}	=	0.34
	ν_{21}	=	0.5
	ν_{13}	=	0.027
Mass density [kg/m^3]	ρ	=	1800

Table 2 Material constants of input and output bar

Young's modulus [GPa]	E	=	205
Poisson's ratio	ν	=	0.5
Mass density [kg/m^3]	ρ	=	7800

The simulations are conducted using an efficient dynamic finite element method [4].

3.3 Conditions

In order to evaluate the effect of experimental condition on estimated dynamic material properties using SHPB, the length of specimen $L = 50, 150$ mm, the angle $\theta = 30, 45, 60^\circ$ and the duration time of impact loading $T = 20, 100 \mu\text{s}$ shown in Fig. 4.

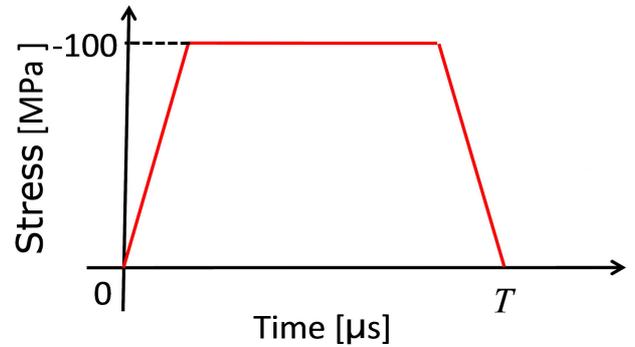


Fig. 4 Impact loading

4 Result

We carried out numerical simulations under several conditions. We compared numerical results between SHPB and specimen only simulation. Specimen only simulation are assumed to be ideal condition to characterize material properties, in these simulations a impact loading was applied to a specimen directly.

4.1 Length of specimen

Figure 5 shows the stress-strain curve for difference length of specimen, other conditions were fixed to $\theta = 0^\circ$ and $T = 20 \mu s$.

In the case $L = 50$ mm, the trend of the stress-strain curves obtained by SHPB and specimen are in good agreement, however in the case $L = 150$ mm the curves are not in agreement.

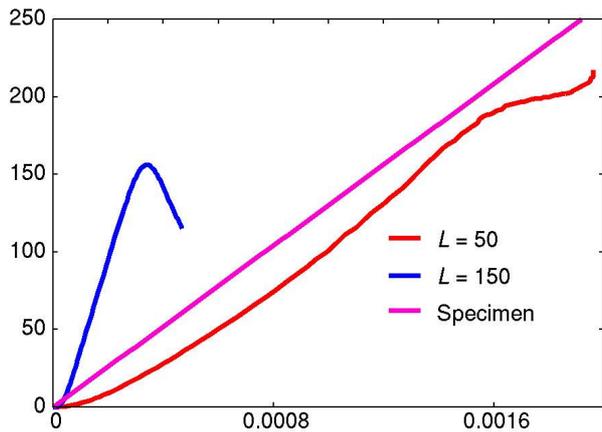


Fig.5 Strain-stress curve for different specimen length

Figure 5.5 compares the time history of strain obtained using specimens having the length $L = 35$ mm and 50 mm, the angle $\theta = 45^\circ$. The length of specimen becomes shorter, the difference between strain histories obtained SHPB and a specimen becomes larger. The reason why the trend was observed is the constraint effect by a jig is stronger when the length of a specimen is shorter.

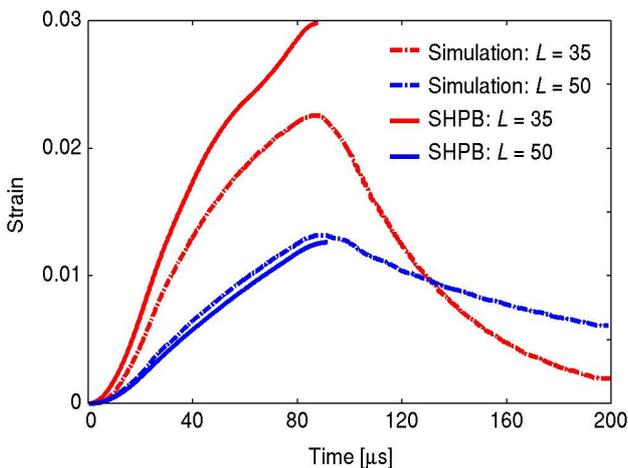


Fig.5.5 Time history of strain for different specimen length

The results Fig. 5 and 5.5 indicate an optimized length of specimen is exist to characterize material properties reasonably.

4.2 Duration time

Figure 6 shows the stress-strain curves for different duration times, $\theta = 90^\circ$ and $L = 50$ mm. In $T = 20 \mu s$, the trend of the stress-strain curve obtained SHPB is not in agree, however in the case $T = 100 \mu s$ these trends are in good agreement.

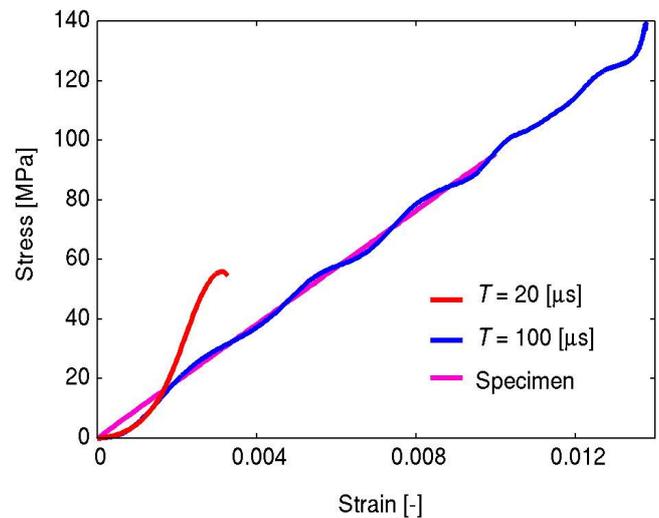


Fig.6 Strain-stress curve for different duration time

Also, considering the stress-strain curves shown in Fig. 5 and 6, if the difference between the (apparent) Young's modulus for the z-direction and the output bar is larger, the longer duration time is required to estimate reasonable material properties using SHPB.

4.3 Angle of fiber

Figure 7 shows the stress-strain curves for different angle $\theta = 30, 45, 60^\circ$, where $L = 50$ mm, and $T = 100 \mu s$. The stress-strain curves estimated by SHPB are in good agreement with the curves simulated using each specimen alone.

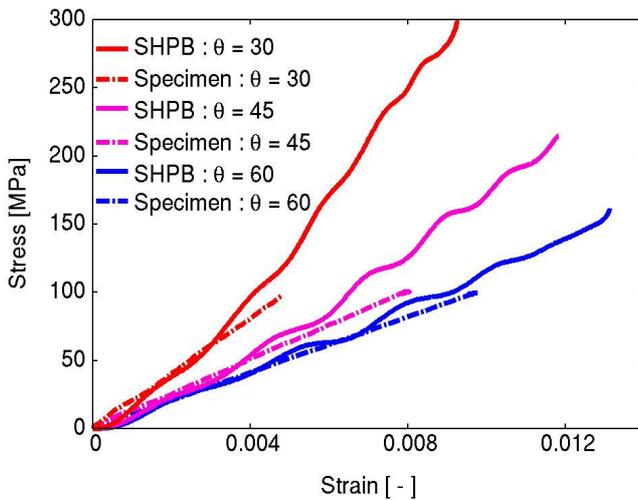


Fig.7 Strain-stress curve for different angle of fiber

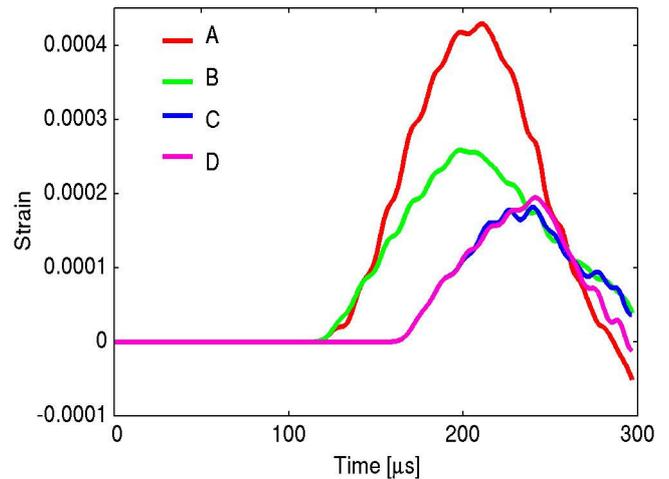


Fig.9 Time histories of the transparent waves for different measuring point

4.4 Observation point

We observed transparent waves at four different locations, *A*, *B*, *C* and *D* shown in Fig. 8. *A* and *B* are at location 50 mm away from the left of the output bar, and *C* and *D* are located at 300 mm away from it. Also *A* and *D* are located at the top, *B* and *C* are located at the side of the output bar.

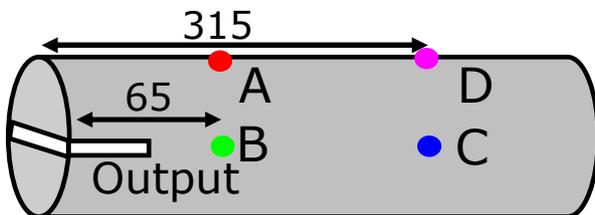


Fig.8 Observation points on output bar

The time histories of the transparent waves are shown in Fig. 9, where $\theta = 45^\circ$ and $L = 50$ mm. At *A* and *B*, the histories have significant difference because of the material anisotropy, however at *C* and *D*, the histories have same trend. These results indicate the possibility to evaluate anisotropic material properties using SHPB from the transparent waves.

5 Conclusions

This study evaluated the effectiveness of the SHPB test for CFRP by numerical simulations. CFRP is modeled as an orthotropic material. The effects of the length of specimen, the duration time of impact loading and the angle of fiber on estimated material behavior by SHPB were evaluated.

The simulations indicate the following remarks.

- An optimal length of specimen is exist to carry out SHPB test for CFRP.
- Sufficient duration time is required to obtain reasonable stress-strain curve.
- Multipoint observation has a potential to obtain anisotropic material properties by SHPB.

References

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