DYNAMIC RESPONSES OF 3D BRAIDED CARBON/EPOXY COMPOSITE

Y. Zhang, P. Wang, B. Sun*
College of Textiles, Donghua University, Shanghai, China
Key Laboratory of Textile Science &Technology, Ministry of Education
* Corresponding author (sunbz@dhu.edu.cn)

Keywords: *3D braided composite, transverse impact, energy absorption*

1 General Introduction

The 3D braided composite has been widely used in aeronautics and astronautics, civil engineering and dynamic protection area due to its excellent mechanical properties, especially the high impact damage tolerance. Flanagan et al [1] observed the damage morphology of 4-step 3-dimensional braided UHMPE composites after ballistic perforation. Jenq et al [2, 3] obtained the quasi-static penetration damage modes from the quasi-static perforation load-displacement curves of two-step and four-step 3-dimensional braided glass/epoxy composites at different penetration displacements and from different regions of the composites, and applied them to ballistic penetration analysis of the braided composites. Zeng et al [4] presented a FE model to simulate the crash behavior and energy absorption characteristics of 3-D braided composites tubes subjected to axial impact loading with LS-DYNA. Gu et al. [5, 6] employed a refined quasi-microstructure model and a microstructure model to investigate the behaviors of ballistic penetration of 3D braided composite, respectively. Sun et al. [7, 8] studied the compressive and uniaxial tensile behavior of 4-step 3D braided composite at high strain rates and obtained the rate dependent properties. For the transverse impact behavior of composite, Sun et al. [9] reported the Aramid/Zylon hybrid composite and obtained the mechanical response of load vs. displacement of the composite under different impact velocity.

This article will study the transverse impact behavior of 3D braided Carbon/Epoxy composite rectangle plate. The load vs. displacement curve, energy absorption and damage model is discussed. The impact morphologies were photographed to find the impact damage mechanisms. Such an investigation could be benefit for the 3-D braided composite under impact loading.

2 Materials and transverse impact test

2.1 3D braided Carbon/Epoxy composite

The 3D braided specimens were made by the 4-step 1×1 method. Table 1 shows the specifications of the composite preform. The braided fiber tow is Toray® T300-6k. The epoxy resin, TDE-86 was injected into the preform by Resin Transfer Molding (RTM) technique. The curing procedures were that the temperature of 130℃ for 2 hours first, followed by 150℃ for 1 hour, and then the 160℃ for 8 hours and finally 180℃ for 3 hours. The fiber volume fraction is about 58%. The photograph of the 3-D braided composite is shown in Fig.1.

2.2 Apparatus for transverse impact test

The transverse impact behavior of 3D braided rectangle composite was tested by a modified spilt Hopkinson bar (SHPB) apparatus. The test apparatus and specimen fixture is shown in Fig. 2. The length of striker bar and incident bar is 300mm and 800mm, respectively. Both of the striker bar and incident bar have the same diameter of 14.5mm and same material of maraging steel. A stress wave was generated and traveled along the incident bar to the composite specimen when the strike bar impacted the incident bar. In order to record the stress wave, two strain gauges were glued on the middle of the incident bar. The equations for the load, displacement, velocity of strain wave and absorption energy of specimen can be expressed by:

$$p(t) = EA[\varepsilon_I(t) + \varepsilon_R(t)] \quad (1)$$

$$\mu(t) = C_0 \int_0^t [\varepsilon_I(t) - \varepsilon_R(t)]dt \quad (2)$$

$$C_0 = \sqrt{E/\rho} \tag{3}$$

$$\begin{aligned} W &= \frac{1}{2}\int_0^t P(t)\mu(t)dt \\ &= \frac{1}{2}EAC_0\int_0^t [\varepsilon_I^2(t) - \varepsilon_R^2(t)]dt \end{aligned} \tag{4}$$

Where E, A and ρ are the modulus, cross-section area, and density of bars, $\varepsilon_I(t)$ and $\varepsilon_R(t)$ are the strain gauge signal of incident and reflect pulses, respectively.

The mechanical behavior of the 3D braided composite can be calculated from equations above. Dependent on the different gas pressure, three different impact velocities: 13.6m/s, 17.8m/s, 22.8m/s were used. At each impact velocity, at least three specimens were tested to get the average load vs. displacement curve.

3 Results and discussion

Fig.3 shows the load vs. displacement curve at different velocities. It is obviously that the peak load and its corresponding displacement of the specimen increase with the increase of impact velocity. For a certain velocity, the peak load decreases during the whole repeating process. It also can be observed the fluctuation of the load-displacement curves. This mainly because the stress wave in the incident bar will hit the composite specimen first and induce the elastic and plastic deformation of the composite plate. As the release of the elastic deformation of the composite plate, there is a reflective stress wave go through the incident bar. The reflected stress wave will reflect again at the other surface of the incident bar and became the strike stress wave. Because of the velocity of stress wave is so large that all the process will take only several microseconds. This process will happen several times until the specimen was damaged or the stress wave was dissipated.

Fig.4. depicts the energy absorption feature of 3-D braided composite under transverse impact. As with the load-displacement curve, the absorbed energy increases as the impact velocity increases. This mainly caused by the severe damages which including resin crack, fiber pullout, fiber breakage under higher impact velocity.

Fig.5 shows the front surface photograph of 3-D braided composite specimen after tests. As the increase of impact velocity, the damage of the braided composite also increased. When the impact velocity was higher than 17.8m/s, the composite specimen broke. It could be found that the damage was in a saw tooth shape. When the impact velocity reached to 17.8m/s and 22.8m/s, there was obvious breakage in saw shape which means the shear failure of the composite specimen. Under the higher velocity impact, the accumulations of fiber tows' breakage and resin crack exceeded the critical damage area. Then the composite will have impact failure.

Fig.6 depicts the fracture morphology of the 3-D braided composite specimen on the back surface under different velocities. It is also easily to find the saw shape crack and breakage of the composite specimen. Similarly, the damage of the composite specimen becomes more serious with the increase of the impact velocity. Resin shear failure, fiber pullout and fiber breakage are the main failure mode on the rear surface of the composite specimen.

The transverse deformation of the 3-D braided composite specimen in Fig. 7 also shows the strain rate effect. The deformation of the composite specimen increases as the impact velocity increases.

4 Conclusions

In this paper the transverse impact behavior of 3D braided Carbon/Epoxy rectangle composite plate was tested with the modified split Hopkinson bar apparatus. The load vs. displacement curve and energy absorption feature clearly showed that the 3-D braided composite absorbed more energy with the increase of the impact velocity. The saw tooth shape of the impact damage of the 3-D braided composite under impact manifests the breakages of fiber tows and resin crack. The energy absorption feature of the 3-D braided composite under transverse impact will lead the precise design of the impact protection.

Table.1. Specification of 3D braided preform

Braided yarn	m×n	α(°)	L(mm)	W(mm)	H(mm)
T300-6k	29×5	28±3	125	25	3

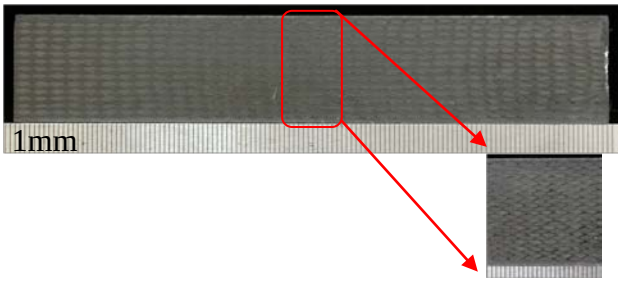

Fig.1. Photograph of the 3-D braided composite

Fig. 2 The modified split Hopkinson pressure bar for transverse impact test

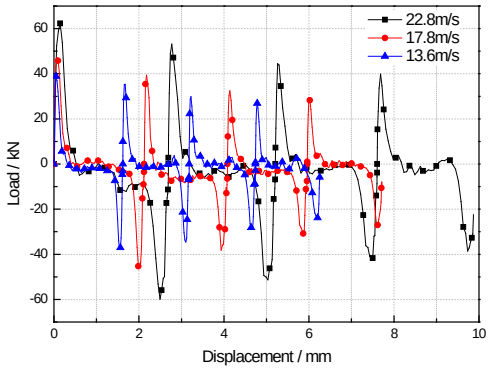

Fig.3. Experimental results of load vs. displacement curve of 3D braided composite under different velocities

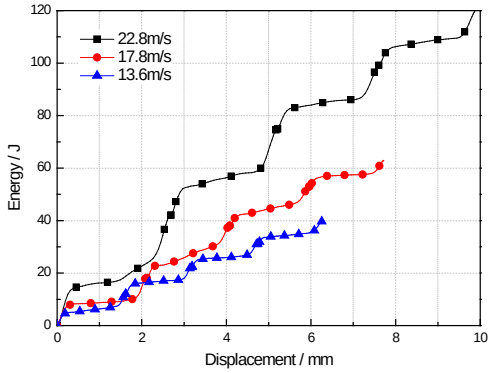

Fig.4. Energy absorption vs. displacement curves of the 3-D braided composite at different impact velocities

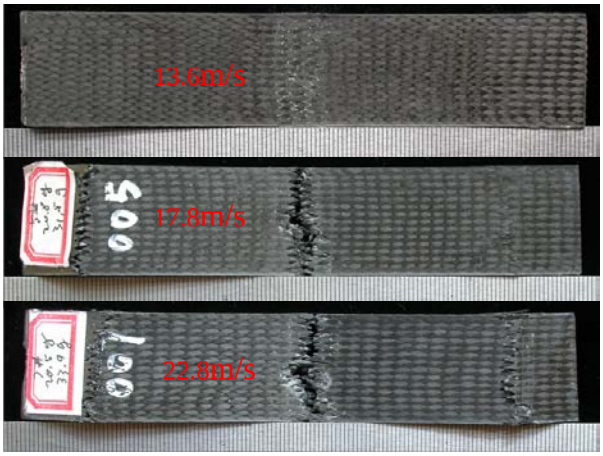

Fig.5. Front view of the failure morphology of 3-D braided composite

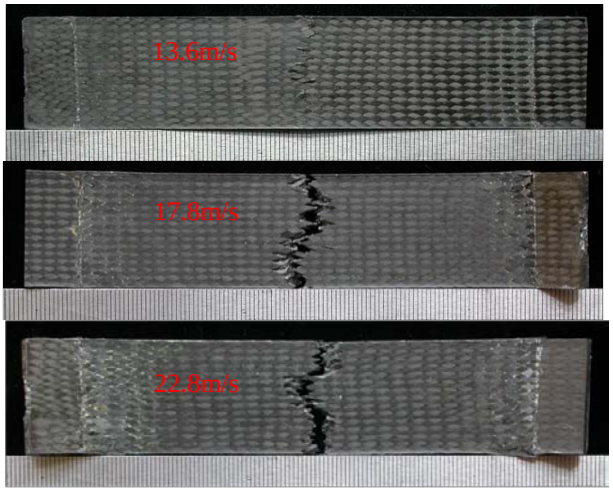

Fig.6. Back view of the failure morphology of 3-D braided composite

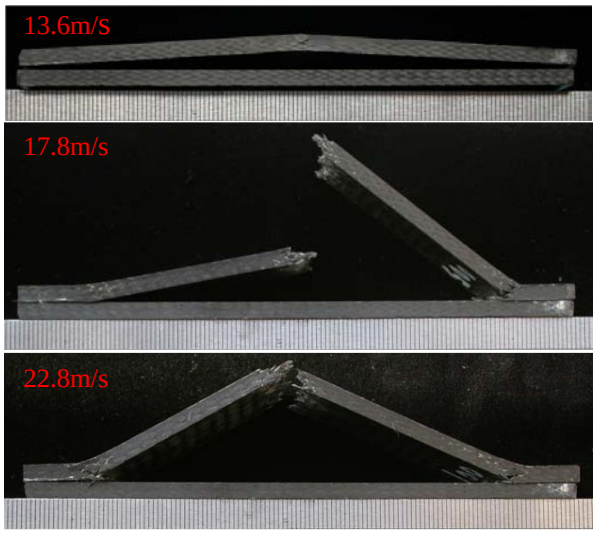

Fig.7. Side view of the failure morphology of 3-D braided composite

References

[1] Flanagan M P, Zikry M A, Wall J W, et al. An experimental investigation of high velocity impact and penetration failure modes in textile composites. Journal of composite materials, 1999, 33(12): 1080-1103.

[2] Jenq S T, Mao J J. Ballistic impact response for two-step braided three-dimensional textile composites, AIAA Journal, 1996, 34(2):375-384.

[3] Jenq S T, Kuo J T, Sheu L T. Ballistic impact response of 3-D four-step braided glass/epoxy composites, Key engineering materials, 1998, 141-143: 349-366.

[4] Zeng T, Fang DN and Lu TJ. Dynamic crashing and impact energy absorption of 3-D braided composite tubes. Materials Letters, 2005, 59(12): 1491-1496.

[5] B. Gu, J. Xu "Finite element calculation of 4-step 3-dimensional braided composite under ballistic perforation". *Composites Part B-Engineering*, Vol. 35, No.4, pp 291-297, 2004.

[6] B. Gu "A microstructure model for finite-element simulation of 3D rectangular braided composite under ballistic penetration". *Philosophical Magazine*, Vol. 87, No.30, pp 4643-4669, 2007.

[7] B. Sun, Y. Liu, B. Gu "Strain rate effect on four-step three-dimensional braided composite compressive behavior". *AIAA Journal*, Vol. 43, No. 5, pp 994-999, 2005.

[8] B. Sun, F. Liu, B. Gu "Influence of the strain rate on the uniaxial tensile behavior of 4-step 3D braided composites". *Composites Part A*, Vol. 36, No.11, pp 1477-1485, 2005

[9] Z. Sun, Y. Gong, C. He, Z. Zhang "Energy absorption characteristics of AF/ZF hybrid composite under SHPB transverse impact". *Acta Materiae Composite Sinica*. Vol. 22, No. 3, pp 21-24, 2005