THE DYNAMIC BEHAVIOR OF FUNCTIONALLY GRADED PLATES UNDER THE IMPACT LOADING

Xiao-Qiong Zhang;Wei-Guo Guo;Jian-jun Wang
School of Aeronautics,Northwester Polytechnical University,Xi'an 710072,P.R.China
jone1108@live.cn;weiguo@nwpul.edu.cn,jianjunw87@126.com

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Abstract

In order to investigate the impact behavior of functionally graded plate of GRFP/CRFP with different proportion, a series of ballistic impact tests were performed with the speed of about 70m/s. Then the damage analysis and residual strength tests were performed. A C-scan ultrasonic device was used to detect the internal damage of the samples at the sub-surface under impact. The results show that with the impact velocity increased, the maximum delamination areas within functional plate would move from the center of the thickness to the non-impact surface plate; the lower GRFP content of impact surface was, the smaller damage zone, therefore, the impact performance of functionally plate was more superior.

1 Introduction

Fiber reinforced polymer matrix composites have been widely used in aircraft, aerospace, marine, and automotive structures due to their high specific strength and stiffness [1,2].Composites that are used in aerospace structural components are often subjected to high velocity and low velocity impact threats like broken engine parts, turbine blades, fragments from bombs, hail and other foreign objects. There are many issues that determine the response of the composite materials to impact threats. These include: energy absorption properties, failure destruction, and the residual strength after impact and kinetic energy of the impactor.

There have been a number of experimental and numerical studies on the impact response of a wide variety of composite laminates constructions. Richardson and Wisheart[3] have made a review of low-velocity impact responses of composite materials. The term 'low-velocity impact' is defined and major impact-induced damage modes are described from onset of damage through to final failure. The damage induced by low energy impact is often a complex mixture consisting of: interlaminar fracture (delamination), interlaminar fracture (transverse matrix cracking and debonding between fiber and matrix) and fiber fracture[4-6]. H.M.Wen[7,8]using impactors with different geometry shape performed a series of ballistic impact tests. Then an approximate method for estimating penetration resistance and ballistic limit velocity of the laminated composite plates were proposed. Recep Gunes[9]studied the 3-D elasto-plastic of functionally graded (FG) circular plates under low-velocity impact loads and proposed a TTO model which can be used to describe the mechanical behaviour of FG plates beyond the elastic range.

In order to improve the impact resistance and energy absorption properties of composite structures plate, the front of structure board often selected materials with high shear resistance and compression resistance. Materials with high tensile resistance and deformation resistance were chose to make the back face of structure plate. For special applications, there is widespread use of engineering ceramics for the front face and high modulus carbon fiber layer board for the back face. To reduce the weight and improve energy absorption efficiency, the functionally graded plate produced by carbon fiber and Kevlar fiber captured the attention of designers and researchers. In order to avoid high-speed impact created by rubber debris, hail, sand etc. which caused the damage and destruction to structure component; considering the glass fiber woven composites has lower modulus, good shear resistance and high strength; while taking into account the carbon fiber composite have advantages such as high toughness and high modulus, the impact response of functionally graded plate of GRFP/CRFP with different proportion and energy absorption were assessed in this paper. Including systematically studied the functionally graded plates damage mechanism, the relationship between quasi-static compression residual strength and composition of the samples while after impact.

2 Specimen and experimental procedure

2.1 Material and specimen

The functionally graded composite plates are represented in Fig.1.Its impact panel is made of glass fiber woven composites SW100/5228A and backplane is produced by carbon fiber CCF-1/5228A, and then solidified them together. The size of all laminated plates were 200mm*150mm*8.7mm.The thickness of glass fiber layer accounted for total thickness 5%, 10%, 15%, 20%, 25% and 30%. The configuration of samples were showed in table1.

Fig. 1. Functionally graded plate of SW100/5228A and CCF-1/5228A

2.2 Experimental procedure

The test device as shown in Fig. 2 (a). The specimen was held between two steel frames. Impact area is a rectangular of 150mm length and 100mm width. Four strain gauges numbered as 1,2,3,4 were attached on the front surface of sample along the length and width direction. While on the back surface two strain gauges numbered as 5, 6 were attached corresponding to strain gauges1, 2. The distance between strain gauge and the centre of sample is 30mm as shown Fig.2 (b).

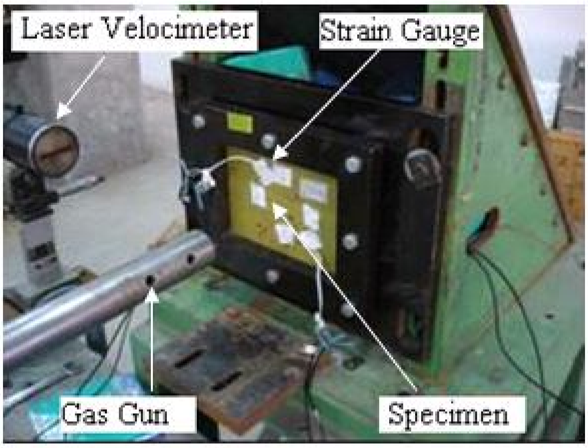


Fig. 2(a) Picture of Impact test fixture

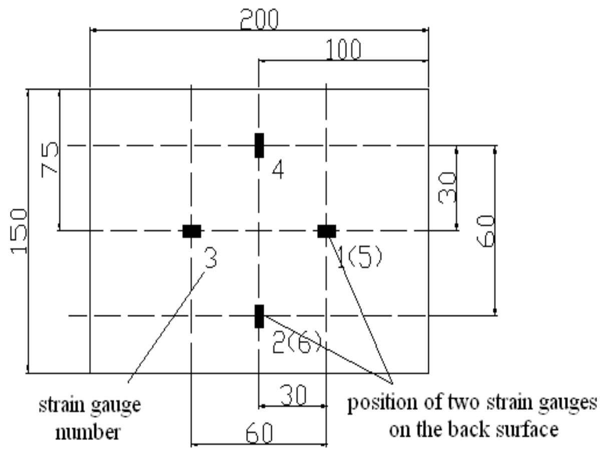


Fig. 2(b) Position of strain gauge

The impact tests were performed using a gas-gun test set up which was fabricated by Northwestern Polytechnical University. The diameter of gun barrel is 25mm and the length is 5m.Gun barrel axis was perpendicular to the board plane. Projectiles were solid hemispherical fabricated by 45 steel quenching and tempering steel. Their diameter is 23mm, length is 29mm, weight is 80g.The speed of projectiles can be adjusted by controlling the nitrogen pressure. To ensure that the projectiles impact the target plate along the normal, muzzle was very close to the target plate. Input velocity was measured by laser velocimeter, measurement error<1%.

The internal damage in target plate can be seen from C-scan. Residual compressive strength tests were performed after impact tests by 60T (hydraulic testing machine) liquid presses. Compression test fixture was illustrated in Fig.3.

Table1 Composite plate configuration

The content of glass fiber	SW100/5228A	CCF-1/5228A
5%	$45_3/0$	$-45(45/-45)_2((0/90(45/-45)_4)_20/90(45/-45)_20/90)_s(-45/45)_4$
10%	$(45_3/0)_245$	$-45((0/90(45/-45)_4)_20/90(45/-45)_20/90)_s(-45/45)_4$
15%	$45_3/0(45_2/0)_245_3$	$-45(45/-45)_3(0/90(45/-45)_40/90(45/-45)_20/90)_s(-45/45)_490/0(-45/45)_4$
20%	$45_2/0(45_3/0)_345_2$	$(45/-45)_2(0/90(45/-45)_40/90(45/-45)_20/90)_s(-45/45)_490/0(-45/45)_4$
25%	$45/0(45_5/0)_245_4/0/45_3$	$(0/90(45/-45)_40/90(45/-45)_20/90)_s(-45/45)_490/0(-45/45)_4$
30%	$45/0/45_3/0(45_5/0)_245_4/0/45_3$	$(45/-45)_3(0/90(45/-45)_20/90)_s(-45/45)_490/0(-45/45)_490/0(-45/45)_4$

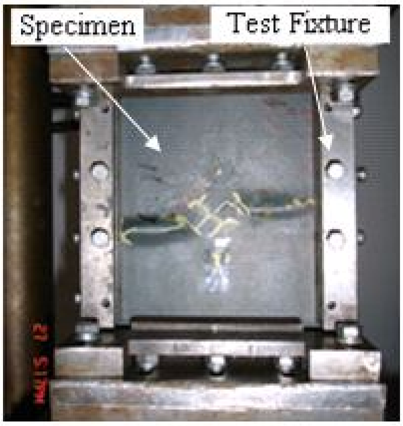


Fig. 3 The post-impact compression test rig

3 Results

3.1 Impact response and compression behavior

After impact tests, typical failures of samples were shown in Fig.4 and Fig.5.The concave pit appeared on the front surface of specimen and on the back surface appeared ±45°cross cracking. Large fracture (plastic) deformation caused the convex of backplane and accompanied massive damage such as matrix cracking, fiber breakage and delamination.Fig.5 shows the damage morphology of specimens that glass fiber content were 5％，15％，25％，30％ respectively. With glass fiber content increased, damage shape changed from square to circular.

Fig.6 shows the relationship of the local deformation and time history of the No.2-1 specimen. (positive is tensile, and negative is compress)Observed the curve, except signal 2, all the signal 1, 3, 4 were coincided better. Because the strain gauge 2 was debonding in the impact process, the signal 2 was weaker than others. Better coincidence of three signals reflected the point of impact was in the target plate center. When the back signal upped 10000με it was returned to 4000με rapidly and the large deformation duration at position 5, 6 were quite different. These results indicated that the surface layer of back plate occurred bending defection gradually with other layers. With the further invasion of the projectile, on the back of each layer where the position corresponded the strain gauges was compression deformation. Therefore, the signal measured by strain gauges would continue to amplify. Because the effect of stress wave and the inconsistency of interlaminar deformation, delamination appeared in back plate. In back plate, caused interlaminar constraint of free surface was derived from adjacent layers, the back plate was subjected to the interlaminar constraint would be significantly reduced when a large area of delamination and ×-shaped crack appeared. And then the back plate has a trend back into plane and this trend could make the deformation of specimen decreased. When the signals5, 6 changed from the maximum value to lower steady state value, the delamination of back plate appeared and the constraint disappeared. Due to the projectile was embedded in No.2-1 specimen that prevented the back plate rebound, the deformation at the place where attached the strain gauges could be maintained at the maximum value for a while.

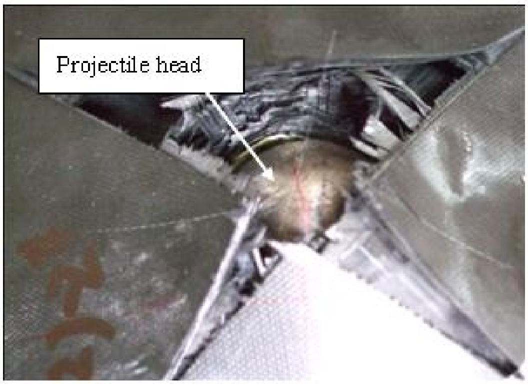


Fig. 4 Damage of CRFP

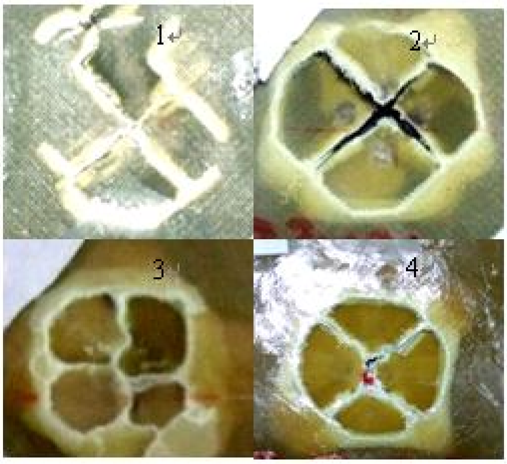


Fig. 5 Damage of GRFP

Whatever the projectile embedded in target plate or rebounded, the deformation of target plate would be vibrate repeatedly.

When the projectile impacted the specimen which has large thickness glass fiber, there was a short "stay phenomenon" occurred before the carbon fiber plate suffered the impact. This phenomenon could make the soft material layer unloading the tensile wave which generated from gradient materials. To a certain extent, it could be prevented if the back plate suffered from strong impact.

3.2 Damage measurement by C-scan

Fig.7 shows the rule of the relationship between damage area and the GRFP thickness percentage. Along with the thickness of the GRFP panel increased, the damage area of laminated plate was expanded. A large area of internal damage appeared in the carbon fiber layer. To observe the outside of the specimens, there were fiber breakage and tore up phenomenon due to the larger impact energy of this series of tests and delamination growth was limited. After the same energy impact, the dispersion of damage area was still larger.

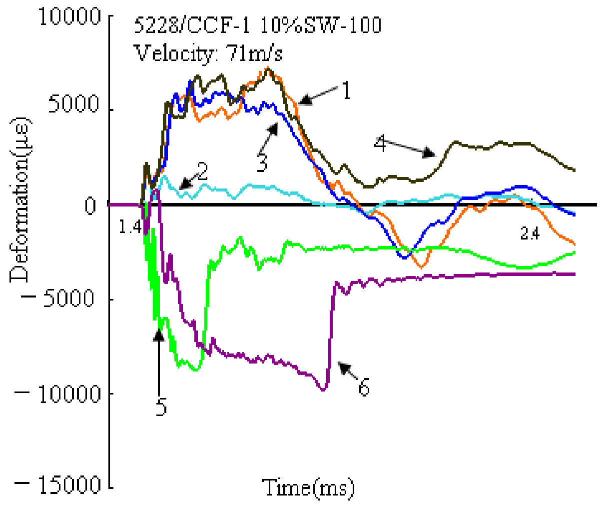


Fig. 6 Time-Deformation curve of No.2-1 specimen

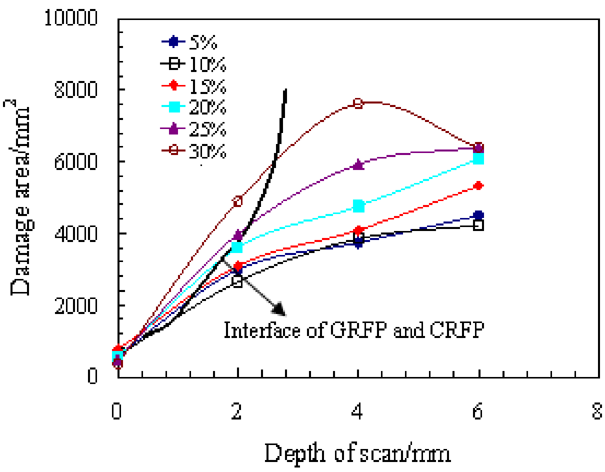
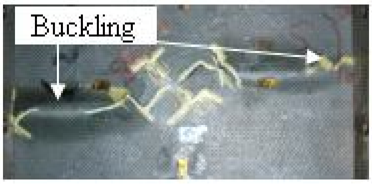


Fig. 7 Relations of proportion of front face，resin crack length and damage area of post-impacted composite laminates

3.3 Residual strength test

The destruction of all specimens started from the impact point and along the direction vertical the loading direction. Fig.8 shows the failure mode of the front, back and side surface of the specimen. During the compression test, when the load was lower there was local buckling on the back plane. As the test continuing, the damage of specimen extended to both sides along the direction that vertical the loading direction.

When the load reached a certain level, the fiber layer of front surface and back surface was fractured. Complete failure of laminates followed by the fiber fractured. As the GRFP thickness increased, the residual strength of laminates decreased which observed from the results of compression tests (Fig.9). It was because stiffness and strength of the GRFP was lower, when its content increased, the strength of specimen was decreased.



(a) The front face

(b) The back face

(c) The side face

Fig.8 Damage of impacted composite laminate when failed

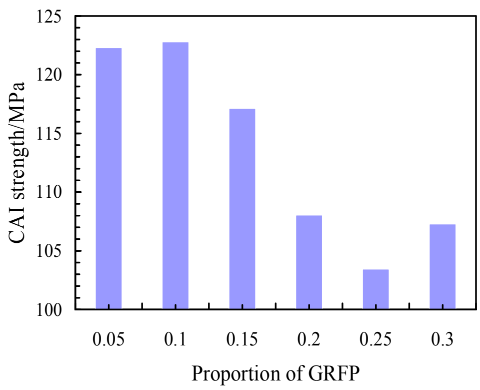


Fig.9 Relations between proportion of front face and compression after impact (CAI) strength

3.4 Ballistic limit velocity

The ballistic limit velocity was the critical speed of projectile embedded in the target plate or breakdown the target plate. In Table2, Only in T1-2 and T2-1 target plate the impactor were embedded in and others were all rebound. Therefore, the ballistic limit velocity of T1-2 and T2-1 were nearby speed of 70m/s. When GRFP proportion were 5% and 10%,functionally graded plate prone to brittle fracture. As the GRFP proportion was increased, it could restrict the projectile tear the target plate more effectively and the penetration resistance would be increased. So increasing the thickness of woven glass could improve the ballistic limit velocity.

Table 2

GRFP proportion	Sample	Velocity(m/s)	Observation
5%	T1-1	70.2	Rebound
5%	T1-2	69.7	Embedded
10%	T2-1	71	Embedded
10%	T2-2	74.6	Rebound
15%	T3-1	74.3	Rebound
15%	T3-2	73.8	Rebound
20%	T4-1	73.5	Rebound
20%	T4-2	71	Rebound
25%	T5-1	76.5	Rebound
25%	T5-2	69.1	Rebound
30%	T6-1	75.1	Rebound
30%	T6-2	69.5	Rebound

Conclusions

Through a series of experiments, the analysis of experimental data indicated that:

(1) As the impact velocity increased, the biggest area of delamination in functionally graded plate would moved from the center of thickness to back surface.

(2) Along with the content of glass fiber increased, the energy absorption would be much better and the destroy deformation of back plate would be much lower.

(3) The residual strength is inversely proportional to the content of the glass fiber.

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