Experimental Study on the Characterization of Low-Velocity Impact to Laminated Composite Material under Different Impactor Shapes

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Abstract - *This work is a further development of research on impact damage to composites. The following main effects are known due to impact loading of composites: 1) delamination that occurs at relatively low impact energies; 2)other types of fracture (fiber breaks, matrix cracks, etc.), which can be united by the general concept of "material crushing", manifested as the impact energy increases. The kinetic energy of the impact is partly spent on local destruction, and partly converted into deformation energy of the entire structure. The combination of these factors can cause instant destruction of a structural element. In other cases, impact damage causes fracture as a result of subsequent dynamic loading. The aim of this work is investigation of impact on composites plates. Provided experimental data which have been conducted by drop-weight impact testing machine, and the punch with different shapes under various impact energies. Delamination was obtained by using non-destructive testing method which is ultrasonic C-scan. Depths were measured by depth micrometer.*

Key Words: composite plate, carbon laminate, low-velocity impact, delamination

1. INTRODUCTION

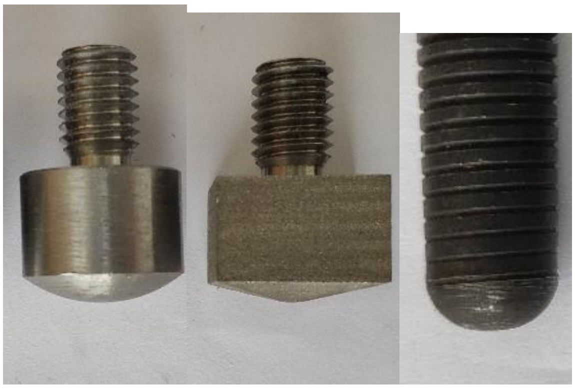
Compared with the penetrating impact damage of composite laminates under high-energy impact, composite laminates often produce visually undetectable internal damage under low-energy impact loads, which is more deadly to the aircraft composite structure. Material laminates are susceptible to low-energy impacts from foreign objects during preparation, transportation, and use, such as stones, maintenance tools, hail and other objects. The damage caused by such impact objects is difficult to detect from the surface. Under the same energy, The impact damage of stone is much more serious than that of hail. The sharp edges and corners of the gravel surface will directly cause the fracture of the surface fiber matrix. The hail will cause invisible damage under a certain energy, which is difficult to detect from the surface, but the matrix has occurred inside. , Delamination and other damage, which is very harmful to composite structural parts. The damage of composite laminates under low-energy impact is divided into two categories: intralayer damage (matrix cracking and fiber fracture) and interlayer damage (delamination). Under low-energy impact, composite laminates are mainly matrix damage and delamination damage. The failure process is mainly shear failure at the impact point, and the bending of the back of the impact point causes the matrix to crack, which causes delamination damage. The delamination area increases with thickness. It is getting larger and peanut-shaped, and the layering direction extends along the fiber direction. Impact objects with the same energy and different shapes have different damages to composite laminates. With the increase of impact energy, sharp impact objects will first cause damage to the fiber matrix of the impact surface, and the round head punch may only cause matrix damage.

The characterization methods of low-energy impact damage of composite laminates mainly include: pit depth, delamination damage area, and residual compressive strength. Due to the limitation of the test conditions, this chapter conducts a low-energy impact test on a composite laminate according to the ASTM test standard for a laminated laminate, and compares and studies the impact damage of the composite laminate by different shapes of punches, different impact energy and other factors Impact.

2. Low-energy impact test of composite laminates

This test was conducted using ASTMD7136 (Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer Matrix Composite to a Drop-Weight Impact Event), using MTS ZCJ9162 drop-weight impact testing machine, and the punch mass was fixed at 5.5kg. Test design: 10mm round ball head, 16mm round ball head, 24mm punch, tapered punch, sharp-angled tapered punch and other five kinds of steel punches, work hardened, as shown in the picture

a) b)



c) d) e)

Fig -1: Punch shape: a) pointed cone punch; b) 16mm ball head; c) 24mm ball head; d) cone punch e) 10mm ball head

The test piece is a T300 fiber-reinforced resin-based laminate provided by Nanjing Chenmao Technology Co., Ltd. As shown in the figure, the material parameters of the single-layer board are shown in the table. According to the test standard, the size of the test piece is 150mm×100mm×4.368mm. The layering of the piece is [45/0/-45/90]3S, and 5 kinds of energy impacts are carried out respectively. Different impact energies are realized by changing the height of the drop weight. The impact energy is 10J, 20J, 30J, 40J, 50J.

Fig -2 Initial drawing of the test piece;

Fig -3 Falling weight impact testing machine;

Table -1: Elastic parameters of composite single layer

E1(GPa)	132000
E2(GPa)	11900
E3(GPa)	11300
G12(GPa)	3400
G13(GPa)	3400
G23(GPa)	3400
μ12	0.34
μ13	0.32
μ23	0.34

Table -2: Strength parameters of unidirectional composite material plates

Xt(MPa)	2489.50
Xc(MPa)	1348
Yt(MPa)	49
Yc(MPa)	148
S12(MPa)	109
S13(MPa)	109
S23(MPa)	82

Where E1 is the modulus in the fiber direction, E2, E3 are the modulus perpendicular to the fiber direction, G12, G13, and G23 are the shear modulus in the three directions respectively, and μ is the elastic modulus in the three directions, respectively. Xt, Xc is the tensile and compressive strength of the unidirectional board in the fiber direction; Yt, Yc is the tensile and compressive strength of the unidirectional board in the vertical fiber direction respectively; S is the shear strength

3. Test results and discussion

The test results show that when the round punch is used for impact, smaller pits appear on the surface, and the depth of the pits increases with the increase of energy. The larger the diameter of the punch is, the larger the impact pits are under the same energy. The depth will become smaller. Figure 5 shows the surface shape of a 30J energy cone punch after being impacted by an electronic microscope. It can be seen that the upper surface has more serious damage, such as obvious fiber breakage, matrix crushing damage and obvious pits. The increase in impact energy becomes more serious. Figure 6 is the surface map of the test piece after impact. It can be seen that the composite laminate will leave a permanent pit in the shape of a punch after being impacted. As the impact energy increases, the bulge area on the lower surface gradually increases, and there is Fiber fracture, matrix cracking, delamination and even partial penetration phenomena. Under the same energy, the smaller the diameter of the ball punch causes the larger the back bulge, and the more serious fiber tearing in the fiber direction of the back. The fiber fracture caused by the impact of a large-angle tapered punch is more serious than the impact damage of a small-angle tapered punch.

When the energy is further increased, more serious damage appears on the upper surface,

Fig -4 16mm ball head 30J impact, view from front and back side;

Fig -5 pointed cone punch, 30J impact view from front and back side;

The characteristic parameters of low-energy impact damage of composite laminates mainly include: pit depth, delamination area, and residual strength. Composite laminates will undergo elastic deformation after low-energy impact. The depth of the pit needs to be measured immediately after the impact. This test uses a depth micrometer caliper to measure the depth of the pit, and the measurement accuracy is 0.001mm. Since the depth of the pit produced by the impact of the tapered punch is inconvenient to measure, only the pit depth of the round punch is discussed here.

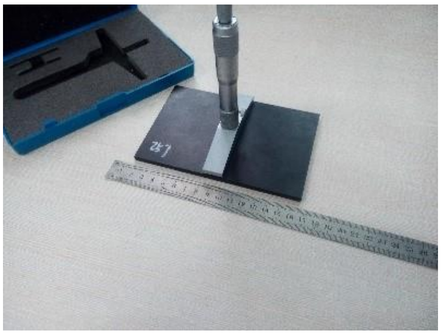


Fig -6 Depth micrometer measuring pit

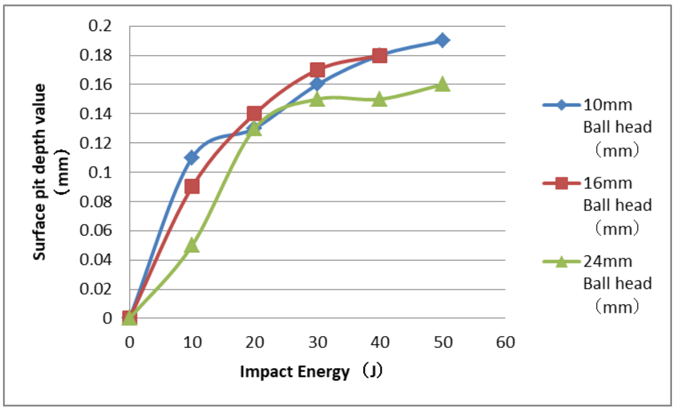


Fig -7 Surface pit depth value for different impact energies

It can be seen from the figure that when the energy of the same punch is small, the pit at the impact point is very shallow. With the increase of the impact energy, the depth of the pit gradually increases, and the increase is slower, mainly due to the impact of the punch. The larger contact area of the test piece leads to a decrease in the impact stress and a smaller increase in the pit depth. From the curve in the figure, it can be seen that the pit depth has a nonlinear relationship with the increase of energy.

Experiments found that the relationship between impact energy and pit depth is the best, and there is an inflection point .Impact energy at the inflection point means the maximum energy that the fiber and the matrix can withstand the impact (damage resistance) as a whole. Afterwards, the depth of the pit still increases approximately linearly with the increase of the impact energy of the punch, but the increase speed is very fast. After the inflection point, it can be seen from experimental observations that damages such as matrix cracking and fiber breakage begin to appear on the back of the laminate, and the overall impact resistance (damage resistance) of the fiber and the resin matrix is gradually weakened, so the pit depth increases faster; As the fibers are broken in a large area, the entire laminate is penetrated by the indenter. Before the inflection point, the matrix and fiber jointly resist impact damage. After the inflection point, matrix damage and delamination damage have occurred, and the fiber alone bears the load, so the pits increase rapidly.

The damage area detection of composite laminates after impact damage mainly includes two methods: destructive testing and non-destructive testing.

Non-destructive testing methods currently include: visual inspection method, X-ray inspection method, ultrasonic inspection method, etc. The visual inspection method is the simplest and the most extensive. The surface fiber breakage and matrix extrusion of the test piece after impact damage can be detected by visual inspection and tools, but the internal damage cannot be observed. The X-ray inspection method is that when X-rays pass through the test piece, the intensity of the rays passing through the defective part is higher than that of the non-defective part, leaving a darker image on the photosensitive film. Optical dislocation speckle interferometry is usually used Infrared thermal loading is used as the excitation method, and then the surface speckle fields that are misaligned before and after heating are superimposed on the image plane, and the displacement derivative and strain field of the object surface are obtained based on the two exposures before and after the surface of the object, and the damage location is accurately determined. Derivative peak value to estimate the size of the defect area. Ultrasonic detection method is based on homogeneous materials, the material discontinuity caused by defects will cause inconsistent acoustic resistance, ultrasonic waves reflect at the interface of two different acoustic resistance media. Ultrasonic testing methods mainly include pulse reflection method, penetration method, reflector method, etc. The composite material laminate with simple structure should adopt the water immersion reflector method.

Ultrasonic C-scan has the advantages of intuitive and fast detection speed, and has become a common detection technique for composite laminates. It uses the C-type display principle, reflects internal damage through color images, and performs qualitative and quantitative analysis of defects. When testing, the ultrasonic probe is placed on the detection surface of the test piece, and the sound wave enters the surface of the test piece through the water medium. If the test piece has no defects, the sound wave propagates to the bottom surface of the test piece and returns. Different colors can be displayed to distinguish the delamination damage in the thickness direction of the laminate

Fig -8 Ultrasound Scan ULTRA-PAC1605

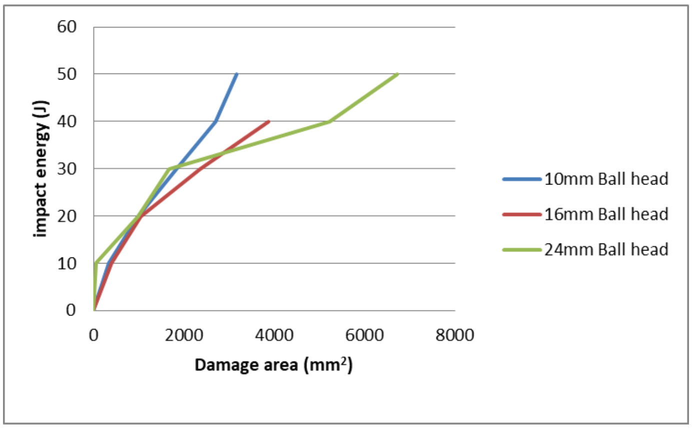


Fig -9 Damage area for different diameter of punches

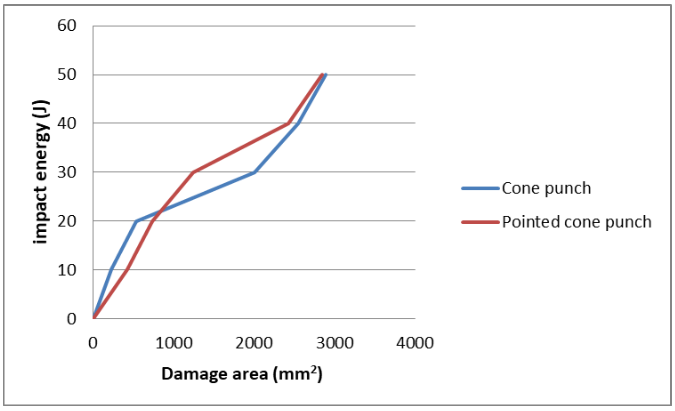


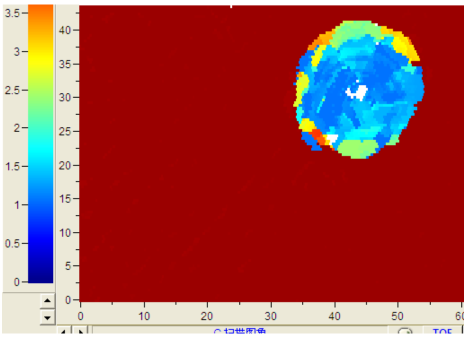
Fig -10 Damage area for different cone punches

It can be seen that the delamination damage area increases with the increase of impact energy, and the pit depth and damage area gradually increase with the increase of impact energy. The damage area of punches with different diameters under the same energy impact is not the same, but the difference is not obvious. When the impact energy is 20J, the difference in the damage area caused by the three different diameters is not large. When the impact energy is less than 20J, The damage area caused by a punch with a large diameter is smaller than that of a punch with a small diameter. When the impact energy is 30J, the damage caused by a punch with a large diameter starts to rise sharply. This is because the contact area between the punch and the composite laminate increases. When the energy is small, the impact contact surface is large, the impact stress is small, and the damage caused is small. When the energy increases to a certain extent, the punch contact surface is large, and the damage range caused by the impact is larger, resulting in more delamination damage.

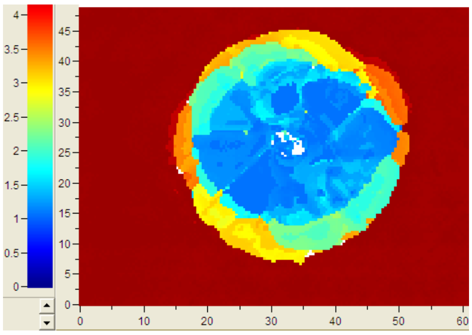
As shown in the figure 10, the delamination damage between the 15-degree tapered punch and the 30-degree tapered punch is relatively close when the impact energy is 22J, and when the impact energy is less than 22J, The delamination damage caused by a 30-degree tapered punch is greater than the 15-degree angle, which means that when the impact energy is small, the sharp angle is more likely to cause delamination damage than the contact area of the punch. When the impact energy exceeds 22J, the 15-degree tapered The delamination damage caused by the punch is greater than that of the 30-degree tapered punch. This is because at this stage, when the punch energy is constant, the contact area between the punch and the composite laminate is an important factor affecting the delamination area.

It can be seen from the figure that when the impact energy is around 30J, the delamination damage area changes greatly. By comparing the test pieces after impact, it is found that when the impact energy is greater than 30J, there are obvious fiber breaks on the upper and back sides of the test piece, and the matrix cracks. The phenomenon appears, and the damage morphology of the surface and back of the laminate when the impact energy is 25J and 50J are respectively given. After the impact is completed, obvious dents are found on the surface of the laminate. The test found that when the impact energy is very low, the deformation can be fully recovered after the impact is completed, and no pits are generated on the surface. With the increase of the impact energy, the fiber breaks a lot. At this time, the pit depth and damage area have changed drastically.

The damage profile of the composite laminate under the impact of a spherical punch with a diameter of 10mm is shown in the figure. The sound wave emitted by the ultrasonic C-scan probe is reflected from the upper surface through the lower surface and the display shows red, and reflects from other layers in the middle of the thickness. Other colors will be displayed. The color corresponding to the thickness direction can be seen from the cloud image on the left side of the figure. The damage area of the laminate is smaller under 10J energy impact, and the area of the layer at the impact point changes from the upper surface to the lower surface not big, the damage shape on the impact surface and the back surface is round. As the impact energy increases, the delamination area from the upper surface to the lower surface increases sequentially, and the layered shape on the back surface also begins to expand from a spherical shape to a fiber layer along the fiber. The peanut shape with increasing direction, the greater the impact energy, the more obvious the delamination phenomenon.



a)



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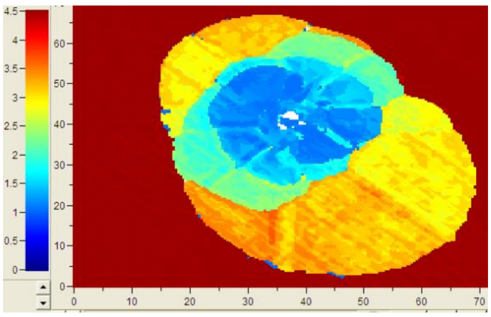
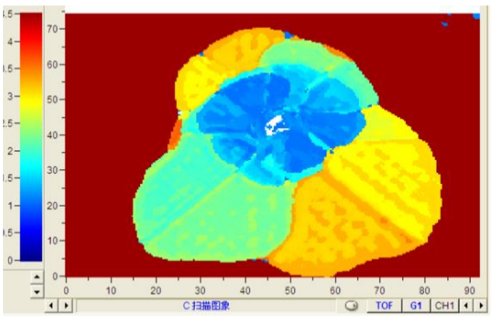
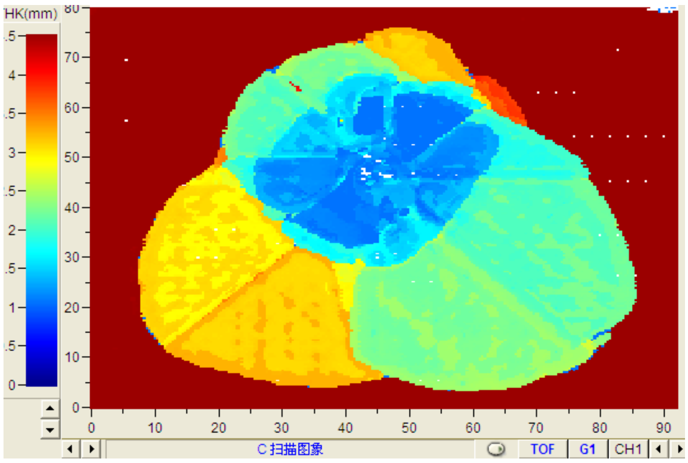


c)



d)



e)

Fig -11 Delamination damage area under impact of 10mm diameter punch for impact energies : a)10J; b)20J; c)30J; d)40J; e)50J

3. Summary

In this chapter, according to the test standards, low-energy impact experiments are carried out on composite laminates. The impact damage pit depth and delamination damage area of the composite laminate structure under different shapes of punches are analyzed, and the punch shape and impact energy follow the relationship between delamination damage area.

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