# Preliminary Study on Evaluation System of Capability of Composites to Withstand Impact

SHEN Zhen[1*], CHEN Pu-hui[2], YANG Sheng-chun[1]
(1 Aircraft Strength Research Institute of China, Xi′an 710065, China;
2 Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China)

**Abstract:** This paper summarizes the authors' experimental study on the characterization system of composite behavior to withstand impact. The content includes: (1) The dent depth is the best parameter describing the impact damage state. (2) There exists the knee point phenomenon for damage resistance behavior (*i. e.* the relationship between impact energy or contact force and dent depth) and damage tolerance behavior (*i. e.* the relationship between dent depth and compressive failure strain or stress) of composite laminates. (3) The physical meaning of the knee point phenomenon is that the failure mechanisms change of damaged composites to fiber breakage in the first front plies from matrix crack and delamination. Some suggestions on the characterization system of composite behavior to withstand impact were proposed.

**Key words:** composite; dent depth; damage resistance; damage tolerance; knee point phenomenon

**CLC number:** TB33 **Document code:** A **Article ID:** 1001-4381(2006)05-0068-05

In the middle of 1970th, it was found that the main weakness of composite laminates was their sensitivity to impact and it limited extensive use of composites in aircraft structures. Usually it was considered that the sensibility came from brittleness of resin matrix. Therefore development of toughened resin matrix has been paid the most attention to by material scientists for the last 30 years. In order to evaluate the toughened resin matrix composites test standards[1,2] by the characteristic quantity of CAI (Compression After Impact) was proposed in 1980th. In the early of 1990th some researchers[3-10] realized that CAI was an amphibolous presentation and pointed out that the capability of composite systems to withstand impact included two separate issues: damage resistance and damage tolerance. Whereas damage resistance is a measure of the damage incurred by a material or structure due to a particular event (such as impact), damage tolerance involves a measure of the ability of a material or structure with damage to "perform" given particular requirements. So far there are still no new characteristic quantities instead of CAI to evaluate their capability to withstand impact although ASTM test standards for damage resistance and compressive residual strength of composites with damage[11-13] have been issued. Recently Authors[14-19] found that the capability of composites to withstand impact exhibited the knee point phenomenon by a great many experimental results, and pointed out that the characteristic quantities at the knee point could be used to evaluate the capability of composites to withstand impact which included damage resistance and damage tolerance. The present paper summarizes some conclusions which were obtained in this study so far.

## 1 Capability of Composites to Withstand Impact

### 1.1 Selection of Damage Parameter

The appropriate damage parameter has to be selected in order to describe the capability of composites to withstand impact. It should meet the following requirements:

(a) For the same impact event the response of composite systems with different toughness (or damage resistance) should be significantly different;

(b) The damage parameter should be easily measurable.

Based on a great many experimental results Authors found the dent depth was the suitable damage pa-

* E-mail: shenzhen@pub.xaonline.com

rameter to describe the damage state (see Fig. 1). In comparison with damage area and damage width the relationship between impact energy (or contact force) and dent depth is the most sensitive to the difference of capability to withstand impact for different composites and it is the easiest measurable quantity. In fact the dent depth depends on many factors, such as the shape and materials of the impactor, but they can be specified during development of these test standards.

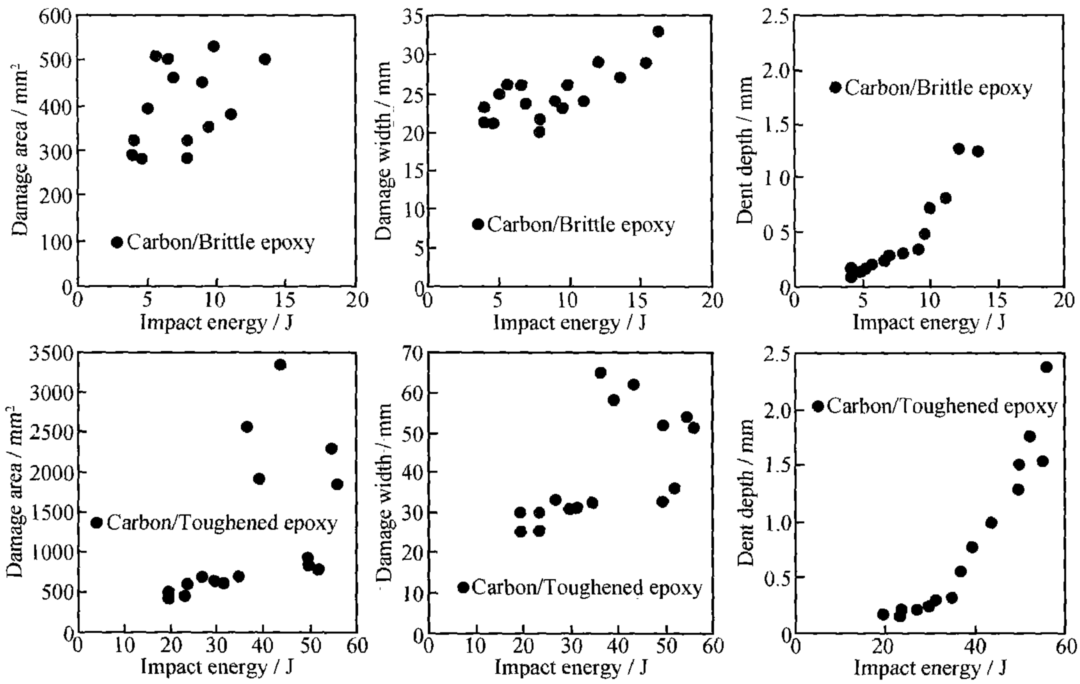


Fig. 1 The relationship between impact energy and different damage parameters for carbon/epoxy

### 1.2 Knee Point Phenomenon of Capability of Composites to Withstand Impact

The experimental study by Authors have verified that the relationship between impact energy (contact force) and dent depth which was obtained by different damage introduction methods (dropped weight and quasi-static indentation) and impactors with different tip diameters (12.7 and 25.4mm) for composites with different lay-ups, thickness and material systems, exhibited obvious knee point phenomenon and the dent depth at the knee point was less than 0.5mm. Authors also found that the dent depth ~ compressive failure strain curves of composites with damage introduced by dropped weight or quasi-static indentation method tended a constant, that is a threshold. Fig. 2 and Fig. 3 are the part of the test results obtained by Authors. The data in Fig. 4 are quoted from [20]. This phenomenon shows that the obvious change occurs at the knee point for no matter damage resistance behavior (characterized by impact energy or contact force ~ dent depth curves) or damage tolerance behavior (characterized by dent depth~ compressive failure strain or stress curves). Therefore it is possible to establish evaluation systems of composites to withstand impact by using this phenomenon.

## 2 Physical Meaning of Knee Point Phenomenon

The failure mechanisms of damaged composites with different toughness (brittle T300/5222 and toughened T700S/5228) were investigated by using deply technique. Table 1 shows the test parameters for each specimen. $\delta_{knee}$ is the dent depth at the knee point. Fig. 5 is the results of the deply technique and shows the damage details and its distributions ply by ply. The following is observed:

(a) Only matrix and delamination could be observed for damaged composites with $\delta < \delta_{knee}$. The mark of the knee point is occurrence of fiber breakage at the impact location on the front surface.

(b) The preliminary observation found that fiber breakage propagated to the middle from the surface of laminates as the dent depth increased when $\delta > \delta_{knee}$.

(c) The influence of damage introduction methods to damage distribution and mechanisms is neglectable as long as the dent depth is the same.

The knee point phenomenon indicates that ab-

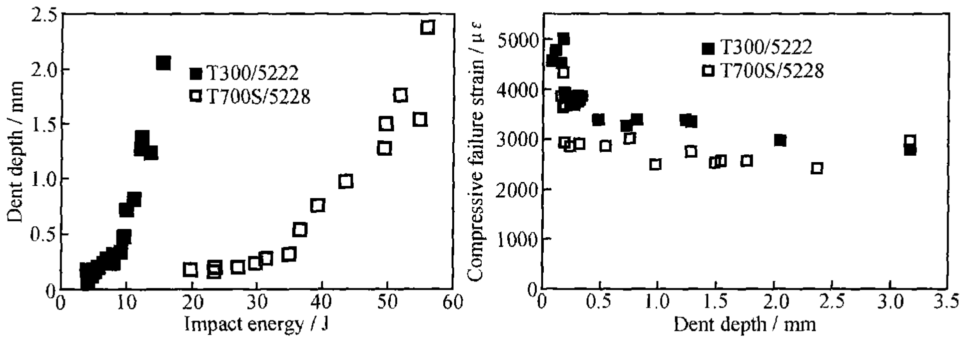


Fig. 2 Damage resistance(impact energy~ dent depth) and damage tolerance(dent depth) behavior for two composite systems with different toughness

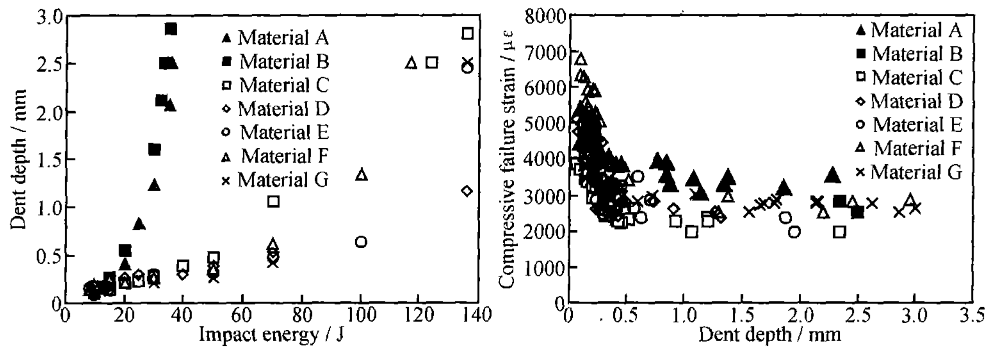


Fig. 3 Damage resistance(impact energy~ dent depth) and damage tolerance(dent depth) behavior for 7 composite systems with different toughness

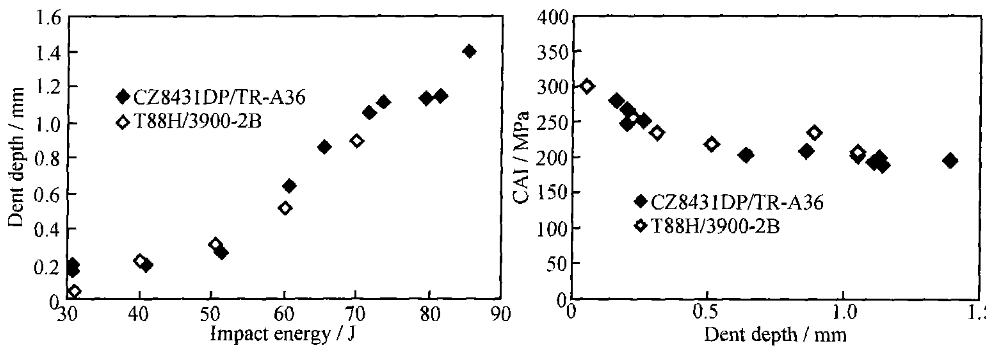


Fig. 4 Damage resistance(impact energy~ dent depth) and damage tolerance(dent depth) behavior for 2 different composite systems (data from referance [14])

rupt change in capability of composites to withstand impact. When $\delta < \delta_{knee}$, composite laminates withstand impact events by means of intact front surface plies (*i. e.*, no matrix cracks and interface failure on the front surface plies, usually the first 3 plies). The consequence of impact is only matrix cracks and interlaminar delaminations in the inner laminates. After the knee point phenomenon occurs, *i. e.* fiber breakage on the front surface plies occurs, composite laminates lose the capability to keep withstanding impact basically. The succeeding damage is mainly fiber breakage propagation to the middle plies from the surface plies and only a little increase of inner delamination area. Therefore compressive strength is basically a constant when $\delta > \delta_{knee}$, because compressive strength depends on inner delamination area.

**Table 1 Test parameters (A-T300/5222, B-T700S/5228)**

| Damage introduction method | Dropped weight | | Quasi-static indentation | | | |
|---|---|---|---|---|---|---|
| | B4-1 | B4-2 | A3-3 | A3-4 | B4-3 | B4-4 |
| Energy/J or contact force/kN | 30.3 | 41.7 | 3.6 | 3.89 | 8 | 11.53 |
| Dent depth/mm | $0.26 < \delta_{knee}$ | $0.94 > \delta_{knee}$ | $0.26 < \delta_{knee}$ | $0.4 > \delta_{knee}$ | $0.34 < \delta_{knee}$ | $0.54 > \delta_{knee}$ |

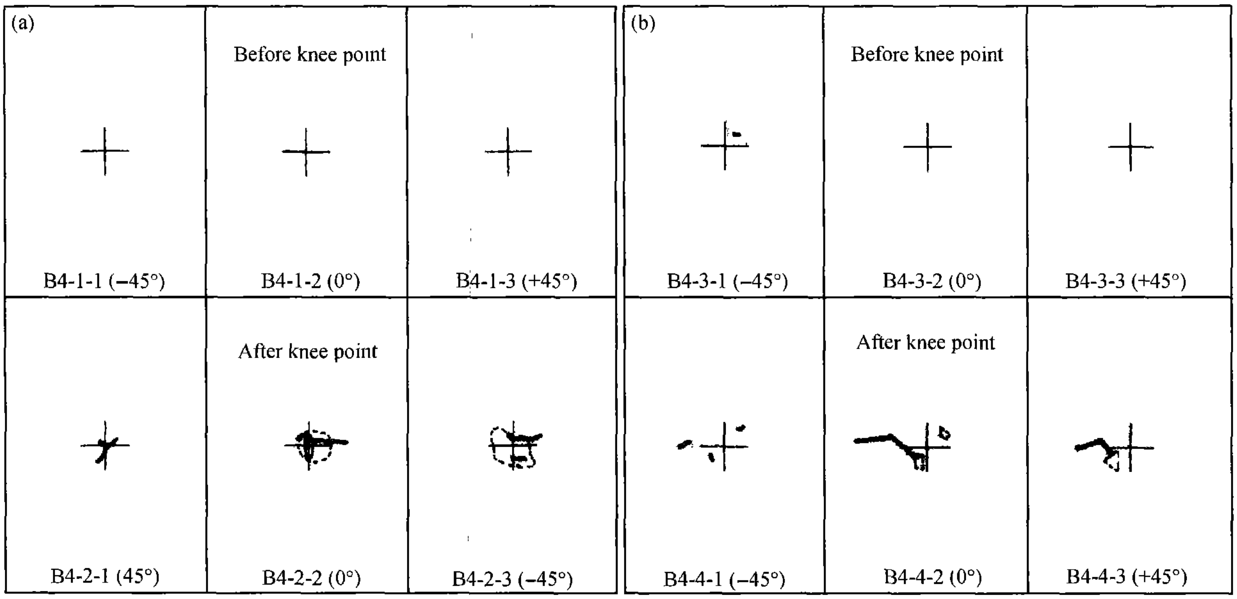


Fig. 5 Damage details of the first three plies of damaged specimens

(where fiber breakage —— matrix crack___delamination)

(a) quasi-static indentation; (b) dropped weight

## 3 Suggestions on Evaluation System of Capability of Composites to Withstand Impact

The following evaluation system of capability of composites to withstand impact is proposed based on the knee point phenomenon of composite behavior to withstand impact (impact energy or contact force *vs.* dent depth curve for damage resistance and dent depth *vs.* compressive failure strain or stress curve for damage tolerance) and its physical meaning:

(a) The maximum capability of composite laminates to keep integration of the front surface plies under impact can be used as characteristic quantity to evaluate damage resistance behavior (so-called toughness) of composite systems. Considering that the influence of damage introduction methods can be neglectable, the maximum contact force using the concentrated quasi-static indentation method with the specified conditions. These conditions can be selected based on [11].

(b) The minimum capability of damaged composite laminates, *i.e.* the threshold of the dent depth *vs.* compressive failure strain or stress curve under the specified conditions can be used as characteristic quantity to evaluate damage tolerance behavior of composite systems. These conditions can be selected based on [12, 13].

## Acknowledgements

The financial support from the National Natural Science Foundation of China under project No.

10472107 is gratefully acknowledged. The authors also wish to acknowledge the supports from the Aeronautical Science Foundation of China under project Nos. 04B23002 and 04B52009.

**References:**


[1] ACEE composites project office. NASA/Aircraft industry standard specification for graphite fiber/toughened thermoset resin composite material[R]. NASA RP 1142. 1985.

[2] SACMA SRM 2R-88, SACMA recommended test method for compression after impact properties of oriented fiber-resin composites[S].

[3] ILCEWICZ L B, DOST E F, COGGESHALL R L. A model for compression after impact strength evaluation[A]. Proc of the 21st International SAMPE Technical Conference[C]. 1989. 130-140.

[4] LEE S M AND ZAHUTA P. Instrumented impact and static indentation of composites[J]. Journal of Composite Materials, 1991, 25: 204-222.

[5] POE C C JR. Demonstrating damage tolerance of composite airframes[R]. N94-29623, 1994.

[6] LAGACE P A, RYAN K F, GRAVES M J. Effect of damage on the impact response of composite laminates[C]. AIAA-91-1079-CP, 1991.

[7] JACKSON W C, POE C C JR. The use of impact force as a scale parameter for the impact response of composite laminates[A]. NASA TM-104189. Proc of 9th DOD/NASA/FAA Conference on Fibrous Composites in Structural Design Vol 2, 1992[C]. 981-998.

[8] LAGACE P A, WILLIAMS J E, TSANG P H W. A preliminary proposition for a test method to measure (impact) damage resistance[J]. Journal of Reinforced Plastics and Composites, 1993, 12: 585-601.

[9] DOST E F, AVERY W B, FINN L B, et al. Impact damage resistance of composite fuselage structure[A]. Part 3 Paper Presented at Fourth ACT Conference[C]. Seattle Wash: Boeing Commercial Airplane Group, 1993.

[10] National research council. New materials for next-generation commercial transport[M]. Washington D C: National Academy Press, 1996.

[11] ASTM D6264-98(04), Standard test method for measuring damage resistance of fiber-reinforced polymer matrix composite to concentrated quasi-static indentation force[S].

[12] ASTM D7136-05, Standard test method for measuring damage resistance of fiber-reinforced polymer matrix composite to a drop-weight impact event[S].

[13] ASTM D7137-05, Standard test method for compressive residual strength properties of damaged polymer matrix composite plates[S].

[14] YANG Xu, SHEN Zhen, YAN Ying, et al. New methodology for evaluating toughness of composite laminates-investigation of damage resistance[J]. Chinese Journal of Aeronautics, 2003, 16(2): 73-79.

[15] SHEN Z, YANG S C, FU S Y, et al. Characterization of damage resistance and damage tolerance of composite materials[A]. Composites Technologies for 2020[C]. Cambridge England: Woodhead Publishing Ltd, 2004.

[16] SHEN Z, ZHANG Z L, YANG S C, et al. Characterization of damage resistance and damage tolerance behavior of composite laminates(in Chinese)[J]. ACTA MATERIAE COMPOSITAE SINICA, 2004, 21(5): 140-145.

[17] SHEN Z, YANG S C. Experimental study on behavior characterization of composite laminates against impact (in Chinese)[A]. Advance and Its Application of Solid Mechanics[C]. Hefei: University of Science and Technologyof China Press, 2005.

[18] CHEN Pu-hui, SHEN Zhen. Failure mechanisms of laminated composites subjected to static indentation[J]. Journal of Composite Structures, 2006, 75(1-4): in press.

[19] SHEN Z, YANG S C. Knee point phenomenon of composites withstanding to impact and its physical meaning (in Chiness)[A]. Proc of NCCM-14[C]. Yichang, 2006.

[20] TOSHIO ABE, KENGO HAYASHI, FUMIHITO TAKEDA, et al. A VARTM for primary aircraft structures[A]. Proc of the 26th International SAMPE European Conference 2005 SAMPE[C]. Paris, April 5-7 2005. 379-384.


(上接第 67 页)


[8] MAJZOOBI G H, FERESHTEH SANIEE F, BAHRAMI M. A tensile impact apparatus for characterization of fibrous composites at high strain rates[J]. Journal of Materials Processing Technology, 2005, 162-163: 76-82.

[9] M GUDENU, YILDIRIMA, HALL I W. Effect of strain rate on the compression behavior of a woven glass fiber/SC-15 composite[J]. Polymer Testing, 2004, 23(6): 719-725.

[10] HADAL R S, MISRA R D K. The influence of loading rate and concurrent microstructural evolution in micrometric talc- and wollastonite-reinforced high isotactic polypropylene composites[J]. Materials Science and Engineering A, 2004, 374(1-2): 374-389.

[11] XU Ai-rong, LIU Yuan-rong. The study of mechanical properties and constructive equation for bismaleimde modified by O, O′-dially phen A[J]. Polymer Materials Science and Engineering, 2001, 17(3): 114-117.

[12] ZHOU Feng-hua, WANG Li-li, HU Shi-sheng. The damage criterion and non-linear viscoelasticity construction of PMMA under high strain rate[J]. Explodes and Attacks, 2002, 12(4): 333-342.

[13] WU Qi-ye, FENG Ying. Polymer Material Introduction[M]. Beijing: China Machine Press, 2004. 133-142.