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EXAMINATION OF THE INFLUENCE OF CROSS-IMPACT LOAD ON BEND STRENGTH PROPERTIES OF COMPOSITE MATERIALS, USED IN AVIATION

BADANIE WPŁYWU POPRZECZNYCH OBCIĄŻEŃ UDAROWYCH NA WŁAŚCIWOŚCI WYTRZYMAŁOŚCIOWE MATERIAŁÓW KOMPOZYTOWYCH STOSOWANYCH W LOTNICTWIE*

Fibre reinforced composites are often used in airplane structures because of their specific strength. One type of the materials are layered composites (laminates) applied inter alia in aircraft's covering production. Laminate is susceptible to damage resulting from impacts, the effect of which is usually invisible during macroscopic observation. The article presents results of a preliminary examination of layered composites obtained from an airplane element loaded impactly with low energy. During testing, pieces were loaded with 2.5; 5 and 10 J energy and then they were put on bend tests. The material bending strength after a shock load with 2.5 and 5 J energy remains almost unaltered, but for 10 J energy, it decreases by more than 30% in comparison to undamaged material. As a result of the examination, it was ascertained that in all cases the exact location of the damage could be difficult to find, which is a significant maintenance problem.

Keywords: *composite, laminate, shock load, delamination, airplane.*

Kompozyty włókniste ze względu na bardzo wysoką wytrzymałość właściwą są często stosowane w konstrukcjach lotniczych. Jedną z odmian tych materiałów są kompozyty warstwowe (laminaty), z których wykonuje się m.in. elementy pokryć statków powietrznych. Laminat jest materiałem wrażliwym na działanie porzecznych obciążeń udarowych, często występujących podczas eksploatacji samolotów i śmigłowców. Praca prezentuje wyniki wstępnych badań kompozytów warstwowych pobranych z rzeczywistego elementu lotniczego, poddanych niskoenergetycznym obciążeniom udarowym. Podczas eksperymentu, próbki obciążano energiami o wartościach 2,5; 5 i 10 J, a następnie poddawano próbom zginania. Wytrzymałość materiału po obciążeniu udarowym z energiami 2,5 i 5 J pozostaje niemal niezmieniona, natomiast dla energii 10 J spada o ponad 30% w stosunku do materiału nieuszkodzonego. W wyniku badań stwierdzono również, że w każdym z przypadków mogą wystąpić trudności z lokalizacją uszkodzenia, co stanowi istotny problem eksploatacyjny.

Słowa kluczowe: *kompozyt, laminat, obciążenie udarowe, delaminacja, statek powietrzny.*

1. Introduction

Fibre reinforced composites, due to their high specific strength (Rm/p) and other beneficial effects of mechanical properties are increasingly used in basic airplane structures. Laminates (layered composites) are often selected for airplane structures and components, whose minimum mass remains the main criterion. Although there are a number of unquestionable advantages in the process of design, production and particularly exploitation of composite structures, work conditions seem to play a much higher role. One should also bear in mind property differences between composites and other construction materials [10].

Metallic materials after applying a shock load become damaged in a way relatively easy to locate. However, in case of fibre reinforced composites, the damage seems to be extremely difficult to spot due to the fact that it can emerge on the surface directly on the side of the shock load, on the opposite side of the shock load or inside the material's structure (laminates) [3, 7]. In aviation, even minor damage to the composite structure may drastically lower the bottom margin of the structure's safety, even after an impact of a dropped tool, foreign bodies thrust by aircraft wheels during a take-off, due to mid-air bird strike, etc. This type of bending strength is characterized by applying a relatively small mass at low velocity, therefore the energy of the impact also reaches low values. It must be emphasized that in literature the term itself and assigning the bend strength after an impact are referred to as low-energy, high-energy, low-velocity, high-velocity impact, etc. [1, 14, 17].

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

2. Damage to fibre composites

Fibre reinforced composites (FRP – fibre reinforced polymer) are materials of heterogeneous anisotropic structure, which makes the damage uneasy to locate. The damage can appear in various forms [6]:

a) base damage – cracking of the base along fibres, caused by their extending, gripping or cutting (Fig. 1);
b) delamination (separation of layers) – caused by stresses among various layers of the laminate (Fig. 1);
c) fibre damage – it commonly appears on the surface directly under the impact of a shock load, as a result of cutting forces which arise while bending the acting element; also on the side of the laminate away from the bending tensions;
d) perforation – it is macroscopic damage which emerges after destroying the base and the fibres, finally leading to the puncture (destruction) of the material's structure.

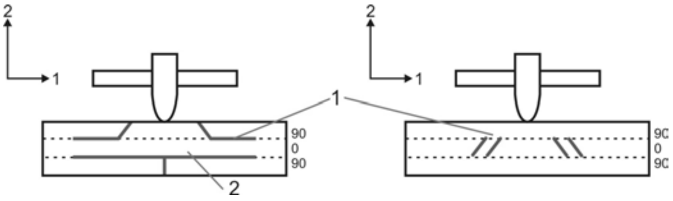

Fig. 1. *Initial damage in 0/90/0 composite due to cross-impact loads: 1 – base damage, 2 – delamination [11]*

The caused effects fall into two energy ranges of the impact load:

- low-energy damage (BVID – barely visible impact damage) as a result of small energy impact load. Within the material, around the impact area, there is a network of separated layers and cross-bending of the layers. However, there is no massive cracking of the fibres. On the surface of the damage there appears a slight spot, whereas on the opposite side the damage is much more extensive [2].
- high-energy damage with fibre cracking, partial or full perforation.

In case of minor impact loading (several joules) around the impact area, there is a slight spot, difficult to identify. The examination of the microstructure shows that beneath the spot there may emerge an area similar to a cut cone (Fig. 2). The tip of the cone overlaps the impacted spot (external surface of the element), whereas the base of the cone lies on the opposite (i.e. inside) surface of the element wall.

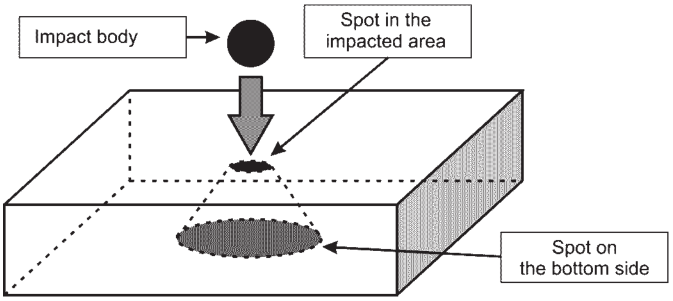

Fig. 2. *Shape of an impacted area in a composite sheet after low-energy impact loading*

The evaluation of structure polymer composites susceptibility to impact-load damage is of highly practical nature. Traditional impact tests (Charpy, Izod, et al) used in the testing of metals and polymer plastics turned out to be of limited application for the estimation of layer structure composites. Specific features of laminates are the reason why these materials need finding new methods for the evaluation of their usefulness for work in conditions which may bring about the occurrence of impact loading damage [2].

3. Experimental research

The aim of the carried out research was to determine the influence of low-energy impact load upon the mechanical properties of the composite material, i.e. laminate, used for the covering of the front part of the aircraft fuselage. The research was conducted on the basis of a programme specified by an algorithm (Fig. 3). It bases upon the assumption that delamination and cracking remain the main causes of laminate strength reduction, after impact loading [5, 9, 12, 15].

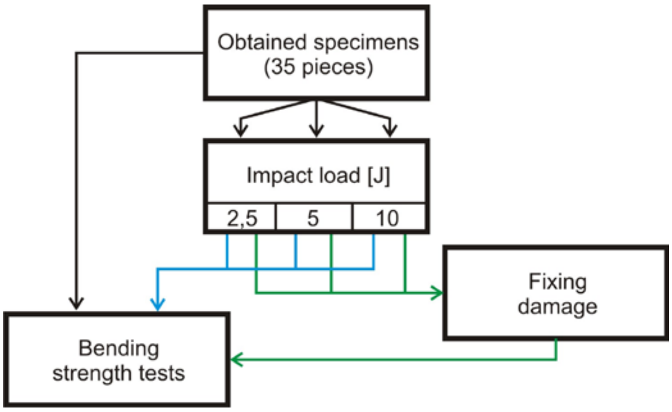

Fig. 3. *Research diagram*

The specimens, rectangular in shape, were obtained from an aircraft covering element – the TS-11 "Iskra", approximately 30 years in service. We paid particular attention to the lack of wear and tear as well damage emerging at a later time, during storage. The specimens were derived from places whose element curving was minimal due to the fact that the shapes had to be close to rectangular. The test material was made with layered composite on the epoxy-resin base, reinforced with three layers of glass fabric, of 300 g/m2 basis weight.

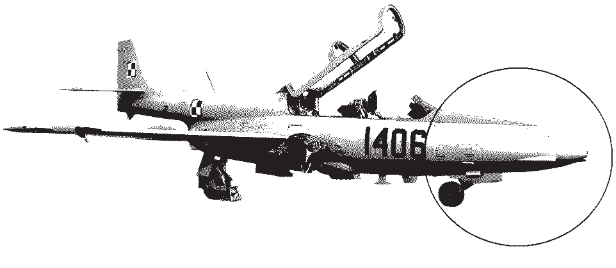

Fig. 4. *The TS-11 "Iskra" aircraft; marked test element (picture by P. Idzkiewicz)*

Prior to the main research we conducted a series of preliminary checks so as to select proper measurements of the specimens and the type of the impact loading. For evaluation purposes of bend strength, we adopted two most common methods, exploited for this type of examination - static expansion test [15, 16] or three-point bending test [4, 3, 13, 18].

In case of the expansion test, it was problematic to select proper specimen measurements for the research. EN ISO 527-2:1998 norm specifies the specimen width as smaller than the aperture diameter in the plates which fix the specimen on the impact loading test machine (40 mm). The specified measurements make it impossible to copy the conditions which give rise to cross-impact bend in the aircraft covering. Finally we decided to carry out a series of tests which adopted different sizes of specimens. The conducted experiments proved that the adoption of such specimens does not solve the problem as even tiny differences in specimens' thickness, (which usually occur), cause breaking of specimens in the place where they were fixed during the check, in spite of making them a bit more narrow (Fig. 5).

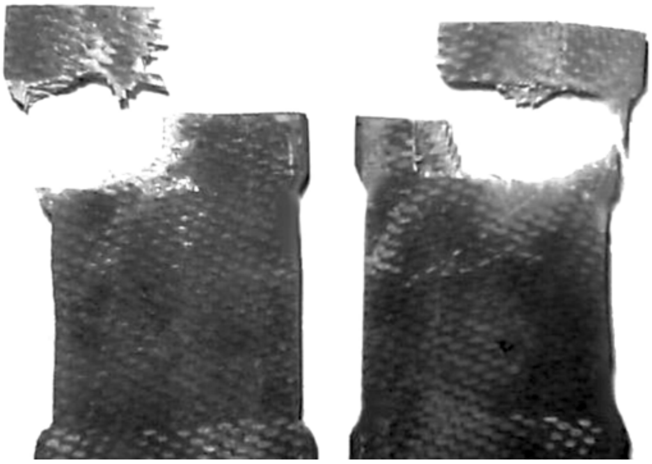

Fig. 5. Specimens for preliminary tests, broken in the fixing point

Qualifying three-point bend tests proved the suitability of the method for the assessment of the composite material bending strength.

In the first phase of the research, the specimens were impact loaded with a certain energy level, perpendicularly to the surface of the specimen. In the second phase, the specimens were checked in order to determine ultimate strength to bending.

For the sake of the research 35 specimens were used, measuring 60 x 80 mm, 4 mm thick. 5 specimens underwent tests on ultimate strength to bending so as to determine the initial strength of the tested material. Next, three series of 10 specimens, underwent cross-impact load of 2.5 J, 5 J and 10 J energy levels. Later, 5 specimens from each series were checked in order to determine the effect of the impact load upon the bending strength of the tested composite material.

In order to conduct tests, we constructed a device for cross-impact bending strength (Fig. 6). The construction of the station enables to adjust the impact energy through altering the height of the impact hammer or through changing the impact load value.

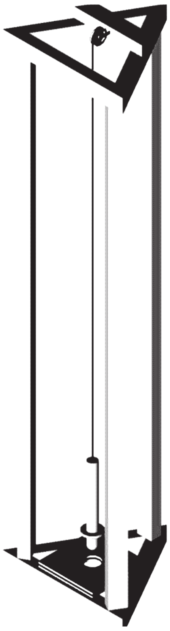

Fig. 6. Research device model

The energy impact is related to the energy conservation law. Ignoring the insignificant resistance, it was assumed that the whole potential hammer energy will be transformed into its kinetic energy at the moment of impacting the specimen. In the conducted research, we used 3 configurations of impacting energy (Table 1).

Table 1. Specification of energies and corresponding device configurations

No	Impact energy	Dart mass	Height of load
1	2.5 J	460 g	55.4 cm
2	5 J	920 g	55.4 cm
3	10 J	1460 g	69.8 cm

After performing impact load tests, we conducted a three-point bending test on a bend test machine Zwick Roell Z100. The test was done in accordance with the procedure specified in PN-EN ISO 178.

4. Damage evaluation

In case of cross-impact load of 2.5 J, the external surface of the element (specimen) does not show visible traces of the impact load; on the other hand, on the inside of the element one could notice a small delamination bulge (Fig. 7). The outer structure of the specimen did not become damaged.

After an impact load of 5 J, the external part of the specimen did not show visible damage; however observation of the inside pointed to the emergence of a clear delamination area, with noticeable base cracking (around 8 mm in length), which had a radial shape, starting at a point of the impact load (Fig. 8). On the small area there were also damaged fibres of the reinforcement.

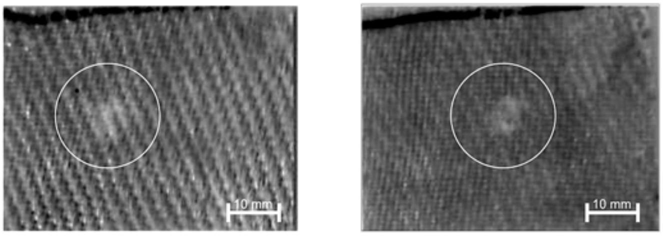

Fig. 7. Specimens after an impact load of 2.5 J (inside)

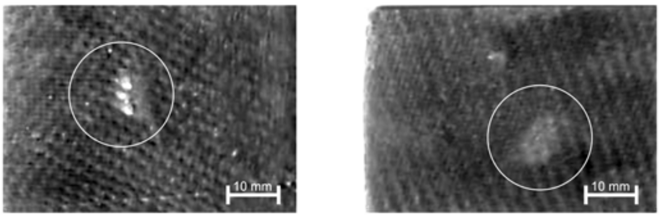

Fig. 8. Specimen after impact load of 5 J (inside)

Cross-bending impact load of 10 J caused much higher damage. On the outer side of the specimen, covered in varnish coat, there was a noticeable varnish chip. The inside surface is bulged. Both the base and the reinforcement within the radius of 10 mm from the impact loading point are damaged. Within the damaged area one can observe broken fibres of the reinforcement. Also the base materials is fragmented in certain parts. (Fig. 9).

In a series of specimens which did not undergo impact load, the character of the damage is of two different kinds (Fig. 10a).

The impact load of 2.5 J and 5 J causes a slight decrease of the bending strength. The specimens which underwent a 10 J impact load

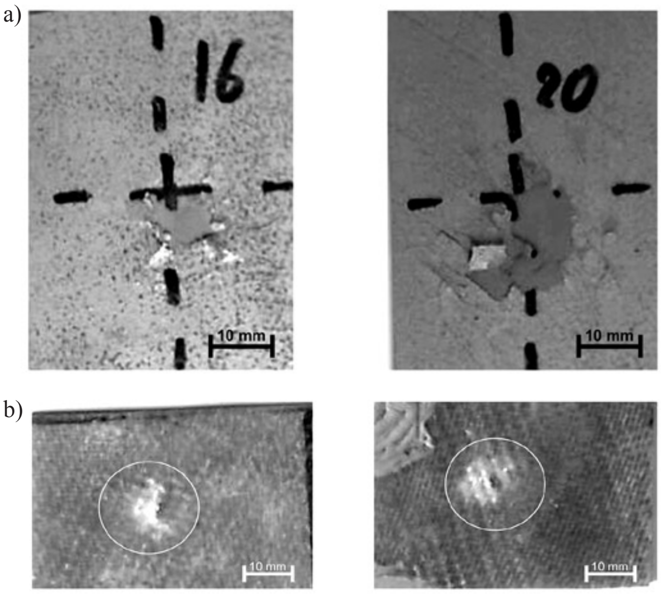

Fig. 9. Specimens after impact load of 10 J energy level: a)external side, b) inside

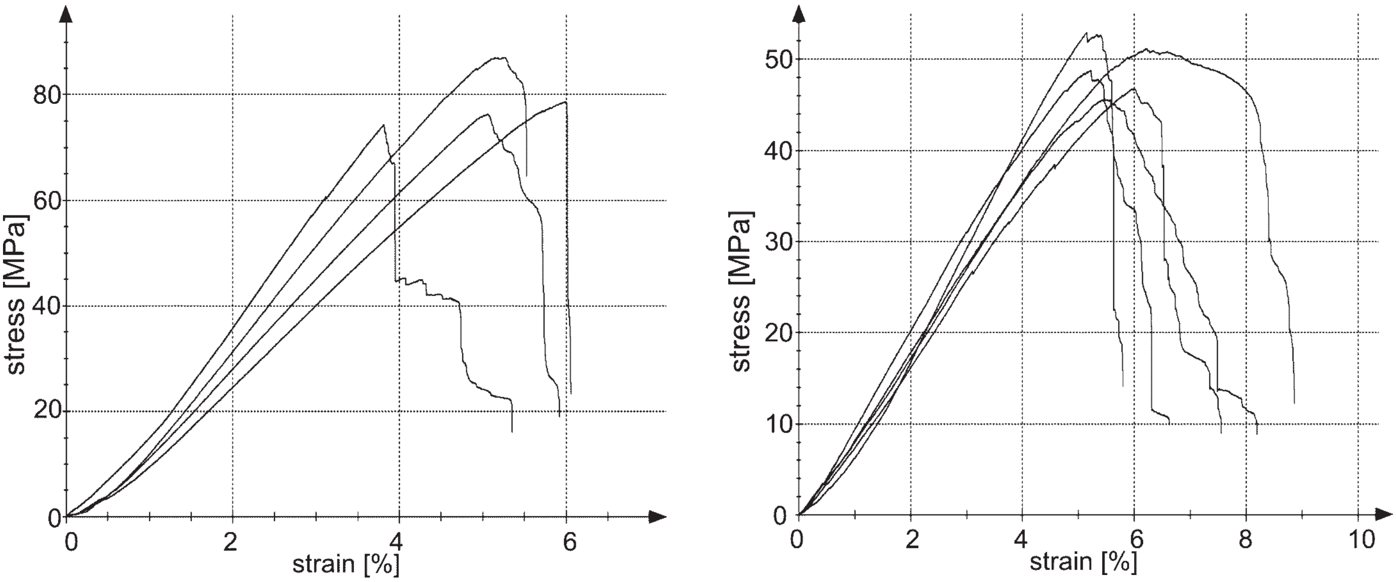

Fig. 10. Characteristics of specimens' bending strength: a) without impact load b) after 10 J energy level impact load

had the lowest bending strength. In this case, the bending strength fell by about 37% as compared to the undamaged material. Also the character of the bending curve became different (fig. 10b). On the basis of the macroscopic observation it was proved that due to a visible perforation of the laminate, the fibres which build the reinforcement material became damaged. The course of the damage, after exceeding the expansion limit Rg may prove that impact load, to a large extent, affects the material base, which leads to a gentle and gradual course of damage.

A clear difference in bending strength among the series of 5 and 10 J energy loads points to the necessity of testing the influence of cross-impact load of 5 J and 10 J, upon the bending strength properties of layered composite materials. The demand to conduct additional research is practical in its nature, since many tools used in aircraft maintenance have the mass, which after falling on the composite airplane or helicopter brings about an impact load, whose energy equals the values within the range of 5….10 J.

It is important to remember that the impact energy of 10 J equals dropping of a tool at a mass of around 1.5 kg at a height of about 70 cm. Therefore dropping a tool of a similar mass at such height can significantly lower the laminate structure.

5. Conclusions

The conducted research proved the effects of low-energy cross-impact load upon the shear strength of the composite material (laminate).

On the basis of the research one can draw the following conclusions:

1. In case of lower energy impact loading, the damage is usually difficult to locate, as the outer coat remains usually intact. It is necessary to prepare and implement non-destructive testing techniques meant to search for this type of damage for maintenance of aircraft construction elements, made with composite;
2. Destruction caused by cross-impact load causes degradation of strength properties of layer composite materials. Specimen bending strength, under the impact load of 10 J energy level, has decreased by about 37%, as referred to undamaged material.
3. The course of damage during the bending of specimens under 10 J impact load may prove that the load effects the composite

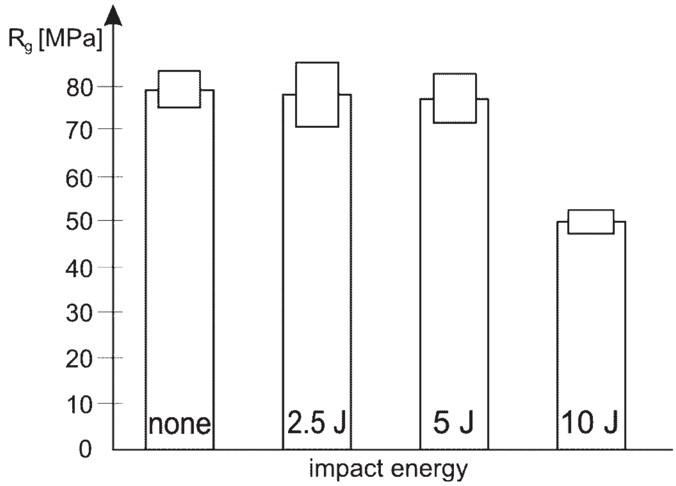

Fig. 11. Bending strength of the test specimens

base to a larger extent than in the case of undamaged material.

4. For the maintenance of aircraft made with composite material, it is vital that even a very low energy impact may endanger the flight's safety.

The carried out tests suggest that, in case of aircraft construction elements which do not bear high tensions during their service, the properties of the base material may have a tremendous importance at a time of low-energy impact damage. In the phase of designing and producing laminates used in aviation, it is important to take into account the bend-strength properties of all composite components. Properly selected material for the base will not lead to the damage of the aircraft covering structure, due to an impact load of a dropped tool, foreign bodies thrust by aircraft wheels, etc., and ultimately will not bring about an accident or an aviation catastrophe.

It seems advisable to conduct research on fatigue of composite materials under cross impact loading.

References

1. Abrate S. Impact on laminated composite materials. Applied Mechanics Reviews 1991; 44: 155-190.
2. Bełzowski A, Rechul Z, Stasieńko J. Uszkodzenia udarowe w laminacie wzmocnionym tkaniną szklaną. Kompozyty 2002; 5: 394-399.
3. Holloway L. Current development in materials technology and engineering-pultrusion. RAPRA reviews No 3 1989; 2(3).
4. Hou J P, Jerominidis G. Bending stiffness of composite plates with delamination. Elsevier. Composites: Part A 2000; 31: 121-132.
5. Kang T J, Kim C. Energy-absorption mechanisms in Kevlar multiaxial warp-knit fabric composites under impact loading. Composite Science and Technology 2000; 60: 773-784.
6. Liu D, Malvern L E. Matrix cracking in impacted glass/epoxy plates. Journal of Composite Materials 1987; 21: 594-609.
7. Mayer R W. Handbook of Pultrusion Technology. London: Chapman and Hall, 1985.
8. Mouritz A P, Gallagher J, Goodwin A A. Flexural strength and interlaminar shear strength of stitched GRP laminates following repeated impacts. Composite Science and Technology 1997; 57: 509-522.
9. Naik N K, Shrirao P, Reddy B C K. Ballistic impact behaviour of woven fabric composites: Formulation. International Journal of Impact Engineering 2006; 32(9): 1521-1552.
10. Ochelski S. Metody doświadczalne mechaniki kompozytów konstrukcyjnych. Warszawa: WNT, 2004.
11. Richardson M O W, Wisheart M J. Review of low-velocity impact properties of composite material. Elsevier Composites part A 27A 1996; 27: 1123-1131.
12. Schrauwen B, Peijs T. Influence of Matrix Ductility and Fibre Architecture on the Repeated Impact Response of Glass-Fibre-Reinforced Laminated Composites. Applied Composite Materials 2002; 9: 331-352.
13. Shim V P W, Yang L M. Characterization of the residual mechanical properties of woven fabric reinforced composites after low-velocity impact. International Journal of Mechanical Sciences 2005; 47: 647-665.
14. Shivakumar K N, Elber W, Illg W. Prediction of low-velocity impact damage in thin circular laminates. AIAA J. 1985; 23(3): 442-449.
15. da Silva Jr J E L, Paciornik S, d'Almeida J R M. Determination of the post-ballistic impact mechanical behaviour of a 45 glass-fabric composite. Polymer Testing 2004; 23: 599-604.
16. da Silva Jr J E L, Paciornik S, d'Almeida J R M. Evaluation of the effect of the ballistic damaged area on the residual impact strength and tensile stiffness of glass-fabric composite materials. Composite Structures 2004; 64: 123-127.
17. Sjoblom P O, Hartness J T, Cordell T M. On low-velocity impact testing of composite materials. Journal of Composites Materials 1988; 22: 30-52.
18. Zhang Z Y, Richardson M O W. Low velocity impact induced damage evaluation and its effect on the residual flexural properties of pultruded GRP composites. Composite Structures 2007; 81: 195-201.

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