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Original Research Article

Sequence of damage events occurring in the course of low energy impact

Piotr Czarnocki *, *Tomasz Zagrajek*

Institute of Aeronautics and Applied Mechanics, Warsaw University of Technology, Nowowiejska 24, 00 665 Warsaw, Poland

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ABSTRACT

Finite element simulation was carried out to better understand damage formation in CF/epoxy plate in the course of a low velocity 8J impact. The plate under investigation was of $[+30/-30]_s$ lay-up. To validate the numerical results a drop test was carried out with the help of a drop tower. The interlaminar damage extent was determined with the help of C-scan. Comparison between the numerical and experimental results showed a good quantitative agreement concerning contact force time history, however, the amount of dissipated energy determined based on the numerical simulation was lower than that from the experiment, consistently, the damage extent determined based on numerical simulation was smaller than that determined by C-scan. Nevertheless, characteristic points on the plot representing contact force time history could be related to the particular damage mechanism onsets and their actions.

1. Introduction

Often, service damage to composite airframes taking place during operation of an aircraft is caused by a low energy impact of a foreign object. Often, primary parts of composite airframes are of laminar structure, for which the interlaminar fracture resistance is the Achilles' heel since such impacts can easily produce delaminations accompanied by intralaminar fracture. The purpose of the presented work was to investigate the sequence of events taking place during such a damage formation to understand better its mechanism.

Some researchers claim that it is possible to take advantage of a quasi-static tests for analysing impact damage events and mechanisms of energy dissipatation assuming the same maximum values of contact force and impact energy [1–4], however, some other investigations indicate that the damage extent and damage modes present depend on impactor mass and impactor velocity even though impact energy is the same [5].

Because of the aforementioned ambiguous results the presented FE simulation of impact damage took into account dynamic effects.

The object of investigation was a laminate plate containing reinforcement layers oriented at $\pm 30^\circ$. Such a reinforcement configuration can compromise on shear and normal strengths and stiffness offered by a structure with 0° and $\pm 45^\circ$ reinforcement orientation. The former can offer simplification of a manufacturing process due to a lower number of different reinforcement orientations and simpler placing process,

* *Corresponding author*. Tel.: +48 222345856.
E-mail address: pecz@meil.pw.edu.pl (P. Czarnocki).
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however, on the expense of mechanical properties. In general, the design of symmetric and balanced laminates is recommended to avoid shear-extensional and extensional-bending couplings which can produce undesirable deformations in the case of both the mechanical and thermal loadings. For this reason the structure under consideration was of $[+30/-30]_s$ layup. Recently, possibility of wide application of just bi-directional laminates has been investigated [6,7]. In fact, this investigation has been focused on thin ply laminates, nevertheless, bi-directional laminates made with plies of a conventional thickness can also be superior to those combining four reinforcement directions. Usually, a balanced, symmetric laminate used for airframes is at least of six layer layup $[0/+45/-45]_s$, that is, it consists of two more layers comparing to the $[+30/-30]_s$ one, therefore, the specific strength and stiffness of both the laminates are similar.

If a penetration is not present the damage caused by a low energy impact is basically confined to an interior of laminate and for this reason a direct monitoring and investigation of damage formation process is difficult. For this reason, to perform this task an advantage of numerical simulation was taken.

Impact modelling with the application of various methods has been presented in a large number of papers. Some early papers provided closed form formulas for the critical values of contact forces, P_c, [8,9] or energy needed for fibre fracture [10], or critical strain energy release values, G_c, corresponding to the onset of delamination. Some attempts were made to relate these force and energy values to the delamination area taking advantage of the Linear Fracture Mechanics [11]. Also, using analytical models the deflection time history and maximum impact force versus projectile velocity were determined for particular laminate structures [12]. Simple FE models did not consider neither damage initiation nor its evolution but they allowed for the determination of deflection versus time and contact force versus time relationships [13] and for the determination of stress distribution in a plate versus time [14]. More advanced FE models provided results on delamination extent assuming that it corresponded to the area over which certain failure criteria were met [15,16]. The aforementioned models did not account for neither damage evolution nor resulting aftereffects. To account for this the VCCT method was used and interlaminar fracture process was modelled to represent also the interfacial debonding [17,18]. However, there is some inconvenience inherently connected to this method consisting in the need for crack presence prior to the impact. Such difficulties were overcome by the use of damage mechanics (DM) for which this requirement did not have to be fulfilled. FE models taking advantage of DM can also provide for inter and intralaminar damage modes and such an approach seems to be, so far, most versatile one. To model the damage process one can use cohesive elements or contact elements with prescribed cohesive material properties [19] for which various traction-displacement relationships can be defined [20–24]. Discussion on the application of various traction-displacement relationships can be found in [25]. Very often due to its simplicity a bi-linear traction-displacement relationship, Fig. 1, is assumed for simulation of interfacial failure [26–28]. Use of cohesive elements or contact elements with prescribed cohesive material properties is not necessary to take advantage of DM [29]. An entire FE model can be composed of solid elements alone. In the case of solid elements, damage initiation and damage evolution modelling can be done in a similar way as in the case of interface elements [30–34]. For detection of damage initiation various damage criteria can be used [35–38]. Tsai-Wu [35], Hashin [36], Chang-Chang [37], Puck [38] criteria, are among most common. For damage evolution, various combinations of the Strain

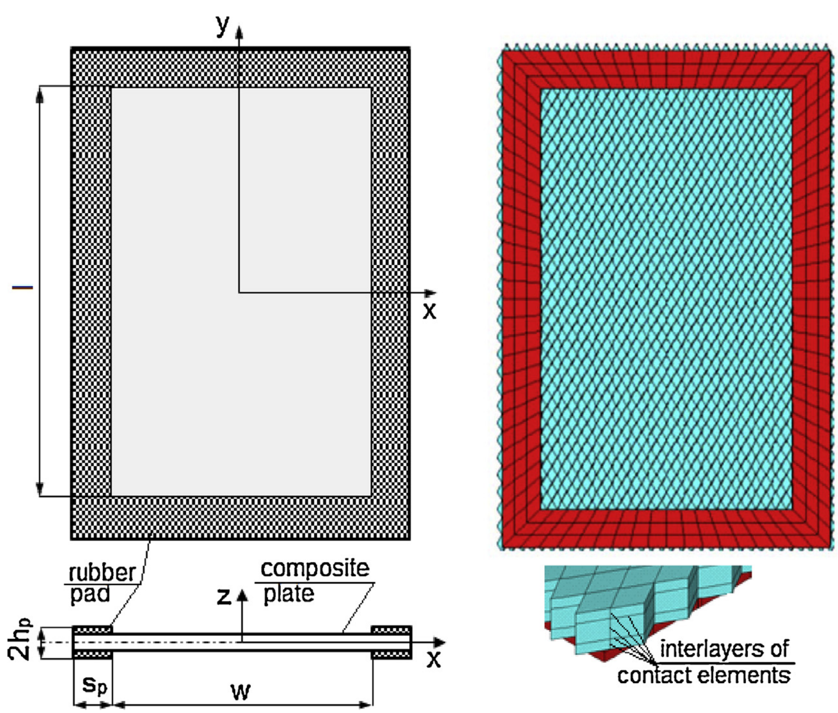

Fig. 1 – Modelled structure (a) and its FE representation (b).