# Numerical models of BVID in laminate structures

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Abstract

The paper deals with numerical model of barely visible impact damages BVID. Thin plate used for compression after impact (CAI) test made of laminate are taken into consideration. Different simple models of damages are prepared i.e. in damaged area the reduction of material properties, layer thickness or delamination have been considered. The thin plate with overall dimension 150 x 100 mm and damage located in mid-with and mid-length subjected to uniform compression have been considered. The FEM analysis with progressive damage methodology employing different failure criteria (Hashin, Puck, maximum stress) have been performed. The numerical results in form of load – shortening curves and failure load have been compared with results of experimental tests described in literature.

*Keywords: BVID, laminates, FEM modelling, laminate failure*

## 1. Introduction

The composite materials are more and more popular with different engineering applications. They are used in many branches of industry e.g. aircraft, automotive, medicine or civil engineering. Composite materials possess not only many advantages, but also some disadvantages. One of them is impact damages resistance. The problem of barely or not visible impact damages coming from impacts with low velocities which can be caused by e.g. dropping of tools or collisions during maintenance. Such a damages can be present in different forms: matrix cracks, debonding of fibres from matrix, delamination or even cracking of the fibres.

Damaged areas can be described in many ways. In the literature there exist works dealing with the problem of strength degradation after impact. The tests which are trying to answer the question how the impact had affected the strength are e.g. CAI or TAI – compression/tension after impact tests [4]. Other ways of describing the damaged areas are physical quantities such as stress intensity factors, energy rates or fracture toughness [2,3] which are mainly describing the phenomena of delamination. In many works damages are considered as regular shaped areas and their influence to the global behaviour is analysed [1]. In authors opinion there is necessary to prepare a simple model of damages which can be applied in real structures. In world literature there are a lot of papers dealing with such a damages in thin plate used for CAI test – results of experimental tests and numerical calculation based on based on increasingly better and more accurate numerical models can be quite easily found. It should be noted that more adequate model considering all possible physical phenomena generate the time consuming analysis. Taking above into consideration authors decide to tests different simple model of damages which gives similar results (structure stiffness and failure load) to experimental tests and can be used in real structures e.g. whole wing of aircraft.

## 2. Numerical models

The laminate plate 100 ×150 mm (Fig. 1) made of carbon fibre reinforced polymer (CFRP) with layer arrangement $[(0/+45/-45/90)_s/(90/-45/+45/0)_s]$ (c.f. [5]) are considered. To find the easiest, simplest and most reliable model of damaged area after impact the numerical compression after impact test have been performed. Two different software i.e. ANSYS® and ABAQUS® have been employed. The obtained results have been compared with results of experimental tests presented in literature [5].

The represented regions of real damage in the numerical model were defined by a simplified damage model (SDM). The influence of different model parameters and assumptions on the failure load have been analysed. The material properties, according to [5] have been considered, and they are as follow: $E_1$= 1.23·10$^5$ MPa, $E_2$= 1.03·10$^4$ MPa, G= 4.73·10$^3$ MPa, ν= 0.3, ultimate tension loads $T_1$= 1867 MPa, $T_2$= 26 MPa, ultimate compression loads $C_1$= -1531 MPa, $C_2$= -214 MPa and ultimate shear load $S_{12}$= 100 MPa.

Damage area is assumed as c.a. 154 mm$^2$ and it has been modelled as real shape (Fig. 1), circular shape ($r$ = 7 mm) or elliptical shape ($a$ = 9 mm and $b$ = 5.4 mm). In case of elliptical shape two different position of main axes of ellipse have been consider, i.e. the ellipse major axis parallel or perpendicular to longitudinal plate edge.

The following models for damaged area have been considered: material properties are reduced with different reduction coefficient; damage with different position of delamination ($D_p$ = 0 no delamination, $D_p$ = $i$ – delamination between $i$-th and $i$-th +1 ply).

The analysis have been performed using progressive damage analysis. The following failure criteria have been assumed: maximum stress criterion, Puck criterion and Hashin criterion. To check the influence of assumed criterion on failure load and load - shortening relation the four following cases are tested: for all damages possibility (i.e. fibre and matrix tensed

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and compressed) the Hashin criterion for the first case, the Puck criterion for the second case and the maximum stress criterion for the third case and different criteria for different damages (i.e. the failure of fibre in tension – the Hashin criterion, fibre compression – maximum stress criterion, matrix tension and compression – Puck criterion) in the fourth case have been considered.

In case of damage with real shape the model assumed a gradient decrease in thickness of individual laminate plies in the damaged regions depending on impact energy. The ply thickness would decrease proportionately toward the external surface of the plate from the side of impact. The proposed method for the modelling of a damaged region of composite material enables a simple determination of thickness of individual plies for any impact energy $E$ in the following way:

- thickness of the first ply: $y_1=z - x_1 \cdot E$;
- thickness of successive $i$-th plies: $y_i = y_{i-1} - x_2 \cdot E$;

where: z is the nominal thickness of the undamaged ply (before impact), $x_1$ is the coefficient determining a decrease in thickness of the first laminate ply and $x_2$ is the constant coefficient of decrease in thickness of successive laminate plies for any impact energy E, expressed as:

$$x_1=(z - y_k)/E_k; \quad x_2=x_k/E_k. \tag{1}$$

In the above relationships $y_k$ means thickness of the first ply (impact side) for the energy $E_k$, and $x_k$ value of reduction of the thickness of the other layers (corresponding to the maximum energy of impact $E_k$, for which were carried out validation of the model). Figure 1 shows model of plate with a rendition of the shape of the damage, wherein defined the SDM model.

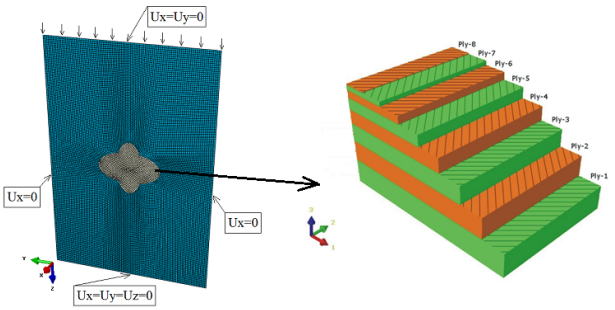


Figure 1: Discrete model of the plate with damage

## 3. Exemplary results

Some exemplary results of numerical calculation in form of load – shortening curves are presented in Figs. 2 and 3.

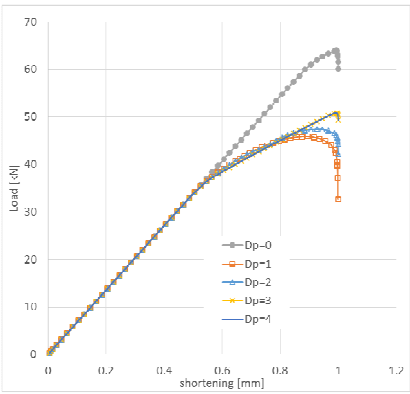


Figure 2: Influence of delamination position on failure load

The maximum load can be tried as failure load. The results presented in Fig. 2 have been obtained assuming circular shape of damage, reduced material properties in damaged area and delamination between different layers. Figure 3 presents the influence of damage shape on load-shortening curve. This results have been obtained assuming reduced material properties in damaged area without delamination.

According to experimental test [5] the failure load is c.a. 45kN, what corresponds to models with delamination $D_p$=1 and reduced material properties in damaged area.

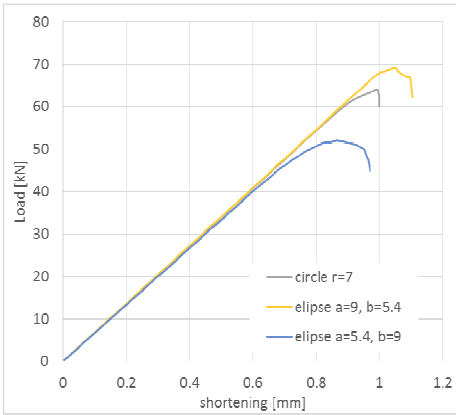


Figure 3: Influence of damage shape on failure load

## 4. Conclusion

Based on the results of preliminary analyses, it was found that the model with the real damage shape and plies thicknesses degradation gives promising results with respect to the results of the experimental studies (e.g. [5]).

The properly prepared SDM needs lots of evaluating tests because structure with BVID behaviour and failure loads depends on many assumed parameters e.g.: shape of damage (real or simplified substitution), delamination and its position, ply thickness and material properties degradation. However, it can be said that it is possible to develop (SDM) simplified damage model, which can be used in real structures.

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