Composite Structures 126 (2015) 314–328

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Edge impact modeling on stiffened composite structures

Benjamin Ostré [a], Christophe Bouvet [a,*], Clément Minot [b], Jacky Aboissière [b]

[a] Université de Toulouse; INSA, UPS, Mines Albi, ISAE; ICA (Institut Clément Ader)

ISAE (Institut Supérieur de l'Aéronautique et de l'Espace),
10, avenue Edouard Belin, BP 54032-31055 Toulouse cedex 4, France
[b] SOGETI High Tech, Parc du Millénaire, Bât A1, avenue de l'Escadrille Normandie-Niemen, BP 90076-31703 Blagnac cedex, France

ARTICLE INFO

Article history:
Available online 24 February 2015

Keywords:
Carbon fiber
Impact behavior
Finite element modeling
Damage mechanics
Discrete Ply Model

ABSTRACT

Finite Element Analysis of low velocity/low energy edge impact has been carried out on carbon fiber reinforced plastic structure. Edge impact experimental results were then compared to the numerical "Discrete Ply Model" in order to simulate the edge impact damage. This edge impact model is inspired to out-of-plan impact model on a laminate plate with addition of new friction and crushing behaviors. From a qualitative and quantitative point of view, this edge impact model reveals a relatively good experiment/model agreement concerning force–time and force–displacement curves, damage morphology or permanent indentation after impact. In particular the correlation is faithful concerning the results of the parameters retained by industry; the maximum crack length on the edge and the permanent indentation.

Finally, it can be noticed that the model quickly answers in crushing mode and goes in an inadequate way from the dynamic behavior to the quasi-static behavior. In order to correct this problem it seems necessary to implement a strain rate effect in the behavior law on the fiber failure in compression. The next step is to apply this model to the compression after impact.

1. Introduction

Aeronautics integrates many composite structures. Unfortunately, during a manufacturing operation, these structures could be significantly damaged by a foreign object and at the same time the damage occurring might remain undetected by visual inspection [1–4]. Today aeronautical engineering needs to replace metallic materials by composites for weight saving consideration. Metallic materials and their associated plasticity is a well-researched area for many years; however, many such things have to be learnt about composite behavior where the damage prediction remains very challenging [5–8]. A composite center wing box of an airplane is a good example of composite structure with many free edge stringers inside (Fig. 1a). They are extremely loaded and are designed to resist buckling to keep the structure safe, but if a tool drops on the stringer edge during the plane's maintenance, its residual properties can be drastically reduced [4,9,10].

Nowadays, structural stiffeners are mostly used for protection against edge impacts, which needs improvement as additional weight, and is a major concern in aircraft industry. Therefore, it is important to study in detail the edge impact phenomenon and to define the damage scenario, in order to identify the parameters that affect the residual strength after impact. By the way, it will be possible to improve the stringer's impact damage tolerance.

The proof of the impact resistance, depending upon the impact damage detectability, has to be made in order to certify these structures for aeronautical industry, which is the concept of damage tolerance [2,4]. With the help of impact damage tolerance and by defining the damage scenario, it is possible to study and improve the edge impact damage tolerance.

Dent depth and crack length drive the current edge impact detectability threshold criterion for aeronautic fields (Fig. 1b). When the impact indentation is smaller than the barely visible impact damage (BVID) the structure has to support the extreme loads that it is subjected to. However, if the damage is detectable, i.e. when the impact indentation is bigger than the BVID, another criterion must be considered, such as sustain limit loads, repair or change the structure [4].

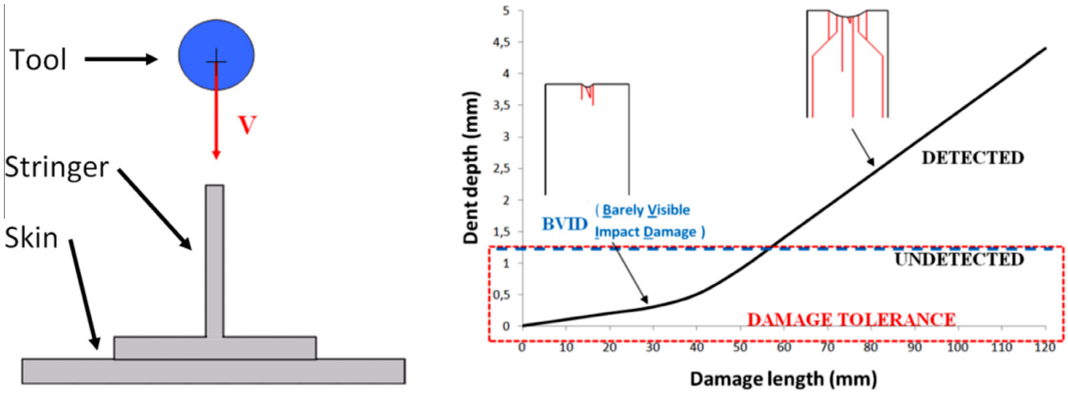
Composite skin impact issues, and the damage mechanism [1,2,4,11,12] are now fairly well developed. The three types of damages are classically induced on a low-velocity/low-energy impact on a uni-directional (UD) composite laminate: matrix cracking, fiber fracture and delamination [2,10,11]. Matrix cracking conventionally occurs first in the damage scenario. Then, as the

---

* Corresponding author.

E-mail addresses: christophe.bouvet@isae.fr (C. Bouvet), clement.minot@sogeti.com (C. Minot).

http://dx.doi.org/10.1016/j.compstruct.2015.02.020
0263-8223/



(a) (b)

Fig. 1. Edge impact principle (a) and detection policy (b).

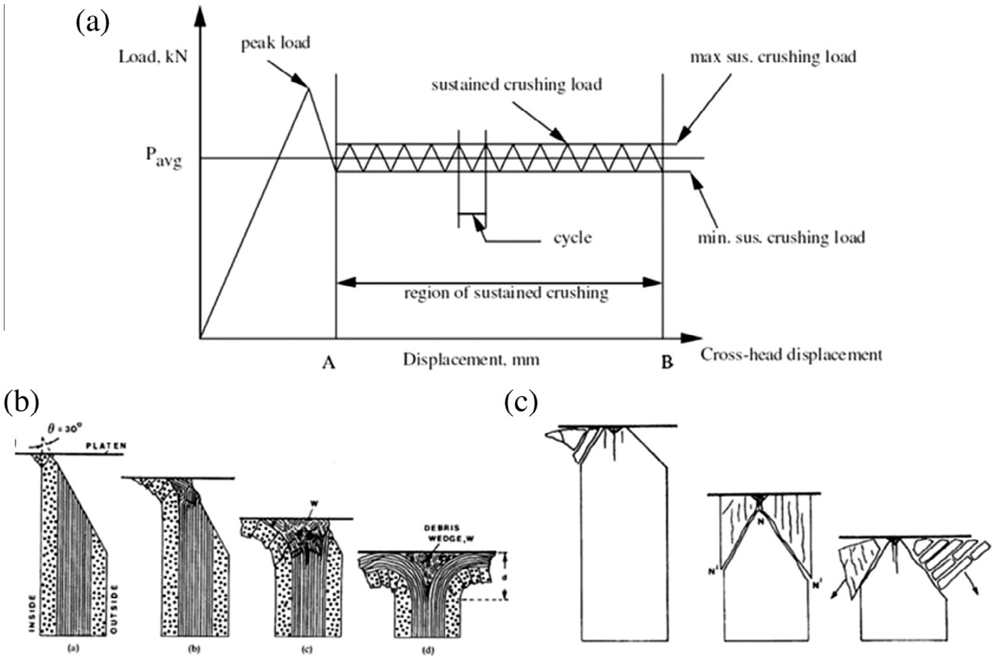


Fig. 2. Crushing test: the typical load–displacement response (a) [13] and the two main degradation modes: splaying (b) and fragmentation (c) [14].

damage grows, delamination quickly occurs. An interaction between these two damage phenomena is also clearly visible during the impact tests [4,10,11].

However, if the focus is shifted from skin to edge, then there seems that the damage tolerance knowledge is missing. As far as the author is concerned, only two researches have been conducted in this regard [9,10], which well elaborate the after impact vulnerability. However, the impact damage scenario is missing to predict an accurate failure by taking into account the physical controlling mechanisms [5]. The understanding and modeling of the edge impact scenario is the key to be able to predict the residual strength, which will be helpful in optimizing composite structures under low-velocity impact. Indeed, some phenomena like compressive fiber failure or wedge effect, which are of minor importance during skin impact, become important in case of edge damage. In addition, the damage scenario of the edge impact test shows similarities with those of the crushing test [13–15], and these studies were the starting point of the edge impact modeling developed in this paper.

The typical load–displacement curve of composite laminate under progressive crushing is shown in Fig. 2a [13,14], where a peak load is generally observed during crushing initiation. After this peak the crushing process turns into progressive crushing that is characterized by a relatively constant force (plateau) with eventual oscillations. This curve is relatively similar to the ones observed during edge impact test [16] (Fig. 20). Hull [14] has classified the crushing process into two main failure modes (Fig. 2b). The first one is known as the splaying mode (Fig. 2a) in which bundles of bending delaminated lamina splay on both sides of a main crack, and the broken fibers and resins trapped at the crushing zone can lead to the formation of debris wedge on the surface of the crushing platen. The second one is called the fragmentation mode (Fig. 2c) in which the plies sustain multiple short length fractures due to pure compression, transverse shearing and sharp