Composite Structures 117 (2014) 17–31

Contents lists available at ScienceDirect

Composite Structures

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

A layer-wise behavioral study of metal based interply hybrid composites under low velocity impact load

Periyasamy Manikandan, Gin Boay Chai *

School of Mechanical & Aerospace Engineering, Division of Aerospace Engineering, Nanyang Technological University, Singapore

ARTICLE INFO

Article history:
Available online 24 June 2014

Keywords:
Low velocity impact
Fibre metal laminate (FML)
Cohesive element
Finite element analysis (FEA)

ABSTRACT

This paper presents an extensive study on the experimental and numerical investigation of metal layered interply hybrid composites subjected to low velocity impact. In an effort to understand the contribution of individual layer to energy absorption and subsequent failure in fibre-metal laminates, the test specimens were fabricated with a layer of metal bonded to a layer of composite. The mechanical response of each specimen to low velocity impact load is compartmentalized through two test cases: (i) specimen impacted on the ductile metal layer and (ii) specimen impacted on the brittle composite layer. For a detailed insight into the response of individual layers, a numerical study was carried out using commercially available software called ABAQUS with elastic–plastic model for metal layer and a user defined constitutive model via a VUMAT subroutine for composite layer. The level of correlation between experimental and numerical results is comparable. Being stiff in nature, with small impact energy absorption, exhibit less concentrated damage, brittle side impact samples are found to provide excellent impact resistance than ductile side impact samples.

1. Introduction

With their enhanced fatigue, corrosion, fire and impact resistance properties, fibre-metal laminates (FML) have found several interdisciplinary applications in aerospace industry [1]. On finding its place on the upper part of a fuselage in a large commercial passenger air carrier, the extension of its use to other industries increases rather rapidly. Thus a complete anatomy of its material behavior and structural response must be known to extend its validity envelope. The present paper concentrates one of the more probabilistic and more severe events that a structure can face during its service life which is the low velocity impact of foreign bodies. Low velocity impacts mostly introduce a barely visible damage which drastically alters the fatigue life of the structure and finally leads to catastrophic failure unless otherwise noticed. The complete morphology of low-velocity impact response of FML was retrieved through comprehensive review made by the same authors in a recent article [2].

Unlike composites which are too brittle and more prone to impact load, FML is the heterogenous candidate having two dissimilar material characteristics in it. A ductile metal layer that consumes most of the energy as plastic work before fracture and a brittle composite layer which spend only a little amount of energy as elastic work and the remaining in the form of different damage mechanisms with negligible plasticity. This anomaly behavior of each material to any kind of mechanical loading must be known elaborately for structural application. Being covered by opaque metal layers in its outer surface, the intensity of damage induced in the internal layers is difficult to quantify. Many researchers utilize the capability of expensive non-destructive techniques to capture the internal cracks and extent of delamination that are dominant in the case of impact loading, but yet their finding still shows ambiguity.

To quantify the damage intensity through visual inspection and study the behavior of each layer, a simple form of FML laminate composed of a metal layer bonded with a layer of composite was fabricated. For compartmentalizing the complete response of each layer to impact load, two extreme test cases were carried out. They are (i) specimen impacted on ductile metal layer side (ii) specimen impacted on brittle composite layer side. In the rest of this article, the former is called soft side impact while the latter is called hard side impact just for simplicity. Also, the impact and non-impact side is denoted as front and back face/surface respectively.

Several researchers have employed such similar studies in interply and intraply based hybrid composites. Prevorsek et al. [3] carried out a series of penetration test on laminates having hybrid configurations made of glass and more ductile polyethylene

* Corresponding author. Tel.: +65 67905756; fax: +65 67924062.
E-mail address: mgbchai@ntu.edu.sg (G.B. Chai).

http://dx.doi.org/10.1016/j.compstruct.2014.06.010
0263-8223/

fibres. They reported that specimens with glass side impact show better penetration resistance. For the same configuration, the penetration threshold of hard side impact is two times larger than soft side impact. Kim et al. [4] reported a similar study on hybrid composites with layers of brittle carbon fibre reinforced plastic (CFRP) bonded with ductile aramid or glass or ultra-high molecular weight polyethylene (UHMPE) fibres. The conclusion was that laminates on hard side impact offers better impact resistance than soft side impact. The reason being that the hard side absorbs most of the energy in the form of fracture and delamination and the rest of the energy is dissipated in the form of plastic work done by the soft ductile layer. Sayer et al. [5] examined the impact behavior and damage nature of Glass–Carbon/epoxy hybrid composites with different impact face i.e. Glass–Carbon (GC) and Carbon–Glass (CG). Significant conclusions obtained from their experimental study are; CG specimen has small energy absorption capability than GC specimens, penetration threshold of CG specimen is one-third times larger than GC, Increasing the carbon layers in CG specimen showed negligible effect in penetration threshold magnitude. On visually inspecting the impacted specimens, there were several minor matrix cracks and some delamination in the glass layers. While the carbon layers showed indentation and matrix cracks with some fibre fractures. Hosur et al. [6] made an experimental study to determine the response of four different hybrid configurations made of twill weave carbon fabric and plain weave S2 glass fabric. They found material on back side plays a dominant role in the impact response especially bending stiffness influence.

From authors' knowledge, such detailed layer wise behavioral study has not yet being carried out for FMLs. The current article attempts such a study through fabricating the laminate with single layer of metal bonded with layer of composite plies.

On the aspects of numerical investigation, many researchers simulate the low velocity impact event of FML with appropriate material model for metal and composite layer with considerable accuracy [2]. With easy availability, cost effective and enhanced strength parameters due to interlacing of fibre tows in in-plane longitudinal and transverse directions, current researches focus on the utility of woven composites in structural application. The experimental study of such advanced material provides enhanced impact resistance over unidirectional composites but can posed quite a challenge in numerical modeling. Most constitutive model and failure criteria are formulated with the assumption on fibre directional properties and transverse behavior of such models are dominated by matrix properties. Having reinforcements in the longitudinal (warp) and transverse (weft) directions, a different constitutive model with appropriate failure criteria is needed to replicate the behavior observed in experimental studies.

Based on the thermodynamic framework of irreversible process for energy dissipation, Matzenmiller [7] developed a constitutive model for anisotropic damage of quasi-brittle uni-directional composite materials. Iannucci [8] derived a continuum based progressive failure model for woven composites under impact loading using damage mechanics approach. Failure mechanisms occurring in the lamina are defined as a scalar damage variable. These scalar damage variables are activated once it attains prescribed damage/failure criteria through damage activation functions. The developed model is restricted only to shell elements because the formulations are able to capture only in-plane failures while the out of plane failure (delamination) which is dominant in the case of impact loading is not considered. In another paper Iannucci and Willow [9] extended the previous model to include delamination phenomenon. They modeled in-plane failure modes with five scalar damage variables associated with tensile and compressive failure on warp and weft direction and in-plane shear failure. Damage due to out of plane failure is assumed to occur only at the interface of adjacent lamina. Interface damage is modeled using three damage variables; each variable corresponds to mode I, II, III failure respectively with no interaction to the in-plane failure modes.

With the work of Ladeveze [10] ply level continuum damage model of unidirectional composites as reference, Johnson [11] extended a similar kind of model for fabric composites under impact load. The damage initiation and evolution formulations are based on internal thermodynamic forces of the system which are frequently called driving forces for the damage. But similar to the previous article this model is also limited only to shell elements. Maimi [12] developed a continuum damage model to reflect the quasi-brittle degradation nature of composite laminates riding from the virgin undamaged response to complete collapse response. Implementing Bazant's characteristic element length concept to alleviate mesh dependency problem during material softening and accounting the crack closure effects during load reversal are the notable scenarios. Camanho [13] developed a novel de-cohesion element that is able to capture the crack initiation and propagation due to mixed-mode loading. Such an element is efficient in modeling the delamination progression of interface layer in composite materials. This emphatic interlaminar cohesive damage model was successfully applied through FE codes like Abaqus/Explicit [14] and LS-DYNA [15].

The key features of numerical model presented in this article are: Metal layer is modeled as elasto-plastic layer with rate dependent behavior. For composite layers, the onset and evolution of intralaminar failure is simulated based on the Maimi [12] continuum damage model with damage activation functions defined by Johnson [11]. The interface adhesive layer between metal and composite layer is modeled based on cohesive damage model of Camanho [13] in order to account for the interlaminar failure.

With these information, the current article is organized as follows: first, a brief description of the material properties and the stacking sequence, and the procedure of experiments are described. Second, the details of numerical model with short description of constitutive model of each layer are reported. Third, the data obtained through experimental and numerical simulations are compared and discussed explicitly. Finally in the epilogue, the conclusions derived from the discussions are commented.

2. Experimental study

2.1. Materials and fabrication procedure

The layers of hybrid laminates examined in this study were made from AL-2024-O Clad aluminium sheets of 0.5 mm thickness and the cross plied 7781/L-530 plain weave glass/epoxy composite prepreg of 0.254 mm thickness. The two different characteristic layers are strictly bonded together using Redux 335 K-300gsm adhesive film. Both metal and prepreg layers were trimmed to 100 × 100 mm dimensions and stacked appropriately over a base plate. To ensure proper bonding, metal layers are subjected to proper surface pretreatment using sandpaper and surface cleaning using acetone. The stacked hybrid plates were cured in an autoclave for 150 min at a constant 0.3 MPa pressure with a maximum of 120 °C temperature and cooled to room temperature with controlled environmental conditions.

2.2. Specimen description

In order to observe the behavior of two dissimilar characteristic layers, the nomenclatures of experimented specimens are broadly classified into two categories. They are soft side impact specimens and hard side impact specimens. To emphasis the preponderance of hybrid configurations, two sets of monolithic specimens with only metal or composite layers are also experimented as depicted in Fig. 1.