Composite Structures 107 (2014) 363–381

Contents lists available at ScienceDirect

Composite Structures

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

Review

Low velocity impact response of fibre-metal laminates – A review

Gin Boay Chai *, Periyasamy Manikandan

School of Mechanical & Aerospace Engineering, Division of Aerospace Engineering, Nanyang Technological University, Singapore 639798, Singapore

ARTICLE INFO

Article history:
Available online 13 August 2013

Keywords:
Low velocity impact
Quasi-static
Fibre-metal laminates
Dynamic response

ABSTRACT

This contribution hopes to give a comprehensive review of past and current research work published on the dynamic response of fibre-metal laminates subjected to low velocity impact. The historical development of fibre-metal laminates is first reviewed in details, and notable researchers and their contributions are chronologically tabulated and reviewed. Included are also reviews on published experimental, numerical and analytical work on the low velocity impact of fibre-metal laminates. Detailed discussions on the two main groups of parameters namely geometry and material based parameters that influenced the structural response of fibre metal laminates to low-velocity impact. The review concludes with detailed discussions on the future works needed for fibre-metal laminates subjected to low velocity impact loads.

Contents

1. Introduction

Fibre Metal Laminate (FML) is a family of hybrid composite structure formed from the combination of metal layers sandwiching a fibre-reinforced plastic layer. The metal currently being used is either aluminium, magnesium or titanium, and the fibre-reinforced layer is either glass-reinforced, carbon-reinforced or kevlar-reinforced composite. In 1950, Fokker Aerostructures of Netherlands found that such bonded laminated structures successfully prevented the rapid fatigue crack growth than the monolithic materials. On the eve of Second World War, the research was ceased for a certain period of time, around 1970s first physical test was carried out with the fibre-reinforced bonded metal laminates. Later, an optimized FML sheet was developed by the Delft

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

0263-8223/$ - see front matter
http://dx.doi.org/10.1016/j.compstruct.2013.08.003

University in the early 1980s called ARALL (Aramid Reinforced ALuminium Laminate) [1]. It consists of Al 2024-T3/7075T6 plate with a 0.2 ± 0.4 mm thickness and uni/bi-directional aramid fibre prepeg stacking in between aluminium plates primarily developed for wing applications. It was found that nearly 20% of weight saving is possible by using ARALL in place of monolithic aluminium. ARALL found its first application in C17 cargo doors. Some of the other major applications of fibre metal laminations in avaiation industry were found in the Ref [2]. By combining the isotropic, plastic behavior, durability characteristic, impact resistance, easy repair of metals and superior strength, stiffness, excellent fatigue, fracture characteristics of composite materials; FML was developed as a material having superior fatigue resistance, excellent impact characteristics, having low density and adequate corrosion resistance property [3,4]. Superior fatigue resistance is due to fibre bridging of fatigue cracks as illustrated in Fig. 2, and having a favorable residual stress system between aluminium alloy layers and composite lamina [5] and exceptional corrosion resistance is because of action of prepegs as a moisture barrier between aluminium layers and vice versa [6].

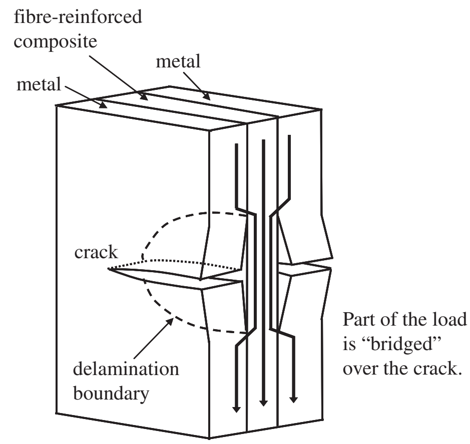

Fig. 2. Illustration of crack bridging by fibres [7].

Due to the inadequate compression properties of aramid fibres, in 1987 a second generation of FML was developed with a name GLARE (GLAss REinforced aluminium laminate) for aircraft fuselage applications [1]. GLARE was tested in A330/340 fuselage barrel in 1989 and registered its civil application in 1995 through bulk cargo floor of B777 and bulkhead of the bombardier 125. Currently GLARE is produced in different standard grades as shown in Fig. 1 and Table 1. The outperforming fatigue nature of FML fulfills the aircraft structural requirements and recently GLARE finds its application in the upper fuselage skin structure of Airbus A380 and saves nearly 794 kg gross weight [3].

Damage and failure of aircraft structures caused by impact has been documented and investigated over the years. From the failure report of 71 Boeing 747 aircraft having 29,500 endurance, it was found 90 out of 688 repairs (13%) are caused by impact of foreign bodies [8]. Impact can be caused either by low-velocity sources like collisions between cars, cargo, maintenance damage, dropped tool or high velocity sources like runway debris, hail, bird strike and having some ballistic impact in military aircrafts. Low-velocity impact event can be treated as a quasi-static deformation process if strain-rate do not exceed 10 m s^{-1} [9–12]. Owing to the ductility nature, impact is not a severe threat for metal structure because it can absorb large amount of impact energy in the elastic region up to yield and the material may develop large strains before failure. In contrast, most composite materials are brittle in nature; it can absorb impact energy only in elastic region before undergoing different modes of failure. On the absence of plastic deformation, damage in composites are classified as barely visible impact damage (BVID) and this will reduce the structural integrity rapidly if unnoticed [11].

FML is the suitable material which makes use of the advantage of metal and combined with the composites to amplify its impact damage resistance. Impact involves the effect of the transverse non-linear dynamic load and with the absence of through thickness reinforcement, transverse impact damage resistance is particularly poor for composites. Due to low strength between the ply, interlaminar stresses (shear and tension) cause delamination

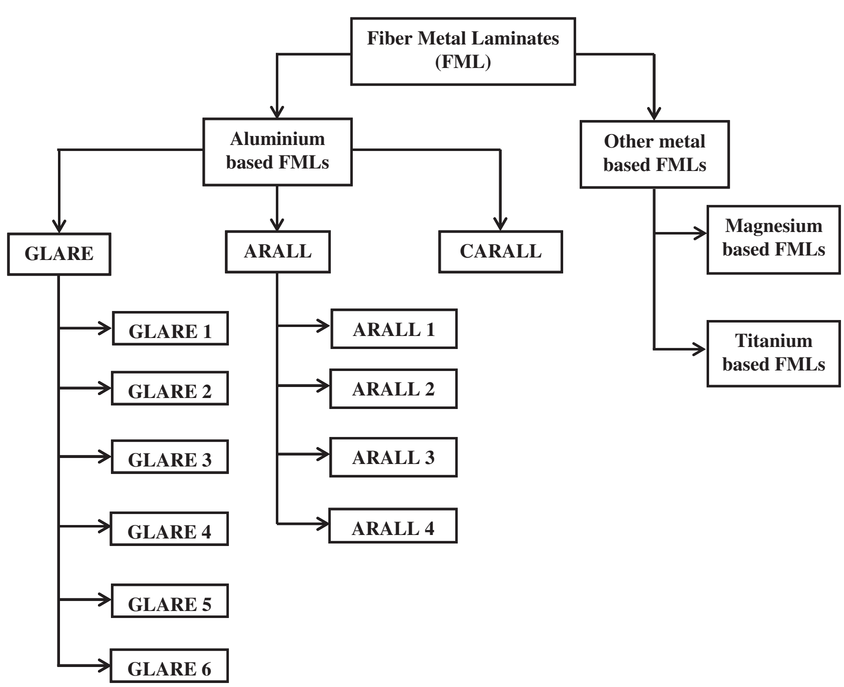

Fig. 1. Typical classes of FMLs.