Chapter 1
Introduction

Abstract Historically, Fibre Metal Laminates were introduced as a laminated material concept to improve the fatigue and damage tolerance properties of metallic structures in aeronautics. However, the concept can be viewed from different perspectives. This chapter discusses that the FML concept can be seen either as reinforcement of metallic structures or as reinforcement of fibre-reinforced polymer composite structures. Cases are given to illustrate how the concept of damage tolerance can be exploited with FMLs, in particular if the concept is viewed as structural concept rather than a material concept.

1.1 Introduction

The concept of Fibre Metal Laminates was first introduced with the development of ARALL, a laminate comprising aramid fibres embedded in a thermoset adhesive system interspersed between aluminium sheets. The concept originates in the metal bonding technology introduced by Schliekelmann at Fokker and the observation of Schijve that laminated thin sheets have superior fatigue characteristics compared to monolithic panels. Attempts to add fibres to the bondline of 1 mm thick laminated sheets did not provide sufficient benefits. However, further research by Vogelesang and Schijve has led to an optimized FML concept. The history of this development process is well documented by Vlot [1].

The fatigue process appeared to be a balance between the crack growth mechanism in the metal layers, failure of the fibre layers and debonding at the interfaces between these layers. The load transfer from the cracked metal layers through the adhesive to the fibre layers caused significant reduction in crack growth in the metal layers. This transfer is often called ‘fibre bridging’.

To tune the fibre bridging and subsequently the overall damage growth under fatigue loading, the resistance against delamination of the adhesive, the stiffness and strength of the fibres and the crack growth resistance of the metal layers are the prime parameters. This has been quantified by the work of Marissen [2] who developed an analytical prediction model for crack growth in the FML ARALL.

R. Alderliesten, *Fatigue and Fracture of Fibre Metal Laminates*, Solid Mechanics
and Its Applications 236, DOI 10.1007/978-3-319-56227-8_1

Initially, the development of the FMLs focussed in collaboration with Fokker on wing applications. However, interest from Messerschmitt-Bölkow-Blohm in Hamburg directed the research to fuselage applications. Because fibre failure was observed in ARALL under fuselage load spectra, FMLs containing glass fibres (GLARE) were then developed [3].

1.2 Development Perspectives

Indifferent of the historical development process, the FML concept can be regarded from various perspectives. Traditionally, the concept is treated as additional fibre reinforcement to laminated metallic sheets. Considering the historical development process [1], this perspective seems obvious. However, with the enormous research effort nowadays in fibre reinforced polymer composites, it may be more appropriate to consider the FML concept as the metallic reinforcement to composite materials. That perspective in itself is not new, because various patents have been filed in that context, as will be discussed in Chap. 3. However, the consequence regarding the FML concept from this still rather new perspective may be opening significant opportunities for composite applications.

1.2.1 Increased Damage Growth Resistance of Metal Laminates

Originating from the poor man's solution to build up aluminium structures using bonding technology, instead of using expensive milling equipment, the major driver in the development of FMLs has been to develop a material concept that has inherently higher resistance to (fatigue) cracking then state-of-the-art monolithic aluminium alloys. High fatigue crack growth resistance results in slow crack growth and thus longer inspection intervals, while a high fracture toughness increases the critical crack length, further increasing the damage tolerance of structures.

While developing GLARE, additional beneficial properties were identified that supported its application to primary fuselage structures: high impact resistance and tolerance, high burn through resistance, which could potentially increase evacuation time (safety aspect), and improved corrosion resistance (durability aspect) induced by its layered structure.

Despite all the effort within the GLARE development programme [4] to achieve technology readiness of GLARE with respect to all relevant aspects, the prime focus remained on the fatigue and damage tolerance characteristics.

The literature on this programme illustrates the process from generic understanding of fatigue initiation and crack propagation, towards more detailed understanding of fatigue resistance of mechanically fastened joints, impacted laminates, external and inter-laminar doubler run-outs, edge notches and rows of holes. The latter topic is considered important to address the resistance against widespread fatigue damage.

1.2.2 *Utilization in Context of Damage Tolerance*

Although clearly explained in the literature, damage tolerance as a development driver has not always been well understood. Academia not related to institutes involved in the development of GLARE has provided useful knowledge and insights. However, its work has never resulted in the development of actual FML applications.

For example, developing structural health monitoring concepts for FMLs without accounting for the inherent high resistance against impacts and (fatigue) cracking [5] makes the developed concepts obsolete or inapplicable for several reasons, especially economic reasons. The need for FML structures originates from the desire to develop damage tolerant structures that are care free (i.e. low inspection and maintenance burden). The need to rely on a health monitoring system to ensure damage tolerance seems to be contradictory to the application of such care (and monitoring) free FML structures. On the other hand, one should realize that such monitoring techniques applied in laboratory experiments may add to the understanding of certain mechanisms. This is illustrated by Austin et al. [6], who utilized fibre Bragg grating sensors to quantify fibre stresses in fatigue crack growth tests; information that previously could only be derived implicitly from other parameters measured.

Inspired by the development of FML as combination of metallic sheet material and fibre reinforced polymer composites, many combinations have been presented in the literature. None of these alternative combinations ever led to actual applications. For example, combining magnesium and carbon fibre reinforced polymer layers as reported by Cortes and Cantwell [7] is inapplicable to actual structures for reasons not addressed in their work. The low stiffness of the magnesium layers and the poor fatigue and corrosion resistance of these materials in comparison with aluminium do not compensate for the lower density, which seems the prime driver for this study [8]. Alternatively, one may think of combining carbon fibres with titanium sheets [9], but that requires addressing titanium pre-treatment challenges together with the high material costs.

This also holds for FML combinations based on thermoplastic matrix systems for which consolidation temperatures need to be applied that exceed thermal stability levels of widely applied aerospace alloys [10, 11]. As a result, only particular applications may be considered for such FMLs. Furthermore, these FMLs often exhibit poor fatigue performance, due to the severe tensile curing stresses in the metallic layers. Here, application of thermoplastic matrix systems should be investigated together with relevant aerospace alloys that can sustain the high curing temperatures.

Another more recent example could be the application of alternative manufacturing processes such as Vacuum Assisted Resin Transfer Moulding (VARTM) presented by Jensen et al. [12]. The introduction of small holes in the metal layers of the FML to enable resin to flow in laminate thickness direction creates a significant number of fatigue critical areas in the FML panel. While usually only the joining areas and cut-outs require a thorough fatigue assessment, this manufacturing concept implies assessment of every square inch. That, together with the fact that every hole implies access from the environment to the composite plies underneath, conflicts with the concepts of damage tolerance and durability, and makes it inapplicable to primary aircraft structures.

The key towards successful development of FML concepts for primary damage tolerant aircraft structures is the capability to provide multiple load paths within one laminated structure. Although crack bridging indeed increases the crack growth resistance of FMLs, this mechanism should not primarily be treated as a way to increase fatigue resistance.

Crack bridging is evidence of multiple structural elements that are joined by the bonding technology that each fulfils their own function within the structure. Whereas the ductility of the metallic layers increases the energy absorption during operational (impact) damage, the fibres provide the second load path in case the metallic constituents crack.

Depending on the combination of constituents, the overall structural performance can be tailored to the structural needs and functions it should provide. Here, the linear elastic fibres may significantly contribute to the static strength of the structures, increasing the strain hardening of the metallic constituents beyond their yield strength.

1.2.3 Increasing Strength of Composites

The aspect of strain hardening relates to viewing FMLs as the reinforcement of metallic structures by adding composite plies. However, the reversed view may solve many issues currently dealt with in fibre reinforced polymer composites. For example, the addition of isotropic metallic layers easily creates quasi-isotropic composite laminates, without the need to place fibres in multiple directions (0, 90, ± 45°). The additional benefit of having ductility in the composite may increase the damage tolerance by creating the ability to distribute local peak stresses to larger areas of the structure.

Especially where the bearing strength of composites is limiting the joining technology, metallic inserts will help. The higher bearing strength of metals, due to their ductility and isotropy, significantly increases the efficiency of mechanical joining in composite structures. The development of FMLs may provide the understanding necessary to design the appropriate joint areas in composite applications.

1.3 From Material Towards Structural Application

FML is often regarded as denoting a material family, rather than a class of structural concepts. This misperception has led to the development of FML material derivatives, which have mostly never progressed to even a technology readiness level of 3 or 4 [13]. As will be explained in the next chapter, the infinite number of combinations that can be made between the different metals, alloys and their heat treatments, the fibre types and the thermoset and thermoplastic matrices, has led to research and development without evident focus towards structural applications. Nonetheless, the vast number of studies addressing even FML types irrelevant for structural applications has generated further understanding of hybrid material technology principles.

1.4 Contribution to the FML Knowledge

This book aims to contribute to this field of hybrid material technology, by describing the current understanding concerning the hybrid material concept of laminated metallic and composite sheets for primary aeronautical structural applications. The first section of this book aims to provide a general background of the FML technology, indicating the major FML types developed and studied over the past decades (Chap. 2) in conjunction with an overview of industrial developments based on filed patents (Chap. 3).

The second section of this book discusses the mechanical response to quasi-static loading (Chap. 4), as well as the fracture phenomena during quasi-static (Chaps. 5 and 6) and cyclic loading (Chaps. 7–10). To consider the durability aspects related to strength justification and certification of primary aircraft structures, the third section will discuss thermal aspects related to FMLs and their mechanical response to environmental conditions (Chaps. 11–13).

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