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Modelling of interactions between Barely Visible Impact Damages and Lamb waves in CFRP laminates.

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Abstract

The improvement of the current design practice, especially for conventional materials, has allowed the production of structures able to better tolerate the presence of cracks and, in general, damages under the in-service loading conditions. As a result, especially in the aerospace field, nowadays, the damage tolerance philosophy is the core of the current design practice. However, conversely to the conventional materials, composite materials still cannot count on established prediction models supporting the damage tolerance approach. Among the critical damages which could affect composite materials, BVIDs (Barely Visible Impact Damages) due to accidental Low Velocity Impact (LVI) phenomena play a critical role. Since they cannot be easily detectable during the inspection intervals, in order to fulfil the damage tolerance targets, large safety factors are applied during the design current practice, resulting in the oversizing of the structure. For these reasons, Structural Health Monitoring (SHM) techniques are being widely used for the improvement of the current design practice, allowing the damage detection. Thanks to the possibility to assess the structural health during the in-service loading conditions, Lamb waves, among the several non-destructive testing (NDT), appear to be the best candidate for damage detection. Studies on this topic are never enough and the literature cannot still count on a Finite Element (FE) procedure able to simulate Lamb wave propagation on LVI damaged plates. This work deals with a FE procedure, developed by using the FE code Abaqus v.6.14®, for the simulation of the interaction between ultrasonic guided waves and LVI damages in composite laminates, whose damages have been modelled by means of Hashin criteria in a previous impact simulation.

Keywords: Lamb waves; SHM; LVI; Composite Materials; Non-destructive testing; FE simulation

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1. Introduction

Composite materials are widely used in several engineering applications, involving primary and secondary structures, where the weight plays a critical factor for designers. Nowadays, thanks to their high specific strength, composite materials applications can be found in both military and civilian fields, such as the aerospace, the automotive fields and there is no shortage of applications in the sport equipment. However, even though their great advantages, their application is limited by many critical aspects, such as the fact that they are prone to a large range of defects and damages due to both manufacturing process and in-service loading conditions. Many of such defects and damages can be very critical for composites structures, because they may be invisible and cause a significant decrease of the residual strength. The importance to consider such problem is more acute for the aerospace field, where the aircrafts operate in harsh conditions, sustaining high loads, fatigue cycles and extreme temperature swings. In this scenario, the better design strategy cannot consist of considering large safety factors, because of the weight importance.

As a result, nowadays, the design current practice involving conventional materials is based on the damage tolerance philosophy, requesting the ability of the structure to endure sudden damages without catastrophic failures.

However, composite materials, conversely to conventional ones, cannot count on established predictive models in support to the damage tolerance approach. This because, the failure mechanisms are completely different and the structure failure is characterized by the onset and the propagation of several cracks in the matrix before and in the fibers later. For such reason, large safety factors are applied to the ultimate design load, by significantly oversizing the components.

In order to improve the current design practice, the research community is focusing its attention on Structural Health Monitoring (SHM) systems, which aims to detect and monitor the presence of a damage in a non-destructive way, during the in-service life. The most important challenge related to such idea, that has been representing a well exploited research field, is the possibility to use "in-flight" methods developed for the structural health monitoring purposes. In this way, even if no established predictive model in support to the damage tolerance approach exists, it is possible to monitor the structural integrity during the real life of the structure.

Nowadays, several techniques are available for damage diagnosis affecting composite materials, allowing continuously and automatically assessing the structural health by means of non-destructive testing (NDT) methods. In particular, this paper focuses on piezoelectric sensors activating ultrasonic guided waves (Lamb waves).

Lamb waves are being increasingly used in thin plates thanks, because of the good compromise between sensitivity to damage, extent of the monitored area and required detection time.

Once the waves are excited, they propagate through the plate and will be recorded by the sensors attached to the component. The propagation properties of the guided waves depend on the properties of the media they travel through. Therefore, once they interact with a damaged area, the wave reflects and refracts. Hence, the most efficient method adopted for damage detection purpose consists of the comparison of the baseline signal achieved for undamaged/un-notched structures with the signal achieved in correspondence of the damaged/notched ones.

In this work, a finite element procedure has been developed to simulate the wave propagation in LVI damaged CFRP (Carbon Fiber Reinforced Polymer) laminate. Such procedure allowed investigating the Lamb wave propagation at different impact energy levels. Lamb wave propagation is simulated onto a plate characterized by an initial stress-strain state and the related failures, modelled by means of Hashin criteria in previous impact simulations.

Nomenclature

LVI	Low Velocity Impact
BVD	Barely Visible Damages
NDT	Non-destructive Testing
SHM	Structural Health Monitoring
CFRP	Carbon Fibre Reinforced Polymer
FE	Finite Element
p	pressure applied to the body
cv	viscosity