Study of the behavior of bi-axially loaded composite laminates

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Composite materials are increasingly used in the industry. Combining light weight and high resistance, they represent a good alternative to metals for weight saving in structures, such as airplanes. The behavior of those materials is intensively studied by researchers all over the world. Since a structure is usually submitted to complex loading, the study of the bi-axial behavior of those materials is a key issue to the understanding of damage progression of in service composite structures. Very few experiments have been done on bi-axial loading. The particular shape of the specimen and the absence of standard specimen make the task complex and the study remains open.

A specific cruciform specimen has been designed to respond to some criteria to allow performing reliable testing, based on already existing geometries [1,2]. The design has been made using a finite element model. The design criteria are:

- Stresses focused in the central area of the specimen
- Fracture in the central area
- Homogeneity of stresses in the central area

The specimen is then manufactured using the liquid resin infusion process, with a specific mold and a specific strategy to match with all the requirements. The material tested is a woven balanced carbon fabric with an epoxy resin. The specimen has a reduced section in the central area.

Damage characterization of materials is a complex procedure which needs to know a lot of data to be performed correctly. Digital image correlation (DIC) is an optical full field measurement method which is increasingly used [3,4]. When strain gages allow an accurate measurement of the strains on a small surface, DIC allows the measurement of the displacements all over the surface of a specimen. The accuracy of the system used is 5 µm. It is also possible to calculate the strains all over the surface.

Damage is also characterized by a local increase of the temperature of the material, due to energy release caused by fracture of the matrix or the fibers. These increases are detectable by infrared thermography, which is also a full field optical measuring method.

Combining those two monitoring systems, a specific monitoring setup has been designed, to get the most information during a bi-axial static tensile test. Two cameras are set on the opposite sides of the specimen to perform DIC and have access to the displacement fields on both sides of the specimen. A thermic camera is also used to get the temperature evolution on the surface of the specimen until complete fracture. Finally, a high-speed camera is used to get successive pictures during the fracture of the specimen at a rate of 3000 images per second to study accurately the fracture kinematic. The specimen is tested on a bi-axial tensile machine. The test consists in a bi-axial tension with the same load on both arms. The load is applied continuously until complete fracture of the specimen.

Finally, X-ray tomography is performed on the broken specimen to determine the fracture profile. X-ray tomography is an efficient way to perform non-destructive control by obtaining a 3 dimensional picture of the specimen, including the inside. It is then pssible to detect delamination, as well as fibers and matrix cracks.

All the data obtained are correlated to attempt to identify the damage mechanisms of those materials under bi-axial loading. A finite element approach is then attempted with a progressive damage model to match with the experience.

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