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HIGH-SPEED DIGITAL IMAGE CORRELATION: APPLICATION TO BI-AXIAL FATIGUE

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ABSTRACT: To study the behavior of a carbon fiber reinforced plastic laminate under a bi-axial stress state, a new type of cruciform specimen has been developed. This specimen is loaded bi-axially under static and cyclic fatigue loadings. The experiments are monitored simultaneously using Digital Image Correlation with two High-speed cameras, and infrared thermography. A comparison between the measurements and finite elements model is used to validate the design of the sample.
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1. INTRODUCTION

Composite materials are increasingly used in industry. Many experiments have been made to develop models to allow very complex structure sizing. But only few experiments have been done to characterize the behaviour of those materials under complex loading, such as biaxial planar loading, and even less dealing about fatigue. The biaxial testing machine owned by the LGP laboratory allows running experiments on biaxial cruciform specimens. The issue of those specimens is that the stress repartition is not constant over the specimen. It is why the Digital Image Correlation technique seems to be appropriate to monitor those tests, since it allows measuring an important area on the specimen with good accuracy. Thermography is as well appropriate to monitor fatigue testing as it permits to measure temperature elevation due to damage and hysteretic phenomenon. In the following study, a new kind of specimen is created to try to better respond to the needs of biaxial testing and to fit with the manufacturing process. Then, this specimen is tested during static and cyclic loading.

2. DESIGN OF THE CRUCIFORM SPECIMEN

2.1 Material and manufacturing process

The material used in this study is a carbon/epoxy composite laminate. The carbon part is a 12K balanced woven fabric. This fabric is made by Hexcel and is referenced as HexForce® 48302. The resin part is an epoxy resin made by Sicomin and referenced as SR1710. The hardener used is referenced as SD 8824.

The coupons are made using the LRI (Liquid Resin Infusion) process. All the manufacturing part was made in the premises of Nimitech Etudes. The stacking sequence was made only with 0° plies (as the fabric is balanc ed on the 1 and 2 directions, we have the same properties on the x and y axis, e.g. the main axis of the specimen).

2.2 Finite Element Model

All the design part was made using the finite elements software ABAQUS 6.10. As many different designs have already been tried in [1] and [2], those have been used as a base for the design of the new cruciform specimens. The design criterions were:

- Stress concentration nowhere else than at the center of the specimen
- Failure should occur in the central zone due to bi-axial stress state
- The central zone must be as flat as possible to allow DIC
- Adaptability to the LRI process
- Easy reproducibility
- Adaptation to the machine (mechanical jaws)

The elements that have been modified during the design procedure were:

- Thickness of the arms and of the central zone
- Width of the arms
- Size and shape of the corners between the arms
- Size and shape of the central zone

The model chosen is a 3D model, using one element per ply in the thickness. The zone considered to be taken in the jaws is considered as a rigid body. All the calculations are run on 1/8th of the total specimen (2 symmetries due to the shape of the specimen, 1 due to the shape through the thickness and the stacking sequence).

3. EXPERIMENTAL SETUP

3.1 Bi-axial tensile test machine

The experiments were made on an Instron 8800 (Fig. 1). It has four cylinders which can be controlled independently for fatigue or static loading. They can handle a 100kN effort and have a maximum travel of 40mm. This machine is driven by the WaveMatrix and Console FT softwares, which allow complete static and cyclic programming of the machine. This machine has mechanic jaws.

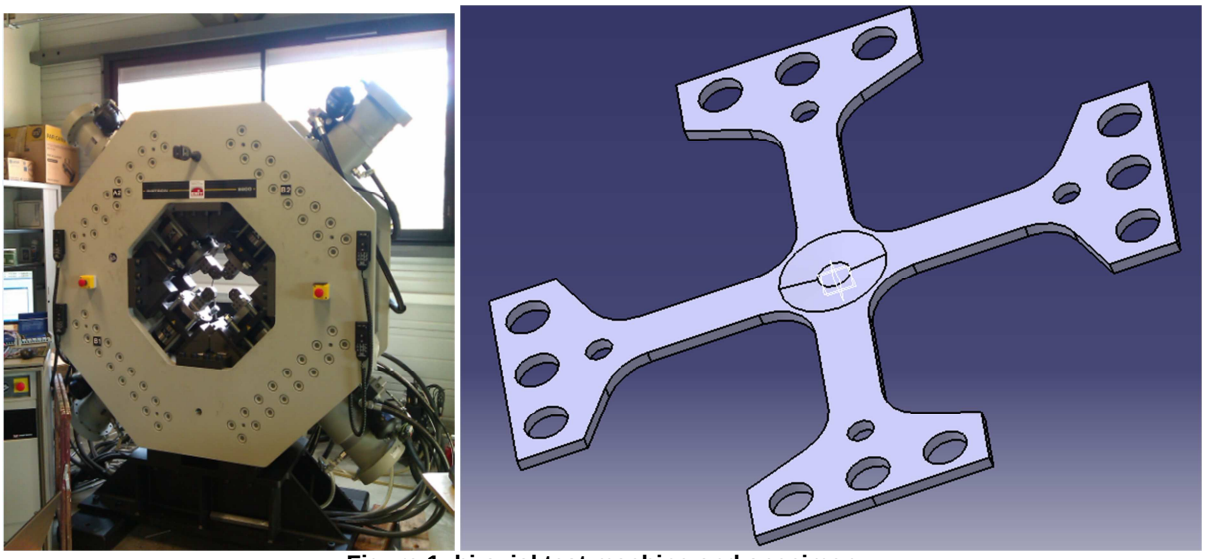

Figure 1- bi-axial test machine and specimen

3.2 High-speed DIC and infrared thermography

DIC is a widely spread way to measure a full displacement field on an extended surface during mechanical testing. It has been used for example in [3] to monitor fatigue testing of cruciform specimens under bi-axial loading, or in [4] for static loading of cruciform specimens.
The digital image correlation is made by the ARAMIS-V6.3.0-5 software. A set of two rapid cameras was used to take the pictures. Those cameras are referenced as Photron Fastcam SA1.1, used with the Photron Fastcam Viewer V3.0 1.08E software. Those cameras are capable of 5400 frames per second at 1 megapixel resolution.

Thermography is a good way to monitor fatigue testing. As developed in [5], it allows reaching the fatigue limit of materials. The camera used is a Flir jade III retrofitted Titanium, with a thermic resolution of 20 mK at 30℃.

3.3 Conditions of the experiments

All the experiments were conducted in the LGP laboratory. Since the machine is vertical, it allows putting simultaneously the two cameras for the DIC setup on one side of the specimen, and the infrared camera on the other side of it. To ensure constant lightning conditions to maximise the accuracy of the DIC measurements, a spotlight was used to lighten the specimen's surface. All the shutters and windows of the room have remained closed for the whole duration of the test.

Both the thermography and the DIC cameras were trigged automatically by signal sent by the machine at different steps of the experiment. High-speed cameras allow taking pictures at precise steps of the loading cycle.

Thermographic images were taken regularly after a certain amount of cycles to measure the increase of the temperature during the test, due to hysteretic or damage effects. Pictures for the DIC were taken after the same amount of cycles as with the thermographic setup. They were taken around the maximum loading value. Several experiments have been made to ensure that pictures were taken at the maximum loading point is reached. The value of the effort and the displacement of the cylinder is known for every picture taken in DIC, as well as the number of cycles. The number of cycles is known as well for the pictures taken with the thermography. This way, the evolution in the elastic behaviour can be measured and compared with tests run on one axis. Beside, a correlation between damage, change in the elastic behaviour and local warming of the specimen has been attempted.

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