11th International Conference on Composites Testing and Model Identification
J. Costa, J. Renart and N. Blanco (Editors)
Girona, 2023

EXPERIMENTAL TESTING AND NUMERICAL SIMULATION OF BEARING AND FILLED HOLE TENSION CARBON SPECIMENS UNDER DYNAMIC LOADING

José M. Guerrero[1], Emilio V. González[1], Pablo Villarroel[1], José A. Artero[2], Adrián Cimadevilla[2], Elisabeth De Blanpre[3] and Vincent Jacques[3]

[1]AMADE Research Group
Polytechnic School, University of Girona, Campus Montilivi s/n, E-17003 Girona, Spain
Email: josemanuel.guerrero@udg.edu, emilio.gonzalez@udg.edu, pablo.villarroel@udg.edu

[2] Department of Continuum Mechanics and Structural Analysis
University Carlos III of Madrid, Avda. de la Universidad, 30, 28911 Leganés, Madrid, Spain
Email: jartero@ing.uc3m.es, acimadev@ing.uc3m.es

[3] Dassault Aviation
75008 Paris, France
Email: Elisabeth.De-Blanpre@dassault-aviation.com, Vincent.Jacques@dassault-aviation.com

Keywords: Polymer composites, Finite elements, Dynamic loading, Strain rate, Split-Hopkinson bar

ABSTRACT

Holes or filled holes with a bolt in a composite lead to stress concentration that may cause complicated damage processes and failure mechanisms, such as matrix cracking, fibre breakage, delamination, etc., leading to catastrophic failure and a reduction of strength [1, 2]. Due to the complex damage mechanisms involved, as well as the complexity in analysing composite materials, predicting the strength reduction due to the presence of holes is quite challenging. Consequently, experimental tests are commonly performed in order to establish the strength reduction due to the presence of holes. In this regard, the Filled Hole Tension (FHT) test is used to determine the strain and strength reductions caused by a fastener-filled hole under tension loading [1]. Similarly, the bearing test is used to obtain the strain and strength reductions caused by having a pin or a fastener connected with another element.

Currently, there are several finite element models able to predict the strength reduction and failure of carbon composites under the presence of holes, pinned-holes or notches [1-4]. Moreover, the experimental tests for the FHT and bearing are well standardized [5, 6]. However, the standards are meant to carry out the tests under quasi-static conditions, while, in addition to this, there is a lack of numerical models able to predict the response of FHT and bearing specimens under dynamic conditions. Indeed, most models are limited to quasi-static loading, neglecting strain rate effects. To test under dynamic loading, the most common is to use either hydraulic universal testing machines, or especially, the Split Hopkinson Pressure Bar (SHPB) [7]. Although testing by means of hydraulic testing machines is generally simpler, performing high rate tests with such methodology is generally not accurate, due to the fact that the test results are affected by the machine inertia, compliance, etc. For this reason, the SHPB is widely employed to obtain experimentally the response under dynamic conditions [7]. In the SHPB, an impactor bar hits another bar at high speed, the latter usually referred to as the incident bar. This impact generates a tensile or compressive wave, depending on the desired loading conditions. The incident bar transmits the wave into a specimen, leading to dynamic loading conditions, see Figure 1. The specimen then transmits the wave to an output or transmitted bar, that can be used to establish the load during the test.

It has been reported that there is a dependence of the material properties due to the strain rate [7]. Consequently, the effect and strength reduction due the presence of holes, notches or pins under dynamic conditions can be different than the one observed under quasi-static loading. However, numerical and experimental work dealing with the dynamic response of composites with holes, filled holes and pinned holes is still scarce. In addition, since the test standards are designed for quasi-static

conditions [5, 6], there is no clear methodology clarifying how to perform dynamic tests of FHT and bearing and how to carry out the data reduction.

In this work we will make use of the SHPB technique to test FHT and bearing specimens under dynamic conditions, see Figure 1. The FHT will consist on a carbon laminate with a preloaded Titanium bolt. On the other hand, the bearing will consist in a carbon laminate bolted into an Aluminium plate, also with a bolt pretension. Two different stacking sequences and two bolt sizes (M4 and M8) will be considered for both. A specific clamping tooling has also been designed to connect adequately the specimens with the bars, and make sure that the wave propagates smoothly from the bars to the specimen (Figure 1). Quasi-static tests will also be carried out. From the tests, the failure strength and strain will be obtained as a function of the strain rate to assess its influence on these material properties. The tests have been designed using finite element simulations including a continuum damage model for carbon composites [3]. The experimental tests are carried out based on the finite element model, and the predictions obtained to design the tests are verified.

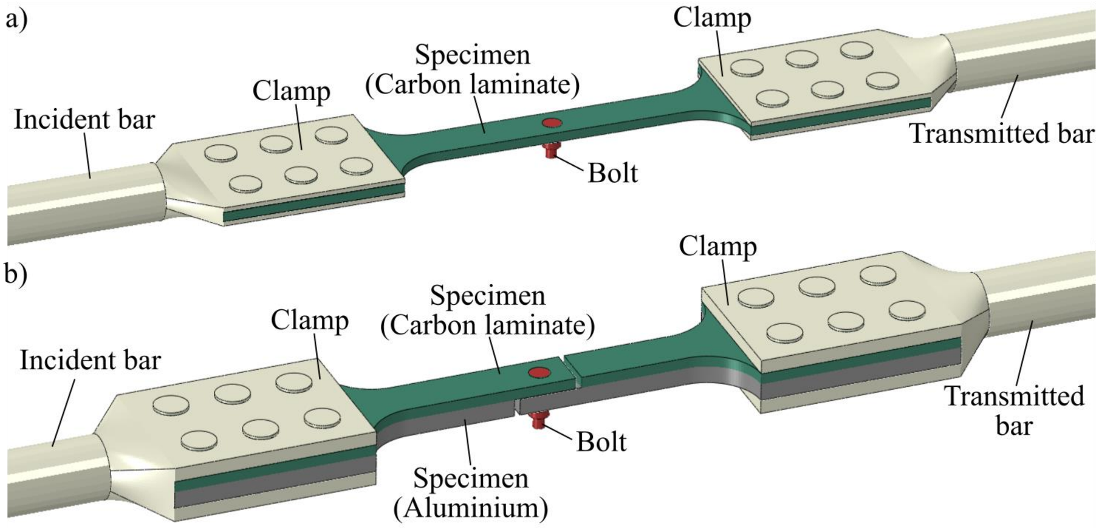

Figure 1: Designed Split-Hopkinson Pressure Bar test. a) FHT specimen and b) bearing.

This work has received funding from the Clean Sky 2 Joint Undertaking (JU) under grant agreement No. 886519. The JU receives support from the European Union's Horizon 2020 research and innovation programme and the Clean Sky 2 JU members other than the Union.

REFERENCES

[1] Shi, J., Tong, M., Zhou, C., Ye, C. and Wang, X., *Progressive failure analysis in open-hole tensile composite laminates of airplane stringers based on tests and simulations*, Appl. Sci., **11**, 2021, p. 1-15.

[2] Abisset, E., Daghia, F. and Ladevze, P., *On the validation of a damage mesomodel for laminated composites by means of open-hole tensile tests on quasi-isotropic laminates*, Compos. Part A Appl. Sci. Manuf., **42**, 2011, p. 1515-1524.

[3] Cózar, I. R., Otero, F., Maimí, P., González, E.V., Miot, S., Turon, A. and Camanho, P.P., *A three-dimensional plastic-damage model for polymer composite materials*, Compos. Part A Appl. Sci. Manuf., **163**, 2022, p. 107198.

[4] Serra, J., Bouvet, C., Castanié, B. and Petiot, C., *Scaling effect in notched composites: The Discrete Ply Model approach*, Compos. Struct., **148**, 2016, p. 127-143.

[5] ASTM Standard D6742/D6742M − 17, *Standard Practice for Filled-Hole Tension and Compression Testing of Polymer Matrix Composite Laminates*, ASTM Int. West Conshohocken, PA, 2017.

[6] ASTM Standard D5961/D5961M − 17, *Standard Test Method for Bearing Response of Polymer Matrix Composite Laminates*, ASTM Int. West Conshohocken, PA, 2017.

[7] Lißner, M., Alabort, E., Erice, B., Cui, H., Blackman, B. R. K. and Petrinic, N., *On the dynamic response of adhesively bonded structures*, Int. J. Impact Eng., **138**, 2020, p. 103479.