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Experimental study and finite element analysis of the elastic instability of composite lattice structures for aeronautic applications

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Abstract

The work presented in this paper is focused on the finite element modelling (FEM) of the failure behaviour of lattice composite hollow structures that have been subjected to an external hydrostatic pressure. Furthermore, the development of an experimental procedure to measure the aforementioned resistance, and to test the FEM model is also presented. Carbon fibres composite hollow cylinders with a lattice structure and with different geometries were produced and tested. In order to develop a design tools for such structures, all the experiments performed were computer simulated using finite element modelling. The results obtained with FEM simulation provide further insight to analyze and investigate the failure mechanism. The elastic instability of the studied structures was therefore analyzed and the influence of element geometry on the collapsing resistance thereof was considered. As a result of the study it has been possible to locate three different failure modes which where strictly related to the length of the cylinders. Both the shape of the broken tube and the lever of failure stresses were correctly predicted by the FEM model.

Keywords: Lattice structures; Buckling analysis; Composite tubes; FEM modelling

1. Introduction

Composites applications in commercial aircrafts have steadily increased as material costs come down and design and manufacturing technology has evolved. As the experience in composites continues growing, nowadays, composites are used more and more in military aircrafts as well as civil ones. The key to success of the use of composite materials in the aeronautic industry is based on the high performance versus weight ratios that it is possible to achieve using these materials and on the necessity to lower the weight of the aircraft as much as possible to enhance its efficiency. For this reason, in order to save weight, the opportunity of using composites in many other functional applications in the aircraft structure is under consideration. Carbon fibre composites, for example, are currently used not only for wings or fuselage parts but also to substitute parts, which are not necessarily structural, but can contribute to take off weight from the airplane such as for example elements of the hydraulic systems or internal parts of the aircraft. The project AEROFIL for example, financed by the European Commission, is dedicated to the development of a "*New Concept of High Pressure Hydraulic Filters for Aeronautics Preserving Environment*", based on organic materials and polymer matrix composites which will replace the metal used in today's technology to produce the structural parts. The present study was developed within the framework of the AEROFIL project and it focuses on the design, construction and structural analysis of lattice composite structures to be used for the new filters. Starting from the necessity to develop a design tool able to provide the necessary composite thickness to avoid the buckling of the filter inner tube this work describes on the ability of the program developed, to predict the onset of buckling in composite hollow structures. The results obtained from the simulation were confirmed by the experimental data obtained using a specific apparatus set up to

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induce hydraulic pressure on tubes and allowed the production of design charts.

2. Choice of the materials and of the production process

The structural part designed and studied in this work is a composite hollow tube containing a series of holes which are not drilled in but they are directly produced using the filament winding technology. A cad picture the filter scheme is shown in Fig. 1. From a functional point of view, the inlet tube represents the most important structural part of the filter. It prevents the filtering media from squashing and in the case of a complete occlusion of the filtering media, it could be loaded by a pressure equal to the circuit operating pressure which can vary from a few bars (for the low pressure filter or fuel filter), up to 250 bar (for the high pressure filters). On the basis of the functional specifications for the inlet tube, the use of carbon fibre composites for the production of this part represented the best choice since their high strength to weight ratio. Moreover, taking into account the presence of holes on the lateral surface of the tube, filament winding was selected as the most appropriate production technology and the choice of the best winding angle was made taking into account the stress distribution over the inlet tube structure. Since in case of occlusion of the filtering paper, the filter would act as a pressure vessel loaded by an external pressure, the pressure vessel theory together with netting analysis [1] could be used for the determination of the optimal winding angle, this approach led to a value for α equal to 54.7°.

High modulus carbon fibres and low viscosity epoxy resin were used to wind the tubes. During the winding process, fibre rowing were pulled through the liquid resin bath and then wound around the mandrel. The deposition process led to composite bands which were 2 mm in width and 0.18 mm thick on average and to final composite tubes having an average fibre content of 44% volume.

Primary tubes that were 1500 mm long and with different geometries were wound; the geometries produced are summarized in Table 1. The transparency T of the tubes was defined as the ratio between the lateral surface of the element occupied by the holes and the total surface (Eq. (1)):

$$T = \frac{A_{\text{holes}}}{A_{\text{total}}} \qquad (1)$$

where A_{holes} is the total area covered by the holes and A_{total} represents the lateral surface for a straight tube without holes. By changing the number of composite bands wound over the diameter of the mandrel to generate the composite lattice structure it was possible to obtain primary tubes having different transparencies.

Table 1
List of the primary tubes produced

Tube label	Diameter [mm]	N_{gen}	N_{lay}
Φ30-N_g13-N_l6	30	13	6
Φ50-N_g17-N_l6	50	17	6
Φ50-N_g21-N_l6	50	21	6
Φ56-N_g24-N_l10	56	24	10
Φ56-N_g24-N_l13	56	24	13
Φ56-N_g24-N_l16	56	24	16
Φ62-N_g28-N_l6	62	28	6

N_{gen} represents the number of composite bands over the diameter, Φ used to wind the tube, N_{lay} represents the number of composite layers in the tube.

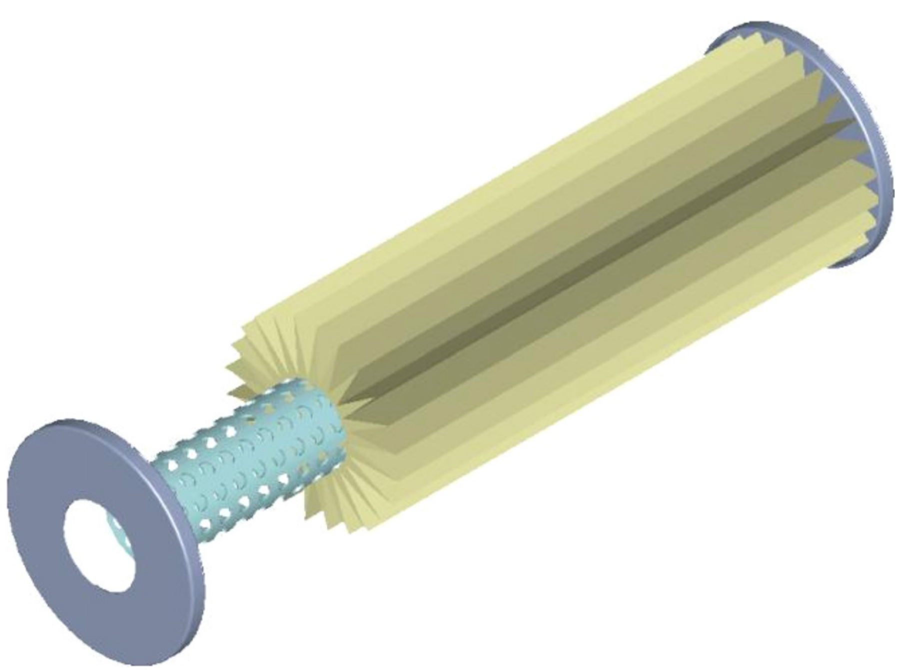

Fig. 1. CAD model of the studied hydraulic filter.