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On the use of selective stitching in stiffened composite panels to prevent skin-stringer debonding☆

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Composite laminates are generally characterized by poor mechanical properties along the thickness direction, therefore they are highly susceptible to delaminations. A potential increase in structural efficiency may be obtained by using 3D reinforcements technologies. In this paper, an experimental/numerical study is presented focusing on the effects of a single reinforcement seam of stitches along the edge of a stringer foot, in a stiffened composite panel. Three-point bending tests have been performed on a skin-stringer configuration by considering variations of the skin thickness, the stitching technique, the pitch and the yarn diameter. Then, a Finite Element Model has been developed capable to simulate the mechanical behaviour of stiffened composite panels with selective stitching and to assist the design of more complex geometrical configurations by estimating the damage behaviour, as well as the onset and the propagation of delamination taking into account the effect of the selective stitching. The numerical results, in terms of load vs applied displacements, have been found in good agreement with the experimental data proving the effectiveness of the introduced numerical model. The numerical results have confirmed the potential beneficial effects of stitching in terms of delay of the crack initiation and growth, of smoother delamination profile, of increase in the stiffness of the structure with a reduction of the delamination area.

1. Introduction

Beyond clear advantages of using composite materials for aerospace structural applications, such as the high specific strength and stiffness, there are also several disadvantages that have to be considered. Indeed, fibre-reinforced plastic (FRP) materials show excellent mechanical properties in the fibre direction, while exhibit poor mechanical properties in the third dimension, namely the z-direction, basically due to the poor mechanical properties of the polymeric matrix. Therefore, the composite laminate is likely to be highly vulnerable to delaminations.

In order to increase the poor out-of-plane inter-laminar strength, mechanical fasteners could be added to the structure, however, this would lead to higher manufacturing costs and weight. An alternative more effective solution is the introduction of translaminar reinforcements (TLR) or through-the-thickness reinforcements (TTR) into the composite in order to create mechanical links between adjacent plies of the laminate leading to an overall improvement of its out-of-plane mechanical properties and damage tolerance behaviour [1–5]. The TTR can be either continuous, such as weaving, braiding, threads, yarns and tows or discontinuous, such as short fibres, whiskers and pins. Stitching is one the most common TTR and involves the insertion along the thickness axis, of one or two high-tensile threads by means of a needle that might be interlocked or not. The material used for the thread is usually glass or aramid fibres but carbon fibres threads could be adopted as well.

A recent research has suggested that stitching in only selected areas may have limited but positive effects, potentially without involving the severe reduction of in-plane stiffness and strength related to full aerial stitching [6–10]. The idea behind the selective stitching is to adopt this technique only in the "weak zones" which can be, potentially, more affected by the delamination phenomenon. As a matter of facts, selective stitching aims to alter or arrest

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damages by using stitching seams at only the necessary locations. The selective stitching is expected to provide not only a better damage tolerance but also weight saving and simplification in the manufacturing procedures with a consequent reduced cost.

The Selective Stitching can be successfully applied to reduce the delaminations occurring between skin and stringers in aircraft fuselages stiffened composite panels which can be considered as a network of stringers connected to thin skins. For these structures, for analytical, experimental and numerical studies at coupon level, a realistic representation of their mechanical behaviour is given by a stringer foot-skin system stitched along the edges [11–31].

The scope of this work is the development of a finite element model able to correctly simulate the mechanical behaviour of stiffened composite panels with selective stitching. This model should also be able to assist the design of more complex geometrical stiffened panels configurations by estimating the damage behaviour, as well as the onset and the propagation of delamination taking into account the effect of the selective stitching.

In order to gain in-house experience of the structural behaviour of selectively stitched stiffeners, Airbus R&T performed some mechanical tests and analytical analyses on the potential effect of selective stitching on the debonding of stringers and on the effect of different parameters related to stitching (stitching techniques, pitch, stitching yarn). These tests were performed by Airbus R&T in collaboration with EADS IW in Ottobrunn and KSL Keilmann Sondermaschinenbau GmbH. Part of these mechanical tests have been reported in this paper for a first validation of the proposed Finite Element Model.

In Section 2, the three-point bending specimen configurations are presented together with the experimental set-up and output data in terms of load vs displacements curves. In Section 3, all the details on the numerical model are provided and the results in terms of load versus applied displacement are introduced, compared to the experimental data and assessed.

2. Three-points bending tests

In order to characterize the flexural behaviour of the selective stitched and unstitched specimens, three-points bending tests have been performed. The mixed-mode stress configuration of this test gives a stress combination close to the real-life situation for a T-section stiffener. From the mechanical behaviour of specimen under three-points bending test it is possible to rapidly estimate the effect of the selective stitching and of the geometry parameters on skin-stringer debonding onset and evolution. In the next subsections the geometrical characteristics of the specimens and the experimental set-up and results for the different analysed configurations are introduced.

2.1. Geometrical description of the tested specimen

The manufactured selective stitched test specimens consist of a skin and a stringer foot (see Fig. 1) with through-the-thickness stitching across both parts along the edge of the stringer foot.

The test rig consists of a centrally acting hydraulic cylinder with a load cell. The specimen is mounted with the stringer foot facing down, resting on two semi-circular supports. The load introduced along the centre line of the stringer foot represents the load from the web which, for the sake of simplicity, is missing in this study and in coupons manufacturing (the focus of the study is on the edge of the stringer foot). Tests have been carried out with displacement controlled centre load, measuring the load and the displacement at the centre. The test rig with the specimen is presented in the Fig. 2.

The geometrical description of the specimens is introduced in Fig. 3.

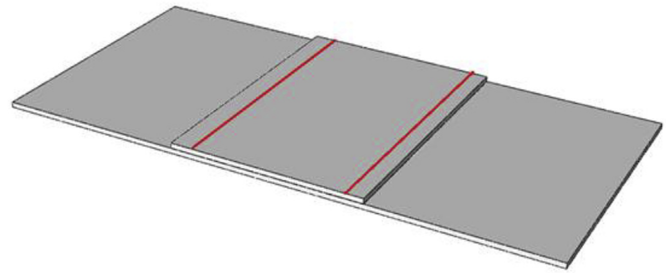

Fig. 1. Selective stitched coupon geometry (stitches are represented by red lines). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

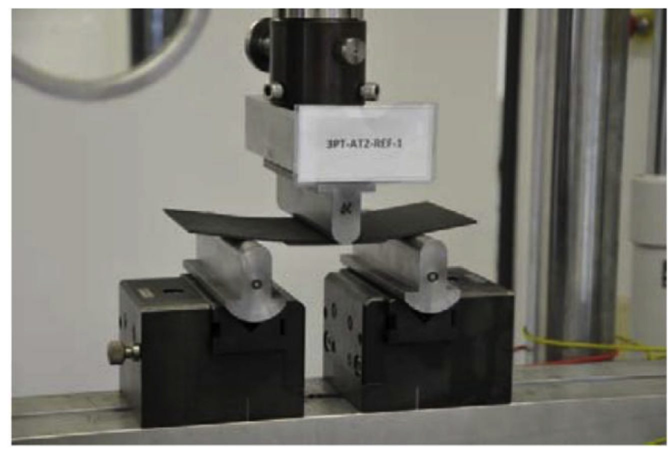

Fig. 2. Test rig.

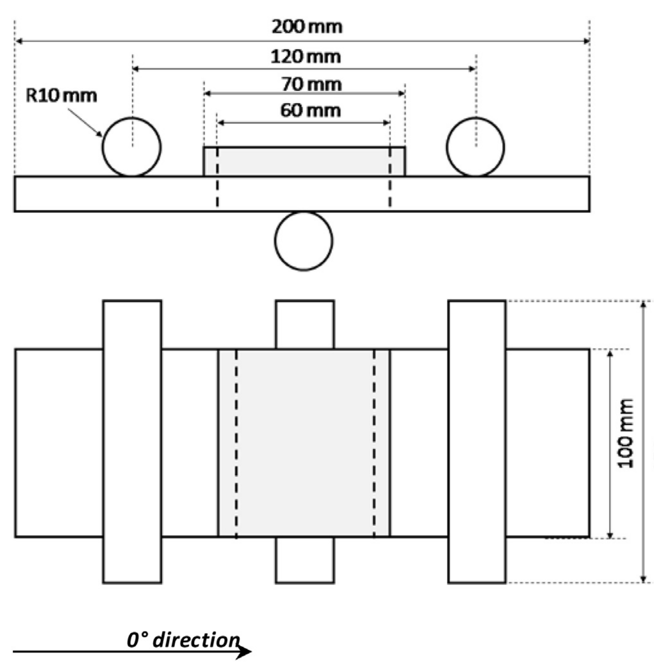

Fig. 3. Geometrical description of the three-point bending test specimens.

The material, for both the parts, is a NCF SAERTEX quadri-axial 505 sgm with 12 k Fiber Tenax HTS, recommended by EADS Innovation Work. The denomination is RTM6/Tenax HTS 12 k. The