AN EXPERIMENTAL INVESTIGATION ON BUCKLING BEHAVIOR OF VARIABLE ANGLE TOW LAMINATES SUBJECTED TO UNIFORM COMPRESSION LOAD

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1 General Introduction

Automated Fiber Placement (AFP) has been increasingly used to manufacture large complex composite structures in the aerospace industry for commercial aircrafts as the Boeing 787, the Airbus A350 XWB and the Bombardier C-series. AFP significantly improves reproducibility and design flexibility of composites manufacturing, it also offers the potential to lay up the fibers along curvilinear paths. This special flexibility of composites manufacturing makes it possible to fabricate variable stiffness laminates [1]. Variable stiffness laminates allow the designer to optimize parts, with better stress redistribution inside the structures. However, to layup variable stiffness composite panels following curvilinear fiber paths, there are inherent defects called gaps/overlaps in the AFP process [2, 3]. Most of published work on variable stiffness composites deals with numerical simulation and there is a lack of experimental investigations particularly for these inherent defects. This could be attributed in part to the fact that AFP machinery is heavily dedicated to industrial composites manufacturing and has limited access to academic researchers. This paper presents the results of an experimental investigation of the buckling behavior of variable stiffness laminates made by Automated Fiber Placement.

2 Experimental procedures

2.1 Materials and panel manufacturing

The material used in the experiment was G40-800/5276-1 carbon/epoxy slit tape (3.2 *mm* wide) from Cytec Engineered Materials. A Viper 4000 fiber placement machine was used. First, two quasi-isotropic laminates with constant stiffness were manufactured to serve as the baseline panels. Then, four variable stiffness panels with 100% gaps and four with 100% overlap configurations were fabricated, respectively. The stacking sequence for these panels is given in Table 1. The purpose of these two panel configurations was to investigate the effects of gaps and overlaps on the buckling behavior of the laminates. The panels were machined into 10 in. x 16 in. flat plates and the loaded edges of the panels were machined flat and parallel to ensure uniform end loading during the tests.

Table 1 Stacking Sequence of tested panels

Construction Technique	Stacking Sequence
Quasi-isotropic	$[+45/0\text{-}45/90]_{2s}$
Full Gap	$[\pm\langle 49\vert 41\rangle/\pm\langle 48\vert 61\rangle/\pm\langle 57\vert 73\rangle/\pm\langle 72\vert 77\rangle]_s$
Full Overlap	$[\pm\langle 49\vert 41\rangle/\pm\langle 48\vert 61\rangle/\pm\langle 57\vert 73\rangle/\pm\langle 72\vert 77\rangle]_s$

2.2 Test set-up

A mounting fixture has been designed and developed to perform the buckling tests. The fixture was expected to exhibit the simple-support end conditions. The panel's edges were captured between two knife-edge supports. A gap between the knives edges at both sides of the unloaded panels were set to 2 *mm* to avoid the Poisson effect during compression. The panels were loaded in compression with an Amster machine by applying an end-shortening displacement to the horizontal edges panels. A typical compression panel mounted in the support fixture is shown in Fig. 1.

2.3 Data acquisition and instrumentation

For data acquisition, sixteen axial strain gages were installed to measure the axial strains as a function of applied load. Additionally, four non-contact Laser displacement sensors were used to record the panel's out-of-plane displacements. Those sensors were focusing on the panel's vertical mid-span. During the test, the data from strain gages, out-of-plane displacements, applied load and end-shortening were recorded at regular intervals. Before applying any load to the panel the strain gauges and non-contact laser sensors were zeroed.

Fig. 1. Test panel mounted in support fixture.

3 Results and discussion

3.1 Buckling load

It has been observed from many studies how difficult to obtain and determine an accurate buckling load experimentally [4]. There are many factors which considerably affect the buckling test in the experiments such as geometry and material panel, the loading machine accuracy and improper mounting fixture that cause a misalignment between the load direction and the panel. Many methods have been used during this study to identify panel-buckling loads from experimental results.

3.2 Membrane strains

Fig.2 shows the experimentally determined axial membrane strains (average of back-to-back strain gages) across the panel at the gages locations 1 through 4 for several values of applied compression load in the pre- and postbuckling range.

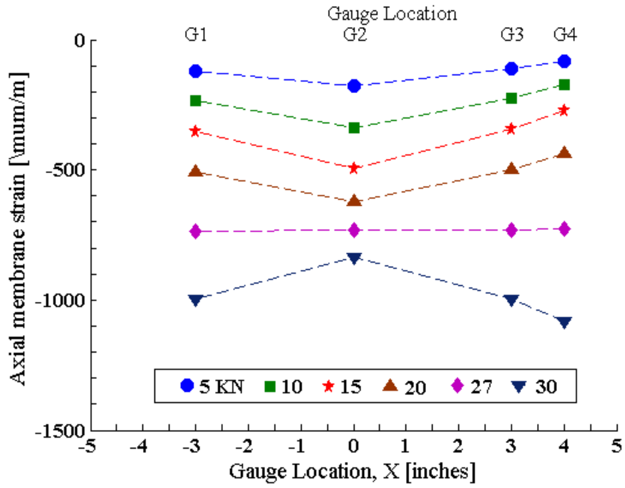

Fig. 2. Axial membrane strain versus gage location for various load levels (for panel with overlap).

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