Composite Structures 137 (2016) 185–195

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Experimental and numerical investigation of stiffened composite curved panel under shear and in-plane bending

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ARTICLE INFO

Article history:
Available online 9 October 2015

Keywords:
Stiffened composite curved panel
Experiment
Buckling and post-buckling
Finite element analysis

ABSTRACT

An experiment was carried out to study the buckling and post-buckling behavior of stiffened composite curved panel under shear and in-plane bending. A test fixture was designed uniquely which was suitable for curved panel subjected to shear or shear and in-plane bending. The results showed that this kind of fixture was feasible. The strain data were recorded by strain gauges. The out-of-plane displacement field was characterized by a 3D digital speckle system. The stability of stiffened composite curved panel subjected to shear and in-plane bending was analyzed by the obtained data. Finite element method (FEM) was used. The influence of transverse frames on the stability of stiffened curved panel was further studied by FEM. Good correlation between experimental and FEM analysis was obtained. The fixture and test method used in this paper provide a reference to the study of curved panel subjected to shear or shear and in-plane bending.

1. Introduction

Recently, stiffened composite curved panels made of fibre reinforced composite materials are increasingly used in numerous structures in aircraft, spacecraft, marine and civil engineering infrastructure fields as a typical structure because of their high strength to weight ratio and their resistance to corrosion. In the aviation area, fuselage made up of stiffened composite curved panel consists of longitudinal stringers and transverse frames. The loading conditions on fuselage are too complex to simulate. Usually, the loading conditions are divided into a typical load, such as axial compression or tension, shear or a combination of compression and shear [1] or others [2], and then the structures can be more easily analyzed.

Typical failure modes of stiffened composite curved panel are buckling and a variety of damage caused by buckling. Buckling and post-buckling behavior of stiffened curved panel under axial compression was studied in many literatures by experiments [3–8], theoretical analysis [6,9] and numerical computations [5,6,8,10–14].

Stability, delamination and failure of stiffened composite panel under shear load was studied by many researchers [15–20]. Most of those panels are flat panels. Test fixture of flat panel is much more easily designed. It is usually designed approximately as the *picture frame* shown in literature [19,21–25]. Other shear-test fixtures such as the three point beam or three point Wagner beam fixture are also used [23]. Wolf et al. [26] used the picture frame method to test the curved panels, but the load eccentricity was introduced and it was found that the problem could be eliminated only if the fixture had enough bending stiffness when shallow panels were tested. Shear-test fixture for stiffened curved panel was usually designed as a box: two panels fixed surface-to-surface at two opposite surfaces [27]. Some researchers just got the tested structure designed as a box [28,29]. There were few researchers to study stiffened curved panel under shear and in-plane bending except C.A Featherston [30] who carried out a series tests to study the behavior of composite panels subjected to a varying combination of shear and in-plane bending. But the fixture they used showed that load eccentricity was introduced on the panels.

In this paper, a fixture called the *double curved picture frame* was creatively designed for pure shear and in-plane bending. This fixture was designed like a barrel, and two panels were fixed on the barrel wall symmetrically. In the test, two curved panels were loaded at the same time. Strain gauges were utilized to record the state of strain. Since the strain measurements are always confined to localized areas, a 3D digital speckle technology was applied to observe the deformation process of the stiffened curved panel.

The buckling and post-buckling behavior of stiffened curved panel was analyzed by strains recorded by strain gauges, and deformations characterized by 3D digital speckle system and

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http://dx.doi.org/10.1016/j.compstruct.2015.09.049
0263-8223/

numerical results gotten from ABAQUS with the user subroutine UMAT. Acting as a role to keep a structure's shape stable, the influence of transverse frames on the stability of stiffened curved panel was also studied by FEM. Good agreement between experimental and finite element analysis was found. The experimental results are helpful to future research and application of such a structure. The test fixture and test method provide a reference to engineers to design or test a curved panel subjected to shear or shear and in-plane bending.

2. Panel description

The dimensions of the stiffened composite panel are shown in Fig. 1(a). The stiffened composite curved panel in this experiment is composed of five longitudinal hat-stringers bonded to the skin and three transverse frames attached to shin by rivet joint. Primarily, it is a cylindrical panel, whose main dimensions are: nominal radius $R = 1645$ mm, arc length $L = 1269$ mm and width $D = 1800$ mm. The intervals between two stringers and two frames are 212 mm and 600 mm. The mechanical properties of material are detailed in Table 1. To be more easily clamped on the fixture and ensure a uniform load application, the surrounding of test area was thicken to 5.6 mm. The laminate lay-up was reported in Table 2 and specified graphically in Fig. 2. Nominal ply thickness is 0.185 mm.

3. Fixture description

Stiffened composite curved panel under shear and in-plane bending was studied in this paper. The test fixture was designed creatively shown in Fig. 1(b). By changing the hole diameter D_2 in Fig. 3, the test fixture can be used to test a curved panel subjected to pure shear or shear and in-plane bending.

1. Shear and in-plane bending: $D_2 > D_1 = D_3$.
2. Pure shear: $D_2 = D_1 = D_3$.

The global view of the test fixture was illustrated in Fig. 4(a). The fixture was designed as a barrel that most of the barrel wall was removed. Two curved panels were symmetrically fixed on the wall face-to-face. The two vertical sides of each panel were clamped by four curved steel plates. Composite panels and steel plates were connected by bolts along the edges. A couple forces were applied to obtain torque. The two panels were subjected to shear and in-plane bending when the test system was rotated under the torque as shown in Fig. 4(b) and (c). A circular disc was used to eliminate the effect of weight of the circular disc and to ensure safety when panels collapsed. Also, a circular orbit was used to ensure that no load eccentricity was introduced.

Table 1
Lamina mechanical properties.

Stiffness		Strength	
E_1	141 GPa	X_T	2700 MPa
E_2	8.85 GPa	X_C	1600 MPa
G_{12}	4.57 GPa	Y_T	88 MPa
G_{23}	4.2 GPa	Y_C	271 MPa
v_{12}	0.33	S	143 MPa

Table 2
Lay-up definition.

Skin	t [45/−45/0/90/45/90/−45/0/−45/90/45/90/0/−45/45]
Stringer	t_1 [45/−45/0/90/90/0/−45/45]
	t_2 [45/−45/−45/45]
Frame	t_3 [45/−45/0/90/90/0/−45/45]
	t_4 [45/−45/0/90/90/0/−45/45]

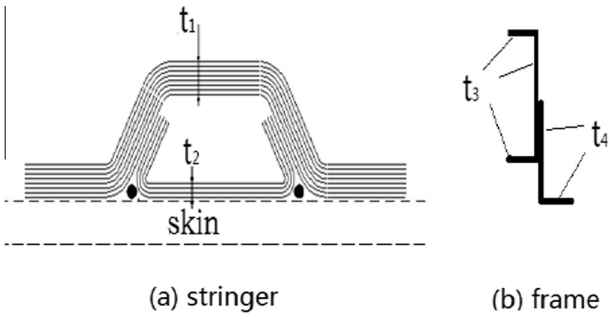
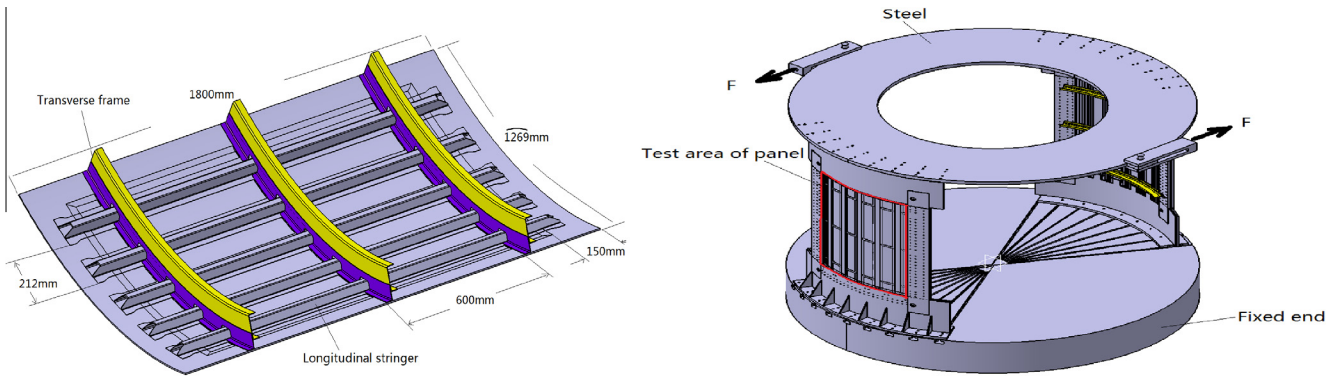


Fig. 2. Layups of stringer and frame.

4. Test procedure

The local buckling behavior was easily studied by strains measured in the test. In the test, strain gauges were bonded back-to-back to the panel surfaces, webs and top flange of the stringers at 0°, 45° and 90° of the longitudinal axis to measure the strains and detect the initial buckling. The gauge locations were depicted in Fig. 5. Gauge rosettes on the front face were numbered from 1 to 119 on panel-1 and from 201 to 319 on panel-2. Gauge rosettes on the back face were marked with "′" after the numbers, such as 1′



(a) Geometry of panel (b) Test device for curved panel

Fig. 1. Sketch of panel and test device.