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Effect of the stiffener stiffness on the buckling and post-buckling behavior of stiffened composite panels – Experimental investigation

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ABSTRACT

The purpose of this paper was to study the effect of I-shape stiffener stiffness on the buckling and post-buckling, up to collapse behavior of stiffened composite panel under the uniform uniaxial compression load. Six stiffened composite panel configurations, which were orthogonally designed with two skin configurations and three I-shape stiffener configurations, were took into account in the experimental investigation. Three specimens for each configuration (18 specimens in total) were manufactured for test. Before tests, the key dimensions of I-stiffener and skin were measured. Furthermore, all the specimens were also inspected visually and detected by the ultrasonic C-scan system. No initial delamination or debonding area was found on all the specimens according to their C-scan images. The experimental results show that the equivalent compression stiffness of I-shape stiffener has great influence on the buckling load and failure mode of stiffened panel, but a little effect on the failure load of stiffened panel. The skin thickness has great impact on the buckling load and the final failure load.

1. Introduction

Weight reduction of primary structures in the aerospace industry is an important and challenging issue to decrease operating costs. Stiffened panels, which are constructed with sheet material stabilized by stiffeners, are often used in the aerospace industry in order to obtain lightweight structures with high bending stiffness and buckling resistance. The use of advanced composite material in the aerospace structures has been demonstrated the advantage of decreasing the structural weight. Post-buckling design, which allows buckling before limit load, can also produce significant structural weight saving compared to buckling-resistant design, i.e., the current design practice for the stiffened metallic panels [1]. Due to the lack of confidence on the calculation of post-buckling and collapse loads of stiffened composite panel, the guideline of the post-buckling design is still not available for stiffened composite panel even though it has been applied in the metal stiffened panel in the airframe structures [1]. Therefore, it is important to study the characteristics and the simulation methods of the buckling, post-buckling and collapse behaviors of the stiffened composite panel. These have been studied by mean of experiment and numerical simulation in several well-known programs, such as EDAVCOS [2], POSICOSS [3] and COCOMAT [4].

The stability design of stiffened panels in the wing and fuselage of aircraft is required to take into account compression, shear and combined compression-shear load cases. Under those load cases, the stiffened composite panels usually experience the local buckling of skin, stiffener buckling, global buckling and collapse. The failure of stiffened composite panel often starts from the interface between stiffeners and skin [5,6] because of the stress concentration induced by different deformation of the stiffeners and the skin after the local buckling of skin. The effect of the stiffener design and the skin thickness on the buckling resistance and post-buckling strength of stiffened composite panel was usually studied by the parameter analysis based on finite element method or analytical model. Guo et al. [7] investigated the effect of stiffener depth to skin thickness ratio on buckling coefficients and buckling mode based on an analytical model, and reported that the stiffener is efficient in increasing the buckling load only up to a certain ratio of the stiffener height to the skin thickness. Dung et al. [8] studied the impact of the number and dimension of stiffeners on buckling and post-buckling load of stiffened cylindrical shells under torsion by an analytical method. Rahimi et al. [9] studied the influence of the stiffener profile on the buckling of cylindrical shells under axial compression load by FEM. Jain et al. [10] analyzed the buckling behaviors of the stiffened composite panels with different

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cross-section shapes (blade-shape, T-shape and hat-shape) subjected to in-plane shear. Pevzner et al. [11] studied the bending, torsional and combined buckling of curved panels stiffened by J-shape and T-shape stiffeners. A parameter study performed by Chen et al. [12] showed that the skin thickness can increase the post-buckling compressive strength.

Many experiments have been carried out on various stiffened composite panels to investigate their buckling resistance and post-buckling behavior under compression or shear load, and to validate the corresponding analytical models. Most of these experiments were performed on a single configuration of stiffened composite panel with different cross-section stiffeners, such as hat-shape [13], blade-shape or T-shape [14–17] and I-shape [18,19], under uniaxial compression load. However, a few experiments were carried out for the parametric study on the effects of stiffener and skin design on the buckling and post-buckling behavior of stiffened composite panel. Zimmermann et al. [20] studied experimentally the buckling and post-buckling behaviors of stiffened composite with different skin thickness and different T-stiffener number. Elaldi [21] compared the post-buckling strength and structural efficiencies of J-shape and hat-shape stiffened panels through experiments. Bisagni et al. [22] performed the buckling and post-buckling tests on the cylindrical shells stiffened by different stringer number under compression load. Kong et al. [23] conducted the buckling and post-buckling experiments on two stiffened panel configurations with I-shape and blade-shape stiffeners. The setup and procedure of buckling and post-buckling test of stiffened composite panel under uniaxial compression load are well-known [20]. The buckling patterns and out-of-plane displacement of the skin were usually monitored by a shadow Moiré technology [13–15,18,19] or Digital Image Correlation (DIC) system [17,20,24]. The first buckling load was usually determined by the analysis on the split point of the two strain–load curves measured on the both sides of skin.

Motivating by the importance of the stiffener stiffness and the fact that a few experiments are performed on it, dedicated experiments have been designed and carried out to investigate the effect of I-shape stiffener stiffness on the buckling and post-buckling behavior of stiffened composite panels in this study. Six stiffened composite panel configurations have been orthogonally designed with two skin configurations and three I-shape stiffener configurations. Three specimens for each configuration, 18 specimens in total, were manufactured and tested. The strains on both skin and stiffeners and the shortenings of specimens have been recorded during the test. The out-of-plane displacement of skin was monitored by the shadow Moiré technique.

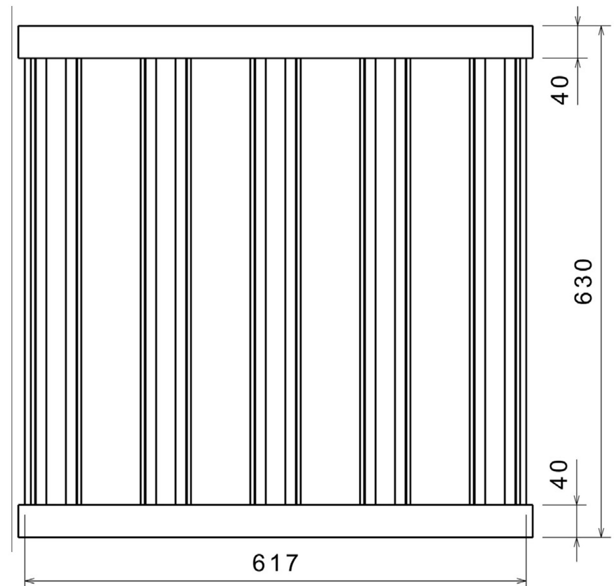
2. Configurations of stiffened composite panel

The dimensions of the stiffened composite panel are shown in Fig. 1. Each stiffened composite panel is composed of five I-shape stiffeners and a skin panel in the co-cured process. In order to ensure the uniform loading and prevent the premature failure at loading ends, the upper and the lower ends of the stiffened panel were reinforced by epoxy resin blocks with steel frames in four sides of each block. The nominal width (W) and the nominal length (L) of the panel are 617 mm and 630 mm, respectively. The interval (B) between two stiffeners is 135 mm. The height of the reinforced block is 40 mm. The thickness of the steel frames is 3 mm.

The material of the stiffener and skin is the woven carbon fiber reinforced epoxy composite CYCOM 977-2, of which the mechanical properties are listed in Table 1.

In order to study the influence of stiffener stiffness on the compression stability and post-buckling capacity of stiffened composite panels, six configurations of specimens were orthogonally designed from two configurations of skin and three configurations of I-stiffener. The cross section of one stiffener and skin is shown in Fig. 2. The stacking sequence of two skins are $[45/-45/0/90/-45/45]_s$ and $[45/0/-45/0/45/0/-45/0/45/90]_s$, respectively. The stacking sequence of the stiffener upper flange and the stiffener web is $[45/0/0/-45/90/-45/0/0/45]_s$. The stacking sequence of the stiffener bottom flange is $[45/0/0/-45/90/-45/0/0/45]$. The thickness of each layer is 0.185 mm.

The key dimensions of all the six configurations of stiffened composite panel, as shown in Fig. 2, are presented in Table 2. It can be seen that the skin thickness in the configurations #2, #3



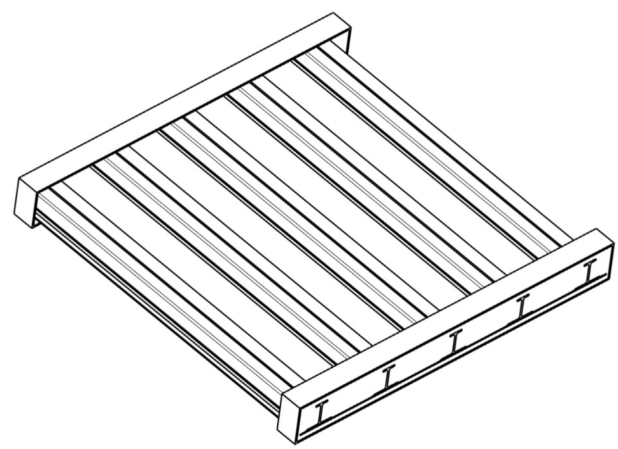


Fig. 1. Configuration of stiffened composite panel.

Table 1
Mechanical properties of CYCOM 977-2.

Property	Value
Compression modulus E_{11} (GPa)	140.5
Compression modulus E_{22} (GPa)	8.54
Shear in plane modulus G_{12} (GPa)	4.37
Poisson coefficient ν_{12}	0.32
Compression strength σ_{11} (MPa)	1602
Compression strength σ_{22} (MPa)	212.8
Shear in plane strength τ (MPa)	111.9