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An experimental and numerical analysis for stiffened composite panel subjected to shear loading in hygrothermal environment

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ABSTRACT

This paper presents a detailed experimental and numerical investigation on absorption and shear behaviors of stiffened composite panel subjected to hygrothermal environment. Due to the special and complex configurations of stiffened composite panel, water diffusion process should be divided to two absorption phases. Compared to conventional single equation by Fick's law, two absorption equations in this model could describe the absorption curve of experimental result perfectly. The combination of empirical formulae and finite element model is used to study buckling and postbuckling behavior for stiffened composite panel subjected to shear loading in hygrothermal environment. The buckling loads and failure loads of unaged specimens decreased approximately 10% and 25%. Good agreement between experimental data and numerical results is observed. According to experimental and numerical results, failure modes of the hygrothermal specimens include panel cracks and debonding of stiffeners.

1. Introduction

In recent years, fiber-reinforced composite laminated plate structures have been widely used in aerospace, marine and other engineering industries. The environmental action, such as high moisture concentration, high temperature, or corrosive fluid, can affect the performance of composite structures during service. Properties deterioration is attributed to the chemical and physical damages [1–3] caused in the polymer matrix, thus lowering the strength of structure and its stability. Therefore, it is important to study the effect of hygrothermal conditions on the mechanical degradation of composite structures.

Stiffened composite panel, as typical thin-walled structure, plays an important role in aircraft designing and is widely applied in aircraft structure. The postbuckling and failure behavior of stiffened composite panel have been widely discussed in the open literatures [4–10]. Many works have focused on the influence of hygrothermal on strength and stability of composite structures through experimental or numerical analysis [11–15]. Shen [11] investigated the influence of hygrothermal effects on the postbuckling of shear deformable laminated plates subjected to a uniaxial compression using micro-to-macro-mechanical analytical mode and Reddy's higher order shear deformation plate theory. The character of in-plane boundary conditions, transverse shear deformation, plate aspect ratio, total number of plies, fiber orientation, fiber volume fraction and initial geometric imperfections were studied. In Ref. [13], the hygrothermoelastic buckling behavior of laminated composite shells was numerically simulated using geometrically nonlinear finite element method. At higher moisture concentration or temperature rise, the buckling behavior and deflection shapes are characterized by multiple wrinkles along unreinforced direction. Marín [15] designed fast multi-objective optimization procedure for the geometric design of stiffened panels under mechanical and hygrothermal loads, by using neural networks and genetic algorithms. In general, these investigations concentrated on buckling and postbuckling analysis of composites under axial compression subjected to hygrothermal environment. The main approaches of these studies were numerical methods rather than experimental methods. So more attention should be paid to the effect of hygrothermal condition on buckling and postbuckling performance of composite structures by using experimental methods.

Functionally graded materials (FGMs) are a new kind of inhomogeneous composite materials, and many industrial engineers and researchers [16–19] have paid increased attention to these new composite materials. Some refined shear deformation theories [20–22] taking into account transverse shear deformation effects were established to study mechanical response of different functionally graded materials under hygro-thermo-mechanical conditions. Tounsi [20] developed a refined trigonometric shear deformation theory (RTSDT) to study thermoelastic bending of

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functionally graded sandwich plates. The numerical results indicated that the proposed theory was accurate and simple in solving the bending behavior of functionally graded materials, since the number of unknown functions involved was only four. Mohamed Zidi [22] investigated the influence of moisture, temperature and other parameters on the stress and displacement response of functionally graded plates by using a four variable refined plate theory. It can be concluded that these theories were accurate and simple to predict the bending and vibration responses of functionally graded plates in hygrothermal environment, compared to other shear deformation theories.

Although the study of composites through conventional theory or refined shear deformation theories in hygrothermal environment is almost sufficient, the effect of hygrothermal on composite panel subjected to shear loading is limited. Botelho [23,24] studied the influence of moisture in shear properties of different composites. The main experimental methods were interlaminar shear (ILSS) and Iosipescu tests. It was observed that hygrothermal conditioning reduced the Iosipescu shear strength of CF/E and Carall composites due to the moisture absorption in these materials. Pavlidou [25] measured the interlaminar shear strength throughout the sorption–desorption cycles. The experiment results showed that strong interface could lead to “matrix-dominated” absorption behavior, where in each successive sorption step the material absorbs higher amounts of water. Yan Zhao [26] designed 3 wet-dry cycles to measure water diffusivity for BMI resin reinforced with unidirectional carbon fiber CCF300/QY9511 composite. ILSS under different test temperatures was also studied with an Arrhenius method after wet-dry step. However, these studies focused on hygrothermal and shear experimental results of composite plates. It is difficult to study the application of composite structures under hygro-thermo-mechanical conditions through these data. Moreover, moisture absorption behavior of composite structures would be different from simple plates due to their special and complex configurations. So it is important and meaningful to explore absorption and shear behavior of composite structures in hygrothermal environment.

To study absorption and shear behavior of composite structures, absorbing moisture experiments and shear experiments on aero stiffened composite panel were conducted in this paper. Numerical analysis based on simplified material property degradation model and finite element model was also presented. Finally, failure modes of hygrothermal specimens were discussed according to experimental and numerical results.

2. Experimental methods

2.1. Specimens

Specimens are made of carbon fiber/epoxy resin prepreg with thickness 0.125 mm, manufactured by AVIC Beijing institute of aeronautical materials. The dimensions of the stiffened composite panel are shown in Fig. 1. Each stiffened composite panel is composed of four I-shape stiffeners and a skin panel in the co-cured process. The lay-up definitions of the stiffeners and panel are different, which are shown in Table 1. Material property parameters of specimens are listed in Table 2.

Two groups of experiments were presented in this paper. Group U is shear experiment of unaged specimens containing three specimens (labeled as U-1, U-2, and U-3). Group H is shear experiment of saturated specimens (aged specimen), whose hygrothermal parameters were 70 °C/85%RH, also containing three specimens (labeled as H-1, H-2, and H-3). All the specimens have the same configurations and material properties.

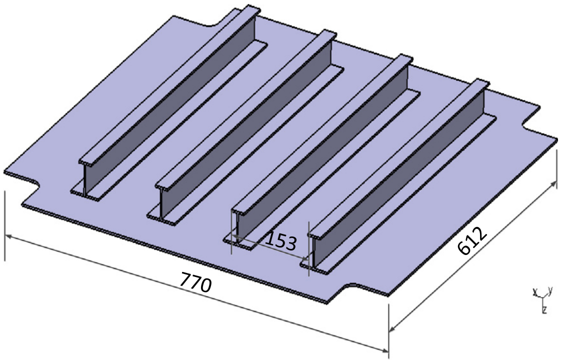

Fig. 1. Configuration of stiffened composite panel.

Table 1
Lay-up definition of stiffener and panel.

Region	Layup sequence
Skin	$[45/-45/0/-45/0/45_2/0/45/90/-45]_s$
Stiffener	$[-45/0_2/45/0_2/-45/0_2/45/90]_s$

Table 2
Material property parameters.

E_1/Mpa	E_2/Mpa	E_3/Mpa	ν_{12}	ν_{13}	ν_{23}	G_{12}/Mpa	G_{13}/Mpa
135,000	9720	9720	0.3115	0.3115	0.46	5260	2630
G_{23}/Mpa	X_t/Mpa	Y_t/Mpa	X_c/Mpa	Y_c/Mpa	S_{12}/Mpa	S_{13}/Mpa	S_{23}/Mpa
2630	1500	55.5	1100	202	92	121	121

Fig. 2. Conditioning chamber.