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The effects of delamination deficiencies on compressive mechanical properties of reinforced composite skin structures

Hanhua Li[a,c], Yongtao Yao[b], Liuyu Guo[d], Qiuhua Zhang[a], Bing Wang[b,*]

[a] Department of Astronautic Science and Mechanics, Harbin Institute of Technology, Harbin, 150001, PR China
[b] National Key Laboratory of Science and Technology for Advanced Composites in Special Environments, Harbin Institute of Technology, Harbin, 150080, China
[c] Beijing Institute of Astronautical Systems Engineering, Beijing, 100076, PR China
[d] Department of Engineering Mechanics, Harbin University of Science and Technology, Harbin, 150080, PR China

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ABSTRACT

In this study, the compressive properties and failure mode of reinforced composite skin structures having different delamination deficiencies were investigated systematically. Different kinds of delamination deficiencies were presented at specific locations in the specimens. The compressive mechanical properties of the materials were performed by axial compression testing, and strain distribution in different parts of the specimen and bearing capacity were monitored during the compressing processes. The ultimate compression bearing capacity, the failure mode and the expansion of internal damage were investigated as well. Results showed that the existence of delamination deficiencies have effects on the ultimate loading capacity of the specimens in different degree, in which the influence of delamination deficiencies in the skin is the most serious. Comparing with the specimen without deficiencies, the ultimate load-carrying capacity of the specimen with delamination deficiencies in the skin and in the stiffener under compressive load reduced by 38.58% and 22.34%, respectively. The failure modes of specimens with and without delamination deficiencies are similar. Compression failure is the main form of fracture for the stiffener, and the skin having different degree of buckling and delamination.

1. Introduction

As a new type of composites structure, the reinforced composite skin structures have excellent characteristic of composites structure, such as high specific strength, high specific stiffness, tailorable design, and so on. In addition, it also has many distinctive advantages, such as low automation manufacturing cost, high structural validity and high structural reliability etc. [1] Thus, the reinforced composite skin structures are widely used in aerospace industry as the bearing structure [2]. The reinforced composite skin structure has been successfully applied in the frame structure, the grid fairing, the grid interstage (Fig. 1) and other aircraft structures, and has become a hot topic in the international research. As an important load-bearing structure in aircraft, once the grid stiffened skin structure is damaged, it will cause catastrophic damage to the whole aircraft. In order to make better use of reinforced composite skin structures, scholars have carried out numerous studies on the macroscopical mechanical properties, and due to their achievements, the reinforced composite skin structures have gradually became a popular research direction of mechanics, especially related to the bearing capacity [3–22].

Like other structures, there will be delamination deficiencies inside the reinforced composite skin structure in the processes of forming, processing and transporting [23–25]. There is obvious difference in thickness between the rib and the skin. It caused one problem of matching and molding between the stiffener and the skin when the stiffener is formed near the skin. Due to the limitation of the process and the defects in selecting design parameters, it is necessary to cut a certain proportion of fibers of stiffener to avoid the condition that the combination of the stiffener and the skin is not complete. This kind of defect can not be seen from the surface of the formed products, but it greatly reduces the load-bearing capacity of structure when structure bears a large loads. Because a certain proportion of fibers does not bind to the skin, the sheared fibers can not carry load, which lead to creaking in advance of structure. Although several decades have elapsed since the recognition of the importance of delamination failure, it still remains a determining factor limiting the use of composite structure consisting of laminated composites elements [26–30]. To provide basis for future structural design, it is necessary to analyze the influence of delamination deficiencies on the load-carrying capacity and failure mode of the reinforced composite skin structures.

* Corresponding author.
E-mail address: wangbing86@hit.edu.cn (B. Wang).

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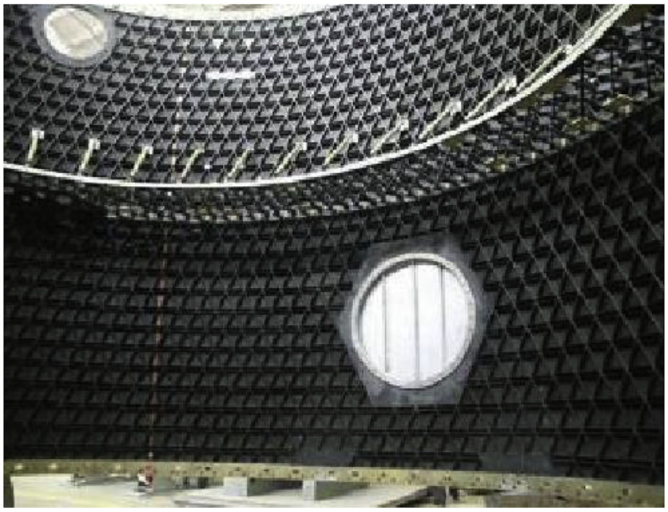

Fig. 1. The grid interstage.

The present work aims to systematically investigate the effection of delamination deficiencies on grid reinforced composite plates. A series of axial compression tests on the specimens with and without delamination deficiencies are carried out. The state of delamination deficiencies is monitored in real time. The strain acquisition scheme is set up by observing the typical delamination growing and failure. In the process of compression, the surface strain of the specimen is collected in real time and the characteristic of the delamination extension and failure mode corresponding to different delamination deficiencies are monitored and compared. It could provide the reference for the design, computation and manufacturing process of the composite grid stiffened structure.

2. Experimental details

2.1. Material preparation

MT300 carbon fiber and 603 epoxy resin prepregs were used to fabricate the composite grid stiffened structure specimens. The stacking sequence in the skin laminate is [± 45°/0°2/45°/0°2/90°/-45°/0°]s, and the single-ply prepregs thickness is 0.15 mm. For the stiffener laminate, the stacking sequence is unidirectional, which is along the X axis for the horizontal stiffener laminate and along Y axis for the vertical stiffener laminate, respectively. In addition, the delamination deficiencies in the specimen is fabricated with a Teflon film. The reinforced composite skin structure specimens without and with delamination deficiencies is shown as Fig. 2. There are three types of specimens in the compression test, and the number of each type of specimen is 3.

2.2. Axial compression test

According to ASTM D7137, the special fixture is designed, which is used to connect the specimen with the loading testing machine to ensure that instability failure of the compression specimen does not occur in the compression process. The diagram and the photos of the assembly between the specimen and the fixture are shown in Fig. 3(a) and Fig. 3(b), respectively.

In this study, all compression tests were carried out on MTS2500 universal testing machine with displacement control. At least three specimens were tested for each materials. The deformation was measured by DH-3820 static strain measurement system manufactured by Donghua test Inc, Jiangsu, China (Sampling frequency is 10HZ). The damage projection area is measured by ultrasonic C scan (Sonoscan D9500) nondestructive testing method before and after static test. Strain gauges are used to monitor each specimen during compression test. Strain information obtained by strain gauges is used to analyze the deformation of the specimen during the testing process. There are three kinds of strain gauge distributions. Among them, 1#/2#/3#/10# specimens follow A distribution, 4#/5#/6# specimens follow B distribution, and the 7#/8#/9# specimens follow C distribution. The sketch map of positions of strain gauges on stiffener and skin of the stiffened skin structure in the test is shown in Fig. 3(c).

3. Results and discussion

3.1. Analysis of bearing capacity and strain

Bearing capacity of specimen with three kinds of pre-existing defects (delamination in the skin, delamination in the interface between the skin and the stiffener, delamination in the stiffener) has been investigated during compressing process and results are shown in Fig. 4. Take specimen without delamination for example, the slope of load-displacement curve is relatively low in the initial stage of loading due to the presence of a certain gap between the fixture and specimen. When the loading amount reaches a certain value, the clamps are in contact with the specimen completely, meanwhile, the slope of the curve is on the increase, and the curve basically shows a linear elasticity. When the ultimate load is reached, the specimen is crushed and destroyed, eventually, the failure occurred.

The load-displacement curves of specimens with delamination in the skin under compression loads is shown in Fig. 4(a_1). For the 2# specimen with Φ20 mm delamination deficiencies and the 4# specimen with two Φ20 mm delamination in the skin, the slope of the curve is relatively low in the initial stage of loading due to the presence of a certain gap between the fixture and the specimen. When the clamp was in contact with the specimen completely, the slope of the curve is on the increase. The curve basically shows a linear elastic change when the loading amount reaches a certain value. The specimen is crushed and destroyed, and the failure of specimen occurred immediately when the ultimate load was reached. For the 3# specimen with Φ40 mm delamination in the skin, there is a reduction of the compression strength and a slight unloading situation before the ultimate load is reached, but the bearing capacity is restored soon afterwards. When the ultimate load was reached, the specimen is crushed and destroyed, and the failure of specimen occurred immediately. The ultimate load-carrying capacity of the specimens with delamination in the skin is 389.03 kN (Φ20 mm), 270.178 kN (Φ40 mm) and 368.277 kN (2 Φ20 mm), respectively. The existence of delamination in the skin reduced the bearing capacity of the specimen seriously. The larger the area of the delamination in the skin is, the more obvious the bearing capacity decreases, moreover, the more concentrated the delamination in the skin is, the more obvious the bearing capacity decreases.

For the specimens with delamination in the interface between the skin and the stiffener, the load-displacement curves under compression loads is shown in Fig. 4(b_1). The curves are basically consistent with the trend of the curve of the specimen without delamination, which indicates that the loading process of the specimen with delamination in the interface between the skin and the stiffener is basically the same as that of the specimen without delamination. The ultimate load-carrying capacity of the specimens with delamination in the interface between the skin and the stiffener is 387.382 kN (1/2 rib), 384.785 kN (1 rib) and 390.104 kN (2 rib), respectively. Compared with the specimen without delamination (439.878 kN), the bearing capacity of the specimens with delamination in the interface between the skin and the