MEASUREMENT OF ACOUSTOELASTIC COEFFICIENT ON CFRP COMPOSITES USING LCR WAVES

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Abstract

Carbon fiber reinforced ploymer (CFRP) composite materials has important application in various parts of the aircraft, including the main wing box, the central wing box, the fuselage skin, fuselage floor beam and back pressure box, etc. However, in the process of laying, molding, machining, assembling and servicing, there will be much defects and damage because of the accidental factors of manufacturing and preparation. These defects and damage, which includes pore, tearing, stratification, deformation and stress, will greatly affect the use and performance of composite material and even cause unexpected consequences of the catastrophe. So, the accurate detection of these defects and damage in CFRP is the foundation to ensure its quality.

Generally, carbon fiber reinforced polymer composites are laid under the environment of high temperature. In the course of cooling down to roon temperature, the difference of thermal expansion coefficient of fiber and polymer matrix will lead to unmatched volume shrinkage, which produce residual stress within the composite materials.

The residual stress is both beneficial and harmful for engineering application. The harmful residual stress will decrease the tensile strength, compression strength, shear strength, and other mechanical properties of composites. Therefore, the accurate measurement of residual stress is very important.

1. Introduction

Composites have many excellent mechanical properties such as high specific strength, high specific stiffness, and low density [1]. In recent years, with the composite development of manufacturing technology and material properties，Large plane began more and more application of carbon fiber reinforced composite materials as bearing construction，which ensure sufficient strength and reduce self-weight of the airframe. Even the use of composite material proportion has become the basis of evaluation of large aircraft advanced degree.

However, in the course from fabricating and processing to assembling and serving, composites will be in a certain stress state because of its inner defects such as delamination and crack, etc. How to detect

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the stress state of composites quickly and accurately is very important for evaluating the lifetime of materials.

Nowadays, the detecting method for stress mainly includes destructive and nondestructive methods, ultrasonic stress method using in this paper is a kind of nondestructive methods.

Crecraft [2] proved that the acoustoelastic law could be used for stress measurement of the engineering materials. He employed the transversal ultrasonic wave; however, it was subsequently proved that longitudinal critically refracted (LCR) waves are more acceptable for stress measurement.
Finally, this paper obtains the acoustoelastic coefficients in five directions along the fibers, and then analyzes the variation tendency, which lays the foundation for detecting the stress state in CFRP composites using ultrasonic stress method.

2. Experimental method

2.1. Theory of ultrasonic stress method

In order to detect the residual stress state in composites, the relation betwteen acoustic velocity and applied stress must be clear. In 1953, Hughes and Kelly [3] derived expressions for the speeds of elastic waves in a stressed solid using Murnaghan's theory of finite deformations and third-order terms in the strain-energy expression. The relation betwteen acoustic velocity and stress is given by:

$$\rho_0 {V_{10}}^2 = \lambda + 2\mu - \frac{\sigma}{3K_0}[6l + 4m + 7\lambda + 10\mu] \tag{1}$$

$$\rho_0 {V_{20}}^2 = \mu - \frac{\sigma}{3K_0}[3m - \frac{1}{3}n + 3\lambda + 6\mu] \tag{2}$$

$$\rho_0 {V_{1x}}^2 = \lambda + 2\mu - \frac{\sigma}{3K_0}[2l + \lambda + \frac{\lambda+\mu}{\mu}(4m + 4\lambda + 10\mu)] \tag{3}$$

$$\rho_0 {V_{2x}}^2 = \mu - \frac{\sigma}{3K_0}[m + \frac{\lambda n}{4\mu} + 4\lambda + 4\mu] \tag{4}$$

$$\rho_0 {V_{1y}}^2 = \lambda + 2\mu - \frac{\sigma}{3K_0}[2l - \frac{2\lambda}{\mu}(m + \lambda + 2\mu)] \tag{5}$$

$$\rho_0 {V_{2y}}^2 = \mu - \frac{\sigma}{3K_0}[m + \frac{\lambda n}{4\mu} + \lambda + 2\mu] \tag{6}$$

$$\rho_0 {V_{2z}}^2 = \mu - \frac{\sigma}{3K_0}[m - \frac{\lambda+\mu}{2\mu} - 2\lambda] \tag{7}$$

These seven equations shown above have covered down all the types in actual. Egle and Bray [4] showed that the LCR wave is the most sensitive ultrasonic wave to the mechanical strain and internal stress. The equation (1) manifests the relation between longitudinal wave and applied stress. After some simplification, the form equation (1) in application is:

$$\Delta T = K_\theta \Delta\sigma \tag{8}$$

Where ΔT is the the variation of the time-of-flight, K_θ means the acoustoelastic coefficient along diffrenct direction, $\Delta\sigma$ is the variation of the applied stress. Obviously, the acoustoelastic coefficient along diffrenct direction is the key to measure the stress along the corresponding direction.

The acoustoelasticsticity theory indicates that the propagation velocity of ultrasonic in solid presents a

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linear relationship with the stress, the relationship is expressed using acoustoelastic coefficient. Nevertheless, considering the disparity of propagation velocity in different direction along the fiber, the acoustoelastic coefficient corresponding to different direction need to calibrate respectively.

2.2. Experimental procedures

For the actual uniaxial tensile test, the longitudinal wave was selected as the incident wave and along the stress direction, whose both the direction of acoustic velocity and applied stress are parallel to the direction of particle polarization. The longitudinal wave's frequency is set as 5 MHz, and the acoustic probe's diameter is chosen as 5 mm. The other properties of the acoustic probe are shown in Table 1 in detail.

Table 1. List of acoustic probe's properties.

Measurement Angle (°)	*Material of Wedges*	*Wedges Velocity* (*m/s*)	*Critically Angle* (°)
0	*Organic Glass; Incident Angle 32°; Propagation Distance 30mm.*	2692	19.9
15			23.5
30			29.6
45	*Teflon; Incident Angle 34°; Propagation Distance 16mm.*	1442	19.7
60			26.5
75			31.0
90			32.6

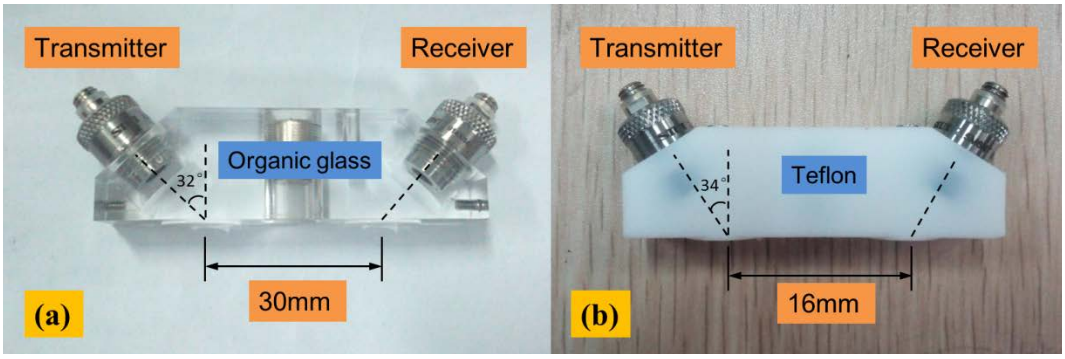

Figure 1. Organic glass (a) and teflon wedge (b).

We firstly used critically refracted longitudinal wave (Lcr) measured the propagation velocity in different direction along the fiber, the direction include 0°, 15°, 30°, 45°, 60°, 75° and 90°, the results are shown in Table 2. Secondly, we calculated the critically angle of every direction according to the Snell law. Furth more, we designed two acoustic wedges by different materials and incident angles, as shown in Figure 1, they are: (1) Organic glass wedge with incident angle 32° and propagation distance 30mm, used for 0° and 30° samples; (2) Teflon wedge with incident angle 34° and propagation distance 16mm, used for 45°、60° and 90° samples.

Fixed the selected wedge and sample, and connected the ultrasonic transducers, the stress increment was provided by the WDW-200E mechanical testing machine, the measurement system used this test is shown in Figure 2. Besides, the propagation distance of wedge is constant, so only record the increment of propagation time by applying the measurement system, can we calculate the acoustoelastic coefficient.

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Figure 2. The measurement system of acoustoelastic coefficient.

3. Results and Conclusions

The results of acoustoelastic coefficient along different direction are listed in Table 2. We can see clearly that the acoustoelastic coefficient is relative to the fiber direction because of the orthotropy of materials.

Table 2. Results of acoustoelastic coefficient along different direction.

Measurement Angle (°)	*Material of Wedges*	*Acoustic Velocity* (*m/s*)	*Acoustoelastic Coefficient* (us/MPa)
0	*Organic Glass; Incident Angle 32º; Propagation Distance 30mm.*	7895	-3.250
15		6757	-2.824
30		5454	-2.754
45	*Teflon; Incident Angle 34º; Propagation Distance 16mm.*	4213	1.209
60		3178	0.650
75		2757	0.468
90		2640	0.386

Now, we have known the ralations between variation of the time-of-flight and applied stress along different direction, which is very meaningful for accurate measurement of residual stress in orthotropic material, such as CFRP composites.

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