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Non-contact air-coupled ultrasonic evaluation of materials

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1 Foreword

Recently, composite manufacturing technology has been developed rapidly for the need of aerospace technology. During the manufacturing process or in use, the composite material tends to produce defects, such as voids and corrosion. These defects are different from volume-type or crack defects and they are difficult to be detected by using traditional ultrasonic technology due to the limitation of working principle. The viscoelastic is an important indicator reflecting the mechanical properties of such materials.

Ultrasonic attenuation coefficient evaluation method is a possible way to solve problems mentioned above[1]. Air-coupled ultrasonic testing method has become a very hot topic due to advantages of non-contact, non-destructive and harmless to the samples. As is well known that traditional ultrasonic testing requires water or special liquids as the acoustic coupling medium between the probe and samples to reduce propagating attenuation in air which might make contamination, or seriously affect the mechanical strength and dimensional elements of stable due to penetration of the lesion.

Therefore, researchers are keen to air-coupled ultrasonic testing methods and have achieved fruitful research results in different applications[2-3]. The authors propose a method for evaluating the material by air-coupled ultrasound in this paper.

2 Evaluation methods

The attenuation coefficient of ultrasonic waves in the air α_{air} can be calculated by equation 1. Here, U_{A1} and U_{A2} are received signals when the distances between two probes are h_1 and h_2. $A_1(f)$ and $A_2(f)$ are the amplitude frequency spectrum obtained by FFT of U_{A1} and U_{A2}.

$$\alpha_{air}(f)=\frac{1}{h_2-h_1}\ln(\frac{A_1(f)}{A_2(f)}) \tag{1}$$

Then we can calculate the acoustic reflectivity of sample and air interface by equation 2. When only air between the probe and the distance between the two probes is H, the incident wave received at this time is referred to as the U_{A3}.Then use the spontaneous self-closing the probe and the distance between the probe and the surface of the material is h, At this point the probe received reflected waves recorded as U_{A4}. U_{A3} and U_{A4} of the waveform to a fast Fourier transform to obtain the amplitude frequency spectrum are denoted as A_3 and A_4.

$$R(f)=\frac{A_4(f)*\exp(a_{air}*h_{air})}{A_3(f)} \tag{2}$$

Here, α_{air} is the attenuation coefficient of the air, R is the acoustic reflectivity, and h_{air} is distance of ultrasonic wave propagation in air.

The principle of evaluation of the viscoelastic of the material as shown in Fig.1. When the material is not placed between the two probes, the probe received incident called U_{A}. When the material is placed in between the two probes, probe received incident called U_{B}. U_{A} and U_{B} of the waveform to a fast Fourier transform to obtain the amplitude frequency spectrum are denoted as A and B. Well, you can obtain the attenuation coefficient of the material by the following formula.

$$a(f)=a_1+\frac{1}{h}\ln(\frac{A(f)}{B(f)}(1-R^2)) \tag{3}$$

Here, h is the thickness of the material, a is the attenuation coefficient of the material. The phase velocity can be obtained by using the real number part and the imaginary part of the complex frequency spectrum of the echo.

$$V_p(f)=\frac{2h\omega}{\tan^{-1}\frac{Im[B(f)]}{\mathrm{Re}[B(f)]}-\tan^{-1}\frac{Im[A(f)]}{\mathrm{Re}[A(f)]}+2N\pi+\omega T} \tag{4}$$

Here, f is the frequency, ω is the angular frequency ($\omega=2\pi f$). Make $U_{\mathrm{A,}}$ U_{B} do FFT. First, we should use window function to define a range. Then, the beginning of A is t_1, the beginning of U_{B} is t_2, finally the difference of t_1 and t_2 is T.

According to theory of the complex elasticity, longitudinal ultrasonic storage modulus E', loss modulus E "and loss tangent tanδ can be calculated by the following formula.

$$E'=\rho V_p^2, E''=\frac{2\alpha\rho V_p^3}{\omega}=\frac{2\alpha V_p}{\omega}E' \qquad \tan\delta=\frac{E''}{E'}=\frac{2\alpha V_p}{\omega} \tag{5}$$

Using the above formula, the viscoelastic of

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the material can be evaluated.

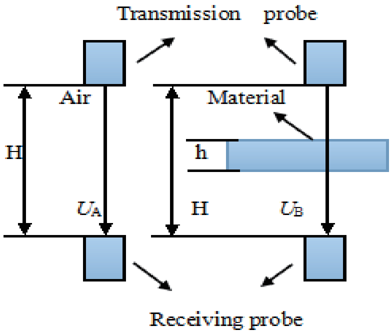

Fig. 1 Evaluation viscoelastic of the material

3 Test Methods and Results

3.1 Experimental Conditions

The experimental device is: ultrasonic transmitter receiver JPR-600C, a pre-amplifier PA-60A with bandpass function and air probe 0.8K20×14N (made by Japan Probe Co., Ltd.)

Test Material: The carbon fiber material with uneven voids

3.2 The experimental results

The detected material is a carbon fiber reinforced composite materials with artificial defects (voids), whose photograph shown in Fig.2. To clarify the presence and distribution of the voids in the sample. First, we do c-scan of material by NAUT21. Detection method is the transmission on the opposite side of the material that means the two probes were placed on both sides of the specimen. The frequency of air probe is 0.4MHz, point focus probe, scan pith is 0.5mm, and scan speed is 300mm/s. The scan result is shown in Fig.3, the red region represents for the ultrasonic of the high energy, blue region represents for ultrasonic can hardly transmit through, namely the existence of pores site. The pore distribution in the sample is shows in Fig.3.

Fig.2 Carbon fiber material

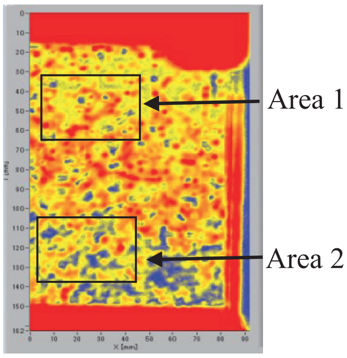

Fig.3 The results of c-scan

After that, we selected two regions of different porosity. The area 1 is low porosity area and the area 2 is high porosity area (as shown in Fig.3), and using the methods described in Chapter 2 to evaluate the area 1 and area 2, and the results are as shown Fig. 4 and5.

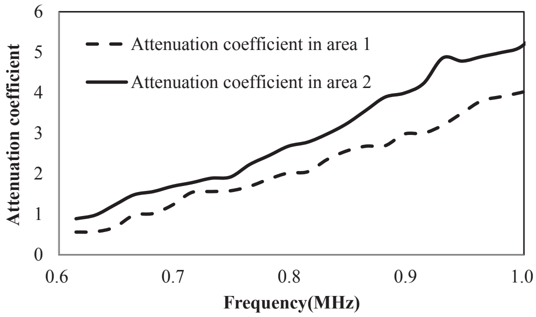

Fig. 4 The ultrasonic attenuation coefficient in sample

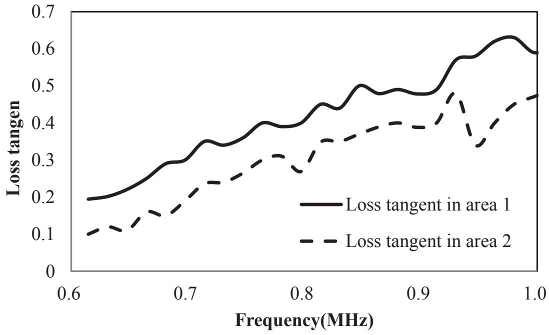

Fig. 5 The loss tangent tanδ of the carbon fiber

The result of ultrasonic wave propagation attenuation coefficient in the carbon fiber material as shown in Fig.4. And the result of loss tangent tanδ of the carbon fiber material as shown in Fig5. From the above results, the different porosity of the material will have some impacts for attenuation coefficient of the material. The attenuation coefficient of ultrasonic wave propagation in large porosity area is smaller than the attenuation coefficient of small porosity area. The tangent of the loss angle of low porosity area is smaller than the tangent of the loss angle of high porosity region.

4 Conclusions

We successfully tested ultrasonic attenuation coefficient and viscoelasticity of carbon fiber composites by use non-contact air-coupled ultrasonic testing method. The given conclusion that is the porosity existence of a carbon fiber composite material will have impact for ultrasonic attenuation coefficient and viscoelasticity of material, and prove the consistency of the distribution of porosity and test results of c-scan by compare with the results of c-scan. It provides a new evaluation method for some materials that cannot be evaluated by the contact method.

References

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3. M. Takahashi: USE2011, Vol. 32 (2011) 69.