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Simulation of electrothermal-based ultrasonic testing for CFRP defects

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1. Introduction

Carbon fiber reinforced polymer (CFRP) is a composite material with resin as matrix and carbon fiber as reinforcement. Since CFRP has the excellent performance of light weight, low density, high intensity, high elastic modulus, high temperature resistance, and electrical conductivity, it is widely applied in industry, transportation, aerospace, shipping, sports equipment and other fields. Due to the existence of defects, such as porosities, they will reduce the performance of CFRP. Therefore, the defect detection of CFRP is indispensable for applications. There are a plenty of nondestructive testing methods for the defect detection of CFRP. Radiographic testing is a method that detects the difference in the intensity of the radiation passing through the CFRP by the high energy of the radiation. This method has advantages that the internal structure information of the part can be given and imaged in real time, and with disadvantages that the equipment is very large, the detection is more difficult, and the radiation has radioactive contamination.[1] Ultrasonic testing is a common way that detects defects according to the sound wave by characteristics such as attenuation of ultrasonics in the CFRP.[2] The advantages of ultrasonic testing are that this method has high sensitivity and strong penetrating power. And it also has disadvantages that it is only effective for large-sized defects in the inspected pattern, its sensitivity is limited by the length of the ultrasonic wave, and it is not effective for the complex workpiece defects.[3] Infrared thermography is another method that identifys material defects with the help of abnormal temperature distribution by using infrared thermal imaging camera to detect the temperature change of the material surface, which is according to characteristics of the material that will be changed by the discontinuity in the material. Its advantages are that detection area is large, speed is fast, and results are intuitive. At the same time, it also has disadvantages with difficulty of detection for deeper defects.[4]

Due to the anisotropy of CFRP,[5] the CFRP can be directly used as a heating source. When a certain voltage is passed through CFRP, it will generate heat by self-resistance electric heating. Temperature distributes inside CFRP evenly, and heating rate is fast. Consequently, an approach is proposed for CFRP defects based on electrothermal ultrasonic testing in this study. The sound pressure level (SPL) of defects is amplified by controlling the voltage and temperature, which makes the small defects easily detected and observed.

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2. Method of CFRP defects

2.1 Schematic diagram of detection

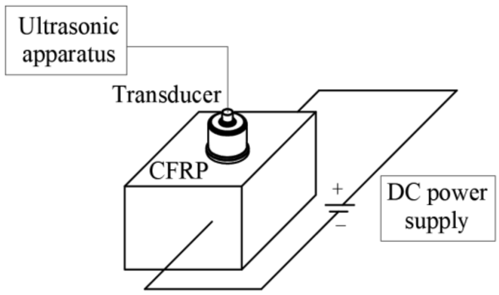


Fig. 1 Diagram of the proposed approach.

As shown in Fig. 1, the two ends of CFRP is connected to the DC power. The temperature of CFRP surface is monitored by an infrared camera. The transducer is used to transmit and receive the ultrasonic waves, and the received signal is processed and identified by the ultrasonic apparatus.

2.2 Parameters of CFRP

In order to simplify the problem, the porosity of the defects is only analyzed, and this defect is replaced by holes in this study. The cross sectional area (CSA) of CFRP is a cuboid as shown in Fig. 2. The length, width, and height of the specimen are 15 mm, 10 mm, and 6 mm, respectively.

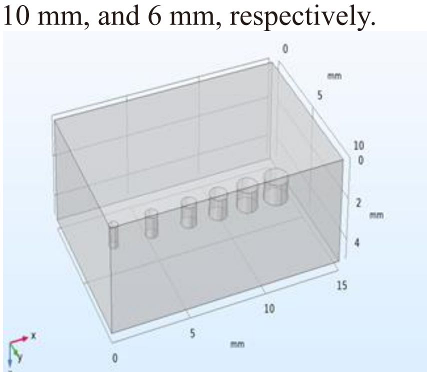


Fig. 2 Cross section shape model of CFRP.

The radius of the porosity are 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.7 mm, and 0.8 mm, respectively. The frequency of ultrasonic is 5 MHz.

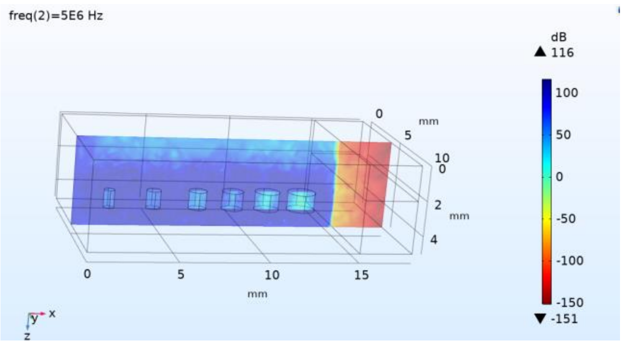
The loading voltages are 220 V, 350 V, and 450 V, respectively. The temperature will rise when different voltages are loaded to CFRP for a while. The other relevant parameters of CFRP used in the simulation are shown in Table I.

Table I CFRP parameters.

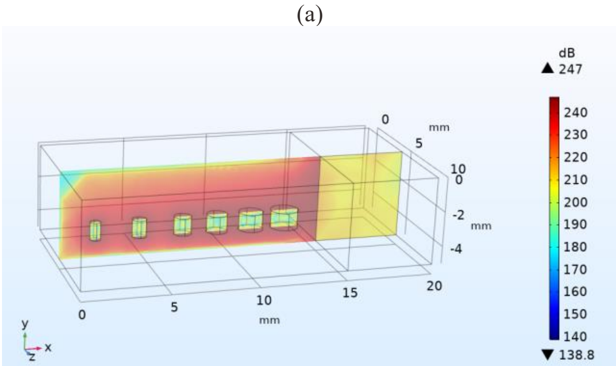
conductivity (s/m)	relative permittivity (1)	thermal conductivity (w/m/k)
5.35	3.5	102
density (kg/m^3)	heat capacity at constant pressure (J/kg/k)	dynamic viscosity (Pa·s)
1620	621	0.17
bulk viscosity (Pa·s)	specific heat ratio (1)	velocity of sound (m/s)
0.12	76	1150

3. Simulation and results

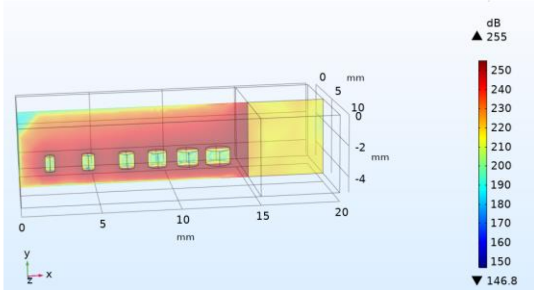
In the condition of loading different voltages with the same frequency of 5 MHz, the simulation is carried out. It can be seen from the figure that the SPL changes from -151 dB to 116 dB in Fig. 3 (a), and SPL of defects is from 27.4 dB to 89.9 dB. In Figs. 3 (b)-(d), the range of SPL is from 138.8 dB to 259.4 dB, and SPL of defects is from 164.4 dB to 216.9 dB. The SPL of defects with load voltage is higher than that of no voltage. Increasing the voltage can increase SPL. There are significant differences of SPL in the areas with defects and without defects when loading different voltages. Thus, it is convenient to find out whether the CFRP has defects, and it can be seen clearly if there are defects.



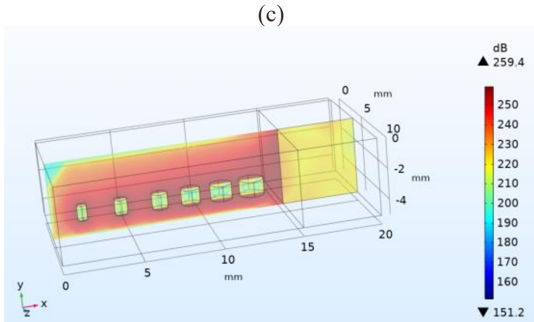
(a)



(b)



(c)



(d)

Fig. 3 SPL with load voltages (a) without voltage, (b) 220 V, (c) 350 V, and (d) 450 V.

By comparison with the conditions of voltage and without voltage, the SPL increases significantly due to the Joule heating effect. According to the Joule heating formula, and the relationship between heat energy and sound pressure is given as,

$$Q= \frac{4\alpha_1}{\rho c}(p_1)^2 \quad (1)$$

where Q is heat energy, α repsents sound absorption coefficient, ρ denots density, c is velocity of sound, and p_1 is sound pressure.

4. Conclusion

Ultrasonic testing and electrothermal effects are combined to detect porosity in CRRP. We have proposed the approach which makes the small defects easily detected and observed. Simulate of the detection was done, and the results showed that the higher the voltage, the higher the SPL, the more obvious the change of defects. Next, experiments of CRRP defect detection will be implemented to verify the proposed method.

References

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