Finite Element Simulation Thermal Analysis of Pulsed Infrared Nondestructive Testing

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Abstract

The main research content of this paper is the heat transfer simulation and analysis of pulsed infrared non-destructive testing. Infrared thermal wave imaging detection technology is a non-destructive testing technology that has become popular in recent years. This technology has the advantages of fast detection speed, large single-detection area, no direct contact with test specimens, and intuitive display of test results in the form of images. It is superior to other conventional nondestructive testing techniques. Therefore, it has been widely used and popularized in the fields of aerospace and aviation, national defense science and technology, military industry, military, and other fields. It has been slowly applied to emerging technologies such as rail transit and new energy. In this paper, the ABS plate is used as the experimental research specimen, and the pulse is used to act on the specimen in the way of thermal excitation. The heat transfer law of infrared excitation non-destructive testing thermal excitation in the specimen is observed and analyzed. In order to better study the analysis of the heat transfer law of pulsed infrared non-destructive testing, thermodynamic analysis of the test piece is performed with powerful ANSYS finite element simulation analysis software to generate the corresponding temperature distribution cloud diagram after the pulse is applied and the temperature and time of the defect. According to the obtained temperature cloud map and temperature-time curve, we can clearly find that the temperature cloud diagram at the defect is clearly different from the temperature cloud map of the normal region, providing us with a certain theoretical basis for finding defects in the specimen. Based on the ANSYS finite element thermodynamic simulation analysis process, we also carried out corresponding experimental research and analysis, the use of flash excitation heat wave non-destructive testing ABS test piece plate, you can clearly find the ABS plate defect temperature is obviously different from the normal area The simulation analysis results are consistent with the analysis results of the experiment. It can be concluded that the pulsed heat wave non-destructive testing can detect and identify the defects of the test pieces well through the heat transfer analysis, and provide the aircraft maintenance inspection and active service testing in the future. The important analysis basis has certain practical application value.

Keywords

Pulsed infrared non-destructive testing, heat transfer analysis, ABS plate, ANSYS finite element simulation analysis .

1. Introduction

Infrared non-destructive testing [1,2,3,4,5] can determine the location and shape of an object's defects, mainly based on the temperature field of the detected object, which is also known as thermal wave imaging detection technology. This technology has the very obvious advantages of no contact with workpieces, large detection area, fast detection rate, and intuitive visualization of results. Compared with other conventional non-destructive testing technologies, it is very suitable for in-situ and in-service testing and is now in aviation. Aerospace and other fields have been widely used and gradually applied to rail transit and other fields. By studying the application of pulsed thermal excitation in infrared non-destructive testing, the transfer law of thermal excitation in the sample is grasped. Infrared heat wave nondestructive testing technology can be divided into active detection and passive detection according to different detection methods. At present, one of the most frequently used detection methods in infrared non-destructive testing technology is active infrared detection. In infrared non-destructive testing, commonly used thermal excitation sources include flash, laser, ultrasonic, electromagnetic, and the like. Because the active infrared detection is a thermal stimulus applied to the material, so that the temperature of the material defect and defect-free place has a certain difference, by virtue of such a method to complete the detection of defect location and size, so this paper uses the initiative Infrared non-destructive testing technology, using powerful ANSYS [6,7,8] finite element simulation analysis software to do thermodynamic analysis of the test piece, generate the corresponding temperature distribution after the pulse is applied to the cloud map and defect temperature and time curve[9,10].

2. Infrared Non-destructive Testing Technology Overview

2.1 Infrared Heat Wave Theory

2.1.1 Sub-Section Headings

The principle of the infrared detector is to convert infrared radiant energy obtained by the measurement into other forms, such as thermal energy or electricity, which is convenient for observation and measurement, and is distinguished according to different ways of energy conversion. This article is based on heat detector analysis.

The electrical characteristics of the detector will change according to the thermal effects of the incident radiation. This is the working mechanism of the thermal detector. This response of the thermal detector[11] is proportional to the absorbed energy. The heat exchange process of the heat detector includes the following types: thermal pneumatic, pyroelectric, thermal volt, and thermal resistance.

The equivalent noise power[12,13] defined here is the incident radiant power on the detector obtained when the detector noise and the output signal of the detector are equal and its unit is watts. Because the measurement of power under certain conditions is not easy, such as when the signal-to-noise ratio is 1, we use the method and theory of measurement at high signal levels, and then perform theoretical calculations based on the following formula:

$$NEP = \frac{HA_d}{V_s / V_n} = \frac{P}{V_s / V_n} \tag{1}$$

For the measurement and calculation of the defined equivalent noise power, the emission of radiation is generated by a black body radiation source, modulated by a certain function of the corresponding reticle, and then irradiated to the photo-sensitive surface of the detector. Radiation intensity values are sinusoidal and the frequency is fixed because the detector response is related to the corresponding modulation frequency. For the output signal of the detector, we record the effective value of the fundamental wave. Here, we use the root mean square voltage meter to measure it. Before the measurement, we need to filter out higher harmonics.

Many theories show that when the square root of the area of the detector is proportional to the output signal-to-noise ratio of the detector, the square root of the area of the detector is inversely proportional to the detection rate of the detector. The frequency content of the detector's output noise is very diverse, so the noise voltage is replaced by a function of the bandwidth of the measurement circuit. Because the total noise power spectrum of the detector is mainly concentrated in the middle frequency band, the measured noise voltage is only proportional to the square root of the measurement bandwidth of the circuit, that is, the detection rate of the detector is inversely proportional to the square root of the bandwidth of the measurement circuit.

2.2 Infrared Heat Wave Non-Destructive Testing System.

The infrared heat wave non-destructive testing system[14] is a high-tech system that combines the advantages of image processing technology, computer technology, and optoelectronic imaging technology together. Infrared heat wave non-destructive testing has different technological innovations in thermal excitation and image processing. Compared with ordinary infrared imaging, having one-way non-contact, large observation area, a wide range of applications, and more measurement results will have very obvious advantages. Infrared heat wave non-destructive testing technology also helps in the extraction of studies such as thermosonics, pulse heating, and phase-locked detection. Deepen the theory and understanding of heat conduction in the application process. In the actual experimental testing process, we chose to implement the detection method by the difference between the material properties and defect types[15,16,17].

The experimental research equipment of this article is the Pulse excitation type desktop flash unit ThermPulse S12. The main parts of this infrared detection device include: flash excitation device, data processing analysis module, and various corresponding external devices of infrared pulse thermal imager.

3. ANSYS Finite Element Thermal Analysis

3.1 First Law of Thermodynamics

In a closed system (where there is no mass inflow or outflow of mass), finite element thermal analysis follows the law of conservation of energy (known as the first law of thermodynamics):

$$Q - W = \Delta U + \Delta KE + \Delta PE \tag{2}$$

In formula (2), Q is heat, W is the work done, is the amount of potential energy change in the system,is the amount of kinetic energy change in the system, is internal energy variation in the system.

3.2 The Definition of Transient Heat Transfer Analysis

In practical engineering applications, the calculation and analysis of temperature field mostly use transient thermal analysis. Transient thermal analysis reflects the process of changes in the energy and other parameters of a system over time. As far as the temperature field is concerned, Generally, the relevant thermodynamic analysis is performed by setting the initial conditions of the corresponding thermal load[18,19].

From the basic steps of transient analysis, it is similar to the steady-state thermal analysis[20]. The main difference between the two is whether the applied load changes with time or not. The load of transient thermal analysis is accompanied by The change in time results in a corresponding change, and the load in the steady state thermal analysis is not affected by the time change. In order to better and more vividly express the changes of the load over time, here we express by the load step, the horizontal axis represents the time, the vertical axis represents the load, the load step is each demarcation point of the curve in the graph or The inflection point is shown in Fig. 1 (a) and (b).

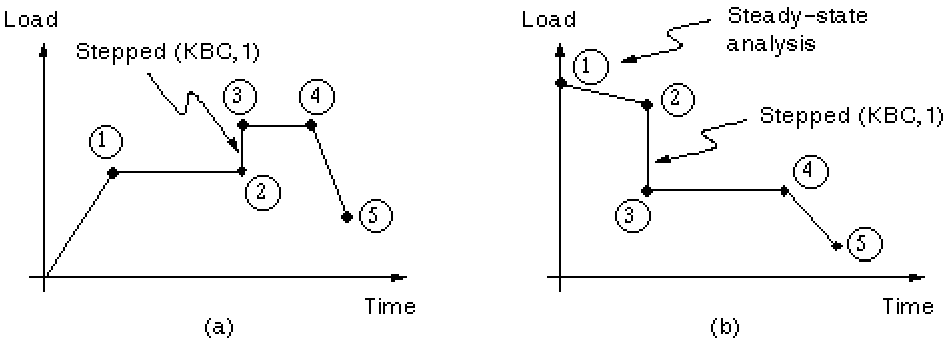


Fig. 1 The layered and hierarchical fault-tolerance control scheme

4. Pulsed Infrared Non-Destructive Testing Numerical Simulation

4.1 Material Description

The material used for the model is ABS. In the transient thermal analysis, the material properties of ABS are shown in the following Table1.

Table 1 Material Properties

Material name	Density (kg/m3)	Specific heat capacity (W/(kg*K))	Thermal Conductivity (W/(m*K))
ABS	1040	1.47	0.3

4.2 Model Introduction

The first step of the finite element simulation is to define the element properties, real constants, material properties, etc. of the analysis model. Then the physical geometry model is created, the mesh is divided, the temperature load time, the solution parameters are set, and the finite analysis is performed. The model used in the paper is externally imported into ANSYS finite element software. The 3D geometry model is created by Soliderworks. The geometry model is shown in the following Fig.2 and Fig.3.

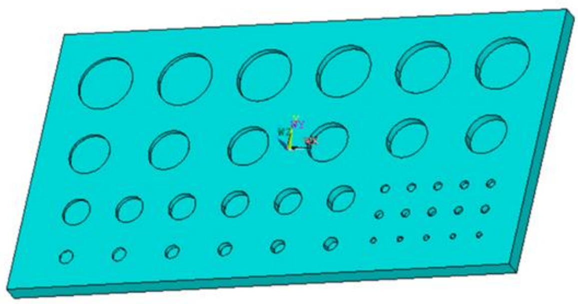


Fig. 2 Structural geometry model

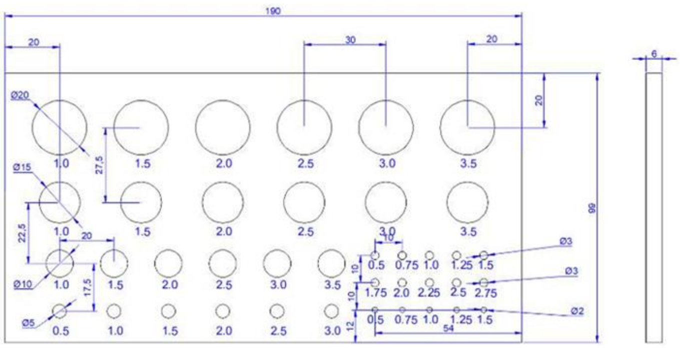
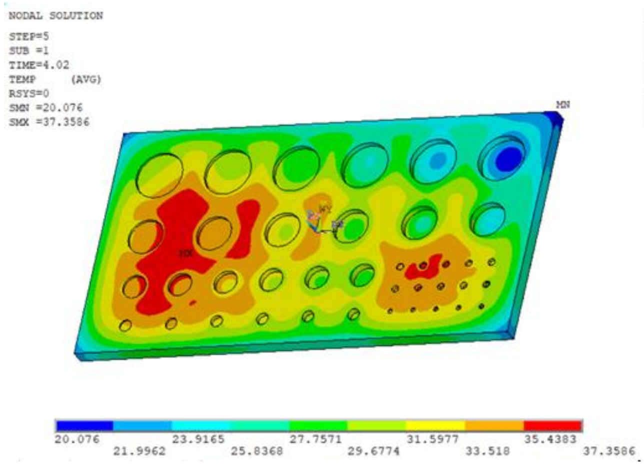


Fig. 3 Geometric model defect size

4.3 Model Introduction

The Fig. 4 shows the temperature distribution of the model after the second step of cooling down for 4s. It can be seen that after 4s cooling, the maximum temperature is 37.3586 ℃, the minimum temperature is 20.076 ℃, and the temperature difference decreases from 88.2511℃ at 3s to 17. At 2826℃, the temperature difference is further reduced. On the defect side, the maximum temperature is still distributed on the left and bottom right corners of the specimen, which may be the reason for the ABS material properties. Below 70℃, the material convection coefficient tends to be stable.

Fig. 5 shows the temperature distribution of the model after the second step of loading cooling for 5s. It can be seen that after 5s cooling, the maximum temperature is 19.0268℃, the minimum temperature is 15.7334℃, and the temperature difference decreases from 17.8262℃at 4s to At 3.2934℃, the temperature difference is further reduced. On the side of the defect, the maximum temperature is still distributed on the left and right bottom corners of the test piece. This is similar to the temperature distribution at the time of cooling down at 4 seconds. The distribution area is smaller and may be caused by the convection coefficient of the material properties.



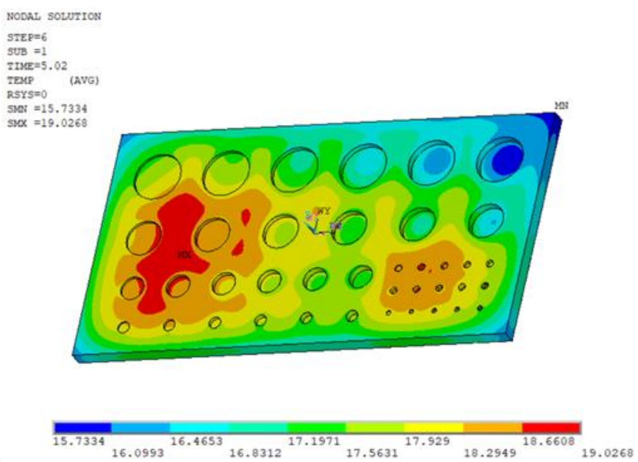


Fig. 4 Temperature distribution cloud after cooling for 4 seconds Fig. 5 Temperature distribution cloud after cooling for 5 seconds

5. Conclusion

The main research content of this paper is the heat transfer simulation and analysis of pulsed infrared non-destructive testing. Using ABS plate as the experimental research sample, the pulsed thermal excitation infrared non-destructive testing equipment is used to study and analyze the heat transfer of the sample during heating. The law, the use of ANSYS finite element simulation analysis software to do thermodynamic analysis of the test pieces, generate the corresponding temperature distribution after the pulse is applied to the cloud map and defect temperature and time curve, combined with ANSYS finite element thermodynamic simulation analysis and experimental analysis, The heat transfer law can be drawn: the temperature map at the defect is clearly different from the temperature map of the normal area. The pulsed heat wave non-destructive testing can be used to detect and identify defects of the test piece through heat transfer analysis. It provides us with a certain theoretical basis for finding flaws in the test piece, and provides the aircraft maintenance inspection and active service testing in the future. Important analysis basis.

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