

THERMOGRAPHIC WAVELET ANALYSIS OF CARBON FIBER COMPOSITES

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Infrared analyzers are now widely used for non-destructive testing of a large number of components made of composite materials in various industries [1]. Infrared thermography has emerged as a viable alternative to other more traditional non-destructive evaluation methods for testing a wide range of materials and structures. As a non-contact method, its ability to test large areas in short periods of time justifies a large amount of work and technical research. Interest in this technique has also been supported by the development of increasingly powerful equipment and data analysis tools in recent years.

The thermographic method typically involves applying heat to the part and using very sensitive infrared cameras to observe temperature transients on the surface of the sample [2, 3]. Anomalies in the part, such as voids, cavities or density changes, will change the temperature distribution and will be interpreted by the infrared camera as brighter or darker areas on the surface of the sample.

The traditional thermographic approach uses a pulsed heat source, and the spatial temperature response at different times after heating is used to detect defects. A key factor in all thermographic inspections is the diffusion mechanism that controls the transfer of heat through the part, and in this respect infrared thermography differs from conventional methods such as ultrasound, which are controlled by the wave propagation mechanism. This diffusion-controlled process presents interpretation challenges, since the solution of the transient thermal problem is very complex even for the simplest geometric and material cases.

Three main types of (optical) active thermography methods are commonly used: lock-in thermography, pulsed thermography and pulsed phase thermography. Continuous injection of low-frequency sinusoidal thermal waves into the sample is typical for lock-in thermography [4]. Monitoring the incident and reflected thermal waves over a period of time allows detection of subsurface voids. This technique relies on the results of amplitude attenuation and phase shift.

Discrete Fourier transform is used to extract frequency information from pulsed phase thermography data. For a given sampling rate ($f_s = 1/\Delta t$), the total number of images N dictates the minimum available frequency ($f_{\min} = f_s/N$). The maximum available frequency is given by half the sampling rate ($f_{\max} = f_s/2$), since $n_{\max} = N/2$, i.e.

the Nyquist frequency f_c . In order for low-frequency components to penetrate deeper below the surface, it is necessary to use a large Δt or a large N .

The wavelet transform (with complex wavelets providing amplitude and phase information) can be used with pulsed phase thermography data in a similar way to the Fourier transform, but with the advantage of preserving the temporal information of the signal, which can then be related to the depth of the defect, thus allowing quantitative assessment. The infrared thermography model proposed in this paper assumed the use of the Morlet wavelet, namely a complex sinusoid in a Gaussian envelope, where the central frequency f_c determines the number of significant oscillations of the complex sinusoid in a Gaussian window. The sinusoidal characteristic and excellent linear phase property make the complex Morlet wavelet an ideal candidate for the analysis of pulsed phase thermography.

Thermal simulation data were used to analyze the theoretical properties of thermal contrast signals. Circular defects ($d = 16$ mm) in carbon fiber reinforced plastic at different defect depths were simulated (with relative anisotropic thermal conductivity and density $k_x = 1.28$, $k_z = 0.64$, $C = 1200$, $\rho = 1600$, axially symmetric simulation). The simulation result was formed as a matrix of the time evolution of the temperature surface line profile ($L = 100$ mm) after pulse excitation. The line profile was "placed" above the defect. The simulation was limited to $N = 1024$ samples with a sampling frequency f_s of 25 Hz, which implies a minimum frequency of 0.024 Hz. The analysis of the amplitude spectra of the thermal contrast signals at different defect depths (from 1 mm to 5.5 mm with a step of 0.5 mm) indicates that most of the signal energy is concentrated in the frequency components below about 0.1 Hz.

The results of the phase correlation for the translation parameter Δ depending on the depth d of the defects in composite samples with a relative characteristic size L_s are shown in Table 1.

Table 1. Phase correlation for the translation parameter Δ

| $d, \text{ mm}$ | $L_s, \%$ | | | | | | | |
|-----------------|-----------|-----|-----|-----|-----|-----|-----|-----|
| | 60 | 80 | 100 | 120 | 140 | 160 | 180 | 200 |
| 2.0 | 205 | 184 | 141 | 116 | 104 | 98 | 82 | 57 |
| 2.5 | 286 | 204 | 164 | 153 | 143 | 125 | 107 | 88 |
| 3.0 | 357 | 246 | 207 | 190 | 179 | 164 | 152 | 139 |
| 3.5 | 482 | 304 | 232 | 224 | 205 | 184 | 173 | 158 |
| 4.0 | 603 | 355 | 291 | 285 | 270 | 257 | 242 | 227 |

In addition, the simulation results indicate that the position of the maximum of the thermographic phase contrast depends linearly on the depth d of the defect.

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ПІДХІД ЩОДО РЕАЛІЗАЦІЇ СИСТЕМИ РЕКОМЕНДАЦІЙ ЗІ СПОРТИВНИХ АКТИВНОСТЕЙ

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Вступ

Спорт відіграє ключову роль у підтримці фізичного і психічного здоров'я людини. Регулярні фізичні навантаження сприяють покращенню загального стану організму, підвищують стійкість до стресу та покращують настрій. Важливість спорту для здоров'я підтверджується численними дослідженнями [1].

Дана робота спрямована на розробку програмного додатку, що надаватиме персоналізовані рекомендації щодо спортивних активностей. Її актуальність пов'язана зі зростаючою потребою суспільства у здоровому способі життя та бажанням людей отримувати індивідуальні тренувальні програми, які відповідатимуть їхнім фізичним можливостям та особистим уподобанням.

Мета роботи полягає у розширенні функціональних можливостей системи рекомендацій зі спортивних активностей, що використовує алгоритми машинного навчання для аналізу індивідуальних потреб користувачів і формування персоналізованих тренувальних програм. Такий підхід дозволить