PHYSICAL AND MATHEMATICAL SCIENCES

UDC 699.88

PROPAGATION OF ULTRASONIC SIGNALS IN A POROUS COMPOSITE

Pysarenko Alexander Mykolayovich,
Candidate of Physical and Mathematical Sciences, Associate Professor
Odessa State Academy of Civil Engineering and Architecture
Odesa, Ukraine

Abstract: In this study, discrete wavelet transform was applied to the case of backscattering of ultrasonic signal propagated in various porous composite samples. The spectrum of the scattered ultrasonic backscattered signals contained both high-frequency and low-frequency components. The correlation analysis between the porosity and the peak amplitude of the ultrasonic signal was performed in the range of the proposed scattering model.

Key words: discrete wavelet transform, composites, ultrasonic backscattered signals, porosity, scattering model.

Composite materials are currently used in many industrial applications. The large amount of research and development in non-destructive testing of composite materials is due to the increased use of these materials in structural applications [1, p. 6083]. Due to the heterogeneous nature of composite materials, the morphology of defects not only differs from metallic materials, but also leads to more complex failure mechanisms. The most common type of defect found in composite materials is porosity [2, p. 189].

Insufficient control of the manufacturing process such as vacuum suction, insufficient release of volatile gases from the resin, loss of curing pressure and improper curing cycle are the causes of porosity in the form of distributed microscopic voids. The saturation of the volume of a composite sample with pores can have a strong influence on the mechanical properties of composite materials such as compressive strength, transverse tensile strength and inter-laminar shear strength [3, p. 1358].

High volumetric porosity content in a composite structure is critical to the overall strength and performance of the structure. Therefore, quantifying the volumetric porosity content present in components is very important for certain applications. The porosity content can be quantified by both non-destructive and destructive methods. Commonly used non-destructive evaluation methods for composite materials include X-ray radiography, ultrasonic testing, neutron radiography, eddy current, shearography, thermography, acoustic emission, etc. A large number of experimental studies point to ultrasonic techniques as the best solutions for detecting damage to composite materials [4, p. 112405].

One of the methods of signal processing and the method of analyzing transient non-stationary signals simultaneously in the time and frequency domains is the wavelet transform. This transform decomposes the original signal into a sum of elementary contributions called wavelets. In addition, the wavelet transform allows you to divide a complex function into several simpler ones and study them separately.

In this paper, all reflected ultrasonic signals were decomposed into five levels using discrete wavelet analysis. The decomposition was performed using Daubechies wavelets from db4 to db10 as the transform function. The analytical model of ultrasonic scattering in composites allowed us to identify the Daubechies wavelet db4 as the most promising candidate for the original function. In addition, the component coefficients of five reflected signal modes from db1 to db4 act as a noise filter. Therefore, wavelets A5 and D5 were used as the basic components. Decomposition by wavelets db2 and db3 indicates the presence of both low-frequency and high-frequency components of the reflected signal.

The proposed model of ultrasonic scattering in composites assumes the relationship between ultrasonic parameters such as peak amplitude and peak frequency and porosity content. The changes in the numerical values of peak amplitude and peak frequency and, accordingly, the backscattered signal for A5 and D5 modes are considered as indicators of porosity in this paper. The exponential decrease in peak amplitude and frequency corresponded to the increase in the porosity content of the sample. Correlation analysis was performed for the relationships between ultrasonic parameters and porosity content. Since the peak amplitude and peak frequency decrease exponentially with the increase in porosity content, a regression model based on the logarithmic function was adopted.

Regression analysis showed that the porosity of the composite material can be predicted using the backscattered signal and wavelet transform. For carbon/epoxy laminated composites, a system of calibration equations was derived that allowed the dynamics of porosity change in local volumes to be described. The developed calibration equations were then used to predict porosity using ultrasonic parameters obtained using the wavelet transform of the ultrasonic backscattered signal. In addition, the regression shows the predicted and measured porosity values and demonstrates the feasibility of the ultrasonic method for porosity assessment. The coefficients of determination (R2) and root mean square errors of the regression models are 0.686 and 1.4% for the carbon/epoxy laminate sample and 0.923 and 1.3% for the reinforced composite sample, respectively.

REFERENCES

1. Shah D.U. Developing plant fibre composites for structural applications by optimizing composite parameters: a critical review. Journal of materials science. 2013. Vol. 48(18). Pp. 6083-6107. DOI: 10.1017/s10853-013-7458-7.

2. Singh A.K. et al. A review of porous lightweight composite materials for electromagnetic interference shielding. Composites Part B: Engineering. 2018. Vol. 149. Pp. 188-197. DOI: 10.1016/j.compositesb.2018.05.027.

3. Lee D.J., Palley I. Simple model to predict the interlaminar shear strength of laminate composites. Journal of composite materials. 2012. Vol. 46(11), Pp. 1357-1365. DOI: 10.1177/0021998311418547.

4. Bang H.T., Park S., Jeon H. Defect identification in composite materials via thermography and deep learning techniques. Composite Structures. 2020. Vol. 246. P. 112405. DOI: 10.1016/j.compstruct.2020.112405.