DETERMINING THE OPTIMAL WAVELET BY THRESHOLD CRITERION

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One of the characteristic features of recent technology development is the use of composites as multicomponent materials, the properties of which together are better than those of each component individually. Moreover, various components improve their performance. Carbon fiber reinforced plastics (CFRP) are increasingly used in the aviation, automotive and civil engineering industries due to their high material properties. Such properties of the polymer matrix include a high strength-to-weight ratio, high rigidity and high corrosion resistance [1].

However, due to the presence of two or more dissimilar phases, composite materials pose challenges in machining as well as material characterization. The use of a multi-level operating mode for composites is often the cause of failures, which include rupture, cracking and pulling out of fibers, crushing and cracking of the matrix, failure of adhesion and delamination [2]. Delamination, in particular, leads to a decrease in strength and elastic modulus if the adhesion between the layers is not strong enough. These types of failures are indistinguishable by visual inspection.

Since the integrity of CFRP structures must be regularly assessed, the acoustic emission method is widely used to detect and locate possible damage. Acoustic emission is a non-destructive technique that can provide on-site monitoring of a structure through a network of distributed sensors and can be used to detect damage at a very early stage, long before the structure fails completely. When a structure is subjected to mechanical, thermal or chemical stress, a stress field is created in the material. As a result of the accumulation of these damages, the material degrades.

The appearance of defects leads to the creation of elastic ultrasonic waves propagating throughout the material. Wave propagation is associated with surface vibrations, which can be measured using appropriate sensors. Thus, acoustic is the short-term elastic release of energy in materials when microstructural changes occur. The microscopic damage created by the cutting mechanism and the subsequent change in the tool's condition releases high-frequency radiation of stored elastic energy, which typically passes through the material in the form of transient elastic stress waves. Such transient waves can be considered as acoustic emission and used as one of the precise monitoring methods in machining conditions. Conducting research to identify the mechanisms of destruction of composites has revealed that the use of acoustic emission methods is more preferable compared to other methods.

Thus, the tool condition can be monitored by integrating suitable acoustic emission sensors onto composite material samples and studying the corresponding response of the material. For example, in [3], the analysis of high-amplitude acoustic waves made it possible to study the process of destruction of multilayer composites. It should be noted that the acoustic waves emanating from the processed material are usually non-stationary in nature and contain overlapping transients. Therefore, an appropriate signal processing method is required to characterize these processes. Non-stationary signals for their processing require the use of Fourier series. However, Fourier series processing of transient components, such as rapidly decaying frequency components, does not allow the extraction of characteristic features, and much of the useful information is averaged out/lost when converting a signal from one domain to another.

Fourier analysis is closely related and can even be considered as the basis for the use of continuous and discrete wavelet transforms in the study of deformation fields of composite structures. A large number of studies are devoted to expanding wavelet analysis for processing signals obtained during processing of an array of data on the kinetics of deformations in a composite matrix. As an example, we can point to work [4], which studies in detail the relationship between the wavelet transform of acoustic signals and the failure modes of fiber-reinforced composites.

In this work, the best wavelet for the acoustic waveform decomposition was determined from a list of 24 wavelets: Haar- (Haar $k = 1$); Daubechies- (db k, $k = 2, \ldots, 11$); Symlet- (sym k, $k = 12, \ldots, 18$) and Coiflet- (coif k, $k = 19, \ldots, 23$) Dmeyers- (Dmey $k = 24$). The choice was made according to the parameters of average entropy H and average energy E_W. The Rényi entropy values were determined using the formula

$$H(S) = -\log \sum_{k=1}^{n} [P(S_k)]^2, \quad (1)$$

where $P(S_k)$ is the discrete probability distribution of the wave amplitude.

The results are presented, respectively, in Figures 1,2 and 3. The diagrams display the results of assessing the critical values of the threshold values for selecting the maximum and minimum parameters “threshold max” and “threshold min”.

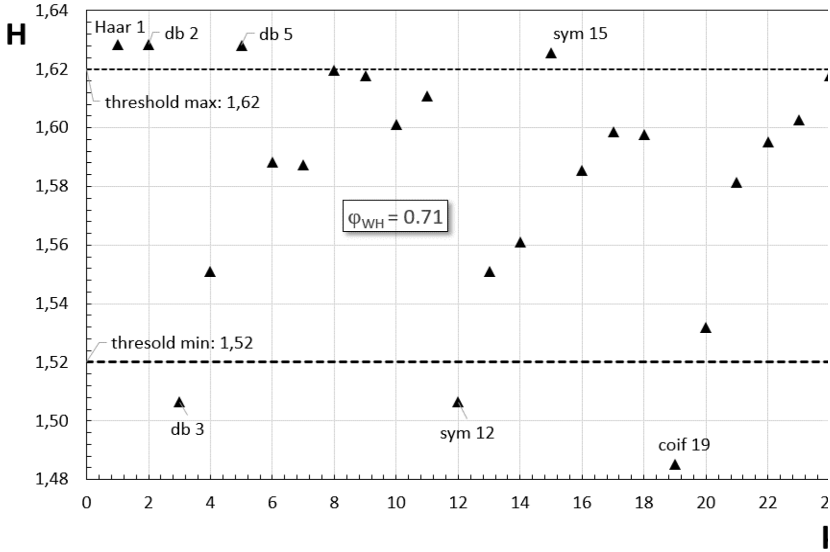

Figure 1. H-distribution for wavelets according to the average entropy

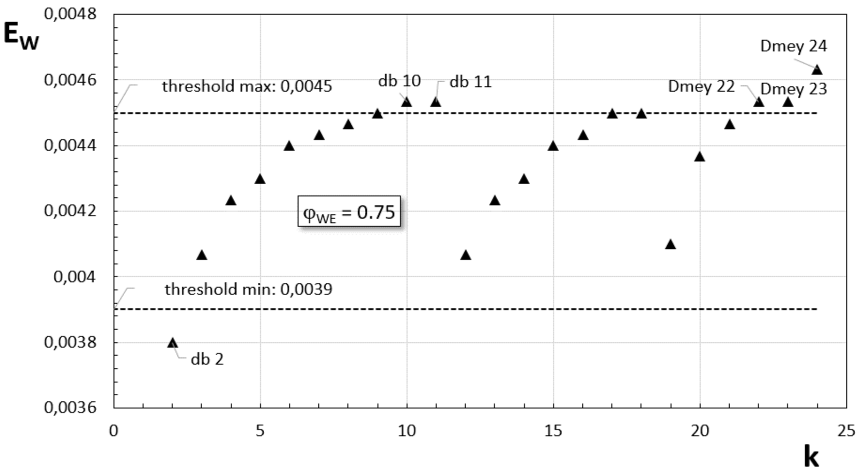

Figure 2. E-distribution for wavelets according to the average energy parameter.

The H-distribution is characterized by a sufficiently large number of wavelets, the average entropy of which is outside the threshold values. In particular, the following wavelets are located above the maximum threshold: Haar- and Daubechies- (subseries db k, k = 2, 5, 15). Three wavelets, namely: Daubechies- (db 3), Symlet- (sym 12) and Coiflet- (coif 19) have an average entropy value less than the minimum threshold value (= 1.52). It is quite natural that preference in terms of the min-max parameter for entropy should be given to Daubechies wavelets with indices k = 2, 3 and 5. Accordingly, Haar- and Coiflet wavelets should be excluded from further analysis in terms of the entropy parameter.

The average energy distribution is characterized by a maximum difference $\Sigma_{max} - \Sigma_{min} = 4$. Exceeding the maximum threshold for average energy is typical for wavelets: Daubechies- (db k subseries, k = 10, 11) and Dmeyers- (Dmey k subseries, k = 22 - 24). Below the minimum threshold for average energy there is only one wavelet: Daubechies- (db 2). Preference for the min-max parameter for the average energy should be given to the Daubechies wavelet with index k = 2. Accordingly, Dmeyers wavelets with indices k = 22, 23 and 24 should be excluded from further analysis for the average energy parameter.

Conclusions. As a result of the analysis, recommendations for choosing the optimal wavelet having average energy and average entropy that satisfy the min-max parameter should be pointed to Daubechies-wavelet (db 2). The wavelets distribution density φ-ranking within threshold values for H and E_W leads to the following chain: φ_{WE} (= 0.75) > φ_{WH} (= 0.71).

References

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