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Investigation of Failure Mechanism of the Composite Tubes Made by Filament Winding Process by Acoustic Emission Method

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ABSTRACT: To study the energy absorption features in composite structures, it is necessary to identify the functional mechanisms and determine the impact of each on the energy absorption. In this study, the behavior of composite tubes under compressive axial load was investigated by acoustic emission monitoring. To make a filament wound composite tube, the optimal parameters were first determined using literature. In determining the optimal parameters, due to the uncertainty effect of fiber angles, from the intermediate range, the angle of 35 degrees was selected. Then, to ensure the experimental results, the finite element simulation method and the use of the VUMAT subroutine based on the 3D Hashin criterion were used. The results showed that the dominant failure mode was a local shear failure and lateral damage, which first caused the plastic deformation of the sample and then caused the growth of cracks in the fiber direction. Also, the highest percentage of failure mechanisms are matrix cracking, fiber breakage, and separation of fibers from the matrix, respectively. Finally, the use of the developed subroutine to predict the behavior of the structure was useful and was able to predict the behavior of the composite tube even after the maximum crushing force.

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1- Introduction

With increasing speed limits in cars, ensuring failure against impact is one of the most important points in the design of structures. Thin-walled structures are widely used for this purpose, and many efforts are currently being made to increase energy absorption capacity. Due to the fact that metal tubes under buckling axial load are degraded and have a high weight, the use of composite tubes due to their lightweight and progressive mode is the most suitable option for energy absorbers [1].

The filament winding process is one of the most suitable production processes for cylindrical structures, which is usually used for the production of pipes, shafts, pressure vessels, etc. This process has high accuracy for positioning the fibers, controlling the volume fraction of the fibers, and making the desired angles (see Fig. 1).

HIWA model pressure device with a capacity of 5 tons was used to load the samples. According to Fig. 2, the test specimens were tested at a speed of 2 mm/min, and AEWin software and PCI-2 system with a sampling rate of 2 MHz were used to record acoustic emission data. The amount of displacement and load was continuously recorded by the testing machine and the Dino-Lite digital camera was used to capture the progressive failure of the composite tube (see Fig. 2).

2- Methodology

In order to calculate the percentage of failure mechanisms created in the structure, in addition to using the components of acoustic emission signals, it is necessary to use complex methods to process these signals. Fast Fourier transform and wavelet transform can be considered as common methods of signal processing. Instead of using the sine and cosine functions used in Fourier transform, which focuses on only one frequency, the wavelet transform uses functions as

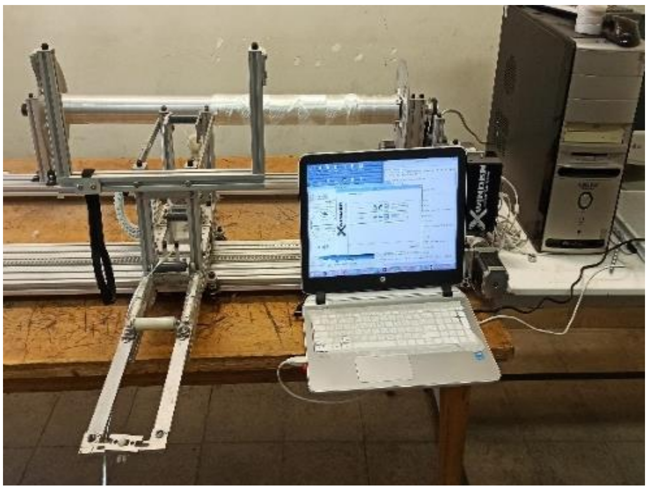

Fig. 1. Filament winding method

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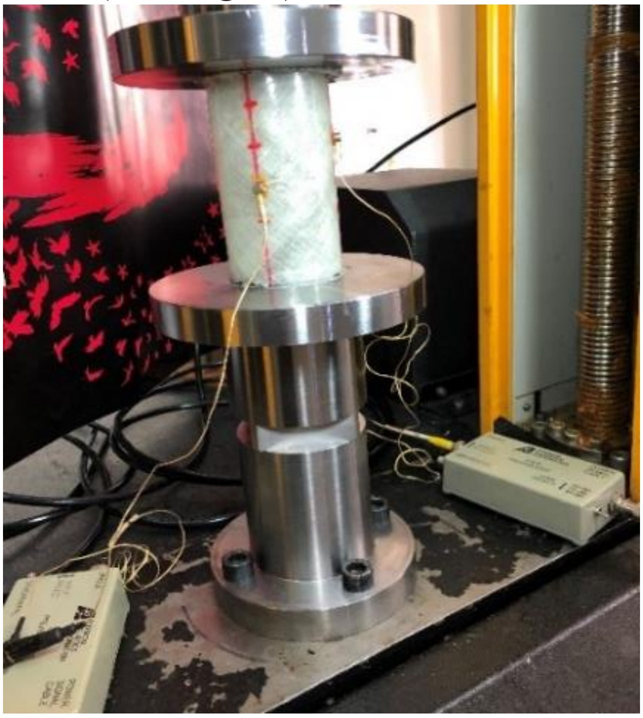

Fig. 2. Image of loading a cylindrical sample under a quasi-static axial load and sensors attached to the sample

wavelets consisting of several different frequencies. Discrete wavelet transform is one of the most widely used types of wavelet transform in which the main signal is broken down into components called generalities and details. In the next levels, the signal generalities are again divided into two parts, details and generalities, and this signal decomposition process continues to the desired level. From a mathematical point of view, discrete wavelet transform is defined as follows:

$$f(t) = c\sum_i \sum_k DWT(i,k) 2^{\frac{i}{2}} \psi(2^i t - k) \tag{1}$$

Inverse discrete conversion is also obtained according to the following equation:

$$DWT(i,k) = \int_{-\infty}^{+\infty} f(t) 2^{\frac{i}{2}} \psi^*(2^i t - k) \tag{2}$$

where $f(t)$, $DWT(i,k)$, and i represent the desired signal, wavelet conversion coefficients, and decomposition level, respectively. Also, k, ψ and ψ^* represent the time domain, the mother wavelet transform and mixed ψ conjugate [2, 3]. Due to the fact that in discrete wavelet transform, high-frequency components are not decomposed, part of the data is deleted and not analyzed. In this research, in order to analyze all the components of the signal, packet wavelet transform has been used. The working principle of this method is that, at the signal decomposition levels, in addition to generalities, the signal detail section is also divided into two sections, generalities, and details, each component having a specific frequency range. Therefore, each signal can be decomposed into a set of wavelet components, each with its own frequency range. Since the different distribution of energy at each level corresponds to a particular failure or failure, the energy percentage of each of the decomposed components is obtained using the energy criterion.

3- Results and Discussion

According to Fig. 3, the acoustic emission signals obtained from the sample test were decomposed into three levels and divided into 8 components. Then, using the energy criterion, the energy percentage of each of the 8 components of the signal decomposed in the third level was obtained. Each component has a specific frequency range depending on the level of decomposition at which it is located and whether the component is a high frequency or low frequency.

Analysis of these acoustic signals shows that the acoustic response of the structure to the load can be divided into four different regions. In the first area, no acoustic activity is observed in the structure. Examination of the amplitude range of the received signals at the beginning of the second region shows that the range of its changes is mainly related to the matrix cracking. The third area is mainly associated with an increase in the number of hits. Finally, the fourth or end region is associated with the reception of various types of acoustic signals, the strongest of which occurs with a very high amplitude, which is related to the fiber breakage (see Fig. 4).

4- Conclusion

In this study, the failure mechanisms created in 35° composite tubes were investigated by experimental methods, acoustic emission technique, and finite element simulation. It was found that:

The most common mode of failure in filament-wound tubes under this angle is local failure due to lateral damage and compressive deformation, which mainly begins with the separation of fibers from the matrix at the head of the sample, and then due to the inability to expand separation continued.

After local deformation creation, the crack begins to grow from that point along the twist angle of the fibers, eventually causing the specimen to cut and the upper part to sink into the lower part, and the crushing continues progressively.

The acoustic emission method was also used to validate the experimental results. The results of the observations showed that the behavior of the force-displacement diagram is completely consistent with the acoustic diagrams so that the force drop in the diagram is always associated with the release of acoustic energy, the amount of this energy varies depending on the type of failure mechanism that occurs in the sample.

Examination of the amplitude of acoustic signals showed that the onset of failure in cylindrical structures begins mainly with the cracking of the matrix and gradually occurs with increasing stress applied to the structure, separating the fibers from the matrix, matrix cracking, and fiber breakage, respectively. These failure mechanisms are recognizable from the amplitude range of acoustic signals.

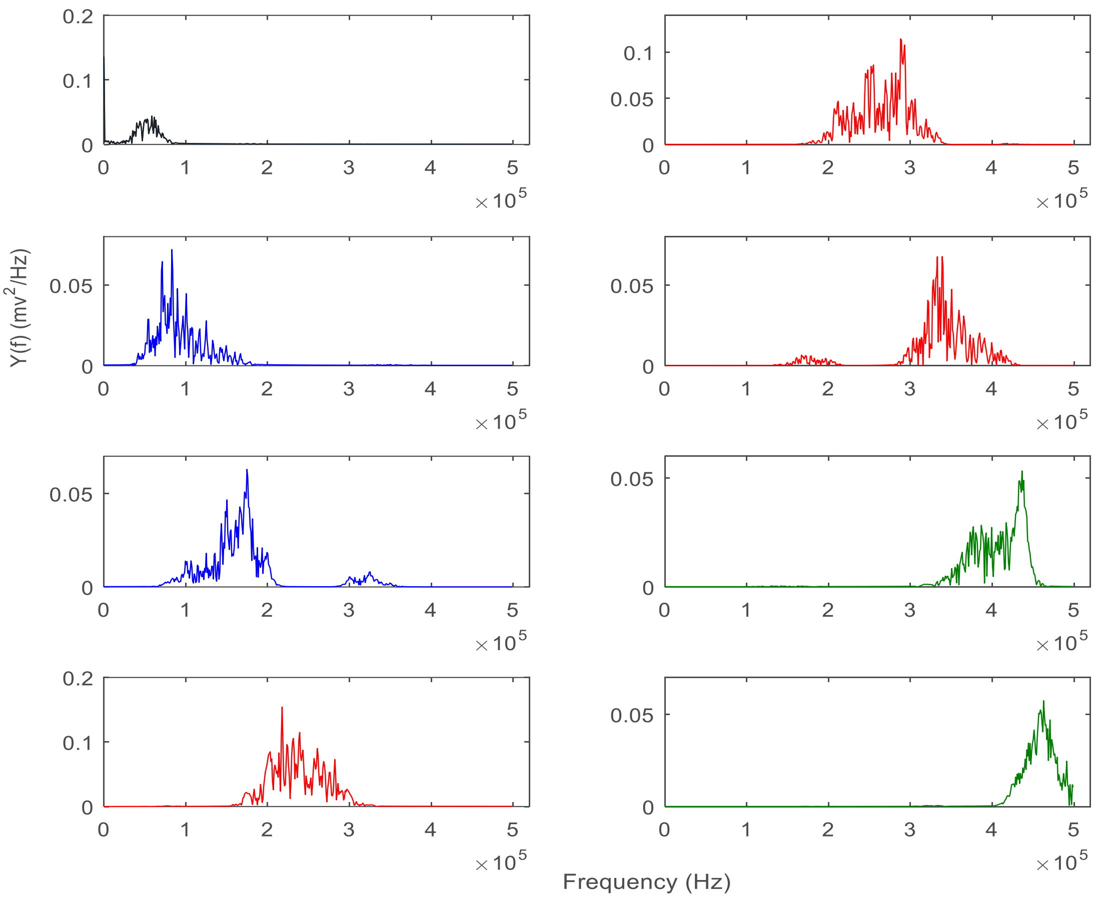

Fig. 3. Frequency distribution percentage of each of the 8 components resulting from the decomposition of acoustic emission signals

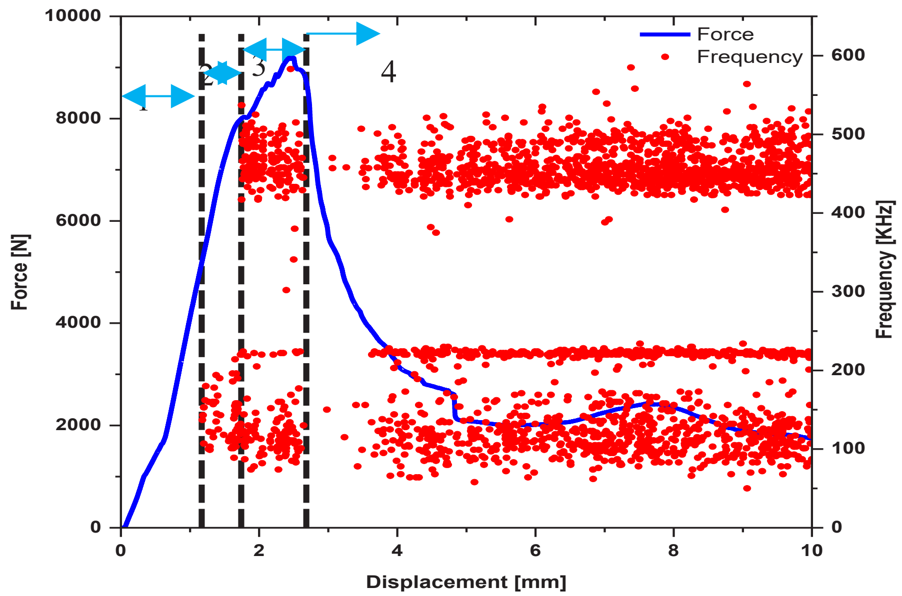

Fig. 4 Frequency of AE signals with respect to the displacement

3D Hashin failure criterion was used in the simulation of composite tubes. The results of finite element modeling showed that the 3D Hashin criterion used predicts the onset and growth of failure well.

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