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Assessing Flexural Damage Mechanisms Induced by Mesoscopic Buckle Defects in Textile-Reinforced Polymer Matrix Composites Using Acoustic Emission Analysis

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Abstract : This paper investigates and categorizes the flexural damage mechanisms in composite materials caused by mesoscopic out-of-plane buckle defects that occur during the initial stage of the resin transfer molding (RTM) process. The findings of this study have significant practical implications for the manufacturing and use of composite materials, as they provide a deeper understanding of these damage mechanisms and their analysis. During the initial stage of shaping a preform, alterations, and distortions in the reinforcement sample can significantly lead to defects, such as buckling, especially when forming double-curvature geometries. These recurring mesoscopic defects have been investigated using a specialized laboratory bench designed to reproduce buckle defects like those found in complex geometric shapes, such as tetrahedrons. The study examined two sample configurations with buckle defects in the longitudinal and transverse directions alongside a reference sample for comparison. An acoustic emission (AE) system, a well-regarded non-contact method for monitoring structural health, was used to analyze the mechanical behavior of material samples in detail. An unsupervised K-means algorithm was employed to classify the damage mechanisms—such as matrix cracking, interface damage, and fiber breakage linked to the samples' failure. A standard was established based on three AE parameters: absolute energy, amplitude, and the number of AE events. This standard helped identify the origin and sequence of damage propagation. Initially, the results of the AE parameters were superimposed with the flexural loading curves to pinpoint the loading phases during which damage began and the specific points at which the samples ultimately failed. The normalized density of AE events related to different damage mechanisms was evaluated by analyzing the number of AE events within the amplitude domain of the AE signals. The ranges of the identified damage mechanisms in the amplitude plane illustrate the progression and order of load transfer among the elements of the composite material. In the reference sample, the AE event signals corresponding to the three classes of damage mechanisms partially overlap with adjacent signals. In contrast, the two defective sample configurations showed that the overlapping AE event signals for the respective damage mechanisms converged within the intermediate damage mode area at specific points, depending on the sample configuration. The convergence points in the samples with transverse defects were identified relatively earlier than in the other samples. Low and high amplitude ranges characterize the matrix cracking and fiber breakage damage mechanisms. The low amplitude damage occurred over a more extended length, while the high amplitude damage began much earlier. This results in the signals from both damage mechanisms converging at the center of the interface damage zone. This convergence suggests that all individual composite components fail concurrently at specific points in the defective samples, resulting in rapid fragmentation and ultimately contributing to failure. Overall, the results show that mesoscopic out-of-plane buckling in all directions affects the composite's flexural response, with more severe effects observed when the load is applied transversely.

Keywords : acoustic emission, composite reinforcement, damage mechanisms, mesoscopic buckle defects
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