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Use of acoustic emission b(Ib)-values to quantify damage in composites

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ABSTRACT

This study reports a new damage quantification method for fiber-reinforced composites using the acoustic emission (AE) *b*(*Ib*)-value. Plain-woven carbon fiber/epoxy composite specimens were prepared and their AE signals were analyzed under cyclic loadings (10 cycles per step, up to 700 MPa of tensile stress). The analysis showed that fiber breakage and interfacial failure occurred in the low stress region, which caused complex macrocracks to form. During the test, *b*-values (given by the relationship between the number and amplitude of AE hits) decreased continuously, providing information on the overall extent of the damage. However, this was not obvious in the large stress region (under 700 MPa) due to significant AE hits with low amplitude from matrix cracking and complex fracture behavior, raising *b*-value. In contrast, a modified parameter (*Ib*-value) showed a continuously decreasing trend in all regions, indicating its suitability as a health monitoring parameter.

1. Introduction

The high stiffness and strength, as well as the low density, of fiber composites has led to their widespread use in lightweight structures. Such composites have enabled an increase in the length of wind turbine blades to 120 m, resulting in improved efficiency. The relative inaccessibility of offshore wind turbines necessitates high reliability of the blades. Thus, conditional monitoring and safety verification are urgently required. Other applications of fiber composites in the automotive, aerospace, and heavy industry sectors also require performance monitoring [1–3].

Many researchers have analyzed the fracture behavior of composites for health monitoring [4–8]. In some cases, microcracks occur due to fiber breakage at low stresses or matrix cracking. These microcracks lead to macrocracks and catastrophic failure. Several non-destructive testing (NDT) methods have been developed to assess the crack state and defects in composites. These approaches include acoustic emission (AE) testing [9–12], ultrasonic testing [13–15], eddy-current testing [16–18], and X-ray radiography [19,20]. Although local inspection techniques are sufficiently developed, they have not been used to determine the overall health status of a structure. Installing and operating local NDT devices throughout a large structure, such as wind turbine blades or aircraft, is costly. Thus, the development of a global parameter indicating the repair and replacement time of a composite is needed.

There are several reports concerning AE-based global NDT methods. The frequency distribution of acoustic emission signals can be divided into frequency ranges that are characteristic of observed failure modes (fiber failure: high frequency, matrix cracking: low frequency, interfacial failure: intermediate frequency) [21–25]. Additionally, AE studies related to architecture and seismology have established that different fracture modes generate different types of AE signals. Shiotani et al. [26] and Colombo et al. [27] carried out AE studies of concrete specimens under bending and cyclic loading conditions. They found that microcracks generated a large number of events having small amplitudes, while macrocracks generated fewer events but with larger amplitudes. Additionally, Ohno and Ohtsu [28] noted that tensile cracks generated large-amplitude events, while shear cracks generated smaller amplitudes. Gutenberg et al. [29] and Shiotani et al. [26,30] focused on the amplitude and number of AE hits, and suggested a static parametric value of the amplitude distribution slope, i.e., a modified *b*-value (*Ib*-value), for a global NDT approach, where the value decreases with damage accumulation. This method has been applied to earthquakes [29,31,32], rock slopes [30,33], and bridges [26,27,34]. However, the *Ib*-value has not been applied to fiber composites, motivating this research.

Herein, we applied the *Ib*-value to woven carbon/epoxy composite specimens under cyclic loadings. The issues raised in this study, and the accompanying methodology, are schematically shown in Fig. 1. The AE

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