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Technical Memorandum 33-564

A Basic Model for Acoustic Emission From Fiber-Reinforced Material

E. Y. Robinson

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16. Abstract

Acoustic Emission (AE) from fiber-reinforced composites can often be conveniently interpreted by use of normalized coordinates in graphical data display. Many aspects of the shape of the acoustic emission pattern are invariant with the signal amplification ratio, and the use of normalized coordinates allows simultaneous comparison of AE pattern shapes from different experiments. In this paper, the first-order model of AE from fiber composites, based on filament breaking rates, is cast into a normalized form useful for correlating experimental data. The general features of the normalized model are shown and compare favorably with available data.

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Technical Memorandum 33-564:

Please note the following corrections to Technical Memorandum 33-564, A Basic Model for Acoustic Emission From Fiber-Reinforced Material, by E. Y. Robinson, dated September 1, 1972:

Equation (3) on page 2 should read

$$\sigma^* = \frac{S(\sigma^*)}{f(\sigma^*)} \quad \text{instead of} \quad \sigma^* = \frac{f(\sigma^*)}{S(\sigma^*)}$$

Therefore, the equation at the bottom of page 2 should read

$$\sigma^* = -\frac{1}{K(\sigma^*)} \quad \text{instead of} \quad \sigma^* = -K(\sigma^*)$$

Very truly yours,

John Kempton, Manager
Publications Section

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Telephone 354-4321

Twx 213-449-2451

PREFACE

The work described in this report was performed by the Engineering Mechanics Division of the Jet Propulsion Laboratory.

CONTENTS

ABSTRACT

Acoustic Emission (AE) from fiber-reinforced composites can often be conveniently interpreted by use of normalized coordinates in graphical data display. Many aspects of the shape of the acoustic emission pattern are invariant with the signal amplification ratio, and the use of normalized coordinates allows simultaneous comparison of AE pattern shapes from different experiments. In this paper, the first-order model of AE from fiber composites, based on filament breaking rates, is cast into a normalized form useful for correlating experimental data. The general features of the normalized model are shown and compare favorably with available data.

I. INTRODUCTION

Interest and investigation are increasing in the area of acoustic emission (AE), and studies are proceeding (Ref. 1) with application to a variety of materials and structures, including fiber-reinforced systems. The techniques used vary in detail but are commonly concerned with the detection of faint, high-frequency stress waves emanating from sources of sudden energy release such as dislocation advances, phase changes, crack propagation, internal friction and sliding, etc. Much work remains to be done on signal processing and data interpretation, but certain basic trends have emerged from the work done on fiber-reinforced systems at various laboratories (Ref. 1). The classic AE pattern for linear loading is a nominally monotonic increase in AE at an increasing rate. It appears possible to distinguish, in some cases, between two types of emission: (1) the emission due to fiber fracture from emission sources in the matrix and (2) emission at the interface of fiber and matrix (Ref. 2). The emission from fiber breaks appears to be more intense and distinct than matrix-related AE. While basic acoustic emission phenomena are apparently quite complex and must depend on microscopic structural details and local stress states, it is desirable to have at least a first-order model of AE from fiber composites to aid interpretation of data trends and to provide a baseline from which refinements of analytical models can proceed.

II. ACOUSTIC EMISSION MODEL

The purpose of this note is to define a basic first-order mechanism for acoustic emission from fiber composites undergoing monotonic loading to failure. The essential premises are that AE phenomena are dominated by the events of filament failure throughout the loading, and that the filament stress σ is carried uniformly by the reinforcing filaments. Unidirectional reinforcement is assumed, with filament strength distribution given by the cumulative survivability function $S(\sigma)$. The filament failure rate is then proportional to the AE rate. The integrated acoustic emission, ΣAE, is expressed proportionally as

$$\Sigma AE \propto 1 - S(\sigma) \tag{1}$$

It is generally convenient to normalize ΣAE so that shape trends of data which differ in absolute scale may be compared. This also avoids the absolute specification of a proportionality constant. The maximum ΣAE at the onset of final failure is taken as the normalizing level. The strength of an idealized bundle of reinforcing filaments is reached when the nominal stress

$$\sigma_{nom} = \sigma S(\sigma) \tag{2}$$

is maximum. This maximum occurs at a critical value of σ, denoted by σ^*, which in the usual cases satisfies:

$$\sigma^* = \frac{f(\sigma^*)}{S(\sigma^*)} \tag{3}$$

where $f(\sigma)$ is the frequency distribution. Exponential statistical distributions are often characterized by the property

$$f(\sigma) = -K(\sigma)S(\sigma)$$

and the critical stress σ^* is then a solution of

$$\sigma^* = -K(\sigma^*)$$

and $S(\sigma^*)$ may be evaluated by direct substitution of σ^*.

The normalized acoustic emission E is given by

$$E = \frac{1 - S(\sigma)}{1 - S(\sigma^*)} \tag{4}$$

The external loading, expressed as a nominal stress, is given by Eq. (2). It is desirable in many cases to normalize the applied load also, using the maximum load at failure as the normalizing factor. This normalized load P is

$$P = \frac{\sigma_{nom}}{\sigma_{nom_{max}}} = \frac{\sigma S(\sigma)}{\sigma^* S(\sigma^*)} \tag{5}$$

The relation between E and P can be written in closed form if $S(\sigma)$ can be inverted to give an expression for σ.

$$\sigma = \mathscr{H}\{S\} \tag{6}$$

Eliminating S between Eqs. (4) and (5) yields

$$P = \frac{\mathscr{H}\{1 - E(1 - S(\sigma^*))\}[1 - E(1 - S(\sigma^*))]}{\sigma^* S(\sigma^*)} \tag{7}$$

Note that the braces identify the argument of the inversion $\mathscr{H}$.

Equation 7 is the mathematical expression of the proposed basic AE model for unidirectional fiber-reinforced systems. Other basic assumptions can lead to similar functional relationships, and Eq. (7) is likely to be a useful algebraic form even in cases which do not meet the stated premises.

This model of acoustic emission will be illustrated using a Weibull distribution for S:

$$S = \exp(-C\sigma^m)$$

$$K(\sigma) = -(mC\sigma^{m-1})$$

$$\sigma^* = (1/Cm)^{1/m}$$

$$S(\sigma^*) = \exp(-1/m)$$

$$\sigma = \mathscr{H}(S) = [(1/C)\,\ln 1/S]^{1/m}$$

Putting these terms into Eq. (7) gives

$$P = \left\{1 - E\left[1 - \exp(-1/m)\right]\right\}\left[me\ \ln \frac{1}{1 - E[1 - \exp(-1/m)]}\right]^{1/m} \tag{8}$$

The contours relating P and E by this equation are shown in Fig. 1. The curvature trend shown, a slight downward convexity, is consistent with some preliminary data on boron/epoxy and graphite/carbon specimens. These data are superimposed on Fig. 1. A rough rule of thumb which may be extracted from Eq. (7) is

$$E \approx P^m$$

This rule of thumb displays a relationship between the statistical dispersion m of the acoustic source and the experimentally measured variables P and E.

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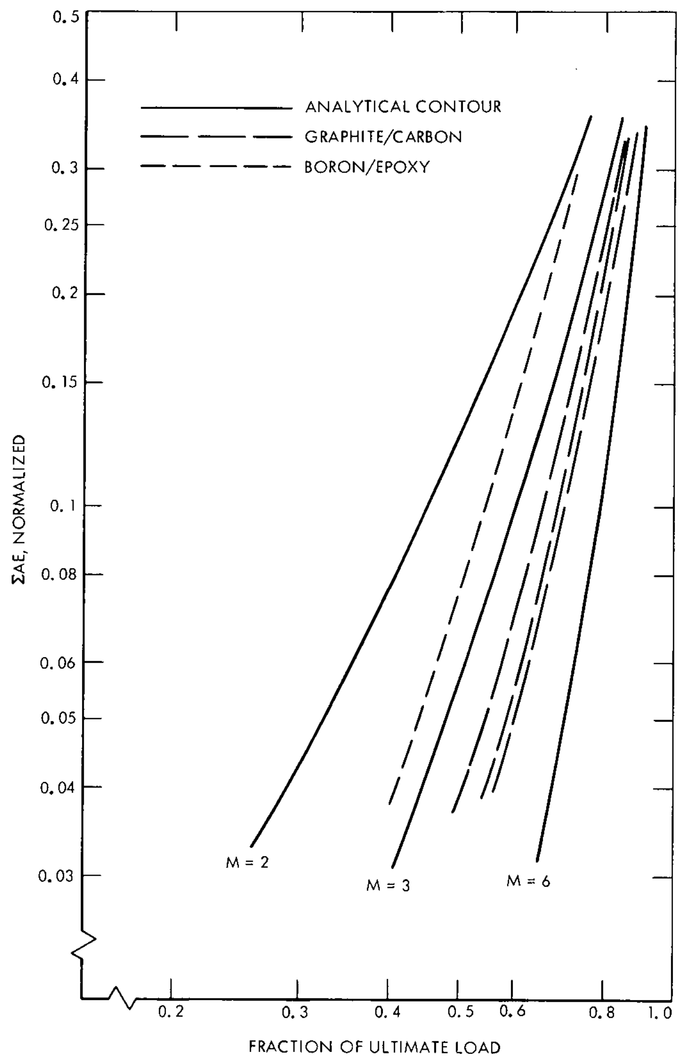

Fig. 1. Normalized acoustic emission vs load; analytical predictions and data from graphite-carbon and boron/epoxy composites