ON COUPLING OF MULTI- AND TRANSCALE DAMAGE IN HIERACHICAL MICROSTRUCTURE OF SOLID

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Summary In this work, we report the progress of the establishment of a novel approach to address the coupling of multi- and trans-scale problem that complicates the characterization and evaluation of solids in hierarchical microstructures.

INTRODUCTION

The mainstream theoretical efforts were delineated by the strain-based approaches of either microdamage mechanics or continuum damage mechanics (CDM). In the former, an internal variable (IV) is employed by defining a representative volume element (RVE) that comprises a damage element (DE) to symbolize irreversible events such as microvoids and cavities, or microcracks indicated by their orientation, quantity and or the size [3], and then, to convert the results of RVE to a coarse or macroscale homogeneously. In the latter, an IV is a measure of the degradation of elastic modulus, yielding strength, or tensile strength to characterize the damage process [4]. The measurement of IV is normally obtained via phenomenological means similar to the state variables defined in the thermal mechanics. However, these approaches were incapable of accounting for the correlations of cascading damage being either too idealistic to replicate the complications of the real damage process or failure to take into account the influence of microscopic characteristics. Although a vectorial model were developed for such a purpose that attempted to consider the distributed microcracks [5], which was questioned seriously for its enormous bookkeeping efforts to resolve the verification difficulties experimentally, and for poor understanding of the evolving damage process [6]. Nevertheless, the correlation between cascading damage events and correlation between various damage mechanisms remain poorly understood. Recently, Bai, et al. proposed a theoretical model based on statistical mesomechanics to take into account the damage processes in multi- and trans-scales [1,2], but, is in need of substantial experimental supports. The objectives of present work are: 1) to reveal the statistic significance of the correlations among the components of the defined variate in spacetime; and 2) to determine the interactions between these components.

MULTI-VARIATE APPROACH

A multi-variate approach to quantify damage state

Let Ω_T and Ω be, respectively, a set comprising parameters of timing, quantity, rate of occurrence, amplitude, energy, location, orientation, pattern, rate and direction of propagation of random damage events (RDE) with various scales, and all other parameters that can be used to describe a damage field, and a subset of Ω_T, $\Omega \in \Omega_T$ that contains only the first four. Let,

$$D_A := \{X_1, X_2, \ldots, X_N\} \quad \text{on } \Omega,\ \ \Omega \in \Omega_T \qquad (1)$$

be a multi-variate, its column and row vectors represent, respectively, ordered damage events by their scales and observations at intervals of time or stress.

Methods of analysis

To categorize the populations of responsive damage events, to investigate correlation relationships, and to investigate the interactive relationships between the scales of damage variate in different stages of loading under pure tension and three-point bending, we employed an approach of exploratory data analysis (EDA), Andrew's plot, Spearman rank correlation, and principal component analysis (PCA), respectively. We have employed this variate is various applications for more details readers are referred to [7-8].

EXPERIMENTS AND MATERIALS

We used acrylic bone cement as a sample material to illustrate the effort. Two groups of specimens were prepared for pure tension and three-point bending. The experiments were monitored by acoustic emission (AE) by glue three-sensor to the specimen's surface.

RESULTS

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Fig. 1 shows the responses of RDE to pure tension and three-point bending and those to different loading stages. It was found that the responses of variation of microstructures to the applied loads and stages can be categorized by different statistical groups regardless of difference between physical damage mechanisms.

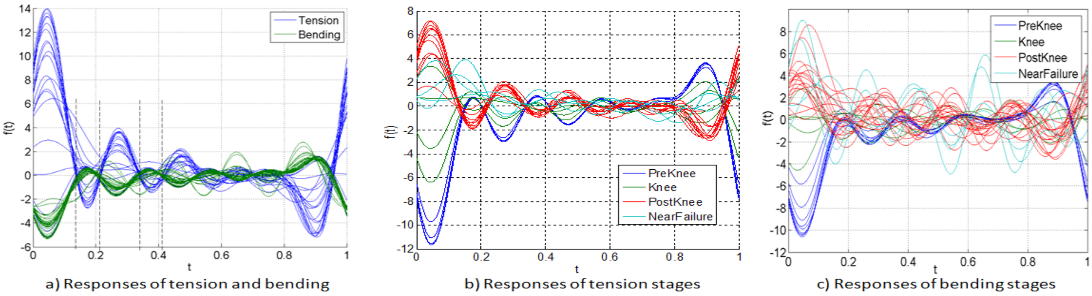

Figure 1. The responses to loading regimes and stages

Fig.2 shows the correlation between damage events and damage mechanisms by employing the Spearman rank correlation, found that damage component of different scales strongly correlated, and the strength of correlation is much stronger under tension than that under bending. The strong correlation in the pre-knee stage is of special interests, it may shed additional light to the understanding of the influence of initial damage on the performance of solids.

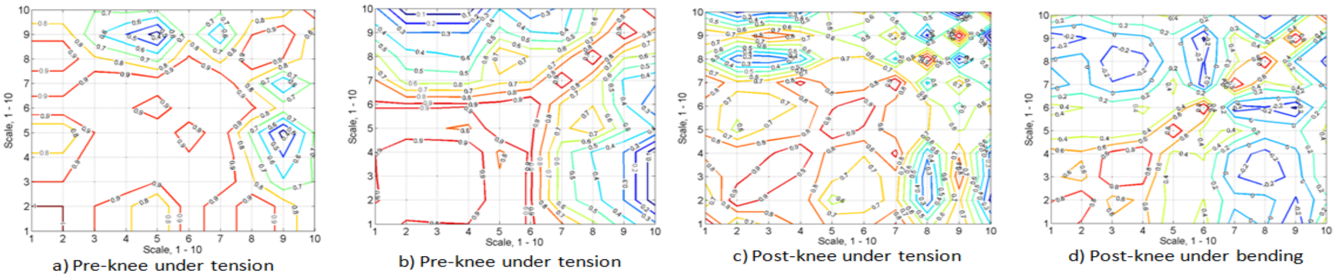

Figure 2. Spearman rank correlation under tension and bending and in different stages of each

The results of PCA are given in Fig.3. Each scale of damage involved nearly parallel in the entire process. The interactions between the scales become extremely sophisticated; there seems no damage of single scale that can dominate.

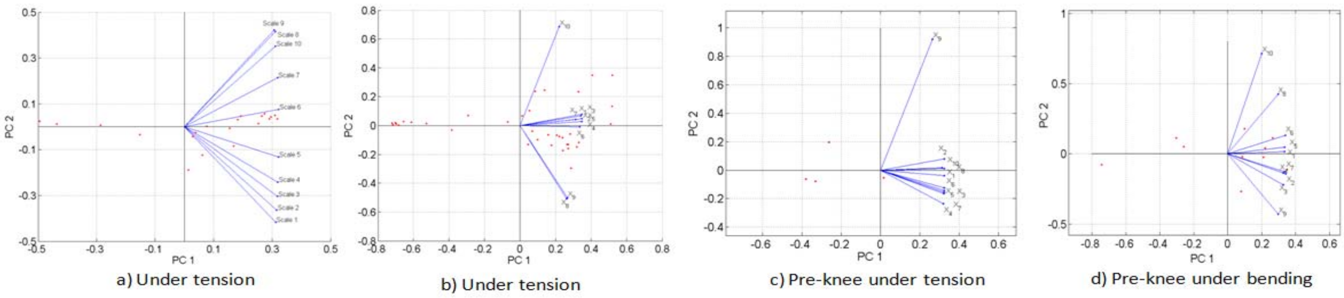

Figure 3. Principal component analysis under tension and bending and in different stages of each

Each principal component is decoupled to be orthogonal, which may contribute additionally to assist further analytical efforts.

CONCLUSIONS

The approach of multivariate analysis addresses problems of hierarchical microstructural evolution at the presence of cascading damage quantitatively. Our data suggest strongly that damage is governed by statistical group instead of individual damage mechanism; there exists strong correlation between multi- and trans-scale damage events, especially in the early loading stages, and between different mechanisms; and there is no indication that damage in any scale may dominates material behaviour at any loading stage revealed by PCA.

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