

GENERATIVE APPROACH TO MICROSTRUCTURE INFORMATICS FOR RELIABILITY ANALYSIS

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ABSTRACT

Microstructure informatics is gaining popularity in materials engineering, especially for predicting the overall mechanical properties of multiphase and polycrystalline composites. Within this framework, data-driven strategies can be exploited to learn the relevant microstructural features and their relationship with the homogenized properties. While this solution has already been well-developed to predict the elastic and strength characteristics of multiphase materials, its application to the analysis of the load-bearing capacity and reliability of structures and devices, accounting for stochastic effects at the microscale, still requires proper attention, particularly in the case of limited or scarce resources. In this work, a strategy is proposed to solve problems characterized by gradients in the stress and strain fields that prevent the adoption of standard homogenization techniques. Specifically, the localization of micromechanical features or defects that may affect the reliability of devices such as micro-electromechanical systems (MEMS) is addressed. Since these features can significantly influence the lifetime of systems subjected to cyclic external stimuli, and because optical inspection of a batch of samples is typically impractical due to its expense and time consumption, a multiscale-like approach is proposed. At a larger scale, the most relevant features of the microstructure are learned from micrographs using an artificial neural network (ANN) with convolutional layers designed for image recognition. At a smaller scale, high-resolution images are used to encode the statistics of the geometry of inclusions; at this stage, only a limited set of sub-samples from the entire domain is considered and assumed to be statistically representative. A generative adversarial network (GAN) is then employed to provide reliable proxies of the actual microstructure and predict the behavior of structural parts experiencing failure, such as cracking. Thus, the stress intensification induced by the microstructure itself, its spatial variation (which could potentially be exploited in a higher-order continuum formulation), and its interaction with boundary conditions is predicted by the proposed generative, deep learning-based strategy. Results are presented for the silver-sintered layer of power semiconductor packages, whose reliability is affected by voids that form from the evaporation of organic materials mixed with silver to enhance process efficiency. Specifically, the position, size, and evolution of these voids under an applied electrical current impact the device reliability and introduce uncertainties in the lifetime estimation.