PhD Proposal 11 in the Framework of CSC Program 2018

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Multiscale fully coupled thermo-piezo-mechanical modeling of fiber reinforced piezoelectric actuators accounting for viscous and damage mechanisms

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The tremendous growth of the materials science and the significant complexity of many modern engineering applications has led to the increasing utilization of composite materials. Many engineering industries, like automotive (Figure 1) and aerospace (Figure 2), require smart composites with advanced multi-functionality that can be applied in complicated structures with high demands in mechanical performance, strength and durability, and at the same time to have extended lifetime during repeated mechanical, thermal, electrical and/or magnetic loading cycles. To match those high requirements, composite materials are often exposed in conditions where dissipative phenomena occur, i.e viscoelasticity, rate-independent or rate-dependent plasticity, damage and phase transformation. Such mechanisms are usually accompanied by a significant temperature change, which influences in return the material behavior. To account for the thermo-mechanical couplings that arise from a structural application it is a vital issue in the case of polymeric composites. Polymers are extremely sensitive to temperature variations, especially in regimes close to the glass transition zones, and their mechanical response can be altered quite significantly due to heat dissipation. Piezoelectric composite materials with polymeric matrix are widely used in the engineering industry due to their excellent actuation capabilities. It is well understood nowadays that the mechanical response of these composites is characterized by the interplay between viscous (viscoelastic/viscoplastic) and damage phenomena (Figure 3) and they have strong dependence on the environmental conditions (relative humidity, temperature etc).

The electromechanical behavior of piezoelectric thermoplastic composites and its sensitivity to temperature variations will be examined in this work, both from experimental and modeling point of view. In terms of modeling, the majority of the proposed models in the literature are phenomenological and they account only macroscopically the effects of the composite microstructural characteristics. On the other hand, the various micromechanics studies on these materials do not consider thermal effects, arising from the energy balance, on the overall behavior. The aim of the proposed Ph.D. is to develop a novel micromechanics framework that accounts for the microstructural complexity, the various nonlinear mechanisms and the thermo-electro-mechanical couplings of the piezoelectric glass fiber composites during cyclic actuation. When considering repeated loading/unloading conditions at relatively high stresses, the activation of viscous mechanisms produce significant intrinsic dissipation, causing in return a strong interaction between thermal, electrical and mechanical fields. This interaction needs to be integrated properly into the proposed homogenization scheme, in order to obtain a better estimation of the macroscopic response of the composite and a more accurate prediction of the various fields that effect the cyclic actuation performance.

Specifically, a proper homogenization scheme in such complicated material systems requires to:

- identify the geometrical characteristics and the short fibers distribution due to the fabrication process,
- consider in a thermodynamically consistent manner the coupling between piezoelectricity, the various mechanisms (viscoelasticity / viscoplasticity) and the accumulated damage,
- correctly identify the damage propagation, with appropriate evolution laws, in all the composite phases (matrix, fibers, interphases), take into account the sensitivity of the polymer matrix with temperature, through appropriate constitutive law, and develop novel homogenization tools that consider the strong coupling between the mechanical, electrical and thermal fields through the various electromechanical loading conditions. The homogenization scheme is going to extend the classical mean-field methods (for instance, the Mori-Tanaka).

As a main outcome of this innovative research project, the developed model will be numerically implemented into the commercial finite element package ABAQUS. It will be utilized as a prediction tool towards optimal functional design and robust simulation of engineering applications using piezoelectric actuators.

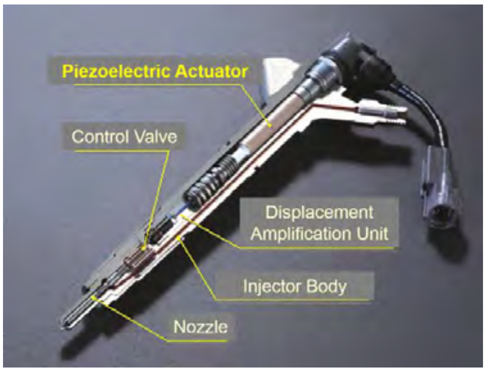

Figure 1: Common rail type diesel injection valve with a piezoelectric multilayer actuator (Denso Corporation, Uchino 2015)

Figure 2: Macro-Fiber Composite piezoelectric device for vibration control (https://spinoff.nasa.gov/)

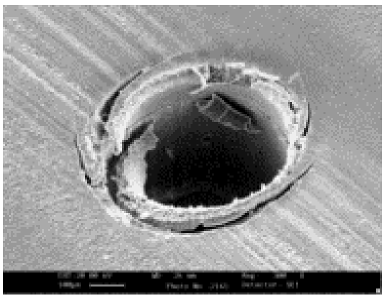

Figure 3: Damaged interface between matrix and fiber in piezoelectric composite

Related Literature

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