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Reliability-based design optimization of composite battery box based on modified particle swarm optimization algorithm

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Abstract

The application of carbon fiber reinforced polymer (CFRP) material introduces great challenges to the optimization design process, such as complex non-linear material behavior, the inherent uncertainty of design variables and multilevel characteristics of the structure. This paper aims at developing a reliability-based design optimization (RBDO) method to solve the CFRP battery box lightweight design problem considering both meso- and macro-scopic parameters. The method has three kernel parts: the uncertainty quantification and propagation part, the finite element analysis part and the optimization part. In the first part, the internal geometry variability of plain woven CFRP was obtained by X-ray micro-CT images. Representative Volume Element (RVE) models are established to predict the elastic and strength properties of the studied composites, and the constitutive model of material was adapted in stiffness and strength analysis of the battery box structure in the second part. Then a RBDO procedure considering design variables across two scales is developed using a modified particle swarm optimization and surrogate modeling techniques. The structure of the CFRP battery box achieved by the proposed multiscale optimization procedure realizes a weight loss of 22.14%, and the performance demands are satisfied with high reliability, which further reveals the advantages of using this methodology.

Keywords: Composite battery box; Multiscale reliability-based design optimization; Finite element simulation; Particle swarm optimization; Kriging surrogate model

1. Introduction

Energy conversation, environmental protection, and safety are key issues in the automotive industry. To improve the fuel economy of conventional vehicles and enhance the driving range of new energy cars such as electric vehicles, lightweight design of automotive structures has gained extensive attention. The utilization of new lightweight material and the corresponding structural design optimization are the main routines to achieve vehicle lightweight. CFRP composites have gained huge popularity of applications in automobile design for their low density, high specific stiffness and strength, excellent design flexibility and energy absorption capability[1-9].

In contrast to the traditional metal materials, CFRP composites present anisotropic properties, along with complicated damage evolution and failure processes under complex external loadings[10-13]. Several material models have been developed to characterize the properties of CFRP composites[14-18], in which phenomenological damage constitutive model is an efficient way to cover the intricate material mechanical responses. Iannucci L[14] presented a damage mechanic based progressive failure model for thin woven CFRP, which is based on an unconventional thermodynamic maximum energy dissipation approach, five damage variables were defined to describe the damage process. Xinran X[16] established damage constitutive law of