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学 位 の 種 類	博士（工学）
学 位 記 番 号	シス博　第 63 号
学位授与の日付	平成 27 年 3 月 25 日
課程・論文の別	学位規則第４条第１項該当
学位論文題名	Homogenization and Localization for Composite Structures with Relieved Periodicity in the Thickness Direction (厚さ方向の周期性を緩和した複合構造のための均質化と局所化)
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【論文の内容の要旨】

This thesis aims to develop a novel asymptotic expansion homogenization and localization analysis for advanced composite structures by relieving the periodicity in the thickness direction. Introduction of relieved periodicity is an enhanced approach in homogenization and localization method whereby the years developed method usually implements the periodicity in three directions, i.e. in-plane and out-of-plane directions. This means that the representative volume element (i.e. unit-cell) is assumed to be infinitely repeated in those three directions. However, composite laminates, especially for aerospace application, are very thin. In addition, several types of composites, e.g. 3-D composites and sandwich honeycomb composites, do not possess repeating pattern in the thickness direction. The analysis of such kinds of composites necessitates a model which represents the whole thickness of unit-cell (i.e. finite thickness unit-cell model). Correspondingly, the periodicity in both in-plane directions is of considered, while that of the thickness direction is relieved. In this regard, a modified periodic function is introduced in the numerical formulation. The developed formulation in this thesis is numerically implemented by an in-house code written in Fortran 90, and applicable for general composites structures.

This thesis is divided into five chapters as follows:

Chapter 1 presents the background and overview of this thesis. Literature study on the

multi-scale modeling approach in composites analysis is given. The published works reviewed in the study show that homogenization and localization are powerful methods to deal with unit-cell in hierarchical multi-scale analysis. Literature reviews on the development of homogenization and localization method are also presented. With regard to the consideration of only in-plane periodicity, several related works are found. However, the available works in the literature are only limited to the extension of plate theory.

Chapter 2 discusses the concept and formulation of asymptotic expansion (AE) homogenization and localization method. An overview of the standard technique with 3-D periodicity (i.e. in in-plane and out-of-plane directions) is also presented. With respect to the enhanced approach implemented in this thesis, a modified periodic function is introduced in order to relieve the periodicity in the thickness direction. This is to facilitate the analysis of finite-thickness unit-cell model in which the unit-cell is considered to be infinitely repeated only in the in-plane direction of the macroscopic structure. For such kind of analysis, the periodic function is modified so that: (i) in microscopic representation, microstructural variables within the unit-cell vary in three-directions (i.e. in-plane and out-of-plane directions) and are periodic only in in-plane directions; (ii) in macroscopic representation, the variables vary only in the in-plane directions. The formulation used in this thesis uses the principle of virtual works as a governing equation, and derived based on linear thermomechanical constitutive relation in both fiber and matrix phases.

Chapter 3 presents the numerical formulation and finite element implementation of AE homogenization and localization method with 2-D periodicity. Utilization of asymptotic expansion series on the displacement field into the governing equation results in three hierarchical equations. The equations are implemented in finite element framework, and then used to perform homogenization analysis (calculation of characteristic displacement vectors (also known as correctors) for both thermal and mechanical problem, and homogenized thermomechanical properties) as well as localization analysis (calculation of macroscopic displacement, and the stresses response within the unit-cell).

Chapter 4 discusses the case studies and results of homogenization and localization analyses. In order to understand the effects of relieving periodicity in the thickness direction as well as the utilization of finite-thickness unit-cell model, the analyses are performed to investigate several types of composites namely 2-D laminated composites, 3-D orthogonal interlock composites and sandwich honeycomb composites. Homogenized thermomechanical properties and the stresses responses within the unit-cell due to application of thermal and mechanical loads are of the main interests. The results are then compared to those of standard analysis with 3-D periodicity as well as the experiments. An extension analysis comprising geometric nonlinearity is also performed to assess the local buckling in sandwich honeycomb composites. The analysis employed linear bifurcation buckling theory whereby the stress stiffness calculation utilizes the obtained stresses from the results of localization analysis.

Chapter 5 summarizes and concludes the findings acquired in this thesis. It is found that relieving periodicity in the thickness direction has a bigger influence in the analyses of 3-D composites as compared to those of 2-D laminated composites, in both homogenization and localization analyses. It is recommended to implement the relieved periodicity when the composites have through-thickness reinforcement. In accordance to the comparison between numerical and experimental results, a good agreement is noted, especially for E_{11}. The obtained numerical results also emphasize that the application of free-traction boundary condition only at the top and bottom of the beam model is not able to accurately simulate the real free-traction condition. Releasing periodic boundary condition throughout the thickness of the unit-cell is necessary. With regard to the results of sandwich honeycomb composites, present method reveals the profound effects of the relieving periodicity particularly for the results of unit-cell model with unidirectional face laminate, for both homogenized properties and the stresses responses. In accordance to this finding, the critical buckling eigenvalue of the face with unidirectional laminate is also affected by the relieving periodicity despite the fact that the buckling shape does not alter.