Effect of off-axis layer on the tensile properties of carbon fiber reinforced polymer multidirectional laminates

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論 文 名　：Effect of off-axis layer on the tensile properties of carbon fiber reinforced polymer multidirectional laminates (炭素繊維強化複合材多方向積層板の引張特性に及ぼす非主軸層の影響)

区　　分　：甲

論　文　内　容　の　要　旨

In this dissertation, the failure mechanism of CFRP multidirectional laminates under tensile load is investigated experimentally and numerically. Special interesting is focused on the effect of off-axis layer on the tensile properties of CFRP multidirectional laminates. Three types of multidirectional CFRP laminates, namely, conventional angle-ply $[\pm\theta]_{2s}$ laminates, unbalanced angle-ply $[0/\theta]_{2s}$ laminates, and cross angle-ply $[\theta/-\theta/(90+\theta)/(90-\theta)]_s$ laminates are used in the present experiments and numerical analysis. This dissertation consists of the following five chapters.

Chapter 1 introduces the general background of CFRP composite materials, the mechanical characteristics of unidirectional laminates and multidirectional laminates, existing experimental and numerical studies in past decades, and the objective and outline of the present dissertation.

Chapter 2 describes the study on the nonlinear stress-strain behavior of CFRP angle-ply $[\pm\theta]_{2s}$ laminates subjected to tensile load by nonlinear finite element analysis. A 3D micromechanical periodic model consisting of transversely isotropic and linear elastic carbon fiber and elastic-plastic matrix is developed to simulate the nonlinear mechanical behavior of angle-ply laminates under tension. Two representative, heterogeneous and periodic models are constructed to simulate the mechanical behavior in the internal region and on the free edge of angle-ply laminates under tension, respectively. Five $[\pm\theta]_{2s}$ laminates (θ =15°, 20°, 25°, 30° 45°) under tension are analyzed. Numerical analysis results of stress-strain curves agree well with previous experimental results in a wide tensile strain range, demonstrating the validity of the present 3D micromechanical periodic model.

Chapter 3 describes the research on the microscopic damage progression in the unbalanced angle-ply $[0/\theta]_{2s}$ laminates subjected to tensile load. In situ investigation of progressive microscopic damage in the laminates is conducted by experiment and numerical simulation. Effect of off-axis layer on the tensile failure of $[0/\theta]_{2s}$ laminates (θ = 15°, 30°, 45°, 60°, 75°, 90°) is revealed based on the experimental results. Matrix cracking, fiber-matrix debonding and fiber breakage are considered in the numerical simulation by using the present 3D micromechanical model and cohesive interface model. A simple approximate formula is

proposed for the evaluation of tensile strength of $[0/\theta]_{2s}$ laminates. Numerical results of tensile strength obtained from the simulations using crack-free micromechanical model and cohesive interface model are close to the experimental results, indicating the limitation of the effect of matrix crack on the tensile strength of the present $[0/\theta]_{2s}$ laminates.

Chapter 4 describes the research on the development of high performance pseudo-ductile CFRP composite laminates by experiment and numerical simulation. A new type of multidirectional $[\theta/-\theta/(90+\theta)/(90-\theta)]_s$ laminates, named cross angle-ply laminates is proposed to explore high performance CFRP laminates with pseudo-ductile stress-strain response in two cross directions. Tensile tests and numerical analysis of three $[\theta/-\theta/(90+\theta)/(90-\theta)]_s$ laminates (θ = 10°, 20°, 30°) are carried out. Excellent pseudo ductility is found in the case of laminate $[30/-30/120/60]_s$ (θ = 30°). This result implies the great potentiality of developing a new high pseudo-ductile CFRP composite laminate based on $[30/-30/120/60]_s$ laminate.

Chapter 5 summarizes the major results of the dissertation and suggests some future research topics which may concern to this study.

〔作成要領〕

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