論　文　の　要　旨

題　目　Evaluation of fracture toughness for CFRP joints with highly toughened epoxy adhesive under mixed-mode (mode I + II) condition and plastic behavior of epoxy adhesive for various stress multiaxialities
（高じん性エポキシ接着剤による CFRP 接着継手の混合モード（モードⅠ＋Ⅱ）状態における破壊じん性の評価と種々の応力多軸度におけるエポキシ接着剤の塑性挙動の研究）

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Adhesive bonding plays an important role in integrating individual parts and transferring loads. In the design of mechanical structures, it is becoming more important to ensure the safety of integrated structure as well as individual parts. There are many factors that must be considered in the design of adhesive joints, including stress concentration, interfacial strength between adherend and adhesive, manufacturing defects, fatigue loading, mixed mode loading, and many others, in order to more accurately predict their strength. Among them, stress concentration occurs at the edges, causing crack initiation and propagation which splits the adhesive layer and leads to failure. Considering this fracture process due to crack propagation, it is necessary to evaluate the energy release rate of adhesive joints and to establish a method of strength evaluation based on fracture toughness.

In recent years, toughened epoxy adhesives have been widely used in many industries to maintain the strength of adhesive joints. In rubber modified toughened adhesive joints, the effect of plastic deformation at the crack tip on fracture toughness should be considered. Cavitation failure of micro rubber particles dispersed in the matrix resin affects the yield behavior of the adhesive. To account for cavitation of rubber particles, it is necessary to apply a yield criterion that allows influence of hydrostatic stress.

This thesis consists of five chapters. In Chapter 1, background of this study, survey of the relevant literatures, objective and structure of this thesis are explained. In Chapter 2, the fracture toughness values of rubber modified epoxy adhesive joints were evaluated under mixed-mode condition. To obtain the *R*-curves, a special loading system featuring a mechanical link was used. The experimental *R*-curves under the various mixed mode conditions were verified by comparing with *J*-integral analysis results.

Chapter 3 describes the FE analysis of crack propagation using CZM. The traction-separation law was defined by using *R*-curves which was obtained in Chapter 2. The peak loads in mixed-mode fracture toughness tests were estimated by CZM simulations. The accuracy of the prediction was verified by two types of energy-based failure criteria i.e. linear criterion and power-law criterion. The analysis results were discussed by comparing with the corresponding experimental results under four types of mixed-mode conditions.

In Chapter 4, yield criterion and plastic behavior of toughened epoxy adhesive joints were evaluated in three different stress multiaxially conditions including bulk adhesive tensile test, thick adherends shear test and butt joints tensile test. The yielding and plastic behavior were evaluated by using exponential

Drucker-Prager yield criterion which depend on hydrostatic stress and hydrostatic-stress-independent criteria including von Mises model and Hill'48 model. By comparing the experimental results and simulation results in three different stress multiaxially condition, it is concluded that hydrostatic sensitivity parameter, which is key parameter of exponential Drucker-Prager criterion, is not constant but depends on stress multiaxially.

Chapter 5 is the conclusion of this thesis. It summarizes the main achievements of this study and their significance, and also discusses future prospects.