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Simulation of Damage in Hybrid Composite Cell Structure

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Abstract: A novel type of hybrid cell composite structure has been developed and used for many practical applications. Main goal of this paper is the simulation of damage of this new composite structure. Experimental results of damage of cell structure are presented at first. Modified Non-uniform Transformation Field Analysis was proposed for simulation of damage progress. Basis of this modification are briefly described.

Introduction

At this time, a novel type of hybrid cell composite structure is a common way to produce thick-walled beam applications. Typical macroscopic sub-cells in the cross section structure are formed by the stamping process of partially cured and axially-oriented high modulus carbon fibre bundles. Each bundle is wrapped around by a thin layer of high strength fibres. Example of the cell composite structure used in hybrid spindle beam is in Fig. 1. This new material structure has its own specific stiffness properties and specific damage behavior and failure modes, respectively. Complex failure can be documented on example of fracture area of beam loaded in bending in Fig. 2. In this example, damage is developed in each sub-cell. Most of the cross-section is failed due to compressive loading and only narrow area by tensile failure. Complex modeling of damage progression even in a few cells would demands of tremendous computational performance.

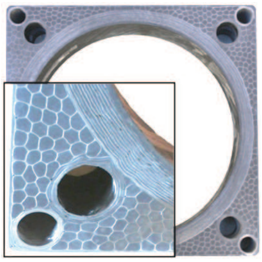

Fig. 1: Example of hybrid spindle beam with cell structure filling the corners

Fig. 2: Fracture area of beam loaded in four-point bending

Simulation of damage progression of the hybrid cell composite structure

The first goal is to focus effort on observation of real properties of cell structure. Static strength of cell structure and its building parts were measured in longitudinal and transverse direction and in shear loading. Static bending behavior was measured in four-point bending configuration and damage progression was monitored during the loading. On this experimental basis, failure and damage behavior of whole cell structure and first of all behavior of building constituents are determined. Generally, cell composite structure is built from parts with mostly brittle micro-behavior (UD composite) and from materials with plasticity. It means the gradual damage of the parts of cell structure and therefore it changes its mechanical response.

Modified Non-uniform Transformation Field Analysis (NTFA) was developed to simulate damage progression. Original method (see [1]) was developed for materials exhibiting elasto-plastic behavior. This method is based on assumption that field of plastic strain in each phase can be decomposed on finite set of fields, called plastic modes. Modification of the method is based on introducing damage modes instead of plastic modes and specific behavior of proposed damage modes. Procedure of NTFA method is based on two steps. Identification of damage modes and calculation of auxiliary operators are calculated at first and these operations are performed only once. In the second step iterative calculation of macroscopic state is performed.

Several nonlinear FEM simulations of failure of building parts have to be performed for identification of damage modes. The FEM model is based on the periodic system of the cell structure and consisting from the cells and their overwinding. FEM model of PUC of cell structure is loaded in normal and shear loading direction. Moreover analyses with loading in normal direction are duplicated for tension and compression. Common failure criteria are used for all parts of PUC. Damage modes have found in specific material directions of each constituents of cell structure.

Macroscopic state can be decomposed into sum of certain contribution of building parts with their damage modes. Evolution of damage in every damage modes is based on experimental observation. In generally, numerical models of damage modes consist of elasticity and ultimate failure and combination of plastic behavior with subsequent degradation mechanism. They have different behavior in tensile and compressive loading. Each material damage mode can fail ultimately but even failed mode can contribute to macroscopic state in certain directions. Moreover failed damage mode in compressive loading has still certain residual stiffness. General material model of damage mode is in Fig. 3. Modified NTFA method was incorporated into FEM code and verified in several four-point bending tests. Example of verification results is in Fig. 4.

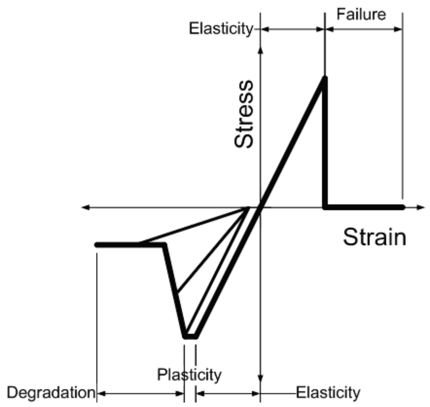

Fig. 3: Schematic material model of damage mode

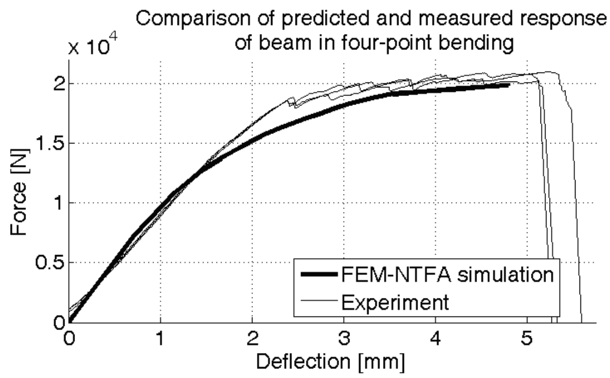

Fig. 4: Verification of the simulation

Summary

Research of newly formed material structure was done. Damage progression was simulated using modified hierarchy homogenization method. New formulation of damage modes and specific material behavior of constituent is used in presented modified NTFA method. Verification of proposed concept is based on comparison predicted bending behavior with experiment.

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