28. APPLYING THE SUBMODELING TECHNIQUE TO BALLISTIC IMPACT OF TEXTILE COMPOSITE STRUCTURES

Walter Nie

Simulia

SUMMARY

The use of braided composite materials is very attractive in aerospace and automotive industries due to their high ratio of strength and stiffness versus mass density, and their outstanding capacity in resisting crack initiation and propagation. Two major seemingly contradictive research directions have existed in parallel in the development of finite element analysis (FEA) techniques for modeling these kinds of materials. One is the macroscale approach, which attempts to simplify the braided composites as homogenous orthotropic materials so as to meet the need for analyzing large-scale structures made of braided composites in a computationally efficient manner; the other is the mesoscale approach, which tries to capture the detailed architecture of the composites and the complicated material behavior as needed in the production design process. Recently, a hybrid multi-scale analysis method, entitled the *Combined Meso-Macroscale (CMM)* FEA approach, in conjunction with the submodeling technique, was proposed by Nie and Binienda (2012) for predicting the performance of braided composite structures subjected to impact loading.

The CCM hybrid FEA method takes full advantage of each of the two major existing approaches, with the mesoscale model using a detailed finite element model of the unit cell with all of the local damage and the delamination mechanisms simulated in order to describe the details of the material response, and the macro-scale model capturing the global overall deformation and failure response of the entire structure. In an analysis of an actual structure, due to computational efficiency issues the mesoscale model should only be analyzed in key regions where capturing the details of the material response are critical, with the macroscale model being employed in the remainder of the structure. There are two different methods that may be employed to connect the macroscale modeled regions and the mesoscale modeled regions: the *direct coupling method* and the *submodeling method* (Nie and Binienda 2012). In the former method, the mesoscale model is explicitly included in the analysis model in key regions, with the remainder of the model being analyzed using the macroscopic model. In this approach, the two different regions of disparate geometries, meshing/element types and /or material properties across the interface are coupled through the use of mathematical interpolations or geometric connections. In the submodeling method, the entire structure is modeled using the macroscopic approach, but in key regions the *submodeling technique* is used to map the solution of the global model analysis performed using the macroscopic model onto the connecting interface of a separately meshed the mesomechanical model– the submodel – by judicious application of boundary conditions (Dassault Systèmes SIMULIA, 2011). The submodel is run as a separate analysis. The only link between the submodel and the global model is the transfer of the time-dependent values of variables to the relevant boundary nodes, known as the driven nodes, of the submodel.

The submodeling technique is preferred to combine the mesoscale and macroscale modeled regions for two reasons: 1) by the use of the submodeling technique the area of the structure which will be analyzed using the more detailed model does not have to be specified prior to the analysis. Conversely, the area to be analyzed in more detail can be chosen either after an initial analysis is completed using the macroscopic model or “on the fly” during an analysis based on when critical stress, strain or damage states are reached. 2) Due to the significant differences in mesh density (and even perhaps element types) between the macroscopic and mesomechanical models, in the direct coupling method a transition zone would need to be inserted between the coarse and the refined mesh of the two model types in order to avoid non-physical response. This kind of transition zone would not be required using the submodeling technique.

The CMM FEA method combined with the submodeling technique enables the capability to analyze large structures while still providing the capability to simulate local details of the material response in areas of critical interest with a refined mesh and, if needed, more sophisticated material models of high fidelity. However, concerns might arise when applying this method to dynamic problems due to incorrect stress wave reflections and propagations occurring across the interface, known as the driven boundary, where the global model and the submodel communicate with each other.

In this research, the applicability of the submodeling technique for homogenized composite materials will be demonstrated. The proof will be carried out by utilizing the uniqueness of the solution for elastodynamics boundary-value problems with wave motion equations, followed by an attempt to extend the approach to plastodynamic problems, as the composite constituents often exhibit elasto-plastic behavior with damage and strain rate effects.

Measures and techniques in FEA modeling that help maintain the effectiveness and validity of the method are discussed in this presentation. Furthermore, the applicability of Saint-Venant's principle and its extension to dynamic problems will be highlighted, in addition to the influence of the detailed modeling of local regions on the overall solution. Some application examples will be provided to demonstrate the validity, accuracy and efficiency of the CMM method implemented with the submodeling technique.