Failures of composites by micromechanics approach

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ABSTRACT

Whereas an elastic property of a composite can be accurately estimated only based on the original properties of its constituent fiber and matrix materials, a failure behavior is not achievable through the same way in the current practice in general. Extensive costs both in time and in money have to be spent to understand the failures and strengths of a candidate composite before the development of, e.g., a new aircraft structure. What is the major barrier to a reasonable estimation on a composite failure only using the original fiber and matrix properties?

The internal stresses in the fiber and matrix determined by a micromechanics theory, with which an effective property of the composite is determined, are homogenized quantities. They must be converted into "true" values in order that a failure of the constituents and further of the composite can be detected in terms of the original strengths of the fiber and matrix. Although the homogenized and the true stresses of the fiber are the same, because of the uniform stress/strain distribution within the fiber, those of the matrix are different. The true stresses of the matrix are obtained by multiplying its homogenized counterparts by corresponding stress concentration factors (SCFs) of the matrix in the composite. This is because a matrix plate with a hole subjected to an in-plane tension generates a stress concentration. When the hole is filled with a fiber of different properties, a stress concentration occurs as well.

The most significant feature is that such an SCF cannot be defined, following a classical approach, as a maximum point-wise stress of the matrix divided by an overall applied one. Otherwise, the resulting SCFs would be infinite if there is a crack on the fiber and matrix interface, as the matrix's stresses at the crack tip are singular. Even though everything is idea, with no defects in the matrix and no interface crack before an ultimate failure, the classical approach would result in an SCF far away from an expected one. Thus, the present definition for an SCF of the matrix due to introduction of a fiber must be made on an averaged quantity.

All of the issues relevant to the new definition have been soundly addressed, and closed-form formulae for the SCFs of the matrix corresponding to all of the six homogenized stress components have been successfully derived. Both perfectly bonded and cracked interfaces between the fiber and matrix have been incorporated.

With this important concept of the true stresses and the breakthrough in determination of them, almost all kinds of composite failures can be addressed essentially based on the original properties of the constituents documented in advance or measured independently. Examples shown in this talk include strength prediction for the composites used in three World-Wide Failure Exercises, detection on delamination initiation of laminates, and assessment on interface debonding between the fiber and matrix when subjected to any load. A general routine to

estimate the ultimate load carrying capacity of a composite structure subjected to any load with only the original properties of the constituents as material input data is highlighted.

Huang's Biography

Zheng-Ming Huang obtained his PhD from National University of Singapore in 1999. He was awarded a Yangtze River distinguished professor at Tongji university by the Ministry of Education of China in 2002. He has created a unified elasto-plastic constitutive theory, Bridging Model, for composites, which is unique from a viewpoint of four aspects, i.e., closed-form expression, high accuracy, versatile applicability, and consistency from two to three dimensions. He has found that the homogenized stresses in the fiber and matrix of a composite obtained by a micromechanics theory must be converted into true values before a failure detection on the composite can be made only in terms of the original fiber and matrix properties measured independently, and has established the routine to achieve the conversion. He is the author of 3 books, 6 book chapters, more than 160 peer-reviewed journal papers, and 19 patents. One of his papers has got a citation of more than 5,000 times world-widely, one of the highest citations gained in China.