20th International Conference on Composite Structures
ICCS 20
A. J. M. Ferreira (Editor)
Paris, 4-7 September, 2017

ON THE FORMULATION OF A TENSORIAL LAMINATE-LEVEL FAILURE CRITERION THROUGH INVARIANTS

Anita Catapano[†], Marco Montemurro[*]

[†] *Bordeaux INP, Université de Bordeaux, I2M CNRS UMR 5295, F-33400 Talence, France
e-mail: anita.catapano@bordeaux-inp.fr

[*]Ecole Nationale Supérieure des Arts et Métiers, I2M CNRS UMR 5295,
F-33400 Talence, France
e-mail: marco.montemurro@ensam.eu

Keywords: Strength, failure, anisotropy, polar parameters, first-order shear deformation theory.

Abstract: *Anisotropic materials, such as fibre-reinforced composite materials, are extensively used in many industrial fields thanks to their mechanical performances. The main characteristic of an anisotropic material is the dependency of physical properties upon the direction. Anisotropy influences strongly also the mechanical strength of a material, usually described by a failure criterion. We can separate the failure criteria into two distinct classes: the phenomenological/polynomial ones and the physically-based ones. The polynomial failure criteria are called in this way because the occurrence of the failure is checked through the computation of a scalar indicator, i.e. the failure index. In this framework, a unique scalar condition has to be verified, regardless the nature of the failure mechanism that is activated. It is noteworthy that all polynomial failure criteria are "ply-level failure criteria", thus, when utilised to analyse the failure of laminated structures, they are applied to each ply composing the structure in order to check the so-called first-ply-failure. However, this approach is not compatible with the methodologies often used for the preliminary design of composite structures. Indeed in this background, the number of design variables is economised by representing each laminate (composing the structure) as an equivalent homogeneous anisotropic plate characterised by a few number of parameters describing its overall mechanical response regardless to the nature of the stacking sequence. In order to include the failure mechanisms within the mathematical framework of preliminary design of composite structure an alternative approach is needed. To this purpose, a method to generalise the ply-level failure criterion of Tsai-Wu to the laminate-level (with the aim of introducing strength requirements at the macroscopic scale within the optimisation process of a composite structures) is proposed in this work.*
The Tsai-Wu criterion is formulated in the framework of the First-order Shear Deformation Theory (FSDT) in order to take into account the out-of-plane shear stress and strain components. Then, through the use of the polar method, the criterion is firstly formulated in terms of invariants. Finally it is extended, via a through-the-thickness homogenisation step, to the laminate-level in order to evaluate the strength of the entire laminate. The laminate-level failure criterion is thus expressed for a laminated plate modelled as an equivalent single layer having the same thickness of the laminate.
Thanks to the polar representation a physical meaning of each tensor appearing in the laminate-level criterion is also given. The resulting criterion is then used in the framework of

a strength optimisation problem in order to show the effectiveness of the proposed method. The multi-scale two-level optimisation strategy is used to firstly optimise the polar parameters of the tensors of the laminate-level criterion (macro-scale optimisation step) and then the lay-up design is carried out to find at least one stacking sequence satisfying the strength polar parameters provided by the first-step of the strategy (meso-scale optimisation step)