A Directed Continuum Damage Mechanics Approach to Model Static Indentation Induced Damage in Composites

Manish Kumar[1,*], Supratik Mukhopadhyay[1]

[1] Department of Mechanical Engineering, Indian Institute of Technology Kanpur, Kanpur, Uttar Pradesh, 208016, India, kumanish@iitk.ac.in

The demand for lightweight and high-strength materials in aerospace, automotive and marine industries has necessitated the use of fibre-reinforced polymeric composites in place of metal alloys. Existing structural design guidelines, therefore, need to be suitably modified considering the specificities in the mechanical behaviour of this new material system. Due to their inherent brittle nature, composite structures tend to fail catastrophically. This aspect is of particular concern to the transportation sector, where ensuring passenger safety is of utmost importance. Among others, low-velocity impact (LVI) is one of the common incidents causing localised damage in composites. Since LVI typically causes damage to the interior of the laminate and the exterior appears intact to visual inspection, it is also known as Barely Visible Impact Damage (BVID). Advanced structural health monitoring techniques are commonly required to identify the extent of this type of damage experimentally, which increases inspection cost and time. Computational realization of LVI events incorporating accurate damage models provides an alternate route to understand better this type of damage in an inexpensive way.

In a Finite Element (FE) framework, LVI-induced damage is commonly modelled at the ply level using continuum damage mechanics (CDM) framework, while interface damage is represented by cohesive zone models (CZM). However, the classical CDM method works by gradually degrading the material stiffness by smearing the damage across the entire element volume, resulting in the loss of information about the discrete nature of ply matrix cracks as well as the crack and delamination interaction during damage growth. Another issue with classical CDM is that the crack growth direction is influenced by the mesh lines of the finite element model [1]. To address the second issue, typically local fibre direction-oriented mesh is used for each individual ply of the laminate [2] which adds to the meshing effort significantly. Additionally, oriented mesh results in mesh mismatch at ply interfaces, requiring enforcement of tie constraints to hold the assembly together, which substantially increases computational time.

Since, quasi-static indentation results in a very similar damage pattern as observed under dynamic conditions in LVI [3], the present work numerically simulates damage onset and growth under quasi-static indentation in a multidirectional laminate [2] using a novel directed CDM (D-CDM) approach [1]. The D-CDM augments the traditional CDM by incorporating an accurate kinematic representation of the sharp crack topology of the ply matrix cracks at the constitutive level. Further, a crack tracking algorithm is applied that eliminates the mesh orientation bias of ply crack growth, which greatly reduces the meshing effort. Also, the analysis time is reduced due to the elimination of tie constraints. This technique is implemented as a 3D user-defined material in Abaqus/Explicit.

The numerical results using this new method are compared with experimentally obtained damage patterns reported in the literature as well as associated load-displacement curves, showing an excellent agreement.

References

[1] S. Mukhopadhyay, S. R. Hallett, A directed continuum damage mechanics method for modelling composite matrix cracks, Composites Science and Technology 176 (2019) 1-8.

[2] X. C. Sun, M.R. Wisnom, S.R. Hallett, Interaction of inter- and intralaminar damage in scaled quasi-static indentation tests: Part 2 Numerical simulation, Composite Structures 136 (2016) 727-742.

[3] Y. Aoki, H. Suemasu, T. Ishikawa, Damage propagation in CFRP laminates subjected to low-velocity impact and static indentation, Advanced Composite Materials, 16 (2007), 45-61.