Finite Fracture Mechanics versus Phase Field models of fracture: A case study on the crack onset from circular holes under biaxial loadings

A. Chao Correas[1,2,*], A. Sapora[1], J. Reinoso[2], M. Corrado[1], P. Cornetti[1]

[1] Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Corso Duca degli Abruzzi, 24, 10129, Turin, Italy, arturo.chaocorreas@polito.it
[2] Elasticity and Strength of Materials Group, School of Engineering, Universidad de Sevilla, Camino de los Descubrimientos, S/N, 41092, Seville, Spain

The phenomenon of brittle crack onset stemming from a circular hole embodied in a biaxially loaded infinite plate is herein investigated. Analyses on the dependence of the conditions upon failure with the loading biaxiality reveal a wide casuistry in terms of the sign and trend distributions of both the stress field and energy release rate. This renders the considered case study exhaustive towards assessing different failure criteria. This feature is thus exploited towards conducting a thorough assessment of the crack onset predictions by three different in vogue approaches: Finite Fracture Mechanics, Cohesive Zone Model and Phase Field models of fracture.

Failure predictions by the original formulation of the Finite Fracture Mechanics' coupled criterion [1] result to be consistently more optimistic than those of the averaged-stress counterpart proposed in [2]. Still, both approaches agree to state that there exists some tension-compression and bi-compression loading states for which a certain range of hole sizes are associated to energy-governed failures, with no direct participation of the stress condition. Remarkably, this implies that Finite Fracture Mechanics may foresee failure nucleation as strength-independent for non-singular geometries.

Furthermore, the well-established Dugdale's Cohesive Zone Model [3] is implemented towards providing some benchmark crack onset predictions, which result to be close to those by the Finite Fracture Mechanics approach. In line with what seen in the literature, there is a better agreement with the latter's original formulation, yet to an extent that varies with the loading biaxiality and the hole size.

Lastly, the Phase Field model of fracture is implemented paying special attention to the choice of the strain energy decomposition (in terms of the energetic contributions of tensile and compressive states), being herein implemented two relevant options: No-Decomposition and No-Tension decomposition (see [4]). As expected, the former model yields an utter unrealistic behavior as for being symmetric in tension and compression. On the other hand, the No-Tension choice results a much more accurate option for it restricts failure to tensioned regions. Furthermore, this model yields failure onset predictions in satisfactory agreement with Finite Fracture Mechanics, specially in the cases where the latter's predictions fall in the intersection of stress and energy conditions. As a result, the Phase Field model of fracture using the No-Tension strain energy decomposition is deemed a solid contender for predicting crack onset in scenarios with combined tension-compression stress states along the prospective failure region. Consequently, it is further used to study the interaction between arrayed holes and the resultant crack onset behavior.

References

[1] D. Leguillon, Strength or toughness? A criterion for crack onset at a notch, Eur J Mech A Solids, 21 (2002) 61–72.
[2] P. Cornetti, N. Pugno, A. Carpinteri, D. Taylor, Finite fracture mechanics: A coupled stress and energy failure criterion, Eng Fract Mech 73 (2006) 2021–2033.
[3] D. Dugdale, Yielding of steel sheets containing slits, J Mech Phys Solids 8 (1960) 100–104.
[4] L. De Lorenzis, C. Maurini, Nucleation under multi-axial loading in variational phase-field models of brittle fracture, Int J Frac 237 (2022) 61-81.