FINITE FRACTURE MECHANICS VERSUS PHASE FIELD: A CASE STUDY ON THE CRACK ONSET FROM CIRCULAR HOLES UNDER BIAXIAL LOADING CONDITIONS

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

[1] *Politecnico di Torino, Turin, Italy*
[2] *Universidad de Sevilla, Seville, Spain*

* *Presenting Author email: arturo.chaocorreas@polito.it*

Abstract
The phenomenon of brittle crack onset stemming from a circular hole embodied in a biaxially loaded infinite plate is herein investigated. Three different approaches are used to determine the biaxial safety domains: Finite Fracture Mechanics, Cohesive Zone Model and Phase Field. In particular, the original formulation of Finite Fracture Mechanics (FFM) proves to be consistently more optimistic than its averaged-stress variant (FFM-avg); likewise, both agree in predicting the existence of a region in the loading space where failure is governed by the energy condition. Besides, failure predictions according to Dugdale's Cohesive Zone Model (CZM) prove to be fairly close to those by FFM, whereas the differences between CZM and FFM-avg result more noticeable. Lastly, the Phase Field model of fracture is implemented paying special attention to the choice of the energy decomposition, being herein implemented two relevant options: No-Decomposition and No-Tension decomposition. In particular, the latter showcases reasonable agreement with FFM (and CZM), thus rendering it a solid contender for its use in applications in which combined tension-compression stress states appear, such as in the dynamic failure of brittle materials.

1. Introduction

Different previous investigations have addressed the onset of failure stemming from a single circular hole embodied in an infinite plate under both uniaxial and biaxial loading conditions. Nonetheless, to the authors' best knowledge, the existent studies considering the latter loading setup have always focused on particular cases of biaxiality, and no piece of research has already shown complete and continuous biaxial safety domains determined through the current state-of-the-art failure initiation criteria. In addition to the previous considerations, the introduction of biaxial loading conditions results in a considerably increase of the casuistry associated to the problem, thus meaning that this case study is a useful benchmark to test different formulations upon a wide variety of failure conditions.

To this end, the present work focuses on obtaining these biaxial safety domains by means of three different failure criteria: Finite Fracture Mechanics, Cohesive Zone Model and Phase Field model for fracture. The characteristic features of each criterion under the different failure scenarios are then herein highlighted and compared against each other, aiming to establish commonalities among them.

2. Results

The fracture initiation criteria here considered for obtaining the safety domains are the following: Finite Fracture Mechanics, both the original (FFM) and the averaged-stress (FFM-avg) versions; Cohesive Zone Model-Dugdale (CZM); and Phase Field model for fracture without energy decomposition (PF-NoSplit) and with the No Tension decomposition (PF-NoTension). In particular, the respective safety domains resulted to have the following characteristics:

- Both FFM and FFM-avg predictions were close, although the latter provided more conservative failure initiation estimates (see Fig. 1(a)). Likewise, both of them agreed to state that there exists some tension-compression and bi-compression loading states for which certain range of hole sizes are associated to energy-governed failures, with no direct participation of the stress condition.

- The agreement between FFM and CZM proved to be generally good (see Fig. 1 (b)), although to an extent that depends of the loading biaxiality and the hole size. Indeed, the agreement was seen to improve for higher stress concentrations at failure, in accordance to the FFM-CZM comparisons present in the literature for different geometries. Likewise, the correlation with FFM-avg was poorer.
- The effect of the energy decomposition in the Phase Field model for fracture was very large as expected. In this sense, the lack of energy decomposition yielded unrealistic failure behavior, as for being symmetric in tension-compression. For this reason, it is not further considered for comparison purposes. On the other hand, the NoTension energy decomposition resulted much more in agreement with what expected, i.e. failure only appeared in fully tensioned regions.
- The safety domains obtained through the PF-NoTension and the FFM approaches resulted to be in great agreement when the latter was governed by the coupled criterion (and not only the energy condition, see Fig. 1(c)). This proved the soundness of the PF-NoTension for its use in multiaxial loading scenarios in which tension and compression stress states are present and failure is expected to only develop in tensile regions, such as the dynamic failure of brittle ceramic-like materials.
- All the considered criteria are able to predict the effect of the hole size in the failure initiation load, despite the geometry being non-singular and the stress concentration factor being independent of the hole size. Indeed, this proves once again the importance of utilizing non-local failure criteria in which the characteristic length is associated with the energy balance upon failure.

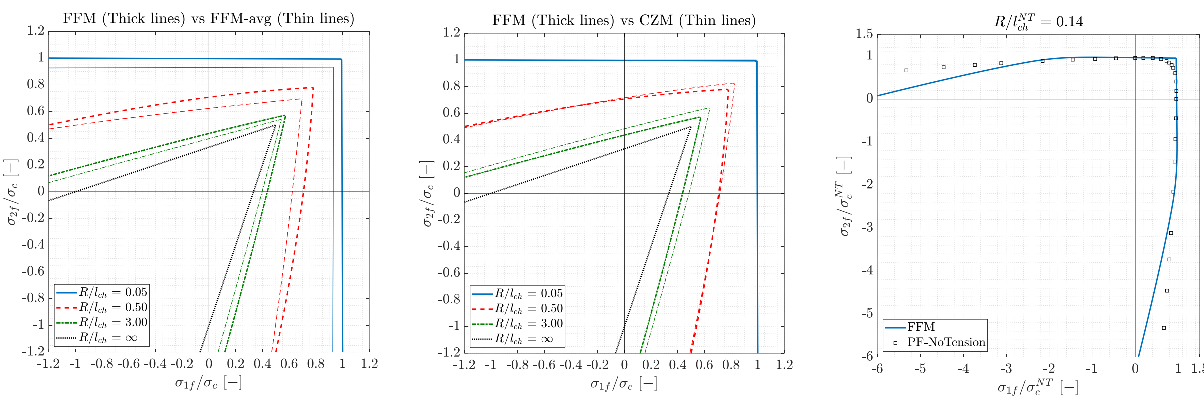

Fig.1 – Comparison of the biaxial safety domains according to (a) FFM and FFM-avg; (b) FFM and CZM; and (c) FFM and PF-NoTension.

3. Conclusions

Failure initiation of a bidimensional, infinite and brittle structural domain that contains a circular hole and is subjected to biaxial loading conditions was herein investigated by means of different failure criteria. The resultant biaxial safety domains resulted in reasonable agreement to each other, despite the large differences in their respective formulations. Likewise, the wide casuistry in the conditions upon failure revealed some behaviors of the failure criteria which would have not manifested otherwise, proving the suitability of the present setup as a benchmark test for failure criteria assessment.

Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska Curie grant agreement No 861061.