Fracture processes and phase field modelling - Discussion of fracture paper #11

Ståhle, P.; Ståhle, P.

2015

Engineering Fracture Mechanics
An International Journal

iMechanica Blog

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2 May 2015

In the latest volume of Engineering Fracture Mechanics there is an interesting paper about the calculation of crack growth paths by use of a phase field model. The considered material is inhomogeneous and that causes the crack to follow a winding path through the material. The material structure is from a CT scanned micro-structure of a cement-based porous material. The paper is:
"A phase field method to simulate crack nucleation and propagation in strongly heterogeneous materials from direct imaging of their microstructure" by T.T. Nguyen, J. Yvonnet, Q.-Z. Zhu, M. Bornert, C. Chateau, Engineering Fracture Mechanics, Vol 139 (2015) pp. 18–39.
The phase field method used, is adopted to fracture analyses. It is according to the authors the first time the method is used in the present context with a modified algorithm to handle the damage due to traction. The phase field model, suggested by Landau and Lifshitz in E. Phys Zeit Sowjetunion 8:153 (1935) is based on the principles of statistical physics and continuous variation of the structure. The original usage was for thermodynamical studies of solidification, coherent interfaces and other problems where the specific physics of surfaces and interfaces are important. Later the models came to be used to keep track of surfaces and interfaces with less interest in the particular physics of the interfaces. The model was successfully used in mechanics and not the least by many for analyses of growing cracks.
In conventional fracture analyses a known or a postulated crack is required, which is not needed in phase field modelling, as is pointed out by Ngueyen et al. This is a serious drawback in studies of fatigue or stress corrosion whereas a large part of the lifetime of cracks and surface flaws is spent during an initiation phase. Further, crack growth and crack path criteria are obsolete in phase field modelling, since the continuous disintegration of the body is an inherent part of the general structural model. In the work by Ngueyen et al., much of the interest concerns the numerical efficiency of the method, which obviously is paying off as the increased efficiency is demonstrated for crack nucleation and propagation in 2D and 3D geometries taken from images of porous cement-based materials.
A couple of perplexing questions got stuck with me after having read the article. One question is: Did it work with the crack path predictions? Of

course the crack grew through the inhomogeneous material following a path that would pass as visually acceptable, but so would a variety of alternative paths. To be more specific, the path is controlled by the fracture processes which in the present case would be the evolving damage in the way that it is governed by the phase-field model. It would be interesting to know what the expected physics are behind the path selected by the proposed model? Is it a path closely following maximum energy release rate as is suggested by the basic principles of the phase-field model, or is it perhaps closer to a pure mode I path since the model is restricted to consider damage solely initiated by tractions? In conventional material modelling these paths become different. I think that similarities between conventional models and the phase field model would give increased confidence to both models and the differences would be interesting to discuss.

Another property of the phase-field model that captured my curiosity is its ability to penetrate bi-material interfaces between materials with different stiffnesses as is observed in the compression cases in the paper. The paradoxical result of brittle materials and sharp cracks is that the crack can only grow from a stiffer to a weaker material whereas the interface is impenetrable in the opposite direction. This was the subject of the ESIS review no. 9. The authors comment that it is desirable to investigate the influence of the length scale, that control the sharpness including the width of the crack tip and the stress level ahead of the crack tip which I agree would be very interesting as regards the described paradoxical behaviour.

Per Ståhle