Damage growth in coal under uniaxial compression

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Quantitative analyses of damage growth during in-situ uniaxial compression are significant to understand fracture and permeability in coal. Given the influence of complex microstructures and pre-existing cracks, it is difficult to quantify damage processes when based upon X-ray microtomography alone. Therefore, an advanced finite element based digital volume correlation (DVC) algorithm is proposed, in which mechanical regularization, damage law, and mesh refinement schemes were considered simultaneously to allow for the measurement of kinematic fields in cracked regions with very fine spatial resolutions. In particular, damage was quantitatively characterized even at levels less than one voxel by estimating crack closure/opening displacement fields of pre-existing/newborn cracks.

The implemented procedure consists of the following four steps.

1. Mechanical regularization based on the equilibrium gap method is introduced into FE-based global DVC as a low-pass filter to dampens out high spatial frequencies, theryby gaining an initial estimation of kinematic fields for which linear elasiticy applies.
2. A brittle damage law [1] was added in the above regularized DVC framework to allow for high displacement gradients in cracked zones. Specifically, a damage variable was applied to reduce the regularization weight of damaged elements that are detected by gray level residuals and maximum principal strains.
3. A mesh refinement scheme was carried out in those damaged elements to better capture crack shapes and kinematic characteristics. A master-slave elimination was utilized to deal with hanging nodes at the junction of coarse and fine meshes. In addition, the mesh size is no longer limited thanks to regularzition, which can even reach the voxel level if needed.
4. All the workflow was integrated into a multimesh DVC [2] scheme to measure internal deformation fields and evaluate crack opening and closure displacement fields. Such information is very useful to understand the damage scenario in the studied experiment.

In the investigated uniaxial compression, damage mechanisms of coal were quantitatively studied based on the initiation and propagation of newborn cracks, as well as the closure of pre-existing cracks. The measurement uncertainty of multimesh DVC was assessed based on the first two scans. Before levels equal to 50% of the ultimate strength, only pre-existing cracks closed. When loaded to 60% of the ultimate strength, microcracks initiated at the end of the pre-existing cracks, then further opened and propagated vertically. Such interactions among pre-existing and newborn cracks explained the damage development process from subvoxel to voxel levels. This study demonstrates the potential of regularized multimesh DVC for damage quantification in quasi-brittle materials using very small spatial resolutions.

References

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