Computational modelling of damage in rubber like materials

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Problem Statement

Localization of damage parameter and the pathological mesh dependency of solution are the main problems in damage modelling of rubber with localized models. Introduction of non local damage variable and its gradient into the solution solve these problems [1]. These are known as non local gradient enhanced material models and involve damage parameters which controls the solution whose effect need to be studied for better understanding. The current work focuses on the study of effect of these damage parameters.

Formulation

Neo Hooken material model is modified inorder to include the effect of damage and the modified strain energy is given as,

$$U_{mod}(\boldsymbol{F},\kappa) = \frac{K}{2}\left[ln(J)\right]^2 + \left[1 - d(\kappa)\right]\frac{\mu}{2}\left[(J^{-2/3}I_1) - 3\right] \tag{1}$$

Here, U_{mod} is the modified strain energy density, $\boldsymbol{F}$ is the deformation gradient, κ is the local damage variable, K is the bulk modulus, $J = det(\boldsymbol{F})$, $d(\kappa)$ is the damage function, μ is the shear modulus, I_1 is the first invariant of left Cauchy Green deformation tensor. The damage function used in the current problem is given below,

$$d(\kappa) = 1 - e^{-\eta_d\,\kappa} \tag{2}$$

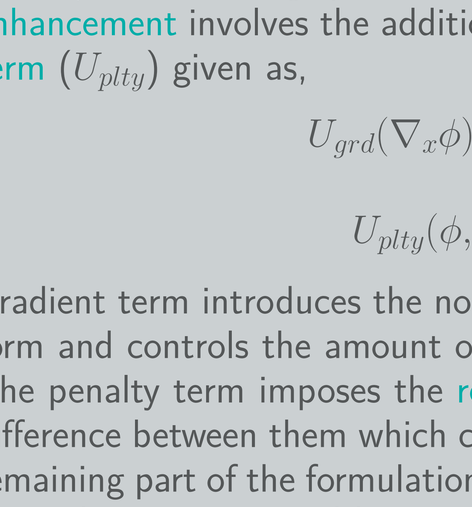
Here, η_d is the damage parameter which controls the damage rate. Gradient enhancement involves the addition of a gradient term (U_{grd}) and a penalty term (U_{plty}) given as,

$$U_{grd}(\nabla_x\phi) = \frac{c_d}{2}\nabla_x\phi\,.\,(\nabla_x\phi)^{\mathbf{T}} \tag{3}$$

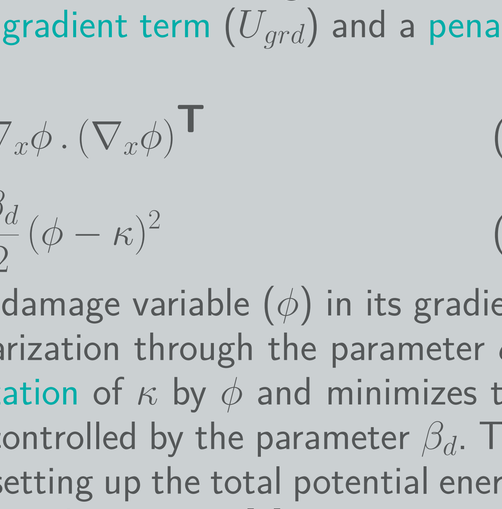
$$U_{plty}(\phi,\kappa) = \frac{\beta_d}{2}(\phi - \kappa)^2 \tag{4}$$

Gradient term introduces the non local damage variable (ϕ) in its gradient form and controls the amount of regularization through the parameter c_d. The penalty term imposes the regularization of κ by ϕ and minimizes the difference between them which can be controlled by the parameter β_d. The remaining part of the formulation from setting up the total potential energy up to discretization and linearization is similar to as in [2].

Results



Boundary conditions



Damage initiation

Figure 1

Results (cont..)

The developed finite element code is applied to a problem whose boundary conditions and expected damage initiation [3] are shown in Fig.1.The effect of various damage parameters is shown in Fig.2.

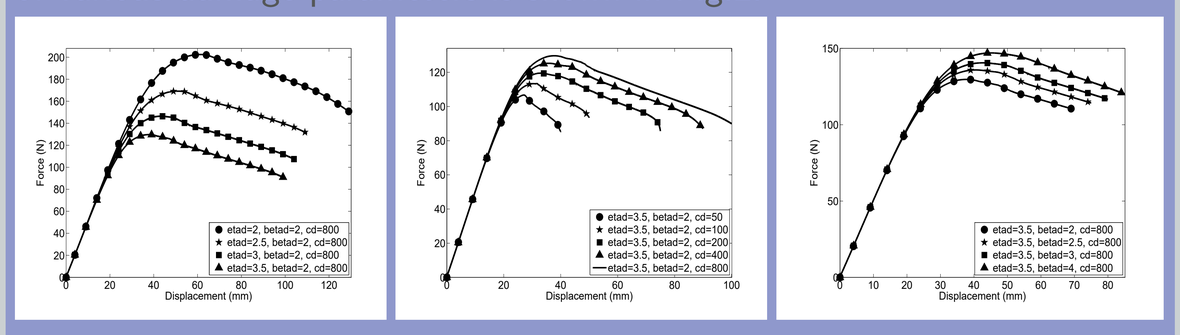


Figure 2

For $\beta_d = 2\,MPa^{-1}$, $\eta_d = 3.5\,MPa^{-1}$, a comparison of damage contours for $c_d = 100, 800\,MPa^{-1}mm^2$ is made in Fig. 3 ($c_d = 100$ (left), $c_d = 800$ (right)).

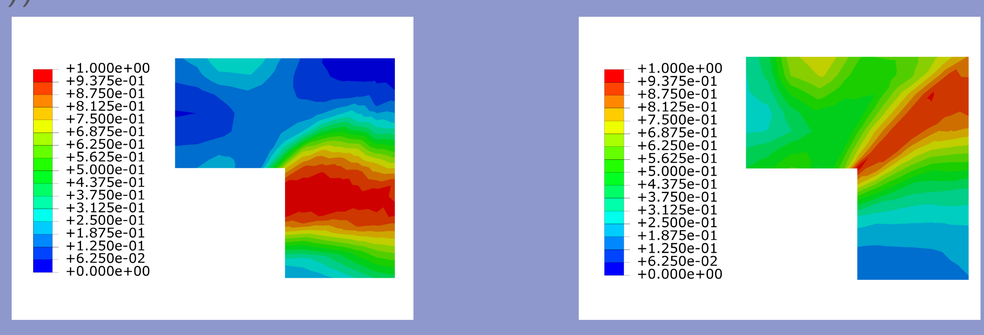


Figure 3

Discussion & Conclusions

The damage initiation is as expected (see Fig.3 (right)). The damage delays with the increase of β_d and c_d and vice versa for η_d (see Fig.2). At lower values of c_d a deviation from expected results is observed when compared to higher values of c_d. This is due to the fact that at lower values of c_d the amount of regularization on κ is not sufficient when compared to higher values of c_d which proves that **c_d** controls the amount of regularization. Mesh independency is also observed for this problem for various mesh densities. Similar results are observed when the current finite element code is applied to the problem of uniaxial tension with notch. Expected results with clear damage evolution without localization and mesh independency proves that the non local material models are suitable for the analyzed problems. More examples need to be studied for generalization of above statement.

References

[1] Jha et al. (2016), A non-local approach to lifetime prediction of cord-rubber composites.

[2] Tobias Waffenschmidt (2013). Modelling and simulation of adaptation and degradation in anisotropic biological tissues.

[3] Christian et al. (2016), On the relation between phase-field crack approximation and gradient damage modelling.

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