Finite Element Solution of Nonlinear Transient Rock Damage with Application in Geomechanics of Oil and Gas Reservoirs

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Abstract

The increasing demand of energy calls for advances in technology which have been translated into more accurate and complex simulation of physical problems. We are looking at the problem of volumetric rock damage which is essential to understand the geomechanics of oil and gas reservoir rocks. The fragile microstructure of some rocks makes it difficult to predict the propagation of damage and fracture in these rocks, therefore a mathematical model is required to predict the fracture mechanisms in such materials. The governing equation of rock damage is a nonlinear parabolic partial differential equation (PDE) which follows a thermodynamic bond breakage mechanism. The physics of the problem impose a number of complexities which should be handled numerically, such as blow-up of the solution when fracture initiates (Figure 1) and the nonlinearity due to non-negative rate of damage. In this paper, we are presenting the results that we obtained using COMSOL 3.5a and we are showing how a complicated problem can be solved using the finite element method incorporated in COMSOL. Moreover, the utilization of MATLAB® in conjunction with COMSOL enabled us to have better control on problem variables. We show how the availability of interfacing option boosts the numerical analysis and post-processing efforts. The main applications of the simulation results that we present in this article are: To understand geomechanics of oil and gas reservoirs; to solve nonlinear time-dependent PDE of the rock damage with a non-healing mechanism in COMSOL; to utilize interfacing option to have a better control on problem variables; and to appreciate the significance of rock damage process in modeling the problems of flow in porous medium. In this paper we have used COMSOL Multiphysics to solve the transient rock damage problem. We analyzed the non-healing process and incorporated the positive rate of damage in the finite element solution obtained from COMSOL. A series of numerical results are presented to show that the diffusion of damage in solids exhibit two regimes of propagation, depending on the pore size of the rock matrix. Due to the strong nonlinear nature of the propagation of fracture in rocks, there is no analytical solution available. Therefore, the equation has to be solved numerically. We have solved the governing time-dependent equation using 1D and 2D geometry (Figure 2 and Figure 3). The results we have presented could be used in similar geomechanical and structural damage problems such as failure and rupture of steel, aluminum, and concrete, etc.

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Figures used in the abstract

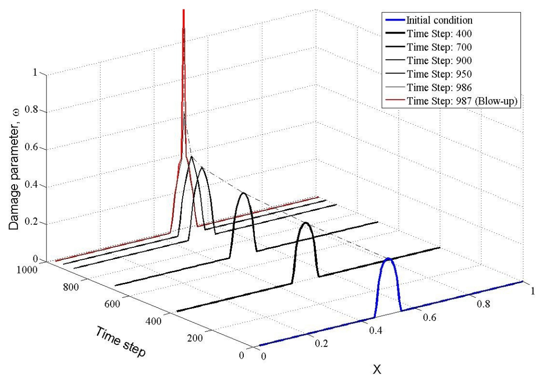

Figure 1: Blow-up of solution for damage diffusion parameter=0.

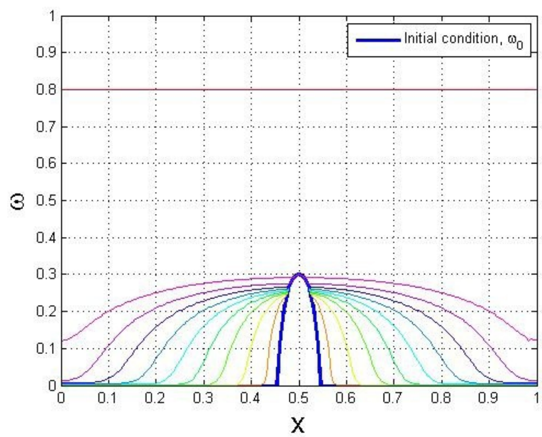

Figure 2: 1D solution of damage propagation in rock.

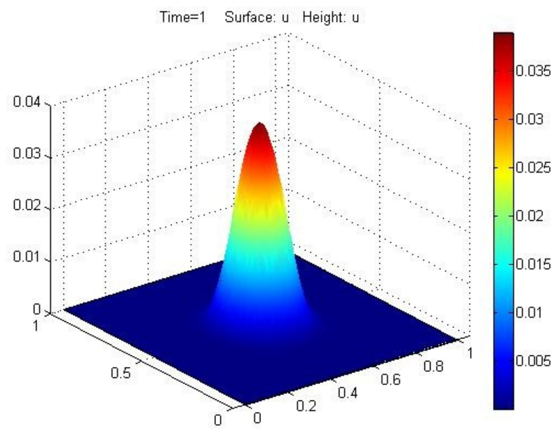

Figure 3: Two dimensional solution of damage propagation in rock.