

ABSTRACT

Considering the potential applications of relatively new materials like toughened structural polymers, metallic foams, plastics, transformation toughened ceramics, vertically aligned carbon nanotubes (VACNTs) etc and their limited exploration till now, it appears that there is a need to investigate more about the behavior of such materials under a wide range of loadings. Even though the effect of plastic dilatancy is neglected in classical plasticity theory, the above materials exhibit plastic volume changes and/or pressure-sensitive flow strength. In a recent study, it has been observed that the deformation of the entangled arrays of carbon nanotubes or VACNTs follow elastic-viscoplastic constitutive relation which incorporates plastic compressibility, plastic non-normality and a hardening-softening-hardening type hardness function. These VACNTs have prospective uses in a variety of applications like viscoelastic energy absorption, compliant thermal interfaces, biomimetic dry adhesives etc and hence it is useful to develop a predictive framework for the mechanical behavior of VACNTs under a wide range of loadings. In this thesis work, finite element finite deformation quasistatic mode I plane strain small scale yielding analysis of crack tip blunting and near crack tip fields was carried out for plastically compressible solids exhibiting a variety of uniaxial stress – strain responses. In particular solids with hardening-softening-hardening responses as can occur for foams and VACNTs have been considered. The novelty of this model includes unique characteristics as mentioned earlier like the hardening-softening-hardening material response, strain rate-dependence, and plastically compressible solids with plastic non-normality.

As for localization studies it needs a finite strain description, using FORTRAN a finite element finite deformation code has been developed in this work for the simulation

purpose. A convected coordinate Lagrangian formulation of the field equations was used. Quasistatic deformation conditions have been assumed and the equilibrium equations were expressed through the virtual work principle. The plane strain calculations were carried out for a semicircular region with a blunt notch. Quadrilateral elements each comprised of four crossed constant strain triangular elements have been used for mesh generation. Such elements with a proper aspect ratio and orientation are extensively used to replicate localized deformation pattern at finite strains. The initial part of the investigation refers to crack tip blunting and field quantities analyses under monotonic load while in the next part studies were conducted for fatigue loading to find the key results of crack tip blunting and fields. Even though most of the results presented are for plastic normality condition, however for comparison purpose some results have also been illustrated for constitutive relations exhibit plastic non-normality. While to simulate fatigue crack growth by means of finite elements, different techniques have been proposed over the years, however, in this work the crack growth modelling strategy employed was crack tip blunting/resharpening mechanism where it is assumed that the crack tip blunts during the maximum load and resharpening of the crack tip takes place under minimum load. The simulations attempt to explain some of the salient features, like crack tip opening displacement, crack tip advancement, plastic zone shape and size, equivalent plastic strain distribution, equivalent stress, and distribution of hydrostatic stress at near crack region. The influences of plastic compressibility, material softening, cyclic stress intensity factor range, load ratio, number of fatigue load cycles on the near tip deformation and stress-strain fields were studied.

Numerical results obtained from the quasistatic mode I plane strain analysis demonstrate that plastic compressibility is found to give an increased crack opening displacement for a given value of the applied loading. The plastic zone shape and size are found to depend

on the plastic compressibility. Even though, material softening does not have a significant effect on the plastic zone size and shape, however, the near crack tip stress and deformation fields depend sensitively on whether or not material softening occurs. The combination of softening or softening-hardening material response and plastic compressibility leads to major deviation in the near crack tip stress and deformation fields from those that prevail for a hardening material. Plastic compressibility coupled with a softening or softening hardening material response leads to localized deformation in front of the initial crack tip, which in turn affects the shape of the blunted crack tip. The present numerical calculations show that the convergence of the cyclic trajectories of CTOD to stable self similar loops and plastic crack growth depend significantly on cyclic stress intensity factor range, load ratio, number of fatigue load cycles.

Keywords: Finite Deformation, Mode I crack, Plasticity, Compressible Solids, Material Softening, Monotonic Loading, Fatigue Loading, Finite Element Method.