ABSTRACT

Snow is a porous material with network of interconnected sintered ice crystals. The mechanical behaviour of snow depends upon its density, arrangement of ice network or microstructure, and deformation behaviour of ice. The microstructure of snow may be anisotropic and this can lead to an anisotropy in its stress-strain relation. The anisotropy in microstructure of snow can be expressed mathematically in terms of a second rank fabric tensor. Here, we present a stress-strain relation for snow which has dependence on microstructure built in it through the fabric tensor.

Relations for fabric-based elastic and strength properties of snow have successfully estimated recently. Motivated by this, we propose a fabric-based macroscopic elasto-plastic constitutive law for snow, which can be used to study avalanche initiation. The fabric tensor and density-dependent yield surface with a provision for isotropic hardening/softening are used in this process. Beyond the initial yield, the yield function grows till the strength of the snow is reached and then softens. Since snow exhibits tension and compression behavior asymmetry, a piece-wise quadratic yield function is used.

The study is performed over different density snow samples comprising of round grain (RG), faceted crystal (FC), and depth hoar (DH) snow classes. Mean Intercept Length based fabric tensor (MIL fabric) for each snow sample is determined from the X-ray micro-computed tomographic (μCT) data. The μCT data is employed to construct the 3D μFE model of each snow sample. Each sample's homogenised stress-strain response and mechanical properties are determined from their 3D μFE model subjected to different boundary conditions. The unknown parameters of the fabric-elasticity and fabric-strength model are evaluated from the snow samples' homogenised elastic, strength, and fabric data. The constant of isotropic hardening/softening function is determined from the homogenised stress-strain and accumulated plastic strain data of snow samples.

The fabric-based failure surface in 3D, biaxial normal-normal and normal-shear are constructed, which depicts the strength asymmetry in tension and compression. The macroscopic constitutive law has been implemented as FE code (VUMAT) to predict the fabric-based stress-strain response. The macroscopic constitutive law and μFE based stress-strain response for high-density RG, FC, DH, and low-density FC snow in uniaxial and confined compression are compared. The fabric and μ-FE data showed a good match.

The macroscopic constitutive law is applied to layered snowpack with strong and weak layers. Recent studies on snowpack, such as subjected to skier and gravity load, Propagation Saw Test (PST), are investigated with the fabric-based model. The stress distribution in a weak layer at the different slab and weak layer thicknesses, and PST output viz. critical crack length, slab failure, fracture propagation speed, and fracture propagation distance are predicted from the macroscopic law-based investigations and compared with the reported data. The reported and macroscopic law-based data matches reasonably. The effect of fabric on the mechanical behaviour in the layered snowpack is shown and compared with the initial fabric value-based analysis.