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Numerical Analysis on the Rheology of Martian Lobate Debris Aprons

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Abstract

Occurrence of ice in Martian subsurface is indicated by landforms such as lobate debris aprons (LDAs), concentric crater fills, and softened terrains. We used a three dimensional non-Newtonian viscous finite element model to investigate the behavior of ice-rock mixtures numerically. Our preliminary simulation results show that when the volume of rock is less than 40%, the rheology of the mixture is dominated by ice, and there exists a brittle-ductile transition when ice fraction reaches a certain value.

1. Introduction

Morphological studies have suggested that underground ice exist extensively in martian mid-to-high latitudes of both hemispheres [1-5]. Examples of ice-related morphological features include lobate debris aprons (LDAs), concentric crater fill, lineated valley fill, and viscous flow features. Using subsurface radar sounding data collected by SHARAD (the Shallow Subsurface Radar) on MRO (Mars Reconnaissance Orbiter), [6, 7] confirmed the existence of large quantities of water ice in the formation and evolution of LDAs in the eastern Hellas region and at the northern hemisphere dichotomy boundary, respectively.

2. Model Configuration

The steady-state viscous strain rate $\dot{\varepsilon} = (d\varepsilon / dt)_{ss}$ of polycrystalline ice is described by a power law relationship [8] :

$$\dot{\varepsilon} = A\sigma^n exp[-E/RT] \tag{1}$$

Where σ is the differential stress, T is the temperature, R is the gas constant. A, n, and E are parameters characterizing the material. A denotes the constant of the viscous parameter, and it can be the function of temperature and bulk pressure. E represents the activation energy. Our numerical specimen is a cylinder containing a mixture of randomly distributed sand and ice grains (Figure 1). The cylinder measure 10 mm in diameter and 40 mm in length. Conventional triaxial compression tests are conducted to calculate the instantaneous strain rate by large-scale parallel finite element simulations. The hydrostatic pressure is fixed to 12 MPa. It is consisted with the pressure inside Martian subsurface at 1 km in depth. The constant temperature T=263 K is considered. B and n are constants for ice and rock. The parameters utilized in our study are listed in Table 1. B =1.0910×108 and n=3.

Table 1: Parameters in ice-rock mixture numerical simulation

Parameters	Symbol	Value	Unit
Temperature	T	263	K
Gas constant	R	8.314	J mol^{-1} K^{-1}
A for ice	A_{ice}	8.8×10^{5}	$MPa^{-n}s^{-1}$
n for ice	n_{ice}	3	
E for ice	E_{ice}	60.7	$KJmol^{-1}$
A for rock	A_{rock}	6.7×10^{-12}	$MPa^{-n}s^{-1}$
n for rock	n_{rock}	6.5	
E for rock	E_{rock}	268	$KJmol^{-1}$

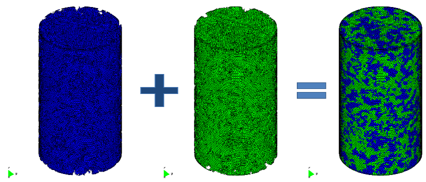

Figure 1: randomly distributed spatial granularity specimen consisted of ice and rock.

3. Results

We calculated the strain, stress, effective stress, effective strain rate and effective rheology. Under different volume fractions of ice and rock, we generated a cluster of numerical models. The strain, stress, the effective stress, the effective strain rate and the effective rheology were also calculated and analyzed statistically. Figure 2 shows the effective rheology of the mixture varies with the volume fraction of rock, which changes from 0 to 1.

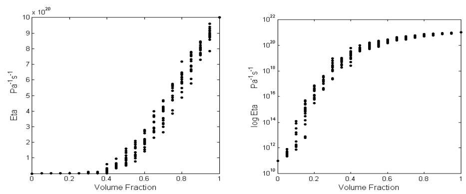

Figure 2: Effective rheology of the mixture varies with the volume fraction of rock which changes from 0 to 1

4. Conclusions

Our numerical benchmark showed that our large-scale parallel finite element numerical simulation method to investigate the rheology of ice-rock mixture in LDA is effective and feasible. If we know the rheology parameters of the components under certain conditions, we can calculate the parameters of the mixtures by numerical experiments and statistical analysis rather that the time-consuming and expensive laboratorial experiments. Since parallel computing is much more convenient and efficient than the laboratorial experiment, by changing the volume fraction and differential pressure conditions, we can establish a direct relationship of rheology parameter of one mixture consisted by any kinds of components. These results will contribute to the knowledge of the porosity and ice content of martian ice-rock mixture. It also can be used to estimate the amount of ground ice at different latitudes on Mars.

Acknowledgements

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