A Numerical Investigation of Microwave-induced Stress in Rocks

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Background

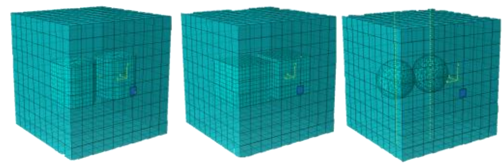
Extremely hard and abrasive rocks pose great challenges to mechanical excavators (TBMs), while microwave heating is a promising technology that can help to achieve low cutter wear and high tunneling efficiency.

Most of the work has been based on laboratories, showing microwave-induced heating damage to rocks on a macro scale, but lacking sufficient microstructural studies. Therefore, this study **aims to simulate microwave-induced rock behaviour from the microstructure.**

Modelling of microstructural geometry: from simplest to complex

Simplest geometry

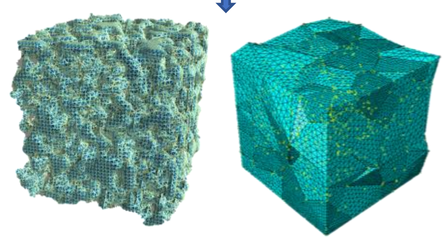
- Several different simple geometric shape are designed and investigated using MEEP. The configurations include different particle sizes, shapes and different distant between the particles.
- The simple geometries gives us an understanding of the nature of EM wave propagation as an intensity profile can be generated from the resulting EM wave profile.



Different geometry shapes and sizes (EM source)

Complex geometry

- Complex geometry that are more closely resemble the real life situation
- The geometry is generated using Python **Voronoi** Algorithm.
- **Voronoi** algorithm generate randomized geometry based on the randomly generated seeds and the distance of each section of geometry is from the seeds.
- The geometry is then transferred to Abaqus using **Convex Hull** algorithm.
- In the figure shown. The solid parts are the microwave-absorbing particles and the transparent parts are the microwave-transparent matrix.
- Ratio of the particles and density of the particles is customized.
- The mechanical property of the micro-structure is also randomized using Weibull distribution.



Mesh generated for MEEP (left) and Abaqus (right)

Electromagnetic field simulation

EM field is generated and propagated in the software MEEP.

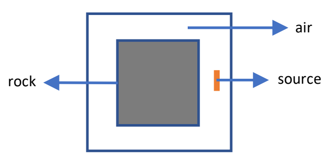
The MEEP is an open source Finite Difference Time Domain (FDTD) software.

We constructed different geometry and materials for EM wave propagation test. A procedure is store the randomly generated geometry in a database and read it in MEEP for simulation.

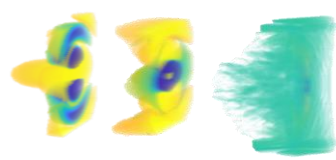
Different frequency of EM wave is also specified to test.

The result of MEEP simulation is analyzed in MATLAB to assert the correctness.

A Root Mean Square (RMS) value matrix is generated to discover the absorption of different parts of the model.

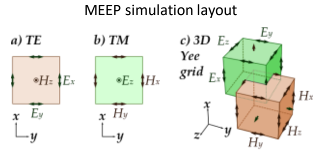


MEEP simulation layout

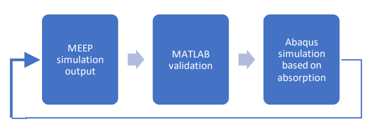


Transient EM Field

Steady-state EM field RMS



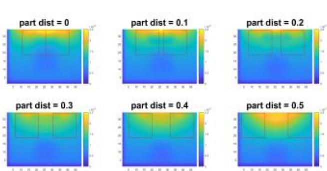
FDTD simulation principle



MEEP simulation procedure

Preliminary results

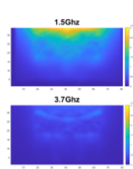
Distribution of the particles greatly affects penetration and power distribution of the EM field. The results show that the less dense particle, the greater the penetration. The particles also focus the beam and increase the strength of the field beyond them.

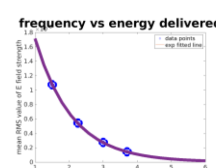


RMS energy profile of Different particle distance

The frequency of EM wave has an dramatic effect on the efficiency of the wave penetration and heating in the rocks.

The results show that the lower the wavelength, the deeper the penetration.

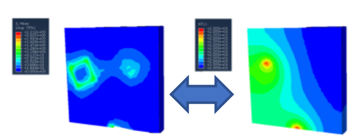




RMS energy profile of E field (left) and fitted line of

The thermal and stress are coupled in simulation in Abaqus.

The results show that the temperature gradient is the major cause of stress.



Co-simulation of thermal and stress on rock sample stress field (left) and temperature field (right)