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Effect of pore water in rock on cryogenic thermal-shock cracking behaviors

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Thermally induced cracks can be created when cold fluid contacts a higher-temperature rock. When rock is dry, it first contracts locally near the fluid/rock interface and then fractures in dominantly in tensile mode. However, when rock is saturated or partially saturated with water, the pore water in a rock complicates the behaviors because expanding freezing pore water may interact with mineral skeletons and compete with contracting mineral solids in driving the fracturing. This all occurs in a complex environment of pore and particle structures. When water becomes ice, the volume increases by 9%, which is larger than thermally-induced shrinkage in geomaterials.

Literature regarding freezing saturated porous media investigated slow freezing under low or cyclic thermal gradients occurring in nature. If frozen slowly, water migrates through the porous media by cryogenic suction, leading to ice segregation and lens growth. However, in rapid freezing under extreme thermal gradient using cryogenic fluid, the cryosuction period is postulated to be too brief to allow water migration and the formation of ice lenses because pore water will freeze quickly. This research centers on the effect of pore water on the thermal cracking behavior.

The behavior of water-saturated rock under cryogenic temperature was investigated by laboratory experiments. Concrete, sandstones, and shale are prepared as blocks (8"x8"x8") and cylindrical core specimens (1.5" dia. x 3"). Each specimen type is prepared as dry, partially saturated, and saturated states. Then the specimens are fully submerged in liquid nitrogen. Temperature at the surface of the block is monitored. In microscale (~particle/pore), we investigated how micro fabric is altered/fractured by cryogenic treatment by using SEM and micro-CT. In macroscale (~core/block), we studied macro-scale changes of internal structures caused by the treatment by using micro-CT. In this scale, we also do mechanical testing such as acoustics, permeability, and strength to see effects on macroscale properties.

After the cryogenic treatment of the water-saturated specimens, all major cracks were created near edges during the cryogenic stimulation. In this case, the ice, which is heavily interconnected through pores, was expanding against mineral matrix. Thus, the outer layer of the block exposed to liquid nitrogen experienced water freezing and expanding, whereas the inner block did not. The outer layer expanded laterally, resulting in shear fractures parallel to the exposed surfaces. If cracks were formed from rock contraction (without the effect of ice), more cracks would be located away from and perpendicular to the edges. The block bottom was in direct contact with the cryogen container limiting liquid nitrogen access resulting in the absence of cracks there. We also present micro CT and scanning electron microscopy results, which reveals interesting interaction between expanding ice crystals and mineral skeletons at specimen surfaces as well as internally.

References

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