

多孔灰岩局部化变形过程的渗流演化机理

The seepage evolution mechanism of localized deformation process in porous limestone

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摘要: 岩石局部化变形是一个普遍存在的地质现象, 在二氧化碳地下封存、油气开采和地下水管理等领域中具有举足轻重的地位。在油气衰竭式开采过程中, 井底孔隙流体压力会逐渐减小, 储层有效应力增大, 引起储层岩石局部化变形, 降低岩石渗透率, 进而影响产能。当前对局部化变形渗流机制宏观研究已有深刻认识, 但对渗流微观机理的研究不足。本研究利用 4D-CT 技术实时扫描常规三轴应力作用下岩石变形的全过程, 在局部化变形阶段的动态 CT 数据基础上, 采用格子-玻尔兹曼的渗流分析手段, 定量表征局部化变形阶段渗流场演化特征。初步研究结果表明, 岩石渗透率的变化主要受其内部孔隙局部化变形的影响。应力加载初期, 连通大孔隙发生坍塌, 孔隙度显著减小, 但岩石渗透率仅略有减小, 表明连通孔隙度和渗透率并非正相关。随着应力增大, 通道关键喉部被压实并伴随着喉道颗粒挤碎致使通道堵塞现象, 岩石渗透率显著降低, 表明渗流通道关键孔吼变形在渗透率变化中起主导作用, 后续将展开进一步的量化分析。

关键词: 局部化变形; 运输特性; 格子玻尔兹曼; 数值模拟

Abstract: Localized deformation of rocks is a common geological phenomenon that plays a crucial role in areas such as underground carbon dioxide storage, oil and gas extraction, and groundwater management. In the process of oil and gas depletion production, the pressure of the downhole pore fluid decreases, resulting in the increase of the effective stress, causing localized deformation of reservoir rock, decreasing the permeability, which would affect production capacity. Currently, there is a well-known understanding of the macroscopic research on strain localization formation and transportation characteristics, but there is less research on the microscopic mechanisms of transportation characteristics during the strain localization formation. We conducted synchrotron in situ CT imaging during triaxial compaction in Leitha limestone. Based on CT data during strain localization formation stage, we adopted Lattice Boltzmann method to analyze transportation characteristics during strain localization formation. The preliminary research results show that the change in rock permeability is mainly influenced by the localized deformation of its internal pores. In the first yielding stage, the connected macropores collapse and the porosity significantly decreases, however, the permeability only slightly decreases, indicating that the connected porosity didn't show a good correlation with permeability. As the stress increases, some key throats of the pore network will be compacted, even with the phenomenon of channel blockage induced by grain crushing, resulting in a significant decrease in permeability. It indicates that the deformation of the key throat of pore network plays a dominant role in permeability changes. Further quantitative analysis will be conducted in the future.

Keywords: strain localization; transportation characteristics; Lattice-Boltzmann, Numerical analysis