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Investigation of single particle crushing characteristics considering non-spherical shape based on DEM

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The evaluation of fracture construction processes hinges on the critical factors of conductivity and the validity period of artificial fractures. It is imperative not to overlook the conductivity damage resulting from the crushing of proppant particles. Being a specialized geotechnical granular material, proppant particles undergo fragmentation when the applied compressive load surpasses their bearing capacity. The smallest unit in breakage behavior, the single particle, serves as the foundation for pertinent mechanical research.
Quartz-sand proppant particles pose a challenge for classical theories due to their complex structures and irregular shapes. Existing studies often neglect the intricate structural shape of the proppant and the complex stress environment in the reservoir, opting instead for investigations based on regularly shaped particles. This study delves into the crushing behavior of irregularly shaped quartz sand single particles, determining the critical conditions of single-particle breakage through a combined approach of numerical simulation and experiments. A discrete element model (DEM) for the crushing of quartz sand single-particles under closure pressure and confining pressure was established. The analysis of crushing characteristics involves examining the dynamic distribution of the crushing belt and stress-strain curves. Additionally, the primary controlling factor influencing the crushing behavior of single particles is investigated.
The results reveal a unimodal distribution in the stress-strain curve for proppant particles. Smaller particle sizes correspond to higher effective peak values of fragmentation and smaller strains. Specifically, under consistent parameter conditions, 40–70 mesh quartz sand particles exhibit stress peaks over twice as high as those of 8–16 mesh particles. Larger particle sizes harbor a greater number of internal natural cracks and defects, thereby diminishing the particles' bearing capacity. The influence of particle sphericity on crushing patterns and crack locations is governed by the mode of contact between particles and the wall surface. Particles with high roundness are more likely to be broken into two parts. Concurrently, as particle irregularity intensifies, secondary cracks emanate within the particles prior to complete fragmentation, resulting in a stress-strain curve exhibiting a multi-peak distribution. For a consistent 8–16 mesh of quartz sand particles, the peak crushing force under conditions of high roundness surpasses that under conditions of low roundness by approximately 15 N. Notably, the crushing strain is significantly greater, nearly 10%, for small-sized particles compared to large-sized particles under conditions of low sphericity, whereas this difference diminishes to 1.8% under conditions of high sphericity. The experimental approach was used to validate the simulation results, immensely contributing to providing theoretical underpinnings for the application and optimization of proppants.

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References

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