Compaction and Fracturing of Weakly-Cemented Granular Rocks

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RESEARCH OBJECTIVES

In weakly cemented porous granular materials, the lack of dilatational forces at the grain scale can lead to the development of an unusual thin slit-like failure feature (Figure 1). In contrast to the typical borehole breakout resulting from KI-mode (opening mode) fractures propagating perpendicular to the direction of local tensile stress, this type of failure feature develops perpendicularly to the local compressional stress and therefore is called an "anti-KI" fracture. Understanding fundamental microprocesses associated with these features is important for design of stable boreholes in weakly cemented rock. Whereas a typical borehole breakout achieves a stable geometry for a given material strength and in situ stress state, observations imply that these features extend indefinitely. In this research, a series of laboratory experiments has been performed to understand the effect of grain shape, cementation and the mechanical removal of debonded grains upon the failure mode of a weakly cemented granular medium.

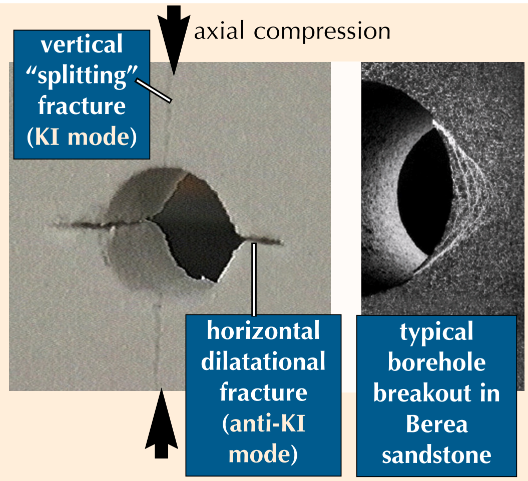

Figure 1. Anti-KI mode fracture formed around a borehole within a synthetic sandstone. This failure feature is markedly different from the classical borehole breakout with fractures developing parallel to the local compressional stress field.

APPROACH

Laboratory uniaxial compression tests were performed on thin rectangular bricks of artificial sandstones made of glass beads and silica sand. Each brick contained a single small diameter hole as an analogue of a two-dimensional borehole. Beads and natural sand were used so the effect of grain shape on the failure behavior of the specimens could be studied. Varying amounts of sodium silicate solution were used as a binder to achieve a range of cohesive strength between grains. The bricks were loaded vertically in the direction perpendicular to the borehole, and the development of compaction zones and fractures around the hole were observed.

ACCOMPLISHMENTS

For glass bead specimens, the characteristic "anti-KI" fracture formed regardless of the amount of sodium silicate binder. In contrast, for silica sand specimens, "dog-ear" shaped compaction/shear zones formed in the direction perpendicular to the axial load. However, if the debonded grains were removed from the failure zone using compressed air flow, the fracture similar to the glass-bead specimens developed. In a silica sand specimen with very strong intergranular cohesion, fractures propagating parallel to the direction of compressional stress were observed (classical borehole breakout failure). These fractures penetrated through individual sand grains, indicating that the dilation due to failed grains allowed the transmission of local compressional stress driving the fractures in this direction.

SIGNIFICANCE OF FINDINGS

The results indicate the importance of grain removal in determining the failure mode of weakly cemented porous granular rock. Rock characteristics such as high porosity, round grains and the existence of a mechanical force that dislodges the grains from the fracture tip can assist in the development of the anti-KI borehole failure. It is likely that this mode of failure can occur even within relatively competent sandstones if liquid flow (water, drilling fluid, etc.) can remove sand grains in a manner similar to the compressed air used in this study.

RELATED PUBLICATIONS

Bessinger, B.A., Z. Liu, N.G.W. Cook and L.R. Myer, A new fracturing mechanism for granular media, Geophys. Res. Lett., 24(21), 2605-2608, 1997.

Myer, L.R., S. Nakagawa and B.A. Bessinger, Role of local dilatation in formation of compaction bands, Eos, Trans. Am. Geophys. Union, 79(45), F1067, 1999.

ACKNOWLEDGEMENTS

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