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# Effect of a heterogeneity on tensile failure: interaction between fractures in a limestone

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Not all rocks are perfect. Frequently heterogeneities will be present, either in the form of pre-existing fractures, or in the form of sealed fractures. To date, investigation of sample heterogeneity, specifically tensile strength and strength anisotropy has focused on layered rocks, such as shales, sandstones and gneisses. Data is lacking on the effect of single planar heterogeneities, such as pre-existing fractures or stylolites, even though these frequently occur in geo-energy settings.

We have performed Brazilian Disc tests on limestone samples containing planar heterogeneities, investigating Brazilian test Strength (BtS) and the effects of orientation on strength. We used prefractured Indiana limestone to represent a planar heterogeneity without cohesion and Treuchtlinger Marmor samples with central stylolites to represent a planar heterogeneity of unknown strength (as an example of a sealed fracture). The planar discontinuity was set at different rotation angles of approximately 0–20–30–45–60–90$^{0}$, where 90$^{0}$ (steep angle) is parallel to the principal loading direction, and 0$^{0}$ (low angle) to the horizontal axis of the sample. All experiments were filmed, and where possible Particle Image Velocimetry was used to determine internal particle motion. Moreover, we used a 2D Comsol model in which we simplified the stylolite surface as a sinusoid. The model was used to qualitatively determine how i) a different period of the sinusoid and ii) relative strength of sinusoid/matrix affect the results.

Our results show that all imperfect samples are weaker than intact samples. The 2D Comsol model indicates that the qualitative results remain unaffected by changing the period (assumed to be representative of roughness) of the cohesive heterogeneity, nor by the relative strength contrast: the location of the first fracture remains unaffected. For both heterogeneity types, the fracture patterns can be divided into four categories, with two clear endmembers, and a more diffusive subdivision in between.

For a cohesion-less heterogeneity:

- steep angles lead to frictional sliding along the interface, and only a small hypothesized permeability increase.
- Intermediate angles lead to a combination of tensile failure of the matrix and sliding along the interface, where for steeper angles more new fractures form which follow the path of the existing fracture.

- Low angles lead to closure of the old fracture and new tensile failure.

For a cohesive heterogeneity of unknown cohesion:

- Steep angles lead to intensive failure of the heterogeneous zone, attributed to the presence of a stress concentrator.
- Intermediate angles lead to partial failure along the heterogeneous zone, and the formation of new fractures in the matrix, potentially instigated by mode II failure to accommodate motion.
- Low angles lead to the formation of a new fracture plus opening within the heterogeneous zone.

These results imply that hydrofracture (i.e. creating tensile stresses) of a stylolite-rich zone will lead to more fractures than fractures in a homogeneous zone, where the orientation of the stylolites and bedding will control the orientation of the permeable pathways.