

Properties benchmark of granular and viscous analogue materials

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An improved knowledge of the mechanical behaviour of granular and viscous materials is essential to determine their suitability for simulating brittle and ductile deformation, respectively. Here we report mechanical tests on granular and viscous analogue materials used by different laboratories worldwide. We performed ring shear tests, uniaxial compression tests, creep tests and analysed grain characteristics by means of sieve analysis and scanning electron microscope analysis. In total, 18 dry sands and 8 silicone polymers have been mechanically/rheologically characterized.

Parameters of frictional strength of dry sands have been determined by ring shear testing at experimental conditions (< 2150 Pa normal load, 3 mm/min shear velocity, 23-25°C, 30-40% humidity). Parameters include the friction coefficient and apparent cohesion during formation of a shear zone ("peak" strength), during sliding on an existing shear zone ("stable dynamic" strength) and during reactivation of a pre-existing shear zone ("stable static" strength). For sand, peak strength is generally highest followed by static stable and dynamic stable strength. For the sands tested, friction coefficients range between 0.65 – 0.82 for peak strength, 0.50 – 0.74 for static stable strength and 0.53 – 0.69 for dynamic stable strength. Apparent cohesion is in the order of 10 – 100 Pa. We found no significant correlation between friction parameters and grain size or grain size distribution but a correlation with grain shape. Accordingly, peak, static and dynamic friction coefficients increase linearly by a value of about 0.1 as the fraction of angular grains increases from 0 – 100 %. This is consistent with previous findings of Mair et al. (2002) who suggested that shear strain in synthetic fault gouges is accommodated by mechanisms of rolling of spherical particles versus sliding of angular particles with the latter requiring higher stresses. Grain shape in combination with grain size and sorting seems also to control frictional stability: A single fine-grained, well-sorted sand from Taiwan dominated by rounded grains shows distinctive stick-slip behaviour. This is consistent with current ideas of stick-slip of bulk solids as a phenomenon controlled by the breakdown of force-chains that is promoted by round particle shape and a narrow particle size distribution (e.g. Mair et al., 2002).

Under laterally confined axial loading, the stress-strain relationship of dry sand reflects both elastic and inelastic deformation (i.e compaction). We determined elasticity and compaction behaviour of dry sands by uniaxial compression tests. We performed 50 loading-unloading cycles up to 2 MPa. Induced strains decrease from about 1 % in the first cycle to 0.1 % in the last cycle. About 50 – 90 % of total strain during loading in the first cycle is inelastic (i.e. remains as compaction). Compaction decreases to less than 10% over 50 cycles. Again, we found that the compaction behaviour of sieved dry sand is controlled by grain shape: Sands composed of dominantly rounded grains compact less under a given load than sands

composed dominantly of angular grains. This is probably due to the fact that rounded sand grains arrange in closer packing during sieving than angular grains. We thus expect analogue models composed of angular grains to accommodate more diffuse volumetric strain than models with spherical grains. Apparent bulk moduli have been determined by regression through the loading branch of the stress-strain curve and range from about 100 – 400 MPa (1st cycle) to 700 – 1500 MPa (50th cycle). The lower ones are representative for experimental conditions (sieved sand layers) and the higher ones reflect the properties of highly compacted sand layers not realized in analogue modelling.

By combining and weighting parameters, which may control strain localization in granular media (i.e. compaction, grain size, density, frictional and elastic strength), we can calculate a “structural attractor index” for each sand reflecting the affinity of a model composed of this material to form new structures during its evolution. The prediction may be tested in future benchmark initiatives.

The rheology of silicone polymers has been investigated using a temperature-controlled plate-plate rheometer. Viscosities have been determined by creep tests after viscoelastic relaxation (imposed stresses 250 – 2000 Pa) at 25°C. At shear rates in the order of 0.01 – 0.1 s⁻¹, all tested silicone polymers showed a quasi-Newtonian behaviour with weak shear rate thinning only (stress exponents $n \sim 1.1$), which makes them appropriate materials to model ductile deformation by diffusion creep. Mean viscosities range from 6 – 42 kPas.

References:

Mair, K., Frye, K.M., and Marone, C. 2002. Influence of grain characteristics on the friction of granular shear zones. *J. Geophys. Res.*, vol. 107, B10, 2219, doi:10.1029/2001JB000516