Press release

Solid-solid interfaces are critical regions in rocks and materials.

How strong are the rocks in the Earth's crust is important for man-made infrastructure, earthquake susceptibility, and potential storage of greenhouse gases in porous rock formations. The mechanical strength of materials largely defines their functionality. To understand which processes are responsible for the weakening or the strengthening of rocks and granular materials, one needs to take a closer look into individual grain boundaries and solid-solid contacts. Such solid-solid interfaces are often critical regions in which deformation processes may start and progress with time, especially in the presence of pore fluids of varied chemical composition.

As rocks and mineral-based materials are often composed of small micro- to nanoscale grains (10^{-6} to 10^{-9} m), it is crucial to identify all major processes that begin at these very small scales before the materials fail. In her Ph.D. thesis, Joanna Dziadkowiec has focused on nanometer-range surface forces between two mineral surfaces and on how these forces are affected by the surface reactivity in confined geometries. - I think the biggest challenge of this Ph.D. project was to design a proper experimental setup to follow both the surface forces and surface reactivity at the same time, in a configuration where the mineral surfaces are nm to µm away from each other – says the Ph.D. candidate. In order to achieve that we used a special force-measuring microscope: the Surface Forces Apparatus (SFA), acquired by the NJORD Centre at the Department of Physics, University of Oslo. SFA is very useful here because it allows us to perform experiments in geometries that are relevant for geological environments and granular materials. We aim to investigate the geometries in which the mineral surfaces are confined, that is they are only separated by very thin water films, much thinner than a micrometer (10^{-6} m) - continues Joanna.

Adhesive or repulsive surface forces between individual mineral surfaces are important for cohesion between mineral grains. The better the cohesion the higher the mechanical strength of rocks and mineral-based materials. What is interesting is that the surface forces are strongly dependent on the chemical composition of water trapped between mineral grains. In rocks, thin water films can persist on mineral grains even at depths of several km. In materials, water films are adsorbed on mineral surfaces in pores and tiny fractures due to air humidity. If we knew which chemical species, that are dissolved in these water films, promote adhesion between mineral surfaces, we could engineer better mineral materials and perhaps improve the cohesion of sedimentary rocks saturated with fluids. However, the interactions between mineral surfaces are often additionally affected by mineral reactivity in confined spaces. - In this project, we have shown that the solid reactivity in confinement can be much different from the reactivity of free, exposed mineral surfaces. This is a step towards the understanding when we can observe the cementing growth of minerals, which keeps the two mineral surfaces together, and when the growth is damaging and may displace the opposing mineral surfaces – explains the Ph.D. candidate.

The thesis focuses on a commonplace mineral - calcite. Calcite (calcium carbonate) is one of the most abundant minerals in the Earth's crust. Large amounts of calcite are also used in man-made materials such as concrete, paints, plastics, paper, and cosmetics. The interactions between calcite surfaces are thus relevant not only for geological processes but also for materials engineering. - Calcite is a very versatile mineral and billions of tonnes of calcite are used annually in different products. In most of them, however, calcite is only a filler or pigment with no advanced functions. On the contrary, calcium carbonate-based materials made by marine organisms, such as pearl oyster, have very specific functions and may for example serve as protecting shells, lenses or gravity sensing systems. Such functionality can be achieved owing to the complex architecture of the individual mineral crystals, which is facilitated by the presence of organic matter. Inspired by these examples, we used soluble organic additives to alter the forces between the calcite surfaces, and this was a very important part of my thesis – underlines Joanna. The Ph.D. candidate is convinced that modifying the calcite surfaces with organic molecules is a very promising way to improve the properties of calcite-based materials that we use daily. The far-reaching goal is to obtain calcite-based materials in which calcite possesses more advanced functions than merely a filler phase. - Interactions between calcite and organic molecules for functional organo-mineral materials have been also investigated by other researchers from the EU Horizon2020 NanoHeal project [1], which I was also a part of – says the Ph.D. candidate.

The main findings of this experimental project indicate that even though in theory strong adhesive forces between calcite surfaces should be present both in water and in saline solutions, this may not be the case. - We generally measured only repulsive forces in a range of fluid compositions, including water. This is caused both by the displacive recrystallization of calcite surfaces and by the presence of water films strongly adsorbed onto the surfaces [2]. Both mechanisms prevented the theoretically expected adhesion, and they may lead to a decrease in the mechanical strength of calcite-bearing rocks. The presence of repulsion between calcite surfaces can also have an undesired impact on the properties of calcite-based granular materials. What remains to investigate is how to simultaneously suppress the recrystallization of calcite and promote the strong adhesion between contacting calcite surfaces – concludes the Ph.D. candidate.

References:

1. NanoHeal European Union's Horizon 2020 research and innovation programme under grant agreement No 642976" https://www.nanoheal.uio.no/
2. Dziadkowiec, J., et al., *Surface Forces Apparatus measurements of interactions between rough and reactive calcite surfaces.* Langmuir, 2018.

Ph.D. thesis title: Interactions between Confined Calcite Surfaces in Aqueous Solutions: A Surface Forces Apparatus Study.

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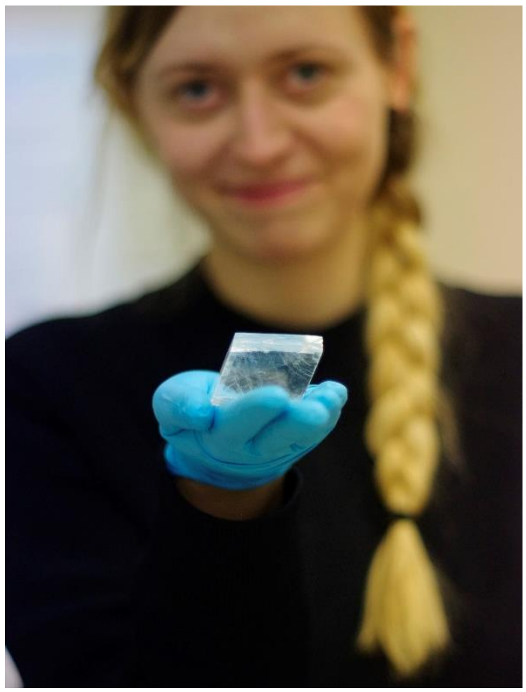
Photo:



Calcite ($CaCO_3$) crystal.