Brittle-to-ductile transition in snow: a microstructural perspective

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Abstract

Snow consists of bonded ice grains, air, and possibly liquid water. It can be regarded either as a porous ice skeleton or as a loose cohesive granular material. Furthermore, as this material generally exists on Earth close to its melting point, it is characterized by rapid thermodynamic evolutions (metamorphism, sintering) and exhibits a wide variety of microstructures. The mechanical behaviour of snow is strongly dependent on strain rate, with a transition from a ductile to a brittle deformation regime as the strain rate increases. At the microstructural scale, snow deformation involves a complex interplay between continuous deformation of the ice skeleton and granular rearrangements of the bonding network. We report here on specific mechanical experiments designed to better unravel the relationship between macroscopic deformation and microstructural evolution in snow, focusing on the brittle-to-ductile transition. Cylindrical snow samples were subjected to displacement-controlled oedometric compression tests over a wide range of strain rates, from 10ˆ-6 to 10ˆ-2 1/s. The tests were performed in situ in an X-ray computed microtomography (micro-CT) scanner installed in a cold room at a controlled temperature (-18.5○C). Full 3D scans taken before, during, and after the experiments were analyzed to follow the evolution of several microstructural descriptors, such as the specific surface area and bond network metrics. 2D radiographs were also taken at a higher frequency to follow fast mechanisms using image correlation techniques. The stress response is characterized by a clear regime transition at a strain rate of about 10ˆ-3 1/s. Micro-CT data show that this transition is associated with a change from an essentially diffuse to a localized deformation pattern. Above the transition, we observe the formation of compaction bands separating deformed and undeformed zones. The bands propagate back and forth in the samples. This pattern is associated with stick-slip-like fluctuations of the stress response, which are presumably the signature of sample-scale rupture events in the bands. Conversely, at low strain rates, the stress-strain curves are smooth. In this regime, snow deformation is controlled by intra-granular visco-plastic deformation and the creation of new bonds. Lastly, when the transition is approached, bursts of

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stress fluctuations are observed. Micro-CT data reveal that these events are associated with intermittent meso-scale localization patterns, which could be regarded as precursors to the compaction bands forming at higher strain rates.