ESRF	**Experiment title:** ***In-situ micromechanics of snow: assessment of grain boundary sliding***	**Experiment number**: MA 753
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Report:

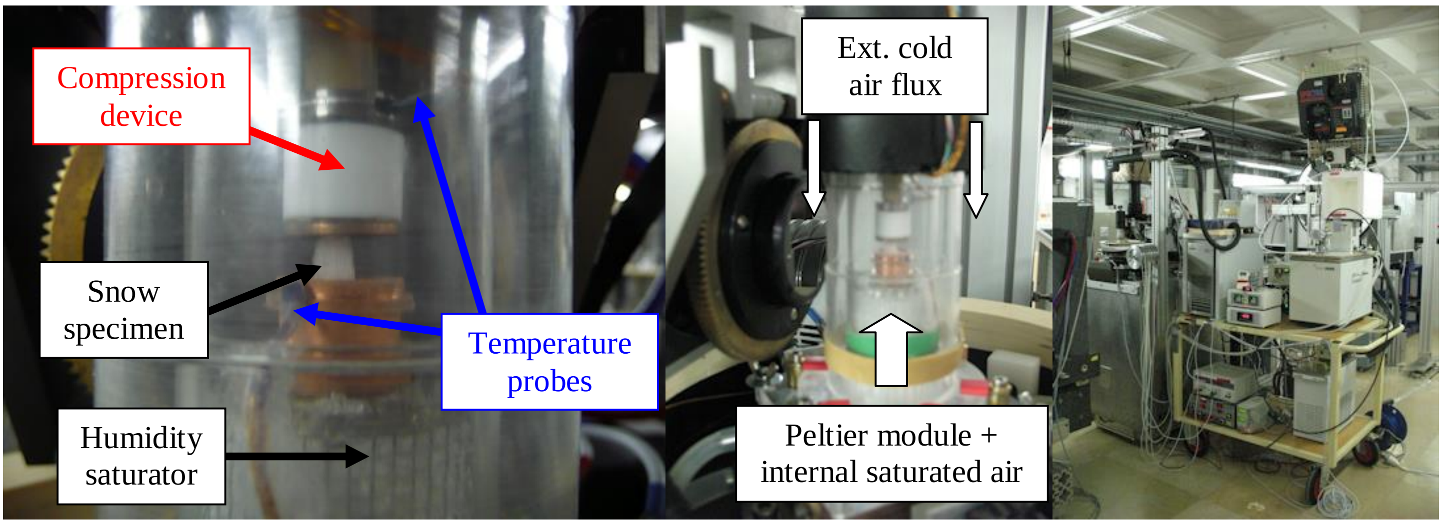
The objective of this work was to understand how snow deforms at the grain scale in the ductile regime. Experiments MA 412 and MA 513 have previously shown that, during in situ compression tests on large grain snow specimens, mosaicity evolves (distorted grains, sub-grain formation), which proves the existence of intra-granular deformation. At the same time, no evidence of grain boundary sliding has been noticed. However, these first results, obtained in very specific conditions, were not sufficient to be generalized to the deformation of snow. The project MA 753 consisted in performing new in situ compression experiments on different natural snow samples by specially analysing the influence of grain size and temperature.

Diffraction Contrast Tomography (DCT) is a non-destructive X-ray imaging technique well suited for in situ deformation of crystalline materials. From the Bragg law, it is possible to simultaneously reconstruct both of the 3D shapes and the crystallographic orientations of each grain. During the experiment MA 753, DCT and µCT were used to obtain the evolution of the microstructure of six samples during compression tests (see Table 1, for pixel size, grain size, temperature and applied loading). The analyses of the reconstructed data validate the mechanism of intra-granular deformation of grains. However, it was still difficult to bring out the grain boundary sliding that was expected at high temperature.

For all the tests, a very precise regulation of the thermal and humidity fields was necessary inside and around the sample. In spite of the specifically developed system (Fig. 1), several difficulties occurred during the experiment (residual temperature gradient conditions, slightly variable humidity content), leading to a loosely control of snow metamorphism during the tests and subsequent problems in data analysis. Overall, snow DCT experiments resulted in the publication of 3 peer reviewed papers, with applications to (i) snow mechanics (Rolland et al, 2011), where DCT was first applied to snow and, through mosaicity measurements, highlighted the intra-granular deformation mechanism; or (ii) image analysis (Wang et al, 2012; 2014), where DCT images were used as "ground truth" to better evaluate the accuracy of grain segmentation algorithms.

Sample name	Grain size	Snow type	Temperature	Pixel size	Data: DCT images and related deformation	Loading
sam-10-1	Ø=0.3-0.7 mm	B11/B10	-10°C	12.7 µm	sam10_dct1_: before loading sam10_dct2_: ~1 % sam10_dct3_: ~3 %	0.05 - 0.16 MPa
sam-11-2	Ø=0.2-0.3 mm	Natural N2	-10°C	7.5 µm	sam11_dct1_: before loading 12.7 µm pixel size sam11_dct2_: before loading sam11_dct3_: ~8 % sam11_dct4_: ~10 %	0.05 - 0.09 MPa
sam-12-3	Ø=0.5-0.7 mm	Natural B7	-10°C	7.5 µm	sam12_dct1_: before loading	0.015 - 0.025 MPa
sam-13-4	Ø=0.2-0.3 mm	Natural N2	-4°C	7.5 µm	sam13_dct1_: before loading sam13_dct2_: ~8 % sam13_dct3_: ~10 % sam13_dct4_: ~10 % sam13_dct5_: ~13 %	0.05 - 0.09 MPa
sam-14-5	Ø=0.3-0.7 mm	B11/B10	-4°C	7.5 µm	sam14_dct1_: before loading sam14_dct2_: ~1 % sam14_dct3_: ~3 %	0.05 - 0.17 MPa
sam-15-6	Ø=0.3-0.7 mm	B11/B10	-9°C	7.5 µm	sam15_dct1_: before loading sam15_dct2_: ~1 %	0.05 - 0.16 MPa

Table 1: List of specimens and applied experimental conditions.
DCT data were obtained at 22 keV.



a) Compression test applied to a snow specimen (ductile regime). b) Cold cell overview, with FRELON camera. c) Overview of the whole system

Fig. 1: Snow compression test and experimental setup,
with the temperature and humidity regulation device developed in 2009.

Analysis of snow microstructure by means of X-ray Diffraction Contrast Tomography

Abstract: Diffraction Contrast Tomographyôô (DCT) is a new, non-destructive, 3D characterization technique for polycrystalline materials. By combining X-ray absorption and diffraction imaging, it reveals simultaneously the specimen microstructure in terms of grain shape and geometry of the porosity, as well as the crystallographic orientation of individual grains. To understand how snow deforms at the grain scale, DCT scans are performed during compression tests on snow. This provides us with the crystalline orientation of the grains in the initial state and during the deformation, which is essential since ice exhibits a very strong anisotropy in the visco-plastic regime.

Curvature-driven volumetric segmentation of binary shapes: An application to snow microstructure analysis

Abstract: Many three-dimensional (3-D) image-based studies concerning granular and sintered materials require a description of the observed microstructures in terms of individual grains. We propose a robust segmentation algorithm which identify groove regions on the objectôs surface in order to locate possible grain boundaries in the objectôs volume. The algorithm relies on the volumetric propagation via Voronoi labeling of curvature information from the surface into the object.

Digital flow for shape decomposition: application to 3-D microtomographic images of snow

Abstract: We propose a fast shape decomposition method for granular microstructures using a 3-D approach based on medial axis. We define a two-step algorithm: the first step relies on a notion of digital flow to obtain a preliminary over-decomposition from medial balls. During a second step, we use geometric criteria to obtain a relevant and precise volumetric decomposition. We apply our algorithm to 3-D objects of materials and, more precisely, to microtomographic images of snow microstructures.

References:

Rolland du Roscoat, S., A. King, A. Philip, P. Reischig, W. Ludwig, F. Flin and J. Meyssonnier, 2011. Analysis of snow microstructure by means of X-ray Diffraction Contrast Tomography, Adv. Eng. Mater., 13(3), 128-135, doi: 10.1002/adem.201000221.

Wang, X., L. Gillibert, F. Flin and D. Coeurjolly, 2012. Curvature-driven volumetric segmentation of binary shapes: An application to snow microstructure analysis, Pattern Recognition (ICPR), 2012 21st International Conference on, 742-745.

Wang, X., D. Coeurjolly and F. Flin, 2014. Digital flow for shape decomposition: application to 3-D microtomographic images of snow, Pattern Recogn. Lett., 45, 181-188, doi: 10.1016/j.patrec.2014.03.005.