Review of Christopher, Wilson et al.'s: "Partial melting in polycrystalline ice: Pathways identified in 3D neutron tomographic images."

General comment on the manuscript:

The preprint article by Wilson et al. presents an innovative approach for characterizing the microstructure of polycrystalline ice using small-angle neutron scattering (SANS) measurements. The authors successfully obtained high-resolution images of the 3D ice microstructure, providing valuable insights into the crystallographic structure of the ice, the distribution of pores, and the connectivity of the pore network. Notably, this study is unique in its use of deuterium ice, which allowed the authors to obtain higher-quality data than previously possible. They explore the role of crystal orientation and pore geometry on the deformation of polycrystalline ice and investigate the effect of stress and strain rate on the microstructural pore evolution of ice resulting from deformation. The paper is well-written and presents a clear and concise overview of the methodology and results. However, there are some sections that may benefit from further clarification or expansion, as outlined below.

We thank this reviewer for these valuable comments and suggestions which have helped to improve the manuscript.

Specific comments for the authors' consideration:

- I'm curious why 90% deuterium ice was chosen. Does this suggest 10% liquid water content when samples deform above the H_2O melting temperature? If so, why not use a higher fraction of deuterium solid to produce water contents more in the range expected of glacier ice? (< 3% liquid water i.e., Vallon et al., 1976). Moreover, assuming liquid water contents are high, I would be hesitant to infer known ice deformation mechanisms in unexplored water-content regimes.

  - Because of the sample size, the small quantities of partial melt generated coupled with the resolution of the neutron diffraction tomographic images any lesser amount of H_2O would have made identification of melting sites very difficult. The value of <3% described by Vallon et al. (1976) is in Firn ice and is not applicable to these experiments. In our initial and final experimental samples, you cannot distinguish differences between H_2O vs D_2O both have a polycrystalline grain microstructure and similar grain sizes.

- It remains unclear why calcite powder was used in some layered samples (or at all). Consider including the objective/ relevance of the calcite layer with regard to the overarching research questions.
- A new sentence has been added in Methods section (at line 114) to explain the calcite helped to provide a rheological contrast in the sample.
- When labeling "pores" (i.e., Line 161), consider being explicit as to whether you refer to liquid water interstices (i.e., veins) or bubble inclusions. Further, are you able to get a sense of the volumetric air content in the samples using tomography?
- A volumetric count of bubbles was attempted, but results were highly variable. Instead, we are only presenting data we are confident about such as the data portrayed in fig. 4d,e.

- Following Nye and Mae (1972), the authors may consider clarifying the differences between their deuterium–H_2O samples and pure ice with regard to textural and thermo-mechanical equilibrium at the melting temperature. My (perhaps limited) understanding is that melt evolution, migration, and distribution during compression will be driven by grain-scale stress heterogeneity and a tendency for liquid in a polycrystal to be drawn from warm to cold temperatures as a result. In a system with two distinct melting temperatures, I'm unsure how applicable this paper's results on molten phase migration will be to glacier ice systems.
- As we point out in this paper there is a major structural factor that controls the redistribution of the melts, namely shear bands and the deformation bands and these exist in other experimental studies (e.g. Rist & Murrell, 1994) and in natural ice masses. From a set of complimentary unpublished in situ studies there is definitely no warm to cold transfer, instead it is controlled on activity of the different slip systems between adjacent ice grains and the degree of grain boundary migration.
- I didn't catch how the textural characteristics (including grain size) were measured and what the errors were. Perhaps you could elaborate? I apologize if I overlooked it.
- All the textural characteristics came from a fabric analyser. Therefore, an additional sentence has been added to line 106 in 'Methods Section'.
- It remains unclear to me how the coordination number was measured (and what the errors are) in the mean CNs (Table 1). Could you elaborate? And do you think the resolution is sufficient to adequately characterize the connectivity of pores in the samples? (i.e., if your voxel resolution is 20 microns, are melt channels smaller than 20 microns overlooked and/or deemed insignificant?)
- Two additional references have been added to the paper (Andrew, 2018; and Berg et al., 2016) plus a sentence has been added at line 145 in methods section and to the caption to Table 1 to clarify the procedure used. In the deformed samples we have images of total porosity showing pores smaller than 20 microns and distribution of melts. These we have not used in this paper as their resolution does not show clear details.
- Were you able to examine the general melt channel shape in your samples? I'm curious whether the mean dihedral angle is greater for deuterium ice (possibly producing more spherical pores), causing the pore connectivity and melt migration rates to be lower than pure polycrystalline ice.
- During the processing of the data an examination of the 3D channel shape was not undertaken, However, as we point out in Figures 1-3, on the margins of all the deformed samples the melt accumulates as circular patches that correspond with the apex of deformation bands indentified in the relevant 2D slices. Whereas, in adjacent slices no melt is identified. Regarding the dihedral angles, determining these was beyond the resolution of our tomographic images. However, we are currently writing up complimentary in situ experiments undertaken on a fabric analyser (similar to those described in Peternell et al., 2019) in which we record melting occurring and redistributed in a matrix of H_2O ice where dihedral angles control melt migration on a localised scale, however, shear bands again control the overall distribution of melt.
- I think the conclusion could be strengthened by summarizing the main findings of this study and their significance in a more succinct way, as well as highlighting the key areas for future work that emerge from the study.
- A short conclusion has now been added to the manuscript.

Overall, this paper presents original, high-quality data on the deformation behavior of laboratory-made ice samples under uniaxial compression tests. The novel use of neutron imaging allows for non-destructive 3D visualization of the internal ice structure during and after the deformation, providing unique insights into the deformation mechanisms of ice. The results have implications for a range of applications, including ice mechanics, ice sheet modeling, glacier dynamics, and englacial hydrology. Therefore, I believe this paper is well-suited for publication in The Cryosphere.

We thank the reviewer for an excellent set of comments and suggestions.

Editorial comments keyed to line numbers:

28 – Insert the word "to" before "suggest" Changed to "suggesting"

43–44 – Consider adding a comma after "masses" and some rephrasing, as the meaning in this sentence I find unclear. Comma added. We believe it is clear.

59 – Change the word "occurs" to "occur" changed

149 – Consider changing adopting to "as they adopt" as it reads a bit awkward otherwise. Thanks now changed

154 – Missing first parenthesis in "Supplementary Fig. 3). Added

164–166 – This reads a bit awkward. Consider changing "its correlation" to "correlating it" perhaps? changed

172 – Consider adding a comma after "sample" for clarity Added

174–175 – "Mix-3 occurs as a fine rim (Fig. 1d-e) and Mix-2 and Mix-3 at the outer rims of the sample (Fig. 2a-c)" reads a bit awkwardly; consider rephrasing for clarity. This has been rephrased.

193 – Change "concentration" to "concentrations" (for agreement with "are") changed

194 – Consider adding comma after "(Fig. 2e, Supplementary Fig. 3a)" added

211 – Add "and" before "blind" added

219 – Change "relative" to "relatively" changed

220 – Add a comma after "samples" Added

224 – Change the word "was" to "were" Changed

232 – Consider adding a comma after "(Kronenberg et al., 2020)" Added

233 – Add a hyphen between "meltwater" and "free" added

243 – Move the hyphen position to be between "dry" and "compacted" undertaken

250 – Hyphenate "quasi steady" added

266 – Add the word “and” after “boundaries,”added

276 – Change the word “are” to “is”changed

278 – Consider changing the word "shears" to "shear bands" for consistency with later usage added “bands”

281 – Hyphenate “dry compacted”; this is a bit inconsistent throughout the paper, so check occurrences elsewhere for consistency.changed

283 – Add the word “and” after “shapes,”added

292 – Consider changing “which preceded” to “that precede” for grammatical correctness.changed

312 – Add a comma after “stresses” added

330 – Add a comma after viscosity, or change “reaching” to “reaches.” With the current phrasing, the meaning of the sentence is unclear. Comma added

356 – Add a comma after “(Fig. 10e)”. added

389 – Remove the hyphen in “ice-sheet” changed

392 – Remove the comma and change “is” to “are.” Otherwise, I think it reads awkwardly. changed

405 – Change the word “control” to “controls” and change “on” to “of.” changed

423 – Consider bracketing “more commonly” with commas on either side. added

559 – I would suggest explaining what is meant by “pore fluid factor” and, additionally, consider adding a hyphen between “pore” and “fluid” here.

This relates to a change made in the caption to Figure 10. In addition, a sentence has been added in text at line 360 explaining the nature of the other factors.

655 – Consider explaining what is meant by a “capped yield surface” as I, and perhaps others, will be unfamiliar with that terminology.

An explanation regarding the use of a capped Mohr-Coulomb diagram has been added to section 4.1.

References:

Vallon, M., Petit, J., & Fabre, B. (1976). Study of an Ice Core to the Bedrock in the Accumulation zone of an Alpine Glacier. *Journal of Glaciology, 17*(75), 13-28. doi: 10.3189/S0022143000030677

Nye, J., & Mae, S. (1972). The Effect of Non-Hydrostatic Stress on Intergranular Water Veins and Lenses in Ice. *Journal of Glaciology, 11*(61), 81-101. doi:10.3189/S0022143000022528

Additional changes

Figure 6. An additional statement has been added to caption to explain stress increase.

Figure 10. An important detail was changed in (b) the shear bands are now inclined at less than 45deg to the compression axis. For (c) this was correct. For (d) the angle had to be greater than 45deg and this modification has also been undertaken.

Reply