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Interactive comment on "Microstructure and texture evolution in polycrystalline ice during hot torsion. Impact of intragranular strain and recrystallization processes" *by* Baptiste Journaux et al.

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We would like to take the opportunity to comment on several statements in the manuscript "Microstructure and texture evolution in polycrystalline ice during hot torsion. Impact of intragranular strain and recrystallization processes" by Baptiste Journaux and co-authors. In this manuscript, the authors report the results of microstructure and texture evolution in polycrystalline ice during torsion experiments.

The manuscript is in general well-structured and the results are innovative. Two re-

viewers already provided constructive comments and recommendations. However, we consider that some aspects are not correctly addressed in this study, especially when the experimental results obtained are compared with previously published full-field numerical simulations. In different parts of the manuscript the authors state that results of full-field simulations by Llorens et al. (2017) do not match those observed in experiments (e.g. 20-25, page 3; 1-6 page 17; 30-35, page 17). The authors essentially state that numerical simulations are unable to predict the "double sub-maximum of the c-axis preferred orientation or the interlocking grain boundaries" observed in simple shear deformation experiments.

First of all, we would like to note that the settings of the experiments are different from those of the numerical simulations, because the shear strain rates in experiments are between four and five orders of magnitude higher than in the numerical simulations of Llorens et al (2017). Therefore, differences in grain boundary geometries can be expected, as the balance between the increase of system energy due to plastic deformation (e.g. strain stored energy, but also boundary energy) and its reduction due to recrystallisation is strain-rate or time dependent. The much higher system energy in the experiments, compared to numerical simulations, becomes clearly visible in the annealing experiment, in which fast grain boundary migration quickly sets in, together with an increase of grain-size and formation of sharp grain boundaries. These observations are in agreement with results by Llorens et al. (2016b), who explored the influence of shear strain rate and dynamic recrystallisation during simple shear deformation. These simulations clearly reveal the influence of strain rate on the increase of internal misorientation, even though the simulations by Llorens et al. (2016a,b) did not yet include the formation of new high-angle grain boundaries by subgrain rotation (polygonisation) or nucleation. These processes were included in Steinbach et al. (2017) and Llorens et al. (2017). Contrary to the claim by Journaux et al., Steinbach et al. (2017) showed that interlocking grain boundaries and even grain dissection (i.e., grain division due to fast, abnormal grain boundary migration) are reproduced by the numerical simulations, depending on strain rate and settings of dislocation energy and effective mobility of grain

boundaries. The simulations by Steinbach et al. (2017) were carried out in pure-shear, but as revealed by Llorens et al. (2017), the differences between polycrystals deformed in pure- and simple shear conditions are small if the same set-up of deformation and recrystallisation is used.

A second aspect that we would like to clarify is the double-maxima (M1 and M2) of the c-axis in the experiments and simulations. Predictions by Llorens et al. (2017) show that the bulk c-axis maximum is obliquely oriented with respect to the shear plane. However, if only regions with maximum shear strain-rate are taken into account, the double maxima can be observed in orientations similar to those in experiments (Llorens et al., 2017). The evolution of these double maxima with increasing deformation is discussed in the manuscript by Qi et al., (2018; Cryosphere Discussions (https://www.the-cryosphere-discuss.net/tc-2018-140/), as a reviewer has already indicated. The arrangement of the c-axis oblique to the shear plane in the bulk texture is a consequence of strain localisation and the associated formation of low- and high-strain (-rate) domains in the models (Qi et al., 2018). The CPO evolves at a different rate in these domains: the c-axis quickly rotates to become parallel to the shear plane normal in high-strain domains, while it rotates slowly in the low-strain domains (e.g., Llorens et al 2016a,b; 2017). As low-strain regions are volumetrically larger than high-strain domains, the bulk CPO mainly reflects the CPO of low-strain domains. The origin of strain localisation is a consequence of the mechanical anisotropy produced by the difference in flow resistance between non-basal and basal slip systems (parametrised using the parameter A). At least for numerical simulations, an increase of A tends to increase the mechanical anisotropy of the aggregate and favours strain localisation. In contrast, low anisotropy tends to induce more macroscopically homogenous deformation (e.g. Gomez-Rivas et al., 2017) and low-strain domains are volumetrically smaller. This has implications for c-axis orientations: low A values produce a faster rotation of the c-axis normal to the shear plane (and higher activation of non-basal planes) than large A values (resulting in lower activation of non-basal planes).

In a torsion experiment, the torque component between the top and bottom of the sample creates a shear gradient, similar to simple shear deformation. However, a strong limitation of torsion experiments is that the main strain gradient develops across the diameter of the sample, as the centre of the sample remains undeformed, and the maximum deformation is attained at the external surface of the sample. Unfortunately, Journaux et al., only show tangential sections (subparallel to large-strain domains). It would be a very useful piece of information for the reader and community if they authors could also show a perpendicular section that includes the centre of the sample. This section may provide more information than the tangential ones because they allow observing the variation of CPO with strain, and therefore the effect of strain localisation in the sample. Llorens et al. (2017) did show a difference in CPO for high- and low-strain domains, which is discussed in Qi et al. (2018) in terms of the M1 and M2 submaxima. The relative strength of these maxima depends on the amount of shear localisation. This is probably different in the torsion experiments and the simulations. The torsion experiments are likely to reduce localisation in the tangential plane, as developing shear bands need to laterally penetrate into the low bulk-strain parts in the centre of the sample. In the semi-2D numerical simulations, shear localisation is laterally unconstrained, which may explain the small volume fraction of high-strain material.

In conclusion, we disagree with the statement that the results of numerical simulations are in disagreement with the results of the torsion experiments. Clearly, there are differences between the two as both approaches are different and have their own advantages and limitations. We would urge the authors to acknowledge these.

Sincerely,

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