Granulation of snow

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ABSTRACT: The mobility of an avalanche, i.e. its potential to move faster and further, can strongly differ for individual avalanches even if the release conditions are similar. Snow avalanches, as many geophysical flows, are often considered as granular flows. Studies on mono- and bidisperse materials in granular flow show a strong relation between mobility and the granular size distribution. Furthermore, the development of different flow regimes, e.g. whether a plug flow or a turbulent fluidized flow is formed, strongly depends on the granule properties in the avalanche. Therefore, the granular structures and size distributions in the deposition zone are often interpreted as indirect indicators for the internal flow dynamical characteristics of an avalanche. Our experiments show that granulation, the generic name for particle size enlargement, is substantially influenced by the properties of the snow before movement. We investigated granules and their properties in the deposition of multiple avalanches and used a concrete tumbler to examine the granulation potential of snow with different properties. Snow layers featuring similar properties were collected and a defined volume was inserted into the tumbler. The experiments showed that granules only formed when a snow temperature of -1°C was exceeded. The formed granules featured typical size distributions observed in avalanche deposits of real-scale avalanches. This confirms recent studies that the snow temperature plays a crucial role on granulation and consequently on the mobility of snow avalanches.

KEYWORDS: snow avalanche, granulation, snow temperature, mobility

1 INTRODUCTION

Snow avalanches can exhibit many different flow regimes, such as a dense core, a fluidized layer, a plug flow or a dilute suspended powder cloud (Gauer et al., 2008). In most cases different regimes exist at the same time at different locations inside a single avalanche. As in the case of many geophysical flows (Roche et al., 2011), the flow dynamical behaviour of snow avalanches is often approximated as a granular flow.

To achieve a better understanding on the effect of granules on the flowing and stopping behaviour of avalanches, granulometric investigations in the deposition area of avalanches (Bartelt and McArdell, 2009) were conducted. These investigations showed that wet avalanches tend to produce more large granules than dry avalanches (Kobayashi et al., 2000). This agrees with Gauer et al. (2008) who concluded that in snow avalanches the particle size is non-uniform and changes over time.

This is of fundamental importance for the flow dynamics of avalanches since studies on mono- and bi-disperse material in granular flow show a strong relation between mobility, i.e. its ability to move faster and further, and the granular size distribution (Moro et al., 2010).

Up to now not many investigations on the granulation of snow, i.e. the generic name for particle size enlargement (Walker, 2007), exist. Furthermore, most laboratory experiments on flow dynamics were conducted with already existing granules, e.g. glass ballotini (Schaefer and Bugnion, 2013).

Since recent studies show the effect of snow cover properties, especially snow temperature, on flow dynamics (Naaim and Durand, 2012, Steinkogler et al., 2013), we investigate which snow cover parameters control the granulation process. In the following, we define the size and properties of the resulting granules by laboratory experiments in a rotating tumbler.

2 METHODS

A standard concrete tumbler (Figure 1) was used to investigate the granulation process of snow in a controlled environment. To assess the initial conditions (temperature, density, grain type, grain size, moisture content, hardness) of the snow as good as possible a regular snow profile following the guidelines of Fierz et al. (2009) was conducted.

Snow layers that showed similar properties were collected and a defined volume was shovelled into the tumbler. This allowed

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investigating the granulation potential of different types of snow. As observed in nature, avalanches not always erode the complete snow cover but often only certain layers are entrained into the avalanche (Sovilla et al., 2007). The experiments allowed taking this into account depending on whether the entire snow cover was put into the tumbler or only certain layers.

According to Mellmann (2001), who identified different flow regimes in rotating cylinders, our experiments mostly followed a cataracting and partly a cascading motion (Figure 1).

Figure 1. Granules in motion in tumbler. Red arrow indicates trajectory of granules.

The experiments were suspended in regular intervals of 5 minutes to measure the change in snow properties. Additionally we noted whether granules formed or not. We defined the initiation of granulation as soon as the snow started to form small snow balls, with a size of approximately 1 cm that were rigid enough not to be destroyed upon touching. Furthermore, we distinguished between dry, according to snow class 'dry' or 'moist' in Fierz et al. (2009), and wet granules, according to 'wet', 'very wet' or 'soaked' snow (Fierz et al., 2009).

The experiments were continued until we could observe the formation of new granules or when the system reached a stable state between introduced energy by the tumbler and cooling by the ambient air and when no granules formed after an extensive time.

If granules were formed, the size distribution was measured at the end of the experiment. Furthermore, we determined the properties of all components of the mixture (large and small granules and remaining fine snow).

Figure 2. Granule size distribution measured at the end of an experiment.

3 TUMBLER EXPERIMENT RESULTS

A total of 23 experiments with different initial snow conditions and ambient air temperatures were conducted. In all cases the same amount of snow was added to the tumbler.

The tumbler allowed successfully reproducing a wide range of granule sizes, ranging from very fine material with no distinct granules (Figure 3a), to small- and mid-sized dry granules (Figure 3b) and large wet granules (Figure 3c).

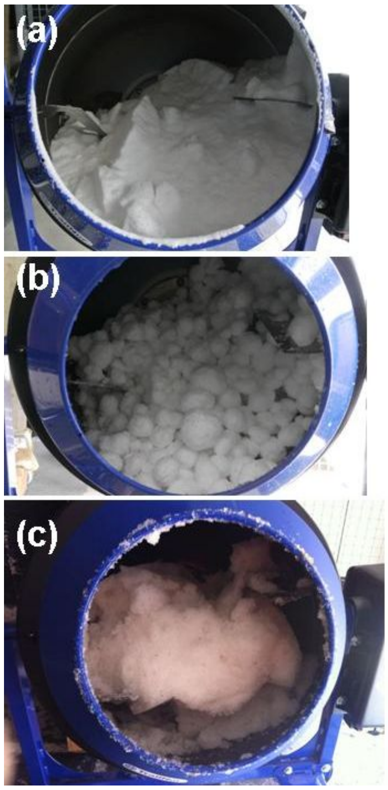

Figure 3. Snow inside tumbler for different experiments where (a) no granules formed, (b) dry granules formed and (c) wet granules formed.

Granule size (Figure 2) showed a typical log-normal distribution (Bartelt and McArdell, 2009), although with a shift towards smaller granule sizes compared to real scale avalanches. Figure 4 shows the granule size distributions for two avalanches and two tumbler experiments. For avalanche #1 three sample areas were evaluated in the deposition zone and for avalanche #2 one area was investigated.

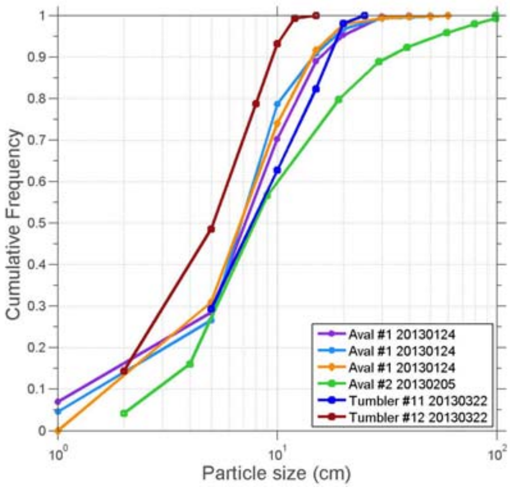

Figure 4. Granule size distributions conducted for selected tumbler experiments and in the deposition area of two artificially released avalanches.

A strong dependency of granulation on snow temperature could be observed (Figure 5). No granule formation could be observed, even for long experiment duration times (gray lines in Figure 5), for snow temperatures below -1°C. Granules systematically formed for snow temperature warmer than -1°C (coloured lines in Figure 5). Granulation happened within a very short time for cases where the initial snow temperature was at or close to 0°C (#13 in Figure 5).

Szabo and Schneebeli (2007) noted that the impact between two ice particles can cause the temporary melting of the interfacial region. Furthermore, they stated that the sintering force increases with temperature and it becomes especially pronounced close to the melting point. This seems to be the case in our experiments too since the most distinct dry granulation occurred close to 0°C. Yet, we could not observe any sintering, which would have lead to granulation, at temperature ranges colder than -1°C.

Many experiments below the threshold of -1°C were run for an extensive duration (more than 100 minutes), yet no granulation could be observed. We attribute this to a thermal balance between warming due friction processes inside the tumbler and cooling by the ambient air temperature.

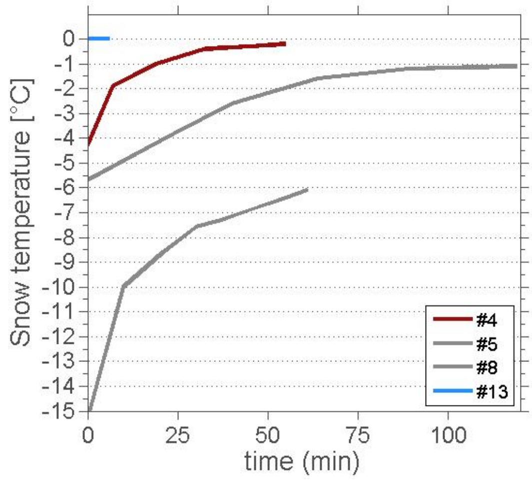

Figure 5. Four selected experiments from the dataset showing snow temperature measurements. Colours indicate experiments where granules formed (#4, #13) and in gray if no granules formed (#5, #8). Experiment was terminated if granules formed or no granules formed even after long experiment duration.

For all dry granulation experiments the moisture content never exceeded 'moist' conditions (Fierz et al., 2009), which indicates that no liquid water was visible by eye or could be squeezed out by hand. Even though many dry experiments were at or close to 0°C they never reached the 'wet' class.

Wet granulation only occurred if the initial snow was already wet or water was added to the tumbler.

4 CONCLUSIONS

We conducted multiple experiments in a concrete tumbler for different initial snow conditions to investigate the granulation process of snow. Our experimental setup allowed producing a variety of granule sizes.

Snow temperature proved to be the controlling parameter whether granulation occurs or not. A sharp transition at -1°C could be observed.

Our results allow quantifying to which extent granulation and thus the granule size distribution depends on snow temperature. Implementation of these findings on the evolution of granular properties based on the properties of the entrained snow and the flow internal temperature in existing avalanche dynamics models, e.g. RAMMS (Christen et al., 2010), could greatly improve their performance and allow more sophisticated flow dynamics calculations of different flow regimes.

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