SNOW IN SCOTLAND: SNOWMICROPEN ANALYSIS OF NATURAL AND ARTIFICIAL SNOW SAMPLES

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ABSTRACT

The avalanche environment in Scotland differs from typical alpine environments. A warmer, maritime climate with regular high winds leads to a prevalence of dense, old but mobile snow. Melt freeze cycles and wind transport dominate snow pack evolution, with wet snow and slab avalanches being the dominant avalanche types. SnowMicroPen (SMP) measurements were performed alongside conventional snowpits in order to identify representative samples of SMP data for six typical Scottish snow types. Artificial snow was aged in a cold lab and tested with the SMP. Comparisons are drawn between the artificial snow and natural Scottish snow. It is found that artificial snow can be considered a good model material for systematic studies of interactions between specific snow types and measurement instruments.

1. INTRODUCTION

Scotland has a temperate, maritime climate. The low altitude and notoriously changeable weather mean that temperatures can rise above freezing at any time of year and snow cover is restricted to the winter months. High winds lead to significant snow mobility. The combination of these factors leads to a prevalence of rounded and decomposed grains, often interspersed with crusts or ice lenses and hardened by wind or freeze-thaw cycles. Most common avalanche types for Scotland are slab and wet snow, the later can occur at any part of the season, and are often full depth (Barton and Wright 2000).

Penetrometers offer much reduced sampling time when compared to traditional snow pit analysis. Adoption of penetrometry in place of some of the snow pits currently undertaken would allow a substantial increase in the number of sites that could be sampled in a typical field trip. The SnowMicroPen SMP also provides an interesting tool for microstructural investigation, as it interacts with snow on a scale similar to that of the individual ice particles. Thus, a SMP test results in a large number of data characterizing the strength of snow on the grain scale. However, to interpret these data and link them to more macroscopic snow properties, a theory of the SMP-snow interaction is required.

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A theory for interpreting SMP results was originally proposed by Johnson and Schneebeli (1999). SMP force distance records were assumed to be a superposition of triangular waveforms caused by the elastic deformation and subsequent brittle failure of single elements. Monte Carlo methods were used to show that these assumptions could produce the observed waveform. Marshall and Johnson (2009) proposed a method to recover microstructural information, based on the same assumptions and again tested by Monte Carlo simulation. However, existing theories might be criticized for over-simplifying the interaction of the penetrometer with snow, since it is not clear to which extent the picture of brittle elastic elements can capture the complex pattern of force chains that emerge in snow deformation due to the granular and disordered nature of the material. As a foundation for further developing our theoretical understanding of SMP-snow interactions, a systematic experimental study using snow of controlled and reproducible microstructure would be highly desirable.

While snow in the natural environment shows a wide range of physical properties, conducting repeatable experiments is hampered by difficulties in finding, retrieving and preserving sets of similar samples. We have developed a method of producing artificial snow with properties similar to typical Scottish snow. This artificial snow can be produced with repeatable, consistent physical properties, and with control over a range of density and grain sizes.

This paper discusses the interactions between the SnowMicroPen instrument and typical Scottish snow types. Further, it proposes that artificially produced snow has many similar properties to typical Scottish snow and can be used as a model material for study of penetrometer/snow interactions.

2. METHOD

The SMP is a field portable fixed speed motor driven penetrometer. The device measures the force required to drive a 6 mm 60° cone through the snow pack and records it at a rate of 250 samples per mm. The usual driving speed is 20 mm/s and the maximum penetration depth of the standard instrument is 1.7 m.

Field tests with the SMP were performed between January and April 2010. In each case a series of SMP measurements were made and the locations marked. A pit was then dug to expose the tested snow and observations of grain size and type were recorded at 5 cm intervals (measured slope normal). Density was measured using a 100 cm^3 Taylor-LaChapelle density cutter and temperature was recorded with a type K thermocouple. A conventional layer based observation was also conducted to complement the 5 cm samples, with hand hardness, grain type and grain size recorded.

The snow pit profiles were examined to identify the thickest layers for each snow type of interest. The corresponding SMP trace was then examined and the layer of interest identified within it. A sample of 30 mm length was selected from within this layer and was then taken as representative of this snow type. Artificial snow was made by a standardised process (Blackford et al, in preparation). Ice chips were ground to a powder like material. This pulverised material can then be separated into different grain sizes by sieving as required. Smaller grain sizes are found to result in 'snow' of lower initial density. For the purpose of this work, a density of 340 kg/m^3 was used, containing a grain size distribution of 0.1 - 0.7 mm.

Artificial snow was sieved through a 1.68 mm aperture sieve into cylindrical containers 300 mm high and 110 mm in diameter. These were covered before being allowed to sinter for 0, 1, 2, 4, 7, 10 or 14 days in a cold room at −10 °C. Samples were uncovered and tested immediately with the SMP. The snow settled with time and did not bond significantly to the container.

3. RESULTS

3.1 Field snow

Samples of natural snow used in this paper originate from one of three snow pits. The first was taken on 5th January 2010 in dry powdery snow on a flat field. Recorded average density was 196 kg/m^3 with temperatures just below zero as indicated in figure 1. Fragmented and decomposed precipitation particles dominated.

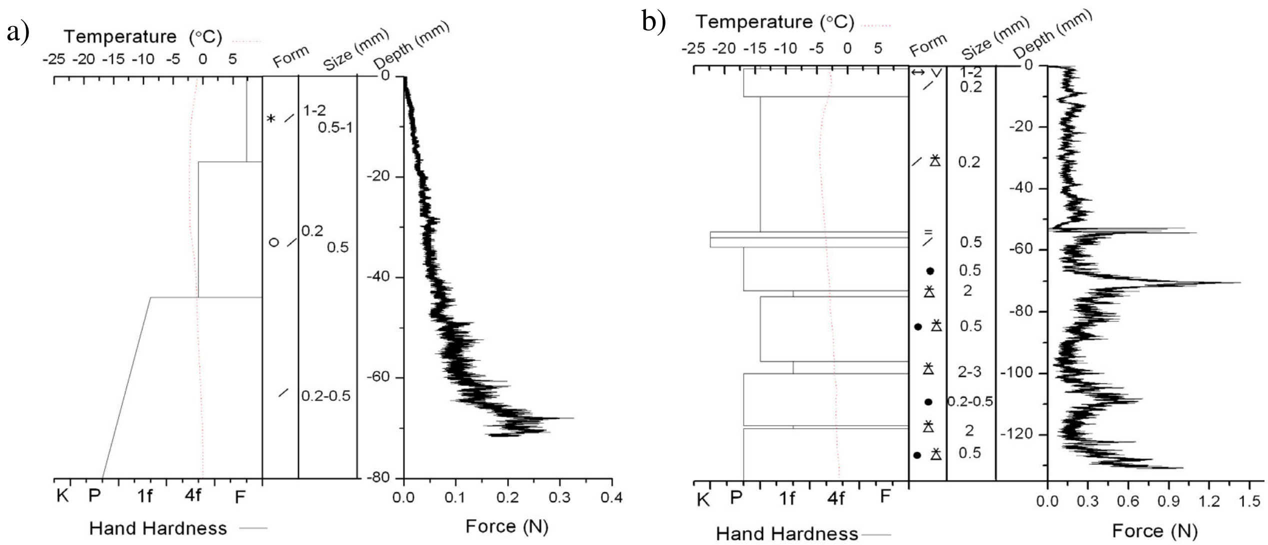
The second test presented here was performed on 10th February 2010. Density ranged from 244 to 384 kg/m^3 with temperatures around −4 °C. The pit was dug on a 30° south east facing slope, in dry snow. Rounds and mixed forms made up the majority of the snow pack with several prominent layers of graupel.

The final snow pit was dug on a south west facing 15° slope on 14th April 2010. Temperatures were near zero and melting was evident. Recorded density ranged from 292 to 579 kg/m^3. The dominant snow types were rounded polycrystals and melt crusts.

All samples were taken in the area near the Cairngorm Ski Resort in the Grampian Mountains. The first one was at an altitude of 320 m and the other two at 1150 m.

The samples show less indication of hard windslab and melt-freeze metamorphosis than normal for Scotland. This is due to the exceptionally cold nature of the winter 2009/2010.

From the three field tests six examples of different snow types were extracted as shown in figure 2. These six forms represent some of the most common snow types found in Scotland.



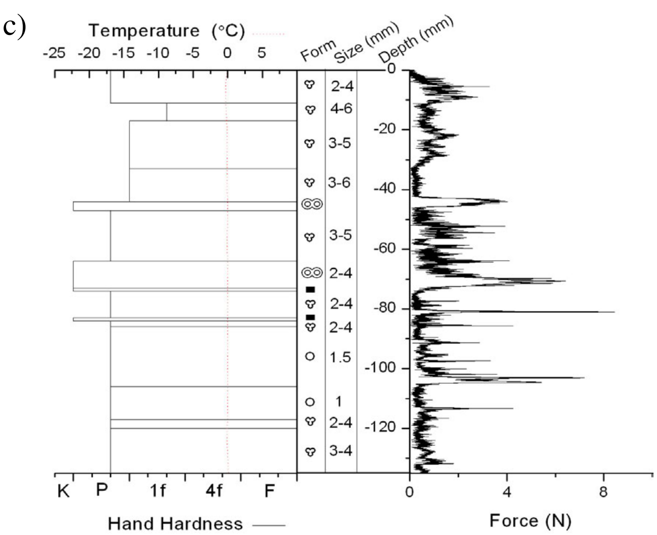


Figure 1: Penetration resistance, from SnowMicroPen measurements, compared to hand hardness. a) soft powder snow from 5 Jan 2010, b) dry snow from 10 Feb 2010, c) old wet snow from 14 Apr 2010. Hardness and grain forms are defined in accordance with the international classification for seasonal snow on the ground (Fierz et al 2009)

3.2 Artificial Snow

Ageing of artificial snow samples leads to an increase in penetration force from 0.04 to 0.26N. The standard deviation of the signals also rose, maintaining a coefficient of variation between 0.24 and 0.42.

The distance travelled by the SMP before a steady state signal level was reached generally increased with age of the sample, ranging from 10 mm in the fresh snow to around 50 mm in harder samples.

4. DISCUSSION

The windslab, graupel and powder snow produce the most homogeneous force-distance series, as seen in figure 2. This may be due to their relatively easily separated, dry grains of a constant size. The meltcrust and polycrystalline wet snow show much more variation. This may be indicative of forces being spread over a larger area and larger volumes of grains acting as single units.

An interesting behaviour may be seen when the SMP strikes an ice lens or crust in the snow. The penetration force builds up rapidly before collapsing and rising again. This behaviour may occur three or four times over a distance of 3-4 mm. It is probable that this is caused when the conical tip flexes and then punctures the ice crust. Subsequent peaks correspond to enlargements of this hole until the probe may pass through. The force recorded over this period may be much higher than in surrounding snow pack and may make detection of any thin layers above or below the ice crust difficult.

Artificial snow hardens with time if left to sinter in an isothermal setting. This sintering process decelerates with time, as would be expected as the snow approaches an equilibrium state.

Older artificial snow takes longer to reach a steady-state force under SMP testing, as seen in figure 3. This may be indicative of the time required for an interaction volume to build up around the tip. Determining the interaction volume of the instrument is one of the aims of continuing work.

In some of the oldest artificial snow, fracture of the entire sample within the canister was observed. This may explain the apparent drop in penetration resistance observed in the 10 day and 14 day old samples in figure 3.

The range of mean forces for penetration of artificially produced snow covers the majority of the SMP traces taken in the field with the exception of the very soft powdery snow tested on the first day, and ice forms. The range of coefficients of variation from 0.23 to 0.42 also covers the majority of the natural snow except meltcrusts and ice lenses (for which a coefficient of variation cannot be easily defined). It could reasonably be assumed that by aging the snow for longer, higher forces could also be reached, up to a limit defined by the sintering processes.

The artificially produced snow consists of irregular angular fragments with a relatively wide grain size distribution, and is similar in appearance and microstructure to decomposed, windblown snow and windslab. These snow types also produce similar SMP results to artificially produced snow, with windslab (figure 2) being comparable to 4 day old artificial snow (figure 3).

The structure of the artificially produced snow is

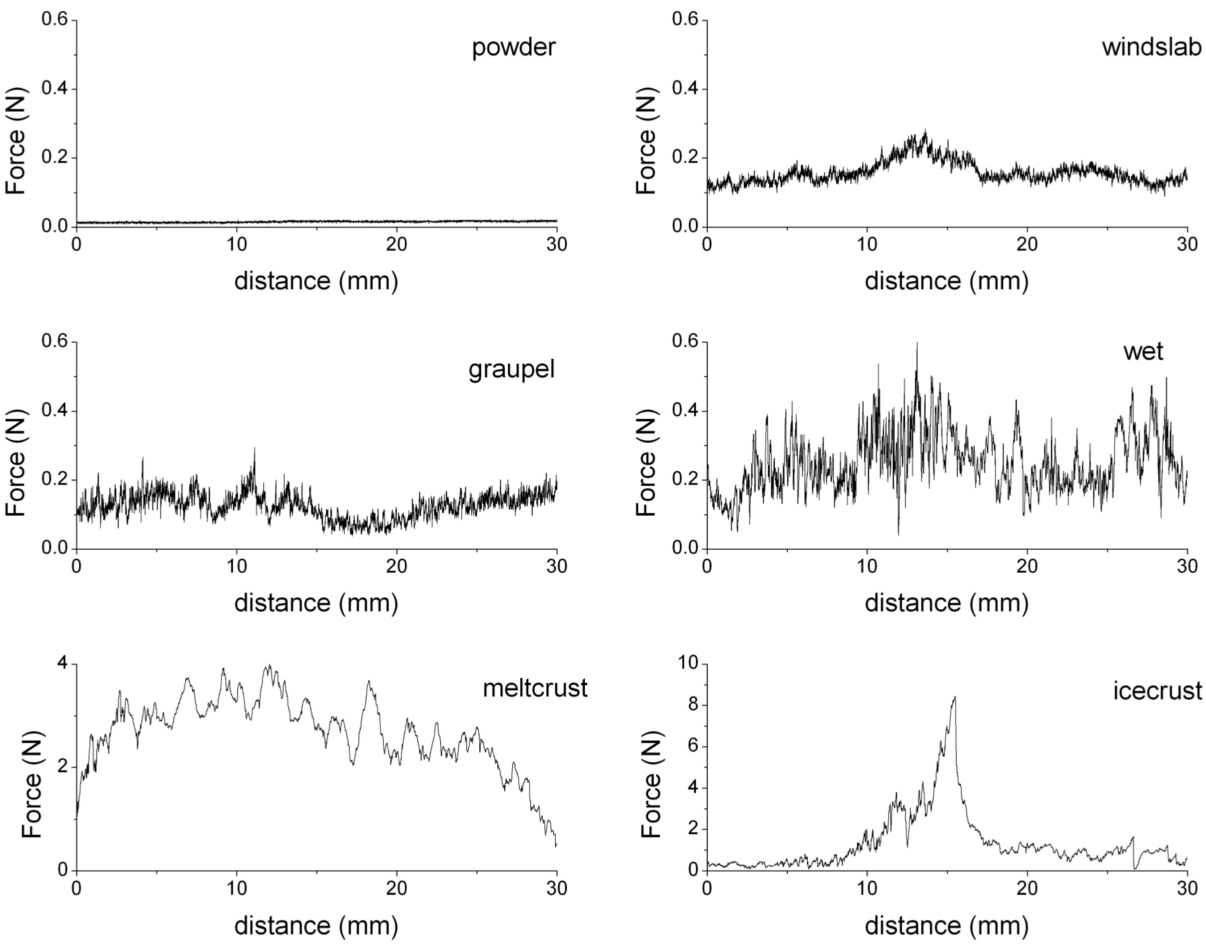


Figure 2: SnowMicroPen traces from six typical Scottish snow types. Note: melt crust and icecrust are to a different scale

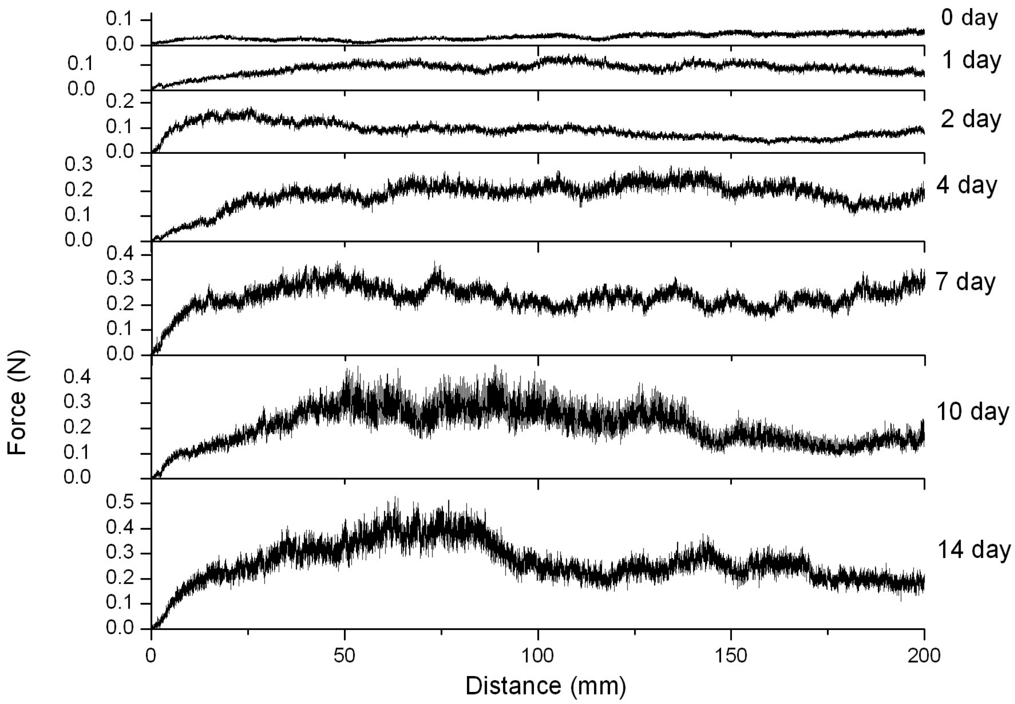


Figure 3: Penetration resistance of artificial snow increases with age

similar to some forms of natural snow (Blackford et al, in preparation). It is proposed that study of this artificial snow could lead to improvements in the understanding of the relationship between microstructure and bulk properties in some snow types.

In addition we hope it will inform our understanding of complex measurement processes such as SMP, and we propose to use artificial snow in controlled conditions to test phenomena that are important for snow pack stability.

5. CONCLUSIONS

Artificially made snow has a penetration resistance as measured with the SMP in a range that covers a considerable proportion of natural snow found in Scotland. Ageing artificial snow at a constant temperature increases the penetration resistance.

Artificial snow is a good model for young, powdery snow and for windslab.

It is proposed that artificially produced snow could be used for a systematic study of interactions between the SMP and some typical Scottish snow types.

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