WET-SNOW FRACTURE PROPAGATION

Ingrid Reiweger[1,*], Markus Zöchling[1], Martin Forster[1], Thomas Wiesinger[1], Christoph Mitterer[2]

[1] Institute of Mountain Risk Engineering, BOKU University of Natural Resources and Life Sciences, Vienna, Austria
[2] ALPsolut S.r.l., Livigno, Italy

ABSTRACT: Fracture propagation within wet snow is a key issue in order to understand and predict wet-snow slab avalanches. In our preliminary field study we investigated the fracture propagation propensity within wet snow layers. This was achieved by performing propagation saw tests in faceted weak layers with different volumetric liquid water contents. Within our propagation saw test measurements crack propagation propensity even slightly decreased at a low liquid water content compared to dry conditions, presumably due to capillary forces. For liquid water contents higher than 3-4%, however, crack propagation propensity strongly increased, which we assume was due to the weakening of bonds between grains within the increasingly wet weak snow layer.

KEYWORDS: wet snow, fracture propagation, wet-snow avalanches, propagation saw test

1. INTRODUCTION

Observations have shown that with the first infiltration of water into the snowpack, the probability of wet-snow avalanche activity increases (e.g. Conway and Raymond, 1993). Yamanoi and Endo (2002) showed that the strength of wet snow is directly linked to the liquid water content within the snowpack. Moreover, the change of snowpack stability due to percolating water is believed to be highly non-linear (Schneebeli, 2004). Wet-snow stability is affected by a number of processes, which may in some cases favor the formation of wet-snow avalanches, but also might lead to an increase in stability. Changes in stability can occur within 30 min (Trautman et al., 2006), so that forecasting of periods with high wet-snow avalanche activity is very difficult. In fact, the prediction of the exact onset, peak and end of a wet-snow avalanche cycle poses difficulties to national warning services and local authorities (Techel and Pielmeier, 2009). Until now, prediction of wet-snow avalanche activity is mainly based on energy and mass balance indices (e.g. Mitterer and Schweizer, 2013), neglecting wet-snow mechanics.

* *Corresponding author address:*
Ingrid Reiweger, Institute of Mountain Risk Engineering, Boku University of Natural Resources and Life Sciences, Peter-Jordan-Strasse 82, A-1190 Vienna, Austria
tel: +43-1.47654-87112;
email: Ingrid.reiweger@boku.ac.at



Fig. 1: Performing a propagation saw test (PST) in a wet snowpack.

At low volumetric liquid water contents – i.e. in the pendular regime, $LWC_{vol} < 3\%$ – air exists in continuous paths throughout the pore space. The capillary pressure in the snowpack is expected to be relatively high and the ice crystals cluster together to form well bonded units. The three-phase system of air, bonded crystals, and water at the crystal menisci has considerable strength and might even gain strength compared to dry-snow conditions. With increasing water content – i.e. in the funicular regime, $LWC_{vol} > 8\%$ – the grain boundaries are unstable and melt easily (Colbeck, 1987). Accordingly, it is expected that snow in the funicular regime has low strength.

Results from field experiments by Techel et al. (2011) where initially dry snow layers were artificially wetted suggest that snow hardness and therewith presumably also snow strength decreases already at lower water content values, namely at $LWC_{vol} < 3\%$, i.e. before the pendular/funicular transition.

In order to describe and understand slab avalanche release, one needs to consider not only snow stability but also crack propagation. We therefore performed a first series of propagation saw tests (Fig. 1) in the field in order to estimate fracture propagation propensity within snow as a function of volumetric liquid water content LWC_{vol}.

2. METHODS AND DATA

The propagation saw test (PST) was developed by Gauthier and Jamieson (2008) in order to quantify the fracture propagation propensity within a weak snow layer and relate it to snow slab avalanche release. A PST requires a free-standing snow block with an upslope length of 100 cm and a width (across slope) of 30 cm, the height has to be sufficient to expose the weak snow layer of interest. The PST is performed by slowly cutting the weak layer with a saw, creating a slope-parallel crack in the weak layer (Fig. 1). At a certain point during cutting, the crack will begin to self-propagate. The length of the crack in the weak layer introduced by cutting (cut length) is recorded and represents a measure of fracture propagation propensity within the weak layer, i.e. the shorter the cut length, the higher the crack propagation propensity. With empirical and mechanical arguments Gautier and Jamieson (2008) defined a cut length of 50% of the block length, i.e. 50 cm, as the threshold between low and likely propagation propensity.

We measured the volumetric liquid water content LWC_{vol} with a Denoth-capacitive plate at the location of the weak layer (Denoth, 1994). Measurement errors were expected to be in the range of LWC_{vol} = 0.5-1% (Fierz and Föhn, 1995), depending on the quality of the snow density measurement and grain type.

The test site for our field measurements was a north-facing slope (“Langwiedboden”) at an elevation of 2000 m.s.l. and with a slope angle ranging from 20° to 30°. The slope was located in the backcountry of the skiing area Kitzsteinhorn in Kaprun, Austria. The snowpack was a typical spring snowpack, with snow heights varying between 70 and 140 cm, grain types consisting mainly of melt forms but also of faceted (weak) layers. Within those faceted weak layers we performed 30 PST tests in the time period March to April 2014.

3. RESULTS AND DISCUSSION

The cut length of our propagation saw tests (PST) as a function of LWC_{vol} is shown in Fig. 2. The volumetric liquid water contents within the weak layers ranged from 0 to 4.6 % and were grouped into three classes: [0-1.5%]: very low, [1.6-3.1%]: low, [3.2-4.6%]: medium. The PST cut lengths took values from 25 to 98 cm.

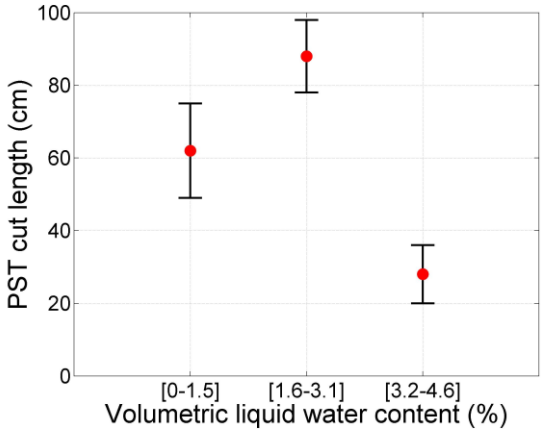


Fig. 2: PST cut length as a function of volumetric liquid water content LWC_{vol}. The red dots and black whiskers represent the mean values and standard deviation, respectively. (N = 30)

It can be seen that for LWC_{vol} higher than 3-4% (class “medium”), the cut length was significantly lower than 50 cm (mean 28 cm and standard deviation 8 cm) which means that propagation propensity was likely according to the rule of Gauthier and Jamieson (2008). Their rule, however, is based on measurements in dry snow. We assume that those low cut lengths i.e. likely propagation propensities were caused by an additional weakening of the faceted weak layer due to the melting of bonds between grains induced already by the “medium” liquid water content within the layer.

As LWC_{vol} increased from “very low” (which might actually also be almost dry, since the values are of order of magnitude of the measurement errors) to “low” liquid water content, the PST cut length even increased, i.e. propagation propensity became even more unlikely. We assume that this decrease of propagation likelihood was due to an increase of weak layer stability within a small range of low liquid water content due to capillary forces which increase cohesion between snow grains. We expect this increase of stability to be of transient nature and to depend very much on an unstable equilibrium between LWC_{vol}, grain size, and grain shape. Thus, the fracture propagation propensity and also stability of wet snow might change rapidly to more unstable (and also more stable) conditions due to changes in either LWC_{vol}.

In agreement with the findings of Techel and Pielmeier (2011), who found a significant decrease of wet snow stability at LWC_{vol} below 3%, we measured a decreasing PST cut length indicating an increase of fracture propagation propensity as the LWC_{vol} increased from 3 to 4%. One percent of change in LWC_{vol} is quite small and about the order of magnitude of the LWC_{vol} measurement accuracy – which in turn depends on the accuracy of measured snow density. We therefore assume that subtle changes – in time as well as in space – may play an important role in wet snow stability.

As liquid water content is subject to strong diurnal changes (Heilig et al., 2015) – other than in dry snow – timing is of crucial importance for performing stability tests within wet snow, as is the case for wet snow avalanche release.

4. CONCLUSIONS AND OUTLOOK

Our propagation saw test results in wet snow showed that a low liquid water content of 3% or lower seemed to strengthen snow and decrease crack propagation propensity, presumably due to capillary forces of the free water between ice grains. At a slightly higher LWC_{vol} content, namely at around 4%, fracture propagation propensity rapidly increased. Both these findings are in agreement with the snow hardness measurements of Techel and Pielmeier (2011).

Note that while propagation saw test results in wet snow are useful in order to estimate the probability of wet snow slab avalanches, they are not indicative of wet snow avalanche release in general, as loose snow avalanches due to increasing loss of cohesion with increasing wetting are an important factor in a wet snow situation.

ACKNOWLEDGEMENTS

We gratefully thank the Gletscherbahnen Kaprun AG, Kaprun, Austria for providing ski passes and transportation to our study site. We further thank the Lawinenwarndienst Salzburg for sharing their knowledge and data.

REFERENCES

Colbeck, S. C., 1997. A review of sintering in seasonal snow. CRREL Report 97-10. Hanover NH, U.S.A., US Army Cold Regions Research and Engineering Laboratory: 18.

Conway, H., Raymond, C.F., 1993. Snow stability during rain. Journal of Glaciology 39(133): 635-642.

Denoth, A., 1994. An electronic device for long-term snow wetness recording. Annals of Glaciology 19: 104-106.

Fierz, C., Föhn, P.M.B., 1995. Long-term observation of the water content of an alpine snowpack, Proceedings International Snow Science Workshop, Snowbird, Utah, U.S.A., 30 October-3 November 1994. ISSW 1994 Organizing Committee, Snowbird UT, USA, pp. 117-131.

Gauthier, D., Jamieson, B. 2008. Fracture propagation propensity in relation to snow slab avalanche release: Validating the Propagation Saw Test. Geophysical Research Letters 35(13): L13501.

Heilig, A., Mitterer, C., Schmid, L., Wever, N., Schweizer, J., Marshall, H.-P., Eisen, O., 2015. Seasonal and diurnal cycles of liquid water in snow – Measurements and modeling, Journal of Geophysical Research Earth Surface, 120, 2139–2154, doi:10.1002/2015JF003593.

Mitterer, C., Schweizer, J. 2013. Analysis of the snow-atmosphere energy balance during wet-snow instabilities and implications for avalanche prediction. The Cryosphere 7(1): 205-216.

Schneebeli, M., 2004. Mechanisms in wet snow avalanche release. Proceedings ISSMA-2004, International Symposium on Snow Monitoring and Avalanches, Manali, India, 12-16 April 2004, Snow and Avalanche Study Establishment, India.

Techel, F., Pielmeier, C., 2009. Wet snow diurnal evolution and stability assessment. International Snow Science Workshop ISSW, Davos, Switzerland, 27 September - 2 October 2009. J. Schweizer and A. van Herwijnen, Swiss Federal Institute for Forest, Snow and Landscape Research WSL: 256-261.

Techel, F., Pielmeier, C., Schneebeli, M. 2011. Microstructural resistance of snow following first wetting. Cold Regions Science and Technology 65(3): 382-391.

Trautman, S., Lutz, E.R., Birkeland, K.W., Custer, S. 2006. Relating wet loose snow avalanching to surficial shear strength. Proceedings ISSW 2006. International Snow Science Workshop, Telluride CO, U.S.A., 1-6 October 2006.

Yamanoi, K., Endo Y., 2002. Dependence of shear strength of snow cover on density and water content. Seppyo, Journal of the Japanese Society of Snow and Ice 64(4): 443-451.