OPTIMAL PREPARATION OF ALPINE SKI RUNS

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ABSTRACT: The demands on the quality of ski runs have grown with the development of sports equipment. A skiing run must nowadays provide perfect grip, have a certain strength and be durable in order to satisfy the users. The preparation of ski runs involves many snow transformations such as recrystallization, vapor transport, and sintering. These processes strongly depend on the weather conditions that can obviously not be influenced. Therefore, understanding the influences of the various processes involved in grooming is crucial to choose the optimal time and procedure to prepare the runs. Our aim is to optimize the preparation of skiing runs from a technical, economical and ecological point of view. We developed a framework in which the physical and mechanical processes of snow, the weather forecast and type of grooming was taken into account. The influence of snow properties on grooming practice for both, natural and machine-made snow was considered. We propose the best suited grooming method and preparation time for both dry and wet snow in order to obtain high quality and durable runs. Regarding its structural and mechanical properties, machine-made snow constitutes a good snowpack and requires less processing than natural snow for its hardening. By following the proposed scheme the best conditions possible for all skier and riders can be created.

Keywords: ski run, snow grooming, weather, snow properties, snow sintering, machine-made snow

1. INTRODUCTION

Since the early days of winter snow sports the aim of preparing the snow surface has been to transform a soft snow into a safe, hard, homogeneous and durable run. Snow compaction was first done by ski or boot packing and later with rollers. Nowadays the quality demand on the snow sport pistes has grown so much with the development of the sports equipment that high efforts must be made for the preparation and the maintenance of the ski runs.

Although the grooming equipment has technically improved considerably, low attention has been paid to the impact of snow and weather on the efficiency of the grooming task. The aim of this paper is to explain the various processes involved in grooming and to show the importance of having a certain snow knowledge in order to optimize the snow preparation work from an economical and ecological point of view. We focus first on the hardening processes of snow, then we present the influence of the meteorological factors and finally we propose different methods of preparation of natural dry snow, natural wet snow and machine-made snow.

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2. SNOW AND WEATHER

2.1 <u>Snow hardening</u>

In order to obtain a run which will resist the impact of the skiers and the influence of the weather it has to have a certain strength. One of the main task of the grooming team is to promote the snow hardening. The following snow parameters have an influence on the snow hardness: bonds between grains, density and temperature. Increasing of the number and of the size of the bonds enables a hardening of the snow (Fig. 1). Lang et al. (1997) have shown that the degree of bonding is the most important parameter regarding snow hardness.

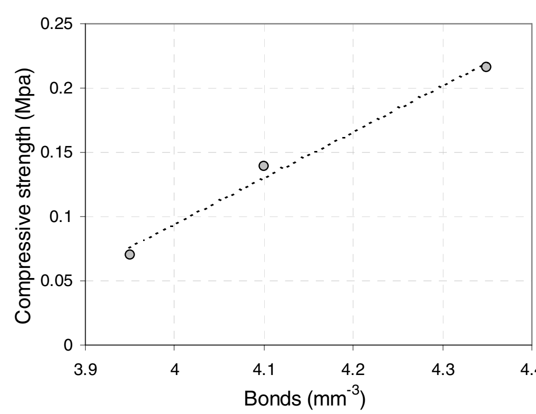

Figure 1. Influence of inter-granular bonds on the compressive strength of snow (Fauve, 1997).

As shown in Fig. 2 and measured by many scientists in the past (Mellor [1988], Ramseier [1966]) the higher snow density is, the higher is its strength. This is explained by the reduction of space between the grains and by the increase of contact points between the grains. High density does not always mean high strength: e.g. in the case of wet snow this is not correct.

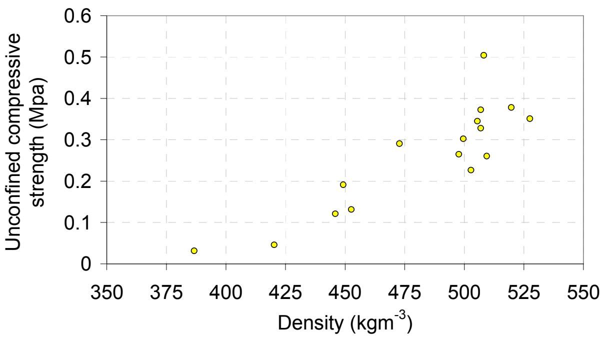

Figure 2. Influence of density on the compressive strength of snow (Fauve, unpublished).

Many authors as Tusima (1974) have studied the effect of temperature on the strength of ice and snow. It was shown that the colder the harder is snow and therefore the more difficult it is to process (Fig. 3).

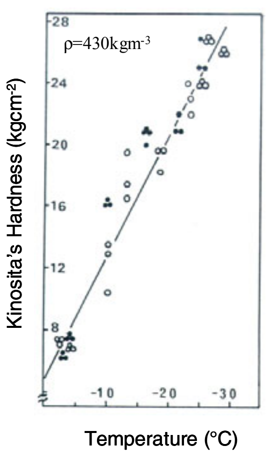

Figure 3. Effect of temperature on snow hardness (Tusima, 1974).

2.2 *Sintering process*

The bonds between the grains are the most important factor regarding snow strength. The development of these bonds can occur by the melt/freeze process but can also be the result of the sintering process.

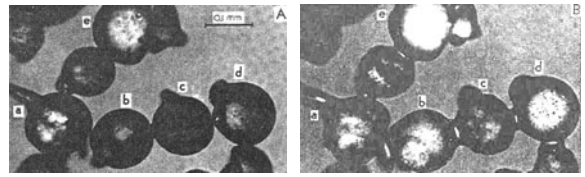

Figure 4. Formation and enhancement of bonds between ice crystals after 165 minutes at –1.5°C (Kuroiwa, 1975).

During the sintering process, bonds form between the grains by evaporation and condensation of ice (Fig. 4). The speed at which the bonds form and grow depends on the following parameters: grain shape, size and distribution, density, temperature and time.

The smaller and the rounder the grains are, the more bonds will form and therefore the harder will be the snow. The optimum condition is a wide distribution of grain sizes with a maximum of fine grains in order to enhance the contact points. An increase of density increases the contact points and therefore more possibilities to build bonds exist. As shown in Fig. 5, the higher snow temperature is, the faster is the hardening process.

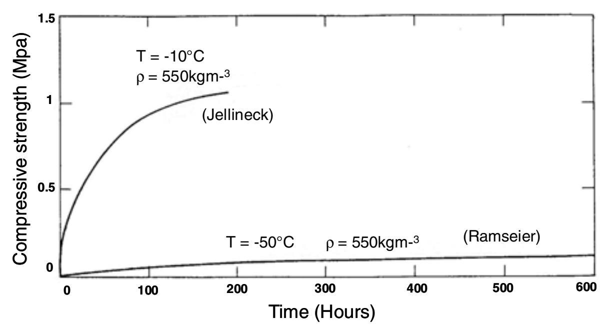

Figure 5. Effect of temperature on the speed of snow hardening by sintering (Mellor, 1988).

2.3 *Meteorological influence on snow properties*

Snow temperature has a high influence on the speed at which the snow will harden and the possibility to modify its structure. Snow surface temperature depends on the thermal balance between the snowpack and the environment which is the result of heat input and output. Heat input at the snow surface is due to solar radiation, rain and warm winds. Loss results from long wave terrestrial radiation and cold winds. Snow is very sensitive to energy input by radiation which is highly influenced by cloudiness as shown in Fig. 6. Radiative heating is mainly caused by the fact that snow absorbs 99 % of long wave radiation and between 10 and 50 % of short wave radiation.

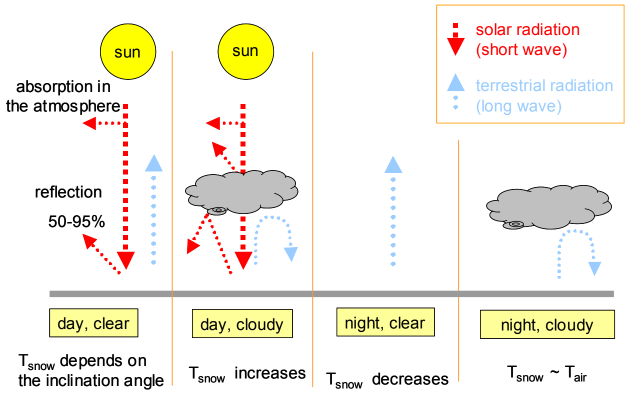

Figure 6. Influence of radiation on snow surface temperature.

3. PREPARATION OF SKI RUNS

If equipment is to be used to its optimum effect and high quality runs maintained at the lowest possible cost, natural processes must be implemented in the best possible way. An optimally prepared run will be more robust, will suffer less damage and will require less maintenance.

3.1 *Combination of machine and nature*

Snow hardening with the use of grooming equipment should actually result in the combination of machine and nature. The machine's task is to prepare the snow for its natural hardening by sintering. It is in this optic that the different equipments and mainly the snow tiller will work. The modification of the snow aims at:

- increasing of snow density
- producing of rounder and smaller grains with a wide grain size distribution in order to maximize the contact points between the grains
- possibly increasing of the snow surface temperature

Such modifications of the snow structure were measured in the field by Guily (1991).

These modifications of the snow structure initiate a faster sintering process which still requires a certain time to reach a sufficient snow strength.

Figure 7 shows the increase of the snow penetration strength by a factor of six due to mechanical preparation. Figure 7 also shows that the effect of grooming is only superficial (upper 5 cm on the example in Fig. 7). The impact of the grooming equipment on the snow does not actually exceed a maximum depth of 30 cm depending mainly on snow density and temperature.

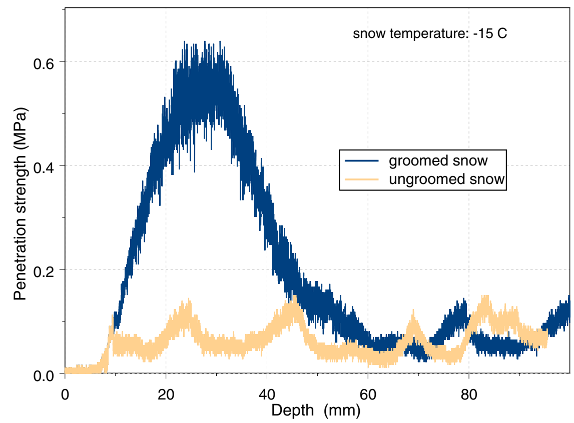

Figure 7. Comparison of the penetration strength of groomed and ungroomed new snow (hardness measurements conducted 10 hours after grooming).

3.2 *Preparation of dry natural snow*

For the processing of dry natural soft snow one should mainly focus on the importance of the sintering time after the mechanical processing. The longer this sintering time is, the higher will be the snow resistance after opening of the piste as shown in Fig. 8 and measured by Guily (1991) and reported in Fig. 9.

Figure 8. Effect of time on snow hardening by sintering. Left: 2 hours sintering, right: 10 hours sintering.

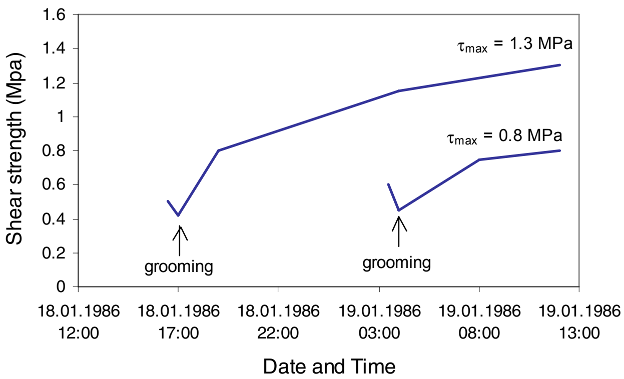

Figure 9. Impact of time after grooming on snow hardening. The snow mechanically treated in the evening at 5 p.m. is almost twice as robust at the opening time of the piste as the snow treated at 4 a.m. (Guily, 1991).

Figure 10 shows the best time for preparing a dry snow ski run in the case of an overnight cooling of the snow surface which is common during a clear night.

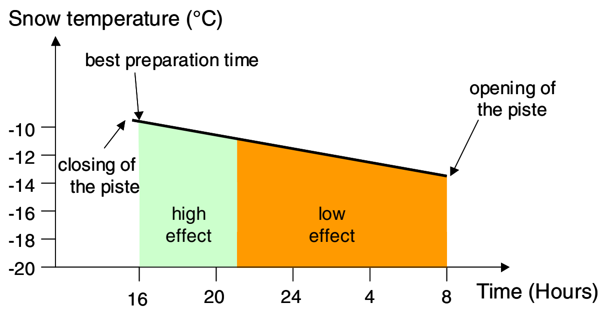

Figure 10. Best time for preparing a dry snow ski run when the temperature decreases over night.

In case of an increasing temperature in the evening, it is recommended to delay the preparation in order to treat a warmer snow which will facilitate processing and accelerate sintering (Fig. 11).

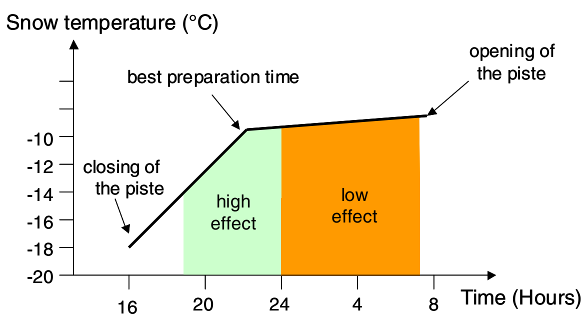

Figure 11. Best time for preparing a cold snow ski run with evening warming (cloudy sky, warm front).

3.2 _Preparation of wet natural snow_

The grooming of wet snow should occur as the freezing of the liquid water starts when the weather conditions allow a refreezing (Fig. 12). If the snow preparation is being conducted too early when the snow is still wet, the liquid water will be squeezed out to the snow surface where it will freeze and form an icy layer which can be dangerous to recreational users. In case of very wet snow, the mobility is limited and the efficiency of the machines is reduced. A too late processing of already refrozen wet snow causes big snow blocks and does not give sufficient sintering time.

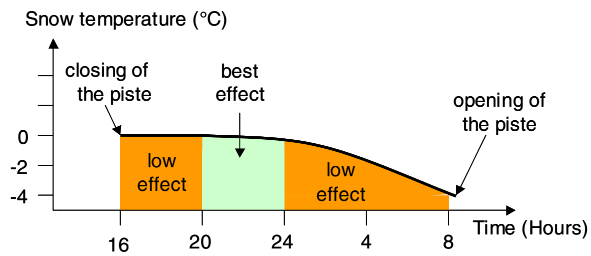

Figure 12. Best time for preparing wet snow with night-time refreezing.

3.3 _Preparation of machine-made snow_

Machine-made snow has different properties than natural new snow. These differences come from the fact that natural snow grows slowly from water vapor while machine-made snow freezes very rapidly from water droplets.
Machine-made snow is made of small round grains (0.1 to 0.8 mm in diameter) with an average density of 400 kgm^{-3} which is about four times higher than natural new snow density. Regarding these two features: small round grains and high density, one can say that this type of snow is very similar to processed snow. Therefore, no additional mechanical processing is needed to modify the structure of the snow. The task of the grooming team is only to equally spread the machine-made snow on the slope.

Often, the inside of the freezing water droplets is not yet frozen when they land on the surface (Fig. 13). A too early treatment, before complete freezing causes a build up of an ice layer at the snow surface.

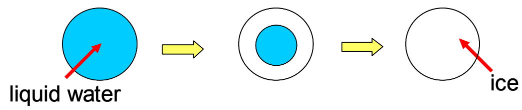

Figure 13. Freezing of a water droplet during mechanical snowmaking (Fauve and Rhyner, 2004).

4. CONCLUSION

We presented theoretical explanations and practical insights on the optimum way to harden a snow ski run by taking the snow and weather properties into account. The best moment to prepare the snow is proposed according to the type of snow. It is of course difficult to prepare all the slopes of a ski resort at the same time but the grooming task can be optimized by focusing on the preparation of the main pistes at the best moment as proposed.

It is also shown that the impact of the grooming equipment is only superficial and therefore several passes of the machine should be made during heavy snowfalls in order to compact homogeneously the snowpack.

The role of sintering is essential to give the snow a sufficient strength.

Regarding its structural properties, machine made snow does not need additional processing for its hardening on recreational ski runs.

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