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Snow - the lubricant for competition

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ABSTRACT

Snow can be described by the properties of grain size, grain shape, temperature, humidity and hardness. There are suitable devices for all five measured variables, which can be purchased or built with little effort. For skiing it becomes useful when friction values are added. The article shows how friction depends on the above mentioned quantities and whether it is predictable.

1 Introduction

Snow, as it falls from the sky, enchants with its variety of forms. If water has time to crystallize, this process leads to perfect hexagonal shapes, one of which is different from the next. Much has already been written on this subject, with Kenneth Libbrecht's pictures giving the most vivid impression [1]. Once it reaches the ground, the snow begins to change, it transforms. From the hexagonal shapes, round grains gradually emerge, which still show corners and edges on their way to the sphere. Only after long transformation times with frequent changes from cold to warm and back, perfectly round and large spheres are formed, see Fig. 1.

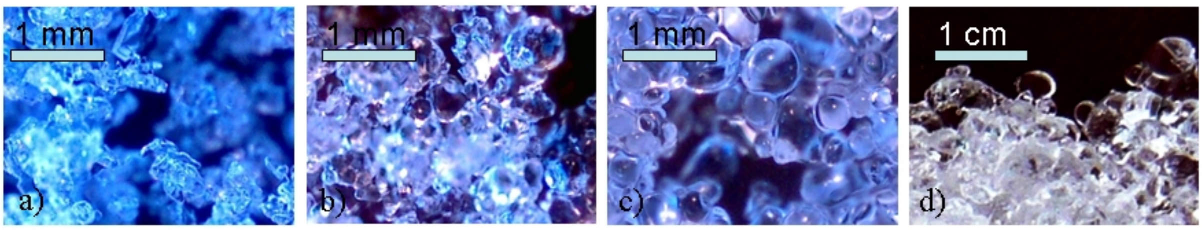

Fig. 1: Snow at different temperatures. a) Edged snow at -6°C and low snow humidity. b) Snow with curves and edges at -0.5°C and medium snow humidity. c) Snow-water mixture at -0.8°C. d) Old snow (June) at 0°C and high snow humidity. The grain size in a) to c) varies between 100 µm and 600 µm. In Fig. d) the grain size is 3 to 5 mm.

In addition to the transformation of shape, the snow grains also form a bond with each other. This process is called sintering. Snow thus forms a compact mass, which can be assigned a medium density and hardness. This article deals with the measurement of important snow properties such as temperature, humidity and hardness and establishes the connection to friction.

2 Results

2.0.1 Snow temperature and snow humidity

Snow temperature can be measured by contact with a penetration thermometer or contact-free with an infrared thermometer. Alternatively, a conventional thermometer will of course also work. For contact measurement, you should give the thermometer 1 to 2 minutes to measure the ambient conditions. As the gliding takes place on the snow grains, the puncture should be made at an angle, i.e. close to the surface. With the infrared thermometer the measured values are immediately available. However, care should be taken to measure in shaded areas to get as little reflected sunlight as possible into the optics.

A selection of measuring instruments is shown in Fig. 2. Humidity measurement is based on the change in capacity of a measuring fork in contact with snow. The electric field between the prongs of the fork penetrates several centimeters deep into the snow. Snow humidity is the amount of free water between the snow grains. Thus snow has the highest snow humidity around 0°C. Figure 3 shows the relationship between snow humidity and snow temperature.

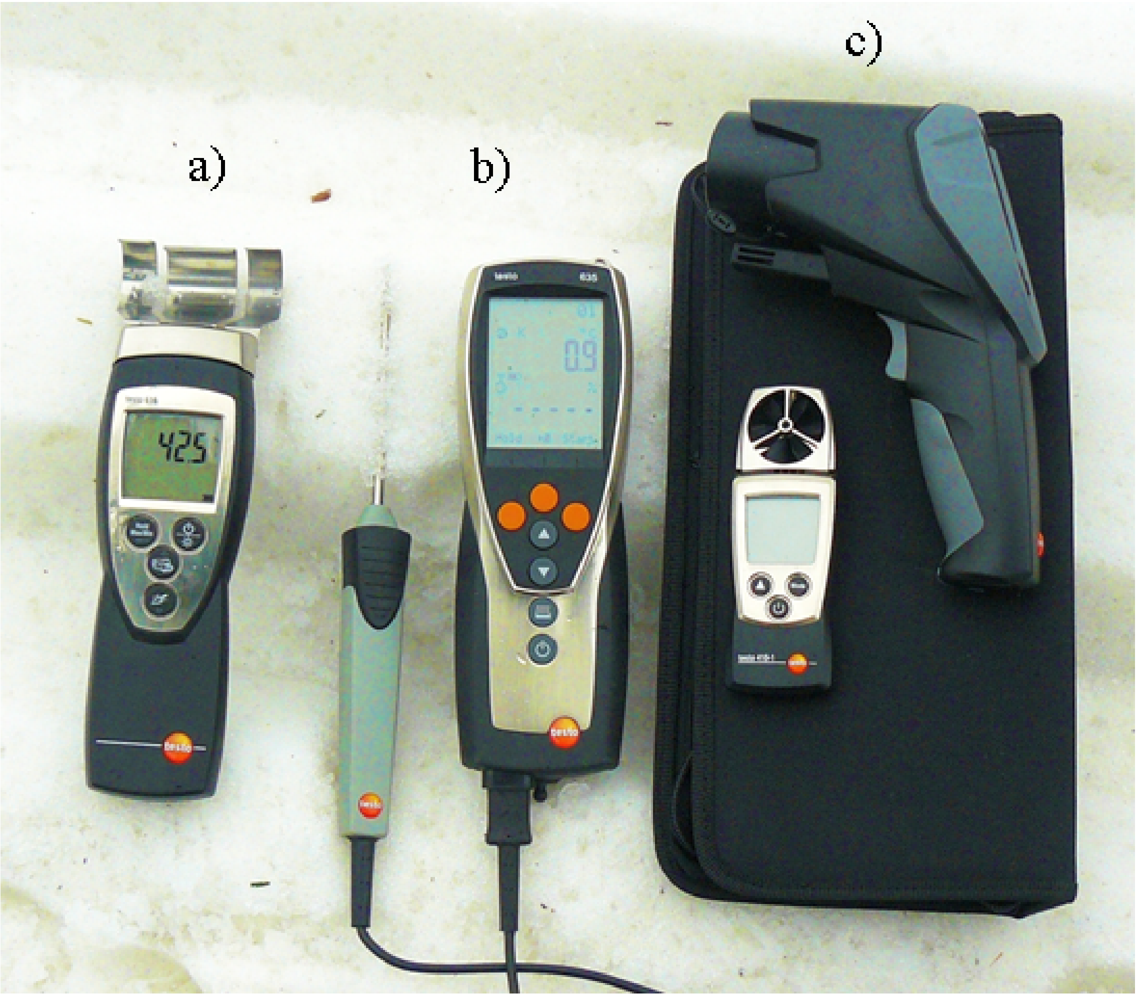

Fig. 2: Instruments for measuring snow humidity a) and snow temperature. b) Probe thermometer; c) Infrared thermometer.

After deducting the measurement inaccuracies, the values for small temperatures are about 20%. From about -8°C the values fan out and cover a range from 10% to 100% at freezing point. This scattering is caused by the inhomogeneous character of snow. As already described, snow consists of a multitude of individual grains. Between the grains there is air at low temperatures and more and more water towards the melting point. The melting process of the individual grains is influenced by parameters such as grain size, grain shape but also by the temperature of the ground and solar radiation. Therefore the snow melts at different speeds and there may be areas where a lot of water has already been formed and others where hardly any water exists. Depending on where the fork of the meter is placed, there may be more or less free water and the meter will give readings from 10% to 100%.

When looking at water, one must distinguish between water on the snow grains and water between the snow grains. Even if there is no free water between the grains, one finds a nanometer-thin film on the grains. Researchers from the Max Planck Institute for Metals Research in Stuttgart have shown that even at -13°C there is a film of water [2]. At even lower temperatures, however, the water film must first be created by friction; skiing then becomes strenuous.

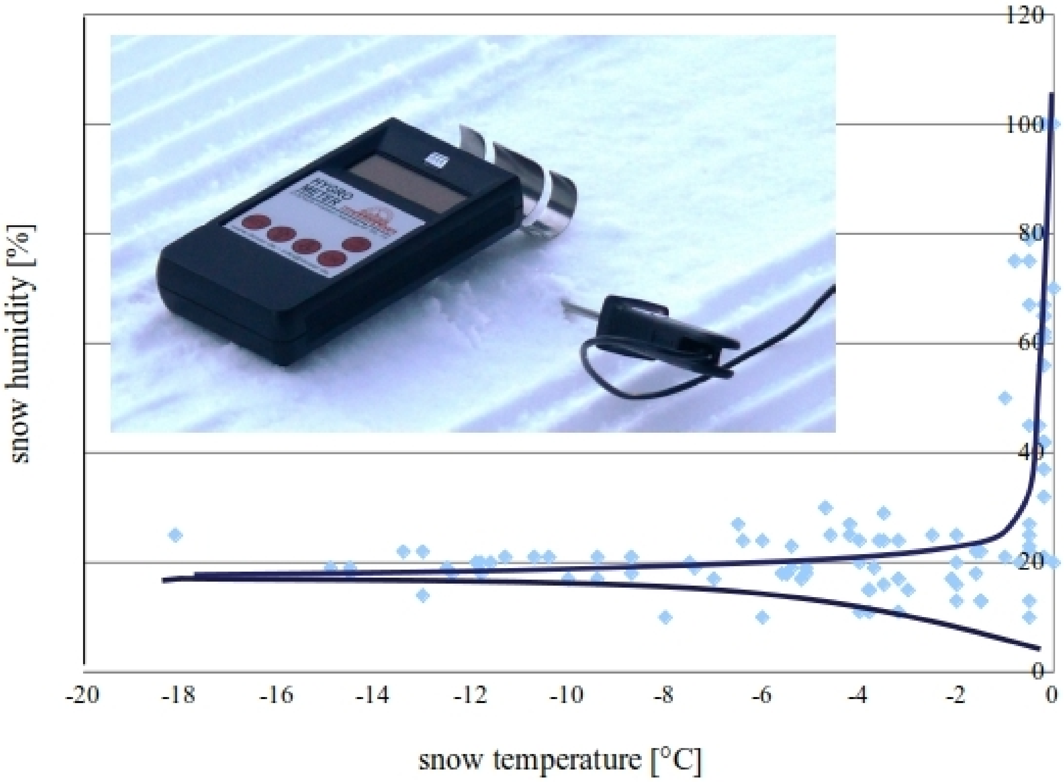

Fig. 3: Snow humidity and snow temperature. The inset of the picture shows a snow humidity meter and a penetration thermometer.

2.0.2 Snow hardness

Hardness represents the resistance when one body penetrates another. The penetrating body exerts a certain pressure with its force over the penetration surface. If the pressure is high enough, the snow caves in. In order to get a feeling for the pressure acting, one can imagine a blunt needle with a diameter of 1 mm being pressed into the snow. A break occurs when the needle is loaded with approx. 1 kg. Figure 4 shows a very simple instrument with which snow hardness can be quantitatively determined. The necessary force is generated by tensioning the spring. This process is infinitely variable. At a certain force the 1 mm thin rod penetrates the ice. This value can be regarded as snow or ice hardness. From force to pressure is achieved after suitable calibration. For this purpose, the device is placed vertically with the tip pointing upwards and a mass is placed on top. Mass multiplied by the acceleration due to gravity results in the effective force. For a mass of 1.25 kg and the acceleration due to gravity of 9.81 m/s^2 ($\approx$ 10 m/s^2), a force of 12.5 N (Newton) is obtained. The effective area is about 0.78 mm^2 ($A = \pi d^2/4$), so that a pressure of about 16 N/mm^2 = 16 MPa (megapascals) results. For comparison, the air pressure is measured in hectopascals (1,000 hPa = 0.1 MPa). The instrument covers a pressure range from 1 MPa to about 40 MPa. Values for snow hardness of around 10 MPa are known from specialist literature [3].

The instrument was used to measure ice, fine-grained and coarse-grained snow. The results are shown in Fig. 4 on the right. From the picture it can be seen that the hardness increases linearly with decreasing snow temperature. It is also clear that ice has the highest hardness values and fine-grained snow the lowest hardness values. In contrast to ice, the individual snow grains have contact points with each other. In his doctoral thesis, Lukas Bäurle succeeded in taking very nice pictures of snow morphology [4]. With the help of tomography, individual contact necks between the snow grains can be identified in

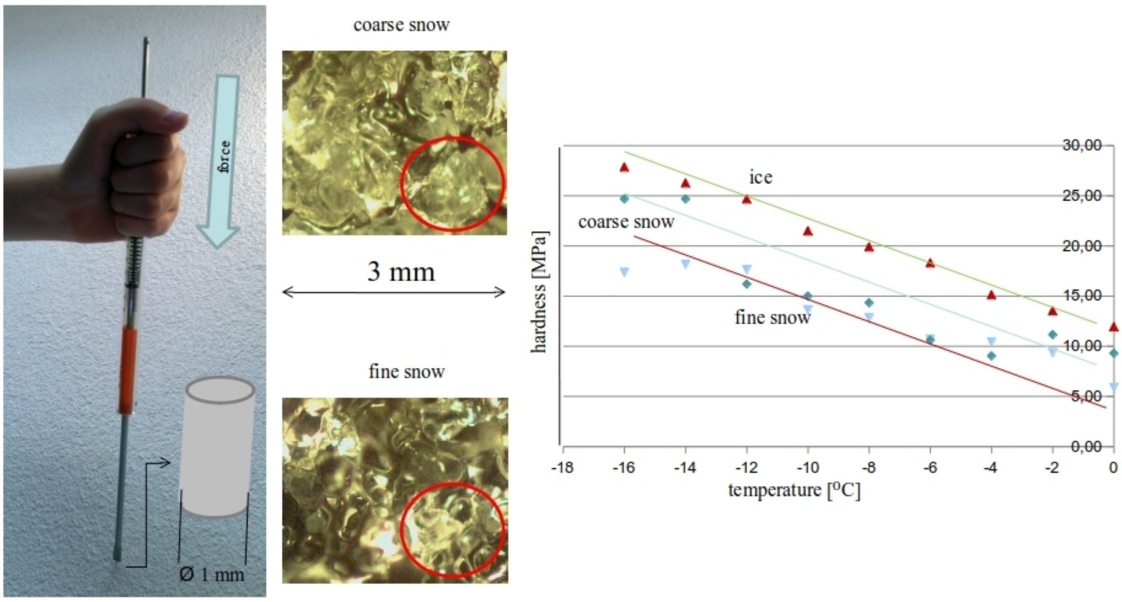

Fig. 4: Measuring instrument for hardness measurement and hardness values of ice, coarse-grained and fine-grained snow. The red circle shows the diameter of the tip.

three-dimensional images. Usually these necks fail before the ice breaks. Therefore, fine-grained snow, in which a large number of grains lie under the rod-shaped indenter, has a lower hardness than coarse-grained snow. Ice is therefore the hardest because it is compact and has no contact points. This frozen compound is lost near the zero point where snow becomes more and more water and individual grains are present. A similar effect can be seen in old snow with impurities. This snow has a granular consistency. The hardness of the snow allows statements about the mobility of individual grains of snow. The more mobile the grains are, the more likely they are to clog the grinding structures of the base and increase friction.

2.0.3 Friction

Friction between ski base and snow was measured with a portable tribometer. Tribometers are the workhorses of friction researchers. The frictional force, i.e. the force that slows down a sliding body depends mainly on the load acting on the friction body. The friction is influenced by the roughness of the friction bodies but not by the size of the contact surface. This relationship is described by Coulomb's law and applies to dry surfaces, i.e. very cold snow. If the surfaces are damp or even wet, a further force is added to the load which presses the friction bodies against each other, the capillary force. This force can be so great that it slows down the movement to a standstill, which can be experienced when driving from the shade to a sunlit section on a towpath in spring. The ski sucks in, the pressure between ski and snow increases and friction increases.

Figure 5 illustrates the forces on a skier. Driven by the gravitational force, the slope downforce is generated via the angle. The angle can also be found in the force triangle under the ski. The acting normal force is created as a component of the gravitational force. The air resistance, which will not be considered here, and the frictional force act as braking forces. The quotient of frictional force and normal force is called the friction coefficient μ:

$$\mu = \frac{frictional\,force}{normal\,force}$$

A distinction is made between static friction, which is the value at which adherence changes into sliding, and dynamic friction as the average value at movement. As a rule, static friction is greater than dynamic friction. However, the coefficient of friction cannot be determined for the skier shown in Fig. 5, since the friction force cannot be measured. To measure it, a force sensor would have to be placed between the binding plate and the ski, and the data would have to be stored temporarily or sent to the outside via telemetry. Such measurements are very complex, but have been carried out sporadically [5].

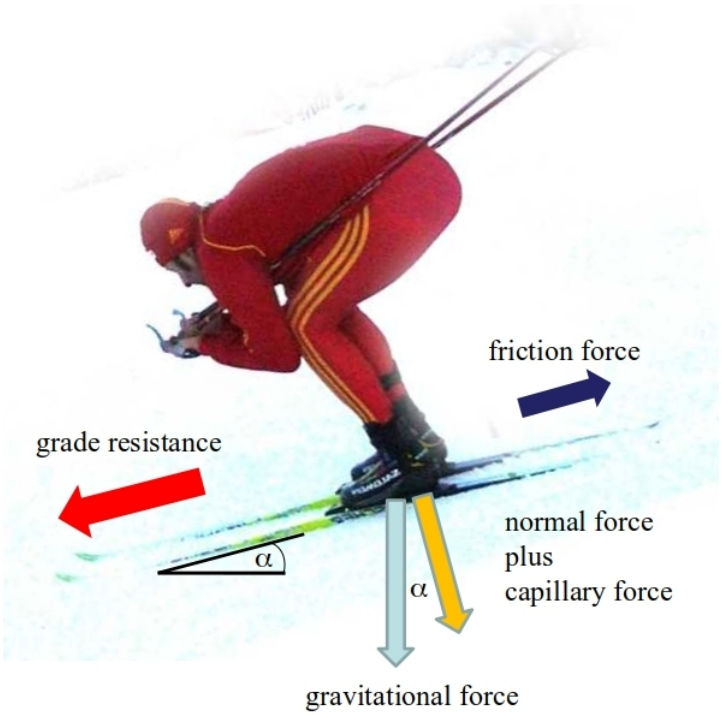

Fig. 5: Forces on a skier.

3 Effects on friction

This section discusses how snow temperature, snow humidity, grain size and grain shape affect friction. Figure 6 shows a spider diagram with 4 typical constellations:

Tab. 1: Color code and Properties.

color code	properties
blue	fine-grained, dry and cold snow with rounded edges
red	larger, slightly moist and cold snow with rounded edges
green	coarse, wet snow with round grain
grey	fine-grained, dry but warm snow with sharp edges

blue: In this sub-figure the grain size is approx. 100 µm. The snow is cold and the individual grains show only a few sinter necks among each other. There is therefore a risk that grains could settle in the grooves of the grinding structure and increase friction. In our example, the width of the grooves of the grinding structure was less than 50 µm, so that this danger did not exist. As the grains are rounded and there is no free water between them (snow humidity 10%), there are no capillary forces and friction is very low. As mentioned above, the static friction is greater than the dynamic friction (approx. 2:1).

red: Here, temperatures and humidity levels are similar to blue. The larger grains compensate for the influence of snow humidity, which is reflected in lower dynamic friction.

green: This snow is at the melting point. Despite large and round grains, the capillary effect is predominant, which leads to particularly high static friction. A sliding friction value of 0.4 corresponds to the resistance that one would feel when sliding over a carpet.

grey: Almost identical coefficients of friction as in the case of green, but significantly lower snow humidity. Therefore, the capillary effect can be ruled out as the reason for high friction. The reason for the high friction are the small and angular grains that penetrate into the grinding structure of the ski base, where they act like sand in the gearbox. This effect can be quantified by measuring the snow hardness. If it is small, many grains - if they are of the right size - will penetrate the grinding structure. In addition, small and angular grains lead to ploughing of the ski base, which in turn increases friction.

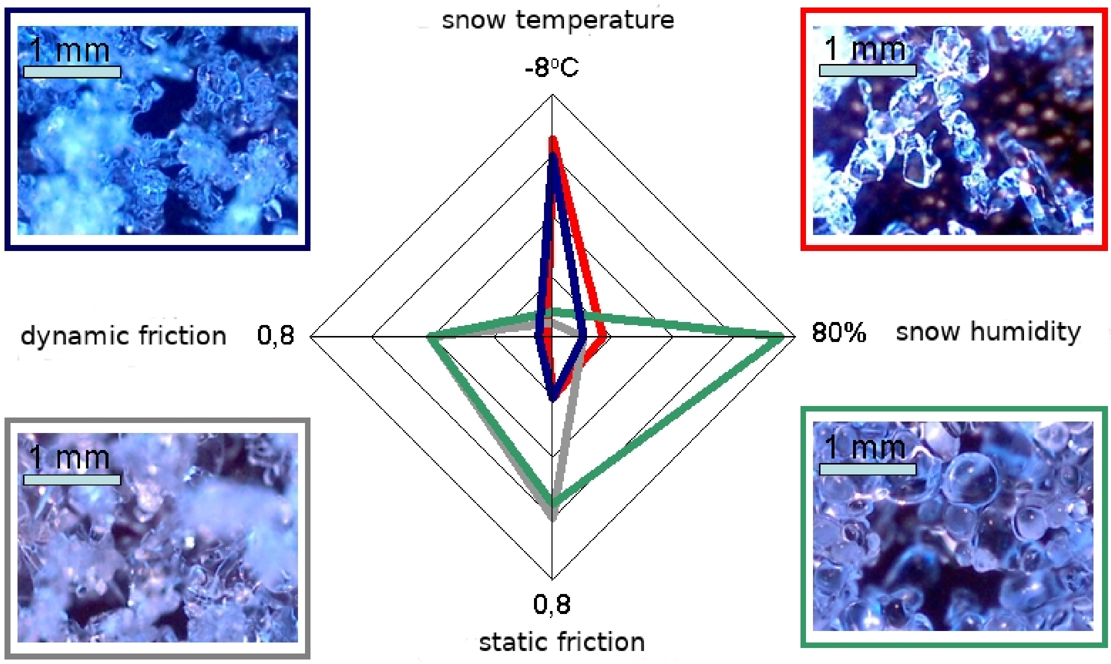

Fig. 6: Friction as a function of snow temperature, snow humidity and grain size and shape.

4 Summary

The friction between ski and snow depends sensitively on external influences such as temperature and humidity. But the hardness of the snow also has a major influence. Even if snow temperature and snow hardness are in the optimum range, high friction can occur with frozen snow (loose grains = low snow hardness). One can react to the above-mentioned influencing variables by selecting wax and grinding structure. These topics will be covered in a future article.

So what are the conclusions for the ambitious skier?

1. A look into the snow before skiing is always worthwhile. A magnifying glass or microscope is recommended for the view. Microscopes with 60× magnification as an attachment for the mobile phone camera are available for under 10 €. With this magnification you can see the size and shape of the grains and the water between the grains.

2. You can get an impression of the snow hardness just by scoring it with a screwdriver. With a little practice, you can develop a feeling for snow just like Miss Smilla.

5 Sources

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