MEASURING THE COEFFICIENT OF FRICTION OF POLYETHYLEN ON SNOW

KINETIC FRICTION ON SNOW

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ABSTRACT: Experiments were done in the freezing chamber with polyethylen specimens sliding on ice using a tribometer. The coefficient of friction was measured as a function of the surrounding temperature (varyied between –25°C and 0°C) and the pressure on the slider (varyied between 50 MPa and 300 Mpa). The coefficient of friction is strongly depending on the temperature of the ice surface. It is on its minimum around –3°C. In the temperature range between –3°C and 0°C the coefficient of friction is increasing with increasing temperature. In the temperature range between –3°C and –25°C the coefficient of friction is increasing with decreasing temperature.
The results correspond well to the idea of three different components forming the overall kinetic friction. At low temperatures dry friction dominates, whereas with increasing temperature a more lubricated friction decreases the coefficient of friction and for even higher temperatures capillary drag effects increase the friction again.

KEYWORDS: coefficient of friction on snow, kinetic friction, tribology.

1. INTRODUCTION

It is well known, that the low kinetic friction of snow is due to a thin water film that is produced by frictional heating [Bowden]. It is well accepted, that the kinetic friction is the sum of dry friction, wet friction and capillary drag effects together with resistance caused by displacing and compressing the snow [Glenne, Colbeck]. In different weather and snow conditions a different type of friction dominates and the total friction can be found by summing the individual friction components [Lehtovaara].

This splitting of the total friction into individual components is related to the formation of the water film between the glider and the snow surface. The thickness of the water film mainly determines the distribution of the different friction mechanisms. Solid-to-solid interactions take place when the thickness of the water film is insufficient to prevent direct contact of snow grains and the glider. As the water film thickens and lubricates the whole contact area the slider is only slowed down by the viscous resis-tance of the water film and the overall resistance is on its minimum. The production of more water increases extrusion and shearing and results in capillary suction that drastically increases the resistance [Colbeck].

The thickness of the water film is believed to be the crucial parameter for the kinetic friction. Since this water film is formed by frictional heating of the contact area, there are a lot of parameters that contribute to the system. These parameters can be roughly divided into two regions: ski and snow. From the ski, there are parameters like roughness, hardness, wetability, thermal conductivity, pressure distribution, vibration and flexion that influence the friction. The snow is determined by temperature, density, water content, grain size, grain shape, ther-mal conductivity, roughness and hardness. Besides these sets, the speed and the load contribute to the system , too.

Focussing on snow there has been done some investigations on different parameters and their influence on the friction. Spring found that the coefficient of friction is increasing with increasing the speed. Ericksson showed that friction is increased for smaller grain size. Shimbo tried to determine the influence of roughness and hardness on the friction. However, the most important snow parameter, the snow temperature, has not been the subject of intense studies, so far. It is crucial to determine the influence of the snow temperature on the friction in order to be able to optimize the system ski/snow for reduced friction. Therefore, the aim of this work is the investigation of the influence of the snow tem-perature on the friction in laboratory measurements and in gliding tests on the field. It is believed, that this

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knowledge enables to contribute the individual friction components to different temperature ranges, which is the key for optimizing the ski parameters in order to reach the best gliding performance.

2. EXPERIMENTAL

A tribometer was placed in a freezing chamber to measure the coefficient of friction (c.o.f.) of a specimen of polyethylen on snow and ice. The tribometer consists of a turning disc (diameter 15 cm), i.e. a mandrel filled with ice/snow, and a stamp that was pressed on the turning surface. The force trying to move the fixed stamp was measured and related to the weight of the stamp. Thus, the quotient of the friction force and the gravity determines the c.o.f.

Special emphasis had to be laid on producing a completely flat surface in order to avoid any jumping of the specimen. The mandrel rotated at maximum possible speed in order to reach at least a comparable speed to field tests. However, the reached 5 m/s are still low compared to field measurements where a velocity up to 30 m/s was reached. The second drawback is the fact, that the specimen glides always in the same track. Nevertheless, the experiment showed that even with these restrictions some clear results were obtained.

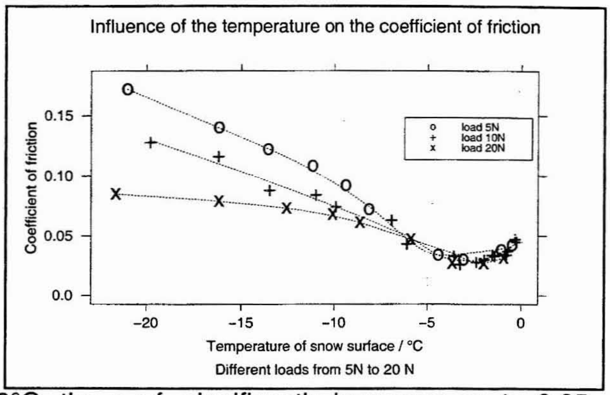
The temperature of the surroundings was controlled between 0°C and –25°C. The load on the specimen was varyied between 5N and 30N. The temperature of the snow was determined during the experiment by measuring the infrared radiation of the surface. The surrounding temperature was measured by ordinary thermocouples.

3. RESULTS

The coefficient of friction (c.o.f) for polyethylen on ice/snow in general is much lower than any c.o.f. on other materials. The measured values may reach a minimum value of about 0.02, which is about one order of magnitude lower than on steel (0.2), for ex-ample. However, the c.o.f. is not constant under the varyied conditions during the experiments, but strongly depends on the temperature of the snow surface and on the load.

3.1. Influence of the temperature

The c.o.f. reaches a minimum of 0.02 at a tempera-ture of about –3°C on the snow surface. When increasing the temperature from –3°C to



0°C, the c.o.f. significantly increases up to 0.05. Decreasing the temperature from –3°C to –20°C increases the c.o.f. to values up to 0.18.

Figure 1: Influence of the snow temperature on the coefficient of friction. Higher friction for low temperatures and close to 0°C. Minimum friction at around –3°C. The friction is de-pending on the load only for low temperatures.

3.2. Influence of the load

The load influences the c.o.f. only in the low temperature region. The correlation between the temperature and the c.o.f. remains the same for any load (highest c.o.f. for lowest temperature, minimum at –3°C, increasing c.o.f. for increasing temperature). As soon as the temperature is higher than –5°C, any difference concerning different loads vanishes and the c.o.f. is the same. However, at cold temperatures below –10°C. the c.o.f. is significantly higher for lower loads. For example, at a temperature of –20°C, the c.o.f. under a load of 20N is 0.09, whereas the c.o.f. under a load of 5N is 0.18 (factor 2). The de-crease of the c.o.f. is direct proportional to the in-crease of the load, but the factor depends on the temperature (the factor is 0.01 per 5N at –15°C). Above around –5°C the factor is 0 which means, that any change of the load produces no shift in the c.o.f. anymore.

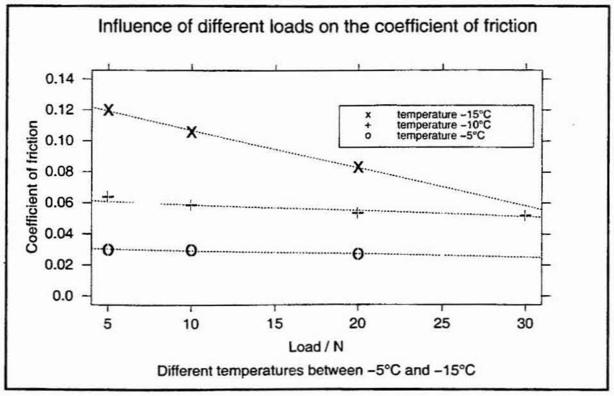


Figure 2. The load influences the coefficient of friction only at low temperatures. For temperatures higher than –10°C, there is no difference between the friction under different loads, whereas at low temperatures the coefficient of friction is lower for higher loads.

3.3. Heating of the surface

The surface of the track is heated by the repeated passing of the specimen. Thus, the surrounding temperature may be several degrees lower than the actual temperature of the snow surface. The increase of the temperature of the snow surface is proportional to the surrounding temperature. At a surrounding temperature of –20°C, the surface temperature is increased during the experiment to –16°C. At higher temperature this increase is less pronounced but still present.

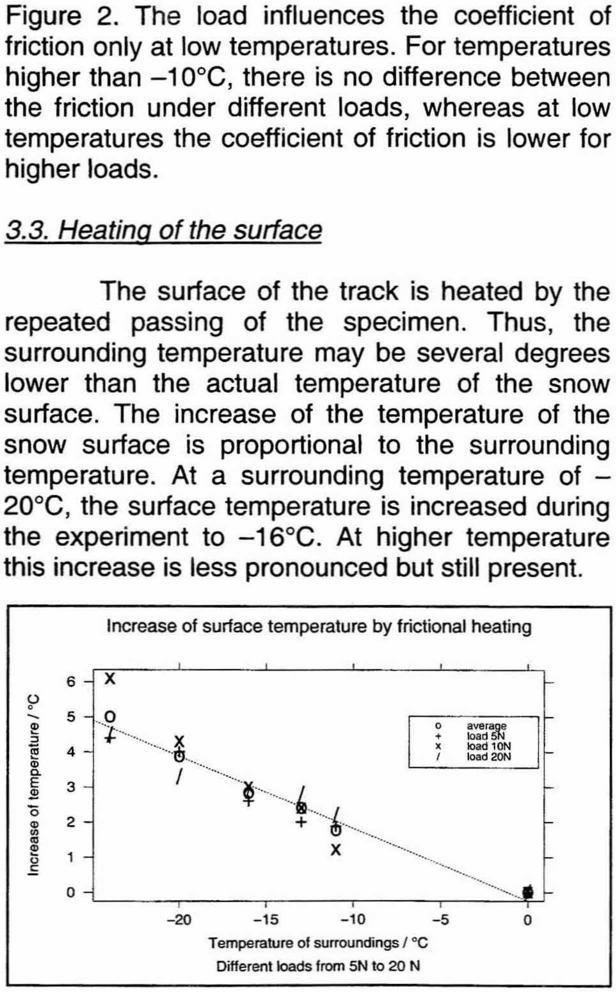


Figure 3. Increase of the snow surface temperature during running because of frictional heating.

4. DISCUSSION AND CONCLUSIONS

Most of the results can be explained by the formation of a water film between the gilding specimen and the snow surface. The generation of this melt-water is controlled by the combination of weight, speed, friction and the energy balance at the interface. There are a lot of parameters from the snow and the surrounding conditions that contribute to this energy balance, such as the snow temperature. The rate of meltwater production decreases as the temperature drops and the thickness of the water film decreases with decreasing temperature. Thus, the composition of the total friction changes with decreasing or increasing the temperature. The total friction is a composition of dry friction, lubricated friction and capillary drag and the distribution of the single components depend on the thickness of the water film.

It is difficult to quantify these effects because the friction, the produced heat, the temperature and the load are depending on each other. E.g., at a low temperature the friction increases because the produced heat is insufficient for a complete lubrication of the tribological interface. Thus, the amount of dry friction increases and therefore the c.o.f. increases. On the other hand, the frictional heating increases for a higher c.o.f. which increases the amount of heat in the contact area and enables to melt more snow. This delicate equilibrium of the components of the friction and the heat production has not been described quantitatively, so far. There exist only some theoretical approaches.

We suggest that in the low temperature region the production of frictional heating is insufficient to form a complete meltwater film. Thus, the amount of dry friction increases and the overall friction increases , as well. In this temperature range, the load contributes to the system: the higher the load, the more heat is produced by the friction. But an increased amount of heat influences shifts the proportion of dry to lubricated friction towards the last one, which results in a decreased overall friction.

As soon as the temperature is increased, the difference of the c.o.f. for varying loads vanishes more and more. We believe that in the temperature region where only lubricated friction contributes to the total friction, the load has no influence on the tribological system anymore. This is the case at around –4°C to –3°C. In that temperature region, the coefficient of friction is at its minimum. The thickness of the meltwater film is sufficient for a complete lubrication of the contact area and the dry friction is eliminated.

However, a further increase of the temperature that is always coupled to an increased frictional heat rate increases the c.o.f. again. In this high temperature region between –3°C and 0°C, much water is produced which results in capillary drag effects. Again, this tribological phenomenon is independent of the load.

The linear dependence of the c.o.f. on the load in the low temperature region corresponds well to the theory of the total friction as a sum of dry friction and lubricated friction. A higher load produces more frictional heating especially by dry friction. Thus, more heat is available for the formation of a melt-water film and the part of lubricated friction is increased which reduces the overall friction.

Increasing the temperature reduces the dry friction that is mainly contributing to the production of frictional heating. Therefore, the heating of the snow surface is most pronounced in the low temperature region. In addition, the heating has to increase when the surrounding temperature closes up to the melting temperature. However, according to theory, the load should also influence the heating the way that more heat is produced for higher loads. This correlation could not be confirmed by our experimental results.

5. ACKNOWLEDGEMENTS

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