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Are Fluorinated Ski Waxes Really the *non plus ultra*?

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ABSTRACT

Fluorinated ski waxes are considered the *non plus ultra* in skiing because of their very good water repellency. However, with the announced fluorine wax ban by the FIS, this quality feature is relegated to the background. With the discovery of the lotus effect, it became clear that the effect of water repellency results from the combination of a non-polar (wax) surface and a corresponding optimal roughness. Therefore, the paper deals with this combination and presents results obtained with 3 differently fluorinated waxes and 5 pairs of differently grinded skis. The evaluation of the gliding properties was carried out under laboratory conditions in a ski tunnel and was flanked by analyses of the water repellency and the topography of the skis.

1 Introduction

The days of fluorinated waxes are numbered since the FIS World Ski Federation decided to ban them for all its disciplines from the 2020/21 competition season. Since then, and in some cases even before, extensive test series have been underway by wax manufacturers to replace fluorine waxes with other substances. This undertaking is laborious, since due to the physical/chemical properties of fluorine, only the application of atomic hydrogen to the ski surface would produce similarly strong water repellent effects, but this is more of a theoretical solution. By means of atomistic simulation – and this is how deep one has to delve into the physical bag of tricks – it could be shown that the termination of a solid surface (physically called termination) by fluorine shifts the cloud of valence electrons so deeply into the solid that the polar water finds no docking possibility and, macroscopically speaking, rolls off [1]. The roll-off effect due to the hydrophobicity is promoted by the microstructure of the surface. This combination is one of the elementary cleaning mechanisms of nature. Plants form ribs or elevations of wax about 5 to 20 micrometers high and 10 to 15 micrometers apart, so that the water, due to the surface tension cannot penetrate into the interstitial spaces and cannot find a hold [2]. The water-repellent effect increases the more non-polar the surface is. Since grinded structures partly have similar dimensions as the leaf structures mentioned above, a way for the detachment of fluorine waxes opens up here.

In tests under laboratory conditions, 3 waxes of different fluorine content were tested, which were applied to 5 cross-country skis with different grinding structures. Before the gliding tests, the ability to repel water was quantified and the ski bases were subjected to an exact roughness analysis.

2 Eperimentel Background

2.1 Ski, Wax and Grinding Structures

Ski

The GERMINA SXC 901 was used as an experimental ski. Due to the cap construction with carbon fibers, the ski has an extreme stiffness and provides very good tracking stability even under strong double poling. The ski has a NANO Graphite racing base. In addition to the Germina ski, a ski from the manufacturer Salomon was used as a reference. This ski was prepared with a base wax.

Wax

A total of three different hard waxes were used. All waxes were glide waxes. Table 1 shows the waxes used and their range of application.

Tab. 1: Wax selection.

	temperature °C	
description	air	snow
wax1	+10 to -4	-0 to -6
wax2	-2 to -11	-4 to -12
wax3	-9 to -30	-10 to -30

Grinding Structures

The grinding structures were provided by Montana Germany. To grind the different structures a cutting speed of 6 m/s, a feed rate of 12 m/min and a pressure of 450 N is used. The grindings differed mainly in the pitch used. A total of five different structures were produced: three linear structures, one multi-layer and one cross-hatched type of structure. Table 2 shows the different structures and their structure parameters. The multi-layer grinding is the result of repeated grindings with different pitches, see also [3].

Tab. 2: Grinding structures.

structure	pitch [mm]	infeed [mm]
MD fine	0.23	0.2
MD medium	0.35	0.2
MD coarse	0.45	0.2
MD multi-layer	0.23	0.1
	0.5	0.2
	1.5	0.2
MD cross-hatched	0.4	0.2
	0.75	0.2

2.2 Glide tests

The glide tests in the Oberhof ski tunnel began with a test on unwaxed skis. This was followed by the application of the first wax, the associated glide test and the creation of a comparable initial state for the further tests by using a wax remover. After the preparation of each ski, a running-in round was performed on the northeast loop (380 m). The gliding test itself was carried out on a sloping track, so that the test could be initiated without the influence of physical force, only by gliding. The gliding distance, outside the track, had a length of 30 m. For the gliding test a lead of 5 m was chosen. An optical sensor on the skier's leg was triggered by a start reflector and stopped by passing a second reflector, see Fig. 1. As with the reference sample, each ski has been tested three times and the average value has been calculated. Finally, in order to minimize changes in external conditions during the entire duration of the glide tests, all average glide times had to be normalized to the glide time of the reference ski. Since the glide speed is inversely proportional to the glide time, a relative glide speed is given in the results section.

A small optical microscope with sixty-fold magnification was used for snow analysis. The average grain size was about 0.25 mm, see Fig. 2. The individual grains had rounded edges and lay loosely next

Abb. 1: Gliding test in ski tunnel. The start and endpoint reflector and the optical sensor on the right calf of the tester can be seen.

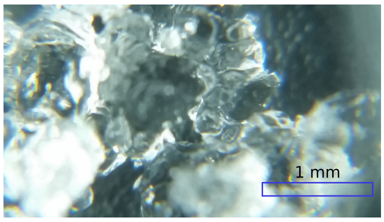

Abb. 2: Microscopical image of snow.

to each other.

2.3 Determination of hydrophobicity

The hydrophobicity was quantified by determining the contact angle [4]. A hydrophilic surface shows a contact angle of about 0° towards water. If the surfaces are hydrophobic or superhydrophobic, the contact angle is about 90° or more than 90° respectively. The contact angles were determined with a microscope directed at the profile of the drop. With the help of an attached digital camera a video of the application of a 1 μl water drop could be recorded. The single frames of the video were then analyzed with the software *VirtualDub 1.9.10* and the tenth image, half a second after the drop was applied, was selected. For each of the experiments three drops were applied and the respective image was extracted. To improve the statistics, the software *ImageJ* was used to determine the left and right contact angle with the ski base surface.

2.4 Evaluation of Topography - Profilometry

The roughness measurements were carried out with a confocal microscope Plμ 2300 of the company Senofar-Tech S.L. For all pictures a lens with twentyfold magnification was used. The microscope produces 3d images of the surface and outputs all relevant roughness parameters. For the characterization of the ski bases the bearing ratio as described in [5] was used, see also [6].

3 Results

3.1 Roughness Parameters

Profilometry knows a large number of roughness parameters that provide suitable information for certain applications. The bearing ratio has proven to be particularly meaningful for the evaluation of ski grinding. The bearing ratio indicates what percentage of a surface bears the load. If the bearing ratio is 100%, the athlete's load is carried by a perfectly flat ski. This shows that the bearing ratio must always be significantly less than 100%. The following summary provides all bearing ratios, see Tab. 3.

Tab. 3: Bearing ratios.

grinding structure	*MD fine*	*MD medium*	*MD coarse*	*MD multi-layer*	*MD cross-hatched*
bearing ratio [%]	7.73	23.2	15.2	19.2	12.7

A top view, the 3d view and a profile of the grinded surface – here using the example of the grinding structure *MD multi-layer* – is shown in Fig. 3. The area shown has a dimension of approx. 0.8 mm × 1.6 mm. In the profile you can see the superposition of waviness and roughness, which was caused by the three times grinding process.

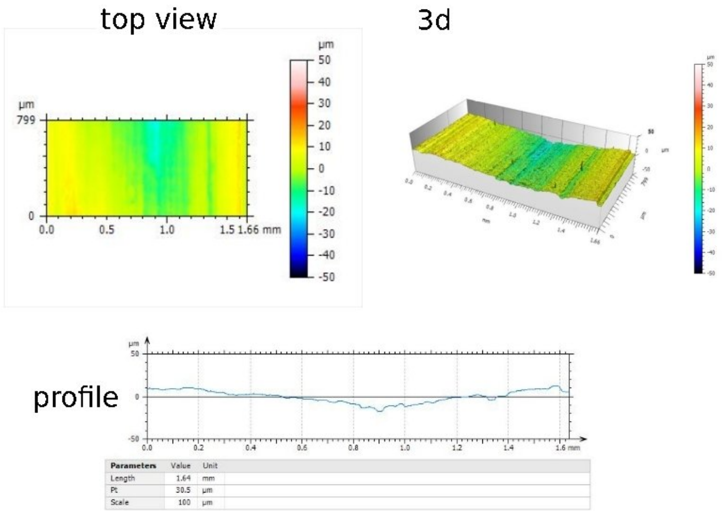

Abb. 3: Topography of the multi-layer grinding structure.

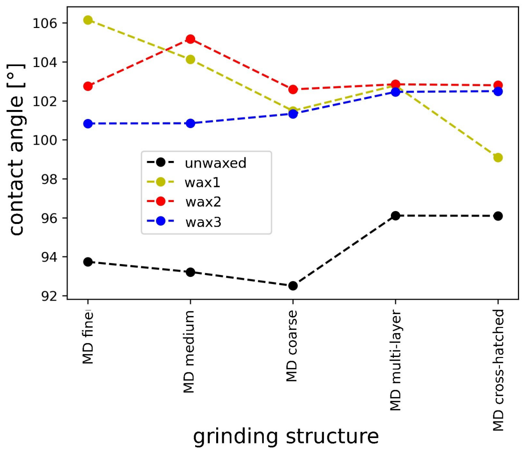

Abb. 4: Contact angle versus grinding structure.

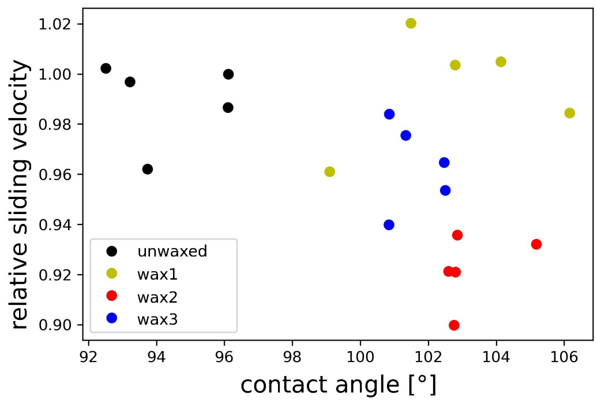

Abb. 5: Normalized gliding speed of the preparations as function of contact angle.

3.2 Analysis of Water Repellency

If the contact angles are assigned to the grinding structure, the result is Fig. 4. It is interesting to note that wax1 produces the largest contact angle with *MD fine*, but the smallest contact angle with *MD cross-hatched*.

3.3 Analysis of Sliding Velocity

The warmer the snow for which the wax was designed, the higher its fluorine content. Thus wax1 has the highest fluorine content, followed by wax2 and wax3. This is also visible in Fig. 5. Since 5 pairs of skis each with different structures were tested, the figure contains clouds with 5 points each. The biggest difference in the contact angles can be seen between the unwaxed ski and the wax variants. A contact angle between 92° and 97° can therefore be achieved by the polyethylene base alone. Figure 5 also shows that different gliding speeds can be achieved with one and the same contact angle, i.e. with the same degree of water repellency. It is also remarkable that only skis with wax1 lead to higher gliding speeds than those with wax3 followed by wax2.

3.4 Analysis of Sliding Velocity and Bearing Ratio

In Fig. 6 the normalized sliding speed was plotted as a function of the type of grinding structure. In addition, the bearing ratios are also shown in the figure. This type of application again shows that wax1 (highest fluorine content) leads to the highest sliding speeds. However, the unwaxed skis already follow, and skis with wax3 are far behind. In the case of cross-hatched grinding structure, even the unwaxed version produces the highest gliding speed.

The contact areas correlate well with the gliding speeds except for *MD coarse*. With this structure, wax2 shows a conspicuous correspondence between the speed and bearing ratio curve.

4 Discussion

As Fig. 5 has shown, there is only a slight correlation between water repellency and sliding speed. Although waxed skis have a much larger contact angle than unwaxed bases, no correlation can be seen between the wax with the highest fluorine content and the highest glide speed. Furthermore, it is noticeable that the water repellency depends very much on the type of grinding structure. However, a systematic approach is not to be found here either.

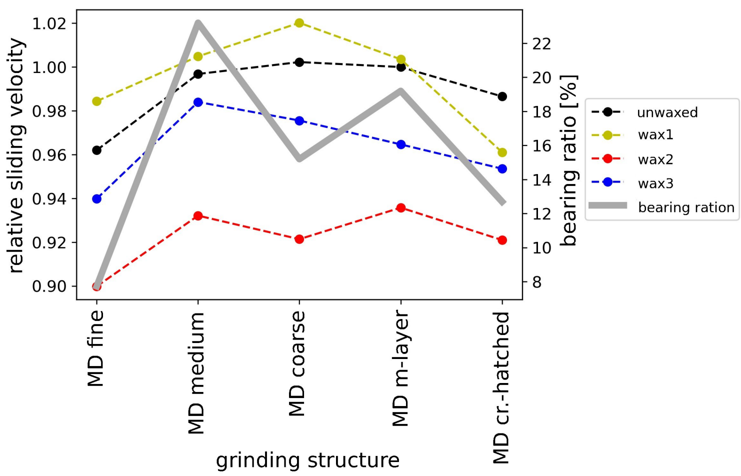

Abb. 6: Contact angle and bearing ratio versus grinding structure.

The situation is different when the bearing ratio comes into play. To simplify matters, it can be stated that the sliding speed follows the bearing ratio, which is particularly true for wax2. This result is unexpected, since friction depends decisively on the contact surface, i.e. it should increase with increasing bearing ratio. The contradiction is resolved as soon as the microscopic structure of the snow is included in the observation. With an average snow grain size around 0.25 mm and a grinding ridge width in the same range, a grinding with a lower bearing ratio offers more space for the penetration of snow grains. This process is intensified because in the tests described here the snow grains had lost their grip on each other. This is called lack of sintering. The filling of the grinding grooves now leads to an increase in the contact area, which explains the increase in friction. Under the conditions described, this effect is stronger than that of water repellence. This makes it clear why the hydrophobicity has only led to higher gliding speeds with the strongest fluorination than with unwaxed skis.

If the snow conditions change, e.g. there is more cohesion between the individual grains, the approach must be adapted. In this case hardly any snow penetrates the grinding structure and good gliding can be achieved by effective water repellency and minimal contact area.

5 Conclusions

The conditions in the ski tunnel were predestined for the use of highly fluorinated waxes (old moist and relatively warm snow). In the article it could be clearly shown that the effects previously attributed to fluorine are to a large extent due to an optimized grinding structure. Further research should be carried out on this in the future. In order to reduce the effect of the penetration of snow grains into the grinding structure, a thorough snow analysis is recommended before waxing to obtain an impression of the snow grain size on the one hand and information on the consistency of the snow on the other. As always, there is one drawback, however, and that is the topographical information about the ski surface. As described above, the bearing ratio is the decisive factor. Unfortunately, this value is not available from the ski service. But maybe this will change in the future. The article has also shown that in the optimal interaction of wax-integrated water repellency and grinding structure there is great potential for achieving the best possible gliding properties. Fluorinated wax is not necessarily required for this. However, due to the very high water repellency of the fluorine, it is to be feared that future races will be slower.

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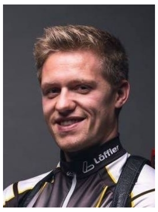
About the Authors



Thierry Langer is a biathlete and cross-country skier from the German speaking part of Belgium. Parallel to his biathlon career, Thierry also took part in cross-country skiing competitions. In this discipline he first represented Belgium at the 2017 Nordic World Ski Championships as 82nd in the sprint and qualified for the 2018 Winter Olympics in Pyeongchang. In the biathlon he achieved several TOP 30 World Cup placements, including a 21st place in Hochfilzen.

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