Open Access Series ISSN 2509-9442

GLIDING

Article 2(2016) 4-6

source: snowstorm-gliding.de

How thick must a wax film be?

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ARTICLE INFORMATION

key words:
friction
wax
ski preparation

ABSTRACT

With physical/chemical surface analytics the layer thickness of wax was measured. The measurements prove that wax as block or powder penetrates the ski base only a few 100 nm and as spray only a few 10 nm. The wax does not use any pores in the ski base but entangles with the molecules of the polymer to form a compact sliding layer. The durability of this layer depends primarily on its thickness, but also on factors such as snow temperature, snow grain shape and the quality of the polymer from which the ski base is made.

1 Introduction

Almost every skier knows the stories that a new ski has to be waxed and scraped several times before it runs well. It is also known that the ski has to be waxed thickly before the summer break so that it does not turn grey next winter. The ski base is usually made of high-density polyethylene (HDPE) or, in the case of competition skis, ultra-high molecular weight polyethylene (UHMWPE). These polymers have different qualities and may also have been produced using different processes, so that the bases oxidize to different degrees, i.e. turn gray. To be precise, oxidation would turn the CH chains of the polmyer just into CO_2 and H_2O. Therefore, oxidation must be understood in a wider sense as a degradation of the polymer structure due to the action of environmental (uv-radiation, oxygen) and mechanical (friction, wear) attacks. High-quality ski bases show hardly any greying and remain stable over long periods of time. If you have a ski that is prone to greying, multiple waxing and scraping helps, as these steps remove the degraded skin. If the degradation zone is thick, a steel blade can be used instead of the plastic blade. Wax covers the ski base and prevents the polymer from coming into contact with oxygen. When the ski is run, it is rubbed by the snow grains, a process that generates local heat. The following article explains to what extent wax offers protection against greying, how long this condition lasts and how it can be improved.

2 Results

After wax has been applied to the surface, then removed with the plastic blade and brushed out, only a hint of paraffin remains on the ski base. The question now is how thick or thin this hint is and whether it is sufficient to protect the ski from oxidation, i.e. greying and deterioration of the gliding properties. To get closer to the answer of this question, a ski base was treated with wax containing fluorine. The processing sequence is shown in Fig. 1.

After preparation, physical/chemical surface analysis was performed at the Fraunhofer Institute. Since the wax contained fluorine, the search was limited to this element and its concentration decrease was

Fig. 1: Ski preparation in the order powdering, ironing, stripping and brushing, polishing.

determined in the depth of the coating. The measuring method used to detect fluorine on the surface was infrared spectroscopy. This method is based on the effect that atoms on the surface of materials react to irradiation with infrared light with different absorption behaviour. The valence electrons of the atoms are able to absorb energy to enter an excited state. However, the atoms cannot remain in this state and return to their initial state after a short time. In the time between excitation and return, the material absorbs energy from the infrared source and this amount of energy can be evaluated very accurately. The spectra obtained (absorption as a function of the wavelength of the infrared light) now allow conclusions to be drawn about the atoms that were excited to absorb energy. In this way, there is a clear assignment whether - for our example fluorine wax - the atom was fluorine, oxygen or carbon.

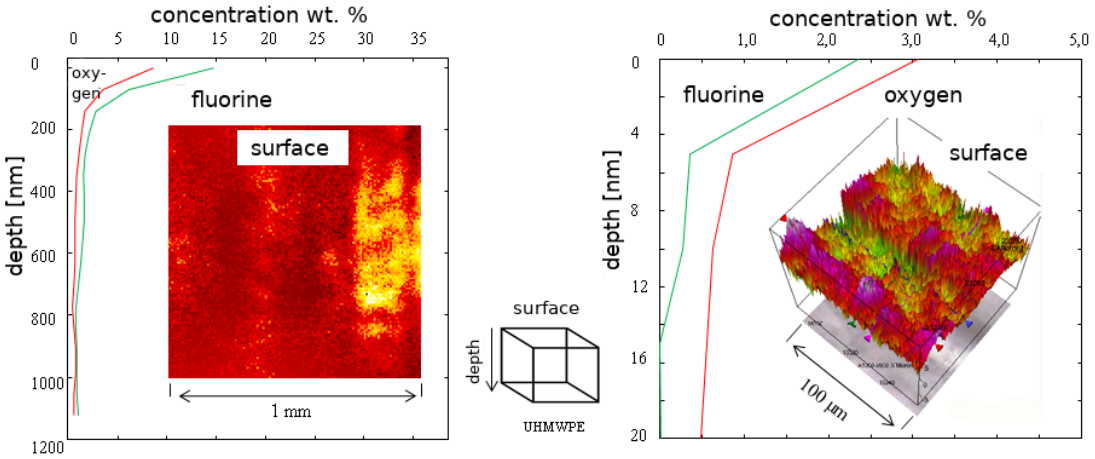

Fig. 2: Left: Depth profile and top view of a cube of UHMWPE after powder waxing. The fluorine concentration is highest at the surface (15%) and decreases to about 1% at a depth of 800 nm. The light colours in the top view stand for high concentrations of fluorine. The dark areas represent the low concentration of fluorine in the grinding grooves. Right: Depth profile and 3d view of the UHMWPE cube after fluorine spray application. Already after about 16 nm there is no wax left. In the cube, the intense red tones represent high fluorine concentrations. The cube surface is covered by a grinding groove from top left to bottom right.

The result of the infrared spectroscopy showed that the wax is mainly found on the ridges between the grinding grooves (red tones), while in the grooves themselves there was hardly any wax (green tones). All in all the wax is unevenly distributed, so it does not form a homogeneous layer, see Fig. 2 right.

X-ray photoelectron spectroscopy was used to determine the penetration depth of wax into the ski base. This method is based on the photoelectric effect for which Albert Einstein was awarded the Nobel Prize in 1922. The surface of the base was irradiated with an X-ray beam. The energy of the beam was adjusted so that only areas close to the surface were excited to depths of approx. 5 μm (= 1/10 of a hair diameter). Excitation in this context means that the X-ray energy is used to remove binding electrons from their atoms. Of these electrons, only those very close to the surface are able to leave the ski base. All other electrons remain in the material. By measuring the electron energy, i.e. the binding energy, very precisely, it is possible to identify the atom which emitted this electron. In this way, fluorine and oxygen could be detected. In order to monitor how deeply the fluorine has penetrated the base, the polymer surface was gently attacked with argon atoms to remove layer by layer of material. After each removal step, the chemical composition of the newly formed surface was analysed. After many ablation steps, a depth profile was created, which proves that after approx. 800 nm (1 nm = 1 billionth of a meter)

almost no fluorine was found, see Fig. 2, left. This means that only a hint of wax was actually available. It becomes even more extreme when fluorine-containing spray is applied instead of fluorine powder. In this case, one only gets about 16 nm of wax on the surface or in other words: after a short time, the wax is rubbed off. Sixteen nanometers correspond to about 40 to 50 atomic layers. A good ski technician is therefore actually a nanotechnologist who knows how to prepare such a layer by hand with manual skill and a lot of experience [1]. It also shows how highly dense and pore-free the ski base actually is.

3 Summary

The measurements have impressively shown that wax forms an extremely thin layer on the ski base. A ski base has a thickness of about 1 mm. The measured wax layer thickness was approx. 800 nm for powder and approx. 16 nm for fluoro spray. Compared to the Burj Khalifa (828 m) a wax layer thickness of 800 nm would correspond to the height of a bar stool and 16 nm to the diameter of the ice cube in a whisky glass. With the model ideas from *Gliding* 1(2016) [2], however, the question arises as to whether one can even speak of a layer on the ski base. Since wax bonds with the polymer chains of the base, the gliding layer is formed, which was chemically characterized by the measurements shown.

So what are the conclusions for the ambitious skier?

1. Since wax and ski base should form a unit, the ski base should be brushed before waxing to increase the wax absorption capacity.
2. Heat treatment is helpful, but must be carried out at a controlled temperature.
3. The final brushing is another energy input. Therefore the right measure should be found by much practice. It is sufficient to examine the finished base with the naked eye under grazing light, as the eye is extremely sensitive under these conditions.
4. The thickness of the wax layer is a negligible factor; what matters is the intimate connection of wax components with the polymer of the high-quality ski base.

4 References

[1] Scherge, M., Böttcher, R. Molecular Effects of Gliding, 3rd International Conference on Science and Nordic Skiing, 2015, Vuokatti, Finnland.
[2] Scherge, M. Wax or no wax - that is the question, *Gliding* 1(2016) 1-3.

Acknowledgment: Many thanks to Dr. Reinhard Groß for his suggestions and corrections!