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Nano ski wax, effects and benefits

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Nano ski waxes, effects and benefits

Enthusiastic skiers spend much time and money in order to optimize their gliding performance. The traditional way to wax skis includes several steps starting from various hydrocarbon waxes to advanced treatments with high fluor content waxes. In recent years liquid gliding products have offered a further possibility.

The effects of ski waxes are often discussed but rarely studied. Ski bases consist of ultra-high molecular weight polyethylene (UHMWPE) in semi crystalline state. Diffusion of ski wax into the base material as a function of time and temperature should be studied. This master thesis will focus on the material changes due to the waxing process: how do liquid gliding products interact with the ski base and which influence have the process parameters (i.e. snow conditions, speed, weather, etc.) on the tribo-system?

Liquid gliding products will form a thin coating on top the ski base material. The characteristics of these coatings and its contribution to a reduced coefficient of friction should be studied.

Methodology: During the project thesis, relevant methods to characterize the ski base were found and used (Raman Spectroscopy, DMTA, XPS). However, there are some results that need to be further developed due to their complexity (i.e. XPS).

A methodology on how to measure wear of the gliding product should be found and defined during this master thesis (material loss, contact angle, chemical analysis, topographical changes of the surface, etc.).

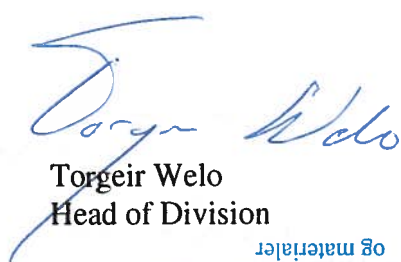
The experiments will be as follows:

- A) Ski base characteristics.
- B) Gliding product characteristics.
- C) Application methods.
- D) Field and/or lab experiments.
- F) Analysis of the results.

The project will be in cooperation with Olympiatoppen and the Norwegian ski team. The thesis should include the signed problem text, and be written as a research report with summary both in English and Norwegian, conclusion, literature references, table of contents, etc. During preparation of the text, the candidate should make efforts to create a well arranged and well written report. To ease the evaluation of the thesis, it is important to cross-reference text, tables and figures. For evaluation of the work a thorough discussion of results is appreciated.

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The thesis shall be submitted electronically via DAIM, NTNU's system for Digital Archiving and Submission of Master's thesis.


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ABSTRACT

The effects of the gliding properties of ski waxes are often discussed and many speculations and assumptions are made. However there are not many studies and documented results in this field. This project is carried out in cooperation with Olympiatoppen and the Norwegian ski team to research and document the effects and benefits of gliding waxes. Ski base material consists of ultra-high molecular weight polyethylene (UHMWPE) in semicrystalline state. The focus will be on the material changes caused by the waxing process. This project examines two different types of ski base material with three different gliding waxes. Essential factors of the friction and the effects of gliding wax on skis were studied. The Fluor content, both in the base material and in the wax, and the Gallium content in one of the gliding waxes, was, given special attention. Experiments on the ski base materials, with and without waxes, were conducted. Material characterisation has been evaluated by using XPS, ICP and contact angle measurement of water droplets on the ski base materials. The friction properties have been tested with outdoor gliding field tests where the two ski bases have been compared with each other and also a reference ski. A tribometer was used in the lab to measure the coefficient of friction. The content of the ski base material were unknown, there is found that both type of bases tested contains Fluor. It was also found that the Fluor content on the top surface is not directly comparable with the surface energy and the contact angle.

SAMMENDRAG

Det er enorm interesse for ski i Norge, spesielt langrennski. Det er mye synsing og meninger om hva som gir best glid, men det er veldig lite vitenskapelig forskning som har blitt gjort på området. Dette prosjekte er et samarbeid med Olympiatoppen og det norske skilandslaget for å undersøke og dokumentere egenskaper og effekt av glider på langrennski. Skisålematerialet er laget av ekstremt lange kjeder med polyetylen, ultra-high molekular weigh polyethylene (UHMWPE). Dette materialet er semikrystallinsk, har lav friksjonskoeffisient og høy slitasjemotstand.

Målet med dette prosjekte var å undersøke materialeegenskaper og friksjonsegenskaper til to skisålematerialer, samt å se på virkningen av tre forskjellige glidere på disse materialene. Materialanalyser ble gjennomført ved hjelp av et røntgen fotoelektron spektroskop, XPS, og ved å måle kontaktvinkelen av vanndråper på materialene. På denne måten vil man se hvor vannavstøtende materialet er. Dette har en sterk sammenheng med friksjonen til materialet. Det ble kjørt glidtest ute i skisporet, her ble de to sålematerialene målt opp mot hverandre og mot en referanseski. Det ble også kjørt friksjonstest i lab, der friksjonskoeffisienten til materialene ble målt. Et veldig interessant punkt var om det var mulig å sammenlikne labresultatene med de resultatene man fikk ute i feltet. Innholdet i sålematerialet var ukjent, ved hjelp av XPS analyse fant man ut at begge sålematerialene inneholdt fluor. Det ble også funnet ut at fluorinnholdet på overfalten av skisålen ikke er direkte sammenlignbar med overflateenergien og kontaktvinkelen sålematerialet lager i kontakt med snø og vann.

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LIST OF SYMBOLS AND ABBREVIATIONS

Symbols	Description
a	Acceleration
F_F	Friction force
F_N	Normal force
g	Gravity
m	Mass
R_a	Arithmetic mean roughness
R_q	Root mean square average roughness
T_g	Glass transition temperature
T_m	Melting temperature
v	Velocity
v_0	Start velocity
x	Distance
α	Contact angle
λ_c	Cut off length
μ	Coefficient of friction

Abbreviations	Description
COF	Coefficient of friction
DMTA	Dynamical mechanical thermal analysis
HDPE	High density polyethylene
HMWPE	High molecular weight polyethylene
ICP	Inductively coupled plasma
LDPE	Low density polyethylene
NTNU	Norwegian University of Science and Technology
PECVD	Plasma-enhanced chemical vapour deposition
ppm	Parts per million
PTFE	Polytetrafluorethylene
RSD	Relative standard deviation
SD	Standard deviation
UHMWPE	Ultra high molecular weight polyethylene
XPS	X-ray photoelectron spectroscopy

1 INTRODUCTION

Norway has a long and proud ski history, they say Norwegians are born with skis on their feet, but that alone is not enough to become world champion. In the biggest races where the skier not only wins a noble gold medal, but also the nations honour and the worlds respect, it is the small details that difference the winner from the loser, or second place. There is a lot of money to be made in the ski industry, neighbours competing for who have the best equipment and the fastest skis and top athletes who have a new pair of ski for every type of snow and temperature. The ski wax industry is no different. Leisure skiers have their own ski preparation room in the basement and the top athletes have hired their own personal ski waxer. Many enthusiastic skiers have done their own gliding tests and know what wax they prefer for the different snow and weather conditions, but very little is documented and proven in this area.

What we do know is the factors that affect friction. Low friction gives good glide. Some of the features that affect friction are the type of weather, snow, skis, the structure of the ski base, the ski base material and the type of wax. It is not easy to optimise friction as many aspects need to be considered. Various types of ski wax exist, both for gliding and kicking. With the right weather and snow information it should be possible to choose the best pair of skis and optimise them with wax.

The ski base material used today is mostly ultra-high molecule weight polyethylene (UHMWPE) or other types of polyethylene and **polytetrafluorethylene (PTFE)**, better known as Teflon. Polyethylene has been the major ski base material since the 1970s. Polyethylene, especially UHMWPE, has very good characteristics; it has high hydrophobicity and low friction, good wear resistance and has relatively easy processability and is therefore a natural choice.

The Winter Olympics is one of the events that gather most Norwegian people in front of the TV screen. The pride in the ski history and the desire to be best in the ski track makes a grand interest for the Norwegian people. To fulfil the nation's desire they need the best people and the best equipment, and also the best ski base and wax. This project aims to document the effects of nano ski wax in cooperation with Olympiatoppen and the Norwegian ski team.

2 GOAL

In a previous project work (performed in the fall semester of 2012), background information for eight ski base materials was found. The primary focus in this master thesis has been to investigate the factors that affect the friction in the ski base material, with and without gliding additives (e.g wax). Two ski base materials from the previous project were selected for thoroughly investigation of material characterisation and friction properties. Field and lab testing was performed to document the material and frictional properties and to analyse which elements that makes the friction lower so the ski glide better.

The aim of this project was to research and document the effects and benefits of nano ski wax on the ski base material. Ultra-high molecular weight polyethylene is the most common ski base material used by the elite. The effect on different additives in the friction and gliding properties of the ski base material was investigated and experiments were conducted. Special attention was paid to the Fluor and Gallium content in the materials and in the waxes. Characterisation of the ski base material was performed and the friction and wear properties was analysed towards skiing.

A modified tribometer for low temperature tests and other materials characterisation techniques will be used for material and frictional investigation. Both outdoor field tests and lab tests will be conducted with the aim to be able to see the feasibility of using lab tests for predicting field performance of ski materials. The Fluor content of two ski bases and in the waxes will be examined as the main elements providing with the best gliding. How the Fluor content and coefficient of friction goes together shall be evaluated.

3 THEORETICAL BACKGROUND

3.1 HISTORY

Skis have existed for centuries. The oldest skis in existence were found in Sweden and are dated all way back to 3200 BC [1]. Skis originate from Scandinavia and through time skis have mainly been used for hunting and transportation. In the 19th century skiing became an activity for enjoyment, and in 1924 the first winter Olympics were held in Chamonix, France, where Norway won the most medals. In Norway skiing is a big part of the history and the national identity, especially cross country skiing. One of the most famous historical incidents took place in the beginning of the 13th century when Norway was in a civil war. The biggest enemies were Birkebeinerne and Baglerne. King Sverre, the leader for Birkebeinerne, had gathered most of the Norwegian country under his dominion. Sverre was succeeded by his son Håkon Sverresson, but himself died 2 years later in 1204. Sverresson's new born son, Håkon Håkonsson, was thus strongly pursued by Baglerne. Figure 1 illustrates Håkonsson's escape over the mountains as a baby in the arms of Birkebeinerne. When he was brought to safety, the civil war ended and Håkon Håkonsson became king of a united medieval Norway. In 1932 a cross country ski competition started to honour Birkebeinerne, and today there are 16 000 participants annually in the 54 kilometre long race [2-4].



Figure 1 Good skiing skills saved the heir to the throne, illustrated by Knud Bergslien.

In newer history Sondre Norheim (1825-1897) from Telemark is said to be the founder of modern skiing. He developed slalom, introduced Telemark and gave the old ski a new shape, binding and technique, this made skiing much more than only a type of transportation [5].

Ski wax has existed for a very long time, both to preserve the skis and also as kicking wax, to get a grip. This was done by mixing resin, paraffin, animal tallow and tar and putting it underneath the ski. In 1943 the Swedish skier Martin Matsbo joined a pharmacy company, AB Astra, to develop new ski wax together with engineers and chemists. It resulted in SWIX. In 1946 SWIX launched three different kick waxes, red, blue and green, depending on the weather [6]. In the 1973-1974 season Blue Extra was put on the market. This was the same season as the Falun world championships (1974) which had the first world champion on fibreglass skis and the last one on wooden skis. Norway was not prepared for the new development in ski material and found that, especially on wet snow, the new plastic skis had a major benefit [7]. It turned out that the plastic skis were very easily able to combine with the old ski wax. After this season everyone was competing with ski soles made of polyethylene. The next big development in the ski industry was Cera F, a gliding wax powder containing Fluor. Some Italians did research using Fluor as additives or a processing chemical in the ski base, which gave them an advantage in the season 1986-1987 when only they had Fluor gliding wax. It was soon possible for everyone to get the new powder, the only problem was that it was very expensive. The advantages were a better glide, reduction in ice build-up and less accumulation of dirt [8].

3.2 SKI BASE MATERIAL

A ski consists of the bulk material and the sole, the ski base material in this project is synonymous with the ski sole material. It is this surface that is in contact with the snow therefore the focus in this project will be the properties of the boundary between the ski base and the snow.

3.2.1 POLYETHYLENE

After the breakthrough in 1974 the ski base material has been made mostly of the polymer *polyethylene*, which is the most common polymer material. Polyethylene is made of long chains of ethylene which transforms into polyethylene via polymerisation, see Figure 2. The double bond between the carbon atoms breaks and reacts with other ethylene monomers. In this way very long molecule chains of polyethylene can be produced. When the chain becomes longer, the molecule weight becomes higher. Extremely long chains are called Ultra-High Molecular Weight Polyethylene (UHMWPE) and are in many cases beneficial, especially when it comes to products that need very low friction, which is the case for skiing (both alpine and Nordic).

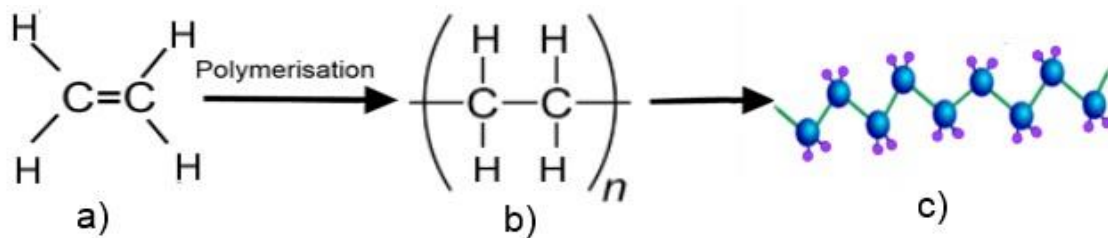


Figure 2 a) Ethylene molecule, b) ethylene monomer, c) polyethylene molecule.

There are many different types of polyethylene in the market, among them the low and high molecular weight and the low and high density polyethylene are the most well-known and used. The first type depends on how many monomers there are in the average molecule. The latter depends on the structure of the molecules, how they are oriented and whether the molecules have branches or not. If the polymers are in a straight line, they are able to crystallise and get a more compact structure, they become High Density Polyethylene (HDPE). If the density is low they are called Low Density Polyethylene (LDPE). Polyethylene is not able to crystallise completely due to the ends of the molecule chain, hence it is only semicrystalline, as shown in Figure 3. The polymers that do not crystallise are of amorphous character, these polymers are more affected by the temperature than the semicrystalline polymers are. They become very brittle below the glass transition temperature due to the low mobility of the molecules

and have rubbery properties between the glass transition temperature and the crystalline melting temperature [9, 10].

The melting temperature, T_m , for semicrystalline polymers it is more accurately called the crystalline melting temperature. It is the temperature where the crystalline parts in the molecular morphology become amorphous and ductile.

The glass transition temperature, T_g , is the phase change where amorphous polymers transform from ductile to brittle. In semi-crystalline polymers it is only the amorphous parts that make the phase change [9].

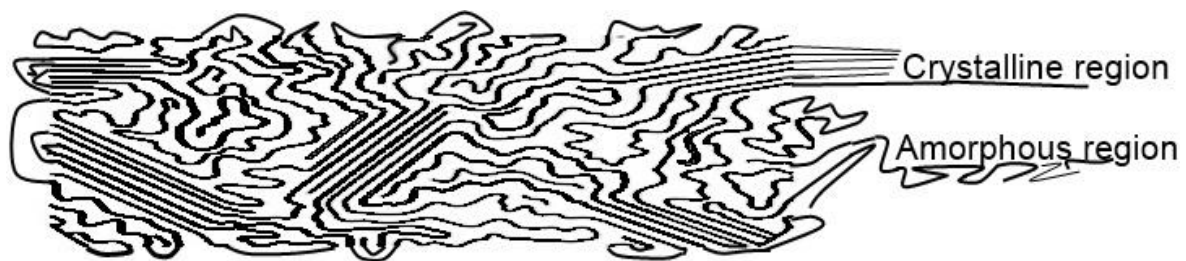


Figure 3 Semicrystalline structure of polymers.

The semicrystalline polyethylene has strong intermolecular forces that prevent softening above the glass transition temperature, and there is no visible phase change, that makes the semicrystalline polyethylene less temperature dependent. The crystalline structure makes the polymer stronger and harder than the amorphous structure, the intermolecular distance becomes smaller and the secondary forces, such as van der Waals, will hold the chain together more strongly. The properties of semicrystalline polyethylene rely on the amounts of amorphous and crystalline structure. The crystalline parts give the polymer strength and hardness, while the amorphous regions provide elasticity and impact resistance. Variations in microscopic structures can change the properties of the polyethylene. If the structure is linear, branched or cross-linked or if the molecule contains copolymers or additives, it will make the polymer properties change. Polyethylene is a thermoplastic, which means it reforms after heating. It is a recyclable plastic and the chemical structure does not break down during heating [9, 10]. Table 1 shows the difference between different types of polyethylene.

Table 1 The differences and similarities between LDPE, HDPE and UHMWPE [9-12].

	Density [g/cm ³]	Mol- weight [g/mol]	T _m [°C]	T _g [°C]	Properties, characteristics and user areas	Limitations
Linear-low density polyethylene LLDPE	0.915-0.925			-120	Similar to LDPE, but higher impact resistance and tensile strength. Use areas: Films, packaging	Not as easy to process
Low-density polyethylene LDPE	0.910-0.925		105-115	-110 to -20	Soft, relatively high toughness, stress and crack resistance. Good chemical resistance. Partly transparent. Use areas: Transparent packaging	Low modulus and strength, UV- degradation
Medium density polyethylene MDPE	0.925-0.940		115-130	-118	Mix of LDPE and HDPE. Higher stress cracking resistance than HDPE Use areas: Packaging, bags	Lower strength than HDPE
High-density polyethylene HDPE	0.941 and higher (normally up to 0.960)		130-145	-200 to -90	Hard. Improved chemical resistance, mechanical and permeation barrier properties can be used in large constructions. Use areas: Bottles and toys	Lower stress cracking resistance than MDPE
High-molecular weight polyethylene HMWPE	Medium high to high density	300 000 to 600 000	130-140		High impact strength, low friction, good wear and chemical resistance. Can be formed by extrusion. Use areas: Cheap ski bases, bearings, hard packaging	Not as good strength as UHMWPE and higher friction.
Ultra-High Molecular Weight Polyethylene UHMWPE	Typically 0.930-0.940 Lower due to crystals and difficult processing	3-12 million	135-150	n.a	Improved characteristics from HMWPE. Very high wear resistance and very low friction. Use areas: Ski base material, artificial joints, bearings	Difficult to process, sintered. Expensive

High molecular weight polyethylene types normally have a high density due to its capacity to crystallise. All polyethylene types are of low density when evaluated against other materials and they are all lighter than water. Notice that Table 1 is produced with information from several different sources [9-12] and the values have some variations and uncertainties, as they are only approximate values. For instance the value for the melting temperature to UHMWPE is in most journal articles for skiing sat to be between 140 °C and 150 °C and in the Material Handbook by Cardarelli [9] it is sat to be 125 °C to 135 °C. This can be due to additives in the ski base material, different molecular weights or the degree of crystallinity. The four lines above the bold line in Table 1 shows the densities that difference the polyethylene, while the two lines below the bold line shows the molecular weight that differs the polyethylene. Ski base materials are either of high molecular weight, HMWPE, or ultra-high molecular weight, UHMWPE. The latter is the most relevant material for this project. . There is not a given value for UHMWPE in the literature, which may be due to the high crystallinity.

ULTRA HIGH MOLECULAR WEIGHT POLYETHYLENE

UHMWPE is the polyethylene with the best properties considering it from a ski base point of view according to history and the previous years. The extremely long chains of polyethylene have crystallised and make a polymer of very high wear and abrasion resistance, very high hydrophobicity and low friction. UHMWPE is also able to **absorb** waxes that make the friction lower in the gliding zone and higher in the kicking zone.

PRODUCTION OF THE SKI BASE

UHMWPE is very difficult to produce due to the extremely long molecular chains and is therefore expensive. UHMWPE is sintered from powder under high pressure and heat. This is a very demanding process, illustrated in Figure 4. Almost all high quality skis today are made with UHMWPE ski base.

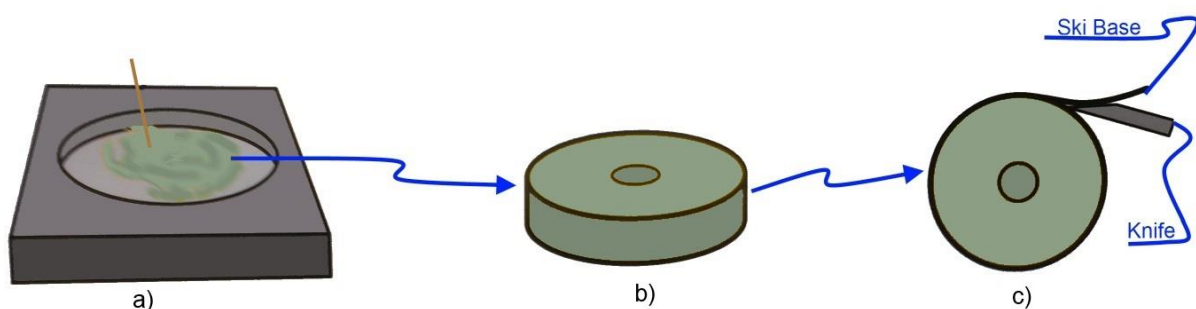


Figure 4 Production of ski base. **a)** UHMWPE granulate is sintered under high pressure and heat. **b)** Sintered plate. **c)** Peeled UHMWPE base, almost ready to use. Adapted from [13].

HMWPE has many of the same good properties as UHMWPE as described in Table 1, however the processing is much easier. Compared to UHMWPE HMWPE can be extruded and many of the good properties of HDPE are generated. From extrusion it is possible to get the wanted shape directly, shown in Figure 5. This is the kind of sole material and process method that is used for the average skis.

Extruded ski bases are anisotropic, the crystalline molecules have an align shape, while sintered soles have homogenous isotropic properties due to the production process, the ski base should have the same strength in all directions [10, 14].

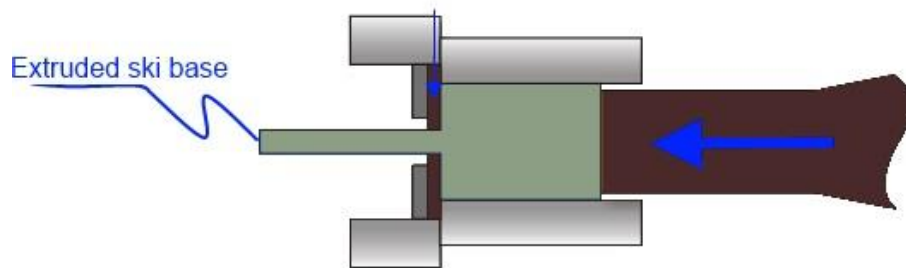


Figure 5 Extrusion of ski base.

3.2.2 POLYTETRAFLUORETHYLENE

If all the Hydrogen atoms in polyethylene are changed with Fluor, one gets polytetrafluorethylene, PTFE. Fluor atoms are larger than Hydrogen and are the most electronegative elements in the periodic table. Therefore, when the PTFE molecule is formed, it gets the form of a spiral due to repulsion forces between the Fluor atoms. The polymerisation for PTFE is shown in Figure 6. PTFE has a lower coefficient of friction compared to polyethylene and UHMWPE, but it lacks mechanical strength especially on cold snow. PTFE has a very high melting temperature of 340 °C and also a very high melting viscosity and is hence extremely difficult to process. Due to the high T_m and the high melting viscosity it very expensive and is mostly used as a thin coating. The glass transition temperature is around 130 °C. PTFE can be used as a ski base, or coating on a ski base, but it is more common to use it as an additive in UHMWPE to decrease the friction in the ski base [15, 16].

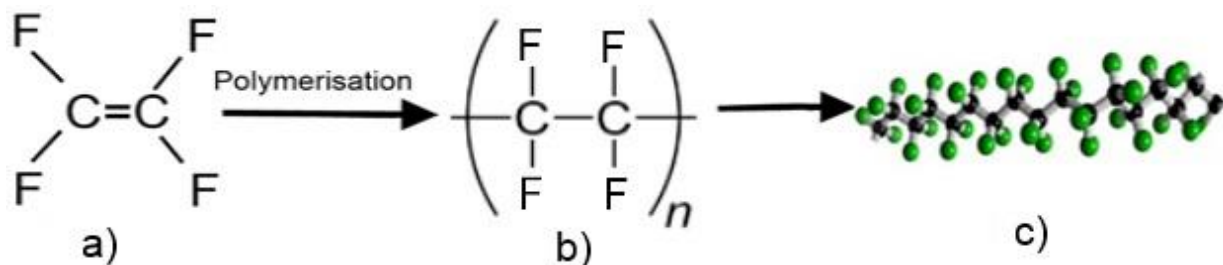


Figure 6 a) Tetrafluorethylene molecule b) PTFE monomer c) PTFE molecule.

3.2.3 ADDITIVES

Additives are used in polymers to change their properties. It is important that the additive improves the specific characteristic without making others worse. To improve the tribological behaviour for polymers different type of fillers are often used. Short fibres can be used to increase the mechanical strength while solid lubricants are used to decrease the coefficient of friction. Antioxidants can be used to avoid the aging of material or degradation from UV light [17, 18]. The features that need to be improved for ski bases are aging of the base and minimising the friction, which is the focus of this master thesis.

The solid lubricant fillers used in the polyethylene ski base are PTFE, graphite and molybdenum disulphide. Carbon black is normally added in the polyethylene to get better strength, lower friction and a black colour. Graphite as additive could change the colour, the hardness, the electrical-, thermal- and frictional characteristics [19]. Graphite is crystalline carbon and carbon black is amorphous carbon. Graphite strengthens the ski base material, the ski base becomes harder which can be beneficial in cold conditions. Close to zero degrees the graphite conducts frictional heat away from the interface, **which may lower the friction**. Most racing skis used today have black ski soles as a result of additives like carbon black and graphite, white ski bases becomes more

common for conditions near zero degrees. One of the purposes of additives is to improve the lubricating water film thickness, the wear resistance and the hydrophobicity of the ski base. Furthermore ski bases also need to be able to absorb waxes. Waxes are used to excel the properties of the ski base considered the snow and weather conditions, further information about waxes is to be found in section 3.

SKI BASE MATERIAL TODAY

UHMWPE is used as the main component in the ski bases of all top model skis and different additives are applied to improve different properties, such as friction. It is the low friction, good wear resistance and the capacity to absorb wax that makes UHMWPE suitable as ski base nowadays. UHMWPE is also relatively cheap and easy to do surface treatments as different grindings.

3.3 WAX

In classic cross country skiing it is common to use both gliding wax and kicking wax, in other disciplines of skiing, including downhill and snowboard, only gliding waxes are used. Gliding wax is used to optimise the glide and prevent the oxidation of the ski base. Selected glide waxes are considered in this work and they will be described in detail later [20, 21].

3.3.1 BASIC WAX

Basic waxes are made of hydrocarbons that have a lower melting temperature than the ski base; the waxes are short chains of hydrocarbons while the ski base is made of extremely long chains. Typical numbers of carbon atoms in waxes can be 20 to 100, while for the base it can be many millions of carbon atoms. This way the wax will have a lower melting temperature than the base for an easy application [8, 10, 20].

To improve the gliding effect the wax should be melted into the ski base material. The semicrystalline polyethylene ski base will expand and the gaps and voids in the amorphous area will open up and letting the melted wax to fill them up, as illustrated in Figure 7.

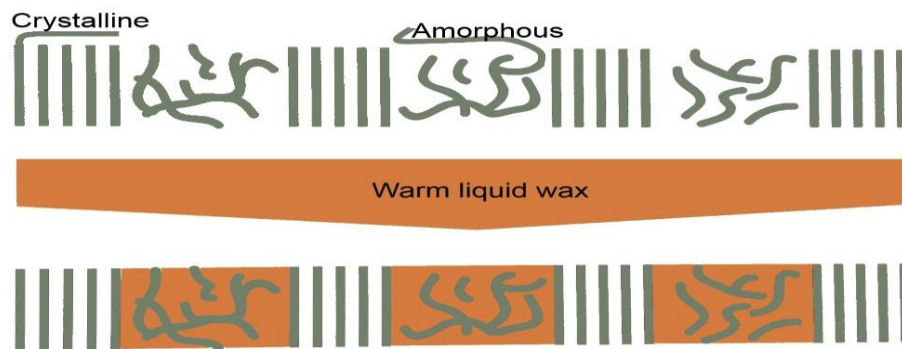


Figure 7 The heated wax is penetrated into the amorphous parts of the ski base material, adapted from [13].

After the wax is applied with a hot iron, it will lie as a thin coating on the ski base material, shown in Figure 8 b). It is desirable to keep the original surface topography of the sole, since it is designed to optimise the ski performance. The ski soles are scraped and brushed back to its original structure while the penetrated wax is left in the base material, as in Figure 8 c).

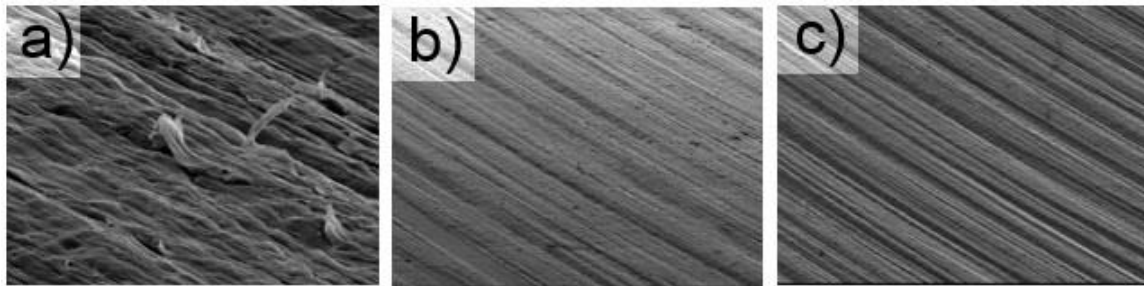


Figure 8 a) Untreated base after steel scraping, b) base with low fluorine wax, c) ski base topography after waxing and brushing, adapted from [21].

The ambient weather and snow conditions affect the wax selection. Air and snow surface temperature are two important parameters to consider [22]. If the temperature is low, the snow will be harder and so should the wax, if the temperature is mild the wax used should be softer [23]. New snow in cold weather has sharp edges, so if the wax is too soft the snowflakes will plough into the wax and create resistance and increase friction, as shown in Figure 9 a). However, it is the soft waxes that have the best water repellence and the lowest coefficient of friction on soft snow. If the wax is too hard the friction will not create the desired water layer between the ski base and the snow. The lubricating effect from the water layer will fail, and the friction force will increase, illustrated in Figure 9 b). Figure 9 c) shows optimal wax strength compared to the snow [13].

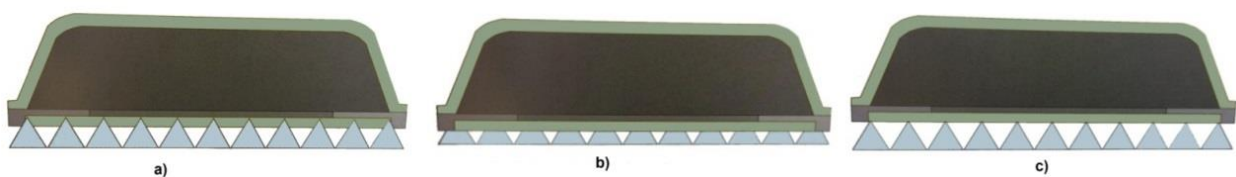


Figure 9 a) soft wax. b) hard wax. c) optimal hardness on wax relative to the snow, adapted from [13].

Hydrocarbon waxes are normally divided into three types; paraffin, microcrystalline and synthetic waxes. Paraffin is the softest type and has the best friction properties, but breaks easily under pressure, microcrystalline has a higher molecular weight and better resistance towards shear stresses. Synthetic waxes have longer chains than paraffin and microcrystalline, are harder and are used to harden the paraffin for use on cold snow [24].

FLUOR CONTAINING WAXES

Fluor containing waxes are commonly used underneath racing skis, especially when the weather is warm or humid. Ski waxes that contain **Fluor** can be found as basic paraffin wax, powder wax or as liquid wax. All or parts of the Hydrogen in the hydrocarbon waxes are changed with Fluor atoms, which is the same primary difference as between PE and PTFE (see section 3.2.2). The Fluor has exceptional physical and chemical properties, the Fluor-Carbon bonds are extremely strong and **Fluor** has the highest electronegativity value of all elements, not including noble gases. The **high electronegativity** means it does not attract other electrons towards itself and therefore has a capacity to not **accumulate dirt and contaminants**. Due to the stability of the Fluor-Carbon bonds the melting temperature is very high and the processability of fluorocarbons is challenging and therefore expensive. A ski wax should have a lower melting temperature than the ski base. The lower melting temperature the wax has, the deeper it can penetrate into the sole. The fluorocarbon waxes have very short chains which decrease their melting temperature. The mechanical strength for fluorocarbons is too low for the cold weather, so other additives are often put into the ski waxes so the wax will have a wider temperature range. Most wax companies have several waxes containing Fluor, each for different weather and snow conditions [15, 20, 21].