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Rethinking Surface Design and Materials of Skis

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Summary

Cross-country skiing has been one of the most popular sports in Norway for a long time, and the saying ”Every Norwegian is born with skis on his feet” is a testimony to this fact. The technical development has been immense, and the money spent in research and development has increased steadily for decades, reflecting the sport´s popularity in Norway but also throughout the world.

The overall goal has been to reduce the friction between the ski and snow to achieve greater speed and, as in all sports, win more medals.

This master thesis work has been done as a collaboration with Olympiatoppen, an organization part of the Norwegian Olympic and Paralympic Committee and Confederation of Sports and works with Norwegian elite athletes, to assist in research and product development. Olympiatoppen has opened the opportunity to look past the traditional research to optimize glide. This master investigates an unorthodox material for use in cross-country skiing, aluminum.

Applying product development, as taught at NTNU as well as from literature research, anodized aluminum oxide (AAO) has been produced and researched as an alternative sole material for cross country skis. AAO is a structure formed on aluminum, with high hydrophobicity and otherwise similar properties to what is used as sole and presently considered to be state of the art, Ultra High Molecular Weight Polyethylene (UHMWPE).

The master thesis investigates how to develop this structure in an inexpensive manner, comparing the test results against the state of the art ski sole material.

To perform the test for the comparison a test table has been developed allowing the table top to tilt in a controlled manner, while looking at the roll off angle of a droplet of water on the material. The roll off angle of the table for each sample is compared and used as an indicator of the material´s hydrophobic properties.

The samples have been inspected using a Scanning Electron Microscope (SEM) demonstrating the development of AAO structures and some samples have shown hydrophobic properties better than that of UHMWPE material.

The outcome of this master thesis shows promising results and invites to further research in this field.

Oppsummering

Langrenn har vært en stor sport i Norge i lang tid. Gjennom flere tiår har utviklingen vært stor, og det investeres stadig større summer i utvikling og forskning. Målet har vært å redusere friksjonen mellom ski og snø, for å øke farten. Det overordnete målet er som i alle andre sporter; vinne flere medaljer.

Gjennom et samarbeid med Olympiatoppen har denne masteroppgaven blitt utført for å hjelpe til i forskningen, og Olympiatoppen har åpnet for muligheten til å se forbi den tradisjonelle forskningen for å optimalisere glid. Denne masteren tar for seg et uortodokst materiale for bruk i langrennski, aluminium.

Gjennom bruk av produktutvikling lært på NTNU samt litteraturstudie, har anodisert aluminumoksid (AAO) blitt produsert. AAO er en struktur som dannes utenpå aluminium, med høy hydrofobisitet og ellers like egenskaper med det materialet som brukes som såle og anses som state of the art, Ultra High Molecular Weight Polyethylene (UHMWPE).

Denne masteren undersøker hvordan man kan utvikle AAO-strukturen på en økonomisk og enkel måte, og sammenligner prøvene som er utviklet opp mot state of the art. Sammenligningen vil bli gjort på er ved å bruke et testbord som kan vippe bordplaten på en kontrollert måte. En vanndråpe dryppes på testprøven og ved å vippe bordet kan man måle vinkelen bordet er på når vannet begynner å gli. Denne vinkelen sammenligner man med resten av prøvene, og dette gir en indikasjon på hvilke materialer som er mest hydrofobisk.

Flere av prøvene produsert har utviklet en AAO-struktur som er dokumentert ved hjelp av et SEM-kamera. Testene utført med det utviklede testbordet viser at flere av disse prøvene har vist bedre hydrofobiske egenskaper bedre enn de UHMWPE besitter.

Utfallet i denne avhandlingen viser lovende resultater og åpner mulighetene for videre forskning på dette feltet.

Preface

This master thesis is written as the closing part of the master´s program in Mechanical Engineering at the department of Engineering Design and Materials at NTNU.

It is a continued work of a project thesis started in the fall of 2016 and has been done in cooperation with Olympiatoppen during the spring semester of 2017.

Olympiatoppen provided the initial problem formulation, knowledge and part funding for the thesis with an objective of reducing the friction on cross-country skis. With freedom to explore different ideas, the master thesis will focus on using metals as sole on cross country skis and looking at Anodized Aluminum Oxide(AAO), in particular.

Acknowledgement

To my mother & father, I express my sincere appreciation for both moral support, helping me with proofreading, and always being there for me.

I would like to express my gratitude to my supervisor Professor Martin Steinert, for all the support given and helping me when problems arise and keeping a steady course.

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I would also like to thank Jan Torgersen for his knowledge in the field of anodizing aluminum. The help with getting the right parts for the set up, and providing me a starting point has been very important.

To Olympiatoppen and my company contact Felix Breitschädel, for providing such an interesting and open research problem, which was very exciting to work on.

Thanks to Morten Dobloug, my fellow student, for cooperation in both the project and master thesis. For brainstorming, testing and exchanging experience and knowledge through this year.

To the people at Sintef, especially Ann-Karin Kvernbråten, for giving me access to the Corrosion lab, and helping me when my limited knowledge in chemistry was tested.

To the guys at the Realization Lab at EDM, for helping me with milling, bandsawing and drilling.

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To Peter Köllensperger and the guys at Nanolab, for helping me get some much needed SEM-pictures.

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Abbreviations

UHMWPE Ultra High Molecular Weight Polyethylene

AAO Anodic Aluminum Oxide

SEM Scanning Electron Microscope

PTFE Polytetrafluorethylene(Teflon)

R&D Research & Development

CF Coefficient of Friction

FIS International Ski Federation

EiT Experts in Team

PD Product Development

CAD Computer Aided Design

MDF Medium-Density Fiberboard

ENT Electroless Nickel-Teflon

Chapter 1

Introduction

This master thesis is written in cooperation with Olympiatoppen and is a part of the work "Forsprang 2018", in the sport of Cross Country skiing. Project work was done prior to this thesis, as preparation to the master(Skoglund, 2016). While the project thesis is independent to this master, the project work is referenced, and some parts of the project work has been borrowed throughout this thesis. The project work is added as Appendix A in full.

In Skoglund (2016) it was found that Anodic Aluminum Oxide(AAO) could work as a replacement for the material used in cross country ski soles (Ultra high molecular weight polyethylene), UHMWPE in short. This thesis will investigate in depth the use of the material AAO, a result of a electrochemical oxidation process with aluminum, and look at exactly what makes it suitable for this use, and how to produce a structure suitable for cross country skiing. A table will be constructed to measure how hydrophobic a surface is, make it possible to compare the results from this master thesis with both the state of the art, and the project work results.

The main purpose of this master thesis is to study new concepts to improve the gliding conditions of cross country skis.

1.1 Ski Background

Different types of wood were used for the very first skis, but mainly hickory, for its high hardness properties. Hickory is still used in some ski production to this day, but technology has progressed, replacing hickory with improved materials, like ultra high molecular weight polyethylene (UHMWPE) and polytetrafluoroethylene(PTFE). The breakthrough of these new materials took place in the 1974 World Cup when polyethylene was proven to have excellent properties for cross country skiing. UHMWPE has since been used as the main base material for cross country ski soles.

Since 1974, many technological improvements have been made, but the base still remains the same. UHMWPE is mixed with other additives, like molybdendisulfide or fluoride, and gliding waxes are also introduced in order to further enhance its gliding properties. Lots of testing and experiments has been done to make UHMWPE even more suited for cross country skiing (Rogowski et al., 2005; Brydson, 1999; Breitschädel, 2014).

As cross country skiing continues to grow, the competition is growing, and the amount of money put into R&D is immense. To be able to develop, or discover materials and new approaches, it is therefore necessary to think outside of the box and look at new ways that are not common in the skiing R&D world today. For this purpose the master thesis work has looked into other industries, other materials has been tested, and other properties than what could be considered the current norm has been evaluated.

Utilizing the product development approach at NTNU, we are able to look at things from a new perspective, and hopefully, discover something of interest and value. Not only for the master thesis, but also for the national cross country skiing team, because better skis result in more medals.

But first, in order to find the solution to our challenge, understanding the problem itself is necessary.

There are two main hypotheses formulating how skis glide on snow, stated by (Takeda et al., 2010):

- **Adhesion theory**

  States that the shearing strength of ice is small when compared with base materials such as UHMWPE and PTFE.

- **Meltwater lubrication theory**

  States that melting ice produces water that acts as lubrication between the snow and ski

1.2 Problem Formulation

With the hypotheses above in mind, the challenge for this master thesis is to look at a new material that would improve the glide in cross country skiing.

One of the materials being tested is aluminum, or more exact, Anodic Aluminum Oxide(AAO). The thesis will consist of two parts, the first part will cover experiments for anodizing aluminum in different ways to achieve a suited nanostructure for use in cross-country skiing, and a second part will include product development to compare the new material against the state of the art.

Referring to Skoglund (2016), and supported by Fuss et al. (2013); Colbeck (1988); Nachbauer et al. (1996), there are four main material properties of importance for cross country skiing. These properties are

- Hardness
- Thermal conductivity
- Wear resistance
- Hydrophobicity

One of the main findings from Skoglund (2016) where that hydrophobicity might not be as important as previously believed. With this in mind, AAO is a perfect candidate to validate this hypothesis, as surfaces with superhydrophobic properties can be constructed, and the remaining properties are similar to those of the UHMWPE.

1.3 Objectives

1. Build a small scale, low-cost setup for anodizing aluminum
2. Anodize aluminum in chemical solutions to achieve a suitable nanoporous structure
3. Create setup for measuring table angle for when water slides off the sample surface
4. Test for hydrophobic properties and compare against results in Skoglund (2016)
5. Compare against state of the art (UHMWPE)

1.4 Limitations

The main limitation for both this master thesis and Skoglund (2016), has been access to snow. Norway has had less and less snow in recent years, and Trondheim had a limited number of days with snow during this master thesis work. practical testing was not applicable until late May, early June, which again caused limited test conditions for the master thesis work. Therefore, other tests have been more important, for instance hydrophobicity testing, and comparing this with results attained in the project thesis, as the project is the base for this thesis.

Accessibility to relevant machines, particularly the SEM (Scanning Electron Microscope) has been limited. The progress of the master thesis depends on microscopic pictures of the samples tested and access to the SEM has been a bottleneck. Attempts were made to work around this limitation by involving other institutes at NTNU to help. This did not turn out as hoped for, as the SEM at Nanolab did not meet the requirements for photo resolution. This has resulted in limitations on the number of photos possible to get from the SEM. The most important samples showing the most important results have been included, and will be discussed in the appropriate chapters.

Another challenge is the lack of experience in the field of chemistry and materials technology. As a student with product development as a major, there have not been many relevant courses within this field. Accordingly, a significant part of this thesis has involved becoming familiar with, and understanding the method for developing a nanostructured Anodic Aluminum Oxide surface.

1.5 Approach

The project approach is the scientific method defined in Oxford Dictionaries (Oxford, 2017b). By systematic observation, measurement, and experiments, followed by testing and alteration of hypotheses, nanoporous structures can be constructed for use in Cross country skiing.

First phase is literature research and gaining knowledge on how to anodize aluminum and second phase is testing different solutions to produce different nanostructures. A Scanning electron microscope (SEM) will be used to observe results and to compare the different tests. These tests will be done on a small scale, and when a suitable structure has been found, it will be tested and compared with the state of the art materials.

Product Development(PD) is an integral part of the TrollLabs philosophy, and based on this approach there will be mock-ups and prototypes involved in the development of the larger scale testing. This approach follows the PD guidelines taught at NTNU, but also follows the scientific definition in Oxford (2017a).

1.6 Structure of the Master Thesis Report

Chapter 2 describes the methodology used for the most part of this master thesis work. Product development and the various ways this can be done is introduced here.

Chapter 3 introduces some theory regarding the different materials involved in this thesis and gives a closer look at the most important material properties for cross country skiing.

Chapter 4 gives an insight into the importance of the material chemistry, describing the experiments performed to achieve a nanoporous structure, including a log of the most important results.

Chapter 5 covers the Product Development phase, showing how this process evolves from simple brainstorming to finished prototypes.

Chapter 6 presents the most important results in a short, accurate way.

Chapter 7 discuss relevant outcomes and findings, while chapter 8 concludes the work, and gives some points on what needs to be done in the future to finish the work started in this thesis.

Chapter 2

Methodology

2.1 Introduction to Product Development

Product Development(PD) is a process in which an idea is brought to life. It covers all phases from initial brainstorming to bringing the product to market, as can be seen in figure 2.1.

The funnel illustrates the different phases from the start, the Fuzzy front end, exploring all possible ideas diverging to cover knowledge gaps, research and learning, converging on an idea or product to pursue.

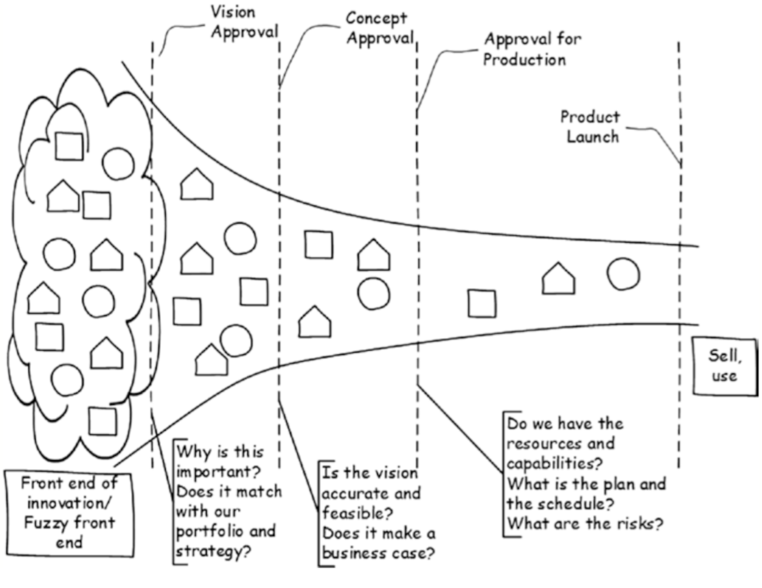

Figure 2.1: Product development funnel, adapted from (Pessôa and Trabasso, 2017)

The product can be tangible (physical entity) or intangible (belief, service, experience). Understanding of customer needs and market environment is the foundation of a solid product (Kahn and Association, 2005).

We separate product development in four phases:

- Fuzzy Front-End
- Product Design

- Product Implementation
- Fuzzy Back End

In this master thesis, the first two are the most important ones, and will be covered more in detail.

The Fuzzy Front End phase is where you define a product idea to pursue and develop. A much as 50% of development time can be consumed in this initial process (Smith and Reinertsen, 1995). Brainstorming and ideation, researching, immersing and empathizing with users are important tools to formulate a concept to develop.

The second phase is the Product Design, in which the *what* turns into *how*. This is the tangible development phase, where, by implementing different PD approaches a tangible version of the idea is produced, also called a prototype. This process can both be sequential or iterative, depending on which style of PD is chosen.

2.2 Wayfaring

Wayfaring

"The intellectual challenge of hunting for the next big idea, whether it is theoretical, empirical, or commercial new product development."

(Steinert and Leifer, 2012)

In the Fuzzy Front End of innovation, it is difficult to know how and where to start. However, some principles have been introduced from Steinert and Leifer (2012), and is used as part of the product development approach in this thesis.

By use of "rules" and guidelines, it is simple to get started in the vast world of innovation. To simplify the idea behind and make it easier to understand, these rules have been illustrated as a "Hunter-Gatherer"- model by Steinert and Leifer (2012), shown in figure 2.2, that simplifies the idea behind. The most important rules are listed below:

1. Don´t go hunting alone
2. Never go home prematurely
3. Bring it home

The concept of the Hunter-Gather model has been thoroughly explained by Steinert and Leifer (2012), so a detailed clarification is not necessary. But in short, by diverging in the start and developing prototypes under way, new knowledge is obtained throughout the entire process. New directions are chosen on the basis of empirical try and fail, not from literature, and makes for products that slowly but steady develops through iterative product development, evolving from the Fuzzy Front End to the product implementation and Fuzzy Back End.

2.3 Approaches to Product Development

In the field of Product Development there are several different approaches. In the not so distant past, sequential non-iterative models like waterfall was widely used. This process model is

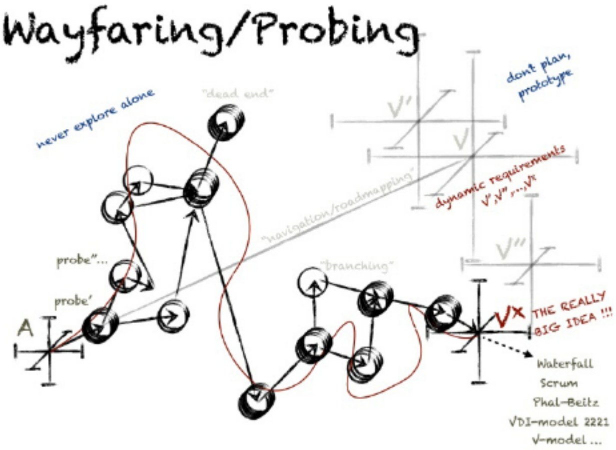

Figure 2.2: Model showing wayfaring, "Hunter Gatherer"-model, adapted from (Steinert and Leifer, 2012)

named from the resemblance of a natural waterfall in the way the process is performed, starting at the highest level and finishing before going down a level.

It is illustrated in figure 2.3, and this is called the traditional way of doing PD (Heizer and Render, 2004). The waterfall model had clear advantages in software development, where one key argument is that "an error found early in the development is far more cheaper to fix than one found in the end" (McConnell, 1996). However, being non-iterative, it means it gives no space to re-visit previous parts of the development. When you are done, you are done.

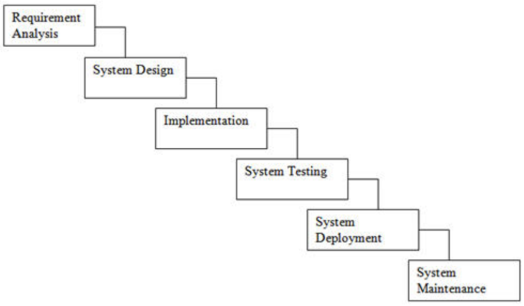

Figure 2.3: Waterfall PD model, adapted from STH (2006).

More modern types of PD models, like agile, relish the iterative and incremental processes. Group oriented work like scrum is often used providing a framework which goes hand in hand with agile-like PD. More than 40% of companies are using agile as their PD approach (PWC, 2012). Scrum can in short be explained as (cited by Foegen (2010)): "Scrum is an agile development methodology. The development is organized in cycles, these cycles are called scrum sprints. The length of a Sprint is defined for a project and lasts usually between two and four weeks. During a sprint the team develops the most important customer requirements from a prioritized list." This works best if used with several prototypes being developed at the same time. As Poppendieck and Poppendieck (2003); Martin (2003) said it: "Agile development is fundamentally based on an iterative and incremental development approach through the creation of a series of prototypes."

Within PD, it is common to distinguish between three different approaches. As can be seen in figure 2.4, type A is the sequential, traditional way of developing products, particularly in the software industry, while type B & C shows the iterative and non-sequential style, which is the most common PD method these days.

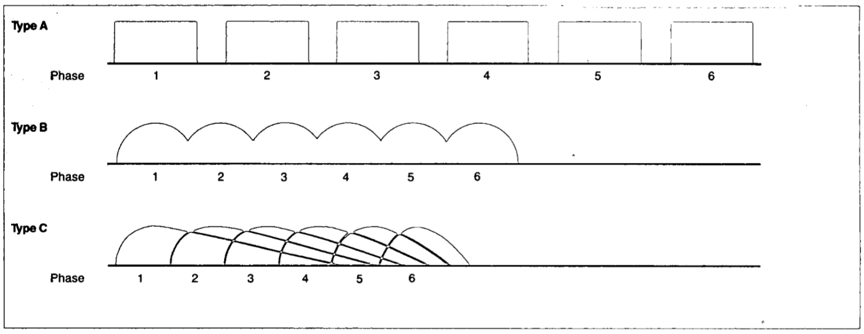

Figure 2.4: Three approaches to PD, adapted from Takeuchi and Nonaka (1986).

2.4 Tools

Regardless of the approach chosen for PD some basic principles remain the same.

- Know your audience
- Know your limitations
- Know your boundaries
- Know your team

You need to know your audience, or customer, when creating a new product. Who you design and create for is all important when making deciding on both the design and technical properties of your product. Teenagers will not be looking for the same design and properties as a senior. This means adapting to, and creating what you anticipate your customers require. Steve Jobs said in Inc. Magazine in 1989 (Burlingham and Gendron, 1989): "The customer don´t know what he needs until you show it to him." This is very often the case and when working with product development, it is important to understand, or anticipate, what the customer might require even before the customer knows themselves.

This can be achieved in several ways. The d.school bootleg (Both and Baggereor, 2015), is a tool kit for design thinking used for teaching within this subject at Stanford University but also implemented in courses at NTNU by Professor Martin Steinert. Some of the most relevant tools for use in the early Product Development phase, known as the Fuzzy Front End, are:

- **Empathize**

  In the empathy stage there are three key steps to be taken. Observe, engage & immerse. By observing peoples behaviour in relevant scenarios, information will be gained that will help understand where the underlying problems or bottlenecks might be. Engaging and immersing by talking to people that are relevant to your process, and understanding user experience, is key to be able to develop new products to suit specific needs. Therefore it is important to immerse one self and gain relevant experience in the developing of new technology.

- **Brainstorming**

  Brainstorming is used throughout an entire development process but is most important in the starting phases. Keeping an open mind with an "everything goes" attitude is a key to produce creative ideas. No ideas are bad and as many ideas as possible should be brainstormed to cover every base or checkpoints in the early phase. This will produce many ideas in different directions, and even though an idea might seem irrelevant at the outset, maybe someone else can build something of it that produces something highly relevant.

- **Extreme Users**

  "Extreme users" is a method to discover meaningful needs or requirements that might not be obvious when engaging with the middle core user group. The needs of the extreme users are amplified, and work arounds are often more notable, making it easier to realize problems. The idea of extreme users is as beautiful as it is simple. "Design for the extreme, make it accessible for everyone." In other words, if you can tailor your product to fit extreme users, in most cases it will be well received with the rest of the users. As shown in figs. 2.5 and 2.6 the extreme users are important for new insights, while the core group is the validation of the product actually working.

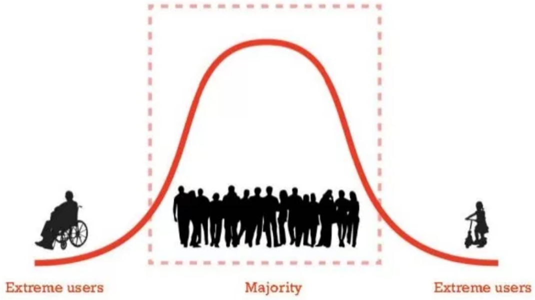

Figure 2.5: Bell curve showing extreme users vs core group, adapted from Brophy (2016)

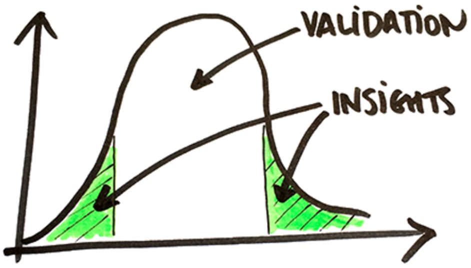

Figure 2.6: Bell curve showing insights vs validation in reference to 2.5, adapted from Gauthier (2016)

- **Prototyping**

  Prototyping is one of the most important tools in documenting progress. By making tangible products you can easily show your work and ideas to the rest of the team, customer or client. This makes it easy for people to give constructive criticism, make their own prototypes to show their take on your work, and is an easy way to "bring your idea to life."

  Rapid prototyping, where small changes are made to each iteration, getting one step closer to the finished product every time, is the product development approach in this thesis. Figure 2.7 shows how the iteration process works when developing several prototypes through iterations. Another approach directly linked with prototyping is probing, which is to develop prototypes to gain completely new knowledge - knowledge impossible to predict regardless of personal expectations. The concept is shown in figure 2.8. Each probe represents a prototype, where new knowledge is deductively, inductively and/or abductively created and tested.

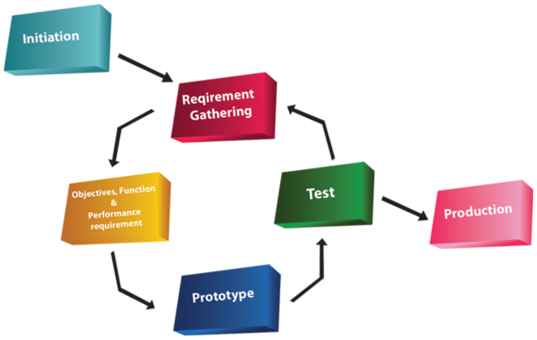

Figure 2.7: Mindset of prototyping

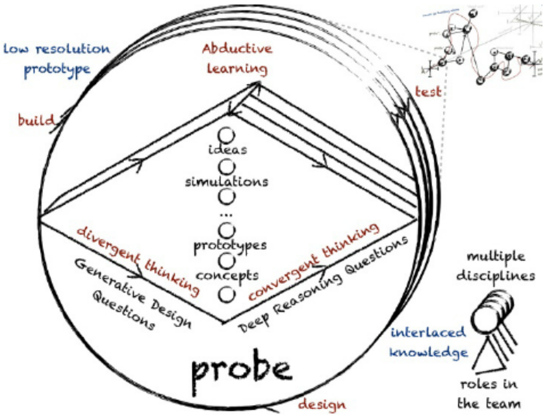

Figure 2.8: Probing cycle, adapted from Gerstenberg et al. (2015)

2.5 Prototyping

Oxford (2017a) dictionary defines prototyping as "A first or preliminary version of a device or vehicle from which other forms are developed." This means that the prototypes are used to show your ideas to like-minded people in the starting process of a development phase.

The most relevant and appropriate approach of PD for this thesis is rapid prototyping. Developing new ideas and bringing them to life as a prototype is a good way of presenting your views to colleagues and customers. It is also a great way for oneself to get a better understanding of how ideas work in a more tangible way than other approaches. As stated by Both and Baggereor (2015), prototyping enables one to "fail quickly and cheaply". What this means is by using limited time and money on making ideas tangible, it is simple to identify required changes, or identify ideas that simply won’t work.

A chapter regarding prototyping has been written in the project thesis from the fall of 2016, so a extensive introduction can be found in chapter 3 of Appendix A, in Skoglund (2016).

The product development in this thesis will be in two part;

- Making a table for comparing friction on surfaces
- Developing a nano structure on the aluminum

In every project there are different needs for prototypes. In the making of AAO, it has been difficult to use the prototyping benefits to its full potential. This is because of lack of experience in the field of chemistry, meaning time was needed to experiment with the chemical solutions, and getting familiar with the how´s and why´s of anodizing. However, this is prototyping in itself, as several different aluminum samples were tried, different material connectors were used, and different acid baths where tried out, based on literature (Liu et al., 2013; Mooney, 1995; He et al., 2009; Wernick et al., 1987).

The development of the test table will follow rapid prototyping progression, with simple sketches and mock-ups to begin with, and then scaling as right solutions are discovered.

Chapter 3

Theory

3.1 Metals

3.1.1 Aluminum

Aluminum is a metal in the boron group. It has the symbol Al, and its atomic number is 13. It is nonmagnetic, ductile and soft.

Aluminum is known for its low density and is excellent at resisting corrosion through electrochemical oxidation. These are properties that make it interesting for cross country skiing, as a ski needs to be both lightweight and able to withstand corrosion and wear.

Aluminum (including all of its alloys) is commonly used in transportation, building facades, and window frames, but is also important in the aerospace industry (Boin and Bertram, 2005; Das and Yin, 2007; Nakai and Eto, 2000).

Fluoride is used as wax to enhance gliding for state of the art materials used in cross country skiing. However, because of fluorides harm to the environment, it is being used less and less in today's competitions. Aluminum on the other hand, is well tolerated both by animals and plants. This means that even if the AAO has lower wear resistance than what would be preferred, there are no problems with environmental issues, as the aluminum does not contaminate in a way that harms the nature (Agency for Toxic Substances and Disease, 2008).

3.1.2 Anodic Aluminum Oxide

Aluminum itself is not very hydrophobic, has a high thermal conductivity, low corrosion and wear resistance. However, a procedure known as anodizing can change both properties and structure of the metal.

The process used to produce this structure is called electrochemical oxidation, and works by introducing an anode and cathode in an electrolytic cell, made from a chemical solution. The solution can vary, but the simplest is sulphuric acid mixed with water. The part that is anodized works as the anode electrode in an electrical circuit, as shown in figure 3.1.

Anodizing can increase both resistance to corrosion and wear. It can also be used to prevent galling of threaded components, as well as making dielectric films for capacitors.

Anodizing will change the micro and nanostructural texture of the metal surface. While normal aluminum is softer than an anodized surface, the wear resistance can be improved by

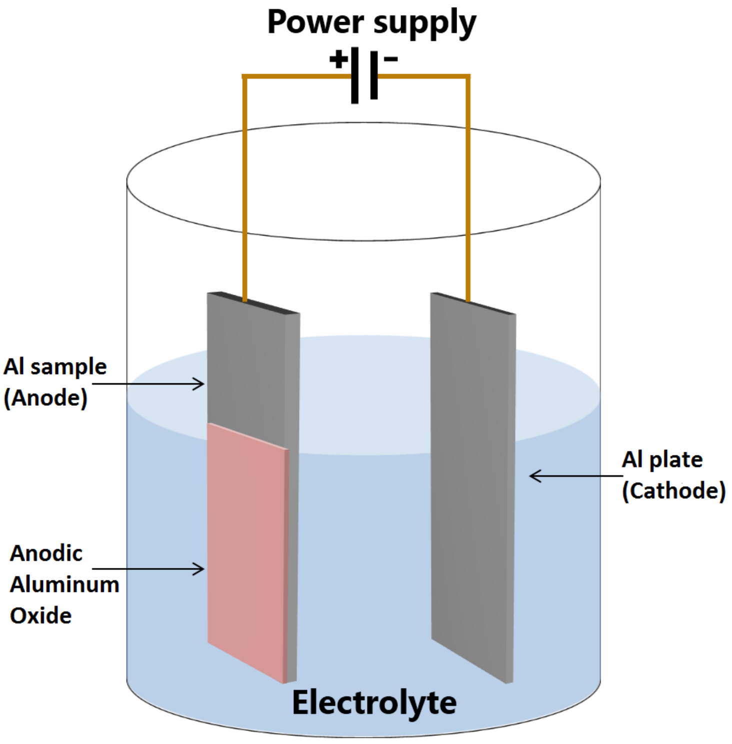

Figure 3.1: Electrolytic cell

increasing the thickness of the anodized part. This is achieved by leaving it in the electrolytic acid bath for an extended time.

Nanoporous Anodic Aluminum Oxide, or AAO, is a structure that has a honeycomb-like texture. It is formed by high-density arrays of parallel, uniform nanopores. While the form is consistent, the diameter of each nanopore can vary between a few nanometers to several hundred micrometers. The length of the pores can be controlled within the same range.

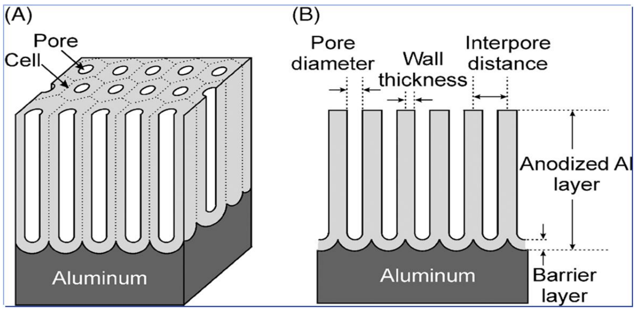

Figure 3.2: Anodic aluminum structure forming as a result of electrochemical oxidation

Figure 3.2 shows how the structure grows from the aluminum. Both pore diameter, wall thickness and length is a result of varying chemical solution, current and time. 3.2 shows what is meant by the self-organizing, symmetric structure that forms from this process.

The procedure of anodizing has been used by companies since early last century. Mostly, this has been used for corrosion protection and decorative coatings. The use of this process in cross country skiing has not been tried previously. Consequently, there is not much research available to support the master thesis work specifically for trying this with cross country skis.

Already in the 1980s AAO attracted interest in several different areas due to its uniform nanostructure, but most important in nanotechnology where the structure could be used as a template for making nanowires (Routkevitch et al., 1996b; Xu et al., 2000; Preston and Moskovits, 1993). Since then, several articles using AAO for nanofabrication has been published (Routkevitch et al., 1996a; Hulteen and Martin, 1997), making it popular for the design of high-density arrays of nanostructures. These articles are used as literature research for this thesis work.

AAO is widely used from everything from dyeing iPod's to making materials corrosion resistant, but its significance within both science and technology is perhaps its most important use. AAO enables a new type of product development with the possibility of engineering the structure at nanoscale on both small and large areas. This characteristic is the basis for this master thesis.

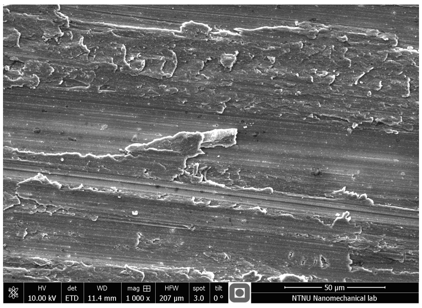

Figure 3.3: SEM picture of untreated aluminum, copied from chapter 4, Figure 4.9

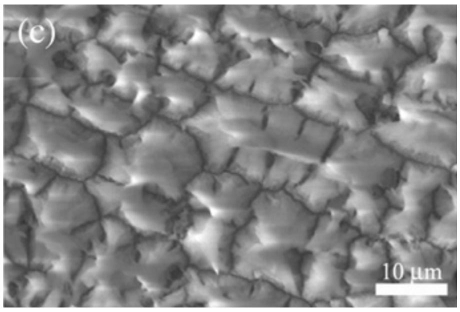

Figure 3.4: SEM picture of AAO, adapted from Liu et al. (2013)

Figures 3.3 and 3.4 shows the changes in the material structure based on the AAO process explained more in detail in chapter 4. The major difference in these materials is while the untreated aluminum (3.3) has a more smooth surface, the AAO processed aluminum (3.4) has a far more coarse surface, on a nanometer scale. The structure resembles mountain tops and valleys, which forms the basis for the hydrophobic properties aluminum develops during the anodizing process.

Hydrophobicity is one of the four important factors in determining whether a given material would work as a sole material for cross country skiing. This will be explained in more detail in the next section.

3.2 State of the Art

UHMWPE

Ultra-high-molecular-weight polyethylene (UHMWPE) is most commonly used as ski base material. It is a subset of the thermoplastic polyethylene, which is a high performance polyethylene with extremely long chains. These chains are what makes the material so tough, and is one of the reasons why it is the standard material for cross country skis (Fischer et al., 2008). It has a very low coefficient of friction, and high wear resistance(Ducret et al., 2005). As an important bonus, it is cheap to produce in large quantities.

An introduction to friction between snow and UHMWPE can be found in chapter 2 in Skoglund (2016).

3.3 Important Factors

This section is borrowed from Skoglund (2016), but due to its relevance and importance to the master thesis work it is has been included in full as part this work. It presents the most important factors for determining materials that would be suitable for this thesis work and was the key factor in selecting AAO.

Before selecting materials for testing, we broke down the problem into several simple factors to make it easier to find materials with the best characteristics fitting the problem formulation. According to Fuss et al. (2013) the four material factors most important for increasing speed while skating in cross country skiing are:

- **Wear Resistance**

  In material science,

  "wear is erosion or sideways displacement of material from its
  'derivative' and original position on a solid surface performed by the action of another surface."

  (Rabinowicz, 1965)

  Wear resistance is related to the interaction between the snow and the base material, and how well the material can withstand deformation as a result of frictional forces from the snow. If a material has low wear resistance, it will gradually be worn down when gliding against a surface, which is something we want to avoid in cross country skiing.

- **Hardness**

  Hardness is measured by how a material resists permanent shape change when exposed to compressive forces, also called plastic deformation. There are different types of hardness;

  - Scratch hardness
  - Indentation hardness
  - Rebound hardness

  Hardness depends on ductility, elastic stiffness, plasticity, strain, strength and toughness.

  There are several hardness scales, but Brinell is mainly used in this master thesis work. The different methods are not scalable above a certain level of hardness, meaning Brinell cannot directly correlate with, for instance, Vickers. It is therefore necessary to keep the hardness scale test constant throughout the project.

- **Hydrophobicity**

  A hydrophobic material seemingly repels water which is poured onto it. However, the correct definition is simply absence of attraction (Ben-Naim, 2012). This can vary to some degree, which can be seen in figure 3.5. According to Giesbrecht et al. (2010), and supported by Fenre (2015); Bowden (1939); Glenne (1987), hydrophobic surfaces experience lower friction than hydrophilic.

  Hydrophobic molecules are usually nonpolar and, therefore, prefer neutral molecules and nonpolar solvents. Water is polar, thus hydrophobes don't dissolve well with water. Water on hydrophobic surfaces will exhibit a high contact angle, which is shown in figure

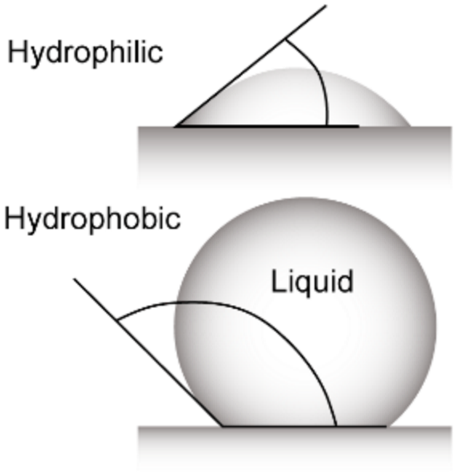

Figure 3.5: Difference between contact angles of water on hydrophobic and hydrophilic surfaces (adapted from Forch and Jenkins (2009)).

3.5, where the hydrophobic surface angle is larger than the hydrophilic. As a reference point, all surfaces with angles >90 are considered hydrophobic (Forch and Jenkins, 2009; Grodzka and Pomianowski, 2006).

- **Thermal Conductivity**

  Thermal conductivity refers to the property a material has to conduct heat (Hetnarski, 2014). A material with low thermal conductivity, will transfer heat at a lower rate, compared with a material with high thermal conductivity. For our project a material with high conductivity, will transfer the heat from the friction forces quicker, and in turn decrease the amount of water film made by friction. Different conductivity properties may be important when looking at snow at different temperatures, because the amount of water melting decreases as the temperature of the snow decreases.

Chapter 4

Experiment

4.1 Introduction to Anodizing

This experiment is based on the knowledge of Jan Torgersen at NTNU, and literature from Liu et al. (2013); Buijnsters et al. (2013); Mao et al. (2008). A more detailed introduction to Anodic Aluminum Oxide has been given in subsection 3.1.2, so this chapter is more specific on how the experiment is done.

While aluminum itself is not very hydrophobic, has a high thermal conductivity with low corrosion and wear resistance, these properties can be changed due to the AAO process that changes both properties and structure of the metal.

This process will be a highly empirical process. It is necessary to test several samples in different chemical solutions to find a suitable structure. It follows a rapid prototype approach where possible. Quick failing and learning is central in this phase, trying out several different acid baths, connector materials and aluminum samples.

The aluminum composition of the alloy used is listed in Appendix D.

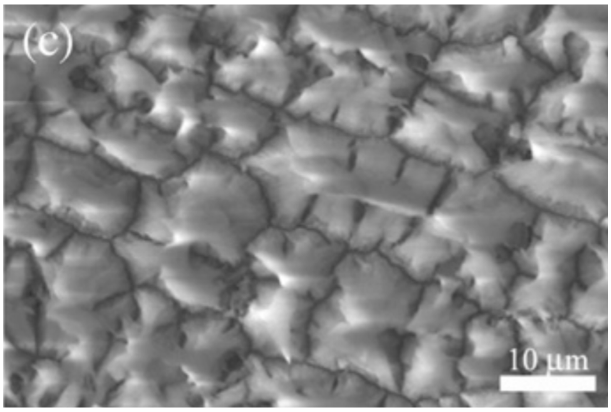

Figure 4.1: Nano structure, adapted from Liu et al. (2013)

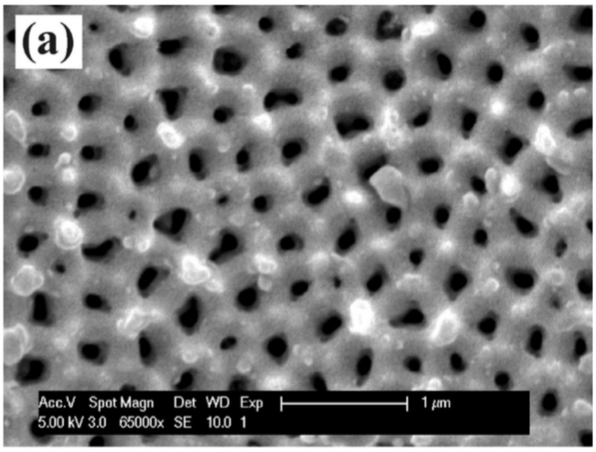

Figure 4.2: Nano structure at higher magnitude, adapted from Buijnsters et al. (2013)

Figure 4.1 shows the required structure after anodizing the aluminum. A "mountain structure" consisting of tiny pillars all over the surface, resulting in a hydrophobic material. This particular structure produces the required hydrophobic properties of interest for this master thesis work. Hydrophobicity is explained in more detail in section 3.3. Looking at the surface at an even greater magnitude, the "honeycomb" structure is clearly visible, as can be seen in figure 4.2.

4.2 Set Up

- Open container (glass, plastic beaker etc)
- Water
- Sulphuric Acid
- Power supply
- Aluminum plate as cathode
- Aluminum sample (anode) (1/3 of the surface area of the cathode for best results)
- Crocodile clamps
- Aluminum rod hangers or similar material for connecting and fixing the cathodes and the samples to the bucket walls.

Fill the bucket with water and add sulphuric acid in a ratio of 1:2 (sulphuric acid: water). Water should always be poured first as sulphuric acid may react explosively if poured first. Place the aluminum plate(cathode) on one side of the container. Use a hanger for the sample.

Connect the crocodile clamps with the charger and connect the negative clamp to the cathode and the positive clamp to the sample hanger (anode). The thickness and arrangement of the surface is a function of current, voltage, bath solution, sample/cathode surface ratio and duration of exposure.

After applying current, small bubbles on both the anode and the cathode should be forming as a result of the anodizing process. The bubbles are hydrogen gas, and ventilation should be used as a safety measure.

As shown in figure 4.3, the cathode is on the right, connected to the black crocodile clamp. The red wire is connected via a thick aluminum foil to the anode submerged in the acid. The duct tape is serving as a safety measure to keep the glass beaker in correct position.

The results will be discussed in chapter 7 with pictures and brief discussions of the most promising test results.

4.2.1 Acid Bath

Different literature was researched for deciding which acids to be used for the anodizing process (Mooney, 1995; He et al., 2009, 2010; Liu et al., 2013; Yao et al., 2011). Most commonly used for low budget experiments is pure sulphuric acid mixed with water. This was the starting point for this thesis work.

The water:acid ratio was 2:1, but it is possible that this solution has been too strong for the aluminum. This will be verified in a later acid bath with weaker solution. The next pages show the different acid baths that have been used in this work, and all the sample tests will have references to the relevant acid bath.

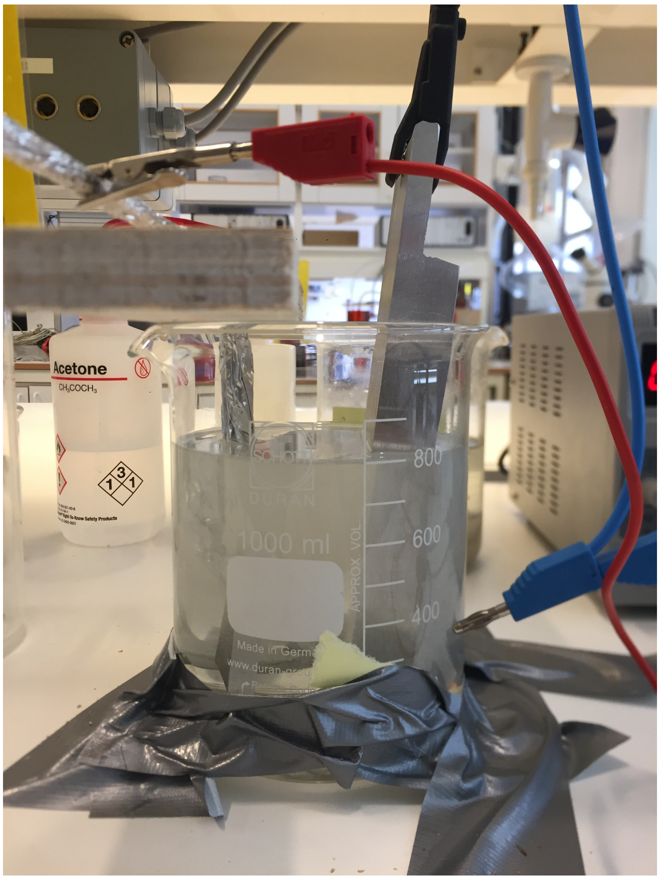

Figure 4.3: Acid bath setup.

Bath #1

Acid bath number 1 was a mix of water and acid in a ratio of 2:1, with 500mL of water, and 250 mL sulphuric acid. This bath was used for the first 4 samples. After leaving the cathode in the bath over the weekend the bath had been polluted by the cathode itself. This was probably due to contamination on the cathode because of insufficient cleaning. The result of the contamination can be seen in figure 4.4. A new bath was made as the used acid bath had become contaminated.

Bath #2

Acid bath #2 was the same mix as bath 1, but the cathode was cleaned properly, which resulted in less pollution and a better working bath.

Bath #3

The results from the first two acid baths were not as expected. Further literature studies were read and carried out. Liu et al. (2013) was used as inspiration for bath #3, which consisted of the following:

- Water
- Sulphuric acid (170 g/L)
- Oxalic acid (10g/l)
- NaCL (1.25 g/L)

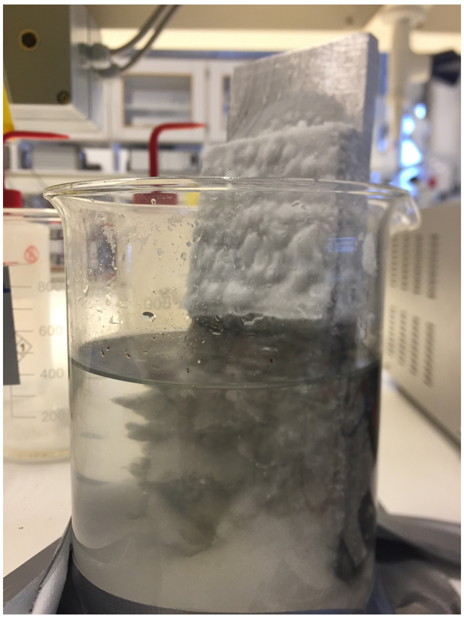

Figure 4.4: Pollution on cathode

According to Liu et al. (2013), contact angles as high as 162 °was measured, which can be described as a superhydrophobic surface. This process has been replicated in an effort of to achieve similar contact angles.

The research literature uses g/L to determine quantities of the different ingredients, so some math was required to calculate the correct quantities. For example, the sulphuric acid solution is defined as 95-97% sulphuric acid, with the rest being water. To get the correct amount of sulphuric acid a factor of 1.05 is applied to account for water. The same process is used for the oxalic acid since the only available acid was an oxalic dihydrate with two water molecules per oxalic molecule. Accounting for this, we get:

$C_2H_2O_4 + 2H_2O$

And from the periodic table we have:

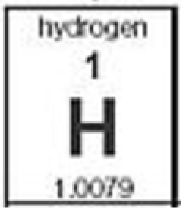

Figure 4.5: Hydrogen Information

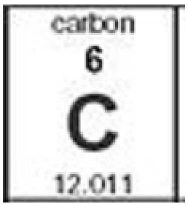

Figure 4.6: Carbon Information

Figure 4.7: Oxygen Information

Calculating molar mass we get:

$(2 * 12.011 + 2 * 1.0079 + 4 * 15.99) + 2(2 * 1.0079 + 15.999)$

$90.03 + 36.062 = \underline{126.065}$

This means water is a total of 36.062/126 = 0.28 or 28%. Accounting for this, the oxalic dihydrate needs to be multiplied by a factor of 1.28, which gives $10 * 1.28 = 12.8$ g/L.

As the acid bath used in this experiment was only half of that stated in the literature, the following quantities were used:

- Water (500 mL)
- Sulphuric acid (90 g)
- Oxalic acid (6.4 g)
- NaCL (0.625 g)

Bath # 4

Bath # 4 was identical to the recipe for bath # 3, except made in full scale. This means:

- Water (1000 mL)
- Sulphuric acid (180 g)
- Oxalic acid (12.8 g)
- NaCl (1.25 g)

This was done in order to berify if bath # 3 and # 4 are directly comparable, which is to be expected. This also allowed anodizing larger samples, a central piece of the next part of experimenting.

Bath # 5

Problems were experienced with the titanium wire anodizing instead of the supposed aluminum. This is further described in chapter 7. This made it necessary to go back to scratch in order to understand the problem and find the solution and bath # 5 was the start of this work.

The current and time required to produce a structure similar to that of Liu et al. (2013) is known, so bath # 5 will be used to see if the results can be consistently reproduced. Three identical samples will be made, then a fourth sample will be made with a substantial amount of time added in the acid bath compared with the three first samples, to compare the growth in the length direction as well.

This bath is a 2:1 ratio of water and sulphuric acid, with 400mL water, and 200mL sulphuric acid.

Bath # 6

As part of the error checking bath # 6 was made to replicate **sample 8**, similar to bath # 5. The purpose of these two baths is both replicating the best sample previously produced, but also to find a solution as to why the titanium starts anodizing instead of the aluminum.

Bath # 6 is made of:

- Water (500 mL)
- Sulphuric acid (90 g)
- Oxalic acid (6.4 g)
- NaCL (0.625 g)

4.2.2 Reference Sample

It is important to establish a reference point when doing comparison testing. This provides the possibility to visually compare both surface finish and to confirm that anodizing has occurred.

The reference samples used have the same dimensions as all the other test samples but has not been through the acid bath. Further, there are some differences between the two reference samples:

Reference sample 1 (4.8) has not undergone any treatment except surface polish with a sand paper grade 40. A SEM picture of the untreated surface can be seen in figure 4.9

Figure 4.8: Reference sample untreated

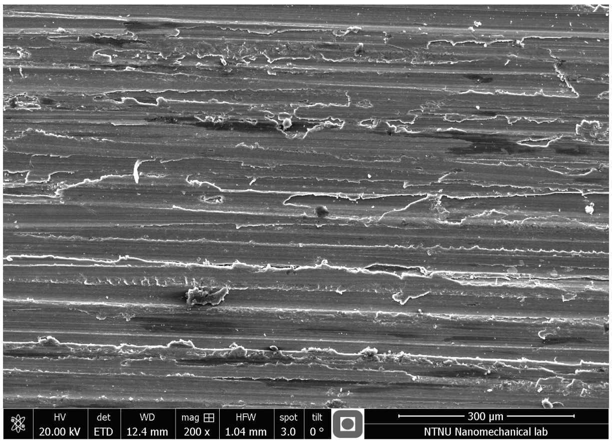

Figure 4.9: SEM picture of reference sample

Reference sample 2 (4.10) has been rinsed with acetone, cleaned off with ethanol, and boiled in hot water for 20 minutes. This has been done to see if any of the pre and post treatments have any effects on the samples.

Figure 4.10: Boiled, untreated sample

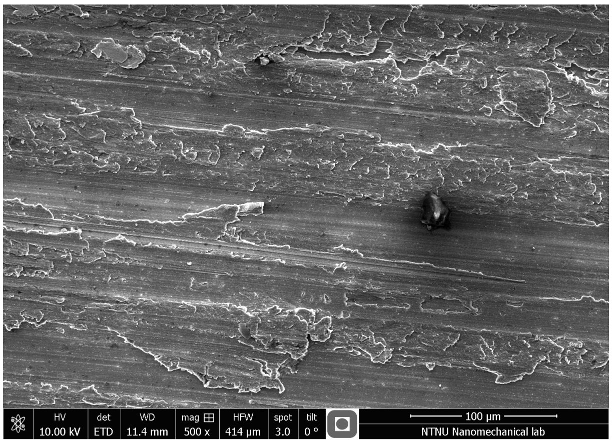

Figure 4.11: SEM picture of untreated sample after boiling

As it is shown in figures 4.9 and 4.11, both reference samples are very similar in terms of structure at a nano level but have different surface finishes. This is due to the boiling process.

4.2.3 Calculating Current

The relation between current, voltage and resistance is given as

$$I=U*R$$

Where I equals current, U equals voltage and R equals resistance.

This relation is called Ohm´s Law and was derived in the 1820s. Ohm´s Law states that "the current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the usual mathematical equation that describes this relationship I=U*R."(Ohm et al., 1969)

In this thesis work, Ohm´s Law is used to verify that the power supply can supply enough voltage to provide a constant current, but also to check if the calculated currents are too high for the power supply which has a maximum voltage of 12 V.

The correct current is calculated based on the surface area of the sample used multiplied by 145-165 mA, where 145 is the lowest current required to perform the anodizing process.

As all the aluminum samples are very similar in size(varying in just 2 grams difference maximum), identical currents can be used for all samples. The calculations were based on the dimensions shown in figure 4.12, and were as followed:

Surface area:
2*(28*52)mm
+ 2*(52*7)mm
+ 2*(28*7)mm
$= 38.36 \text{ cm}^2$

Converted into square feet, which is used for calculating the current, it gives $5\ ^{61}/_{64}$ inch^2, approximately 6 inch^2 and a minimum value of 6 inches$^2 * 145$ mA, and a max value of 6 inches$^2 * 165$ mA.

Based on these values, the current needs to be somewhere between 870mA and 990mA and is set at 910mA.

Figure 4.12: Dimensions on aluminum samples.

4.2.4 Connecting Material

As listed in section 4.2, the connecting material between the anode and the power supply was intended to be aluminum and preferably in the same alloy composition as the anode itself. Stated in different literature (Mooney, 1995; He et al., 2010), either a similar aluminum alloy or titanium would work. However, it proved difficult to locate an aluminum alloy of this sort within a reasonable time span of the thesis work.

The connecting materials had not been tested prior to the start of the actual tests. Therefore, different connecting materials were used, in order to see what worked best.

A rapid prototyping approach was chosen to find the most suitable materials. Basically, locating several different materials, testing them separately and verifying the result with SEM pictures showed which materials worked, and which did not.

Aluminum foil in different thickness and composition, steel wire, aluminum wire and titanium wire in two different diameters were tested.

If an unknown material(composition) was found to be working well pictures would be taken at the Nanolab to establish the alloy composition, as done in Haaland (2013), and facilitate further ordering.

4.2.5 Pre Treatment

Gloves are worn at all time when dealing with the test samples. This is to make sure no grease marks or fingerprints are on the sample when submerging it in the acid. The samples are also air dried post treatment, to make sure no contamination happens when drying.

Acetone

The first step is to submerge the test sample in acetone which is a solvent that is used to degrease the samples, removing fingerprints and similar contamination. This can be seen in figs. 4.13 and 4.14, which shows how the sample has been degreased, removing a finger print in the middle of the sample.

Figure 4.13: Sample before acetone treatment

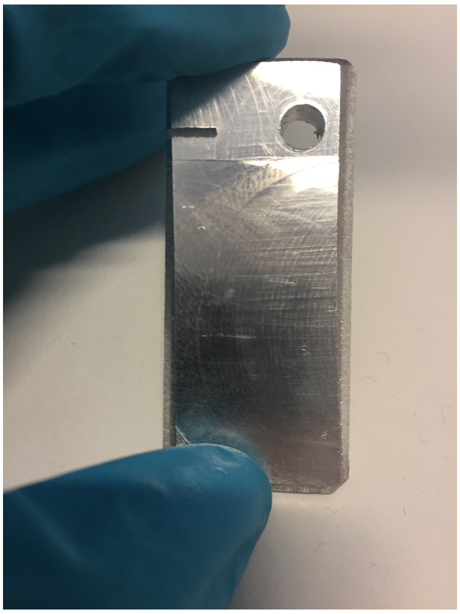

Figure 4.14: Sample after acetone treatment

Ethanol

After the acetone treatment, the sample is hung by a titanium wire and sprayed with ethanol. Ethanol is the alcohol found in alcoholic beverages. It works both as a solvent to remove contamination on the sample, and evaporator to dry of the samples.

4.3 Anodizing

In this section, the most important tests are included to show the progress of the tests. It will include brief discussion of some of the most important results. A more detailed discussion can be found in chapter 7, and the remaining test results can be found in Appendix C.

This section has been written directly off the logbook used in performing the experiments, therefore, some text will be the same, as the experiments are near identical.

Test 1

Test sample **number 2**

- Date: 18. April
- Time: 11.30 AM
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 15 minutes
- Current = 0.91 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, to get rid of smudges and other contamination, then rinsed by spraying with ethanol. Following this, the sample was placed in the acid bath for 15 minutes.

According to the instructions, the test sample(anode) should be connected to the positive contact of the power supply with the cathode plugged to the negative. However, this led to the cathode reacting heavily, while nothing happened to the anode. According to (Wernick et al., 1987), bubbles should be produced both on the anode and cathode and given only the cathode reacted, the wiring was switched.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores", which is a common and necessary practice when dyeing the samples. However, this may not be necessary for this specific project, so tests will be done without boiling to verify if this is required.

The connecting material was a wire made out of aluminum, normally used in mechatronics. As can be seen in figure 4.16, the wire turned black during the anodizing, which means the process did not work as intended. (Mooney, 1995). This is caused by the alloys in the aluminum wire reacting with the sulphuric acid, which results in anodizing of the wire itself, and not the intended anode.

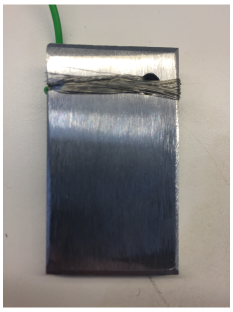

Figure 4.15: Aluminum wire on top, pre anodizing

Figure 4.16: Black aluminum wire, showing anodizing has failed

Result: Reversing the poles and failure in the aluminum wire led to a procedure that resulted in no anodizing on the actual sample. This is confirmed with the SEM-pictures, showing that the sample is similar to the reference sample, although a lot sharper colors, but this is simply due to contrast and brightness differences in the picture.

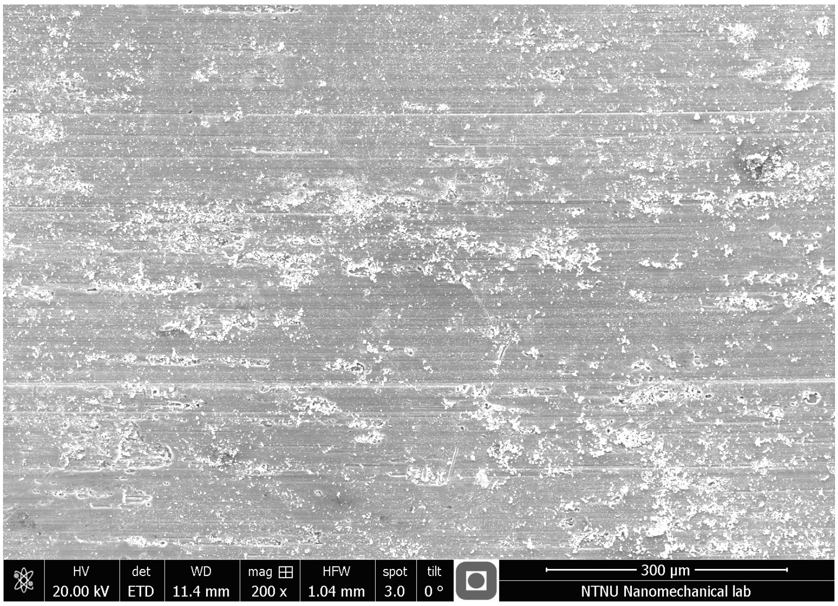

Figure 4.17: SEM picture of sample 2

Test 2

Test sample **number 3**

- Date: 18. April
- Time: 12.30 AM
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 15 minutes
- Current = 0.91 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly onto the sample and then placed in the acid bath for 15 minutes. Test 1 was done with the wiring switched, but this time the wiring was left as it originally intended, negative on the cathode, positive on the anode. Both samples started bubbling, which verifies that the process is working correctly.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores", which is a common and necessary part when dying the samples. However this might not be necessary for this specific project, so there will be done tests without boiling to look at differences.

The connecting material was aluminum foil, with 99% pure aluminum, which worked very well as a contact between the anode and the power supply. After the process, the aluminum foil had not changed color, a sign that it had not been anodized itself. This is shown in figure 4.18.

Figure 4.18: Aluminum foil still same color after anodizing

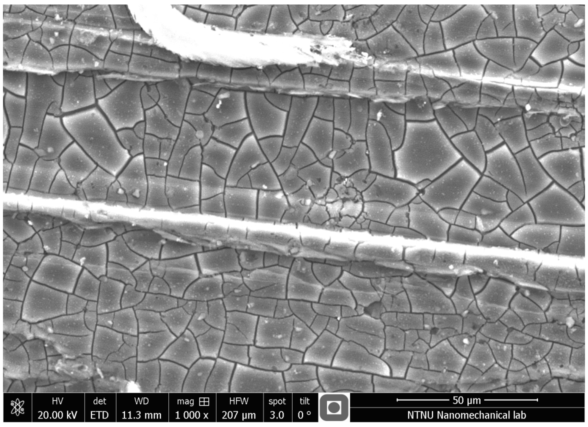

Figure 4.19: SEM picture of sample 3

Test 3

Test sample **number 1**

- Date: 18. April
- Time: 13.30 AM
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 60 minutes
- Current = 0.91 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 60 minutes.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores", which is a common and necessary part when dying the samples. However, this might not be necessary for this specific project, so there will be done tests without boiling to look at differences.

The connecting material was aluminum foil, with 99% pure aluminum, which seemed to work very good as a contact between the anode and the power supply. However, the anodizing process has not been done correctly, as can be seen in figure 4.20. Further discussion will be done in chapter 7.

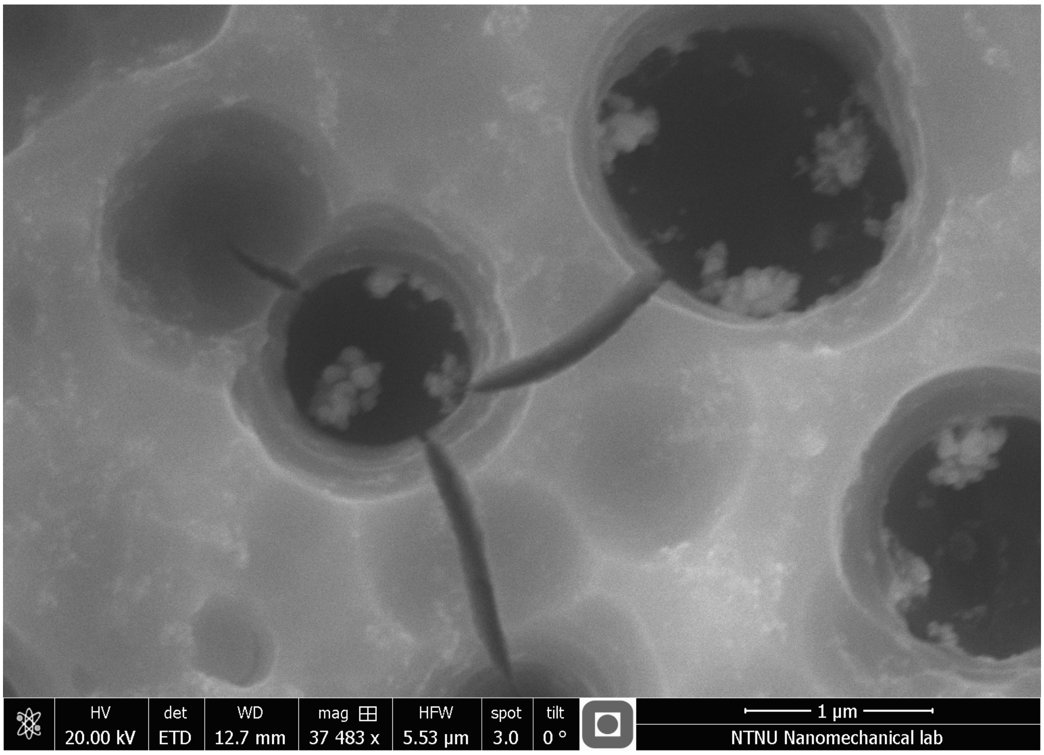

Figure 4.20: SEM picture of sample 1

Test 4

Test sample **number 4**

- Date: 18. April
- Time: 15.30
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 30 minutes
- Current = 0.91 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 30 minutes.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores".

The connecting material was steel wire, to test different materials for connecting, but it did not seem to work at first, as no bubbles emerged from the anode. However, after 25 minutes there were several more bubbles forming on the sample, which could mean that the anodizing process was correct after all.

After looking at the SEM pictures, it clearly shows that figure 4.21 looks like figure 4.9, in terms of structures at a micro level. While it is not identical, it is far more similar to this structure than the intended nanostructure, as shown in figure 4.1, which means that no anodizing took place, in accordance with Wernick et al. (1987), that states that titanium and aluminum are the only materials suited for this process.

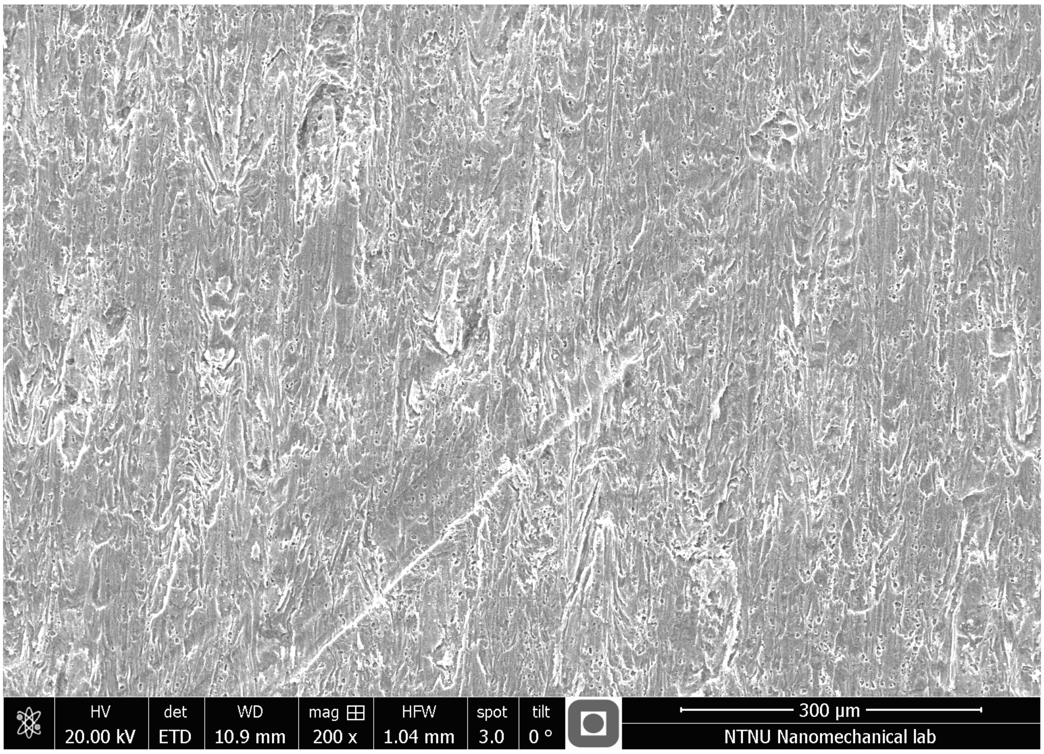

Figure 4.21: SEM picture of sample 4

Test 6

Test sample **aluminum foil number 2**

- Date: 20. April
- Time: 11.20
- Location: Corrosion Lab
- Acid bath: 2
- Time in acid bath: 15 minutes
- Current = 2.64 Ampere

Approach:

The foil was cut into an appropriate size, around 15cm * 15cm, before it was soaked in acetone for 5 minutes and then rinsed by spraying ethanol on the sample. After this, it was air dried to let all the ethanol dry of. It was then placed in the acid bath, where the clamps were placed directly on the aluminum foil instead of a connecting material.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores".

As shown above, the current was raised to 2.64 amperes, an increase in almost 2 amperes, comparing with the aluminum samples, because of a larger surface area. This means that aluminum foil sample 1 had a far too low ampere, and therefore not sufficient to anodize correctly.

The structure formed after 15 minutes (4.23) can be compared with the structure made in **sample 8** (4.27), which might be an indication that this structure can be replicated on aluminum foil as well as aluminum plates. However, there is far more "breaking" of the structures, which could mean the anodizing has happened too fast, making the structure break when forming (Yao et al., 2011).

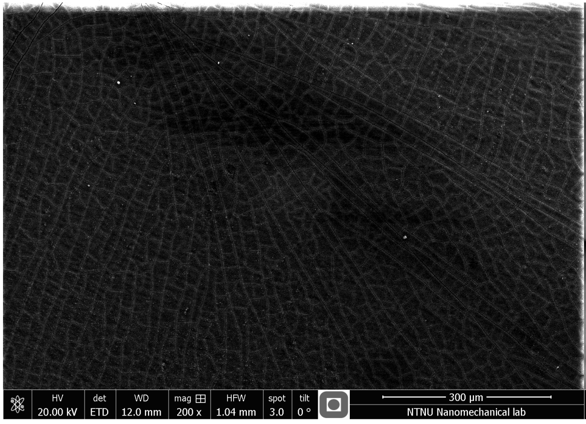

Figure 4.22: SEM picture of aluminum foil 2

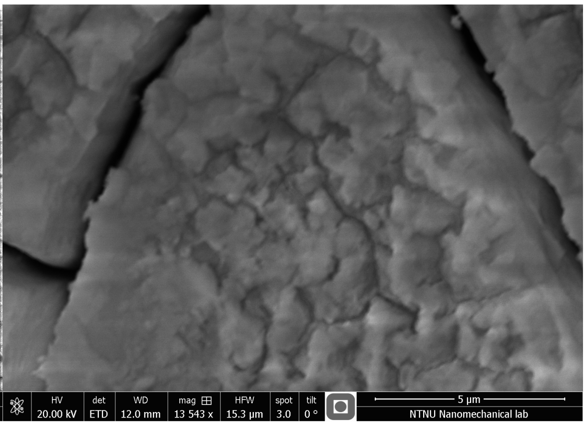

Figure 4.23: SEM picture of aluminum sample 2

Test 8

Test sample **number 6**

- Date: 24. April
- Time: 12.45
- Location: Corrosion Lab
- Acid bath: 2
- Time in acid bath: 40 minutes
- Current = 0.4/1 Ampere

Approach:

After some more literature reading (Liu et al., 2013), it was stated that optimum acid mix was oxalic acid, sulphuric acid and NaCl at a specific mix discussed in section 4.2.1 This worked best at 40 minutes in the bath, and at a current of 0.4 V. It was therefore tested with pure sulphuric acid at the similar time and current to compare at a later stage.

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 15 minutes.

No boiling was done in the literature study, so no boiling will be done post acid bath, just simple rinsing in distilled water.

The connecting material was aluminum foil, but this was wrapped tightly to make a thicker foil, which seemed to work great as a connection material, at least before looking at the SEM-picture.

Update: Forgot to calculate new current based on sample size. 0.4 amps were used, as stated in the literature, but a correct current would be 1 amp after calculation. This can be substantiated by figure 4.24, as it resembles figure 4.9 or figure 4.21 more than the preferred 4.1, that too low current does not result in preferred anodized structure.

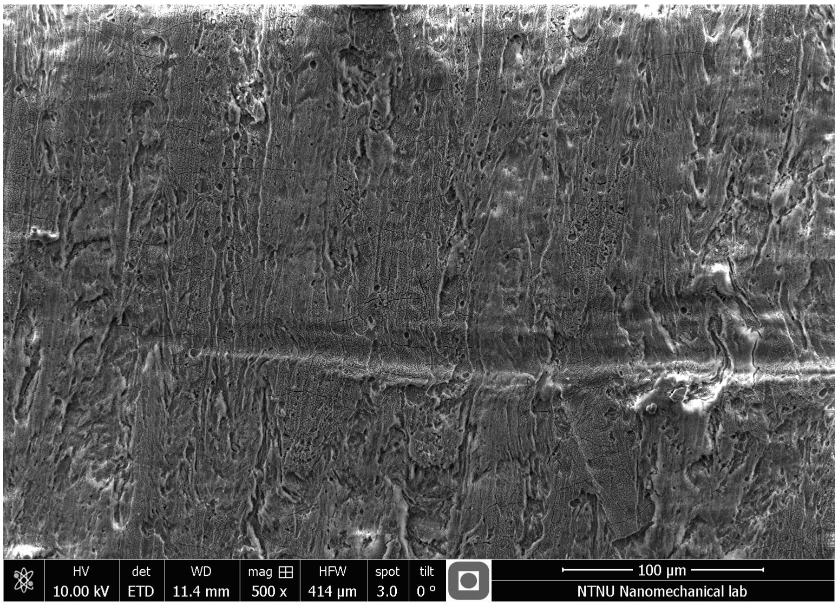

Figure 4.24: SEM picture of sample 6

Test 9

Test sample **number 7**

- Date: 24. April
- Time: 14.45
- Location: Corrosion Lab
- Acid bath: 2
- Time in acid bath: 120 minutes
- Current = 1 Ampere

Approach:

This test sample was made to look at length in the nanostructures.

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 120 minutes.

No boiling was done in the literature study, so no boiling will be done post acid bath, just simple rinsing in distilled water.

The connecting material was aluminum foil, but this was wrapped tightly to make a thicker foil, which seemed to work great as a connection material, at least before the SEM-picture.

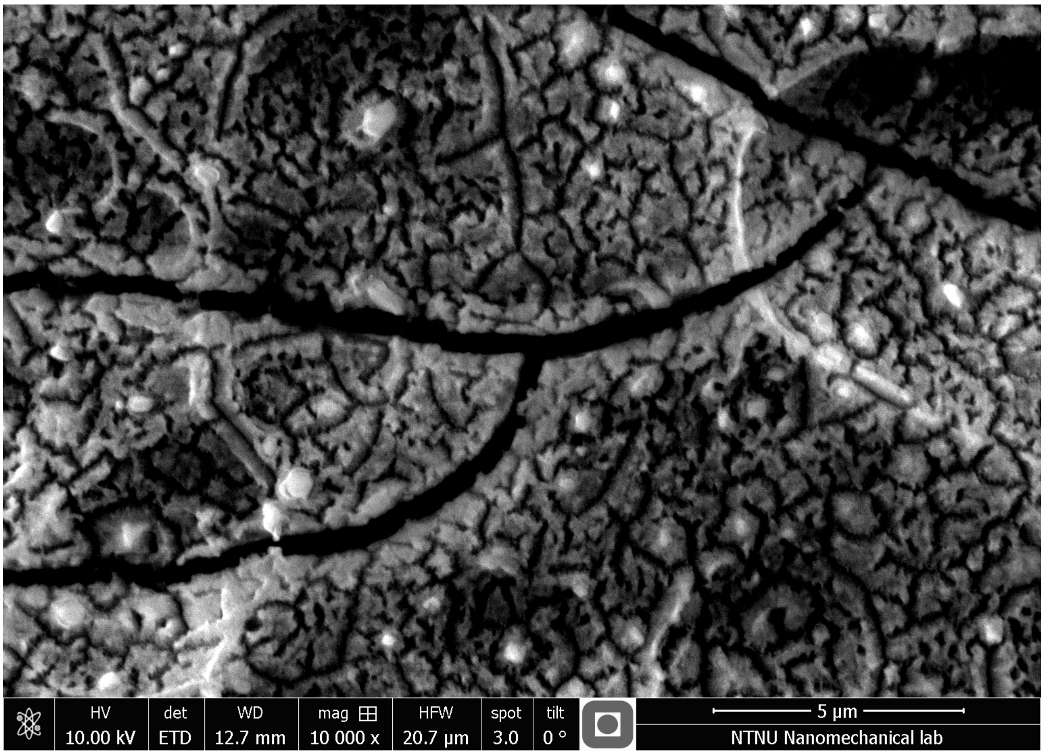

Figure 4.25: SEM picture of sample 7

Test 10

Test sample **number 5**

- Date: 3. May
- Time: 14.20
- Location: Corrosion Lab
- Acid bath: 2
- Time in acid bath: 15 minutes
- Current = 0.88-0.9 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 15 minutes.

After the acid bath, it was rinsed by placing it in distilled water and spraying water on it after.

Titanium wire was used as connecting material, as Mooney (1995); Li et al. (1998); Wernick et al. (1987) & Lee et al. (2013) states that titanium does not anodize in contact with aluminum, and is a suited conductor of electricity. Titanium will also be used in the following tests until told otherwise.

There was a problem with the power supply, in which the supply used voltage as controlling measurement, instead of current. This meant that the current needed to be constantly watched and changed when it was lowered because of less resistance in the acid bath. This means the current was not precisely and constant at 0.9 A, but more in the range of 0.88-0.9 A.

First impressions are that titanium looks to be a suited conductor for this experiment, and there are clear signs on the surface of the aluminum that anodizing has occurred. This is also the first test where the SEM pictures are directly comparable to those of Liu et al. (2013). **Sample 5** will be further discussed in chapter 7.

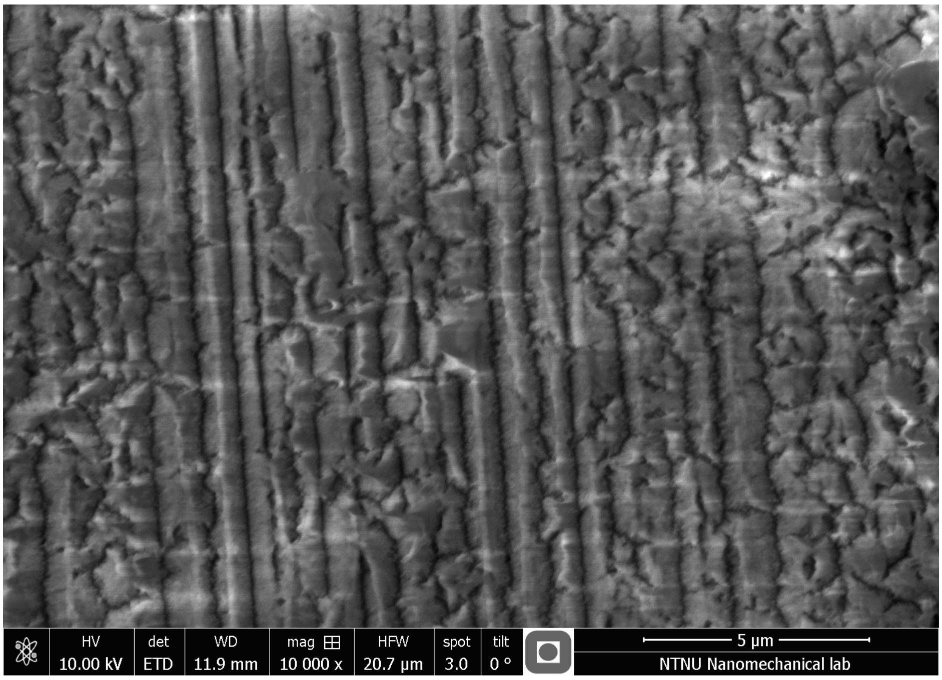

Figure 4.26: SEM picture of sample 5

Test 11

Test sample **number 8**

- Date: 3. May
- Time: 15.10
- Location: Corrosion Lab
- Acid bath: 2
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 30 minutes.

After the acid bath, it was rinsed by placing it in distilled water and spraying water on it after.

Controlling medium was back at current, which means a constant current of 0.9 A.

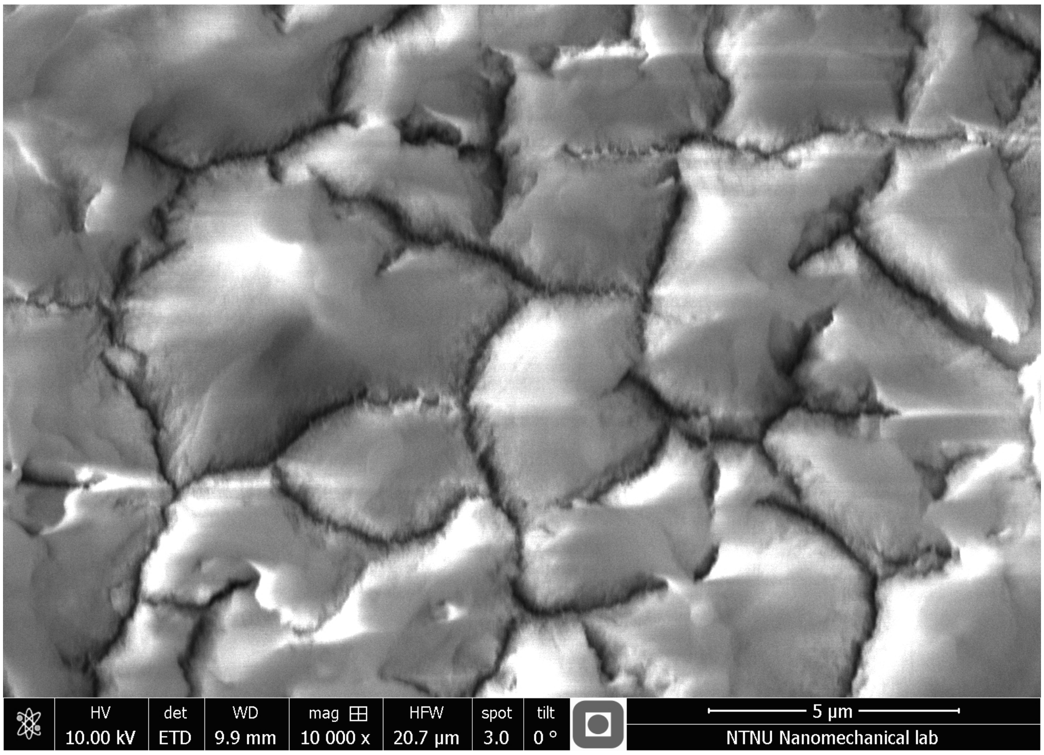

Figure 4.27: SEM picture of sample 8, promising anodic results.

As figure 4.27 shows, this is the closest result achieved, comparing with Liu et al. (2013) in figure 4.1, this will be discussed in chapter 7. The SEM pictures were not attained until test 15 had been completed, so every test after this will be trying to replicate this result, to make sure it can be reproduced. It can be argued that the results have been far better when using titanium as the contact material, which is what literature suggests.

Test 12

Test sample **number 9**

- Date: 3. May
- Time: 16.00
- Location: Corrosion Lab
- Acid bath: 3
- Time in acid bath: 40 minutes
- Current = 0.9 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 40 minutes.

After the acid bath, it was rinsed by placing it in distilled water, and sprayed water on it after, leaving it to dry of hanging in room temperature.

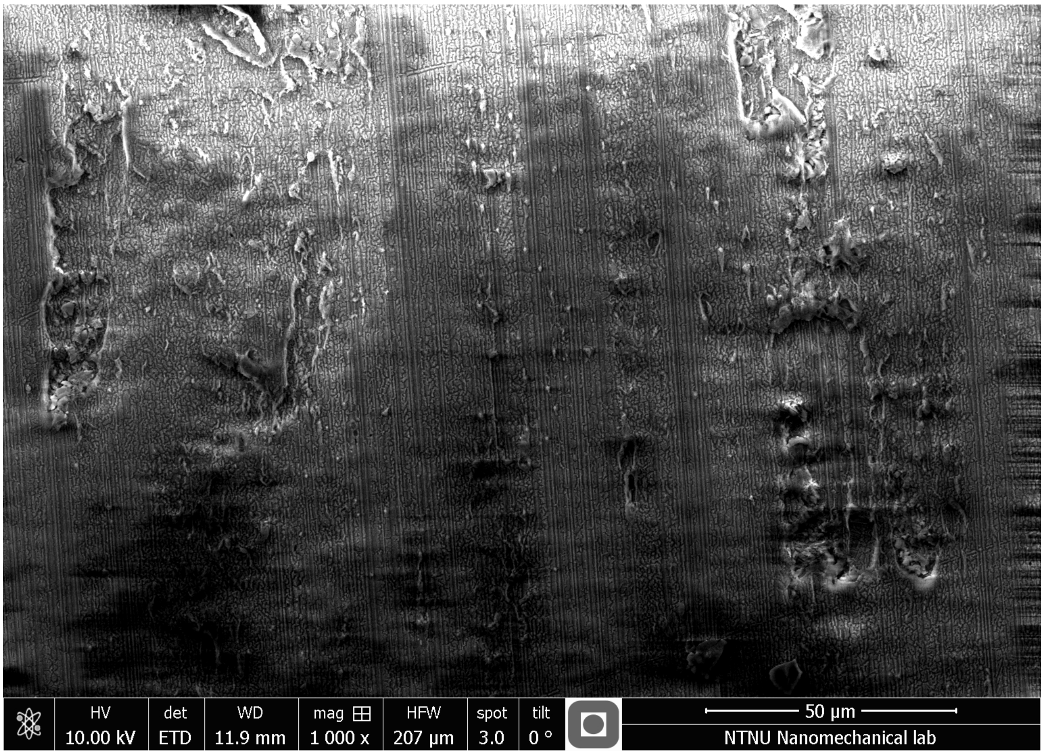

Figure 4.28: SEM picture of sample 9

Test 13

Test sample **number 13**

- Date: 8. May
- Time: 16.20 PM
- Location: Corrosion Lab
- Acid bath: 3
- Time in acid bath: 15 minutes
- Current = 0.9-0.92 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 15 minutes, using acid bath number 3.

Issues with the controlling medium, but midway current was controlling. Therefore a bit more change in the current, but still well inside max and minimum values.

Test sample has inexplicable black marks after acid, unknown for what reason. However, it is shown that the sample has some signs of anodizing, but far too much breaking in the structure, which might be because of the voltage controlling, so more tests are necessary.

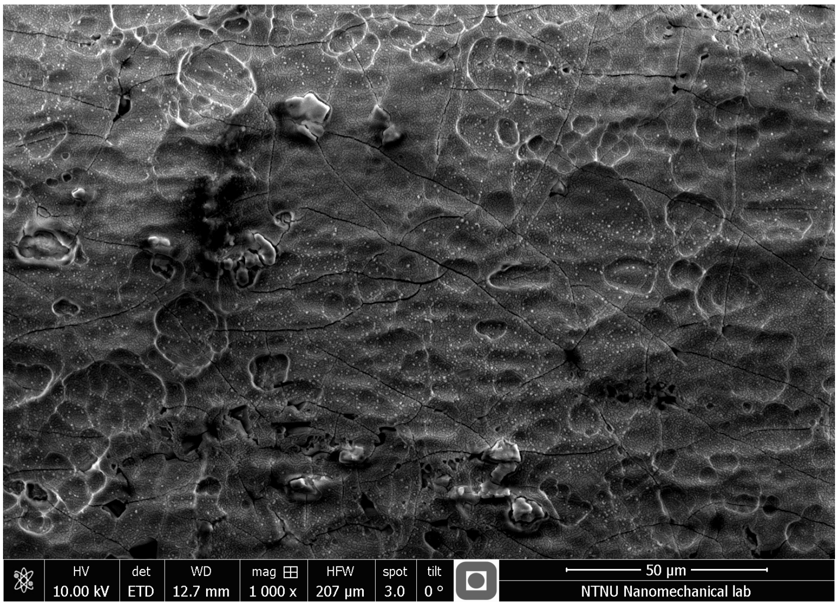

Figure 4.29: SEM picture of sample 13

Test 14

Test sample **Big aluminum plate**

- Date: 23. May
- Time: 17.00 PM
- Location: Corrosion Lab
- Acid bath: 3
- Time in acid bath: 60 minutes
- Current = 0.5 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 60 minutes.

This test was performed by following the principles of the 720 anodizing guide. While the previous samples used current based on (surface area*145-165mA), the 720 anodizing guide is based on how thick structure one wants. This was just a test to see how this compares with the most used process in this thesis. This means that with an expected oxide growth of 0.5 mils (0,0127 mm), the new current is only 0.5 A, and a longer bath time of 60 minutes. 0.5 mils are just used to check if projected length growth is accurate when checking actual growth in SEM pictures.

The plate was longer than the depth of the acid, so the electrical contact was placed directly on the plate, and the plate was cut to a more suited shape afterward, for SEM pictures.

After the acid bath, the sample was soaked in distilled water for cleaning and then hung for air drying for 3 hours.

The SEM picture show correlation with sample 1, which shows the same kind of inverted pedestals forming without any symmetric signs. The reason for this is unknown, but it might be as simple as the process used (720 anodizing guide) just does not work as good hoped, so the rest of the samples will be done by using the previous current calculation, shown in subsection 4.2.3.

Figure 4.30: Big aluminum plate. Above the hole one can see where the acid surface has stopped reacting with the metal

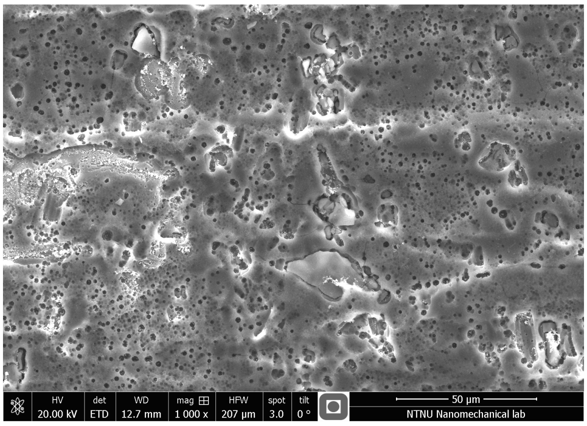

Figure 4.31: SEM picture of aluminum plate

Test 15

Test sample **number 15**

- Date: 24. May
- Time: 17.40 PM
- Location: Corrosion Lab
- Acid bath: 4
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for 30 minutes.

After the first SEM pictures were analyzed, it was seen that test **number 8** yielded the most promising structures, as can be seen in figure 4.27. Therefore, the next experiments will be identical to that one, in hopes of being able to replicate it, every time if possible. This is a necessary step before proceeding to do the same process with other materials (aluminum foil for example).

However, some problems occurred while the current was applied. It seemed the titanium reacted instead of the aluminum, creating an oxide layer outside the titanium wire, which stopped the current from flowing. This should not happen, according to Wernick et al. (1987); Buijnsters et al. (2013), because titanium is less reactive than aluminum. The reason this happened is unknown, but new titanium wire needs to be ordered to see if reuse has made the wire weaker, or if other factors have been introduced to make the tests fail.

Therefore, this test was incomplete, and further replications are necessary.

Figure 4.32 shows how the titanium wire changed color after being soaked in the bath, which suggests anodizing.

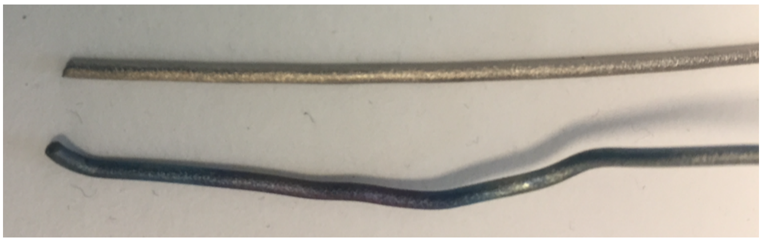

Figure 4.32: Unused titanium on top, anodized blue titanium on bottom

Test 18

Test sample **number 19**

- Date: 11. June
- Time: 15.00 PM
- Location: Corrosion Lab
- Acid bath: 5
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This is a new attempt at replicating the results in **sample 8**.

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample, and letting it dry of. It was then placed in the acid bath for 30 minutes.

Acid bath number 5 was used, which is the same as the first made. This is to verify if the titanium was reacting to the oxalic acid or the NaCl. By excluding these chemicals, it can be suggested that either one of these might be the reason if the titanium does not anodize this time. This time titanium wire with a diameter of 1 mm was used, as it was much easier to wrap tightly around the sample. Some leftover titanium was found that had not yet anodized, which was used as connecting material. As they are both the same grade it should not matter which one is used, as long as there is enough contact with the anode.

No titanium was anodized this time, but a far better connection was made between the connecting material and the anode, which means both the chemicals and connection can still be the reason for failures in previous tests.

Test 19

Test sample **number 20**

- Date: 11. June
- Time: 16.00 PM
- Location: Corrosion Lab
- Acid bath: 5
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This test was done exactly the same as test 18. No titanium anodized this time either.

Test 20

Test sample **number 21**

- Date: 11. June
- Time: 16.40 PM
- Location: Corrosion Lab
- Acid bath: 5
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This test was done exactly the same as test 18, however, boiling was introduced post-acid, to see if this changes any properties of the material. No anodizing of the titanium occurred this time either.

Test 21

Test sample **number 22**

- Date: 11. June
- Time: 17.30 PM
- Location: Corrosion Lab
- Acid bath: 5
- Time in acid bath: 120 minutes
- Current = 0.9 Ampere

Approach:

This test was done exactly the same as test 18. In addition the time was extended by 90 minutes, making it a total of 120 minutes. This is so that comparisons can be made in terms of how long the structures grow. This is important in order to find the optimal length in regards to wear resistance and hardness. No titanium anodized in this test.

Test 22

Test sample **number 23**

- Date: 11. June
- Time: 19.45 PM
- Location: Corrosion Lab
- Acid bath: 6
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This test was done exactly the same as test 18, but bath 6 was introduced. This is both to be able to determine what is the cause of the anodizing of titanium, but also to see if the surface structure from **sample 8** can be replicated with this bath. No titanium anodized in this test, which seems to point in the direction of low contact between titanium and aluminum as a cause of the titanium anodizing.

One notable thing that occurred in this bath is that the voltage is far higher in this mix. While the bath with pure sulphuric acid maintains a voltage around 5-6 V at 0.9 Amps, the mix of sulphuric acid, oxalic acid, and NaCl needs 12-13 V to maintain the same current. This will be discussed in chapter 7, hopefully with an explanation as to why this is.

Test 23

Test sample **number 24**

- Date: 11. June
- Time: 20.20 PM
- Location: Corrosion Lab
- Acid bath: 6
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This test was done exactly the same as test 22, and adding a 20-minute boil post acid bath, to see if the structure is changed.

Test 24

Test sample **number 25**

- Date: 11. June
- Time: 21.10 PM
- Location: Corrosion Lab
- Acid bath: 6
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:
This test was done exactly the same as test 22.

Test 25

Test sample **number 26**

- Date: 11. June
- Time: 21.50 PM
- Location: Corrosion Lab
- Acid bath: 6
- Time in acid bath: 120 minutes
- Current = 0.9 Ampere

Approach:
This test was done exactly the same as test 22, but adding 90 minutes, making the total time 120 minutes. The reason is the same as for test 21, to see how the length of the structure is compared to 30 minutes.

4.4 Chemical Etching

Chemical etching, also called chemical milling or industrial etching, is the process of using an etching chemical to remove unwanted material of a specific part of a sample (Çakır, 2008). It can be used to create art or name plates, and has been a process used in industry since the early Renaissance (Huang et al., 2011).

Some of the key benefits of chemical etching are that it is stress-free on the material, can achieve high complexity and accuracy, and it is low risk, fast and economical.

Etching is performed either by submerging the cutting area of the part into a corrosive chemical, an etchant, or introducing the etchant directly on the part via cotton pads for instance. Either way, to protect specific areas from getting etched a maskant can be used (Qian and Shen, 2005).

For this thesis work, no protection of the materials required. The reason for testing this is to see if there are more efficient and better ways to achieve a surface as smooth as possible. While other samples have been milled, either on a machine mill or with sand paper, one sample in this thesis will undergo chemical etching using the appropriate solution of those available. The surface finish will then be compared to the reference samples in the SEM, before submerging it in acid if the pictures shows promising results.

Three initial solutions were prepared to test the chemical etching process. Acetic Acid was the acid used, mixed with NaCl and water to get the desired solution strength. In addition, a regular household acetic acid with a strength of 7% was introduced later in the testing. As shown in figure 4.33, the total amount in each glass is 70 ml, with water ratio varying from 1:1 to 19:20 of the total volume.

Figure 4.33: Overview of the three solutions used. Acetic ratio from the left is 1:1, middle 1:20, right 1:8

The test setup can be seen in figure 4.34. The sample is connected to the positive side of the power supply, while the ground is used to close the circuit. At the end of the crocodile clamp, a cotton pad submerged in the acid solution is pressed against the sample to produce the chemical etching. The etching process then dissolves material in the area undergoing treatment. The process is somewhat slow, but it is not necessary to etch for a long time to achieve a change in the surface smoothness.

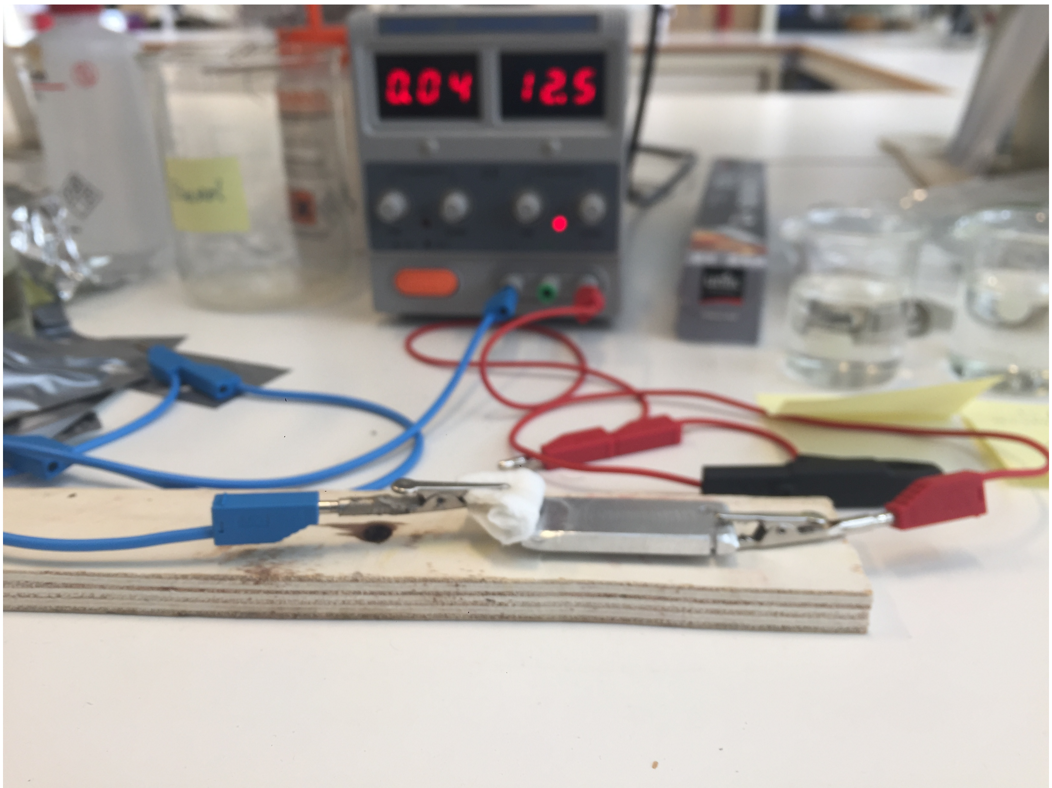

Figure 4.34: Overview of the chemical etching setup

Testing

Four tests were done by submerging the cotton pad in the acid solution, and then applying it on the sample. Literature research stated that a weak solution works best for chemical etching (Jakob and Chabal, 1991), which was verified by all performed tests. The test was done with 1-minute etching and then visually inspected. While acid solutions 1:1 and 1:8 showed no etching on the sample, solution 1:20 and the 7% strength household acetic acid produced promising results. Etching was then performed on the sample, applying the cotton pad for 2 minutes with a low, exerted pressure. The result again supports the literature research suggesting that a diluted acid solution works best for etching (Jakob and Chabal, 1991).

The result of the chemical etching can be seen in figs. 4.35 and 4.36. The bottom part of the samples have been etched, and there are clear evidence that the surface has been "milled". The question still remains if this process produces a smoother surface. This will not be concluded until the results from the SEM can be analyzed.

Figure 4.35: Results of store bought vinegar, a 7% etchant solution

Figure 4.36: Results of acetic acid mixed with water at a 1:20 ratio.

After finishing the etching, the sample was soaked in water to remove any acid, and then it was checked with the SEM, to compare the surface structure of the sample to the reference sample (4.9). The SEM pictures of the chemical etching is shown in figs. 4.37 and 4.38.

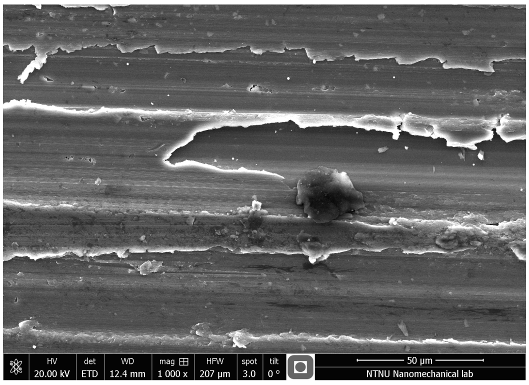

Figure 4.37: SEM results of 7% etchant solution

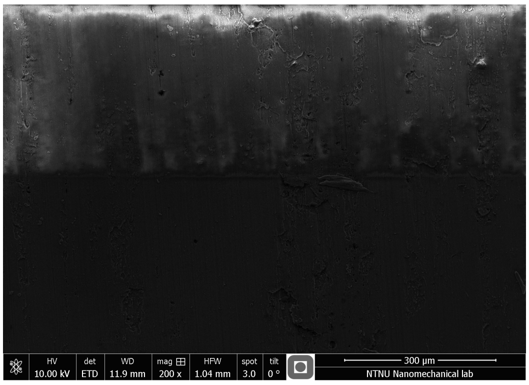

Figure 4.38: SEM results of 5% etchant solution

The chemical etching process achieved small changes in the surface structure, compared with figure 3.3. Therefore it was no longer pursued, as the anodizing of **sample 8** (7.5) showed a very promising result of making an AAO structure at the same time as the chemical etching tests were done. It was therefore argued that a smooth AAO surface can be construed without etching the sample, so the idea was put aside.

As can be seen in figure 4.38, there is a marked difference between the etched surface and the untreated surface. However, because of the darkness it is difficult to see the exact nature of the structure. The structure was easier to see in the SEM machine, and since it was very similar to figure 4.37 the idea of etching the samples was not pursued further in this master thesis project.

Chapter 5

Product Development & Testing

The water table idea came to life in the fall of 2016, during the project thesis. The thesis required tests of different materials to look at hydrophobic properties. As there were no equipment to measure this at the institute, it became an objective for this master thesis work. This means all tests can be done in house, with easy access for all students and we no longer depend on other institutes for these tests.

The table measures the roll-off angle of a water droplet, and by doing so, one can estimate the hydrophobic properties.

5.1 Concept

In accordance with the objectives stated in section 1.3, the concept chosen is a table that can measure at what angle water starts running off a surface. This is a simple way of testing the surface friction. If the surface is hydrophobic the water will slide off at a lower angle than if the surface was hydrophilic. There are exceptions to this, as materials with very high adhesion forces can still be superhydrophobic, but these materials are not relevant for this thesis. A key parameter is making this model small enough to be mobile which will increase its usefulness.

After introduction of the concept basic brainstorming was initiated in the form of writing and drawing every idea that comes to mind. This involves details like tilting mechanism, how to measure the angle accurately, or involving assembly details such as deciding the maximum size, how to build the design and what materials would be best suited. The main focus is producing as many ideas as possible, to make good decisions for the development of mock-ups.

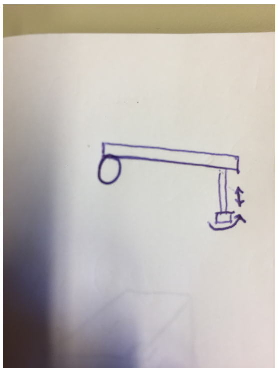

Figure 5.1: End tilt mechanism

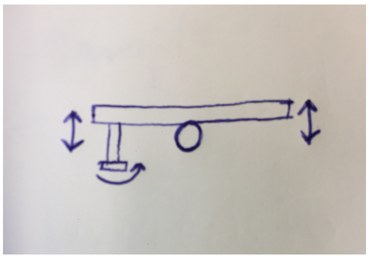

Figure 5.2: Middle tilt mechanism

Figures 5.1 & 5.2 shows two different ways of making the table tilt mechanism. Figure 5.1 shows a fixed end of the table while figure 5.2 shows a fixed bar in the center of the table. Making it fixed in one end allows the table to rest on the table legs making it easy to keep the table level before measuring. Making the balancing point in the center of the table requires resting points on both sides of the table to keep it steady when measuring the angle. This could easily be achieved with two screws, one on each side, but this would require more manual work.

Another possibility is introducing a weight on one end, which shifts the mass center towards the side of the screw, as shown in figure 5.3.

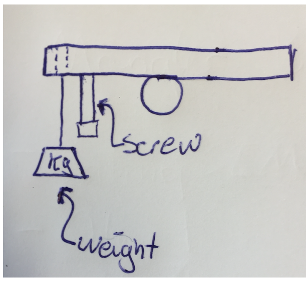

Figure 5.3: Center of mass shifted towards screw

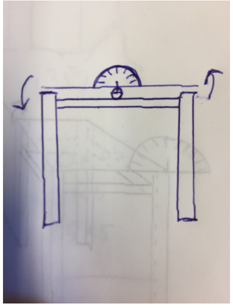

Figure 5.4: Model 2

Figure 5.4 shows a table with the balance point in the middle part. The top part of the table will move "between" the legs of the table, and the angle measuring mechanism is placed in the center of the table. Figures 5.5 and 5.6 shows how it would look if the table is fixed at one end. The angle measuring mechanism is placed where the table is fixed to the legs, and the table top itself will rest on the table legs.

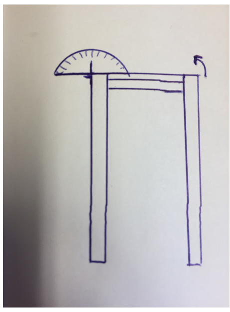

Figure 5.5: Model 1

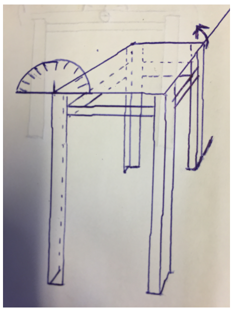

Figure 5.6: Model 1, 3D

These are the two most promising ideas produced by the brainstorming, and thus the ones pursued in the further stages of the prototyping process.

Two different approaches allows comparison as they are further developed, which means gaining more experience and knowledge to troubleshoot and improve the design. This is a key characteristics in the early stages of a prototype development process.

5.2 Mock Ups

The first mock-ups are made out of cardboard, which is a light and easy material to work with. It is also stiff enough to avoid the mock up collapsing. The cardboard mock-ups can make the brainstormed ideas "come to life" in an easy way making it simple to demonstrate ideas and pitch improvements from working with a tangible prototype rather than a drawing. As can be seen in figs. 5.1 to 5.6, many ideas were pitched demonstrating that this approach encourages creative thinking.

After the initial brainstorming, it was concluded to further pursue two of the produced ideas. These are described in more detail the next section. The selected ideas were the most promising ideas, based on several criteria, but the most important one was simplicity, as further development does not require an advanced process to make it functional.

The two models are similar in both design and size and for identification purposes they will be described as Model 1(hinge at end of table) and Model 2(hinge in the centre of the table), for easy identification.

Figure 5.7: Model 1, shown from the front

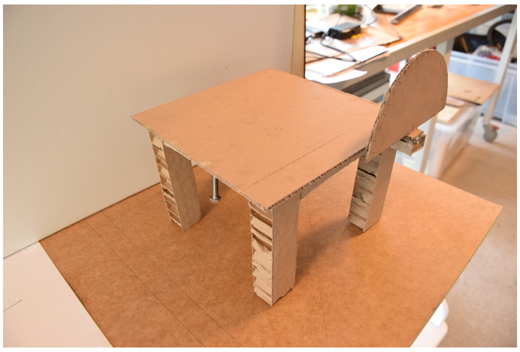

Figure 5.8: Model 1 shown from a diagonal angle

Figures 5.7 and 5.8 shows Model 1 after a quick mock up session. This model is very similar to figure 5.6 and proved to be suited for the established objectives. However, some challenges were identified concerning the angle measurement mechanism, as it needs to be exactly in line with the hinge which is connecting the table top to the legs.

Figure 5.9 shows the side of Model 1, the "backside" of the table. This shows the hinge mechanism used in the mock up. It is simply a screw inserted through a spring, where the spring is glued to the legs, and the screw is glued to the table top. This allows the table top the possibility to change angle while still being attached to the legs. This may not be the final solution to the tilting mechanism, but it is a very basic design while still meeting objectives.

Figure 5.9: Model 1 shown from the back

Figures 5.10 and 5.11 is showing Model 2 with the parts needed for the angle measuring mechanism (screw and protractor). These mechanisms will be further discussed in the next subsections, but in short, this design requires the table to work independently of the legs. It will need a stronger structure, and it also requires a feature to ensure that the table is at a zero degree angle prior to testing. This is not necessary for Model 1, as it rests on legs parallel to the floor.

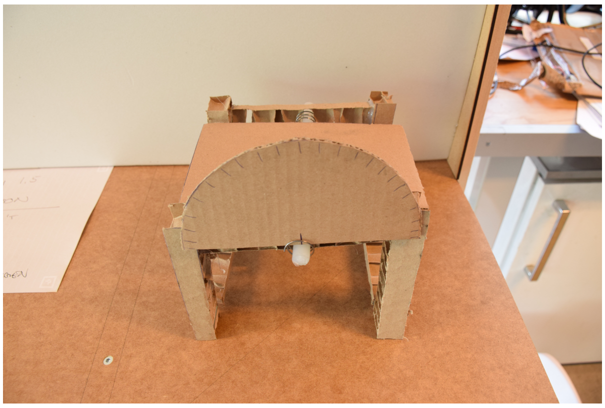

Figure 5.10: Model 2

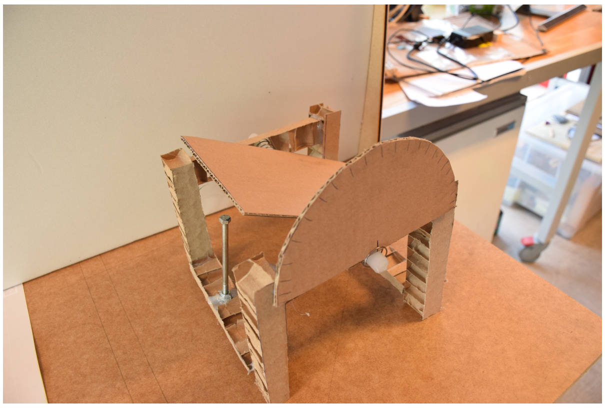

Figure 5.11: Model 2 diagonal view

Angle Measurement

The angle measurement mechanism proved to work well on both models and based solely on angle measurement both designs qualified for the next prototype stage. Both protractors have the origin directly in line with the hinge, which is necessary for correct angle measurement. This is at the back of Model 1, and in the middle of Model 2. This can be seen in figures 5.12 & 5.13.

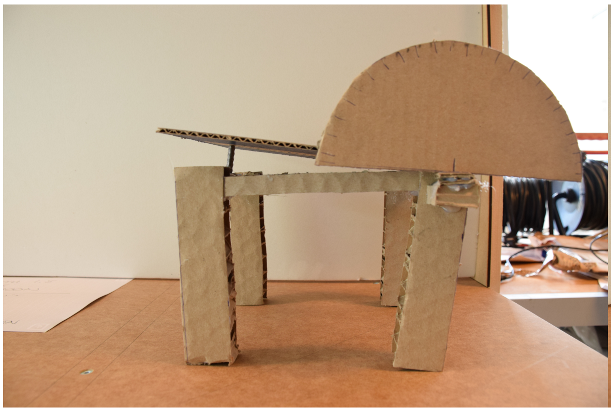

Figure 5.12: Model 1 showing the protractor indicating an angle of the table

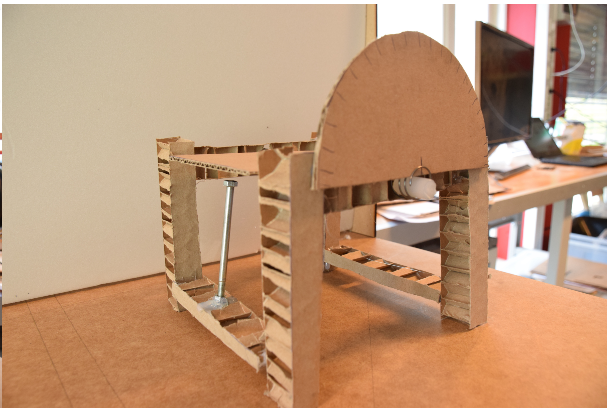

Figure 5.13: Model 2 showing the protractor in the middle of the table

Tilting Mechanism

Figures 5.14 and 5.15 of table Model 1 show the screw located in front of the table pushing the table upwards, on Model 1. This allows for a controlled and accurate lifting mechanism for the table top, with full control also of the lifting process. This mechanism produced very accurate results stopping the table at the exact moment the drop starts to move on the surface. For the prototype phase a longer screw might be necessary but since the thesis work involves testing of hydrophobic surfaces, the required angle should be no more than ~ 30 °, as it shows low hydrophobic properties (Buijnsters et al., 2013).

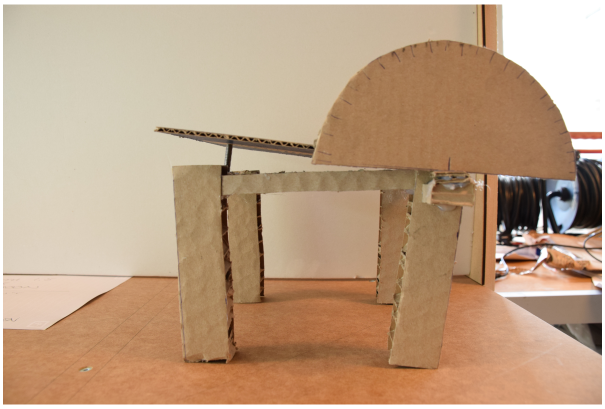

Figure 5.14: Model 1 showing the tilting mechanism

Figure 5.15: Model 1 side view of the tilting mechanism

Figures 5.16 and 5.17 depicts how the tilting mechanism in Model 2 is solved. While the center of mass is over the bar in the middle of the table (5.17), a screw is used in the opposite way of Model 1, here allowing the end of the table to decline in a controlled manner. However, on a larger scale, this model would need 2 screws, one on each side. This is required to keep it level before starting the tilting.

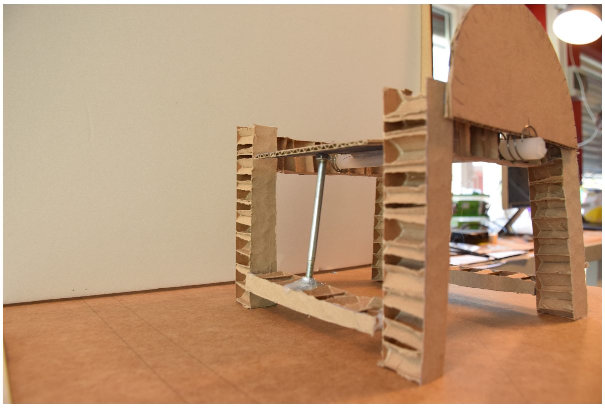

Figure 5.16: Model 2 tilt mechanism from the side

Figure 5.17: Model 2 underneath, showing the tilting mechanism

Conclusion

While both tables proved to measure the angle accurate, Model 1 was marginally better. Model 1 had also the advantage of resting on the table legs, leaving it at a zero degree angle every time the test was started.

For Model 2 the screw had to be reset accurately every time, making it harder to "nullify" the set up before testing again. Model 2 had also some stabilizing issues, as the table had to move independently of the table legs. This made the cardboard structure much weaker than Model 1, but this could easily be accounted for in the later stages of product development. However, the mock ups demonstrated became that Model 1 was both easier to assemble and did the measuring more precise. In addition Model 1 had a better aesthetic design and was selected as the preferred model for further development.

5.3 CAD & Prototypes

After the initial mock ups, CAD was used to get an even better understanding of how the different parts work together, and to make it easier to implement changes between prototypes. The program used is OnShape, a software-based online, which is free and both simple and intuitive to use.

The first attempt is a very basic table, simply to integrate all the parts necessary, and to get a feel for the right size of both table top and legs.

CAD 1.0

As can be seen in figure 5.18, the first sketch is simple, showing support structure both at the bottom and the top of the legs. In the top right of the table, space can be seen between the table top and the leg support, with a hole in the center of the support. This hole is shown in figure 5.19. This was initially thought of as the place to implement the mechanism to lift and lower the table. The idea was for the table to rest directly on the support, but in the later stages, this was improved, as seen in the next CAD attempts.

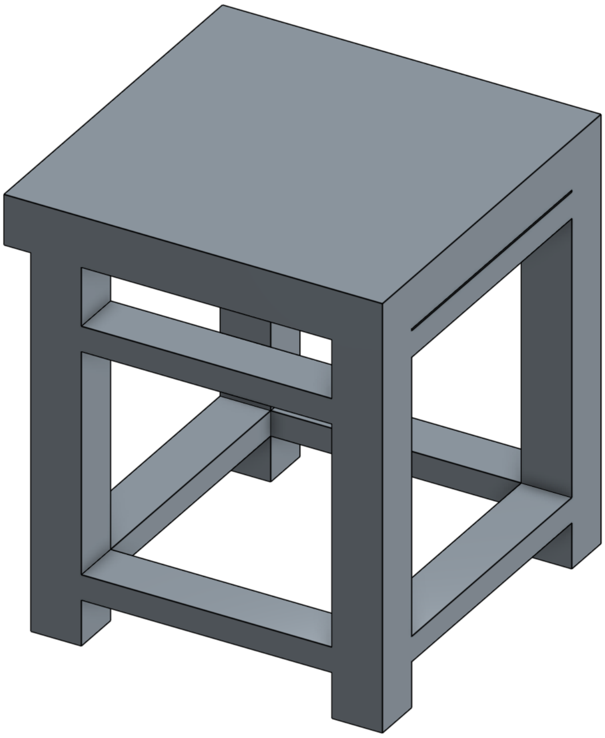

Figure 5.18: CAD 1.0

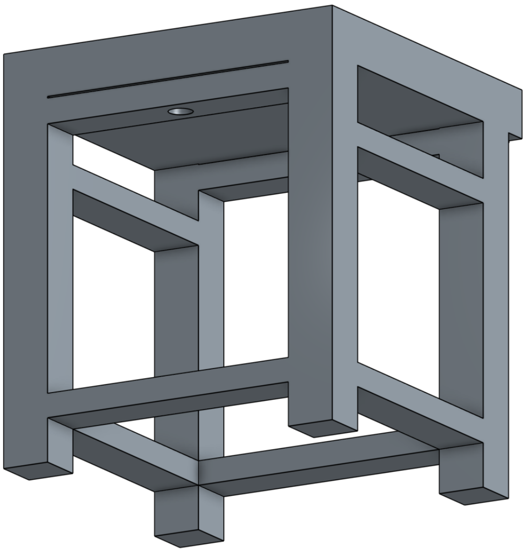

Figure 5.19: CAD 1.0 underneath

In figure 5.20, one can see the implementation of the hinges, which is keeping the table in place when tilting on the other side. This means that with the center of rotation being on the hinges, the protractor needs to be centered on a line directly across the hinges, to make sure the angle measurement is as accurate as possible.

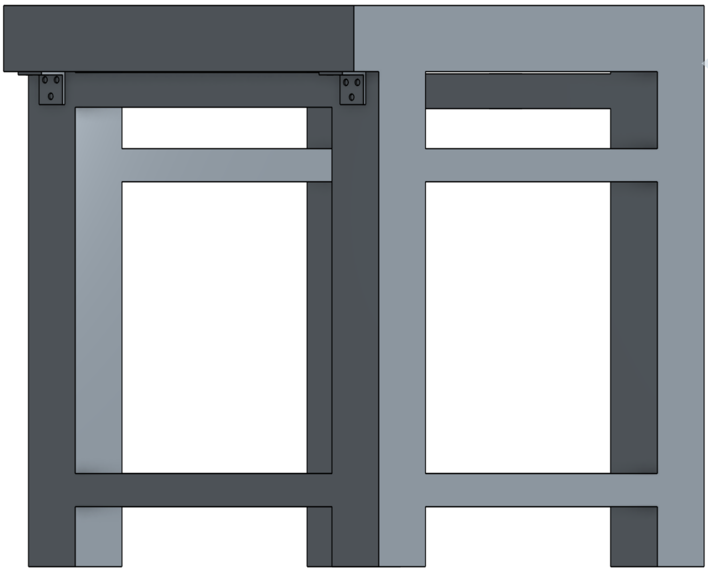

Figure 5.20: CAD 1.0 hinge mechanism

Prototype 1.0

This prototype was the first one that was made, and it was made to resemble the Model 1 mock up and CAD 1.0. No time was spent on looking at how to connect the different parts, so at this point, glue was used, as can be seen just below the protractor in figure 5.21. This made the table very wobbly and made it clear that a more robust solution was required.

Figure 5.21: Prototype 1 from the side

After the prototype was glued together and tested, it became clear that some challenges needed solving. First, as figs. 5.21 and 5.22 shows, no "walls" had been introduced on the table top, making the samples slide when tilting the table. Also, it made more sense to turn the protractor in the opposite direction, in order to see the samples and the protractor at the same time.

Figure 5.22: Prototype 1 with raised table top

As with any rapid prototyping, the first prototype did not meet all requirements and original ideas, but it was an important step in the right direction. It clearly showed that the table did not need to be very advanced to measure the angle, and with some improvements, a simple, cheap and easy measuring device was available for testing hydrophobic surfaces on small test samples.

CAD 2.0

In the 2nd attempt, the support structure in front was lowered (5.23), making the table top resting on the legs instead of the support structure, which gave more room for implementing a robust feature for tilting the table. There were also added four "walls" on top of the table, for leaning test samples on, as shown in figure 5.23. This provides the possibility to test several samples at once, and this is a key feature of the table.

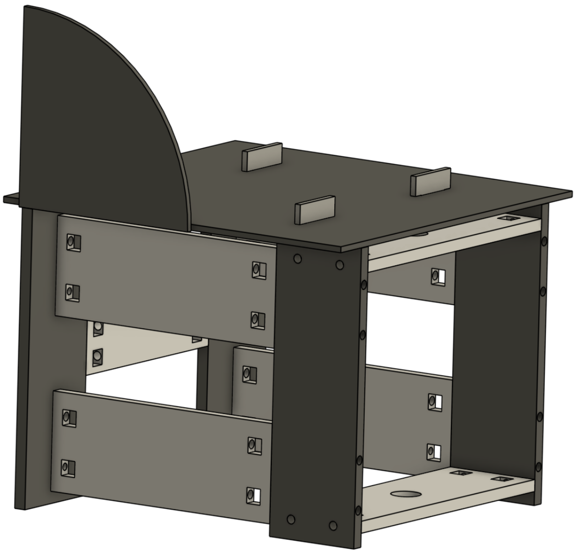

Figure 5.23: Sideview of CAD 2.0

There was also added holes for screwing the pieces together, as is shown in both figs. 5.23 to 5.25. The idea was originally to have long screws going through the legs and tightening it with nuts on the other side, with the quadratic holes in the support structure showing where the nuts would go. This would give the table a far more robust structure than with just use of glue, but it also meant many single parts, as all the parts have to be screwed together.

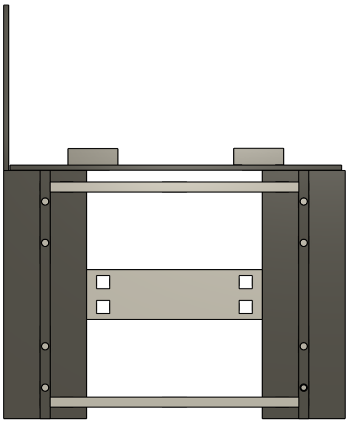

Figure 5.24: CAD 2.0 front

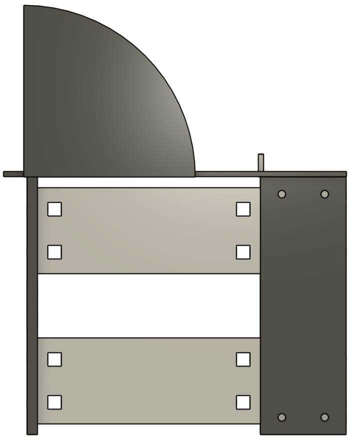

Figure 5.25: CAD 2.0 side

Prototype 2.0

Prototype 2.0 was made primarily to address the flaws discovered in Prototype 1.0. The protractor was flipped, as shown in figure 5.26. This made the measuring easier, and also enables taking photos of both the angle and the samples at the same time, important for comparing large sample pools.

The next step was introducing several holes in the structure to implement a nut/bolt solution for tightening the parts together (5.27), making it more stable and easier to handle. However, the first attempt did not work exactly as planned, as argued in section 5.3.

Figure 5.26: Prototype 2.0 from the side

Figure 5.27: Diagonal view of prototype 2.0

The last implementation in prototype 2.0 was introducing the "walls" on the table top, for keeping the samples in place. This is shown in both figs. 5.28 and 5.29, and worked as intended. The samples were held in place and making it easier to test several samples at the same time.

Figure 5.28: Prototype 2.0 showing table top

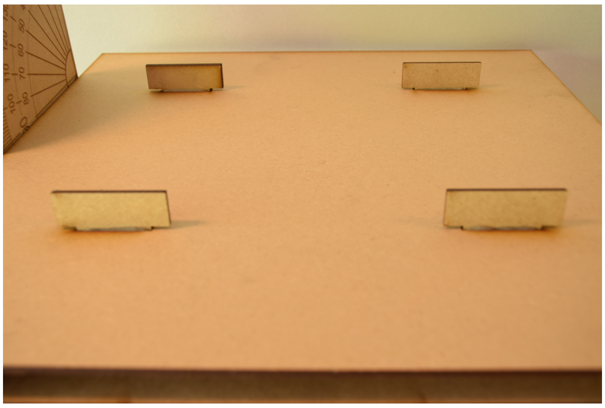

Figure 5.29: Prototype 2.0 sample placers

Figure 5.30 shows a flaw discovered in the prototype. Even though most samples tested should be hydrophobic, meaning that water should start running off the surface at a low angle, there are no guarantees for this. Therefore, the tilting angle should be able to reach somewhere close to 90 degrees. This means extending the screw used for lifting and lowering the table top, shown in figure 5.30. However, after some literature research, it was argued that samples reaching and going beyond $\sim 30^\circ$ are no longer relevant, so as the table at present point goes well over 40 degrees it is found to meet the requirements presented in different literature (Liu et al., 2013; Buijnsters et al., 2013; Zaraska et al., 2009).

Figure 5.30: Prototype 2.0 front

CAD 3.0

The next CAD-sketch solved a problem not known when making the previous sketch. When laser cutting sketch 2.0, all the circular holes for implementing the screws (thin side of front legs, as seen in figure 5.23), had to be added manually. This made for large potential errors, as millimeter accuracy was necessary to make the table legs level. This proved almost impossible to achieve, so a new solution had to be found.

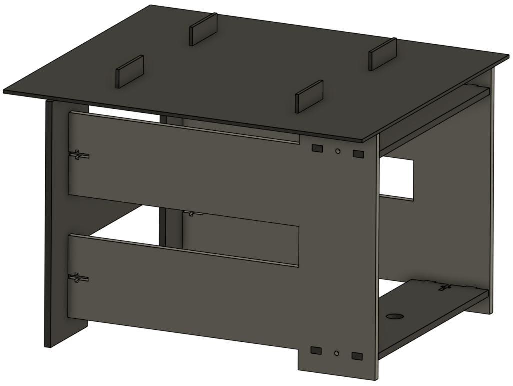

Figure 5.31: CAD 3.0 side view

A bolt procedure was introduced, where a hole for both the nut and the bolt was added in the support structures, as shown in figure 5.33. This meant every hole in the structure was laser cut, improving both accuracy and finish.

Also, the support structures were now made as one part, combining with the legs, shown in figure 5.31. This meant fewer parts all together, but also fewer parts that could be potential flaws introducing wobbling or swaying of the entire table. The parts were connected by making one piece with the nut and bolt space, and having two pillars sticking out on either side of the bolt structure, as shown in the bottom parts of figure 5.37. On the corresponding part, two quadratic holes were made, fitting with the pillars made, and one circular hole in the middle, to fit the bolt in. This means the structure is robust even when just fitting the pillars, but adding the bolts makes an even stronger connection and structure. The connection can be seen on the right side of figure 5.32

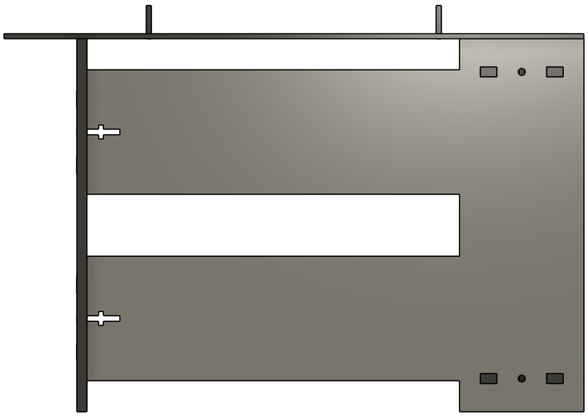

Figure 5.32: CAD 3.0 tightening structure

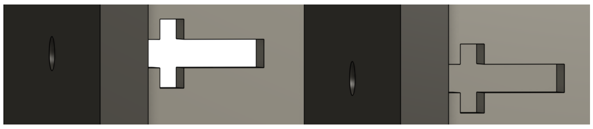

Figure 5.33: Zoomed view of the nut/bolt solution for tightening the parts

CAD 4.0

CAD 4.0 is the last drawing made with Onshape. It shows some significant improvements to the table. First, as can be seen in figs. 5.34 to 5.36, a large rectangular hole has been added to the table top. This was introduced to be able to test the surfaces on cross country skis. This is an integral part of the thesis itself, and making a table that can both tests small scale samples with the state of the art gives a very quick determination if a material shows more promising hydrophobic properties, which is the goal of this table, and a vital part of the thesis.

Also, what can be noticed is that there are two more test "walls" introduced on top of the table. The reason for this is simply because there has been made well over 40 test samples of aluminum in this thesis, and being able to compare the 6 most promising samples at one time makes for higher accuracy and fewer iterations.

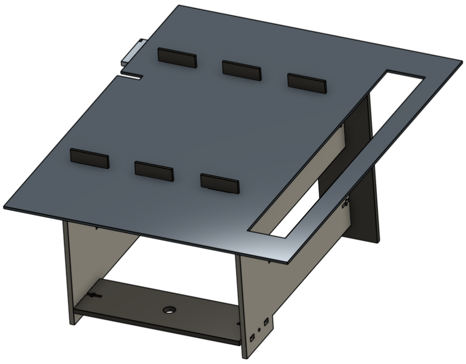

Figure 5.34: Diagonal view of CAD 4.0

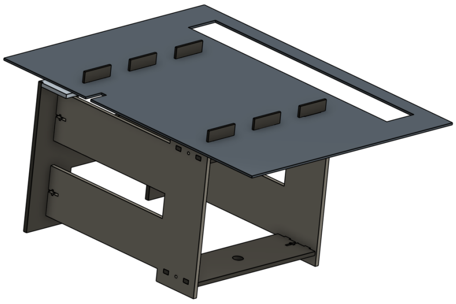

Figure 5.35: Opposite diagonal view of CAD 4.0

An extra part has been added to the support structure, which is the light gray part to the bottom left of figure 5.37. This part gives a larger surface for the protractor to be placed on, making it both more robust and keeping it in line with the table.

Lastly, a small hole is added to the table top, seen in the lower left of figure figure 5.36. This is because a more accurate measuring device has been introduced, using a laser diode attached to the table. This diode points at exactly the degree the table is at, which makes it easier to measure when the water starts running off the samples. This feature is discussed more in detail in section 5.3.

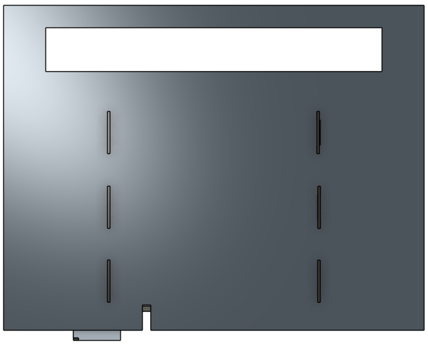

Figure 5.36: Table top of CAD 4.0, showing both the hole for the ski, and the test sample holders

5.37 shows all the parts needed for the table, and there is also an additional machine drawing in Appendix B, available for future use.

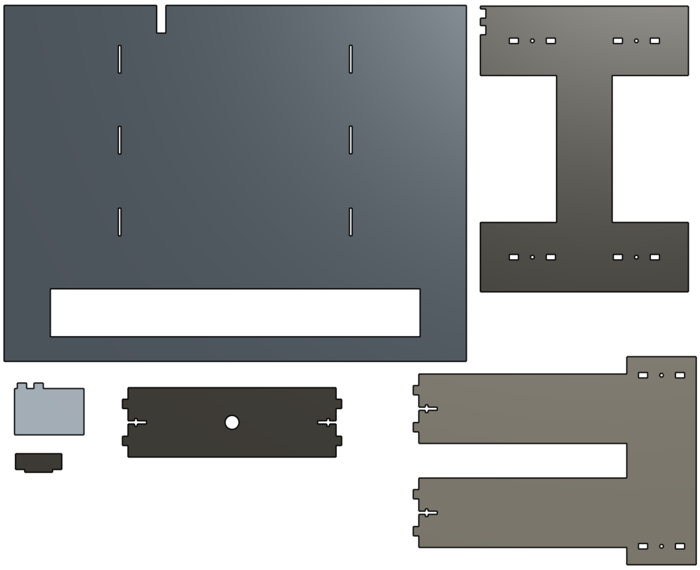

Figure 5.37: Overview of all the parts for the structure used in the last prototype

Final Prototype

This is the last prototype made, and it is based on CAD 4.0. As previously discussed in CAD 4.0, several improvements have been implemented. The prototype is larger, more robust, and can be used for several samples at the same time.

In figure 5.39 one can see the implementation of the laser diode used for measuring the angle of the table. The diode is exactly in line with the table itself, making it a very accurate way of measuring. It is connected to a 9 V battery installed underneath the table.

Figure 5.38: Side view of the final prototype

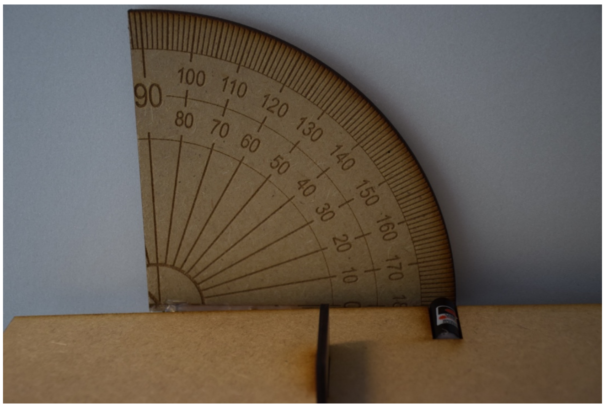

Figure 5.39: Laser diode placement for showing measured angle on the protractor

Figure 5.40 shows how the laser diode is attached to the table, and a self-made switch is installed underneath, made out of tin. It works as simple as two arms of tin, not connected by default. By bending one of the arms, a connection is made and current is flowing, resulting in laser emitting from the diode.

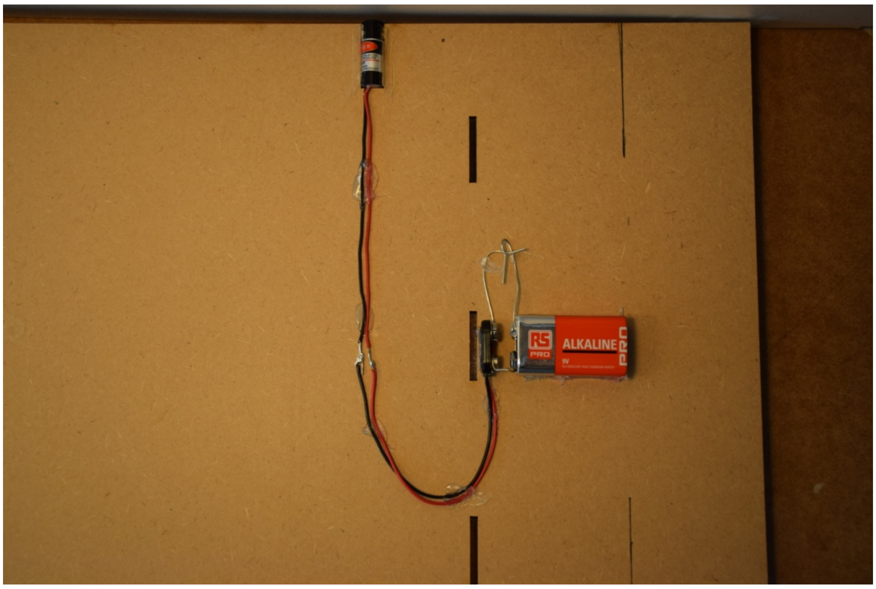

Figure 5.40: Electrical set up for the laser diode

The next couple of figures shows how the measuring works while doing a test on a hydrophobic surface made out of Electroless Nickel-Teflon (Skoglund, 2016). As can be seen in figure 5.42, the water droplet on the aluminum sample with the AAO structure glides off before the droplet on the Electroless Nickel-Teflon coated material. This was just an initial test to see if the table works, and a more complete test will take place at a later stage.

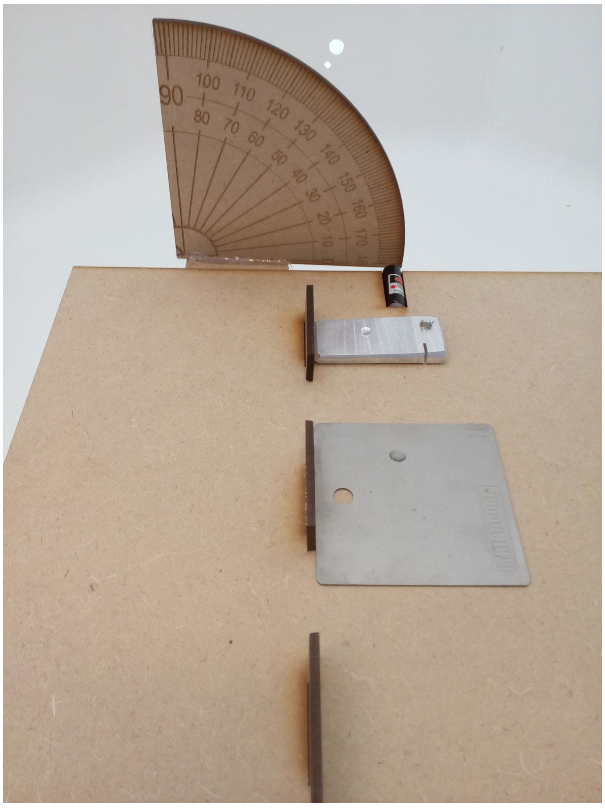

Figure 5.41: Water droplet on both AAO **sample 5** and Electroless Nickel-Teflon, used in Skoglund (2016), prior to angle test

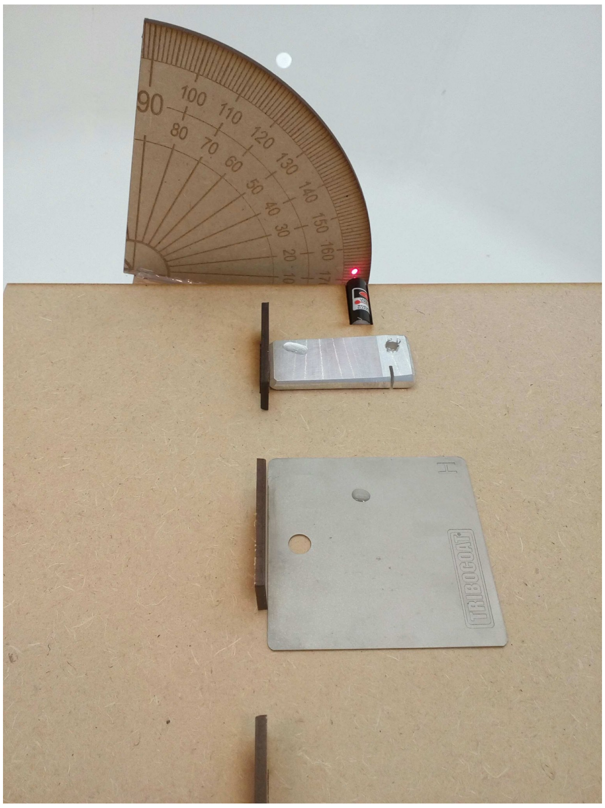

Figure 5.42: Laser diode measuring angle when water droplet starts gliding on the aluminum surface

Figure 5.43 is the final picture, showing how the prototype can work when measuring skis alongside test samples. As a main part of the thesis is just that, it is shown that it works well.

Figure 5.43: Final prototype with both cross country ski and sample materials

5.4 Testing

When the table was done, all the samples were tested for hydrophobic properties. In addition, a untreated Madshus cross country ski (shortened M in table 5.1) and Electroless Nickel-Teflon (ENT) coated plate is included. These serve as state of the art and a sample used in Skoglund (2016).

The way this is done is by measuring the roll-off angle, when the water droplet starts rolling of the surface. Stated by Kruss (2017): "The roll-off angle is an empirical variable which is highly dependent on the particular measuring conditions, such as drop size and tilt speed." This means, as discussed in chapter 7, that this table does not serve as an international measurement system. It is made for quick checks of different materials, to establish a difference in hydrophobic properties.

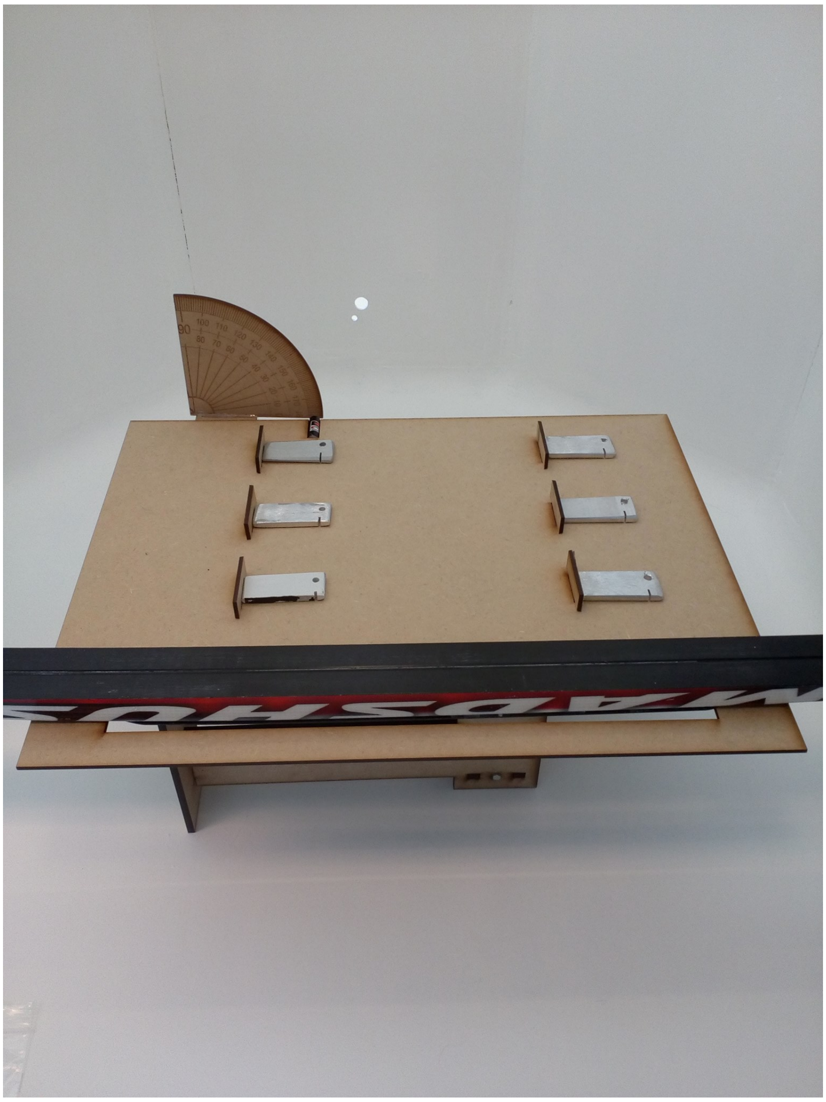

Figure 5.44: Set up for testing roll-off angle of test samples

The setup is shown in figure 5.44, and shows how the samples are placed prior to tilting the table.

The tests were done by applying a single water droplet from a 1 mL pipette directly on each sample. The table was then raised slowly, and notes were taken when each droplet started moving.

The results of the most relevant samples can be seen in figure 5.1.

Table 5.1: Table showing the results of the most promising samples on the measuring table

Sample	5	8	Foil 2	19	20	21	22	23	24	25	26	ENT	M
Table angle	17°	7°	21°	9°	10°	11°	16°	8°	11°	$\sim 8.5°$	15°	29°	-

Although some of these angles are low, they can not be compared to those of Liu et al. (2013), in which angles as low as 2.5°were attained. The reason for this is unknown, but as the droplet size were unknown in the literature, this is surely one of the reasons.

It is interesting to see how well samples 19-26 did. Although there are no SEM pictures of these structures, they seem to do similar to that of the AAO-structure achieved in sample 8. This may be an indication that the procedure can be replicated, but this cannot be confirmed until new SEM images have been attained.

It is however clear differences between the samples that spent longer time in the acid bath and the rest. 120 minutes seems to have affected the samples in a negative way, but it is unclear why. According to the literature, the length of the bath only affects the length of the structure, not the structure itself. Because there were no SEM-pictures of these samples it will need to be worked on at a later stage, to confirm that there actually is a difference between these samples. But just based on the tests done, too long time in the acid bath seems to result in a less hydrophobic surface. Why this is one can only speculate, but it might be because of the hardness of the material dropping when the length increases over a certain length. Further discussion will be made in chapter 7

ENT showed a very large angle before starting to roll off, but this might have to do with contamination and prior use of the surface, damaging it unconsciously. It was used early fall 2016, and has since been lying on a desk until needed this spring, so this is a possible reason for such low results as it showed promising results in Skoglund (2016).

Not surprising, the polyethylene cross country ski had an angle to high for measuring. This is in accordance with Skoglund (2016), in which it was discovered that water droplets on a ski surface perpendicular to the floor would still stick to the ski. These finding will be further discussed in chapter 7, but this was one of the key findings in the project thesis, and the main reason for challenging UHMWPE.

Chapter 6

Results

6.1 Anodic Aluminum Oxide

6.1.1 Important Samples

The low-cost anodizing set up has been successful in producing samples resembling an AAO-structure. The setup is easy to construct, and can be done with equipment available at NTNU.

These are the most promising samples from the anodizing process.

Sample 8 shows the most promising structure, indeed, it shows a nearly identical structure to that achieved by Liu et al. (2013), shown in section 4.1. The desired "mountain structure" consisting of tiny pillars all over the surface have been achieved in all these samples, but sample 8 is the one closest to Liu et al. (2013).

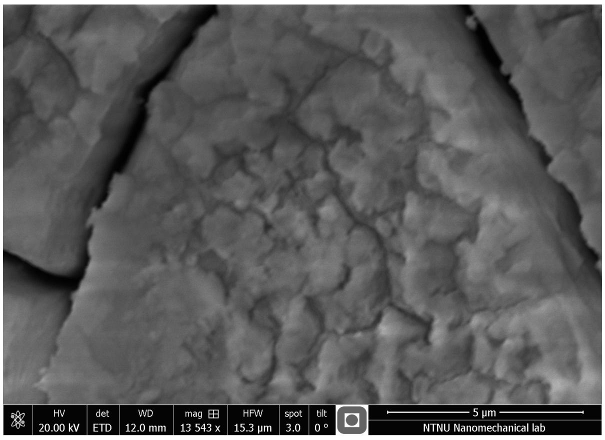

Figure 6.1: Aluminum foil 2

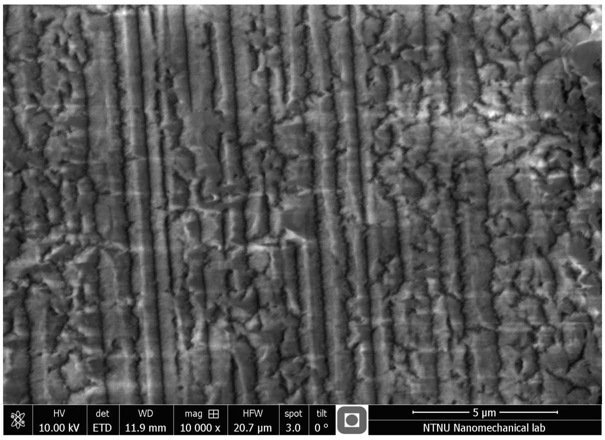

Figure 6.2: Sample 5

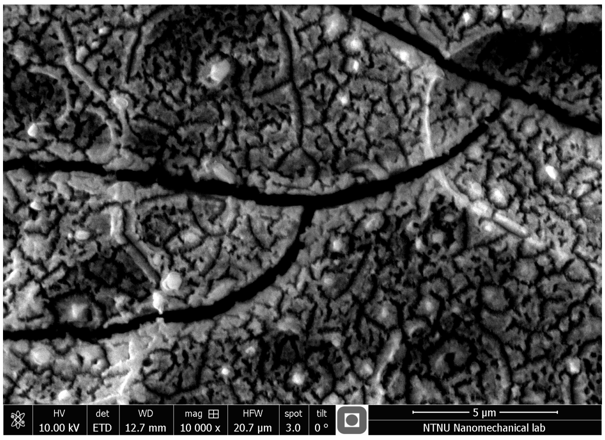

Figure 6.3: Sample 7

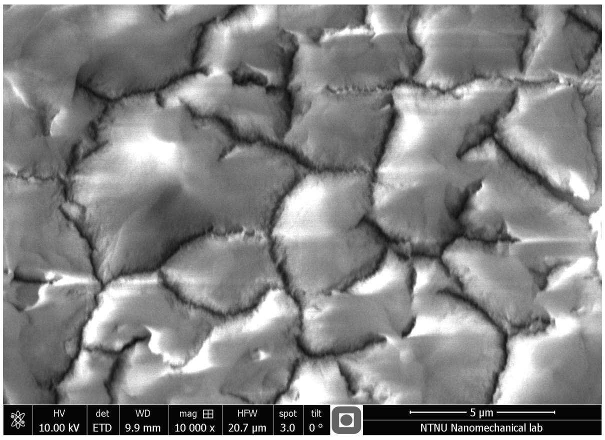

Figure 6.4: Sample 8

6.1.2 Contact Material

Aluminum foil was used in various thickness and composition, while steel wire and aluminum wire available in the mechatronics lab was also tried. Titanium wire was tested with two different diameters, 1 mm & 2 mm.

Titanium wire with a diameter of 1 mm proved to be the best contact material, thin enough to wrap tightly around the sample, and with no anodizing as long as the connection was good.

Aluminum foil wrapped around itself, to achieve a thicker contact material, also worked well, but not quite as well as the titanium. With time, the acid will dissolve the aluminum foil, breaking the connection. This can be seen in **sample 12**.

While the titanium itself works well, titanium wire with 2 mm diameter proved too thick to wrap around the samples and is not suited for this type of use.

Steel wire did not work at all, which is in accordance with literature research (Wernick et al., 1987).

6.1.3 Sulphuric Acid & Acid Mix

It is difficult to conclude which acid solution produced the best result in this process. The last eight samples were made specifically to test which acid solution was best suited, but due to unavailability of the SEM lab this part could not be completed. However, the testing done in section 5.4 showed that both solutions can work well, producing similar surface properties as **sample 8**.

6.1.4 Chemical Etching

Chemical etching did not show signs of improving the surface smoothness. The purpose was to get a smoother surface prior to anodizing the material, but as evident from the SEM pictures there were minor changes comparing with the untreated samples. This may indicate that the etching process did not function as it should, but no conclusion could be made within the time frame of the master thesis work.

During the etching process, it could be heard that the acid was "working" on the sample, and indications of this can also be seen in figs. 4.36 and 4.37. This experiment should be repeated to verify if something went wrong in the initial test. A longer etching process may be the solution, as this procedure was tested at two minutes only, and the etching process is a rather slow process with this particular acid.

6.2 Measurement Table

The table was a direct development product of the rapid prototype approach. Chapter 2 shows the step by step progress from simple concept drawings to the finished product. The PD approach used in this master thesis work has been based on knowledge acquired from the study at NTNU supported by literature research.

Table 6.1 shows the 11 best samples with the measured angle for when the water starts gliding off the surface.

In addition, a sample from the project thesis (Skoglund, 2016), and from a cross country ski with state of the art sole material, is included in line with the objectives of the thesis work.

Table 6.1: Table showing the results of the most promising samples on the measuring table

Sample	5	8	Foil 2	19	20	21	22	23	24	25	26	ENT	M
Table angle	17°	7°	21°	9°	10°	11°	16 °	8°	11°	∼8.5°	15 °	29°	-

As can be seen in table 6.1, **sample 8** measured the lowest angle. Also, the samples based of the same procedure shows similar angles, but still neither of these can be compared with those of Liu et al. (2013), which will be discussed further in chapter 7. There are distinct differences between the samples submerged 30 minutes vs 120 minutes in the acid bath.

6.2.1 Angle

The table can measure angles in the range ∼ 0°- ∼ 30°. This is sufficient to determine which samples show the most promising hydrophobic surface, but not sufficient to measure all samples included in this master thesis work. As it was stated in Skoglund (2016), the untreated UHMWPE showed low hydrophobic properties, where the water drop did not start gliding with the ski perpendicular to the floor. This is not possible to demonstrate with the constructed test table. However, as stated in chapter 5, this is not relevant for this project as low hydrophobic properties and high adhesive forces is the opposite of what is required.

It is therefore concluded that the developed test table meets the requirements of this master thesis.

A picture of the finished test table is shown on the next page.

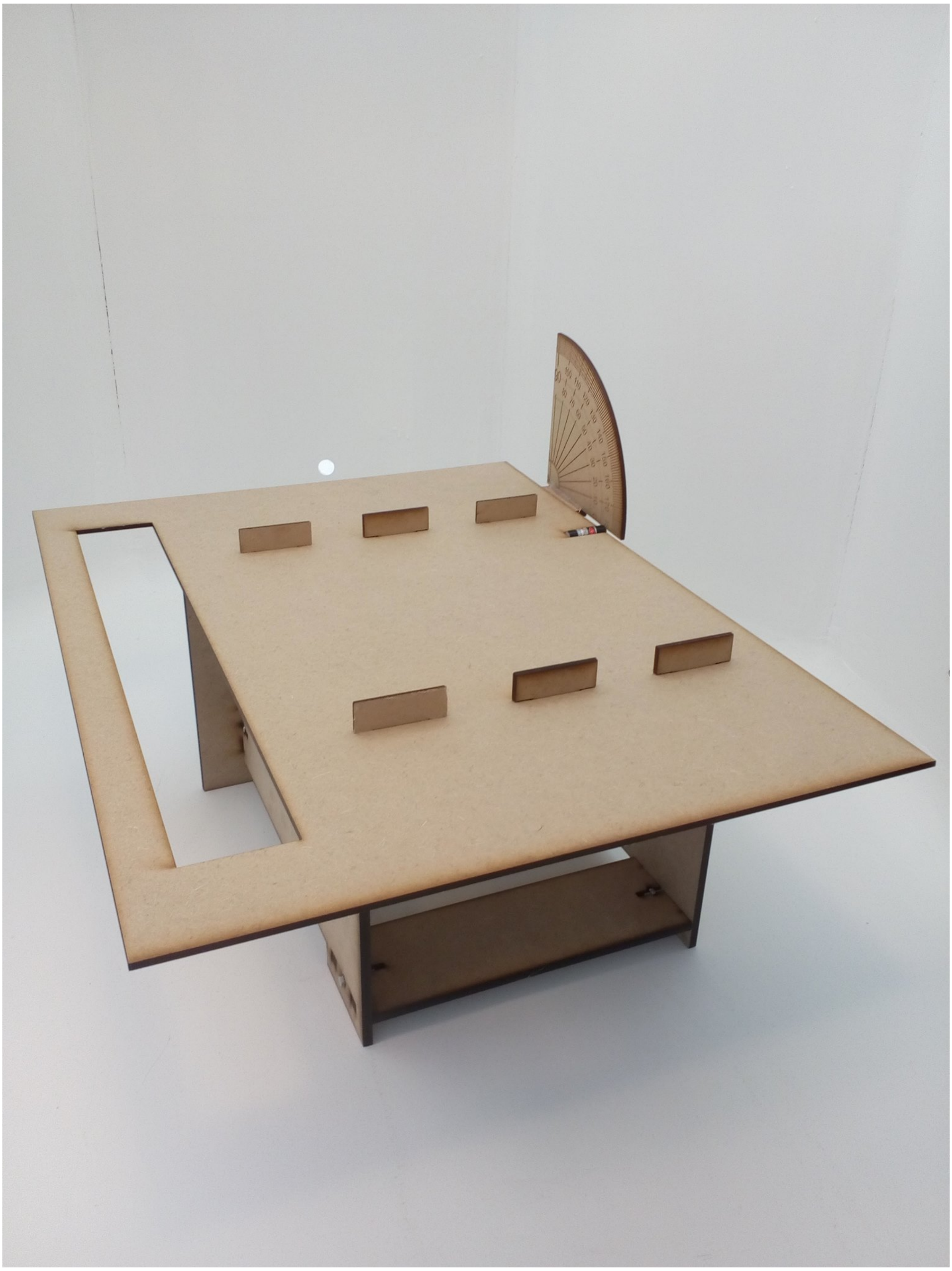

Figure 6.5: Final test table developed as part of the master thesis

Chapter 7

Discussion

This chapter will cover the most relevant findings and discuss both results and project approach.

Extensive experimental work has been performed, particularly in the development of the nanostructures, and while all is important for the result, only the most significant results will be discussed.

The discussions will be separated in the chemical experimental side and the product development stages, chapter 4 & 5, respectively.

The master thesis objectives are listed below, and each objective will be discussed in this chapter, concluding whether or not the objective has been met.

1. Build a small scale, low-cost setup for anodizing aluminum
2. Anodize aluminum in chemical solutions to achieve a suitable nanoporous structure
3. Create setup for measuring table angle for when water slides off the sample surface
4. Test for hydrophobic properties and compare against results in Skoglund (2016)
5. Compare against state of the art (UHMWPE)

7.1 Anodic Aluminum Oxide

7.1.1 Discussion

This discussion is based on the results listed in chapter 6.

Comparing the test results with those of Liu et al. (2013), it is evident that AAO-structure has been created. The honeycomb structure shown in Buijnsters et al. (2013) is not evident, but this is due to restricted magnification range available at the NTNU Nanolab. Nevertheless, this is an important milestone in itself, as it shows that AAO structures can be achieved with low cost equipment.

Of the results listed, **sample 8** shows the most promising results and should be the basis for the selected procedure in further development work. The process is written in section 4.3. It was intended to confirm the results of the procedure, but because of unavailability of the SEM lab this was not achieved within the master thesis time frame. A confirmation of the procedure used for **sample 8** would document that the results can be replicated and, consequently, be able to transfer the process to a structure on a larger scale. However, the procedure has been established and it will be easy to replicate the process equipment available at NTNU.

It can also be argued that the samples 19-26 show similar traits of the most promising sample when doing the water roll-off test, as shown in table 6.1. This goes to prove that the results can be reproduced successfully.

There were distinct differences between the samples that spent 30 minutes in the acid bath solution versus 120 minutes. This indicates a point where the structure loses its hydrophobic properties. According to Liu et al. (2013) the highest contact angle reached was with 40 minutes submerged in the acid bath solution. This observation should be further investigated and concluded.

7.1.2 Potential Errors

As shown, and briefly discussed, regarding **sample 15, 16 and 17**, there occurred some problems with the anodizing of the aluminum. Apparently, the titanium connecting material reacted instead of the aluminum, which meant an oxide layer was produced on the outside of the titanium, cutting the circuit. This is because the oxide layer inhibits the current from flowing, and when the entire contact material is oxidized, the circuit breaks. This was not an issue described in the researched literature and the only way to resolve the issue was by performing additional experiments, changing one variable at a time.

Four possible reasons were listed:

- Oxalic Acid
- NaCl
- Connection Problems
- Pollution

The titanium did not anodize in the early parts of the experiment. It was not until the second acid mix, consisting of sulphuric acid, oxalic acid and NaCl, that the titanium started to anodize.This gave reasons to assume that the sulphuric acid alone, used in the first acid baths, was not the problem. However, to be sure everything was checked out two new acid baths were prepared. One similar to bath 1 & 2, with just sulphuric acid and water, and one identical to bath 3, the mix listed above. One last bath, excluding the NaCl was made purely for the error solving test, and was not used to produce AAO structure. The titanium wire was tightly wrapped around all samples and current and time was constant throughout all tests keeping all remaining variables constant.

A total of six samples were tested for this purpose, two in each bath. None of these samples showed any problems with the anodizing process, meaning the titanium did not anodize at all.

Therefore, it was stated that the problem was poor connection between the aluminum and the titanium. This was verified by inserting a pure titanium rod in the acid baths, which caused the titanium wire to turn blue, as can be seen in figure 7.1. This also broke the current flow, as was the case with **sample 15, 16 and 17**.

This solved the problem with the titanium anodizing, and focusing on maintaining a strong connection between the materials were strong, no further problems occurred.

A stronger connection was achieved by machining out more space in the sample to tighten the titanium wire. The first samples had a small cut on the side, allowing for the wire to be tightened, as shown on the right side of figure 7.2. After the anodizing error was solved, the rest of the samples had cuts similar to those on the left side of figure 7.2, to ensure an adequate connection.

Figure 7.1: Unused titanium on top, anodized blue titanium on bottom

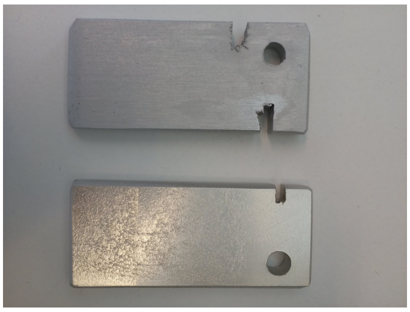

Figure 7.2: Added cuts to increase connection between titanium and aluminum sample

The last potential error was from pollution on the cathode. As can be seen in figure 7.3, large crystal structures form on the surface, while the cathode itself dissolves. This results in a polluted acid bath which in itself required the preparation of new acid baths for testing to eliminate this error potential.

It is unknown what causes the crystal formation, but the polluted acid bath is simply the cathode itself dissolving when no current is applied. The cathode shows clear signs of dissolving, as can be seen in figure 7.4. For this reason the cathode was milled down and then brushed with sandpaper to avoid contamination as long as possible in every new acid bath. In addition, the cathode was thoroughly cleaned with soap prior to submerging it in a new acid bath, to minimize risk of pollution. Contamination from the cathode itself might be the reason for the forming of crystals, but this could not be proved and no reference has been found in literature research regarding this particular problem.

Figure 7.3: Cathode after developing crystal structure on the surface

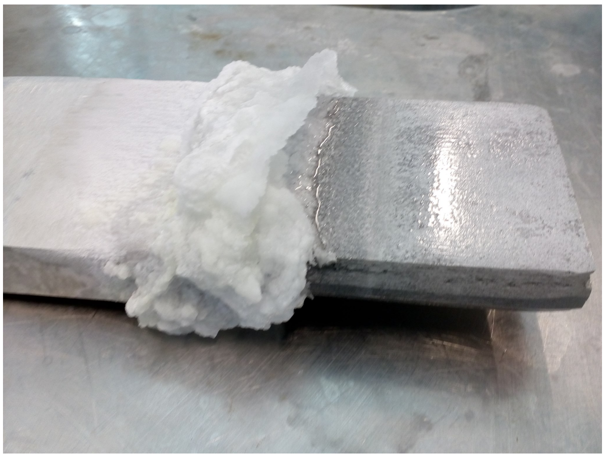

Figure 7.4: Cathode showing clear signs of dissolving because of acid

7.1.3 Voltage Difference

As stated in **test 22**, there were observed some significant differences in the voltage supply when maintaining a current of 0.9A. While the sulphuric acid only showed a voltage peak of 6.5V, the mix of oxalic acid, sulphuric acid and NaCl reached voltages of above 13V. This is a result of the oxidized aluminum growing quicker in the latter acid mix. Because the layer is non-conductive, as the aluminum layer grows, the connection becomes weaker (Mooney, 1995). Therefore, more voltage is required to maintain the necessary current. This results in a higher voltage peak in a solution that reacts quicker with the anode.

7.1.4 Conclusion

As it can be shown in the comparison between figure 7.5 and figure 7.6, a proper nano structured AAO layer has been achieved. This has been done using a low-cost setup, at less than 1000 NOK, and with a setup that can be used for a long time.

It is therefore concluded that the two first objectives have been met.

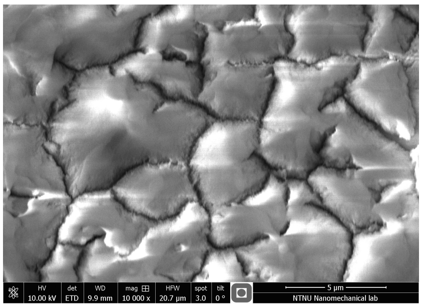

Figure 7.5: SEM picture of sample 8

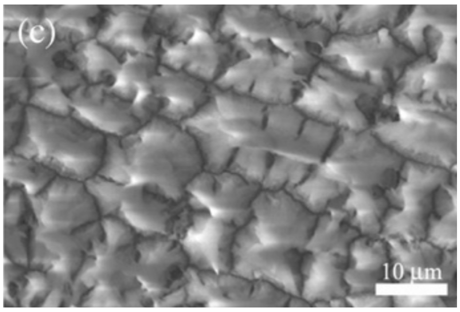

Figure 7.6: SEM picture of AAO, adapted from Liu et al. (2013)

1. Build a small scale, low-cost setup for anodizing aluminum ✓
2. Anodize aluminum in chemical solutions to achieve a suitable nanoporous structure ✓
3. Create setup for measuring table angle for when water slides off the sample surface
4. Test for hydrophobic properties and compare against results in Skoglund (2016)
5. Compare against state of the art (UHMWPE)

7.2 Table

The water table itself is a pretty simple idea and by controlling the angle one can measure when the water droplets starts gliding on the surface. It is important to note that this table is not made to fit an "international standard", but rather as a quick comparison method between different materials at hand. This procedure is highly empirical, with factors like tilt speed and droplet size impacting the results. This table is designed to give a rapid and simple way of investigating several samples at the same time.

Therefore, while the table could be made more technologically advanced, it serves the purpose for this master thesis work, it is lightweight and mobile, and is usable for several different shapes and sizes. It is made of 6mm MDF which is both solid and lightweight, and easily available at NTNU.

7.2.1 Final Product

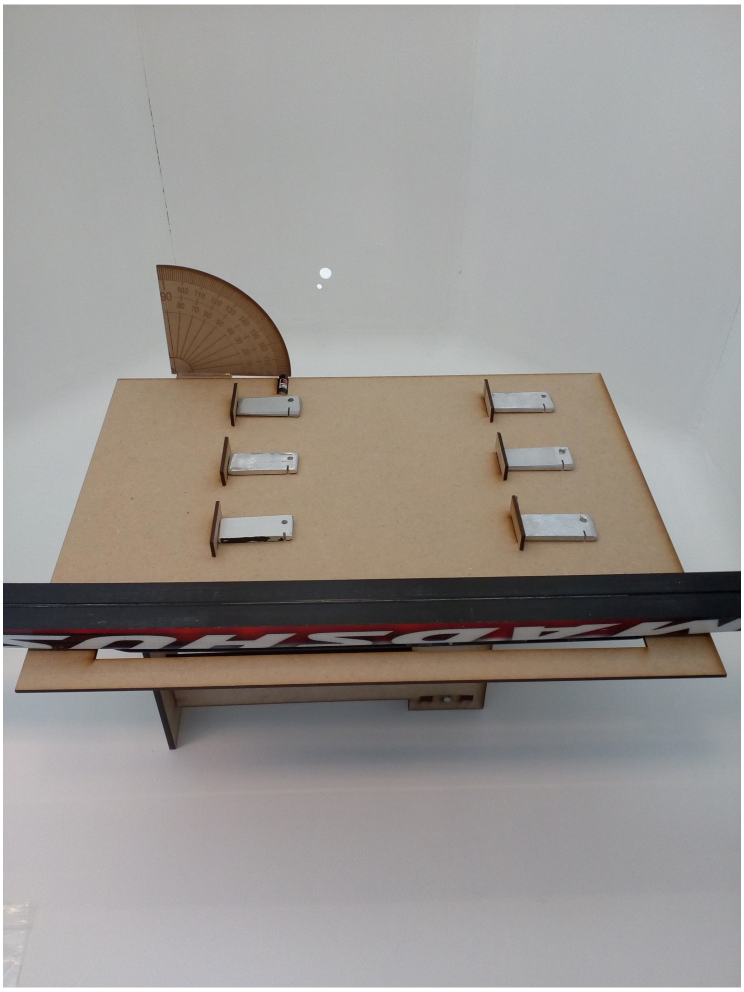

Figure 7.7: The final prototype with both test samples and cross country ski mounted

The final version of this table is larger than first intended. It was initially made to measure the small aluminum samples shown in chapter 4, but at a later stage it was enhanced to fit cross country skis as well. This made it possible to test the hydrophobic properties of the ski and the sample at the same time, which is shown in figure 7.7. This enhancement added important value to the test table. The table can now compare more samples than initially planned, which is very useful as this master thesis involves testing of many samples. Being able to test several samples simultaneously have some obvious benefits, like making it quicker to sift out the most promising samples.

There is little literature on the actual making of this type of table so the objectives were discussed and defined in cooperation with supervisor Martin Steinert.

7.2.2 Use

The table is very easy to use. Manually turning the bolt, located at the front of the table, makes the table top rise or lower. The manual operation of the table means high accuracy for measuring exactly at what angle the water starts gliding.

An idea from the brainstorming phase was to make the table controlled by a servo-motor, but testing the prototypes made it clear that better control was obtained by manually turning the bolt.

One disadvantage by using a servo-motor is the lack of feedback between the tilting mechanism and movement of the water droplet. This will result in the table continuing to tilt after the water starts gliding. A potential solution for this would be to install a laser diode with a sensor at the opposite side, and when the water breaks the laser barrier the light on the sensor would decrease, and an angle would be recorded.

However, the table was supposed to be simple, cheap and user friendly, so adding more advanced solutions was decided against.

As shown in figure 5.41, the samples can be tested alongside the samples produced from Skoglund (2016), which is one of the objectives for this master thesis. From the tests in the project thesis, it was found that gallium and Electroless Nickel-Teflon was the most promising materials. As figure 5.41 shows, **sample 5** has the highest hydrophobicity, based on this test.

Since both full-scale skis and small scale test materials can be tested and directly compared, it is argued that the test table can establish a good foundation for verifying the most hydrophobic surface among the test samples.

It is stated that the thesis objectives of making a test table capable of measuring the angle of the table top, and comparing the hydrophobic properties of different materials, has been achieved.

7.2.3 Conclusion

The table can measure the angle for when the water starts gliding, it gives direct comparability to the materials tested in Skoglund (2016) and the state of the art material, UHMWPE.

It is therefore concluded that these **objectives have been met.**

1. Build a small scale, low-cost setup for anodizing aluminum
2. Anodize aluminum in chemical solutions to achieve a suitable nanoporous structure
3. Create setup for measuring table angle for when water slides off the sample surface ✓
4. Test for hydrophobic properties and compare against results in Skoglund (2016) ✓
5. Compare against state of the art (UHMWPE) ✓

Chapter 8

Conclusion & Further Work

8.1 Conclusion

- A low cost, simple set up for anodizing aluminum has been created at the Corrosion Lab at NTNU. It is easy to replicate, and can be scaled up as necessary.
- **Sample 8** is the most promising structure achieved in this master thesis work, and the procedure to make this sample is the one that should be replicated in future work.
- A table that can control roll off angle of samples has been made. It is scaled to fit both samples of different sizes as well as full scale cross country skis.
- All sample surfaces has been tested and compared with each other through roll-off angle tests performed with a test table developed for this master thesis. A table listing the best results is shown in section 6.2.

Based on the results described in chapter 6, and the discussion of the results in chapter 7, it is concluded that all the objectives listed in section 1.3 has been met.

1. Build a small scale, low-cost setup for anodizing aluminum ✓
2. Anodize aluminum in chemical solutions to achieve a suitable nanoporous structure ✓
3. Create setup for measuring table angle for when water slides off the sample surface ✓
4. Test for hydrophobic properties and compare against results in Skoglund (2016) ✓
5. Compare against state of the art (UHMWPE) ✓

8.2 Further Work

- The confirming results of the tests replicating **sample 8** should be done (**samples 19-26**). Therefore, the last 8 aluminum samples are stored at TrollLabs.
- It was interesting to note the difference in table 6.1, regarding the last couple of samples. It seemed the longer acid bath time used for two of the samples (22 & 26) affected the roll off angle negatively. This should be further investigated, to see if the SEM pictures shows distinct differences to **sample 8**, shown in figure 6.4.
- To improve the test table a motor could be installed, tilting the table for instance 1°every time a button is clicked. Even though the table is accurate as is, it would allow for more control, and improve the user interface, if done correctly.
- A larger scale setup should be constructed. Starting with a 1:2 scale of cross country skis for instance, testing could be done when the snow comes at the end of the year. This setup can be constructed by making a custom plastic container with large enough dimensions to fit 1:2 cross country ski. Starting with this in august would provide enough time to get the test prototypes done in time for the winter season.
- The chemical etching process should be revisited. It is possible to etch the samples at a longer period, to make sure the etching has made the surface as smooth as possible. As the procedure is described in this thesis, it is straight forward to make this setup and do the tests to confirm whether or not chemical etching can contribute to improving the surface finish after the anodizing has occurred.

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Appendix A

Prosjektoppgave

This is the project thesis written in the fall of 2016.

NTNU – Trondheim
Norwegian University of
Science and Technology

Rethinking Surfaces and Designs for Ski

Andreas Skoglund

December 2016

PROJECT THESIS

Department of Engineering Design and Materials

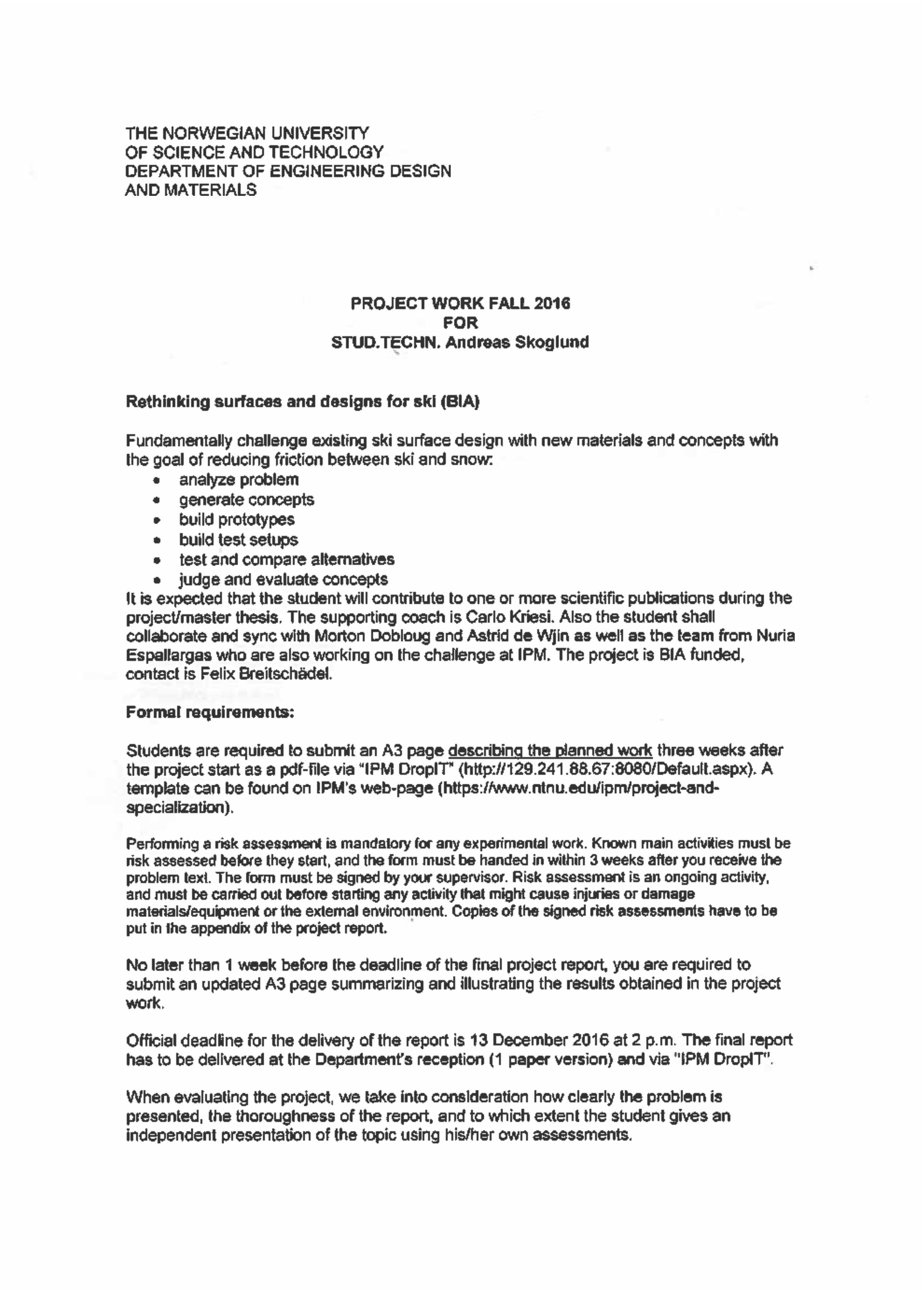
Norwegian University of Science and Technology

Supervisor 1: Professor Martin Steinert

Supervisor 2: Carlo Kriesi

Company Contact: Felix Breitschädel

TrollLABS



THE NORWEGIAN UNIVERSITY
OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF ENGINEERING DESIGN
AND MATERIALS

PROJECT WORK FALL 2016
FOR
STUD.TECHN. Andreas Skoglund

Rethinking surfaces and designs for ski (BIA)

Fundamentally challenge existing ski surface design with new materials and concepts with the goal of reducing friction between ski and snow:

- analyze problem
- generate concepts
- build prototypes
- build test setups
- test and compare alternatives
- judge and evaluate concepts

It is expected that the student will contribute to one or more scientific publications during the project/master thesis. The supporting coach is Carlo Kriesi. Also the student shall collaborate and sync with Morton Dobloug and Astrid de Wjin as well as the team from Nuria Espallargas who are also working on the challenge at IPM. The project is BIA funded, contact is Felix Breitschädel.

Formal requirements:

Students are required to submit an A3 page describing the planned work three weeks after the project start as a pdf-file via "IPM DropIT" (http://129.241.88.67:8080/Default.aspx). A template can be found on IPM's web-page (https://www.ntnu.edu/ipm/project-and-specialization).

Performing a risk assessment is mandatory for any experimental work. Known main activities must be risk assessed before they start, and the form must be handed in within 3 weeks after you receive the problem text. The form must be signed by your supervisor. Risk assessment is an ongoing activity, and must be carried out before starting any activity that might cause injuries or damage materials/equipment or the external environment. Copies of the signed risk assessments have to be put in the appendix of the project report.

No later than 1 week before the deadline of the final project report, you are required to submit an updated A3 page summarizing and illustrating the results obtained in the project work.

Official deadline for the delivery of the report is 13 December 2016 at 2 p.m. The final report has to be delivered at the Department's reception (1 paper version) and via "IPM DropIT".

When evaluating the project, we take into consideration how clearly the problem is presented, the thoroughness of the report, and to which extent the student gives an independent presentation of the topic using his/her own assessments.

The report must include the signed problem text, and be written as a scientific report with summary of important findings, conclusion, literature references, table of contents, etc. Specific problems to be addressed in the project are to be stated in the beginning of the report and briefly discussed. Generally the report should not exceed thirty pages including illustrations and sketches.

Additional tables, drawings, detailed sketches, photographs, etc. can be included in an appendix at the end of the thirty page report. References to the appendix must be specified. The report should be presented so that it can be fully understood without referencing the Appendix. Figures and tables must be presented with explanations. Literature references should be indicated by means of a number in brackets in the text, and each reference should be further specified at the end of the report in a reference list. References should be specified with name of author(s) and book, title and year of publication, and page number.

Contact persons:

At the department	Martin Steinert, Carlo Kriesi
From the industry/BIA	Felix Breitschädel

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Preface

This sports science project report is written as a part of the masters program in Mechanical Engineering at the department of Engineering design and Materials at NTNU.

The report has been written during the fall semester of 2016, and has been done in cooperation with Olympiatoppen. Olympiatoppen provided the initial problem formulation, experience and funding for this thesis, and the idea from Olympiatoppen was to reduce the overall friction on cross-country skis.

Trondheim, 2016-13-12

Andreas Skoglund

Acknowledgment

I would like to thank the following persons for their great help during this project.

My supervisor Martin Steinert, & co-supervisor Carlo Kriesi, for continuous supervision and helping me stake out a course for the project, and to stay on course.

Felix Breidtschädel, my contact person at Olympiatoppen, and also the leader of "Forsprang 2018", for useful reading material, and for allowing me to get some inside knowledge from the national skiing team.

To my fellow project partner Morten Dobloug, for good team work, and getting the best out of each other in terms of brainstorming and massive amounts of research.

To all the guys at BAT, SIAT and TrollLabs, for helping when we needed, and last but not least, the national skiing team, for inviting us to Beitostølen November 2016, giving us much appreciated knowledge regarding ski treatment.

A.S.

Acronyms

UHMWPE Ultra high molecular weight polyethylene

PTFE Polytetrafluorethylene(Teflon)

BAM Boride aluminium magnesium

R&D Research & Development

GLF10 Glidewax Low Fluor

GL40 Glidewax

CH10 Glidewax

BAT Department of Civil and Transport Engineering

SIAT Centre for Sport Facilities and Technology

CF Coefficient of friction

FIS International Ski Federation

EiT Experts in Team

Summary and Conclusions

This project has revolved around two main components, skis and snow. The challenge is to reduce friction between the two surfaces, resulting in improved glide. Several tests has been done, to establish the ground work for the master thesis, and developing knowledge about this challenge.

Tests including hydrophobic properties, ski gliding tests in Beitostølen and sodium reactions with snow has been accomplished, with both expected and unexpected results. The main surface material for skis, Ultra High Molecular Weight Polyethylene has been tested and found to have disappointing hydrophobic properties. This contradicts both research and selling arguments surrounding this material.

There has been built a test rig for testing materials against the state of the art, and is built in a 1:4 scale. This gives the possibility to test materials directly against state of the art, comparing every test run. The rig is built similar to how the ski tests are performed as of today, with what is called a parallel test. This means the test rig can give accurate and constant results, that should be comparable to state of the art tests.

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Chapter 1

Introduction

1.1 Background

Competitive cross country skiing has been around for a long time, but even earlier, skis where widely used as a transportation device for travelling long distances.

The first skis where made of different types of wood, but mainly hickory, for its high hardness properties. Although hickory is still used in some ski production to this day, technology has progressed, replacing hickory with improved materials, like ultra high molecular weight polyethylene (UHMWPE) and polytetrafluoroethylene(PTFE). The big breakthrough took place in the 1974 World Cup, when polyethylene was discovered to have excellent properties for cross country skiing, and has since been used for the main base material. After 1974, many technological improvements has been made, but the base still remains the same. UHMWPE is being mixed with other additives, like molybdendisulfide or fluoride, in order to further enhance its properties, making it even more suited for cross country skiing (Rogowski et al., 2005; Brydson, 1999).

The main purpose of this project thesis is to study new ways to improve the gliding conditions on skis.

As the sport continues to grow, the competition is growing, and the amount of money put into R&D in cross country skiing today is immense. For this project to be able to develop, or discover, materials and new approaches, it is therefore necessary to think outside the box, and look at new ways that are not common in the ski world today. This project has looked at other industries,other materials, and other properties than what could be considered the current norm.

Utilizing the product development approach at NTNU, we are able to look at things from a new angle, and hopefully discover something of interest. Interesting not only for the project, but also for the national cross country skiing team, because better skis could result in more medals.

But first of all, in order to find the solution to our challenge, understanding the problem itself is necessary.

There are two main hypotheses formulating how skis glide on snow, stated by (Takeda et al., 2010). The first one is the adhesion theory, which states that the shearing strength of ice is small when compared with base materials. The second hypothesis is the melt-water lubrication theory, which states that melting ice produces water that acts as lubrication between the snow and ski.

Problem Formulation

With the hypotheses above in mind, the challenge for this project is to look at new materials and design, that will improve the glide in cross country skiing.

To do this in a systematic and controlled manner, we need a test rig for doing measurements and comparing different alternatives. The main purpose of the rig is to control as many different variables as possible. This is not an easy task, but trying to imitate the way the national team is doing it right now, and taking it into an even more controlled environment should be a good starting point.

1.2 Objectives

The main objectives of this project are

1. Analyze the problem(s)
2. Generate concepts
3. Build prototypes
4. Build test setups
5. Test and compare alternatives
6. Judge and evaluate concepts

1.3 Limitations

Starting the project in the early fall will impose some important limitations. Lack of snow means we may not able to get out and do field tests as early as we would like, and the project is also dependant on good snow conditions throughout the winter season. As we know these are variable we have no control over.

We are exclusively looking at the skating version of cross country skiing for this project, because that means we can focus solely on the glide zone. The challenge for the project is to improve ski gliding, which means grip wax is not included.

1.4 Approach

Using knowledge based on the education here at NTNU, and resources available at NTNU, the project will start by trying to analyzing and understanding the challenge. Understanding the challenge and associated problems will be helpfull in taking the next steps. This will include literature search, and information gathering, both to understand what research has already been done, and to better understand the main challenges.

The project approach will be to narrow down the variables as much as possible, for each test. There are many variables that are difficult to compare to one another, and it is easier to obtain data that can confirm or disregard a hypothesis if we can be specific in our testing.

Prototyping is an integral part of the TrollLabs approach, which means there will be several mock ups and prototypes involved in the development of the test rig. Finding the best materials for better ski gliding involves testing these on the rig, which will give us the possibility to evaluate how the different materials behave, compared with the current state of the art.

Chapter 2

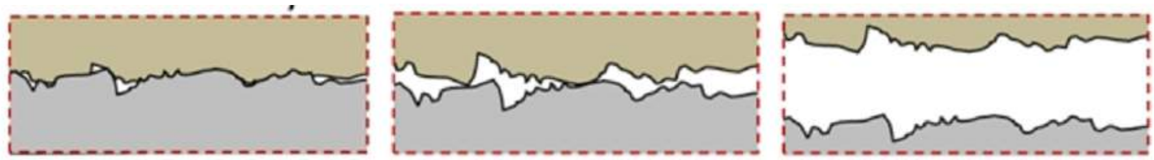
Gliding theory

2.1 Friction

Friction is defined by Merriam-Webster (2016) as "the force that resists relative motion between two bodies in contact." It is a subtopic in the field of tribology, derived from the Greek, which is the study of friction, lubrication and wear, on interacting surfaces (Williams, 2005). This is an essential part of this project, where the base material and the snow is the interacting surfaces, or bodies as stated in the definition. It is critical to understand how friction works, to fully comprehend the challenges in trying to reduce friction. Friction consists of several different types:

1. Dry friction
2. Fluid friction
3. Lubricated friction
4. Skin friction
5. Internal friction

The three relevant types of friction in this project is dry, fluid and lubricated friction (Bowden and Hughes, 1939; Fuss et al., 2013). As stated by Bowden and Hughes (1939), the friction heat between the snow and base material results in a waterfilm, showed in 2.3. This waterfilm acts as a lubricant between the two surfaces (Burniston et al., 2007). Dry friction is related to the kinetic and static friction that occurs especially in cold snow conditions, where the waterfilm requires more heat to develop. Dry friction is also what happens early in a ski race, before the athletes has started. This feels as your ski is stuck in the snow. Lubricated friction is a state where you have a mix between dry and fluid friction, while fluid friction means you have a full layer of fluid between the two interacting surfaces. These three stages is shown in the figures below (2.1).



(a) (b) (c)

Figure 2.1: a) Dry friction b) Lubricated friction c) Fluid friction

As stated above, dry friction, lubricated and fluid friction are the three most important friction methods when it comes to ski friction (Bowden and Hughes, 1939). Fuss et al. (2013) has made a simplified equation for which friction coefficients that is at work when skiing on snow 2.2.

$$\mu = \mu_{Plough} + \mu_{Dry} + \mu_{Lub} + \mu_{Cap} + \mu_{Dirt}$$

Figure 2.2: Simplified equation for friction on snow (adapted from Fuss et al. (2013).

While μ is the total friction,

μ_{Plough} is caused by wear of the material

μ_{Dry} is caused by solid deformation

μ_{Lub} is caused by the water film

μ_{Cap} is caused by capillary attraction

μ_{Dirt} is caused by surface contamination

Our aim is to decrease the total friction, this can be done by reducing these friction factors individually:

$\mu_{\text{Plough}} \Rightarrow 0$ by using a material for the ski base that is harder than snow

$\mu_{\text{Dry}} \Rightarrow 0$ sufficient water film to prevent dry friction

$\mu_{\text{Lub}} \Rightarrow 0$ by achieving optimal thickness of waterfilm

$\mu_{\text{Cap}} \Rightarrow 0$ by using materials with high hydrophobicity

$\mu_{\text{Dirt}} \Rightarrow 0$ by using materials with dirt repellent properties

2.2 Snow

The project is revolving around two main components. The ski, and the surface the ski is working on. Understanding the problem at hand, means understanding how the base material interacts with the snow. Snow will react different with the base, as a function of several variables. Newly fallen snow will behave in a different way than snow that has been lying for days. Old snow has higher density than new snow because the snow grains change form and loose surface area as they get older, and this in turn affects the way the water film is made (Burniston et al., 2007; Moldestad, 1999).

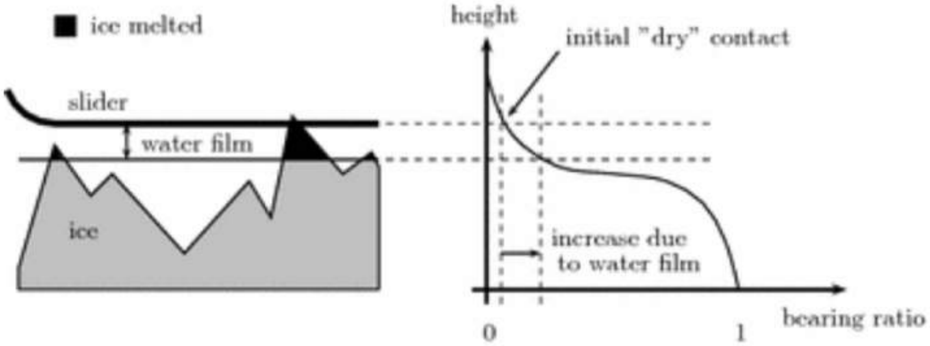


Figure 2.3: Initial relation between water film as a result of friction. This is called bearing ratio, and is the relation between thickness of water film and real contact area. When the ice peaks melts, more ice/snow is in contact with the water film, resulting in a larger contact area. (Bäurle et al., 2006)

As shown in 2.3, the water film is a thin layer of water, developing between the snow and the base, based on frictional heat (Bowden and Hughes, 1939). This heat is a product of the kinetic friction, made from dry friction, wet friction and capillary drag effects (Glenne, 1987; Colbeck, 1988).

There are many theories, and there has been done a lot of research, on water thickness. Coupe and Spells (2009) measured it to be 5-20μmeters, Ambach and Mayr (1981) measured the water film at zero degrees Celsius and at a velocity of twenty km/h, to be 13.5 μmeters, while Fuss et al. (2013) stated that it was about 5-14 μmeters under similar conditions. These results show that there are similarities between the tests, but there are large uncertainties as to what thickness is optimal (Bäurle et al., 2006). However, there are evidence that to much water film leads to a higher friction between the snow and the base (Armstrong-Helouvry, 1993; Nachbauer et al., 1996), which means it is important to find the optimum condition, having lubricated friction from the water film, but still not introducing capillary action (Ishida and Rimdusit, 1998; Colbeck, 1996). "Capillary action is the tendency of a liquid to rise in narrow tubes or to be drawn into small openings such as those between grains of a rock." (Rank,

2007) In relations to the base material, too thick water film will make the water draw itself up towards the base, because of surface tension. This decreases friciton, and is unwanted.

Armstrong-Helouvry (1993) showed in 1993, that the coefficient of friction(CF) changes depending on the thickness of the water film, seen in figure 2.4. As presented in section 2.1, we have three important differences in friction. Dry, lubricated and fluid. In figure 2.4, we can see that the friction is constant in the first zone(dry friction). It then steadily decreases as lubricated friction is introduced. This is both dry and fluid friction. Lastly, we can see that with full fluid lubrication, the friction starts increasing again, because of the previously stated capillary effects (Colbeck, 1996).

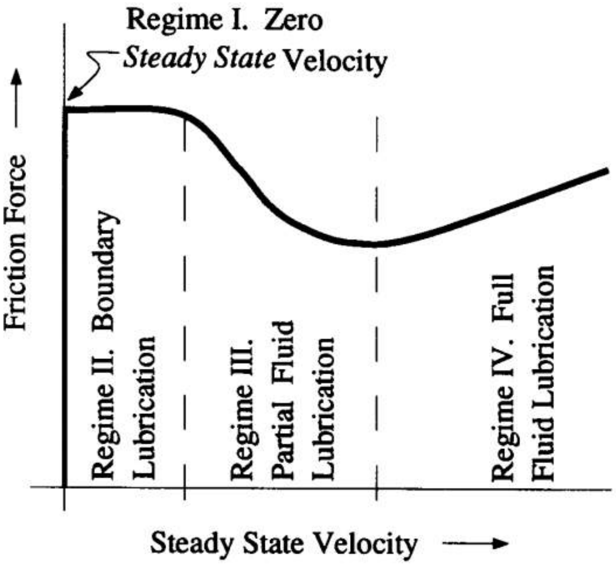


Figure 2.4: Stribeck curve showing CF depending on waterfilm thickness

It is shown by Bowden and Hughes (1939); Schindelwig et al. (2014), that there is a direct correlation between temperature of the snow and the thickness of the water film provided at equal velocities. This is related to the hardness of the snow, which is shown by Tusima (1975); Magono and Chung (1966), stating that increased hardness is linearly correlated to decrease in temperature(from -0° to -40° Celsius) .

There are many different types of snow, each with its own characteristics. It is important to know the main differences between the snows, to better understand how they behave with the base material.

Our project started at a research level, in order to gain a better knowledge of how snow actually works and in order to formulate our approach to solving the project challenge and problems.

Starting at the boundaries, which are easier to define, we have:

- Cold, hard snow
- Warm, soft snow
- Natural snow
- Artificial snow

2.2.1 Cold, hard snow

Cold snow is much harder than warm snow (Tusima, 1975; Glenne, 1987), so the snow crystals can withstand more kinetic energy before they melt and turn into water film. This means there is a higher demand in terms of shear resistance and hardness from the material, to prevent damage to the sole. Cold snow will also result in a thinner water film, as it takes more energy to melt. In order to create a thick enough water film, it requires higher kinetic friction, which leads to a higher friction between the ski and sole (Bowden and Hughes, 1939).

2.2.2 Warm, soft snow

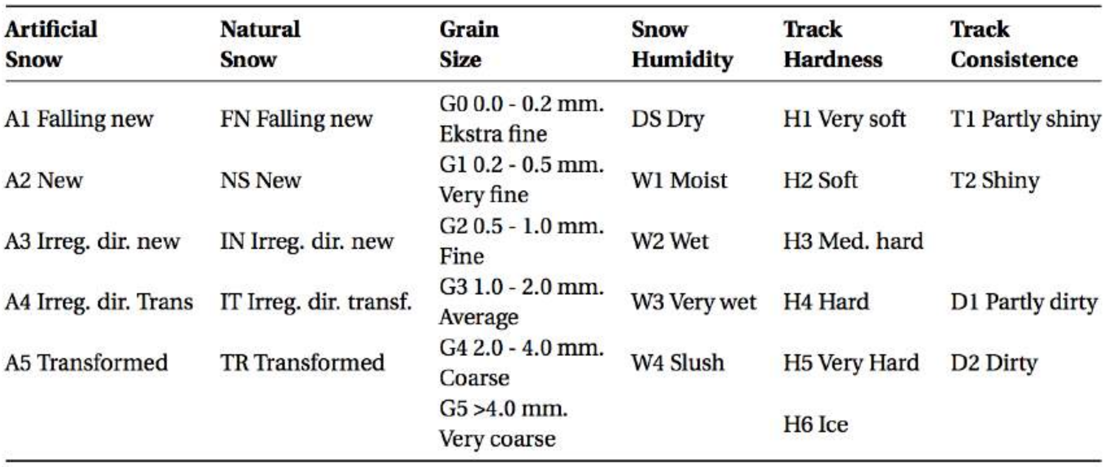
Warm snow will melt easier than cold, meaning there will be an increased thickness of water film compared to cold snow, at equal velocities (Glenne, 1987). This reduces the importance of hardness, but increased thermal conductivity might be necessary to remove heat from the surface, to prevent too thick water films which will decrease glide because of capillary effects (Colbeck, 1992; Ishida and Rimdusit, 1998; Colbeck, 1996).

2.2.3 Natural snow vs artificial snow

In later years, the use of artificial snow has increased. This is partly because of environmental issues regarding global warming, where an increase in average temperatures makes the weather more unpredictable, so that places where there used to be stable snow conditions during the winter, are now experiencing far bigger uncertainties (Breiling and Charamza, 1999). Artificial snow is easier to control, and can be produced whenever it is needed, which makes it a good substitute, or supplement, to natural snow, when necessary.

There are, however, some distinct differences between artificial and natural snow. The biggest difference is in the forming of snow. While real snow freezes from the inside out, expanding over time, creating perfect snow crystals, the artificial snow is made from water droplets that freezes outside in (TOKO, 2010; Lind and Sanders, 2013). Freezing outside in, they expand in the center, resulting in breaking of the crystal, producing sharp edges, which is contrary to natural snow. Artificial snow also has higher density, hardness and contact area, meaning that there are different specifications required from the ski base for skiing on natural snow versus skiing on artificial snow.

Table 2.1: Swix snow characterization table adapted from Sætha and Lukertšenko (2014).



Artificial Snow	Natural Snow	Grain Size	Snow Humidity	Track Hardness	Track Consistence
A1 Falling new	FN Falling new	G0 0.0 - 0.2 mm. Ekstra fine	DS Dry	H1 Very soft	T1 Partly shiny
A2 New	NS New	G1 0.2 - 0.5 mm. Very fine	W1 Moist	H2 Soft	T2 Shiny
A3 Irreg. dir. new	IN Irreg. dir. new	G2 0.5 - 1.0 mm. Fine	W2 Wet	H3 Med. hard	
A4 Irreg. dir. Trans	IT Irreg. dir. transf.	G3 1.0 - 2.0 mm. Average	W3 Very wet	H4 Hard	D1 Partly dirty
A5 Transformed	TR Transformed	G4 2.0 - 4.0 mm. Coarse	W4 Slush	H5 Very Hard	D2 Dirty
		G5 >4.0 mm. Very coarse		H6 Ice	

2.1 is a table adapted from Swix, which shows a standardization of different snow types. This is very helpful and vital in the search for optimal glide in ski races. However, the collection procedure of the different values are very important, as different testing parameters yields different results, and standardazied tables like this will no longer be relevant. Therefore it is important that one follows a standard format for extracting these results.

2.3 State of the art

2.3.1 Ski base

UHMWPE

Ultra-high-molecular-weight polyethylene (UHMWPE) is most commonly used as ski base material. It is a subset of the thermoplastic polyethylene, which is a high performance polyethylene with extremely long chains. These chains are what makes the material so tough, and is one of the reasons why it is the standard material for cross country skis (Fischer et al., 2008). It has a very low coefficient of friction, and high wear resistance(Ducret et al., 2005). As a bonus, it is cheap to produce in large quantities.

PTFE

Polytetrafluoroethylene (PTFE) is a fluoropolymer of tetrafluoroethylene, and has many different uses. It is best known as Teflon, developed by DuPont Co. in 1938. PTFE is the result of changing all the hydrogen atoms in UHMWPE with fluoride atoms.

In cross country skiing, PTFE is both used as powder or wax-additions, but can also be used as an additive to UHMWPE, in order to reduce the friction coefficient (Brydson, 1999). The reason for adding fluoride can be explained by its place in the periodic table. It is in the top right corner, which implies it has a very high electro negativity, making it dirt repellent (Swix, 2011). PTFE also has a lower CF, compared to UHMWPE, but worse mechanical properties like hardness (Haaland, 2013). Because of this it is best used as an additive.

2.3.2 Glide wax

Glide wax is widely used, although not without some controversy. Research has been made, that is substantiating the notion that gliding wax is not enhancing the properties of the ski, but actually, making them worse (Kuzmin and Tinnsten, 2006; Kuzmin, 2006). This needs to be viewed at with skepticism, as much of this research is done by one scientist, who may have some personal interest in disproving wax enhancing (Scheve, 2012; Kuzmin, 2016). Nevertheless, the majority of research support glide wax as the best option to enhance glide (Rogowski et al., 2007; Karlöf and Axell, 2005, 2008; Buhl et al., 2001; TOKO, 2010; Coupe and Spells, 2009).

Wax comes in large varieties. From rock hard, to silky soft, depending on the snow conditions. From tribology, we know that the friction coefficient is lowest when two materials of similar hardness glides against each other (Förch and Jenkins, 2009). While UHMWPE has a constant hardness, wax with different hardness is applied, depending on the snow conditions. One can therefore argue that wax is being used, not to increase the hardness, but to best imitate the hardness of the snow, decreasing the friction (Karlöf and Axell, 2008).

However, it is proven that most wax has been removed by abrasion during the early part of a ski race (Kuzmin, 2006; Karlöf and Axell, 2005). This implies that there is an advantage by using wax, but it is uncertain for how long it will remain an advantage during a race.

The main reason for including this part in the materials section, is because we think it could be interesting to use materials from waxing, directly in the ski base, before extruding and sintering the base. It was shown by Hasler et al. (2014), that different base grinds will respond different to different waxes. This means if you could use the wax as an additive, you can disregard these factors, and possibly enhance the characteristics of the base, without loosing the positive sides of the wax as early as one does now.

2.4 Key factors

Before starting to look at materials for testing, we narrowed down the problem into simple factors, which made it easier to find suitable materials fitting the problem challenge. Research carried out during the project concluded with four different material factors that are the most important for increasing speed while skating in cross country skiing (Fuss et al., 2013)

- **Wear resistance**

  In material science, "wear is erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface." (Rabinowicz and Tanner, 1966)

  When we talk about wear resistance, it is related to the interaction between the snow and the base material, and how well the material can withstand deformation as a result of frictional forces from the snow. If a material has low wear resistance, it will gradually be worn down when gliding against a surface, which is unfavorable for achieving the optimum ski glide.

- **Hardness**

  Hardness is measured by how a material resists permanent shape change, when exposed to compressive forces, also called plastic deformation. There are different types of hardness; scratch hardness, indentation hardness, and rebound hardness. Hardness depends on ductility, elastic stiffness, plasticity, strain, strength, toughness.

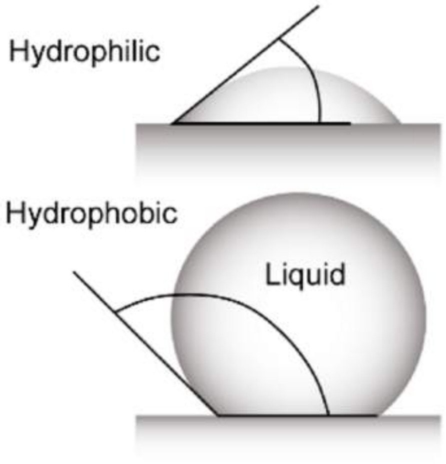


Figure 2.5: Difference between contact angles of water on hydrophobic and hydrophilic surfaces (adapted from Förch and Jenkins (2009)).

There are several different hardness scales, but the one we mainly will use for our tests is Brinell. The different methods are not scalable above a certain level of hardness, meaning you cannot directly correlate Brinell with for instance Vickers, so it is necessary to keep the hardness test as a project constant.

- **Hydrophobicity** If a material is hydrophobic, it seemingly repells water poured on it. However, the correct definition is just an absence of attraction (Ben-Naim, 2012). This can vary in some degree, which can be seen in 3.1. According to Giesbrecht et al. (2010), hydrophobic surfaces experience lower friction than hydrophilic.

  Hydrophobic molecules are usually nonpolar and, therefore, prefer neutral molecules and nonpolar solvents. As known, water is polar, thus hydrophobes don't dissolve well amongst them. Water on hydrophobic surfaces will exhibit a high contact angle, which is shown in figure 3.1, where the hydrophobic surface angle is larger than the hydrophilic. As a reference point, all surfaces with angles >90 are considered hydrophobic (Förch and Jenkins, 2009; Grodzka and Pomianowski, 2006).

- **Thermal conductivity**

  Thermal conductivity refers to the property a material has to conduct heat (Hetnarski, 2014). If a material has low thermal conductivity, heat will transfer at a lower rate, than if it has high thermal conductivity. For our project, this means that a material with high conductivity, will transfer the heat from the friction forces quicker, and in turn decrease the amount of water film made by friction. This means that different conductivity properties are important when looking at snow at different temperatures.

Based on this list, the project looked for materials with properties that could be of interest for further testing. The result of this work is listed below.

2.5 Materials

- Gallium
- Molybdenum disulfide(MoS2)
- Steel
- BAM
- Electroless Nickel-Teflon (EN)
- PTFE
- Graphene
- Zirconia (ZrO2)
- Aluminosilicate (gorilla glass)
- Teflon spray
- Anodized aluminium oxide

These are the materials of most interest, and table 3.1 below shows a comparison to the materials used in todays skis, emphasized on the four most important material properties established above. (note: as many of these materials are difficult to find mechanical properties on, this table is preliminary data, and is in no way complete. 1=unknown)

Table 2.2: Material data (Dobloug, 2016).

	Hardness	Wear resistance	Hydrophobicity	Thermal conductivity
UHMWPE	360	0.0092	High	0.93
UHMWPE+	365	0.0037	High	1
PTFE	34.3	1	High	0.25
PTFE X	1	1	High	1
Aluminosilicate	552	High	1	1.16
Hexagonal MoS2	271	1	1	2.3
Graphene	1	1	1	1
Zirconia	145	High	1	2
BAM	1	1	1	1
EN	1	1	1	1
Gallium	62.75	1	1	40.6
Aluminium foam	71	1	1	50
BNP	1	1	1	32.5

Chapter 3

Materials

3.1 Key factors

Before we started to look at materials for testing, we tried to narrow down the problem into simple factors, which could make it easier to find materials fitting our need. After some research, we ended up with four different material factors that are the most important for increasing speed while skating in cross country skiing (Fuss et al., 2013)

- **Wear resistance**

  In material science, "wear is erosion or sideways displacement of material from its "derivative" and original position on a solid surface performed by the action of another surface." (Rabinowicz and Tanner, 1966)

  When we talk about wear resistance, it is related to the interaction between the snow and the base material, and how well the material can withstand deformation as a result of frictional forces from the snow. If a material has low wear resistance, it will gradually be worn down when gliding against a surface, which is something we don't want.

- **Hardness**

  Hardness is measured by how a material resists permanent shape change, when exposed to compressive forces, also called plastic deformation. There are different types of hardness; scratch hardness, indentation hardness, and rebound hardness. Hardness depends on ductility, elastic stiffness, plasticity, strain, strength, toughness.

  There are several different hardness scales, but the one we mainly will use for our tests is Brinell. The different methods are not scalable above a certain level of hardness, meaning you cannot directly correlate Brinell with for instance Vickers, so it is necessary to keep the hardness test constant.

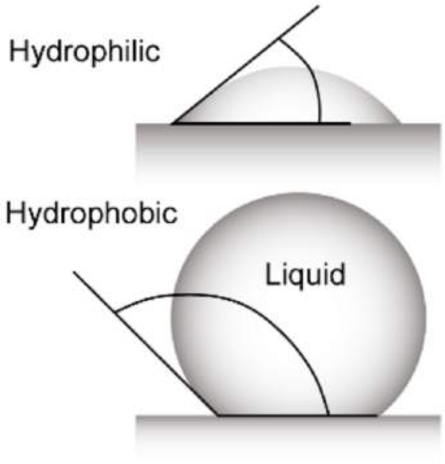


Figure 3.1: Hydrophilic vs hydrophobic
Difference between contact angles
of water on hydrophobic and hydrophilic surfaces (adapted from Förch and Jenkins (2009)).

- **Hydrophobicity** If a material is hydrophobic, it seemingly repells water poured on it. However, the correct definition is just an absence of attraction (Ben-Naim, 2012). This can vary in some degree, which can be seen in 3.1. According to Giesbrecht et al. (2010), hydrophobic surfaces experience lower friction than hydrophilic.

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- **Thermal conductivity**

  Thermal conductivity is a term that refers to the property a material has to conduct heat (Hetnarski, 2014). If a material has low thermal conductivity, heat will transfer at a lower rate, than if it has high thermal conductivity. For our project, this means that a material with high conductivity, will transfer the heat from the friction forces quicker, and in turn decrease the amount of water film made by friction. This could mean that different conductivity properties are important when looking at snow at different temperatures.

Based on this list, we began looking for materials that, in some ways, could be interesting for further testing. The most interesting materials are listed below.

3.2 Materials

- Gallium
- Molybdenum disulfide(MoS2)
- Steel
- BAM
- Electroless Nickel-Teflon
- PTFE
- Graphene
- Zirconia (ZrO2)
- Aluminosilicate
- Teflon spray
- Anodized aluminium oxide

These where the materials we found most interesting, and table 3.1 below shows them compared to the materials already used in skis, emphasized on the four most important factors established above.

Table 3.1: Material data (Dobloug, 2016).

	Hardness	Wear resistance	Hydrophobicity	Thermal conductivity
UHMWPE	360	0.0092	High	0.93
UHMWPE+	365	0.0037	High	1
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Aluminium foam	71	1	1	50
BNP	1	1	1	32.5

Chapter 4

Product development

Introduction to Product Development

The product development of this project is in accordance with the objectives listed in chapter 1.2.

The most important part of product development, in relation to this project, is the objectives about prototyping. Developing new ideas, and bringing them to life as a prototype is a good way of presenting your views to partners, colleagues and customers. It is also a great way for oneself to get a better understanding of how ideas work in a way that is more tangible than other approaches.

In every project there are different needs for prototypes, and in this particular project it has been difficult to exploit the prototyping benefits to its full potential. This is partly because time was needed to research the proper materials we were looking for, and parts because of the lack of snow, which is critical for the value of these types of prototypes. It remains important to have a working prototype ready for the master thesis project starting in January.

4.1 What is prototyping

Prototyping is a tool that is very often used, especially by product developers, in the early stages of a project. The main purpose is to get a tangible understanding of how the product is shaping, and making it easier to look at what needs to be done differently and what works well.

By developing a simplistic version of an idea, including only the most essential elements, it is possible to test and get a better understanding of how the different elements work together. This, in turn, provides the developer a better possibility to improve things for the better, and make a better prototype with the actual changes. By making several prototypes, and testing them over a short amount of time, also known as short term sprints, it is much easier to get an understanding of how things are progressing. "If a picture is worth a thousand words, a prototype is worth a thousand meetings." (Maeda, 2015)

What this means is that while there are some advantages in performing brainstorming sessions

Figure 4.1: Mindset of prototyping

in order to develop ways to create, or improve a product, an early stage prototype gives even better visions and understanding on how developers imagine their creations. This in turn, gives people outside the project a far better understanding, and a better chance to get inside the mind of the creators. Working with prototypes chances are, people will easier come up with creative ideas based on this design, compared to a more theoretical approach.

Inside the world of prototyping, there are different ways of working, depending on many factors. For instance, a designer would look at different elements than an engineer (Creative, 2016). While the engineer looks at possible technological solutions and whether the proposed solutions are within budget, if it can be done efficient and proper with cheaper production equipment, or if there are factors involved that makes some of the solutions too far fetched. On the other hand, the designer looks primarily at the aesthetics. User experience and feasibility won‘t necessarily be top priority, but more to get a feel on how it can look. This can be achieved with simple photo editing softwares, for instance. The objective is to get a feel of the essential ideas behind, the concept, and not spending time on perfecting the first proposal. The main purpose of this prototype is for both developer and colleagues to get a deeper understanding of the idea, or concept. A first mock up could be as simple as a cardboard version of the idea, simply a sketch coming to life. It should tell something about what the product *could* look like, what it *could* feel like, or what it *could* do, but these are not absolutes.

As shown in figure 4.1, you may easily discard the whole idea after the first couple of mock ups, if you see that the idea is not working. This is one important reason low cost prototyping is a good approach in the early project stages. A simple mock up in cardboard based on drawings is easier to discard than a three weeks development of a 3D-printed model. Not only does it give efficient and tangible results, but it also gives a production team the option to build several mock ups based on different ideas at an early stage of the project. This allows for comparing different solutions, and ideas, before concluding on the project development. This also helps avoiding design fixation, which is a known phenomenon where the project invests so heavily in the original idea, that no other, possibly better options, are considered any more.

There is however, different approaches to prototyping, depending on how far along in the development process the project is. If the project is still at the front end of the idea and still pitching possible solutions, trying to look as broad as possible for solutions in order to not overlook good ideas, simple and cheap prototyping is the best method. This is also the mindset used in one of my previous courses, Fuzzy Front End (Steinert and Leifer, 2012). The idea is to diverge at the start of the project, considering all possible solutions, leaving nothing behind. All ideas are good ideas in the beginning, and serves the purpose of looking at the problem from all possible angles. When a project is spending as little time as possible making their visions into tangible prototypes for others to see, it is easy to stay on the same page, and for others to participate in a constructive product development. One approach to achieve this is whats called "Wizard of Oz" (Kelley, 2016), which really means to "show" how the intentions of your idea is supposed to work, by for instance using your hands instead of motors. This means you circumvent the time consuming process of making a code and wiring a motor to do what it should, instead you just use your hands instead, moving the parts as they are intended, with as little effort as possible in the making of a simple "prototype". This can be a real time saver, while still giving the team good insight to thoughts and ideas and this leads to a wide range of possible solutions. This takes us to the next part of the Fuzzy mindset; converging. After brainstorming, finding as many solutions as possible, the next goal is to single out the best ideas, converging and focusing on bringing the best out of these ideas. The end result will be an idea that looks good, solves the problem at hand and is tested against other possible solutions before concluded.

If the prototype will be shown to potential investors, clients or buyers, the prototype needs to be of sufficient quality. High quality 3D-printing or laser cutting would be good options. Although this is still a prototype, it needs to have both the aesthetics and the technological solutions, to convince the user groups/investors. This means more time is needed, more quality materials, and overall more time spent on prototyping. This is for a later stage of the process, and since the project for this semester is in its early phase, rapid, simple prototyping is preferred.

4.2 Concept development

The progress toward the making of prototypes was slow. For many weeks, we were brainstorming the challenge, trying to find out where the potential nuggets were, rather than getting tangible information by developing prototypes. However, this turned out as a good approach, defining the challenge more clearly, making it easier to develop a fitting mock up for the first prototype of the test rig. So because of the way we started, where analyzing the problem itself was prioritized, prototyping started later in the semester. However, the number of prototypes exceeded what was planned, and each of these were looking at different things to implement. The last prototype is a combination of all the things we took from the previous ones, and ended up with a prototype that can do accurate time measurements without interference from humans, which means the measurements should be both constant and accurate.

What is important to note, is that our project is dealing with a research question that has been around for years. Many research papers were studied prior to making the prototype, and we observed that nearly all testing was done in relatively uncontrollable environments. The procedure for testing skis was pretty much the same, a man standing on the top of a hill, with a pair of skis attached, and then gliding down the hill. One example to substantiate potential errors, as we also got confirmed at Beitostølen, is that the test results depend heavily on the skills of the athlete doing the test. If the test cannot be replicated identically each time, wind forces and pressure distribution will be different (Bäckström et al., 2008), which will result in large variations in the tests. We felt that the potential errors in including humans as a variable could be very big, so we decided to do our best to take the human factor out of the equation.

Another factor of great importance for this process, has been the snow conditions in Trondheim, or rather, the lack of snow. We have had close to no consecutive snow days, which makes it difficult to test the prototypes in relevant conditions. We compensated by doing simple tests like covering the prototype with a thin plastic film, and letting water run down the film, just to observe how the different test materials behave. However, this is very far from the actual condition, and might not be relevant for the project. As mentioned earlier, this has been part of why the materials part of the project has been more interesting to work with, simply because we have had no possibility to actually do the work with snow.

Prototyping

Mock Up

After the initial brainstorming sessions, we made progress in developing how we thought a rig should look like. Simple drawings were prepared to illustrate different ideas and approaches. The mock up is made out of simple card box, just to demonstrate how the rig is supposed to work, seen in 4.2. It consists of four straight legs, with a flat surface on top, and a ramp attached to it, with a 30° angle. There are also markers attached in four different places where the time measurement equipment is being placed. On top there is also a mechanism to release the test specimens when the test is starting, to avoid potential errors that could appear if we were to release them ourselves.

Figure 4.2: Card board mock up

CAD-model

Before constructing the mock up, a CAD-model was developed, just to get a real sense of the dimensions involved, and to make sure the dimensions added up. This was a very plain, simple CAD-model, based on the mock up discussed in the previous paragraph. Railings were added for the guidance system, which is shown in 4.3. This was implemented at a later stage, and was therefore not implemented in prototype 1. The model was deliberately made without the timing system, as that would be a lot of unnecessary work that would be easier to implement in the prototype.

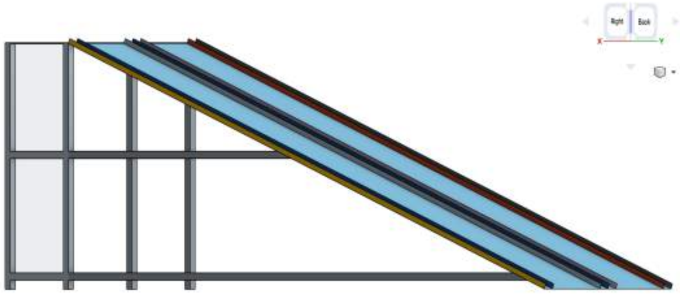


Figure 4.3: CAD-model of mock up

Prototype 1

Prototype 1 is a product of the CAD-model, and is a 1:4 scaled version of the rig. It is made out of MDF and wood.

Laser diodes and photo resistors were added for measuring the time it takes for a specimen to glide down the ramp, and the code itself works out good. It starts the time at the first breaking of the laser barrier, and stops when it breaks the second barrier.

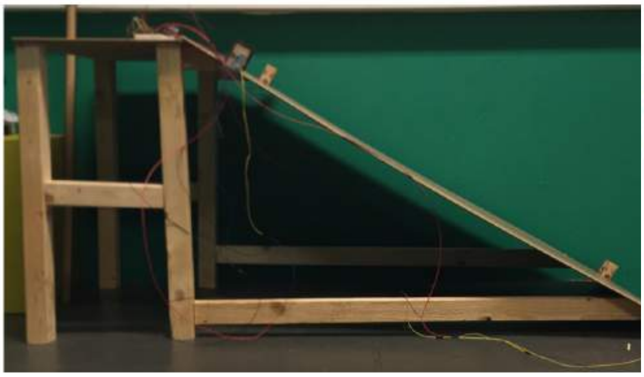


Figure 4.4: Side view of test rig

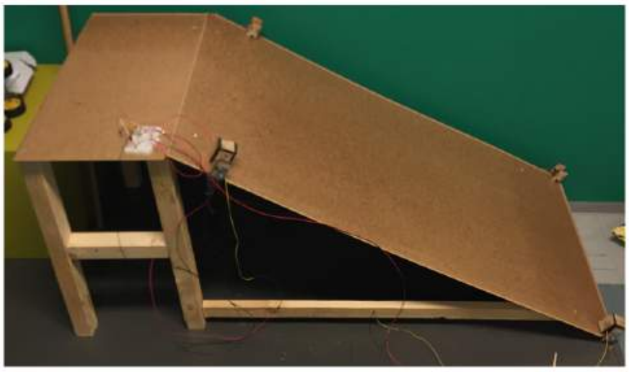


Figure 4.5: Top view of test rig

Prototype 2

After the first prototype was done, we discovered some problems that required solving.

1. **Photo resistors**

   The photo resistors are supposed to activate the timing system when the test material breaks the laser beam. However, the resistor is very sensitive to light, so in a bright surrounding it did not register the laser beam pointing at it. This was solved by building a small "house", to build around the resistor, shielding it from light from other sources, shown in 4.7.

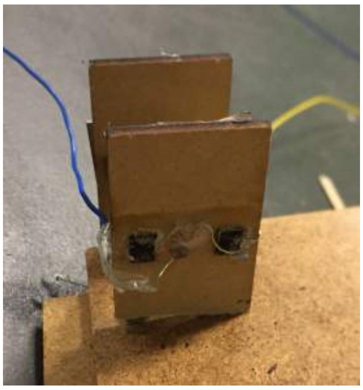


Figure 4.6: Resistor mount

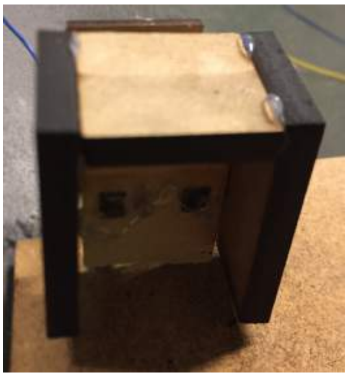


Figure 4.7: Resistor mount with housing

2. **Gliding direction**

   The next problem we discovered was getting the test specimen to glide down without changing direction. The prototype already made was further developed by implementing a system for keeping the test specimen gliding in a straight line.

   There were several suggestions as to what could work best. By trying out different alternatives like ball bearings, rubber wheels, and metal rods, it was decided to use rubber wheels, as it was easier to implement without changing the set up for the laser diodes.

4.3 Electronics

This is an overview of the Arduino set up used for the electronics part. The picture shows how the wiring is done, to connect the laser diodes and the photo resistors to the Arduino. The programming code is added as Appendix A.

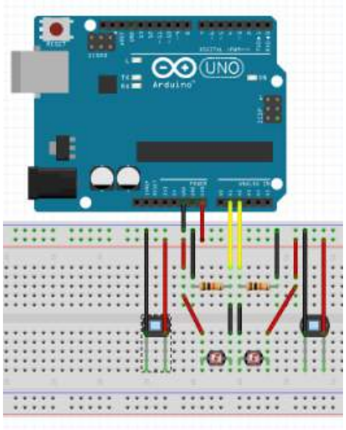


Figure 4.8: Arduino wiring

The electronics part of the set up is detachable, intended to allow the rig to remain outdoor exposed to snow and all set for testing by attaching the electronics before the actual testing, to avoid unnecessary damage to the electronics. This solution is shown in 4.9 & 4.10.

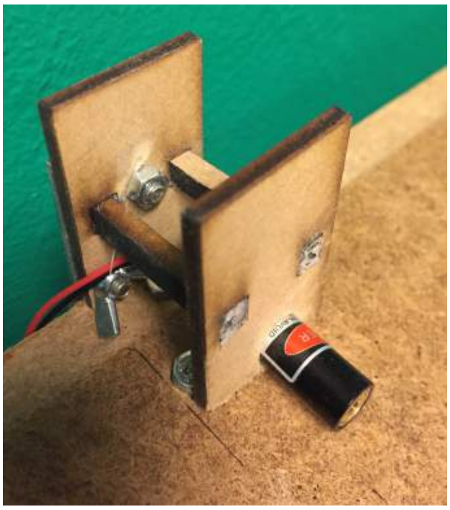


Figure 4.9: Scraped gallium surface

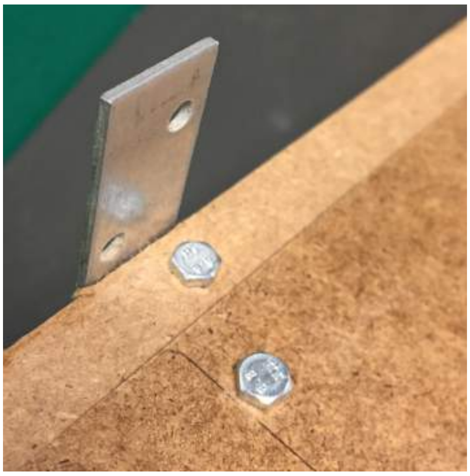


Figure 4.10: Unscraped Gallium surface

4.4 Concept ideas

This is a listing of ideas that could be of interest to look into for next semester. As of now they have not yet been investigated by the project.

1. **Heating patch**

   It is possible to make small patches made of silicone, that acts as a heating element, while also being waterproof. This may possibly be implemented in the front of the ski, to increase water film thickness. This could be particularly interesting for cold snow conditions, where it is a higher demand for frictional heat. It could also be possible to use this in the EiT program(section 6.3.3), to help control the amount of water film produced, simply to get a better understanding of how it affects gliding.

2. **Anodized aluminium oxide**

   An interesting approach could be to anodize aluminium. This creates a macroporous surface that show very high hydrophobic properties, around 146 ° (Buijnsters et al., 2013). The droplet test is shown in figure 4.11.

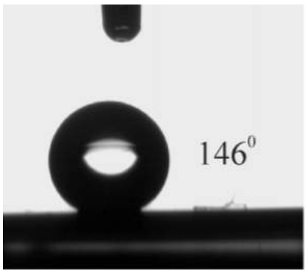


Figure 4.11: Anodized aluminium oxide surface

3. **Linear patterning**

   As stated in section 2.2, waterfilm is made as a result of friction heat. This increases in thickness along the ski. However, there have been little research done to how different grinds on different parts of the ski affects the waterfilm. This could be an interesting approach for next semester, to try out different grinds, to see how the waterfilm reacts.

4. **Self lubrication**

   It is possible to make micro structures in the sole material, that will act as a sponge, meaning every time the athlete puts all the weight on one ski, it will release a little bit of lubrication or wax, to decrease friction.

Chapter 5

Testing

5.1 Test 1

Hydrophobic test

Our first test was done with 2 individual skis, with different base preparation. The base grind was unknown, but we could clearly see that they were different, just by looking at them. The ski we used are borrowed from SIAT, and has been used for student projects earlier, so there is no way of knowing what exactly has been done to the surface before, but they work fine as test samples for this purpose. In this test we wanted to look at the angle between the water and the base, to see how it differs from different materials. This is also a reference point for our own material tests later on. The test was performed 21.11.

Hypothesis

Our predictions were that both the unprepared base and the different waxes should show clear signs of hydrophobic surfaces. One of the main arguments for using UHWMPE is because of the hydrophobic properties, so this should be confirmed in this test (Colbeck, 1992).

Equipment

- 2 Madshus skis
- Base cleaner
- Fiber cloth
- Heating iron
- Gliding wax
  1. RODE GLF 10 (-10 -> -20)
  2. SWIX GL 40 (0 -> 4)
  3. SWIX Graphite (2-> - 10)
  4. SWIX Alpine Racing (2 -> -4)
  5. SWIX CH10 (0 -> 10)
- Scrape

- Other test liquids
    1. Teflon spray
    2. Citrus degreaser
    3. Jif kitchen spray
    4. Sun light (hand soap)
    5. Antibac
    6. Gallium (tested a week later)
- Syringe
- Water
- Gallium (see section C.1)

Method

We began by scraping the skis, to get of any excess dirt, before applying the base cleaner. This cleans of all existing wax, which gave the two skis similar starting points. As you can see in the picture at 5.1, even though the ski is unprepped, there are clear signs of grinding, which has been done before we got our hands on the skis. After the cleaner, we taped up specific areas for each wax, in order to keep track of which we tested where. Then we applied one layer of gliding wax, by heating the iron to the right temperature, and melting the wax on the ski. Then we applied light pressure with the iron on the ski, to melt the wax on, and creating a homogeneous surface on top of the ski. We then let it rest for 10 minutes, before we scraped it of, and brushed to polish the surface. After this we applied water droplets from a syringe, to make the droplets as similar as possible each time. We applied water both at the prepared parts of the ski, and at the unprepared, clean UHMWPE.

Figure 5.1: Water test on unwaxed ski surface

As we can see in 5.2, there is a clear difference between the GL40 on the left, and the unwaxed ski on the right. This is also the case in 5.3. We did not have a angle measurement device on this test, but eye sight is more than good enough to see that the hydrophobic properties are better on the wax. The test itself consisted of looking at the angle the water makes with the surface, and comparing

Figure 5.2: Comparison between GL40 and unwaxed

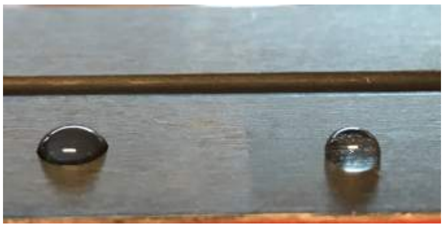


Figure 5.3: Comparison between unwaxed and graphite

the different waxes. This gives us knowledge about how the state of the art works now, and gives us comparable data when we test our own materials. We also did a simple test of checking at which angle the water started gliding of the surface. This was done by raising the front end of the ski, and looking at when each droplet started to glide.

Results

Table 5.1: Ranking test 1 & 2

Wax	Place(test 1)	Place(test 2)
GLF10	5	5
GL40	4	2
Graphite	3	4
Alpine Racing	1	1
CH10	2	3
Unwaxed	6	6

Table 5.2: Ranking test 3

Wax	Place(test 1)
Teflon	5
Citrus degreaser	4
Jif Kitchen	2
Sun light	1
Antibac	3

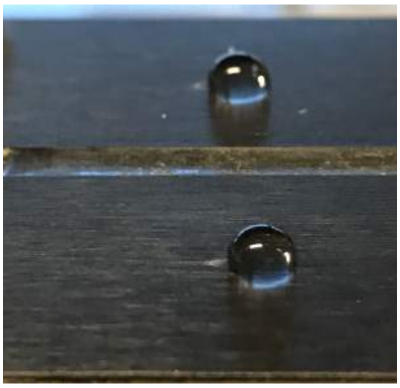


Figure 5.4: Best gliding surface, Alpine Racing

Discussion

We were quite surprised that none of our tests showed significant hydrophobic surfaces. It has been argued that the reason for adding gliding wax is more in its dirt repellent properties, rather than hydrophobic (Swix, 2011), but this has been challenged by the works of Kuzmin and Tinnsten (2006). Nevertheless, the waxing surfaces still showed angles slightly above 90 degrees, the limit between hydrophobic and hydrophilic (Förch and Jenkins, 2009).

The tables presented above show the results of the gliding tests. As we can see, Alpine Racing won both times, and was superior to the others, as we watched the tests. After that, the remaining droplets started gliding at various angles, in the order listed. Lastly, the unwaxed and unprepped base got a very disappointing result. The water droplet never started gliding, and was stuck, even at a 90 degree angle. This show major doubts regarding the hypothesis we presented at the start of this test, and might show that the properties we see as the most relevant, based on scientific research, might not be as accurate as we thought.

Potential errors

There are several factors that could potentially decrease the validity of these tests.

1. **Ski base**

   We did not know how the skis had been treated before we got them. They could potentially have been used in a way that ruined the base grind. They seemed fine with just looking at them, but we can´t know for sure

2. **Ski preparation**

   Neither of us are professional ski waxers, and we have very little experiance in this area. This means the wax could be applied wrong, which would affect the outcome of both glide test and hydrophobic tests.

Conclusion

There were major differences between some of the angles, as shown by the pictures above. This shows that there are hydrophobic properties in the waxes, and they could in fact enhance the properties of the base material, because, according to this test, the UHMWPE was not especially hydrophobic.

5.2 Test 2

Gliding test - Beitostølen

This test was a replicate of the test the national ski team does when they test and compare skis. The test was meant as a way of seeing how close our performance could get to the professionals, to see if this test could be applied by us back in Trondheim. We also tested one set of skis prepared by us, which consisted of applying regular hand soap on the base of the ski, to compare against the ones that were prepared by the guys at Olympiatoppen. This test was performed 15.11.2016

Equipment

- Test skis
- Test athletes (2 or more)
- Downhill slope
- Timing device (optional)

Method

Two skiers start at the top of a hill, either at zero velocity, or constant, starting further back. One of the test athletes grabs and holds on to an elbow from the other person, and holds until the velocities are equal. Then they release, and see if there are any differences in gliding, to check which skis are best (5.5). This is usually done on a downhill about 100m, but in Beitostølen it was a bit shorter.

Figure 5.5: Paralell test in Beitostølen

Results & discussion

When it comes to the test itself, we were surprised to see how easy it was to seemingly achieve equal velocities. We only needed a few tries before we matched up very good, and none of us has a lot of experience with cross country skiing. This means this is a test that can easily be used anywhere, which is a good result for us.

We could early state that this is a easy test to replicate for rough testing. With just a few tries we were able to get reasonably close velocities when letting go, which means this test could be applied very simple to full scale tests, for easy discarding of ideas where the results are worse than the state of the art-prepared skis.

It could be worse when separating the best from the nest best skis, particularly for us, because we are not experienced in these situations, but even so, it became clear to me that this is not an ideal test for scientifically testing glide properties. This is because of the possible human errors, mentioned underneath. It is very difficult to achieve an identical position every test, and we clearly saw big changes in gliding distance with small changes in body positioning.

However, it was very cool to see that the way they test skis out in the slopes are identical to the test rig I am building, where our goal is to exclude the potential human errors. And it needs to be said that we chose this test design before we went to Beitostølen, so we did not know that this was the actual method for their testing.

We did a total of 6 runs with the soap underneath, freshly applied between each run, but we could not get any clear results as to if it was quicker or slower. The speeds were very close every time, except one, which showed that the soap ski started gliding past the regular ski, and ended up with well over 50cm between them at the finishing point. This is interesting, and will need to be tested further to get definite result.

So it is difficult to state any results regarding the soap, because there are many potential errors here. Even though we got 6 runs, it is difficult to state a conclusion one way or the other, because it was very similar to the other pair of skis every time. This could however be an indication of interest, and we are definitely going to continue research on this type of gliding enhancer. It is also a sign, as well as Test 1, that hydrophobicity might not be as important as we thought, because soap, as it is known, consists of both hydrophilic and hydrophobic parts, which removes the surface tension in water, making it near impossible for droplets to form. This is a result to note.

Potential errors

- **Equal velocity**

  Regarding the test as a whole, it is dependant on achieving equal velocities when releasing, otherwise the results are not comparable. This could be solved by applying accelerometers on the skis, or using timing measurements with start and stop marks. It is very difficult to just use eye measuring to judge if the speeds are equal, as there are very small differences. In professional testing, differences of 10-20cm when crossing the end line is considered much, and this requires accurate testing conditions, which could be hard for us to do.

- **Constant body positioning**

  Good test results means the tests needs to be as close to identical as possible every time. This means the test athletes needs to be in an identical position every time, and this is very difficult. Small changes in bending, forward or backward-leaning, and gaps between arms and body may affect pressure distribution wind resistance a great deal, which could render the data useless, without us even knowing it.

- **Wear resistance of soap**

  Errors with the application of the soap could be that it is worn of even before we start the test. We don´t know how quick the soap wears of, which means we would need more testing, unrelated to how this test went.

Conclusion

This is a test easy to replicate, as long as we have access to skis and snow. This means we could do full scale tests easy, when we have the materials for it. This would probably be after materials have been tested in small scale, but we know it is difficult to compare 1:2 scale, to 1:1 scale, because of changes in water film, pressure distribution, friction, and many more variables. So this should be a test done with all materials that could be interesting, because of its simplicity. Should be implemented some timing device for this, maybe accelerometer of some sort for precision measuring.

Too early to state any conclusion regarding soap additive.

Chapter 6

Summary and recommendations for further work

6.1 Objectives

1. Analyze the problem(s) ✓

   Through many hours of reading scientific papers and research regarding friction and surface, together with gaining knowledge in Beitostølen around the ski tests them self, this objective has been met.

2. Generate concepts ✓

   Several concepts has been generated, both in terms of materials, and prototypes. Concepts has also been generated without actually making them into prototypes.

3. Build prototypes ✓

   As chapter 4 shows, prototypes has been built.

4. Build test setups ✓

   As chapter 4 & 5 shows, prototypes and test setups has been built, and used, for different purposes.

5. Test and compare alternatives ✓

   Every test has been tested against state of the art, and prototypes has been compared to similar alternatives used by the national ski team.

6. Judge and evaluate concepts ✓

   Based on our understanding of how the parallel test is the most common use for testing ski glide, we can conclude that the way the test rig is formed, it can work good. Still, more testing is necessary to find out exactly how to replicate the method in the best possible way. But the concept itself is definitely worth pursuing.

6.2 Summary and Findings

1. UHMWPE is not as hydrophobic as we expected, this might suggest the hydrophobic properties are not as important as our research gave impression of. It is probably rather that the combined properties makes this so much used, together with the cheap price. Still, surprising to see such poor hydrophobic results, compared to our research.

2. Gliding wax definitely improves both gliding and hydrophobic properties. While several studies aim to disprove this (Kuzmin and Tinnsten, 2006; Kuzmin, 2006), we could clearly see positive changes after applying wax. This also means waxed surfaces will be our state of the art comparison material for next semester.
3. The test rig has been built in 1:4 scale, or something around that. It is hard to know the exact scale of a full sized rig, but it needs to be bigger to get better results. This has mainly to do with the timing measurement. A longer gliding zone will show larger differences between the materials, making it easier to separate materials from each other.

   This could have been done by delivery of this project report, but delayed deliveries from suppliers made this impossible. The base design of the rig seems to be working very well, and is also a close replication of actual testing performed by the national ski team (5.2). But with the addition of hopefully being more accurate because the reduction of human interference.
4. As of now, the gallium & the Electroless Nickel-Teflon seems to be the material with the highest hydrophobic properties, as showed in C.1 and chapter 5. We still need to perform tests in larger scale, and we want to test how wear resistant it is. This could be done by doing a quick ski trip, and testing the material afterwards. We also want to try adding gallium as an additive in the extruder at NTNU, to see if we can attain the properties gallium can offer in a more constant form. The Electroless Nickel-Teflon would have to be ordered in a larger scale, which will be significantly more expensive, and it requires further testing before this step is taken.
5. Sodium seemed interesting when we read about it, but when we actually tried it, we came across a pretty significant problem. The second it touches water, it curls into a ball. This is because it wants to reduce its surface area to volume ration to as low as possible. This results in a perfect sphere, which, unless we can prevent it from reacting this way, is useless in our project.
6. Preliminary work on the data sheet from Olympiatoppen regarding machine learning has been very interesting. With some more dedicated work this could help the waxing team with their decisions regarding which wax to choose. This should definitely be pursued

6.3 Further Work

We seem to be getting similar feedback from our tests over and over. The results do not meet our expectations, based on the research we have done. This just proves that you can never really know how things will work, until you actually test it. And this will be the base for next semester. We need to try out things sooner. We need to make prototypes faster, and we need to get tangible information from our own testing. A mindset of rapid prototyping from start to finish, where small scale tests of different materials will be able to give us more definite results than just reading about it will.

However, we have had trouble with not getting materials when we order them, shipping taking very long, not getting answers from teachers in order to get access to labs, and this will of course affect how quickly we can get things done.

6.3.1 Rig set up

A 1:1 scale of the prototype is to be built at the start of next semester. This has not been prioritized because we have had limited time to actually test the previous prototypes in relevant conditions, and lack of materials because of delays. As the rig looks now, we will be able to replicate the state of the art-test, but as stated earlier, with less interference from humans. This also means that a proper test set up for the actual test materials needs to be implemented. Our test materials will come in different shapes and sizes, and it is important to have a set up that works for all types. Listed possibilities below.

1. Adjustable ski, that can be both retracted and extended, based on the length of the material. This is difficult because we still need an identical test model made of UHMWPE, which probably will just be a ski cut at correct length.
2. **Separate test models for each material**. If we cut up a ski, at preferred length, and make space underneath for the test material, this can be achieved fairly easy. This means we will need a new ski for each material we test, which could mean a high consumption of skis.
3. Use one standardized length of the test ski, and cut the materials to fit in a best possible way. Probably the least favourable way, as we don't know how test materials and coating will react to machining.
4. Using the material as they come. Might not give us correct results in terms of comparing with a similar state of the art-test, difficult to compare with other test materials as well.
5. If we turn option two on its head, it might be possible to make the state of the art-test **based on our material**. What we are interested in is the base material, UHMWPE, which we in theory could attach to any surface. This means we can have the material we are testing in mind when we develop the test model, and then make an equal one, attaching it with UWHMPE.

If we can get access to the base extruder at NTNU, option number two would be reasonable, and might be a good approach. We have had trouble getting in contact with the people in charge, but we will be even more forward next semester, to gain access if we need it.

As it looks now, option two and five seems to be the best ones. This will be investigated rapidly in the start of next semester. It is important for future testing, but it will probably be easier to actually choose preferred options when we have a specific test material to relate to. (Short term)

6.3.2 Machine learning

After our trip to Beitostølen we got to take a look at a data sheet Olympiatoppen has been collecting for some time. It consists of around 10000 lines of potentially useful data, that could be used in some way, to predict which wax is best for certain conditions. This has been made into an article, which can be read in Appendix B. (Medium term)

6.3.3 Experts in team

We have been appointed a group in next years EiT, at NTNU. This means we have access to a group of students, working on a problem of our choosing. The problem are we chose is looking at the water film thickness, and try to get a better understanding of how it works. We know from Bäurle et al. (2006), that the water film thickness is important for optimizing glide, but we do not know if there is an optimal thickness, in different conditions (Nachbauer et al., 1996). We would also like to find out how the thickness changes along the ski, and if there is a possibility of manipulating the ski to get a constant water film. This could perhaps be done by measuring electric conductivity, and grinding the ski with different grinds on different areas. This is a side project that is not directly related to our progress, but is very interesting, so we do not want to miss the opportunity of getting some extra hands working on this. (Short term)

6.3.4 Search for materials

We have not yet found any materials that could solve the project problem. Even though we have found some interesting ones, we still need to keep looking for new materials to test. Hopefully, because of the knowledge attained this semester, we will find more, and get to test them faster.

6.3.5 Concept ideas

All the ideas proposed in section 4.4, should be pursued, to see to which degree it is possible to achieve. Particularly linear patterning seems very interesting, and could yield simple results with minimal work, and could be a quick way to get insight to how much the water film is dependent on the grind of the base.

Appendix A

Coding

```
int lightPin1 = A2;
int lightPin2 = A1;
int Value1=0;
int Value2=0;
int y=0;

void setup()
{
    Serial.begin(9600);
    pinMode( ledPin, OUTPUT );
}

void loop(){
    Serial.println("dette er sensor 1");
    Serial.println(analogRead(lightPin1));
    Serial.println("dette er sensor 2");
    Serial.println(analogRead(lightPin2));

   if (analogRead(lightPin1)<500 && y==0){
      Value1=(float) millis();
      Serial.println("Starter tidtaking ved tidspunkt");
      Serial.println(Value1);
      y=1;
      delay(10);
   }
      if (Value1>0 && analogRead(lightPin2)<300){
        Value2=(float) millis();
        Serial.println(Value2);
        Serial.println("Tiden fra A til B er:");
        Serial.println(((int) Value2-(int)Value1)/1000.00);
```

```
            delay(5000);
            y=0;

        if (Value1>0 && Value2>0){
         Value1=0;
         Value2=0;
        }
          }
     delay(10);
}
```

Appendix B

Machine Learning

Implementing machine learning in Olympiatoppen;

Cross country skiing

Abstract Cross country skiing is a sport that is ever growing in Norway, and becomes larger and larger every year internationally, so the competition is always increasing. One of the key factors involved is the glide of the skis. The variations of how to prepare a ski for a competition is enormous, which makes for potential pit falls for the waxer in charge of prepping the ski.

Weather conditions influence the way they prepare for a race, and in this project we look at a new way of understanding the data collected, regarding cross country skiing. The method recommended is called supervised machine learning, and this project would be in cooperation with both Olympiatoppen and the Norwegian national ski team.

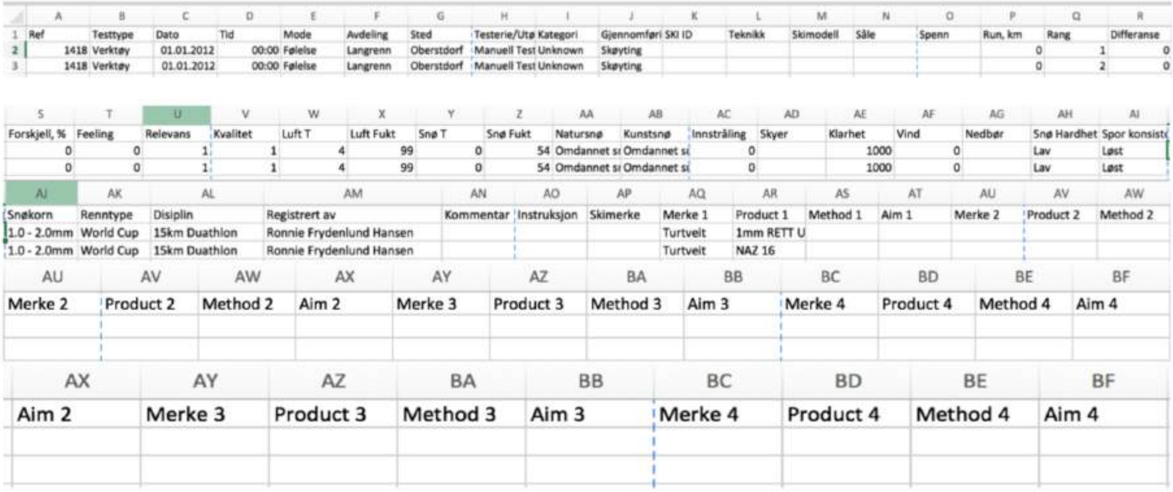
Keywords: machine learning; cross country; prediction; preparation; weather

State of the art

The approach used today is mainly based on empirical knowledge. With years of practice and knowledge, the people in charge know how to best prepare skis. This is confirmed when we time and time again see the Norwegian team come out on top in competitions. But that is not to say that the approach is optimized, it is just that no one has found any other way that could be better. Until now. Based on my recent visit to the national team at Beitostølen, I will lay out the procedure in simple terms. These approaches are used both for classic and skating skiing, but I will mainly focus on the skating part.

Each time the team prepares ski, they start out with a test set of 8 pairs. They are base prepared with a grind, based on current conditions. Warm snow and weather would use a coarser grind than cold snow, for instance. The base grind is identical for all pairs, to ensure similar boundary conditions. The skis are then waxed and prepped with different accessory, like gliding wax or fluoride powder. These are just some possibilities; the point is that every ski is treated with a different gliding enhancer. The number of different waxes is high, and the waxer uses empirical knowledge to decide which wax to test. The next step is brushing the wax with a brush made of for example nylon, bronze or steel could be used, for cleaning of excess wax and polishing the surface. Lastly, the waxer adds a “rilling” on top of the wax, based on current and predicted conditions. The national team has over 60 different rills to choose from and choosing the appropriate rill is based on experience and knowledge. The skis are now ready for testing, and the athlete tries out all 8 pairs, and the athletes best pair are then used for the upcoming race.

Adding up the different preparation steps, we end up with hundreds of different possibilities, if not thousands. This



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	Ref	Testtype	Dato	Tid	Mode	Avdeling	Sted	Testerie/Utø	Kategori	Gjennomføri	SKI ID	Teknikk	Skimodell	Såle	Spenn	Run, km	Rang	Differanse
2	1418	Verktøy	01.01.2012	00:00	Føleise	Langrenn	Oberstdorf	Manuell Test	Unknown	Skøyting						0	1	0
3	1418	Verktøy	01.01.2012	00:00	Føleise	Langrenn	Oberstdorf	Manuell Test	Unknown	Skøyting						0	2	0

S	T	U	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI
Forskjell, %	Feeling	Relevans	Kvalitet	Luft T	Luft Fukt	Snø T	Snø Fukt	Natursnø	Kunstsnø	Innstråling	Skyer	Klarhet	Vind	Nedbør	Snø Hardhet	Spor konsist
0	0	1	1	4	99	0	54	Omdannet s	Omdannet s	0		1000	0		Lav	Løst
0	0	1	1	4	99	0	54	Omdannet s	Omdannet s	0		1000	0		Lav	Løst

AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW
Snøkorn	Renntype	Disiplin	Registrert av	Kommentar	Instruksjon	Skimerke	Merke 1	Product 1	Method 1	Aim 1	Merke 2	Product 2	Method 2
1.0 - 2.0mm	World Cup	15km Duathlon	Ronnie Frydenlund Hansen				Turtveit	1mm RETT U					
1.0 - 2.0mm	World Cup	15km Duathlon	Ronnie Frydenlund Hansen				Turtveit	NAZ 16					

AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF
Merke 2	Product 2	Method 2	Aim 2	Merke 3	Product 3	Method 3	Aim 3	Merke 4	Product 4	Method 4	Aim 4

AX	AY	AZ	BA	BB	BC	BD	BE	BF
Aim 2	Merke 3	Product 3	Method 3	Aim 3	Merke 4	Product 4	Method 4	Aim 4

Figure B.1: Overview of data sheet from Olympiatoppen. (Adapted from Breitschädel (2016)).

makes it very hard for a waxer to hit the jackpot every time he is prepping a ski. This is a short summary of the process of prepping skis. But why are there so many different variations? Simple. Weather conditions.

Weather - a fickle adversairy

The weather is the most difficult condition to predict, and even if you know the weather conditions when you test the skis, they could change dramatically in the next 10-20 minutes. There are many variables, but the important ones are temperature in both air/snow, humidity, solar radiation, snow grain size, and “age” of the snow. These variables often change, which makes it very difficult to prepare. But what if there was a computer program that, with the database of weather conditions and different waxing preparations, could decide which prep is best suited? Let me introduce you to machine learning.

“Machine learning is the science of getting computers to act without being explicitly programmed.” (Ng, 2016)

Machine learning is widely used today; for instance, the voice on your iPhone, Siri, is a product of machine learning. Online advertising learn your habits, and show you ads based on what it thinks you would like. The idea is that the machine, based on some initial data, teaches itself to see patterns that would be difficult for humans to see, and to do this in no time. For instance, Olympiatoppen has given me a spread sheet of data they have recorded (Breitschädel, 2016). This list includes features that might not be relevant for this purpose, but as a starting point it is good to have as broad a base as possible, and then just narrow it down as one makes the learning model, and getting a better understanding of the importance of various features. Let’s have a look at the sheet in B.1:

A total of 70 features are included, although some are missing in these particular lines, the total spread sheet is with over 10000 lines, which makes for an excellent dataset for dividing into data sets.

Preparing

The first step is extracting the most important features. The sheet is full of information, but every feature might not be necessary for this purpose, which is to recognise which prepping should be applied. In this case, the most relevant features are notes as “Product 1-4, Merke 1-4 and Method 1-4”, and are what we would call target in this context. As it is shown above, the data is missing for these lines, but these are the 3 features we seek to predict. By using important features as

- Snow/air temperature/ humidity
- Location
- Rang
- Precipitation
- Snow hardness/consistency
- Snow grain size
- Ski race lenght

one could be able to predict the possible 3(or more) preparation methods for optimizing glide in skiing. One feature I would implement, is heat generation as a result of pressure distribution throughout the ski. This feature would be different from athlete to athlete, and could prove important in making decisions regarding gliding wax.

Machine learning, a technical introduction

I won’t go in detail about the technical details of implementing machine learning, but a basic introduction appropriate. The way to solve this problem would be with what is called supervised learning, with a decision tree classifier, or maybe an instance-based algorithm like nearest neighbour. The procedure consists of a set of training examples, with some inputs(features), that results in a certain output(target).

By letting the algorithm go through enough of these examples, it could recognise patterns that could solve the complicated task of choosing the right type of gliding waxes.

By splitting up the data in what is called training, validation and test data, the computer will read and search the training data for patterns, trying to optimize its understanding of the different features, and their connections with the target. This results in a model that hopefully will be very accurate in predicting the proposed target. Then the model is used on the validation data, to see if the algorithm works on a more “general” area, because these are validation examples it has not used for analysing. The training data should be applied to some different models, varying in parameters such as number of features, depth of decision trees and so on, to see which model fits best. Lastly it double checks the best model against test data. Optimally, the model should then be able to determine which output is most used in certain scenarios, allowing for a much more specific reading of the data. For instance, as it is now, snow grain size might be measured in mm, but if you leave it to a computer to look for patterns, you can measure in for instance μm, making the individual features more precise, which could result in more accurate predictions, that otherwise would not be possible by empirical testing. This means a more scientific approach to a very difficult problem, which could mean decreasing the possibility of human errors.

I do have some immediate thoughts about implications in introducing this. The first being the fact that weather is a very tricky condition to understand. Both in terms of measuring all necessary data, but also because the weather is in constant change. But these are the same conditions the waxers are dealing with every day, so it will be no different for the computer.

Another challenge are the waxers. They are used to doing things a certain way, and this has not changed for many years. Introducing new technology to “replace” their empirical way of thinking might be difficult, so a better approach would be to offer this new technology as support. It would work both as a way to confirm their way of thinking, and, given time, making it easier to deliver under difficult scenarios with more predictable results.

Also, one important feature, that is impossible to both distinguish and predict, is the form of the athlete. If they have an exceptionally good day, skis could have less impact on the overall performance. There is no way of predicting this, and will always be a huge importance to how the competition develops.

Appendix C

Testing

C.1 Gallium test

Hydrophobic test

Test two was done in the exact same way as test one, only that we used Gallium as the material. This means method and equipment are identical in hydrophobicity test 1 & 2, and can be read above(section 5.1). The test was done on 01.12.2016.

Results

Figure C.1: Untreated surface

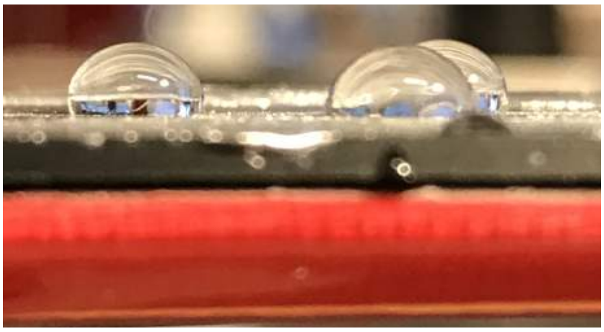


Figure C.2: Scraped Gallium surface

Discussion

The zero test was as before, a droplet applied on an untreated area of the ski. And as before, these results were not very hydrophobic C.1. If nothing else, at least the surface is consistent. But when we applied a layer of gallium, and then scraped it off after 10 minutes, there were clear signs of hydrophobicity (C.2). Since we only do the measuring by eye, it is hard to tell exactly, but this is definitely one of the most hydrophobic materials we have tested. We then reapplied gallium, and let it work for a couple of days before we scraped it of, but this result was not very promising. What we get from this is that gallium scraped of after short time, is the biggest potential here. We are therefore going to apply it to a bigger test surface, and try it out on snow, as soon as we have the chance.

Potential errors

1. **Ski base**

   We did not know how the skis had been treated before we got them. They could potentially have been used in a way that ruined the base grind. They seemed fine with just looking at them, but we can´t know for sure

Health risks

Gallium is not a toxic material, and with a high boiling point (2204°celsius), no dangers of gases occur. However, gallium attacks other metals by diffusion in crystal structures. This means some precautions has to be taken to ensure computers and such does not get into contact with it. We are also using gloves and safety glasses, to be on the safe side.

Conclusion

It is very hard to draw conclusion on these tests, but it looks promising to keep gallium as a test material for when we can do this outside in real snow conditions.

C.2 Sodium test

This is the first radical test we have done. Sodium is a metal that reacts spontaneous with water, and releases sodiumhydroxide gas. It can be explosive in large quantities, therefore security measures needs to be implemented

Hypothesis

The hypothesis is that the gas that is made, sodiumhydroxide, will make the sodium-material "float" on top of the water, decreasing the contact are, thus the friction. If this is true, this could maybe be transferred to a moving ski, where the reaction between the sodium and the snow decreases the friction for a limited amount of time.

Equipment

- Security glasses
- Security gloves
- Safety wall
- Sodium
- Glass with water
- Knife

Method

We started this test by setting up a shield made of acrylic plate, to cover ourselves in case anything happened when the sodium was put in the water. We then proceeded by cutting the sodium into small pieces. Sodium was then dropped into a large tank of water.

Results

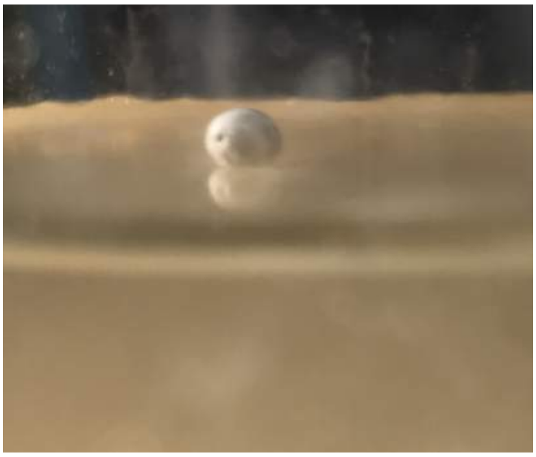


Figure C.3: Sodium ball on top of water surface

Discussion

The sodium behaved exactly like we stated in the hypothesis, which was expected due to prior research. Because of the release of gas, it is floating on top of the water, which can be seen in figure C.3 This means it could in fact work as a buffer between the base material and the snow. However, this is too early to tell, as the pressure on top of the ski might be too big for it to have any affect.

Health risks

As stated earlier, sodium may react explosive with water, and is also releasing NaOH. Security measures was taken.

Conclusion

Our hope is that sodium could be implemented as a layer between the base material and snow, to decrease friction for a limited time. So far, we can only conclude that sodium reacts the way it is supposed to, and we need further testing, in relevant conditions to make any statements.

Appendix D

Test pictures - Hydrophobicity

These pictures are meant to show the specific walk through of our test, and how each droplet acted on the individual surfaces. For detailed reading about the test see section 5.1.

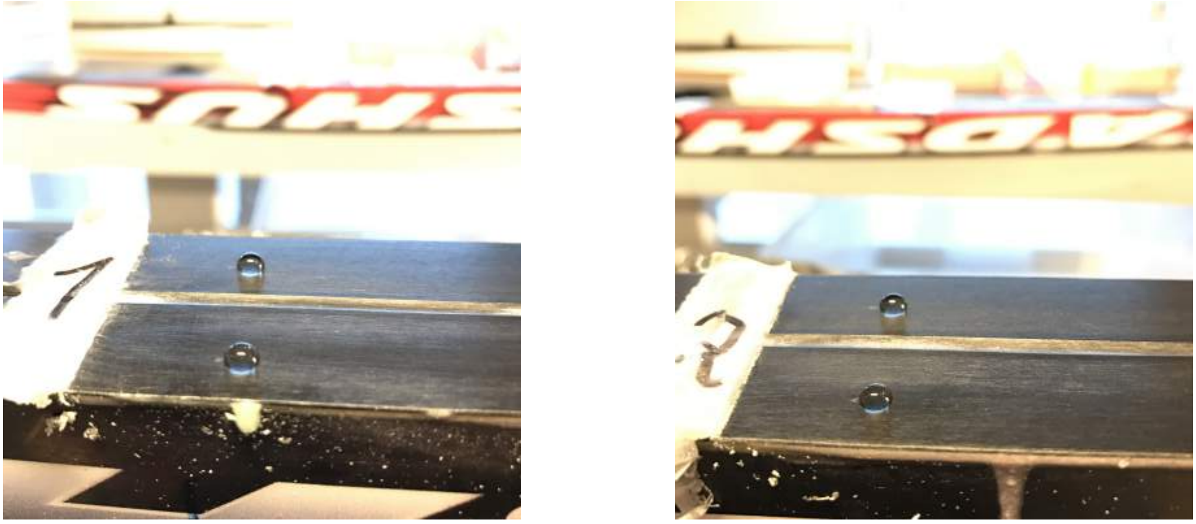
Pictures D.2-D.4 are waxed, while D.5-D.7 are waxed and rilled.

The last five pictures are with different types of soap and cleaning appliances.

(a)

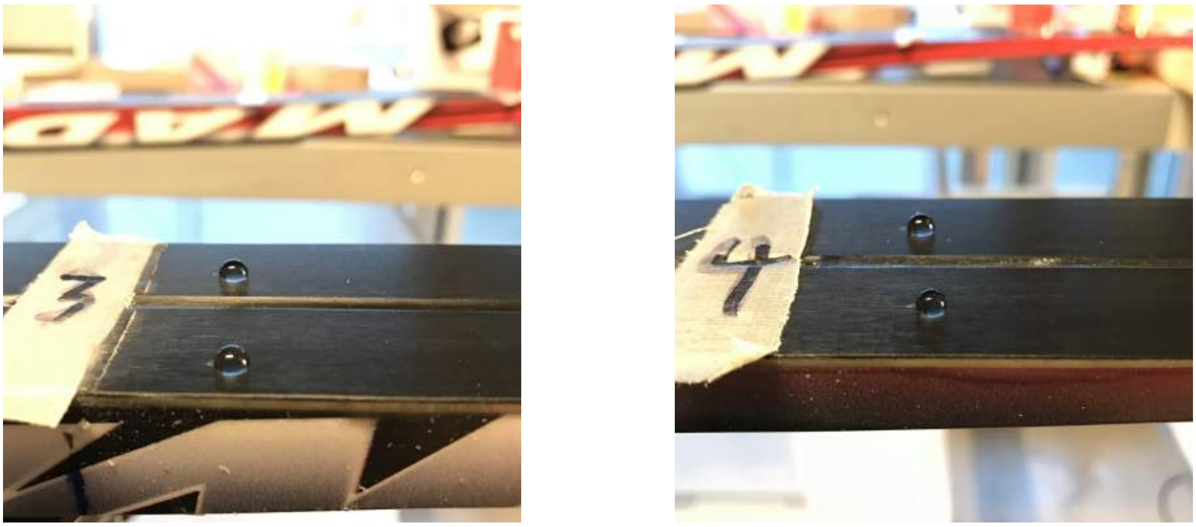
(b)

Figure D.1: a) Wax selection b) this is how the areas were divided, between the 5 different wax tests



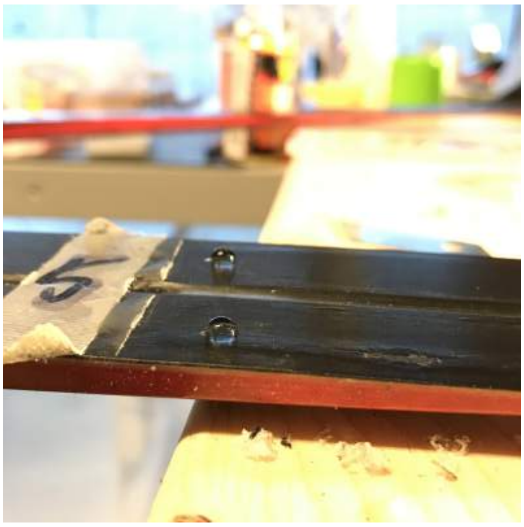
(a) (b)

Figure D.2: a) GLF10 b) GL40



(a) (b)

Figure D.3: a) Graphite b) Alphine Racing(winner of glide test)



(a)

Figure D.4: a) CH10

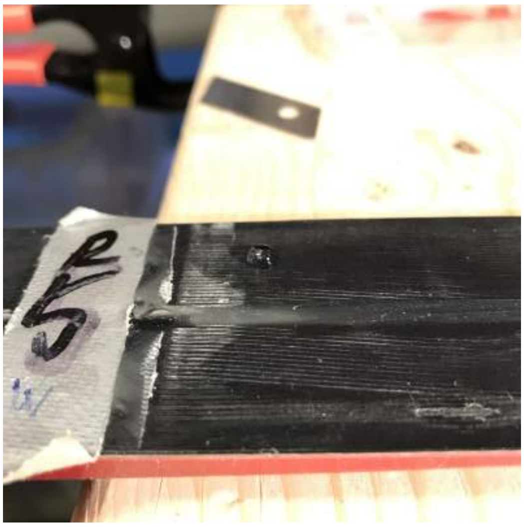
(a)

(b)

Figure D.5: a) GLF10 (rilled) b) GL40 (rilled)

(a) (b)

Figure D.6: a) Graphite(rilled) b) Alphine Racing(rilled)



(a)

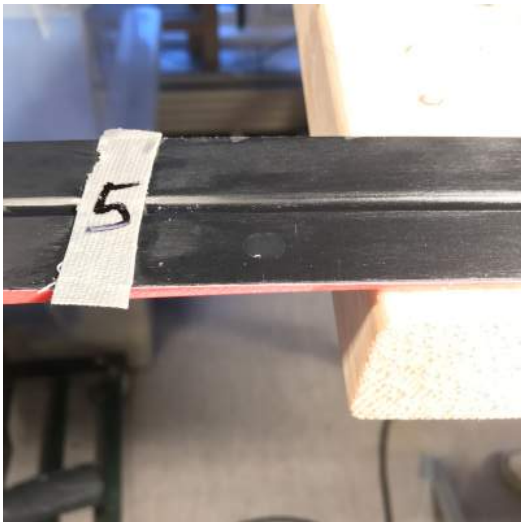
Figure D.7: a) CH10(rilled)

(a) **(b)**

Figure D.8: a) Teflon b) Citrus degreaser

(a) **(b)**

Figure D.9: a) Jif b) Sun light



(a)

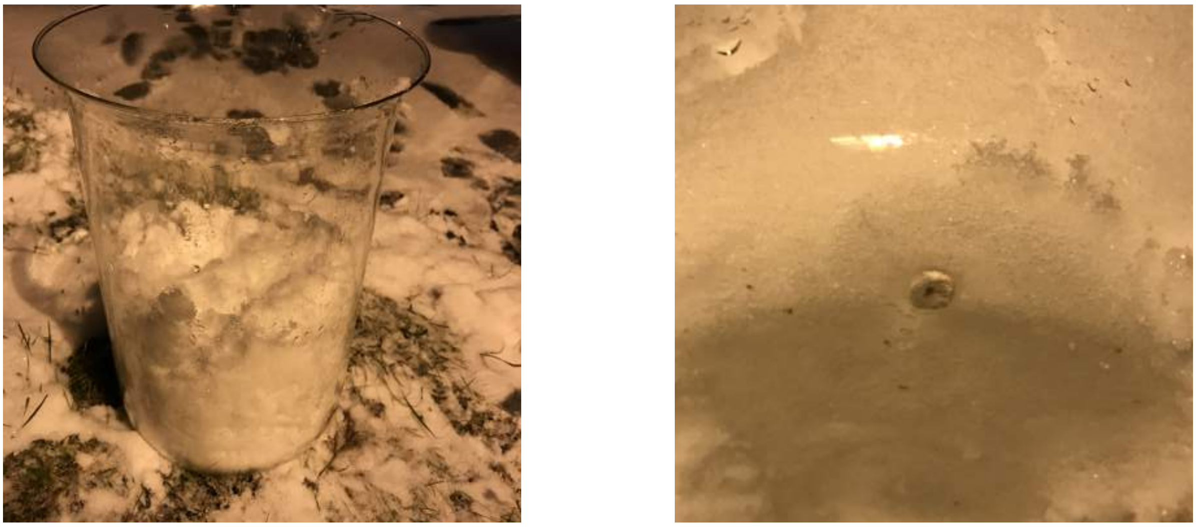
Figure D.10: a) Antibac

Appendix E

Outdoor test - Sodium

We were lucky enough to get some snow just before delivery date, so we did this test to get a sense of how the sodium reacted on snow. The test is done 11.12.2016.

These pictures are meant to show how the sodium reacted when we tried it outdoors, in accurate conditions.



(a) **(b)**

Figure E.1: a) We started by filling up a big glass with snow, and then placing a piece of sodium on top. As shown in b), the sodium pellet melted directly through to the bottom.

(a) (b)

Figure E.2: a) We then tried melting the sodium on a wooden block, to see if it enhanced the gliding properties.

(a) (b)

Figure E.3: The test was concluded by putting the wooden block on top of a hill, with the sodium melted on. We then let go, to see if it would slide at all. As seen in b), it just caught fire, and quickly came to a full stop.

Figure E.4: As we can see here, the sodium reacts with the water, changing shape into spheres, and falling through, as discussed in section 6.2.

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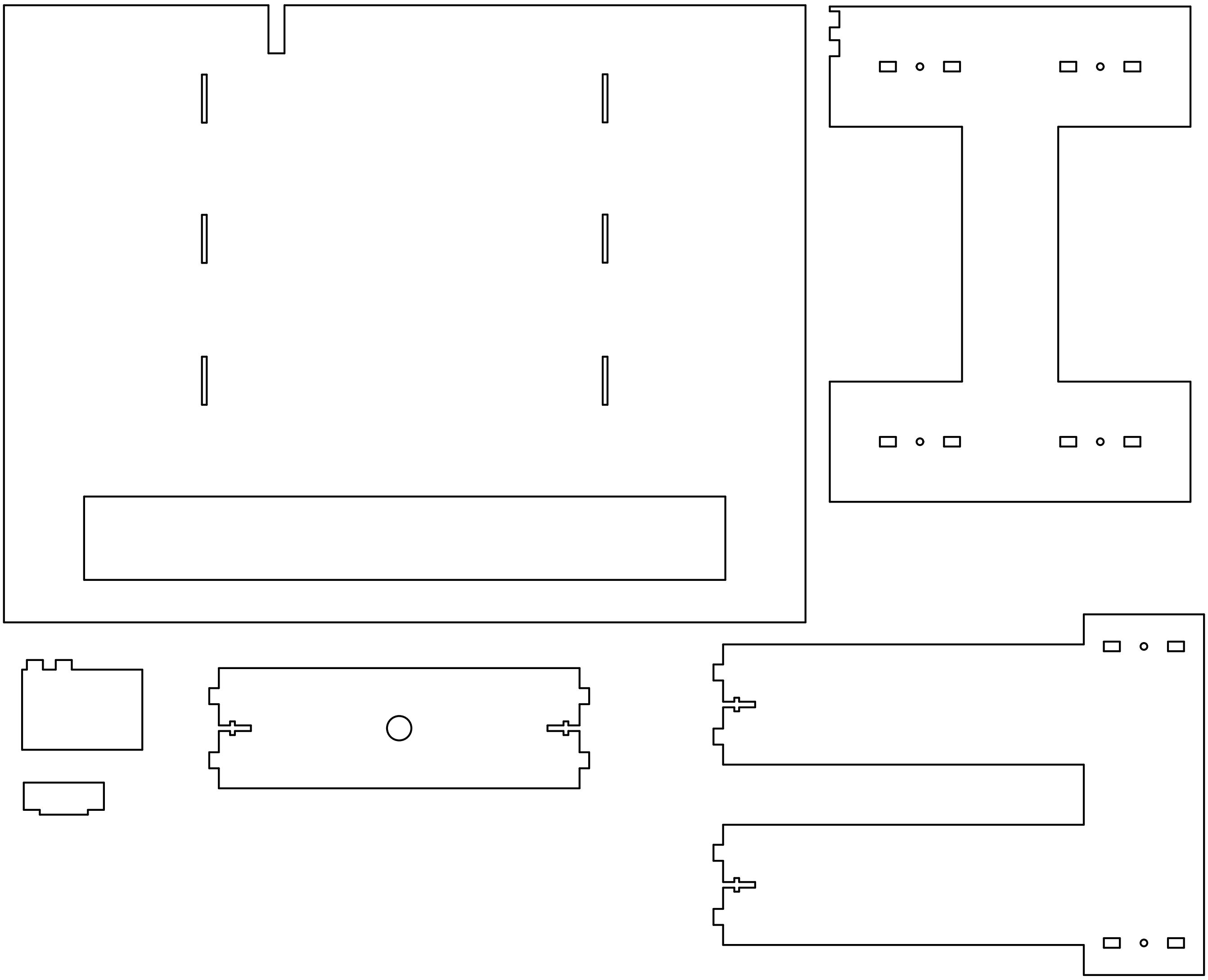
Appendix B

Machine Drawing

Machine drawing in 1:3 size for future use



Appendix C

Logbook

Test 5

Test sample **aluminum foil number 1**

- Date: 20. April
- Time: 10.25
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 15 minutes
- Current = 0.91 Ampere

Approach:

The foil was cut into an appropriate size, around 15 cm * 15 cm before it was rinsed with acetone, and then sprayed with ethanol. It was then placed in the acid bath, where the clamps were placed directly on the aluminum foil instead of a connecting material. It was noticed that a thin aluminum foil will dissolve if it is put in the acid for too long, this could be a problem for later tests in large scale.

After the acid bath, the sample was soaked in distilled water for cleaning and then boiled in water for 20 minutes to "close the pores", which is a common and necessary part when dying the samples. However this might not be necessary for this specific project, so there will be done tests without boiling to look at differences.

No calculations were done in regards to the current, so this is probably far too low current, as the surface area is larger than the test samples made out of aluminum.

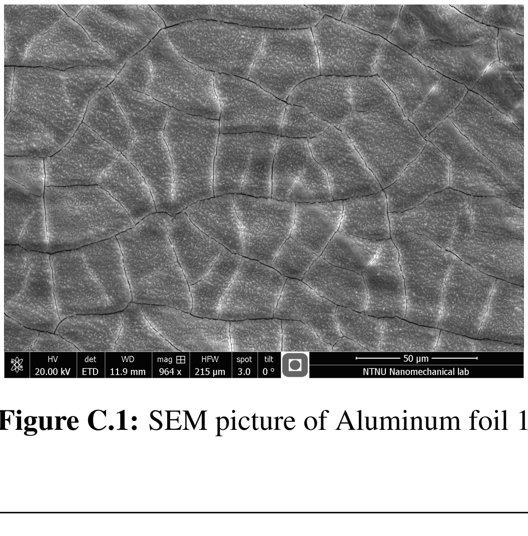


Figure C.1: SEM picture of Aluminum foil 1

Test 7

Test sample **number 12**

- Date: 20. April
- Time: 14.00
- Location: Corrosion Lab
- Acid bath: 1
- Time in acid bath: 120 minutes
- Current = 0.91 Ampere

Approach:

The aluminum sample was soaked in acetone for 5 minutes, then washed off by spraying ethanol directly on the sample. It was then placed in the acid bath for what was supposed to be 120 minutes.

The connecting material was aluminum foil. However, this was a thin aluminum foil which tore apart during the bath at around 40 minutes. As the sample was not constantly monitored, an accurate time frame is not applicable, but it is assumed somewhere between 40-50 minutes before the contact material tore, as the sample was checked every 10-15 minutes. This means an incomplete sample test, and no SEM pictures are necessary. Figure C.2 shows how the acid has started working on the surface of the sample after the circuit was broken.

Figure C.2: SEM picture of sample 12

Test 16

Test sample **number 16**

- Date: 6. June
- Time: 14.40 PM
- Location: Corrosion Lab
- Acid bath: 4
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

This is an attempt at recreating sample **number 8**. New titanium wire was ordered, as the old one had anodized in use. This is the same grade(purity), which is grade 2, however it is 1mm thicker in diameter(2mm total). This introduced a new problem, which was that the strength of the metal made it very hard to bend tightly around the sample. As test 15, the titanium changed color and lost electrical conductivity, losing connection to the aluminum piece. This means several tests have been ruined because of the titanium anodizing instead of the aluminum. The reason will be more thoroughly discussed in chapter 7, but possible reasons for this could be that the oxalic acid or the NaCl is reacting with the titanium in a different way than the sulphuric acid, or that the connection between the titanium and the aluminum is not strong enough. While the last reason seems the more sensible, more testing is necessary to confirm this.

Test 17

Test sample **number 18**

- Date: 6. June
- Time: 15.40 PM
- Location: Corrosion Lab
- Acid bath: 4
- Time in acid bath: 30 minutes
- Current = 0.9 Ampere

Approach:

Test 17 was done exactly as test 16, to see if the titanium wire turning blue was a one-time thing. However this happened this time as well, so more thought has to be put into the next tests to come out with a better result.

Appendix D

Aluminum Alloy Composition

This is the composition sheet for the aluminum used in this thesis. It is important for future use, to make it possible to order more of the exact same material, now that we know it works well for its purpose.

AMAG ROLLING

Abnahmeprüfzeugnis 3.1 (EN 10204)
Inspection certificate - mill certificate

Nr.: 85174654 **03 / 5**
Rev.: 0

Seite / page: 1 von / of 2

Zertifiziert nach / certified to ISO 9001, ISO/TS 16949, EN/AS 9100, ISO 14001, NADCAP

Datum / date: 2015 04 01

Auftraggeber / customer:
E.A. Smith AS
Dep. Smith Stal Nord Trondheim
N-7493 TRONDHEIM

Warenempfänger / consignee:
E.A. SMITH AS
Avd. Smith Stal Nord Trondheim
Nedre Ila 66
N-7018 TRONDHEIM

Bestell Nr. / order no.:	2026337
Datum / date:	2015 02 12
Auftragsbest. Nr. / order confirm no.:	688548
Datum / date:	2015 02 12
Lieferschein Nr. / delivery note:	85174654
Datum / date:	2015 04 02

Produkt / product

Form / form: Platten
Werkstoff / material: EN AW 5754
Zustand / temper: H111
Dim. / dim.: [mm]: 20,00x1020,0x2020,0

Bedingungen / terms

Technische Lieferbedingungen / techn. spec.:
EN 485-2 : 2008
EN 485-3 : 2003
EN 573-3 : 2003
EN 602 : 2004

Sondervorschrift / special terms:

AB-Pos. ord.-item.	BNr/Los/Teillos Lot/No./Part	Guss Nr. cast no.	Werkstoff material	Kollo packno.	Gewicht netto weight net	Stk. pcs.
04	35358/01/00	01/0067417/5	EN AW 5754	6885480005	896 kg	8

Chemische Zusammensetzung ([%] Gewichtsanteile) / Chemical composition ([%] weight proportion (OES))

Guss Nr. / cast no.	material										
01/0067417/5	EN AW 5754	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Mn+ Cr	Sonst Einzel
	spec. min.	-	-	-	-	2,6	-	-	-	0,10	-
	spec. max.	0,40	0,40	0,10	0,50	3,6	0,30	0,20	0,15	0,6	0,05
	actual	0,29	0,37	0,08	0,29	3,3	0,04	0,07	0,03	0,33	0,02
		Sonst Summe									
	spec. min.	-									
	spec. max.	0,15									
	actual	0,05									

Zugprüfung LT / tensile test LT

BNr/Los Lot/No.	Zustand temper	Richtung direction			Rm [MPa]	Rp0.2 [MPa]	A5 [%]			
				spec.min.	190	80	17			
				spec.max.	240	-	-			
35358/01	H111	LT			218	103	26			

Abnahmeprüfzeugnis 3.1 (EN 10204)
Inspection certificate - mill certificate

Nr.: 85174654 **03 / 5**
Rev.: 0

Seite / page: 2 von / of 2

Zertifiziert nach / certified to ISO 9001, ISO/TS 16949, EN/AS 9100, ISO 14001, NADCAP

Datum / date: 2015 04 01

Sonstige Prüfungen / other tests
Maßkontrolle: OK. / Dimensional Check: OK. Oberfläche: OK. / Surface inspection: OK.

Bemerkungen / notes

CE

0036
11
EN AW 5754 H111
CPR Nr.: 0036-CPR-M-46-2011
DIN EN 15088: 2005
Verwendung für DIN EN 15088 Tabelle ZA.1 – Produkte, Verwendungszweck und System der Bescheinigung
/
0036
11
EN AW 5754 H111
CPR Nr.: 0036-CPR-M-46-2011
DIN EN 15088: 2005
use for DIN EN 15088 table ZA.1 – products, structural application and system of certification

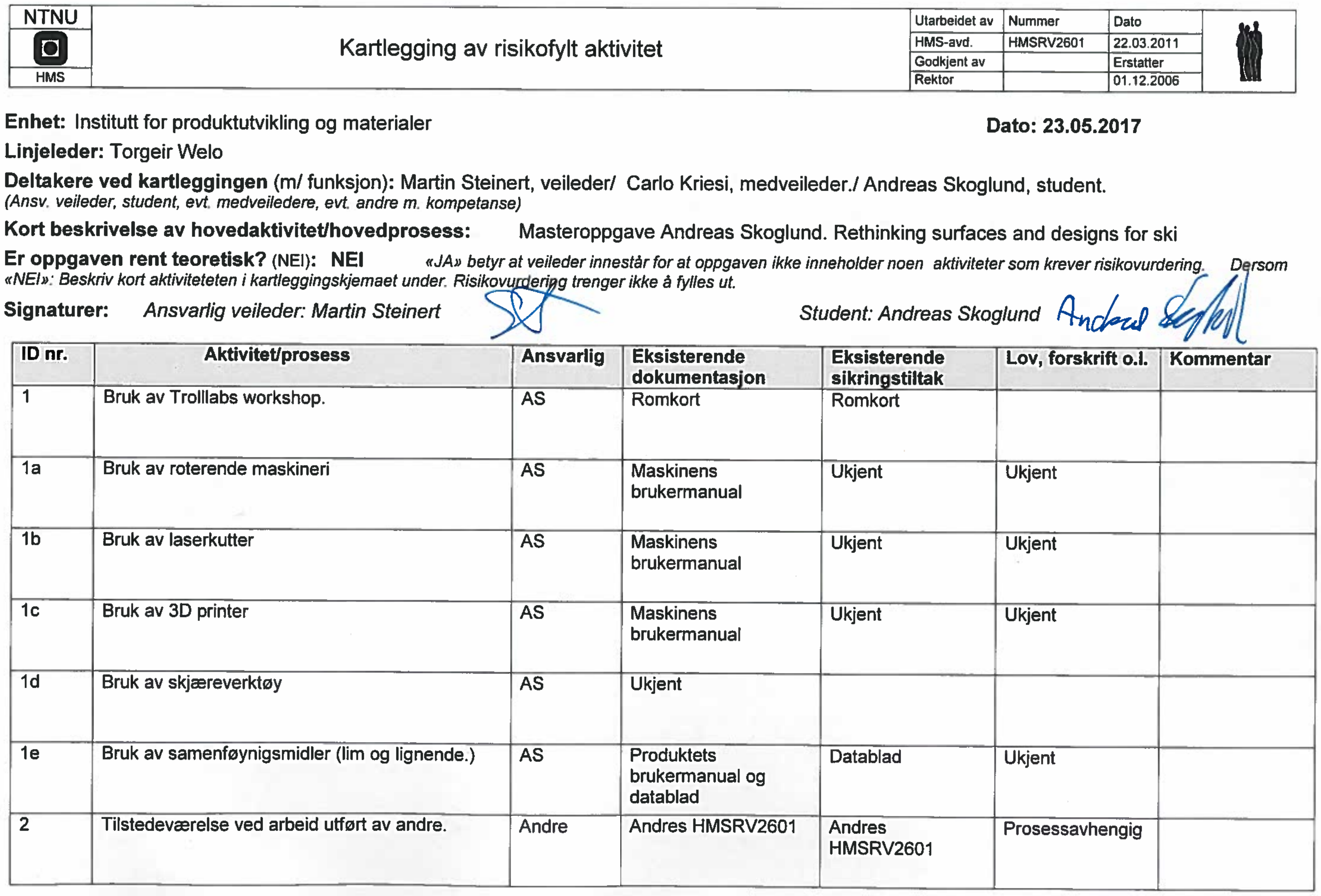
Es wird bestätigt, dass die Lieferung geprüft wurde und den Vereinbarungen bei der Bestellung entspricht.
We hereby certify that the material described above has been tested and complies with the terms of the order contract.

Werksachverständiger / factory specialist	E-Mail / e-mail
Josef Klampfer	josef.klampfer@amag.at

Herstellerland: Österreich / goods origin: The goods are of Austrian origin.
Maschinell erstellt - Gültig ohne Unterschrift / Automated - valid without being signed.

Appendix E

Risk Assessment



NTNU	Kartlegging av risikofylt aktivitet	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
HMS		Rektor		01.12.2006

Enhet: Institutt for produktutvikling og materialer **Dato: 23.05.2017**

Linjeleder: Torgeir Welo

Deltakere ved kartleggingen (m/ funksjon)**:** Martin Steinert, veileder/ Carlo Kriesi, medveileder./ Andreas Skoglund, student.
(Ansv. veileder, student, evt. medveiledere, evt. andre m. kompetanse)

Kort beskrivelse av hovedaktivitet/hovedprosess: Masteroppgave Andreas Skoglund. Rethinking surfaces and designs for ski

Er oppgaven rent teoretisk? (NEI)**: NEI** *«JA» betyr at veileder innestår for at oppgaven ikke inneholder noen aktiviteter som krever risikovurdering. Dersom «NEI»: Beskriv kort aktiviteteten i kartleggingskjemaet under. Risikovurdering trenger ikke å fylles ut.*

Signaturer: *Ansvarlig veileder: Martin Steinert* *Student: Andreas Skoglund*

ID nr.	Aktivitet/prosess	Ansvarlig	Eksisterende dokumentasjon	Eksisterende sikringstiltak	Lov, forskrift o.l.	Kommentar
1	Bruk av Trolllabs workshop.	AS	Romkort	Romkort		
1a	Bruk av roterende maskineri	AS	Maskinens brukermanual	Ukjent	Ukjent	
1b	Bruk av laserkutter	AS	Maskinens brukermanual	Ukjent	Ukjent	
1c	Bruk av 3D printer	AS	Maskinens brukermanual	Ukjent	Ukjent	
1d	Bruk av skjæreverktøy	AS	Ukjent			
1e	Bruk av samenføynigsmidler (lim og lignende.)	AS	Produktets brukermanual og datablad	Datablad	Ukjent	
2	Tilstedeværelse ved arbeid utført av andre.	Andre	Andres HMSRV2601	Andres HMSRV2601	Prosessavhengig	

3	Eksperimentelt arbeid	AS	Egen risikovurdering- må gjøres for hvert enkelt eksperiment		Prosessavhengig	
4	Tribologi-lab	AS				Må gjennomgå opplæring før bruk
5	Korrosjonslab	AS	Romkort	Sikkerhetsdatablad Brannslukker Briller og hansker påbudt	Ukjent	Sikkerhetskurs og test må godkjennes før bruk

NTNU	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
HMS		Rektor		01.12.2006

	Aktivitet fra kartleggingsskjemaet	Mulig uønsket hendelse/ belastning	Vurdering av sannsynlighet	Vurdering av konsekvens:				Risiko-Verdi (menneske)	Kommentarer/status Forslag til tiltak
ID nr			(1-5)	Menneske (A-E)	Ytre miljø (A-E)	Øk/ materiell (A-E)	Omdømme (A-E)		
1	Bruk av Trolllabs workshop.								
1a-i	Bruk av roterende maskineri	Stor kuttskade	2	D	A	A	D	2D	Sørg for at roterende deler tilstrekkelig sikret/dekket. Vær nøye med opplæring i bruk av maskineri.
1a-ii		Liten kuttskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iii		Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1a-iv		Flygende spon/gjenstander	3	C	A	A	B	3C	Bruk øyevern og tildekk hurtig roterende deler (Fres og lignende.)
1a-v		Feil bruk-> ødelagt utstyr	3	A	A	C	A	3C	Vær nøye med opplæring i bruk av maskineri
1b-i	Bruk av laserkutter	Klemskade	2	D	A	A	C	2D	Vær nøye med opplæring i bruk av maskineri. Ikke ha løse klær/tilbehør på kroppen.
1b-ii		Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskineri. Bruk hansker ved håndtering av varme materialer.

1b-iii		Øyeskade-laser	2	D	A	A	C	2D	Bruk øyevern! Skru av laser når maskinen ved oppsett.
1b-iv		Brann	2	B	A	D	C	2B	Vær nøye med opplæring i bruk av maskin. Ha slukkeutstur tilgjengelig
1c-i	Bruk av 3D-printer	Brannskade	3	B	A	A	A	3B	Vær nøye med opplæring i bruk av maskin.
1c-ii		Innhalering av plast/ printemateriale	5	A	A	A	A	5A	Bruk åndedretsvern/ vernebriller
1c-iii		Feil bruk-> ødelagt maskineri	3	A	A	C	A	3A	Vær nøye med opplæring i bruk av maskin.
1d-i	Bruk av skjæreverktøy	Stor kuttskade	2	D	A	A	D	2D	Bruk skapre verktøy og riktig skjæreunderlag
1d-ii		Liten kuttskade	3	B	A	A	A	3B	Bruk skapre verktøy og riktig skjæreunderlag
1e-i	Bruk av samenføynigsmidler (lim og lignende.)	Eksponering på øyet	2	D	A	A	B	2D	Bruk øyevern, ha datablad tilgjengelig
1e-ii		Eksponering hud	4	A	A	A	A	4A	Bruk hansker, ha datablad tilgjengelig
1e-iii		Eksponering åndedrett	4	A	A	A	A	4A	Bruk åndedretsvært/ god ventilasjon. Ha datablad tilgjengelig.

NTNU	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
HMS		Rektor		01.12.2006

1e-iv		Søl	4	A	B	A	A	4A	Ha papir/ rengjøringsmateriell tilgjengelig. Ha datablad tilgjengelig.
2	Tilstedeværelse ved arbeid utført av andre.	Se andres risikovurdering om sikkerhet betviles.	3	C	C	C	C	3C	Hold et øye med hva som foregår rundt deg.
3-i	Eksperimentelt arbeid	Drukning	1	A	A	A	D	1E	Bruk redingsvest i båt og lignende.
3-ii		Elektrisitet- strøm	3	B	A	A	A	3B	Typisk lite energi involvert. Bruk isolerte verkøty
5	Korrosjonslab								
5a	Bruk av syre	Etseskader, innånding av giftige gasser	3	C	A	A	A	3B	Briller og hansker er påbudt, luftavtrekk brukes.

NTNU	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
HMS		Rektor		01.12.2006

Sannsynlighet vurderes etter følgende kriterier:

Svært liten **1**	**Liten** **2**	**Middels** **3**	**Stor** **4**	**Svært stor** **5**
1 gang pr 50 år eller sjeldnere	1 gang pr 10 år eller sjeldnere	1 gang pr år eller sjeldnere	1 gang pr måned eller sjeldnere	Skjer ukentlig

Konsekvens vurderes etter følgende kriterier:

Gradering	**Menneske**	**Ytre miljø Vann, jord og luft**	**Øk/materiell**	**Omdømme**
E **Svært Alvorlig**	Død	Svært langvarig og ikke reversibel skade	Drifts- eller aktivitetsstans >1 år.	Troverdighet og respekt betydelig og varig svekket
D **Alvorlig**	Alvorlig personskade. Mulig uførhet.	Langvarig skade. Lang restitusjonstid	Driftsstans > ½ år Aktivitetsstans i opp til 1 år	Troverdighet og respekt betydelig svekket
C **Moderat**	Alvorlig personskade.	Mindre skade og lang restitusjonstid	Drifts- eller aktivitetsstans < 1 mnd	Troverdighet og respekt svekket
B **Liten**	Skade som krever medisinsk behandling	Mindre skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1uke	Negativ påvirkning på troverdighet og respekt
A **Svært liten**	Skade som krever førstehjelp	Ubetydelig skade og kort restitusjonstid	Drifts- eller aktivitetsstans < 1dag	Liten påvirkning på troverdighet og respekt

Risikoverdi = Sannsynlighet x Konsekvens
Beregn risikoverdi for Menneske. Enheten vurderer selv om de i tillegg vil beregne risikoverdi for Ytre miljø, Økonomi/materiell og Omdømme. I så fall beregnes disse hver for seg.

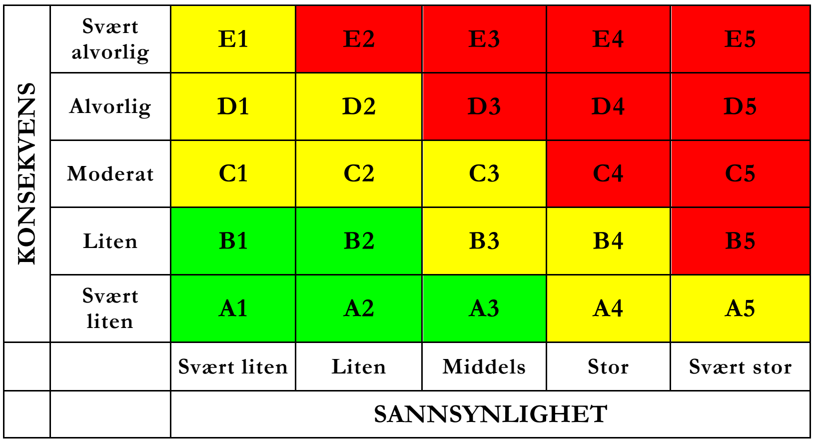
Til kolonnen ”Kommentarer/status, forslag til forebyggende og korrigerende tiltak”:

NTNU	Risikovurdering	Utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2601	22.03.2011
		Godkjent av		Erstatter
HMS		Rektor		01.12.2006

Tiltak kan påvirke både sannsynlighet og konsekvens. Prioriter tiltak som kan forhindre at hendelsen inntreffer, dvs. sannsynlighetsreduserende tiltak foran skjerpet beredskap, dvs. konsekvensreduserende tiltak.

NTNU	Risikomatrise	utarbeidet av	Nummer	Dato
		HMS-avd.	HMSRV2604	08.03.2010
		godkjent av		Erstatter
HMS/KS		Rektor		09.02.2010

MATRISE FOR RISIKOVURDERINGER ved NTNU



KONSEKVENS	Svært alvorlig	E1	E2	E3	E4	E5
	Alvorlig	D1	D2	D3	D4	D5
	Moderat	C1	C2	C3	C4	C5
	Liten	B1	B2	B3	B4	B5
	Svært liten	A1	A2	A3	A4	A5
		Svært liten	Liten	Middels	Stor	Svært stor
		SANNSYNLIGHET				

Prinsipp over akseptkriterium. Forklaring av fargene som er brukt i risikomatrisen.

Farge		Beskrivelse
Rød	🟥	Uakseptabel risiko. Tiltak skal gjennomføres for å redusere risikoen.
Gul	🟨	Vurderingsområde. Tiltak skal vurderes.
Grønn	🟩	Akseptabel risiko. Tiltak kan vurderes ut fra andre hensyn.