



U i T

THE ARCTIC
UNIVERSITY
OF NORWAY

Department of Engineering and Safety

Friction tests on polyurethane and concrete

Rolling friction tests and sliding friction tests on anti-abrasion polyurethane, anti-seepage polyurethane and concrete.

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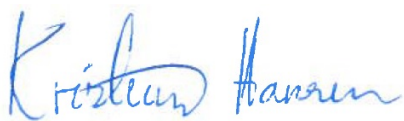
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Master thesis in Technology and Safety in the High North – June 2018



Preface

This master's thesis is prepared by me, Kristian Hansen, at the Department of Technology and Safety. I study Technology and Safety in the High North at UiT – Arctic University of Norway, and this master thesis is a completion of my master's degree. It is an independent work by the author. This master's thesis contains approximately 12308 words, 25 figures and 15 tables.



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Abstract

The climate in arctic areas of the world is a challenge for airports. Snow and ice accumulates on the runway, forcing airports to close the runways for snow clearing, which affect both departing and arriving flights. Pilots arriving at an airport with big passenger airplanes needs to know that the runway is free of snow and ice, and that the friction is at a respectable level. If not all of the friction requirements are met, arriving airplanes may have to return to the airport they departed from, or land at another airport nearby.

This master's thesis will look at the rolling friction and sliding friction on a polymer called polyurethane, and compare the results to concrete. The thesis will also look into how ice on top of polyurethane behaves when a car is driven on top of the ice. This is to find out if polyurethane can be considered as a new material on runways. Three boards were made to do friction tests, where two of them were coated with two different types of polyurethane, and one was coated with concrete. The result from the tests on the polyurethane boards, were then compared to the tests on the concrete board. The friction testing was done both with and without ice.

The results show that the difference in coefficient of friction with ice is slim to none, but some differences could be observed. The friction testing on polyurethane with ice made big cracks in the ice, something that did not happen during the friction testing on concrete. This shows that it is easier to remove ice from polyurethane than concrete. The results from the friction tests without ice are different from material to material. Polyurethanes coefficient of friction when it comes to rolling friction is higher for both types of polyurethane, compared to concrete. The sliding friction tests show that one of the types of polyurethane got almost the same coefficient of friction as concrete, and the other polyurethane got a higher coefficient of friction. Driving over the polyurethane and concrete, both of them covered with ice, gave very different results. The ice on top of the polyurethane cracked a lot, and the ice could easily be removed. The ice on top of concrete got very few cracks. The ice could not be removed without keeping the board in a room above freezing point, so the ice could melt by itself. This shows that both type of polyurethane can be considered as a new runway material.

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1 Introduction

1.1 Background

Runways that are covered with ice and snow are a big challenge in the arctic regions of the world. Snow and rain can easily be removed from a runway, and there are very good plans for this removal. They can also be prepared by taking the next day's weather forecast into consideration. Problems occur when snow and/or ice accumulate on the runway. Airplanes travelling from Gardermoen Airport outside of Oslo to Tromsø Airport, need to bring double amount of fuel so they can return to Gardermoen if they cannot land at Tromsø Airport. Airplanes that have to turn around and fly back to its original airport, costs the airline companies a lot of money. The crew in the airplane, pilots and flight attendants, gets overtime payment and the airplane has flown double mileage without any passengers getting off. There are also very strict rules when it comes to resting time for both pilots and crew. When the airplanes land at the airport it departed from, all the passengers need to be booked to another flight, or booked into a hotel until the next available flight. The passengers also get food coupons and toilet requisites if needed. These are just some of the expenses when an airplane has to return to the original departed airport. Runways have to close sometimes to clear it of snow and ice. Tromsø Airport had to close for 50 minutes January 9th to remove ice (Pedersen and Høyer, 2017). Incoming flights from Oslo and London were affected by this, and they had to land at a different airport. There were a lot of ice and tracks on the runway, and all of it had to be removed before the runway could reopen.

Visiting the arctic is becoming more popular for tourist from all over the world. Tromsø Airport in Northern Norway have had an increase in flight traffic from abroad the last year (Thoresen, 2018), and direct routes from Copenhagen and Gdansk are just two of many this year. Tromsø Airport had an increase in passengers of 5.3 % in January 2018 compared to January 2017, and this is 9355 passengers more than the year before. There was also an increase in domestic flights of 1.7 %. The increase in flight traffic to an airport means more take-offs and landings each hour, and this will result in less time for the snow-clearing crew to clear the runway.

When it's winter in Norway, all the airports have to do friction tests on the runways, to make sure that it's safe to take-off from and land on. If the tests say that the friction of the runway is

not acceptable, no airplane can land until something is done to make sure the friction is better. Most of the runways today are made of asphalt or concrete. These two materials are very hard, so the ice layer on top will not burst that easily when a force is applied. One normally uses a modified car to do the friction tests on a runway. The special thing about this car is that it has an extra tire to measure the friction on the runway. This tire is lowered when the car is on the runway, and the car keeps a steady pace when measuring the friction. This is done regularly when the conditions are not known. The friction test is not particularly time consuming and can be done in between landings (Sørdal and Ervland, 2014).

Safety for passengers and crew is the most important thing when it comes to airplanes. An accident with fatalities for an airline company can mean bankruptcy in the worst-case scenario, because of a bad reputation. The worst thing about an accident is not the potential bankruptcy, but the loss of passenger lives.

1.2 Research objective

The objective of this thesis is to see if there are any other materials that can be used on a runway instead of asphalt or concrete. The materials that will be tested should go through a friction test on both rolling friction and sliding friction. A material must have a rolling coefficient of friction and sliding coefficient of friction equal or better than the current material to be considered as a new runway material. This is because we do not want a new material with less friction. If the coefficient of friction on a new material is equal to the old material, this does not necessarily mean that it is pointless to replace the old material, because the new material may have other advantages. The material that will be tested is two types of polyurethane called anti-abrasion polyurethane and anti-seepage polyurethane. The contact pressure for an airplane tire is very high and will be difficult to reconstruct in small scale testing. Because a car would be accessible throughout the testing period, the tests are conducted with a contact pressure similar to a car.

Based on the research problems mentioned above, three research questions were formed:

1. How does the rolling friction of anti-abrasion polyurethane and anti-seepage polyurethane compare to concrete?
2. How does the sliding friction of anti-abrasion polyurethane and anti-seepage polyurethane compare to concrete?
3. How does the ice on top of polyurethane behave when a car is driven on top of it, compared to concrete?

1.3 Structure of thesis

This thesis will go through four main points, and these four points are:

- Literature review that goes through how snow and ice are dealt with at an airport and how the friction is measured. It will also go through the different materials used for testing, adhesion, the different types of friction, two types of tires used on airplanes, and abrasion.
- Methodology will go through how the different boards are made with all three materials, the two objects used for friction testing, and how the testing is conducted.
- Results and discussion will go through the results from the friction testing and discuss them. There will be a comparison of the results from the different materials.
- Conclusion that sums up the results and discussion. This part will also go through future work with thoughts on what could be done regarding this subject.

2 Literature Review

This chapter discusses the relevant literature and will go through how friction is measured at airports, the different materials, adhesion, different types of friction, tires and abrasion.

2.1 Snow and ice on runways

“Airports view fighting mother nature as war against cancelled flights, with runways as the battlefield” (Golson, 2015).

Snow and ice can make the runway friction get very low, and something may have to be done to increase the friction. Snow and ice do not only lower the friction on the runway, but heavy snowfall may close an airport for several hours. If there are too much snow on the runway, airplanes are not allowed to land. Heavy snowfall may also cause bad visibility for the pilots, so that they are not able to land. To handle the heavy snowfall in Tromsø, Tromsø Airport bought the World’s largest motor snowplough in 2011 (Bendiktsen, 2011). This snowplough weights 46 tons and can plough 12 000 tons of snow per hour.

Tromsø Airport is used to a lot of snow during winter, but sometimes the airport needs to close due to heavy snowfall. If the Airport has to close to remove the snow from the runway, it may take between 20-25 minutes until it can reopen. This may cause several airplanes to be in a holding pattern until the runway is cleared. Clearing the runway does not just delay airplanes landing, but also airplanes waiting to take off. It may also affect connecting flights at another airport, and thus cause passengers distress because they will not be able to board this flight.

2.2 Measure of friction at airports

Before the pilots land an airplane, they need to know the conditions of the runway. The information they get about the runway, should be given as close to the landing as possible. The Norwegian Civil Aviation Authority (Luftfartstilsynet, 2009) recommends using these five values to determine the friction level:

- Good - friction level 0.40 or higher
- Medium/good – friction level between 0.36 – 0.39
- Medium – friction level between 0.30 – 0.35
- Medium/poor – friction level between 0.26 – 0.29
- Poor – friction level 0.25 or lower

The pilots get a report ranging from “good” to “poor”. The information that is reported to the pilots is called SNOWTAM (SNOW Warning To Airmen). This is information about the type of ice and snow, how much of the runway is covered in snow or ice, and what is used to get better friction (sand or chemicals). The use of chemicals on runways are divided into three categories (Wåhlin and Klein-Paste, 2014). The first one is anti-icing, and this prevents a wet road from freezing. The second one is de-icing, and this removes snow and ice. The last one is anti-compaction, and this is used to prevent snow from compacting into a hard crust on the road. Different temperatures are also included, like air temperature, runway temperature and dew point temperature. One takes into account all of this information and get one of the five values above. An extra category called “NIL” may be used, and this category means that it is considered unsafe to land (Tunstad, 2012). There is a total of seven factors that are evaluated, and it can be expressed with the given equation below.

$$P = x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 \quad [2.1]$$

All of the values from x_1 to x_7 got its own factor, and they are listed in table 1 below.

Table 1: SNOWTAM factors

X ₁	Type of contamination
X ₂	Spatial coverage
X ₃	Depth of loose snow/slush
X ₄	Runway temperature
X ₅	Humidity
X ₆	Presence of anti-/de-icing chemicals
X ₇	Presence of sand

Variable x_1 is the base prediction, and ranges between 1 and 5. This is the observed contamination present on the runway. The next six variables range from -2 to +2, and they upgrade or downgrade the base prediction. The value P is always between 1 and 5, so if the value exceeds 5, it will be set to 5. If the value becomes lower than 1, the same rule applies, and P is set to 1 (Klein-Paste et al., 2015).

2.3 Polyurethane

Polyurethane was discovered in Germany by Otto Bayer and his coworkers in 1937 (Sharmin and Zafar, 2012), and they worked at I.G. Farben in Leverkusen. Polyurethane accounts for approximately 6 % of the global consumption of plastic (Sonnenschein, 2015, page 2). There are many places in the daily life where one can find polyurethane. Sonnenschein (2015, page 1) mentions how polyurethane surrounds your daily life, for instance inside shoes, seat cushions, fiber of clothes, refrigerator, dishwasher and so on.

This thesis will work with two different types of polyurethane. This is anti-abrasion polyurethane and anti-seepage polyurethane, where the hardness degree is highest for the anti-abrasion polyurethane.

2.4 Concrete

Concrete is made by mixing cement with water. The cement reacts with water, and a hard surface is made. Concrete is usually mixed with an aggregate, and the cement mixed with just water is called water-cement paste. The aggregate can be sand, gravel or crushed stone. A lighter concrete can be made by using a lightweight aggregate (LWA), and this LWA is made of porous burned clay (Thue, 2018). Concrete is often used in the United States of America as the road surface, but concrete has many areas of application. Concrete is used for dams, piers, bridges and so on. Reinforcement bars are often used to make the concrete stronger.

2.5 Adhesion

Adhesion is the molecular attraction between two materials. Ice on concrete has one adhesive bond strength, and ice on woodwork has another adhesive bond strength. The Good-Van Oss-Chaudhury theory shows how the adhesive bond strength between two materials, A and B, can be calculated. The adhesive bond strength is computed in terms of their respective surface free energy components (Wright et al., 2016).

$$\Delta G_{BA}^a = 2\sqrt{\gamma_B^{LW} + \gamma_A^{LW}} + 2\sqrt{\gamma_B^+ + \gamma_A^-} + 2\sqrt{\gamma_B^- + \gamma_A^+} \quad [2.2]$$

γ^{LW} is the Lifshitz Van der Waals component, γ^+ is the Lewis acid component and γ^- is the Lewis base component.

Researchers have divided the ice adhesion force into four categories (Houwink and Salomon, 1965; Xue and Khawaja, 2016), and the difference is how they stick to the surface. The four categories are electrostatic adhesion, diffusive adhesion, mechanical adhesion and chemical adhesion. Ice that freezes on concrete or polyurethane goes into the category mechanical adhesion. Most surfaces have microscopic pores, and mechanical adhesion happens when water flows into these pores and freezes. The water expands inside these pores, and interlocks between the walls of the pores (Bikerman, 2013; Xue and Khawaja, 2016). This means that a surface with more pores will have a bigger ice adhesion because of its roughness. The difference in ice adhesion can be seen by comparing general stainless steel and polished stainless steel.

Ice adhesion of general stainless steel is 1.65 MPa, and ice adhesion of polished stainless steel is 0.07 MPa (Kulinich and Farzaneh, 2009; Xue and Khawaja, 2016). Figure 1 below shows how water flows into a pore on a material.

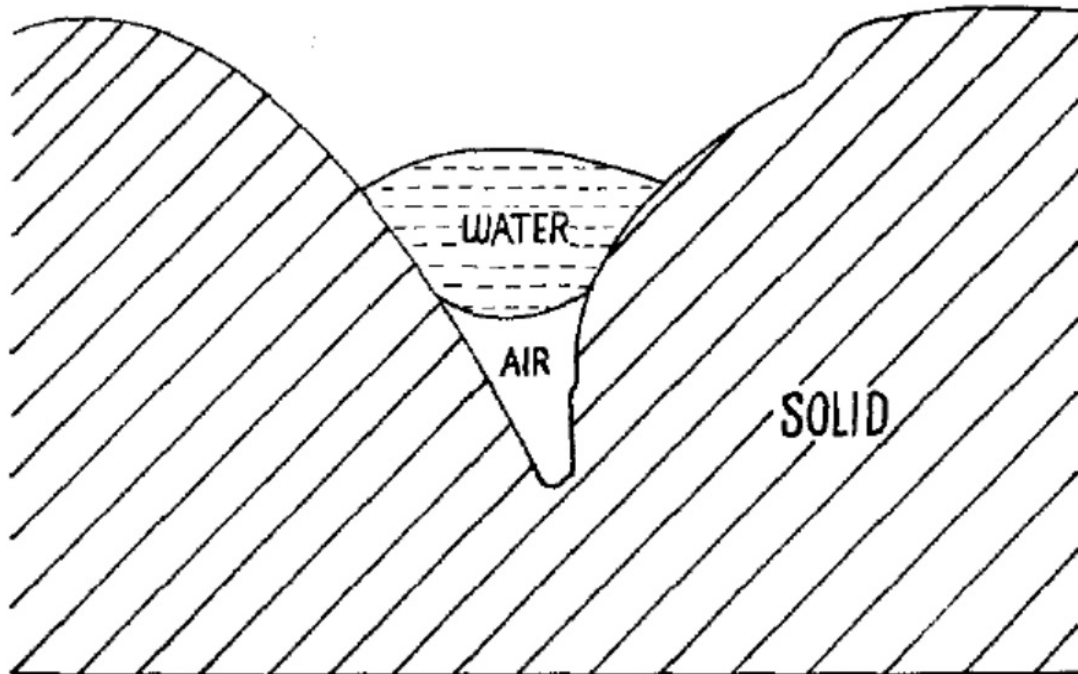


Figure 1: Water droplet inside a microscopic pore (Bikerman, 2013; Xue and Khawaja, 2016)

2.6 Friction

Friction is the force resisting movement between two surfaces. The friction force is in opposite direction of the force acting on the object. Friction can be divided into several groups, for instance static friction, dynamic friction and rolling friction.

2.6.1 Static friction

Static friction is the resisting of movement between two surfaces. When a force is applied to an object, the static friction force will have the same value but in the opposite direction. The friction will be equal to zero if there is no force applied to the object. The static friction will increase as more force is applied to an object, and it will reach its maximum value in the moment right before the object starts moving (Ormestad, 2017). The friction force can be written as:

$$f = \mu * N \quad [2.3]$$

Where f is the maximum value before the object starts moving, μ is the friction coefficient, and N is the normal force.

2.6.2 Dynamic friction

The dynamic friction is the force between two surfaces that slide relative to each other. The static friction is bigger than the dynamic friction and can be seen in figure 2 below.

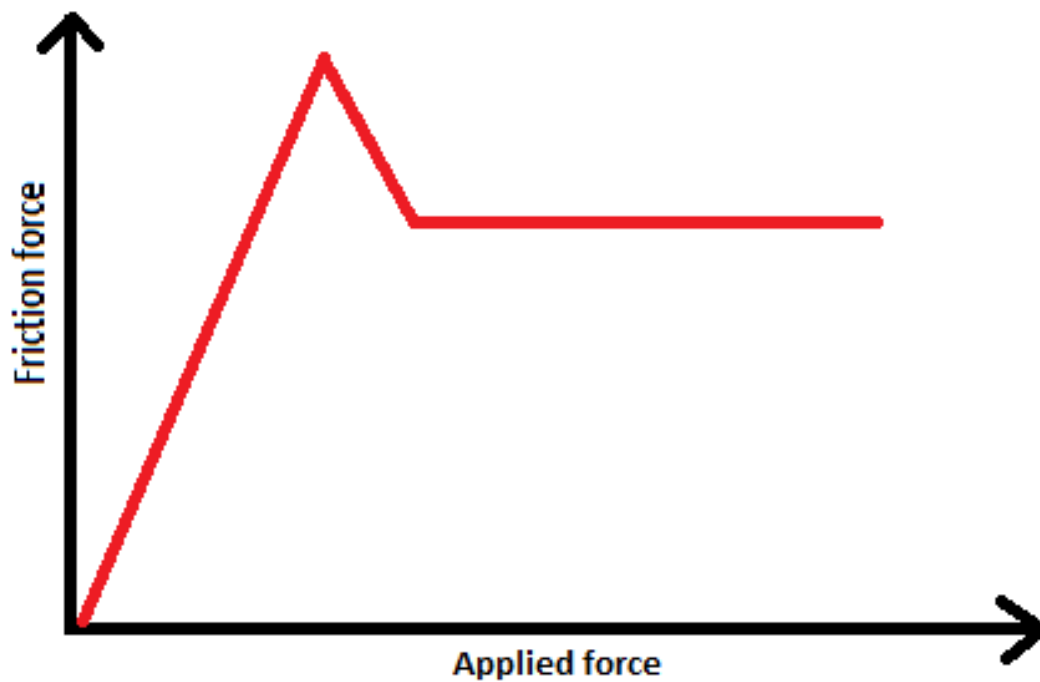


Figure 2: Static and dynamic friction

The figure above is a simplified model that shows the static friction and dynamic friction. The friction force will get bigger as more force is applied, and when the top of the graph is reached, one got the maximum force before the object starts moving. The maximum point on the graph

gives the highest static friction. When the maximum is reached, the friction force gets lower, and the result is dynamic friction.

The dynamic friction is calculated in the same way as static friction:

$$f = \mu * N \quad [2.4]$$

There are two parameters that can change the friction force, and that is the coefficient of friction and the normal force. The coefficient of friction is different for different objects that is moving relative to each other. Steel on steel will have one coefficient of friction, and a tire against a road will have another coefficient of friction. Gravel or salt is usually used on roads during winter to change the coefficient of friction, so cars get better grip. The normal force (N), is a force acting perpendicular on the object from the surface. If two objects with similar size, but different weight are tested on a surface, the object with the heaviest weight will have a bigger friction force, because of a bigger normal force.

2.6.3 Rolling friction

Rolling friction is much smaller compared with other types of friction. Coefficient of rolling friction can be defined like this:

“The horizontal force needed for constant speed on a flat surface divided by the upward normal force exerted by the surface” (Young et al., 2014, page 169).

Typical values for the coefficient of friction is 0.002 – 0.003 for trains on steel rails, and 0.02 for rubber tires on concrete. Rolling friction is the loss of energy during rolling and is therefore often called resistance to rolling.

2.7 Tires

The tires of an airplane are one of the most important things when it comes to take off and landing, and the tires need to be able to support the airplane when parked at an airport. Number of tires on an airplane depends on the size and weight. Antonov An-225 is the biggest airplane in the world with a total of 32 tires (Ege et al., 2015). This airplane may be an exception,

because it is only one An-225 in the World. Cessna 172 is an example of an airplane that have just three tires.

Airplane tires can be divided into two categories, and these are radial and bias. This is two different designs when making tires. During wintertime in arctic regions, one is required to put winter tires on cars. Airplanes do not need winter tires during wintertime, because a lot of the deceleration comes from the jet engines or propellers during landing. A take-off does not need that much traction from the tires, because the forward thrust does not come from the tires, but from the jet engines or propellers.

2.7.1 Radial

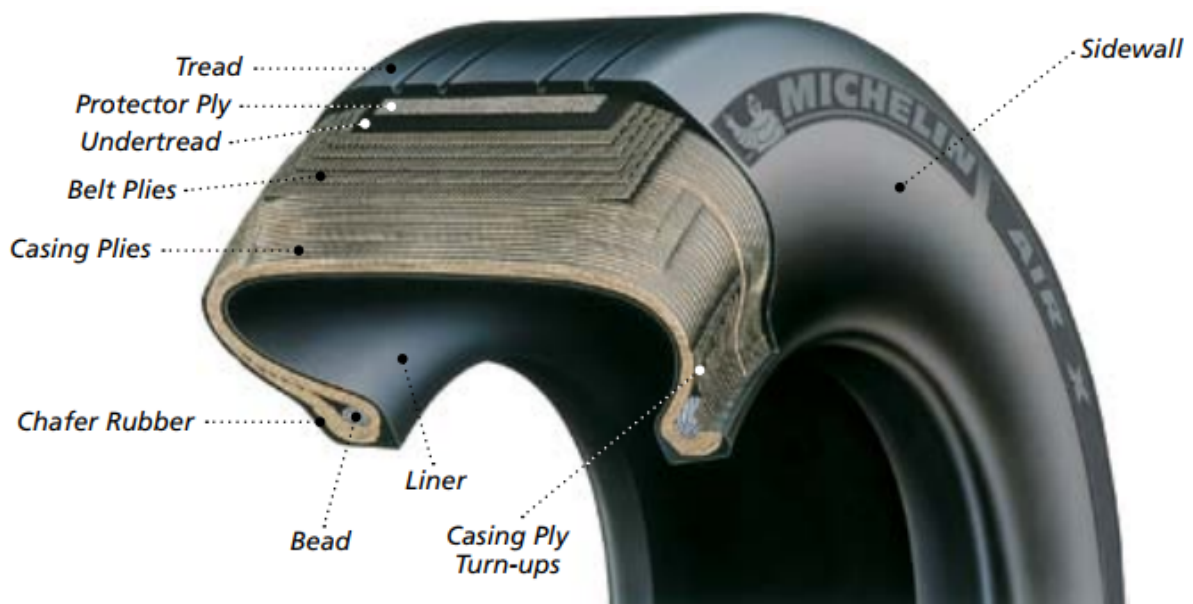


Figure 3: Michelin radial tire (Michelin, 2011)

The figure above shows the different parts of a radial tire. The tread is the part that comes in contact with the runway. This part protects the underlying layers from wear, cutting, cracking and heat (Michelin, 2011). In the tread, one can find the tread groove. This helps the airplane from aquaplaning, that can lead to an accident. Qantas Flight 1 to Bangkok on 23. September 1999, is a flight that skidded off the runway due to heavy rain. The airplane landed, but the pilots were not able to stop it from skidding off the runway (Medianti and Sulistiawan, 1999). The sidewall is also a part of the outer layer. This is a protection layer and is also used to show information about the tire.

The protection ply can be found under the tread and is made of steel or nylon fabric. This layer protects the plies that lay underneath. The protection ply is usually found in tires that are retreadable (Michelin, 2011). Underneath the protection ply, one can find the undertread. The undertread is a layer of rubber, that is helpful if a tire needs retreading.

The next two layers are called belt plies and casing plies. Belt plies are made of nylon or special fabric, and the casing plies are made of nylon. The belt plies help the tire resist to squirm and provides a uniform pressure distribution. The casing ply is laid at a 90° angle to the centerline of rotation. There are fewer casing ply in radial tires compared to bias tires, because the radial tires use the casing cords more efficiently (Michelin, 2011). From the figure one can see one bead on each side of the tire. The bead is made of steel wire and connects the tire to the rim.

2.7.2 Bias

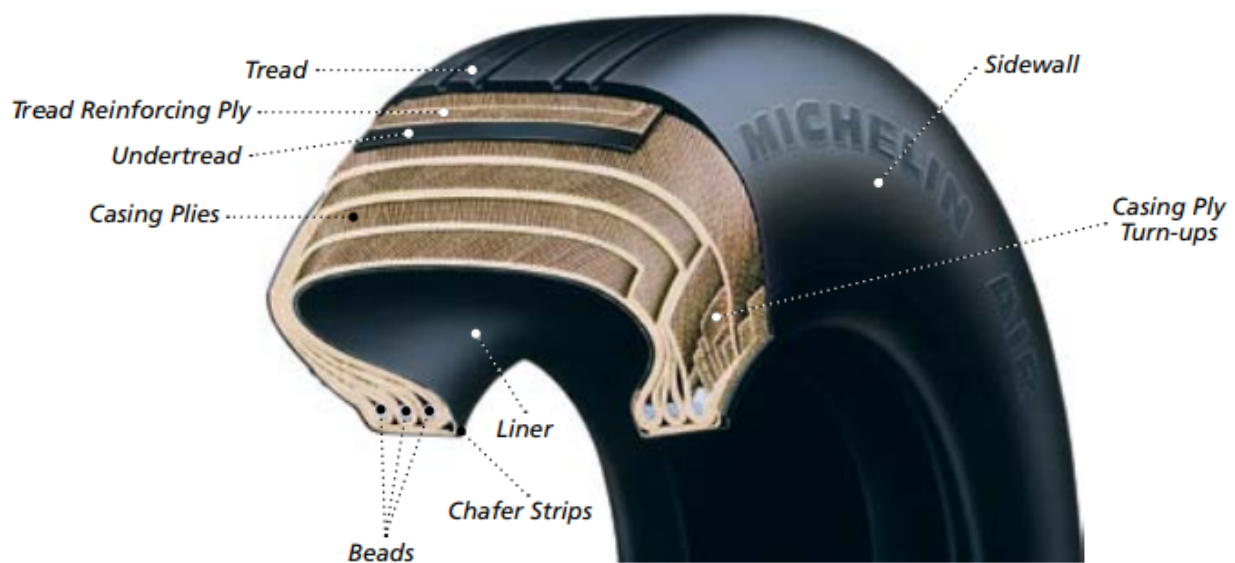


Figure 4: Michelin bias tire (Michelin, 2011)

The next tire, seen above, is the bias tire. Many of the components are the same in the radial tires and bias tires, like the tread and undertread. The casing plies are called the same in both tires, but they are not made in the same way.

The tread on bias tires can be made in different ways, depending on the area of application. Tread dimples are half-spheres in the tire and are used when the airplane is landing on grass or unimproved runways. Bias tire can also be made with fabric tread and spiral wrap. Fabric tread

is used on high speed military airplane, and spiral wrap is used with retreaded tires (Michelin, 2011).

The tread reinforcing ply is underneath the tread and is made of special nylon fabric. This layer increases the high-speed stability, and resist puncture. The casing ply is different from the radial tire because it is laid at angles between 30° and 60° to the centerline of rotation. They are also laid in the opposite direction for each layer (Michelin, 2011).

Unlike the radial tire, that has one bead on each side, the bias tire got one to four bead bundles on each side of the tire. Number of beads depends on size and design application (Michelin, 2011).

Both the radial tire and bias tire have longitudinal grooves in the design. They do not need transverse grooves, because airplanes do not turn at high speed. Airplanes have high speed during take-off and landing, and they are then moving in one direction on the runway. The longitudinal grooves in an airplane tire prevents aquaplaning.

2.8 Abrasion

Materials that is to be used on roads and runways need to withstand abrasion from the environments, caused by weather and by cars and trucks. A new material needs to be as good or better than the materials being used at the moment, to be considered. Abrasion tests have been conducted as reported by Wang et al. (2014) on polyurethane and concrete to see if polyurethane can withstand abrasion better than concrete. The testing was done with three different types of polyurethane with different hardness degree, and an abrasion-resistant concrete. Four concrete specimens were used during the testing, where three of the specimen where coated with the three different types of polyurethane, and the last one was a concrete specimen without any coating. The testing was done over a period of 72 hours with a water flow of 60 m/s. The water flow contained small steel balls to simulate abrasion conditions.

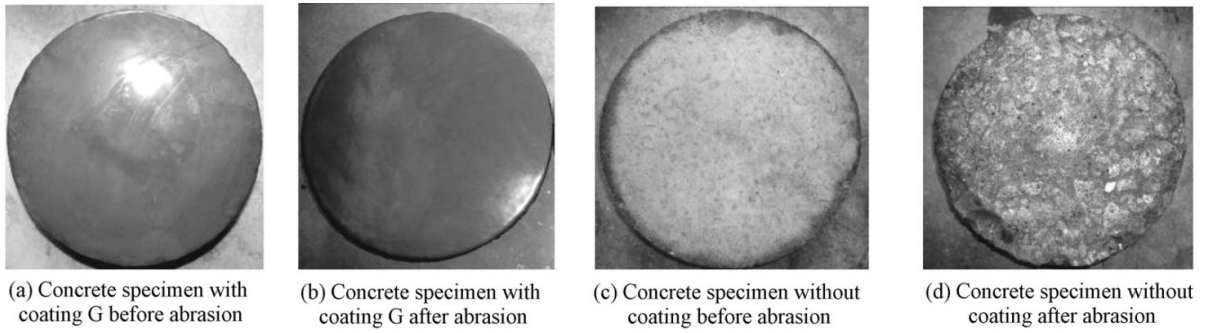


Figure 5: 72 hours of abrasion (Wang et al. 2014)

These tests showed no mass loss from the specimen coated with polyurethane, but the specimen without coating had a mass loss of 1.016 kg (Wang et al. 2014).

3 Methodology

To be able to compare polyurethane to concrete, it was necessary to conduct a quantitative experiment. The following chapter will describe how the experiments were conducted, using boards coated with polyurethane and concrete. It will also go through how the friction is measured and calculated.

3.1 Boards

The boards made for the thesis are made of the same woodwork. Each board is made with a board with 240 cm length, 60 cm width and 1.2 cm height. The board is an Oriented Strand Board (OSB), made by wood. Planks with the same length are used to shore up the board. Four planks were used on each board, and twelve screws to hold it together. There were placed two planks on each end of the board, and these planks also work as an edge, so the materials stay on the board. Both boards are made in the same way, to make it easier to compare the results. One also avoids sources of error. The only difference is the material on top, and they are the two types of polyurethane, and concrete.



Figure 6: Board under construction

3.1.1 Board with polyurethane

The first board was coated with polyurethane on both sides. One of the differences between the two samples of polyurethane is the hardness degree. Approximately four liters of polyurethane were used on each side of the board. The viscosity of polyurethane is high, when in liquid form. The first side was coated with anti-seepage polyurethane, and this side was made without the help of a concrete float, just some short planks to attempt to make a smooth surface. This was not that successful, because the surface was a little uneven when the surface had dried. The polyurethane wasn't self-leveling when it was poured onto the board, so a concrete float was used to make a smooth surface when anti-abrasion polyurethane was poured onto the other side of board. The use of a concrete float made the result from the anti-abrasion polyurethane board better than the anti-seepage polyurethane board. A picture of both sides can be seen in figure 7 below.



Figure 7: Anti-abrasion polyurethane (left) and anti-seepage polyurethane (right)

3.1.2 Board with concrete

The second board was coated with concrete, but just on one of the sides. The concrete was 20 kg of self-leveling concrete, mixed with 4 liters of water. Before the concrete was poured on top of the board, a primer was used to secure good grip between the layers. The concrete and water were mixed together in a bricklayer bucket for several minutes before it was poured onto the board. The mixing was done with a mixer attached to an electric drill. When the concrete was poured onto the board, it had to dry for approximately four hours before use. The concrete is self-leveling, so a concrete float was not needed to make a smooth surface on this board. A picture taken right after the concrete was poured onto the board, and a picture of the final result can be seen in figure 8.



Figure 8: Concrete board under construction

3.1.3 Waterproofing

Since the boards were to be tested with ice on top of them, the boards needed to be waterproof. This is because the boards are taken into the cold room, and water is poured on top of them. A plank was screwed into each end of the boards, but this doesn't make the boards waterproof. A sealing compound made of silicone was therefore used to seal the gap between the board and planks. This was done on both the polyurethane board and the concrete board. The sealing compound has a drying time of 2 millimeter per 24 hours, so the board could not be used for approximately 48 hours after applying the sealing compound. The picture below shows a part of the final result of the sealing compound on the board with anti-seepage polyurethane.



Figure 9: Sealing compound on board

3.2 Friction calculations

To find the coefficient of friction between a material and an object, a friction test with a ramp was carried out.

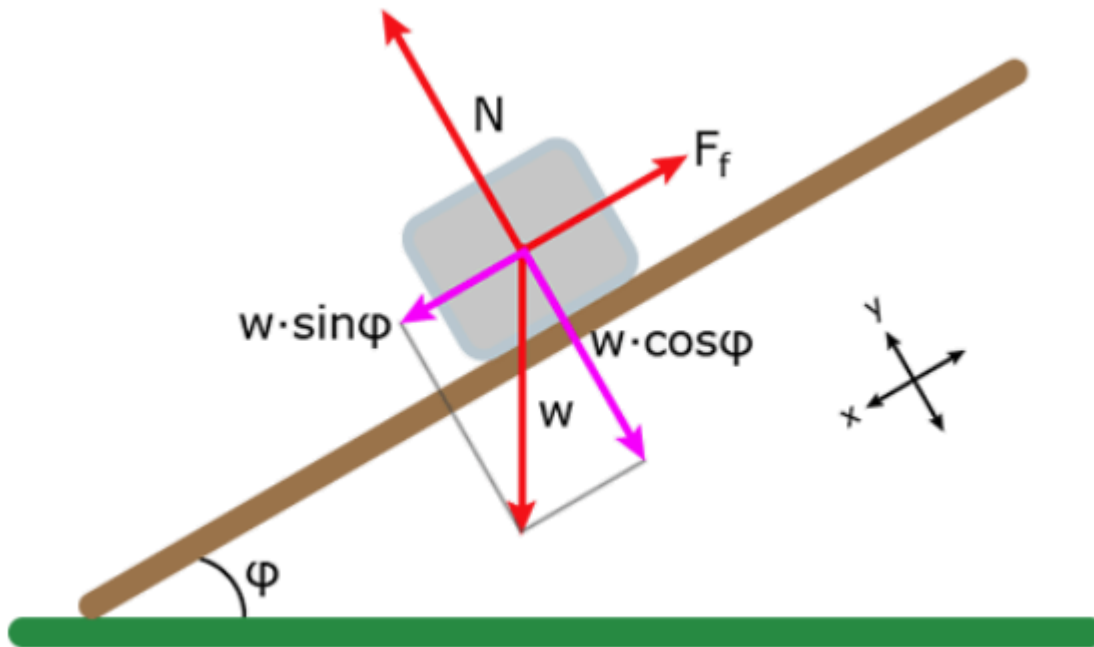


Figure 10: Ramp for friction test (Helmenstine, 2014)

From the figure above, one can see that the x-direction follow the angle of the ramp, and therefore the forces in x-direction are:

$$\Sigma F_x = w * \sin(\varphi) - F_f \quad [3.1]$$

Where F_f is the force of friction. ΣF_x must be equal to zero to find the static friction. The force of friction is defined in equation 2.3, so the formula can now be written as:

$$\begin{aligned} w * \sin(\varphi) - \mu_s * N &= 0 \\ w * \sin(\varphi) &= \mu_s * N \end{aligned} \quad [3.2]$$

The sum of the forces in y-direction will be zero as well, because the system is in equilibrium.

$$\begin{aligned}\Sigma F_y &= N - w * \cos(\varphi) \\ N &= w * \cos(\varphi)\end{aligned}\tag{3.3}$$

Now it is possible to put the value for normal force, from the forces in y-direction, into the equation for forces in x-direction:

$$\begin{aligned}w * \sin(\varphi) &= \mu_s * w * \cos(\varphi) \\ \mu_s &= \frac{w * \sin(\varphi)}{w * \cos(\varphi)} \\ \mu_s &= \tan(\varphi)\end{aligned}\tag{3.4}$$

This final equation is used to find the static coefficient of friction. An object will be placed on top of a sample that is mounted to the ramp. The ramp will then be lifted until the object starts moving. The coefficient is then found by measuring the angle of the ramp, and by using the formula above.

Another way to find the coefficient of friction is to measure the length of the sides. The length of the board is 240 cm, so the height of the plate will be measured during the testing.

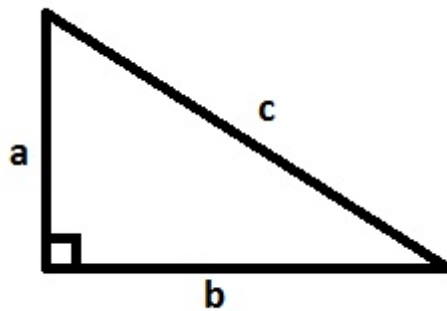


Figure 11: The Pythagorean Theorem

The calculation was done with the help of The Pythagorean Theorem:

$$\tan(\varphi) = \frac{a}{b} = \frac{a}{\sqrt{c^2 - a^2}}\tag{3.5}$$

Side c is constant 240 cm, and the two other sides are unknown. Side b will become shorter as the board is lifted, and this makes it is easier to measure side a than side b .

3.3 Contact pressure

The friction testing could not be done inside the cold room with a normal tire, because the contact pressure would be much smaller with less weight, so a round object with a smaller contact area were used. One of the most selling car in the World is the Volkswagen Golf, and this car is used to find an average contact pressure between a tire and the ground. The contact pressure for an airplane is much higher than the contact pressure for a car, and it is hard to do small scale testing with a contact pressure of an airplane. The friction testing is therefore done with the contact pressure similar to a car. The rest of this chapter will go through the different objects used for friction testing, both rolling friction and sliding friction.

3.3.1 Object for rolling friction

The object used for the rolling friction testing is touching the ground with two parts in the middle. To find the contact patch of this object, a stamp pad was used. The object was first pressed down on the stamp pad, and then down on a sheet of paper. The object made a mark on the paper, and this mark was measured to find the contact patch between the ground and the object. This was done several times, and the paper with marks can be seen in the appendix. The weight of the object was also needed to calculate the contact pressure.

- 60 mm²
- 1.088 kg

$$A = 60 \text{ mm}^2 = 6 * 10^{-5} \text{ m}^2$$

$$F = 1,088 \text{ kg} * 9.81 \frac{\text{m}}{\text{s}^2} = 10.67328 \text{ N}$$

$$\text{Contact pressure} = \frac{F}{A} = \frac{10.67328 \text{ N}}{6 * 10^{-5} \text{ m}^2} = 177888 \text{ Pa} = 177.888 \text{ kPa} \quad [3.6]$$

The calculations show that the contact pressure of the object is 177.888 kPa. The calculation for the Volkswagen Golf can be seen in chapter 3.3.2.

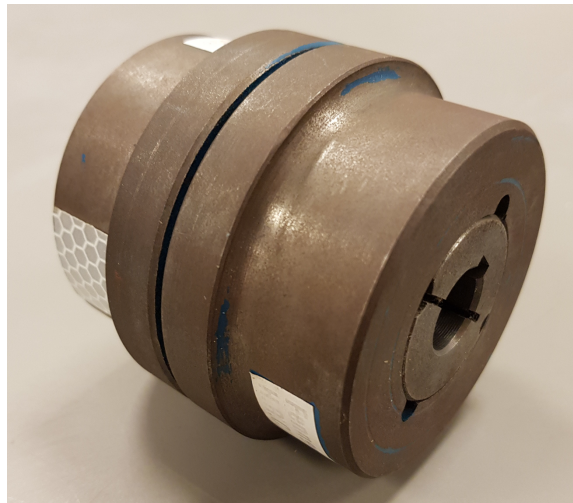


Figure 12: Object for rolling friction tests

3.3.2 Car

The contact patch is needed to find the contact pressure for a car. The contact pressure is calculated from a Volkswagen Golf, because it is one of the most selling cars in the World. The information about the car is taken directly from the car's registration book. The car is a Volkswagen Golf 1.6 TDI, made in 2011. An online tire data calculator is used to find the contact patch for this car (Mazzei, 2009). Information about the tires and the weight of the car is needed to calculate the contact patch. The information below is typed into the online calculator, and one can get the contact patch area, and other information about the tires.

- Tire: 195/65 R15
- Rim: 6J X 15
- Tire load index number: 86
- Tire speed index letter: T
- Air pressure: 2.3 bar
- Weight of the car: 1337 kg

The weight on each tire will be 334.25 kg if the total weight of the car is 1337 kg. This will not be completely true, because the weight of the car is not uniformly distributed, so there will be

a difference between the front tires and rear tires. The calculator calculates a contact patch area of 0,020813 m² from this information.

$$A = 208.13 \text{ cm}^2 = 0.020813 \text{ m}^2$$

$$F = 334.25 \text{ kg} * 9.81 \frac{\text{m}}{\text{s}^2} = 3278.9925 \text{ N}$$

$$\text{Contact pressure} = \frac{F}{A} = \frac{3278.9925 \text{ N}}{0.020813 \text{ m}^2} = 157545.4043 \text{ Pa} \approx 157.55 \text{ kPa} \quad [3.7]$$

The contact pressure from the Volkswagen Golf is approximately 157.55 kPa.

3.3.3 Comparison for rolling friction

The calculations show that the contact pressure from the object is a bit higher than the contact pressure from the Volkswagen Golf. The contact pressure from the object is 177.888 kPa, and the contact pressure from the car is 157.55 kPa. Different cars will have different contact pressures, so the object can be used for friction testing, although it has a bigger contact pressure than the Volkswagen Golf. A bigger truck would have a contact pressure bigger than the object, so one would need several objects if one wants to test for every kind of car.

3.3.4 Weight for sliding friction

For the sliding friction tests, a dumbbell weight was used. The contact area between the weight and board should be small, because the contact pressure should be around 150 kPa. The rubber from a used car tire was used to get this small contact area. A piece of rubber was cut from the tire with a knife, and glued onto the weight.



Figure 13: Rubber from a car tire

A total of three rubber pieces were glued to the weight. Just one weight of 2.5 kg was used, because that would give a lower centre of gravity. If the centre of gravity is too high, the weights could tip over before sliding.



Figure 14: Weight for sliding friction

Figure 14 above shows how the rubber pieces were glued to the weight. Some calculations were done to find the length and width of the three rubber pieces.

$$\begin{aligned}
 \text{Contact pressure} &= \frac{m * g}{A} = \frac{2.5 \text{ kg} * 9.81 \frac{\text{m}}{\text{s}^2}}{A} = 150\,000 \text{ Pa} \\
 &\downarrow \\
 A &= \frac{2.5 \text{ kg} * 9.81 \frac{\text{m}}{\text{s}^2}}{150\,000 \text{ Pa}} = 1.635 * 10^{-4} \text{ m}^2 = 1.635 \text{ cm}^2 \qquad [3.8]
 \end{aligned}$$

The rubber piece taken from the tire had a width of 0.5 cm, so the next thing was to find the length of each of the three pieces.

$$\begin{aligned}
 A &= \text{length} * \text{width} \\
 &\downarrow \\
 \text{Length} &= \frac{A}{\text{width}} = \frac{1.635 \text{ cm}^2}{0,5 \text{ cm}} = 3,27 \text{ cm} \qquad [3.9]
 \end{aligned}$$

The total length of the three rubber pieces is 3.27 cm, and this gives a length of 1.09 cm for each of them. Cutting the rubber pieces will not be faultless, so the contact pressure will be approximately 150 kPa.

3.4 Conducting the tests

The friction testing will be done with two temperatures, and these are approximately 20°C and -16°C. To get the most accurate result, a hydraulic jack is used to lift the board for testing the rolling friction. The boards are lifted approximately 20 cm in one end, and the hydraulic jack is placed on the other side, seen in figure 15. The rolling object is then placed on top of the board, and the hydraulic jack is used to lift the board until the object starts rolling. One can then

get the exact height when the object starts rolling. This method is used both in normal temperature (20 °C), and inside the cold room with ice on top of the board.

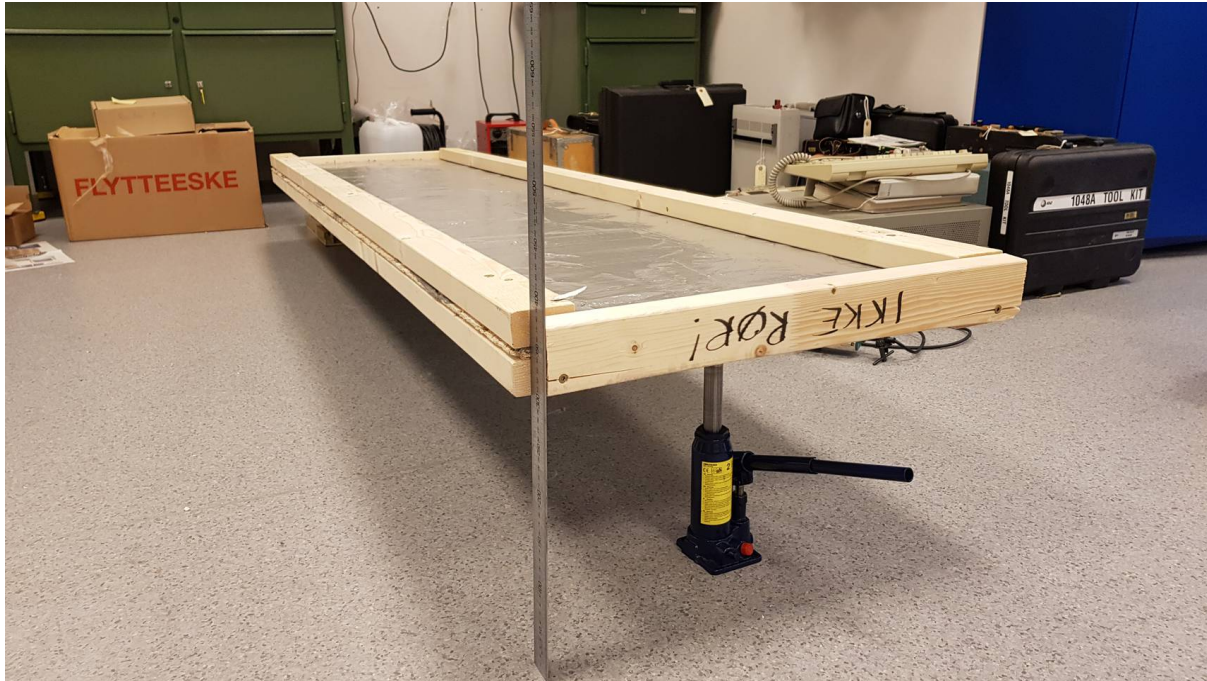


Figure 15: Setup for rolling friction testing without ice

When the board is lifted from the ground, a leveler is used to make sure that the board is level. The height of the board is then measured to find the height when it is level. One can now place the test object on top of the board and use the hydraulic jack to lift the board until the object starts moving. When the object starts rolling, a ruler is used to measure the exact height. Lifting height will then be the measured height, minus the height measured before lifting started.

The method for rolling friction cannot be used when testing the sliding friction. The lifting height is just 116 mm for the hydraulic jack, and this is not high enough to get an object to slide on the board. The board was therefore lifted by hand, and the height was measured when the object started sliding. The lifting had to be done very slowly, because it is easier to get the exact height. This was done with two persons, where one lifted the board and informed the other person when the object started moving, so the other person could measure the height. A tape line was fastened to the ground in one end, and one person could measure the height. The dumbbell used for sliding friction testing was placed in the same direction for every sliding test, to get comparable results.

The same method was used for friction testing inside the cold room, for both rolling friction and sliding friction. Water was poured on top of the board at least one day before testing, to make sure it was solid ice. There were used 8 litres of tap water from the laboratories at the University. The length of the board is 240 cm, and the width is 46 cm.

$$V = 8 \text{ litres} = 8000 \text{ cm}^3$$

$$V = \text{length} * \text{width} * \text{height}$$

↓

$$\text{Height} = \frac{V}{\text{length} * \text{width}} = \frac{8000 \text{ cm}^3}{240 \text{ cm} * 46 \text{ cm}} = \frac{50}{69} \text{ cm} \approx 0.72 \text{ cm} \quad [3.10]$$

The thickness of the ice will be approximately 0.72 cm during the friction testing, and all three materials will get the same ice thickness. The ice thickness will not be 0.72 cm on the entire board, so there will be places where it is a little thinner, and places where it is a little thicker. Both the rolling and sliding object used for testing is put inside the cold room at the same time as the board, to get the same temperature. If the test objects are taken inside the cold room right before testing, they may melt the ice because of a higher temperature. Both rolling friction tests and sliding friction tests is done with help of a hydraulic jack inside the cold room. The setup for rolling friction is the same as the one in the laboratory, and can be seen in figure 15 (setup for rolling friction testing without ice). The setup for sliding friction testing with ice can be seen in figure 16 below.



Figure 16: Setup for sliding friction testing with ice

This setup gives a very accurate result because it is possible to see exactly when the object starts sliding. The start position for the lifting will be approximately 50 cm, because the sliding on ice will start higher than this height.

Safety is important when working in cold environments, so some precautions had to be taken into account. The cold room will have a temperature of $-16\text{ }^{\circ}\text{C}$ during testing, but the apparent temperature will be lower due to two fans. Clothing to cover most of the skin will be used to prevent frostbite. Clothing will be a thermal suit, mittens with gloves underneath, multi-functional headwear (buff) to cover the neck, a poofball hat, a woollen sweater, and warm shoes with woollen socks. The interval between breaks will not be longer than ten minutes, and the breaks will last for a minimum five minutes.

There will also be done testing on how the ice breaks when a car is driven over the different boards. This is done to see how the ice behaves, and check if there are any differences between polyurethane and concrete. The testing will be done on the anti-seepage polyurethane side of the board, and not on the anti-abrasion polyurethane side. The testing will be done with a Hyundai Getz with summer tires. Winter tires are not required to do this test, because the contact area will be the same with summer tires and winter tires. The only difference would be if the winter tires got spikes because the spikes may help crush the ice. Two of the planks, on the opposite side of the ice, will be taken off the board to make as little flex in the board as possible when it is placed on the ground. The car will then be driven over the board at low speed.



Figure 17: Tire used for ice breaking test

4 Results and discussion

This chapter will look at the results from the friction testing, and go through how the ice came off the materials when a car was driven over them. There will be one part for each material, which goes through both rolling friction and sliding friction. A comparison is done in the end, to show the differences between the materials. There will be a total of 12 results from the friction testing, six from rolling friction and six from sliding friction. The six results from each friction testing is also divided into two groups, where three is done inside the cold room with ice on top of the board, and a temperature of $-16\text{ }^{\circ}\text{C}$. The other three were done with a temperature of $20\text{ }^{\circ}\text{C}$. The numbers inside the tables are given in millimetres, and it is the measured height. The height measured can be seen in figure 18 below.

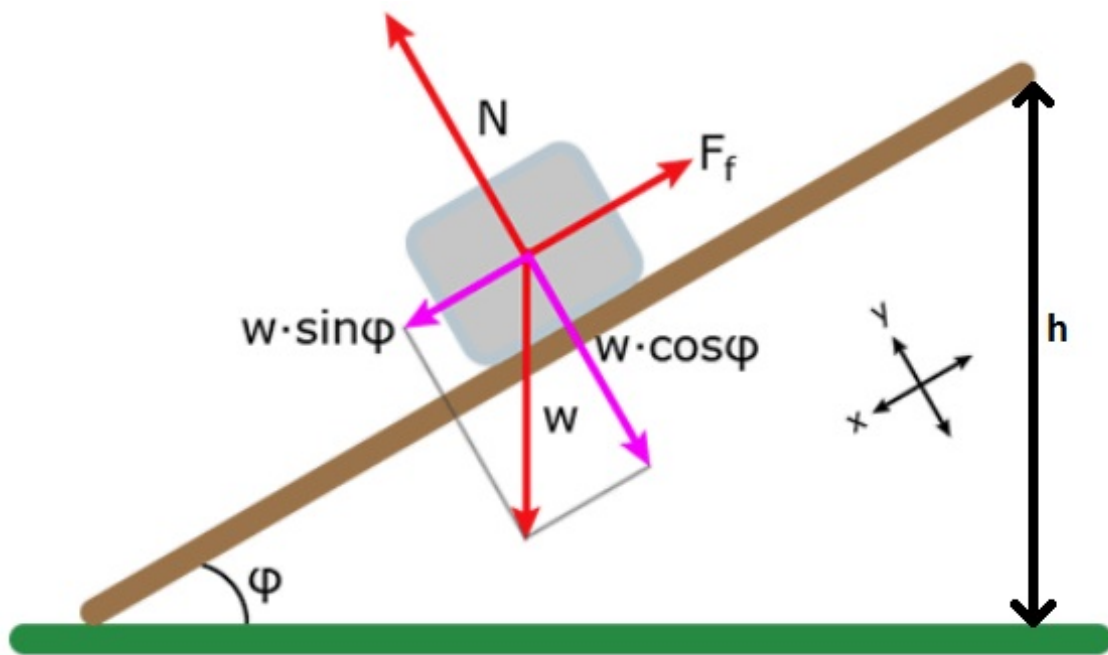


Figure 18: Height measured during testing (Helmenstine, 2014)

All boards and objects used for friction testing were cleaned before each test, because dirt can affect the results. A white powder was observed at the start of the sliding friction test on anti-abrasion polyurethane, and this stuck to the sliding object. This can be seen in figure 19 below.



Figure 19: White powder on dumbbell

A few tests were done without removing this powder, and the coefficient of friction was lower with the powder, than without the powder. The boards were being stored in a laboratory where many people have access, so other people at the University can easily contaminate the boards.

There are given one table for each of the friction tests. The table consist of the measured heights, the average height, standard deviation, friction coefficient, and the error in friction coefficient calculation. The error coefficient calculations are given with a confidence interval of three sigma (σ). Three sigma equals 99.7 %, so a new test with the same conditions will have a 99.7 % certainty of being between the given values.

4.1 Anti-abrasion polyurethane

The first material to be tested was the anti-abrasion polyurethane. This side of the board got a very smooth surface, with just a few air bubbles. This made it easier to find a smooth area on the board to carry out the friction testing.

4.1.1 Rolling friction

4.1.1.1 With ice

Table 2: Rolling friction test on anti-abrasion polyurethane covered with ice

	Height (h)
Experimental data for 25 cases (mm)	40, 31, 29, 35, 31, 37, 33, 39, 29, 39, 26, 30, 35, 37, 30, 32, 33, 29, 38, 29, 30, 30, 29, 39, 32
Average (mm)	32.9
Standard Deviation	3.98
Friction coefficient (Equation 3.4)	0.014
Error in friction coefficient calculation (3σ)	± 0.0017

These values give an average height of 32.9 mm, where the highest high was 40 mm and the lowest low 26 mm. Average coefficient of friction is approximately 0.014. The error in friction coefficient gives a friction coefficient between 0.0123 and 0.0157.

4.1.1.2 Without ice

Table 3: Rolling friction test on anti-abrasion polyurethane without ice

	Height (h)
Experimental data for 25 cases (mm)	43, 50, 48, 53, 48, 46, 50, 47, 51, 50, 50, 49, 52, 51, 53, 47, 53, 47, 52, 50, 52, 43, 46, 44, 54
Average (mm)	49.2
Standard Deviation, σ	3.11
Friction coefficient (Equation 3.4)	0.020
Error in friction coefficient calculation (3σ)	± 0.0013

These values give an average height of 49.2 mm, where the highest high was 54 mm and the lowest low 43 mm. Average coefficient of friction is approximately 0.020. The error in friction coefficient gives a friction coefficient between 0.0187 and 0.0213.

4.1.2 Sliding friction

4.1.2.1 With ice

Table 4: Sliding friction test on anti-abrasion polyurethane covered with ice

	Height (h)
Experimental data for 25 cases (mm)	573, 571, 570, 570, 571, 572, 572, 571, 571, 575, 570, 574, 573, 570, 574, 566, 573, 576, 576, 575, 574, 575, 572, 573, 572
Average (mm)	572.4
Standard Deviation	2.26
Friction coefficient (Equation 3.4)	0.246
Error in friction coefficient calculation (3σ)	± 0.001

These values give an average height of 572.4 mm, where the highest high was 576 mm and the lowest low 566 mm. Average coefficient of friction is approximately 0.246. The error in friction coefficient gives a friction coefficient between 0.245 and 0.247.

4.1.2.2 Without ice

Table 5: Sliding friction test on anti-abrasion polyurethane without ice

	Height (h)
Experimental data for 25 cases (mm)	1337, 1267, 1377, 1222, 1282, 1312, 1237, 1367, 1287, 1282, 1272, 1242, 1292, 1297, 1257, 1302, 1267, 1257, 1277, 1257, 1387, 1272, 1237, 1282, 1247
Average (mm)	1284.6
Standard Deviation	42.3
Friction coefficient (Equation 3.4)	0.634
Error in friction coefficient calculation (3σ)	± 0.090

These values give an average height of 1284.6 mm, where the highest high was 1387 mm and the lowest low 1222 mm. Average coefficient of friction is approximately 0.634. The error in friction coefficient gives a friction coefficient between 0.544 and 0.724.

4.2 Anti-seepage polyurethane

The board with anti-seepage polyurethane is a bit uneven. There are some areas that are better than others are, so the friction testing is done on the smoothest areas.

4.2.1 Rolling friction

4.2.1.1 With ice

Table 6: Rolling friction test on anti-seepage polyurethane covered with ice

	Height (h)
Experimental data for 25 cases (mm)	35, 32, 34, 35, 35, 37, 34, 31, 30, 34, 35, 35, 32, 40, 33, 32, 29, 36, 32, 29, 30, 34, 28, 34, 33
Average (mm)	33.2
Standard Deviation	2.69
Friction coefficient (Equation 3.4)	0.014
Error in friction coefficient calculation (3σ)	± 0.003

These values give an average height of 33.2 mm, where the highest high was 40 mm and the lowest low 28 mm. Average coefficient of friction is approximately 0.014. The error in friction coefficient gives a friction coefficient between 0.011 and 0.017.

4.2.1.2 Without ice

Table 7: Rolling friction test on anti-seepage polyurethane without ice

	Height (h)
Experimental data for 25 cases (mm)	58, 54, 54, 57, 57, 53, 57, 52, 56, 53, 58, 57, 53, 59, 55, 55, 52, 53, 56, 53, 58, 53, 56, 54, 54
Average (mm)	55.1
Standard Deviation	2.08
Friction coefficient (Equation 3.4)	0.023
Error in friction coefficient calculation (3σ)	± 0.003

These values give an average height of 55.1 mm, where the highest high was 59 mm and the lowest low 52 mm. Average coefficient of friction is approximately 0.023. The error in friction coefficient gives a friction coefficient between 0.020 and 0.026.

4.2.2 Sliding friction

4.2.2.1 With ice

Table 8: Sliding friction test on anti-seepage polyurethane covered with ice

	Height (h)
Experimental data for 25 cases (mm)	574, 572, 577, 574, 577, 567, 573, 576, 570, 575, 569, 571, 574, 571, 572, 581, 574, 573, 575, 573, 577, 569, 575, 574, 572
Average (mm)	573.4
Standard Deviation	2.98
Friction coefficient (Equation 3.4)	0.246
Error in friction coefficient calculation (3σ)	± 0.004

These values give an average height of 573.4 mm, where the highest high was 581 mm and the lowest low 567 mm. Average coefficient of friction is approximately 0.246. The error in friction coefficient gives a friction coefficient between 0.242 and 0.250.

4.2.2.2 Without ice

Table 9: Sliding friction test on anti-seepage polyurethane without ice

	Height (h)
Experimental data for 25 cases (mm)	1878, 1848, 1848, 1848, 1848, 1888, 1898, 1853, 1848, 1878, 1898, 1863, 1848, 1888, 1863, 1878, 1848, 1838, 1868, 1848, 1828, 1863, 1828, 1858, 1868
Average (mm)	1860.8
Standard Deviation	19.3
Friction coefficient (Equation 3.4)	1.228
Error in friction coefficient calculation (3σ)	± 0.097

These values give an average height of 1860.8 mm, where the highest high was 1898 mm and the lowest low 1828 mm. Average coefficient of friction is approximately 1.228. The error in friction coefficient gives a friction coefficient between 1.131 and 1.325.

4.3 Concrete

The concrete board got a very smooth surface, so there was no problem to find an area to place the objects, although, the objects were placed in the same area each time.

4.3.1 Rolling friction

4.3.1.1 With ice

Table 10: Rolling friction test on concrete covered with ice

	Height (h)
Experimental data for 25 cases (mm)	39, 36, 31, 38, 33, 45, 38, 33, 29, 31, 44, 33, 36, 30, 30, 39, 33, 29, 32, 33, 38, 28, 33, 28, 31
Average (mm)	33.4
Standard Deviation	4.02
Friction coefficient (Equation 3.4)	0.014
Error in friction coefficient calculation (3σ)	± 0.005

These values give an average height of 33.4 mm, where the highest high was 44 mm and the lowest low 28 mm. Average coefficient of friction is approximately 0.014. The error in friction coefficient gives a friction coefficient between 0.009 and 0.019.

4.3.1.2 Without ice

Table 11: Rolling friction test on concrete without ice

	Height (h)
Experimental data for 25 cases (mm)	29,29, 33, 24, 29, 27, 24, 28, 31, 27, 22, 23, 32, 23, 32, 33, 25, 31, 29, 30, 28, 25, 33, 27, 26
Average (mm)	28
Standard Deviation	3.32
Friction coefficient (Equation 3.4)	0.012
Error in friction coefficient calculation (3σ)	± 0.004

These values give an average height of 28 mm, where the highest high was 33 mm and the lowest low 22 mm. Average coefficient of friction is approximately 0.012. The error in friction coefficient gives a friction coefficient between 0.008 and 0.016.

4.3.2 Sliding friction

4.3.2.1 With ice

Table 12: Sliding friction test on concrete covered with ice

	Height (h)
Experimental data for 25 cases (mm)	577, 570, 573, 574, 570, 573, 571, 572, 570, 573, 575, 575, 573, 573, 570, 570, 574, 571, 569, 569, 574, 570, 575, 572, 573
Average (mm)	572.2
Standard Deviation	2.12
Friction coefficient (Equation 3.4)	0.246
Error in friction coefficient calculation (3σ)	± 0.003

These values give an average height of 572.2 mm, where the highest high was 577 mm and the lowest low 569 mm. Average coefficient of friction is approximately 0.246. The error in friction coefficient gives a friction coefficient between 0.243 and 0.249.

4.3.2.2 Without ice

Table 13: Sliding friction test on concrete without ice

	Height (h)
Experimental data for 25 cases (mm)	1400, 1400, 1375, 1380, 1405, 1425, 1405, 1395, 1390, 1405, 1400, 1390, 1400, 1375, 1395, 1370, 1395, 1405, 1395, 1405, 1385, 1390, 1410, 1385, 1415
Average (mm)	1395.8
Standard Deviation	12.7
Friction coefficient (Equation 3.4)	0.715
Error in friction coefficient calculation (3σ)	± 0.029

These values give an average height of 1395.8 mm, where the highest high was 1425 mm and the lowest low 1370 mm. Average coefficient of friction is approximately 0.715. The error in friction coefficient gives a friction coefficient between 0.686 and 0.744.

4.4 Comparison

The comparison will be divided into two parts: rolling friction and sliding friction. These two parts will compare the friction with ice and without ice. The results in the table is the coefficient of friction with the different materials, and the results are given with three decimal places.

4.4.1 Rolling friction

The rolling friction tests got some very interesting results. A table with the average coefficient of friction from each test can be seen in the table below.

Table 14: Summary of rolling friction tests

	Anti-abrasion polyurethane	Anti-seepage polyurethane	Concrete
Without ice	0.020	0.023	0.012
With ice	0.014	0.014	0.014

One can see in table 14 that the friction tests with ice inside the cold room gave the same coefficient of friction for all three materials, and that was 0.014. The ice on top of concrete did not get any cracks after the testing, and it could not be seen that anything had rolled on top of it. The ice on top of both the anti-abrasion polyurethane board and the anti-seepage polyurethane board behaved differently. The cracks could be seen both during and after the testing on these two materials. The ice did not come off the board, but this may be because the contact area is not as big as a car tire. The picture in figure 20 is just a small area of the board with cracks, and there were other areas with similar cracks. The full length of the board was used during these tests, and no sliding was observed on the boards during any of the rolling friction tests on the three materials. Another reason for using the full length of the board, was to check if more cracks would develop as the rolling object accelerated down the board. Most of the cracks on the board developed where the rolling object had rolled about 1 meter and got a bigger velocity.



Figure 20: Cracks on polyurethane board with ice

The difference between the materials without ice is much higher. The anti-seepage polyurethane got the highest coefficient of friction, with 0.023, and this is the softest polyurethane. The coefficient of friction with anti-abrasion polyurethane is not as high as the anti-seepage polyurethane, but it is 0.020, and that is 0.003 lower than the anti-seepage polyurethane. The biggest difference can be seen between anti-seepage polyurethane and concrete. The coefficient of friction with concrete is just 0.012, and that is 0.011 lower than anti-seepage polyurethane. The coefficient of friction is almost halved with concrete compared to anti-seepage polyurethane.

One of the reasons that the coefficient of friction is higher on the polyurethane is caused by the flexibility of the material. This can be compared with rolling a marble on a sponge. The marble would start rolling, but quickly sink into the sponge. The same will happen when an object is placed on top of polyurethane. The object will sink into the polyurethane, making it more difficult to start rolling.

4.4.2 Sliding friction

The results from the sliding friction testing without ice is not as accurate as the rolling friction tests. This is because the board had to be lifted much higher, so the hydraulic jack could not be used. The rolling friction height was measured in millimeters, but the sliding friction height was measured in centimeters, with an interval of 0.5 centimeter.

Table 15: Summary of sliding friction tests

	Anti-abrasion polyurethane	Anti-seepage polyurethane	Concrete
Without ice	0.634	1.228	0.715
With ice	0.246	0.246	0.246

The same object was used to do all of the sliding friction testing, and that was a dumbbell weight with rubber from a tire. This is because it is the best way to compare the results. The testing was first done on the concrete board, then the anti-seepage polyurethane board, and the lastly one was the anti-abrasion polyurethane board. To see the first movement, a line was drawn with a marker in front of the object, to make it easier to see the movements of the object. The line was very helpful during the first two tests, on concrete and anti-seepage polyurethane, because the first movement was very little. The tests on the anti-abrasion polyurethane board were very different. The acceleration of the object on this board was much bigger than on the other two materials.

The results from the sliding friction tests without ice got some interesting results. The anti-seepage polyurethane got a friction of 1.228, and this is much higher than the other two materials. One can see in table 15 above that the friction on concrete is higher than the friction on anti-abrasion polyurethane. This was not expected after the results from the rolling friction testing, because the rolling friction was much higher on the anti-abrasion polyurethane than the concrete. The friction for concrete is 0.513 lower than anti-seepage polyurethane, and anti-abrasion polyurethane is 0.594 lower than anti-seepage polyurethane.

Figure 21 below shows how good the sliding friction is on the anti-seepage polyurethane board without ice. All the other tests were done with a metal ruler with a length of 1.5 meters, but

something else had to be used to measure this height. A tape line was therefore used, because this could measure height up to 5 meters.



Figure 21: Sliding friction on anti-seepage polyurethane without ice

The rolling friction tests on ice gave the same coefficient of friction for all three materials. The same thing happened with the sliding friction tests with ice on all three materials, because the coefficient of friction was the same. The coefficient of friction was 0.246 with ice. The sliding friction with ice was the most difficult to test, because the movements of the sliding object were very small, and one had to be very careful when using the hydraulic jack. The ice did not come off the board during the friction testing on the three materials, and there were no cracks in the ice, as it was during the rolling friction tests. The same reason applies why the ice did not come off, and that is because the contact pressure is the same, but the contact area is much smaller. A bigger contact area would make more of the two types of polyurethane to flex under the ice, and the rolling object and the sliding object would probably make more cracks in the ice.

4.5 Ice Removal

This part goes through the results from the ice removal tests. The first part goes through how the ice was removed from the boards inside the cold room with a hammer, and the second part looks at how the ice on top of the materials behaved when a car was driven over them.

4.5.1 Ice removal with hammer

The two boards that were used for friction testing were both taken out of the cold room after testing. The boards were filled with ice that would melt and turn into water in room temperature, so the best thing would be to remove most of the ice before taking them out from the cold room. A hammer was used to try to remove the ice. The board with anti-seepage polyurethane was the first board to be taken out of the cold room. The hammer was used on the ice, and big bits of the ice came off immediately. All of the ice was broken in just a couple of minutes, and a broom and bucket were used to collect the ice. The picture below shows how the ice came off after just a few blows with the hammer.



Figure 22: Ice removal from anti-seepage polyurethane

The same method was used in an attempt to remove the ice from the board with concrete. The hammer was used on the ice, but the ice would not come off. The picture below shows how the ice looked after about 50 blows from a hammer.



Figure 23: Ice removal from concrete

No cracks developed on the concrete board, and the cracks that can be seen in the picture were already on the board before the ice removal test. Since the ice would not come off inside the cold room, the board had to be taken outside the cold room, so the ice could melt by itself.

4.5.2 Driving over the boards

The board with anti-seepage polyurethane and the board with concrete, both with ice, was taken outside to do further testing. Both boards were filled with the same amount of water and kept in the cold room the same amount of time before testing. The boards were placed on top of asphalt, and a car was driven over them. Pictures were taken before and after the driving, and a video was also made, and can be found in the appendix. The pictures will show the board after the car has driven over the board with two tires.



Figure 24: Before (left) and after (right) driving over concrete board

Figure 24 shows the concrete board before and after the car was driven over it. There were not a lot of cracks in the ice, and the cracks that developed were at the place where the car drove onto the board. There is a little edge between the asphalt and ice at approximately 3 cm that the car had to drive over to come on top of the board. This is the place on the board where the cracks developed, and the rest of the board got no new cracks.

The next board to be driven over was the board coated with anti-seepage polyurethane. The board was placed at the exact same place as the concrete board, to get comparable results. The tire did not hit the middle of the board when driving over concrete, so the same thing had to be done when driving over the anti-seepage polyurethane, so the driving was done a little to the right of the middle.



Figure 25: Before (left) and after (right) driving over anti-seepage polyurethane board

One can see from figure 25 and the video how polyurethane behaves compared to concrete. There were some cracks in the ice before the testing started, and these cracks developed when the board was taken outside the cold room. The ice breaks a lot when the car is driven over anti-seepage polyurethane, compared to concrete.

This is a big advantage for the polyurethane. Runways should be ice-free, and it is better if the ice can be removed with less working hours. This is both time-efficient and good for the environment. An instrument with some spikes, that slams the runway, could be used to loosen the ice from the runway. One could then use a rotating brush, connected to a truck, to remove the ice from the runway. This would require much less machinery, and this would mean less salaries, less fuel consumption and less emission to the environment. The use of salt and chemicals on runways and roads are not good for the environment, and salt (NaCl) affects the

water quality of both surface water and ground water (Godwin et al. 2002). If the ice is easy to remove from a surface made of polyurethane, the environment would benefit from this because there would be used less chemicals and salt. Salt can also make planes and machinery rust, so less use of salt would mean less maintenance.

5 Conclusion

This chapter will conclude on the research objectives as stated in chapter 1.2. The research questions will be repeated and answered, for the sake of clarity.

- *How does the rolling friction of anti-abrasion polyurethane and anti-seepage polyurethane compare to concrete?*

The rolling friction tests with ice got very similar coefficient of friction for all three materials. The only difference that could be seen during the rolling friction tests was that the ice got some cracks on both the anti-abrasion polyurethane and anti-seepage polyurethane. This did not happen on the concrete. The rolling friction tests without ice got different results, where the coefficient of friction for both types of polyurethane were higher than concrete. Both types of polyurethane with ice got a higher coefficient of friction compared to concrete. This means that polyurethane is suitable considering rolling friction, because of a higher coefficient of friction.

- *How does the sliding friction of anti-abrasion polyurethane and anti-seepage polyurethane compare to concrete?*

The coefficient of friction for all three materials are also very similar when it comes to sliding friction with ice. Cracks that arose during the rolling friction tests did not arise during any of the sliding friction tests. The sliding friction tests without ice got the highest coefficient of friction for anti-seepage polyurethane, and the coefficient of friction is higher for concrete than anti-abrasion polyurethane. The sliding friction tests show that the coefficient of friction is higher or similar for anti-seepage polyurethane compared to concrete, so it is suitable considering rolling friction. The anti-abrasion polyurethane can also be considered, because there is a very small difference considering the coefficient of friction between anti-abrasion polyurethane and concrete.

- *How does the ice on top of polyurethane behave when a car is driven on top of it, compared to concrete?*

The ice removal tests show that ice is easily removed from anti-seepage polyurethane, but not that easily on concrete. One could see big differences between polyurethane and concrete when a hammer was used on top of these materials to remove the ice. The ice on top of polyurethane came off easily after just a few blows with the hammer, but the ice on top of concrete just got some marks, and no cracks. Driving over concrete and anti-seepage polyurethane got very

different results. The ice on top of concrete barely cracked, but the ice on top of polyurethane had a lot of cracks. Because the ice is easy to remove from polyurethane, one can say that this is a big advantage.

5.1 Future work

After the completion of this master's thesis, these are some ideas for future work:

- Do the rolling friction and sliding friction test with a higher contact area, to see how the ice on top of polyurethane behaves.
- See how polyurethane decompose in the environment, compared to concrete and asphalt.
- See if there are any other materials that can be used apart from polyurethane.

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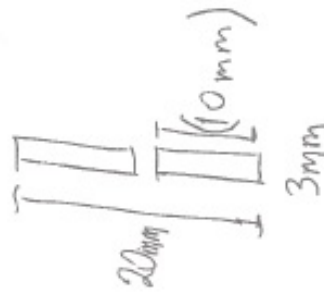
Appendix

- Appendix A: Sheet of paper for calculating the contact area

- Appendix B: Video

5

8



$$60 \text{ mm}^2 = 6 \cdot 10^{-5} \text{ m}^2$$

$$1,088 \text{ kg}$$

4

$$10,67328 \text{ N}$$

5

$$6 \cdot 10^{-5} \text{ m}^2$$

$$= 177,288 \text{ kPa}$$

5

mm^2

5

25TK