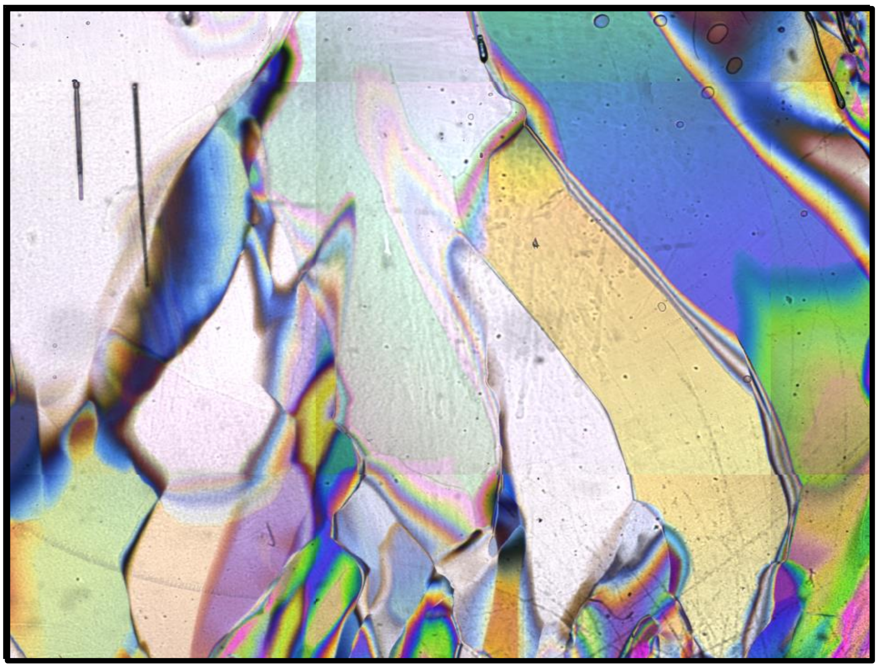
UNIVERSITY OF GOTHENBURG

DEPARTMENT OF EARTH SCIENCES

COLUMNAR ICE FORMATION

Examination of ice growth variations and effect of microplastics through light absorption and thin sections



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Abstract

The aim of this study is to develop a method for producing lab-grown standard columnar ice cores. The cores are one inch in diameter and about 2,7 cm in length. The cores are examined using light absorption and thin section analysis. Three cores are produced with microplastic particles and examined using light absorption. The temperature of the water that was poured into the cylinder mold was the main variable tested. The best cores were produced using 50°C water. The absorbance measurements for all cores yielded the same result, producing similar looking curves. The thin section analysis was made with three sample cores. The columnar ice growth pattern with the vertical growth direction can be seen in the thin sections. The cores containing microplastics were measured using light absorption. The result showed similar curves for all three cores, but the cores produced were sub-optimal. This study is a first step into the world of microplastics and its effect on ice, but more research is needed.

Keywords: Columnar ice, ice core, light absorption, thin section analysis, microplastics.

Sammanfattning

Syftet med studien är att ta fram en metod för att producera artificiella iskärnor av kärnis (columnar ice). Iskärnorna är en inch i diameter (ungefär 2,5 cm) och ungefär 2,7 cm långa. Kärnorna undersöks med hjälp av ljusabsorption och tunnslipsanalys. Tre iskärnor innehåller mikroplaster och undersöks därefter med ljusabsorption. Temperaturen på vattnet som hälldes i den cylinderformade gjutformen var framför allt den variabeln som testades. De bästa iskärnorna gjordes med hjälp av 50°C vatten. Absorbansen för alla iskärnor visade samma resultat, med kurvor som liknade varandra. Tunnslipsanalysen gjordes för tre av iskärnorna. Den vertikala tillväxtriktningen som finns hos kärnis syns i analysen. Iskärnorna som innehöll mikroplaster mättes också med ljusabsorption. Resultatet visade liknande kurvor för alla tre iskärnor, men själva utformningen av iskärnorna var inte optimal. Studien är ett litet första steg in i den stora världen fylld av mikroplaster och dess påverkan på is, och mer forskning behövs.

Nyckelord: Kärnis, iskärnor, ljusabsorption, tunnslipsanalys, mikroplaster.

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1. Introduction

The changing climate on Earth calls for action. Ice cores, which shows past climate data, are a helpful tool for predicting future climate (National Centers for Environmental Information, 2016). The evidence is clear that global warming is caused by anthropogenic activities (Intergovernmental Panel on Climate Change, 2023). Simultaneously, the rise of microplastics is yet another issue caused by anthropogenic activities. This thesis explores both ice cores and microplastics. The main part of the thesis is to produce a lab-grown standard ice core which yields the same result each time. Microplastics are also added to the water in the ice core in a later experiment. Light absorption and thin sections are used to examine the cores. It is a first step towards later research, where the method developed will be used in other types of experiments. The thesis is a pilot study for a master thesis coming this autumn.

1.1 Literature review and background

There is limited research done on laboratory-grown ice cores like the ones in this thesis. Prior et. al. (2015) uses synthetic ice for the experiments in the article, where several types of ice samples are grown with different methods. Columnar ice is one of the methods, and much inspiration is taken from Prior et. al. (2015) for the methods in this thesis. Perovich & Govoni (1991) also produces laboratory-grown ice. The method used is a more advanced setup, with a large tank (0.3 x 0.3 x 3.0 m), cooling coils in the bottom plate, four stirrers and with a water change every few days. The resulting ice was free of bubbles and with vertically oriented crystals. That is also the goal for this thesis, by using a variation of the method from Prior et. al. (2015). Gharamti et. al. (2021) produces columnar ice in an experiment which uses freshwater, and where the nucleation process starts with a fine mist that is sprayed in the air on top of the ice tank. The tank used for the ice growth is the Aalto Ice tank, which is 40 x 40 x 2,8 m. The setup is much more advanced than in this thesis and uses freshwater as the medium for ice growth. Nevertheless, the resulting columnar ice serves as a valuable point of reference for the columnar ice grown in this thesis.

Weyhenmeyer et. al. (2022) describes two types of ice often existing in an ice-covered lake - black ice and white ice. Another name for black ice is congelation ice, and white ice can also be called snow-ice. White ice is much weaker than black ice (Weyhenmeyer et. al. (2022). White ice was initially a part of this thesis, but due to limited time it was eliminated from the experiments. Black ice has a columnar structure, and the ice formed can therefore also be called columnar ice (Bengtsson, 2012). The transparent columnar ice and its growth is the focal point of this thesis.

It is possible to study ice crystals the same way one studies rocks since they share properties with regards to crystallography (Ashton & Meier, n.d.). Thin section analysis therefore plays a part in this thesis, where three sample cores are examined. The setup for columnar ice growth in Wei et. al. (2020) and Gharamti et. al (2021) both provide reference points regarding thin section analysis. Even though both setups differ from this thesis, they include thin sections of columnar ice, showing the vertical crystal growth pattern.

Albedo is defined as the light which is reflected by a body or surface and is measured on a scale from 0-1 (Ashton & Meier, n.d.). A low albedo means the surface has low reflectivity (Britannica, 2024). Pigmented microalgae living on glaciers and ice-sheet surfaces lowers the albedo of the surface and this can lead to significant changes in surface melt (Chevrollier et. al., 2022). Indeed, these particles known as light-absorbing particles (dust, black carbon, microbial growth) can lower the albedo of snow and accelerate snowmelt (Skiles et. al., 2018).

Microplastics are particles of plastic smaller than 5 mm (Emberson-Marl et. al., 2023). They can be either produced as small particles, called primary microplastics, or become this size through breakdown of larger plastic particles, called secondary microplastics (Emberson-Marl et. al., 2023). Microplastics can potentially pose a risk for marine life due to its size being close to primary producers, and therefore be mistaken for food (Emberson-Marl et. al., 2023). They are also able to carry chemical pollutants which can negatively affect feeding, growth, and reproduction of aquatic organisms (Liu et. al., 2023). It is suggested that microplastics can also have a similar effect as other dark substances such as microalgae, black carbon, or mineral dust, having the ability to lower the albedo of polar regions and accelerate the melting of snow (Zhang et. al., 2022). With increasing amounts of microplastics accumulating in the polar regions of the Earth, it is imperative to intensify research efforts aimed at assessing the potential risks with their presence.

1.2 Research aim

The aim of this project is to develop a method for producing standard ice cores. The water used in the experiments, which is degassed, deionized, microparticle-free water, does not represent natural conditions. Thus, artificial ice, or laboratory-grown ice is created. Evaluation of the ice cores are done through light absorption and thin section analysis. One type of microplastic is also added into the water to compare cores with and without microplastics. Three different concentrations of microplastics are used. The developed method will be used and further improved upon in upcoming research.

2. Materials and method

2.1 Study design

The research was divided into several sections. The first section was to design a standard ice core that yields the same result each time, meaning the same type of ice structure every time. The design of the cores is a continuation from Liebl (2018). The study includes several different methods of producing ice, but in this thesis only the columnar ice setup is relevant. The experiments conducted in this thesis uses degassed, deionized, microparticle-free water. The first part of the research was to produce a standard ice core setup. The goal was to minimize the number of variables and having only temperature of the water as a variable for ice growth.

After the standard ice core was developed, the experiments continued by testing how microplastics might affect the light absorption of the core. Absorbance was measured for both cores without and with microplastics. Ice core thin sections were also produced. The goal for the thin sections was to find similarities between the cores, to further compare them and examine the crystal structure.

2.2 Setting

The research was carried out at the ice lab at Natrium, University of Gothenburg, Sweden. The whole lab consists of a room temperature lab, a cold room which acts as a pre-chamber for the freezer room, and lastly the freezer room. The temperature in the freezer room is approximately -18°C, the cold room is approximately +4°C. Most of the work was carried out in the freezer room.

2.3 Materials

The equipment for the columnar ice had almost the same setup throughout all experiments. The equipment was suggested from my thesis supervisor Mark Peternell, but some components changed dimensions. The equipment used in the experiments are shown in Figure 1. The main variable measured was temperature. Minimizing the influence of other variables was also a part of the research.

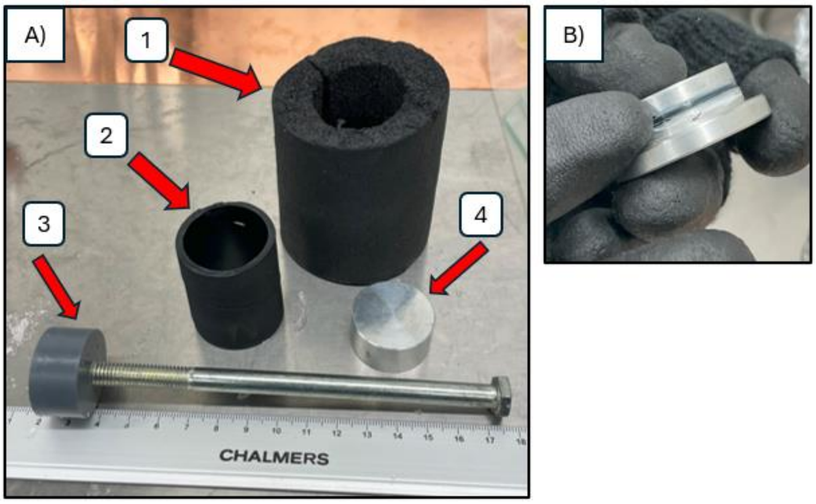

Figure 1: The equipment used in the experiments. Figure 1A shows the following: 1. Pipe insulation foam tube, in this thesis called insulation. The insulation is placed around the cylinder mold. 2. Rubber hose, which works as the cylinder mold for the water in this thesis. The diameter of the hose is one inch (about 2,5 cm). 3. Custom made instrument that has the same diameter as the inside of the cylinder mold. Used to remove the core from the mold. 4. Metal cylinder which has the same diameter as the inside of the cylinder mold. Two of these metal cylinders are used as a bottom and a lid for each of the cylinder molds. Figure 1B shows another type of metal cylinder bottom which is also used. This version has a flange, which works as a stop when the metal cylinder is pushed inside the mold.

2.4 Procedures and preparations

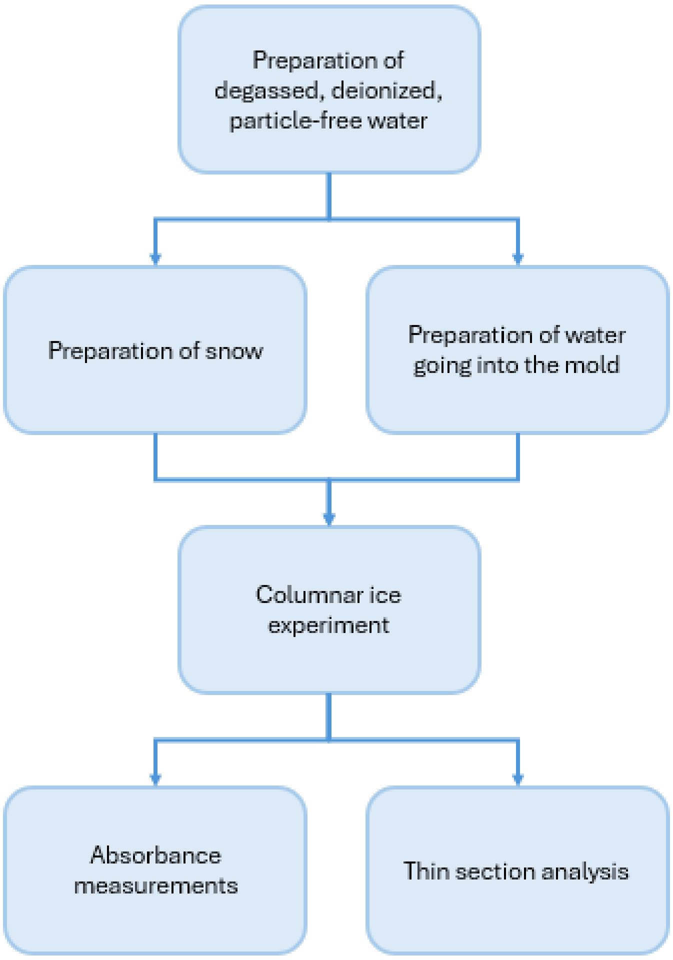

Figure 2: Flow chart of the experiment setup.

The experiment followed the structure shown by the flow chart in Figure 2. The water was prepared first and then used for both the preparation of snow and the water going into the mold. The snow and water together made up the columnar ice experiment, which was analyzed by absorbance measurements and thin sections.

Preparation of degassed, deionized, particle-free water to be used. The deionized water was run through a filter setup shown in Figure 3A. The filter is a silica microfiber filter with a mesh size of 2 micrometer. After filtration, all microparticles are caught in the filter. Later in the experiments microplastics are added and to ensure no other disturbances existed this filtration process was an important step. After filtration, the now microparticle-free deionized water was boiled for 1,5-2 hours to remove as much gases as possible, shown in Figure 3B. The beaker of prepared water was covered with aluminum foil to prevent contamination.

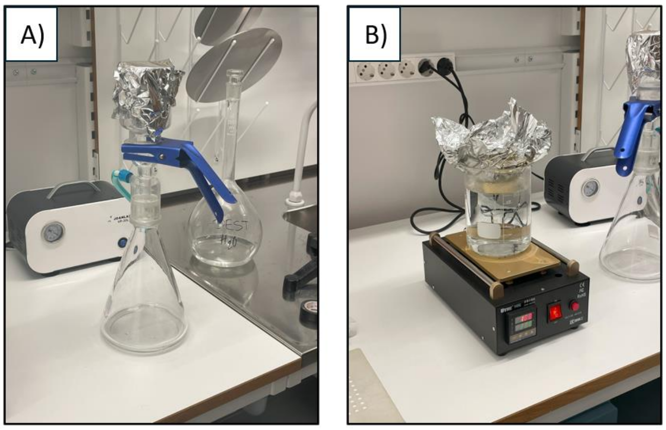

Figure 3: Preparation of the deionized, microparticle-free water used in the research. 2A shows the filter setup, 2B shows the boiling of the filtered water.

Preparation of snow. Snow will be needed in the experiment to start the freezing process. The prepared water was placed in a metal container and allowed to freeze. Then, the ice went through an ice crushing machine shown on the far left in Figure 4A. The machine crushes the ice into much smaller components, shown in the middle metal container in Figure 4A. In Figure 4B this crushed ice is placed in a 500 micrometer sieve with a 100 micrometer sieve underneath as a catchment. The ice was sieved, and the result is shown in Figure 4C.

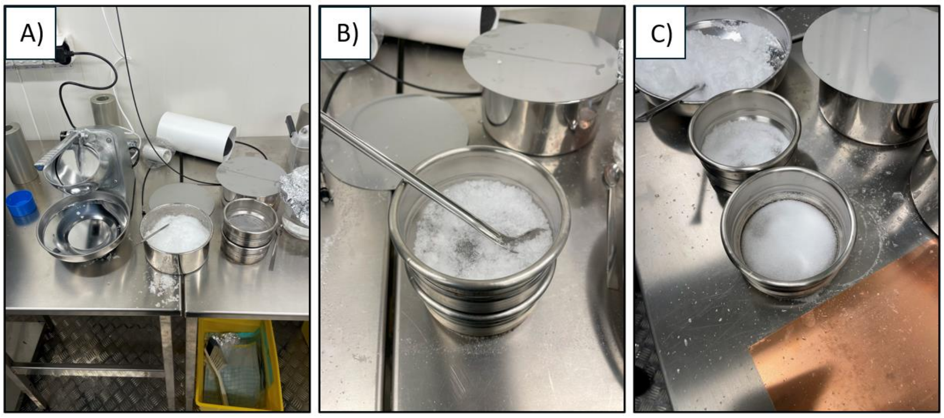

Figure 4: Making of snow in 3 steps. 3A shows the setup, with the ice crushing machine on the left, Figure 3B shows the sieve used, and Figure 3C shows the finished snow.

Preparation of columnar ice. As shown in Figure 1, the base setup for making the cores included a one-inch diameter (about 2,5 cm) cylinder mold. The cylinder mold had one metal cylinder as a bottom and one as a lid. The cylinder was encased with foam insulation. The first step of filling the cylinder mold was to place a small amount of "molykote 33 light" grease (a silicone-based grease used for ensuring a tight seal between the metal top and bottom and the cylinder mold) along the sides of the metal bottom. Then, the prepared water was poured into the mold. A small spoonful of snow was sprinkled on top of the water. Another metal cylinder was greased and placed as a lid, ensuring contact with the water to create a smooth surface. The foam insulation was placed around the cylinders and another foam insulation on top. The completed setup was placed on a copper plate to ensure the correct growth of the needles through the ice. The cores were allowed to freeze overnight. Examination of the cores happened one day after preparation. The cores were removed from the cylinder mold with the custom-made tool shown in Figure 1. Figure 5 shows part of the steps for making the columnar ice cores. Figure 6 shows a drawn cross-section of the finished setup.

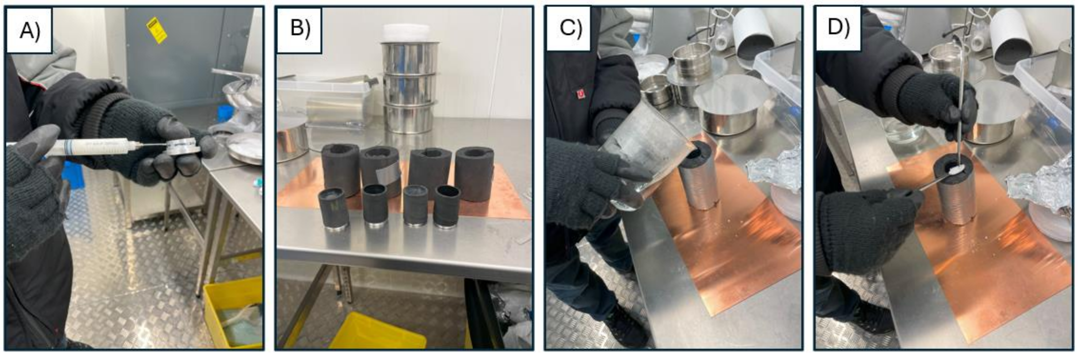

Figure 5: The setup for the columnar ice. Figure 4A shows the metal cylinder bottom, with flange, when molykote 33 light is added. Figure 4B shows the setup of the cylinder molds with the insulation placed behind. In Figure 4C, the cylinder mold is filled with the prepared water. The insulation is placed around the mold. Figure 4D shows the snow being sprinkled into the cylinder mold.

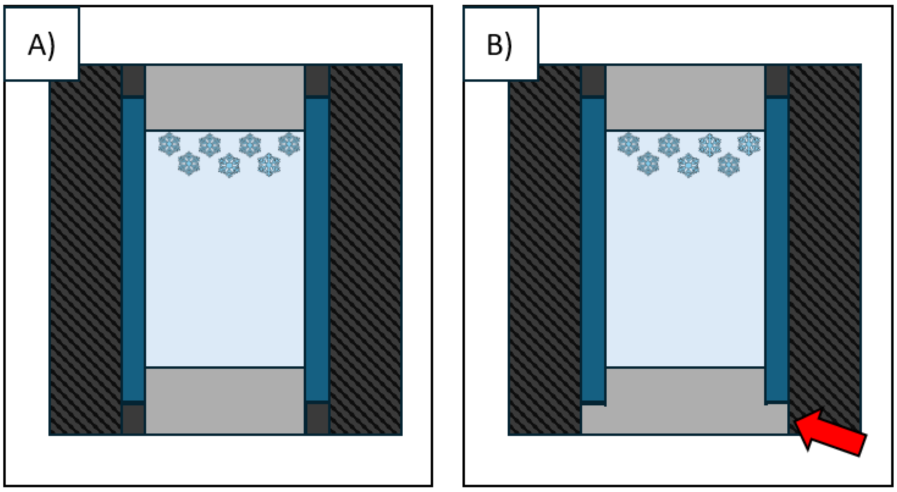

Figure 6: Cross-section of the finished setup. The setup includes the following: the dark blue areas represent the cylinder mold which has two identical metal cylinders (gray) as both a bottom and a lid. The cylinder mold is filled with the prepared water (light blue), and snow is sprinkled on top of the water (snowflake symbols). A foam tube insulation (black) is placed around the cylinder mold. Figure 5A and 5B shows the same setup except for the bottom metal cylinder. The bottom metal cylinder in Figure 5B has a flange, highlighted with a red arrow.

Light absorption measurements. The spectrometer used was "Ocean SR Miniature Spectrometer" with a "DH-2000" light source and optical fiber cables, everything manufactured by Ocean Insight. Absorbance measurements were made using the software OceanView. The software uses the following equation for determining the absorbance in each sample:

$$A_{\lambda} = -log_{10}\left(\frac{S_{\lambda} - D_{\lambda}}{R_{\lambda} - D_{\lambda}}\right)$$

Where:

$A = Sample\ intensity\ at\ wavelength\ \lambda$

$D = Background\ intensity\ at\ wavelength\ \lambda$

$R = Reference\ intensity\ at\ wavelength\ \lambda$

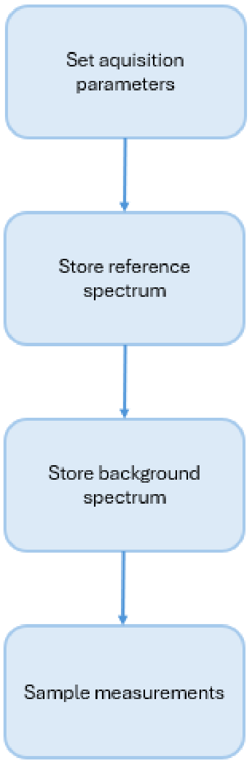

Figure 7: Procedure for the absorbance measurements.

The software calculations are based on the procedure shown in Figure 7. The first step is to set acquisition parameters, where the most important parameter is the integration time. The next step is to store the reference spectrum. This is done by having the light source turned on, but no sample in the chamber. The background spectrum is measured without a sample in the chamber and with the light source turned off. After this calibration is finished, the samples are ready to be analyzed.

Figure 8A shows the setup for the light absorption measurements in the freezer room. An identical cylinder mold as the ones for making the cores act as an outer chamber for the measurements. The blue cables shown in Figure 8A go into the control room where the spectrometer is stored, shown in Figure 8B. The sample core is placed in the cylinder mold shown in the Figure 8A, and the two metal parts connecting to the blue cables are placed into the cylinder on both sides. This is to ensure that the cylinder is tightly sealed, and the measurements are as accurate as possible. The two metal parts shown in the figure are almost identical to the one in Figure 1B. The difference between them is that the metal parts here in Figure 8 have small holes in the middle, enabling light to pass through.

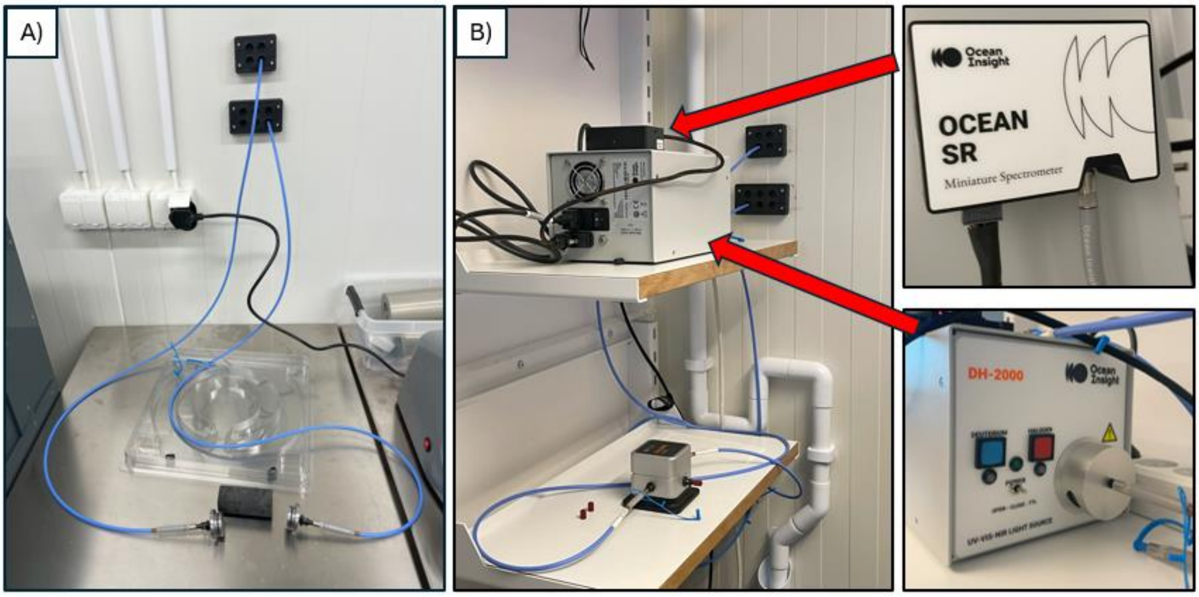

Figure 8: Setup for absorbance measurements. The two red arrows indicate the placement of the spectrometer (top) and the light source (bottom) in the control room. The blue cables that go into the wall in Figure 6A can be seen go out of the wall in Figure 6B.

Preparation of thin sections. The Russell-Head Crystal Imaging System G60 Fabric Analyzer was used for the thin section analysis. Three thin sections were prepared from three samples by cutting the cores vertically. The cut side is then frozen to a glass plate, shown in Figure 9A. The sample was cut again close to the glass plate to create a flat surface. The surface was sanded down with sandpaper and polished until smooth and then placed in the fabric analyzer, shown in Figure 9B.

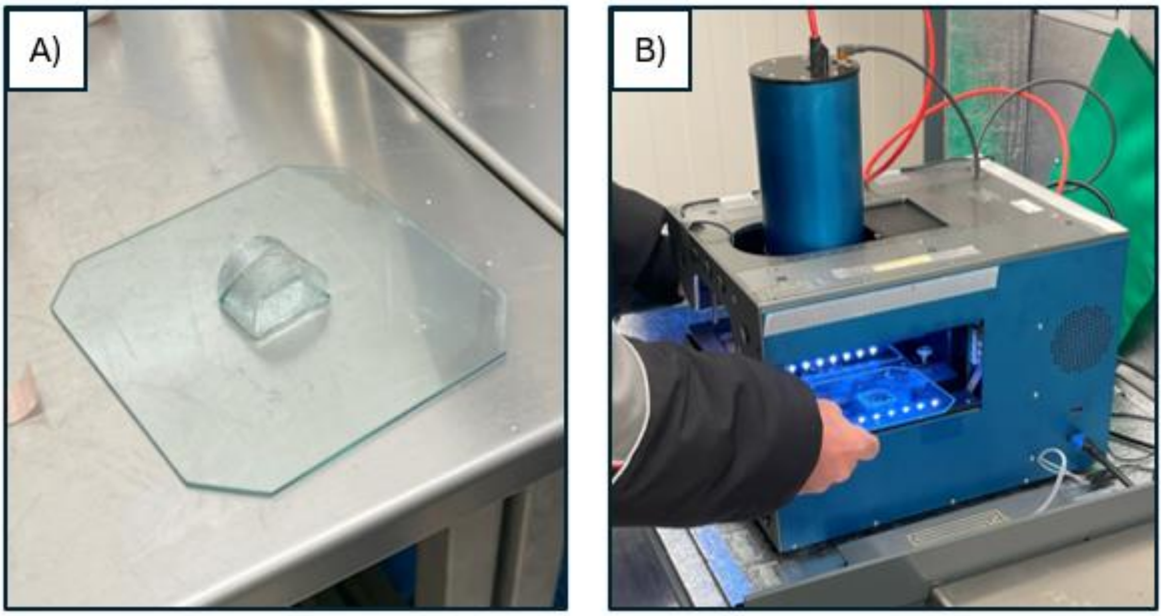

Figure 9: Preparation of thin sections. 7A shows preparation of one thin section sample. 7B shows insertion of a thin section sample in the fabric analyzer.

Preparation of microplastic samples. Only one type of microplastic was used in this experiment. Poly(n-butyl methacrylate), CAS number 9003-63-8, was chosen because of its density being 1.07 and therefore similar to water. Three cores were prepared with different amounts of plastic.

Sample 1: 0.1650 g

Sample 2: 0.3880 g

Sample 3: 0.5842 g

3. Results

3.1 Ice core development

The first round of cores had 21 ml of water poured into the molds. The amount was calculated with regards to the metal cylinder sizes and the size of the cylinder mold. This was adjusted to 16 ml of water in the following cores. Changing the amount of water from 21 ml to 16 ml did not have a significant impact on the length of the cores. Therefore, 16 ml of water was used for the rest of the cores. The length of the cores varied between 2.7 cm and 2.9 cm, however, the first core produced was 3.5 cm.

Temperature was the main variable for ice growth, and the prepared water was heated to a desired temperature before poured into the cylinder molds. Figure 10 shows the result from four different temperatures of the prepared water: 4°C, 20°C, 30°C and 50°C respectively. The cores became more consistently transparent with an increased water temperature. In Figure 10A, the ice core is opaquer than in the other three cores. All the cores produced had a horizontal line through the top layer of the core, which can be seen in all four of the cores in Figure 10. The vertical needle growth can be seen in all the cores in Figure 10, and they are all slightly tilting inwards towards the center of the core. This is best seen in Figure 10B. The cores produced with the 50°C water was deemed most successful, and experiments continued with this temperature.

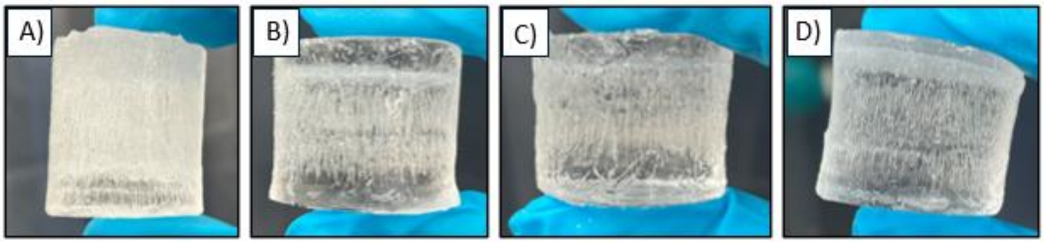

Figure 10: Cores made from four different temperatures. 8A is made from 4°C water, 8B is made from 20°C water, 8C is made from 30°C water, and 8D is made from 50°C water.

The best-looking cores were made from 16 ml of 50°C water. Figure 11 shows cores made from 50°C water. The horizontal line in the top layer of the core is visible in all five cores, as well as the inwards tilting of the needles. They show some degree of variability in how transparent they are, but overall are quite transparent.

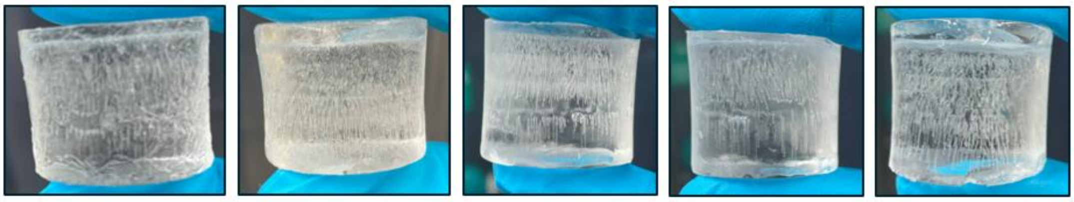

Figure 11: Cores made from 50°C water.

3.2 Absorbance measurements

Absorbance measurements were done for selected samples. Figure 12 shows the data from four samples, all made from 50°C water. The curve looks similar in all four samples, although the highest and lowest values on the y-axis are slightly different. The curve starts off with a peak in the UV spectrum. In the visible light part of the spectrum, between 400 and 750 nm, the curve shows two small peaks. In the IR spectrum, the curve declines but does a small jump before declining again. This can be seen in all four samples.

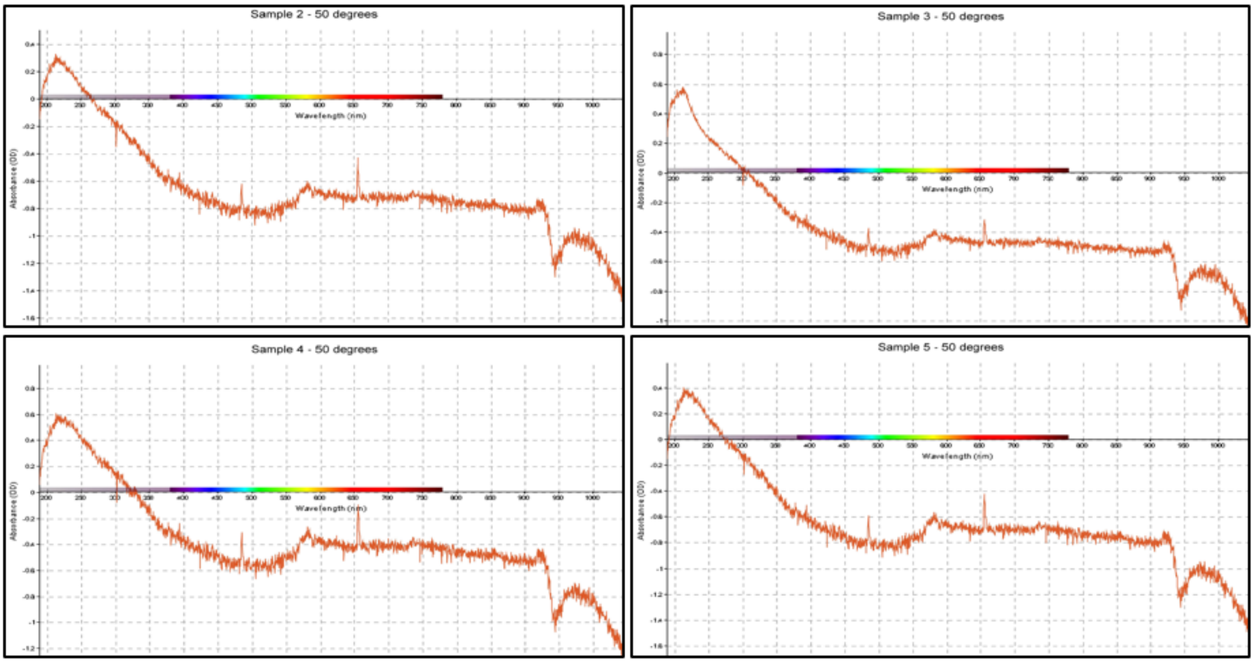

Figure 12: Absorbance measurements from four samples.

Two other measurements are also worth noting. They are shown in Figure 13, where the sample on the left is prepared with 4°C water. The sample on the right is prepared with 50°C water. The curve on the left looks similar to the curves in Figure 12. The curve on the right, which is made from 50°C water, looks nothing like the other measurements presented so far. The curve is instead smoother and has no peaks.

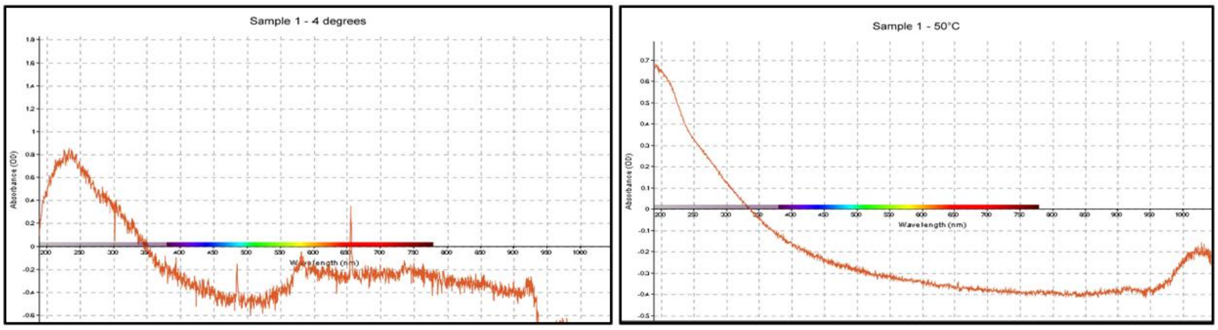

Figure 13: Absorbance measurements from one sample made from 4°C water, and one sample made from 50°C water.

3.3 Thin sections

The thin sections prepared were made from three samples with 50°C water. The sample number in section 3.2 and 3.3 are the same, meaning that Sample 1 is the same core shown in the absorbance measurement and the thin section. Figure 14 shows the vertical thin section of Sample 1. The horizontal line visible in the cores in Figure 11 is clearly visible in the top part of the core. The area above the line shows small impurities. The area under the line shows the elongated crystals. The crystals can be distinguished from one another by the color, seen more clearly in the image on the right. An area with one color represents one crystal. Parts where several colors blend together have several needles on top of each other. The crystals seem to bend inwards, towards the middle of the core.

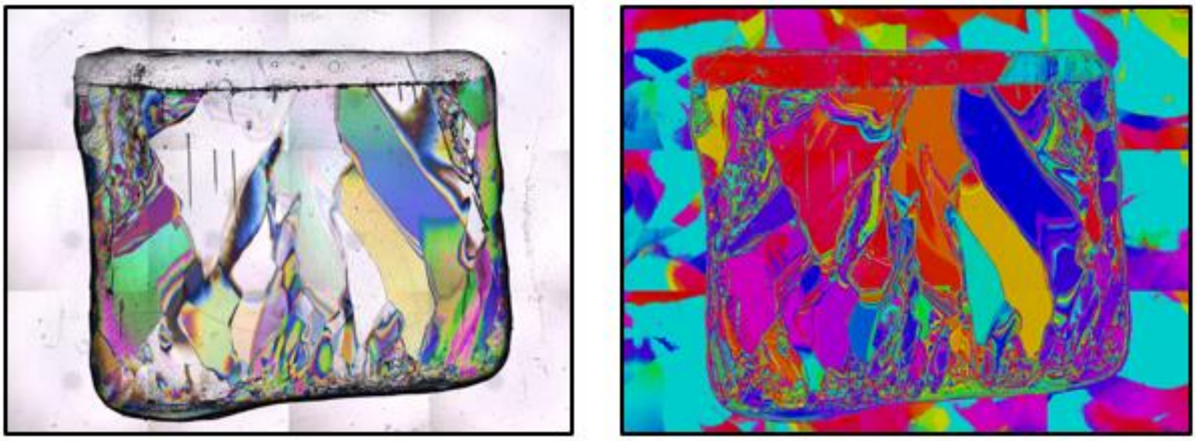

Figure 14: Thin section of Sample 1. The image on the left is the thin section under plane polarized light, and on the right is a "trend flat" image.

Figure 15 shows the thin section of Sample 3. The crystal growth is straighter than what can be seen in Sample 1. Sample 3 exhibits the same horizontal line in the top part of the core. The largest crystals are visible in the center of the core. Closer to the bottom of the core there seems to be a more unorganized growth pattern. In the image on the left, some air bubbles can be seen above the horizontal line.

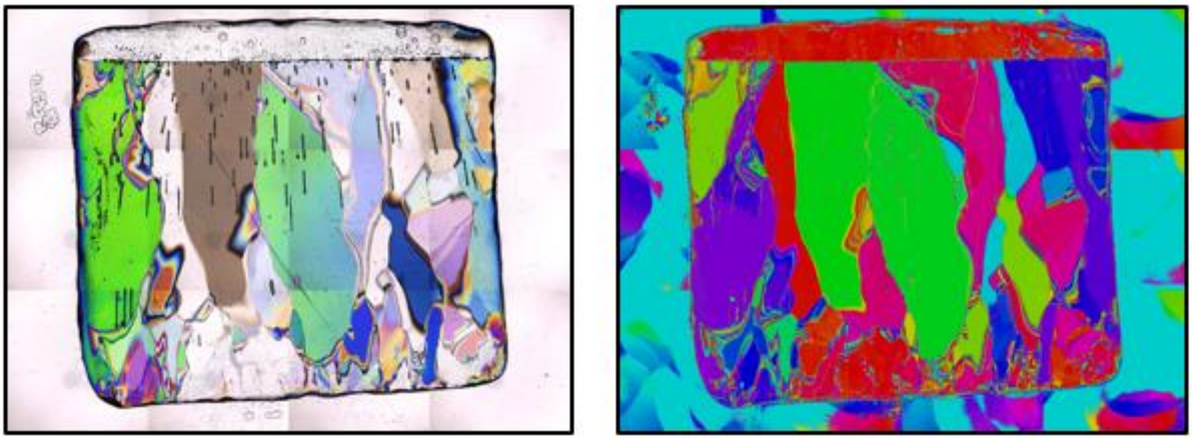

Figure 15: Thin section of Sample 3. The image on the left is the thin section under plane polarized light, and on the right is a "trend flat" image.

The thin section of Sample 5 can be seen in Figure 16. The horizontal line is present in the top part of the core. The crystal growth direction is not as clear in this sample as can be seen in Figure 14 and 15. The crystals are similar in size as in Sample 1, but they exhibit a more chaotic growth pattern, especially in the left part of the core.

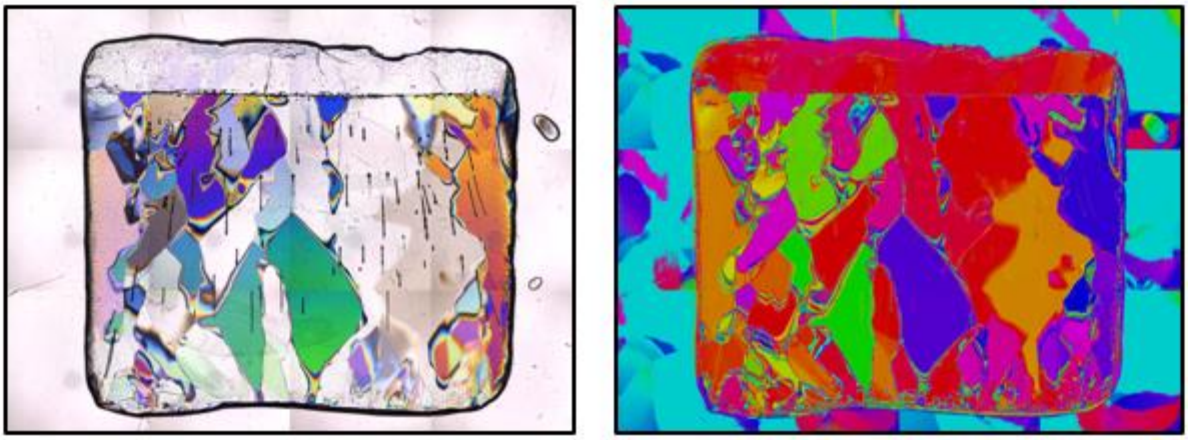

Figure 16: Thin section of Sample 5. The image on the left is the thin section under plane polarized light, and on the right is a "trend flat" image.

3.4 Microplastics experiment

As part of the research, three cores with microplastics were also prepared. Five cores in total were prepared at the same time, two controls made with 16 ml of 50°C water, and three cores with Poly(n-butyl methacrylate) added. The three amounts of microplastic were weighed by Mark Peternell and placed into each cylinder mold. The cylinders containing the microplastics were then brought into the lab and filled with 16 ml of 50°C water. Figure 17 shows the two control cores. The horizontal line can be seen in both cores, and the needles are tilting slightly inwards. Both cores are quite transparent.

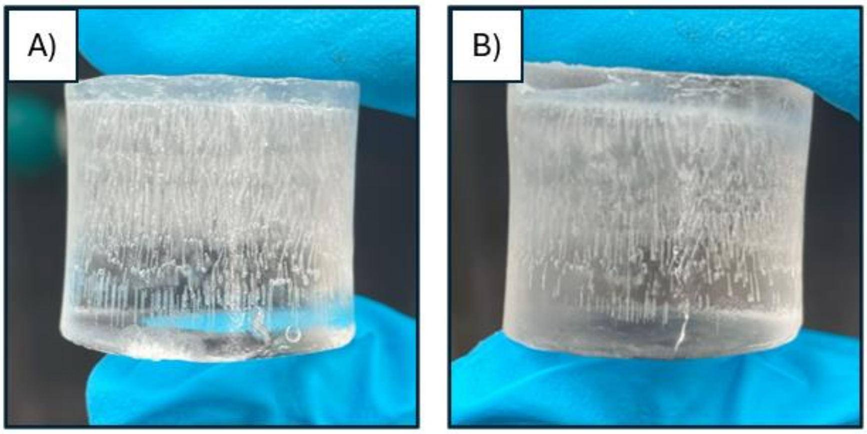

Figure 17: Ice core samples. Figure 15A shows Control 1, and Figure 15B shows Control 2.

Figure 18 shows the first core containing microplastics, and the lowest concentration of microplastic. The microplastic particles are concentrated to the bottom of the core, with some particles floating to the top. The image on the right shows the bottom of the core, where the microplastic particles can be seen. Besides the microplastic, the core looks similar to Control 1 and 2 in Figure 17.

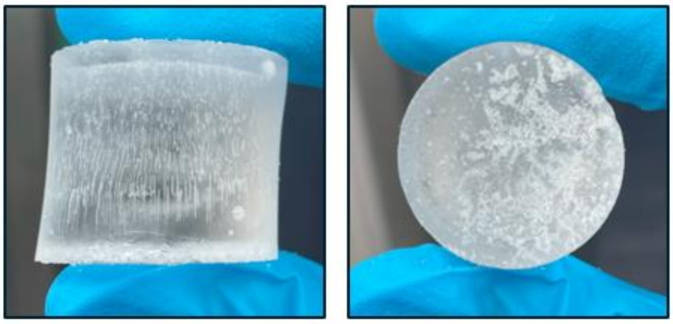

Figure 18: Ice core containing 0.1650 g microplastics.

For the second core containing microplastics, the concentration was increased. The core is seen in Figure 19. Just like the first microplastics core, the particles have settled on the bottom. When removing the core from the mold, the bottom part of the mold was not entirely covered in ice, meaning a large part of the microplastics did not reach contact with water. The image on the right in Figure 19 shows the bottom of the core. The microplastics is more evenly distributed across the whole bottom, whereas in Figure 18 it was more concentrated to one half of the bottom.

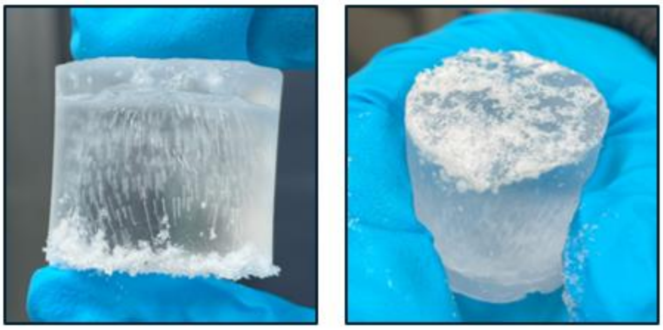

Figure 19: Ice core containing 0.3880 g microplastics.

Figure 20 shows the last core containing microplastic, and the highest concentration. The particles are again not evenly distributed in the whole core, but only present in the bottom part of the core and a small amount in the top part. In the image on the right, showing the bottom of the core, the microplastics have settled around the edge of the core, as well as one half of the core.

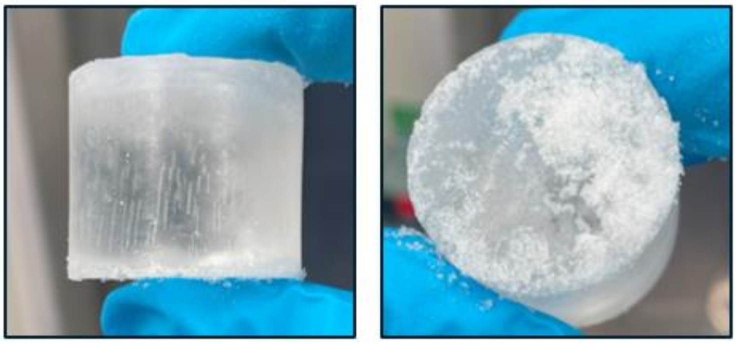

Figure 20: Ice core containing 0.5842 g microplastics.

Absorbance measurements were made for the control cores 1 and 2 and the three microplastic cores. Figure 21 shows the absorbance curve for Control 1 and 2. The curve follows a similar pattern as can be seen for the previous cores, in Figure 12. Control 2 exhibits a higher value for the peak in the UV spectrum, as well as the two peaks in the visible spectrum. The two curves in Figure 21 otherwise look similar.

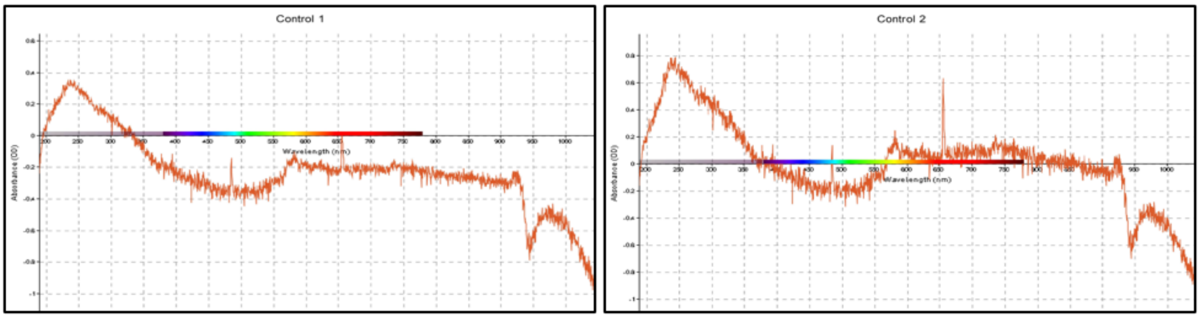

Figure 21: Absorbance measurements for Control 1 and 2.

In Figure 22, the absorbance curve for the first core containing microplastics is shown. The curve bears resemblance to the control cores. The UV spectrum peak is present, the two peaks in the visible spectrum are present, and the rapid decline in the IR spectrum is present. However, the values on the y-axis differs significantly. All values are now in the positive, unlike the control cores and the first cores measured, as seen in Figure 12. There are also three dips present in the curve, two around 300 nm, and one close to 750 nm.

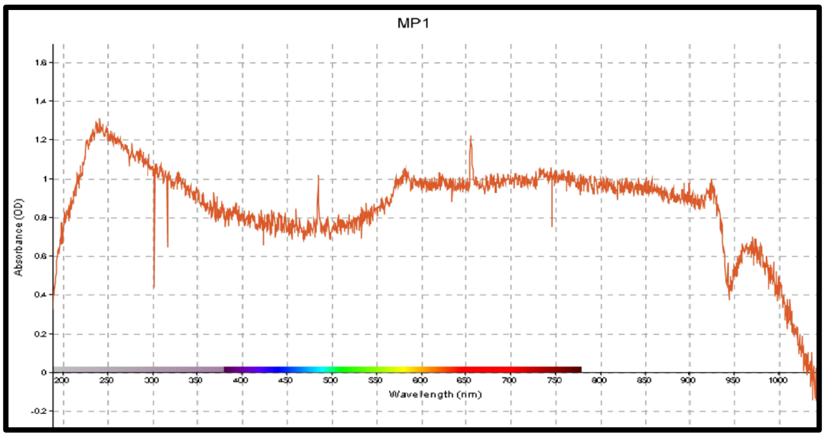

Figure 22: Absorbance measurements for Microplastic Core 1, containing 0.1650 g of microplastic.

The absorbance curve for the second microplastic core can be seen in Figure 23. The curve looks similar to the first microplastic core, except for the peaks being slightly more pronounced. Figure 24 shows the last core containing microplastic, which also has the highest concentration. The curve in Figure 24 shows the same peaks and dips as in Figure 22 and 23, with slightly higher values on the y-axis.

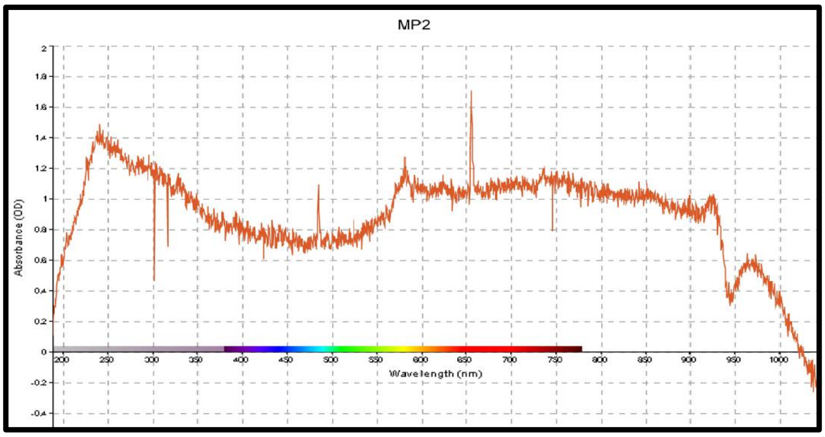

Figure 23: Absorbance measurements for Microplastic Core 2, containing 0.3880 g of microplastic.

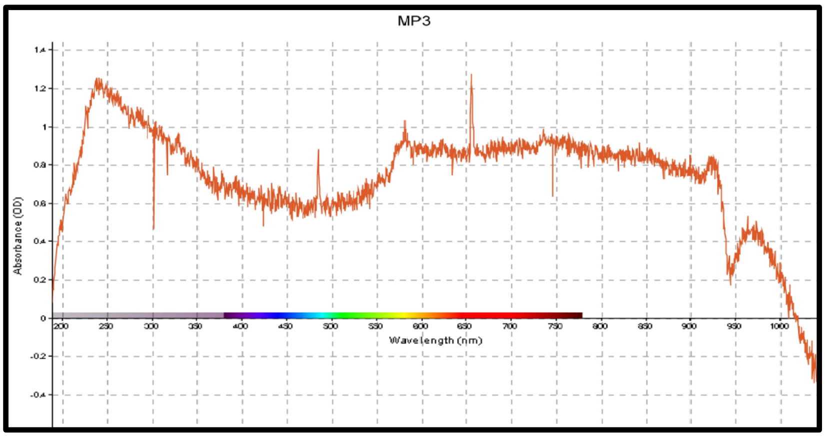

Figure 24: Absorbance measurements for Microplastic Core 3, containing 0.5842 g of microplastic.

4. Discussion

4.1 Results

All cores exhibit a thin section of ice which is separated from the rest of the core, creating a horizontal line through the core. At first, this was thought to be because of the temperature of the metal lid which is placed on top of the cylinder. Both the metal cylinders which act as a bottom and a top are kept in the freezer room, meaning there might not be the clear temperature difference desired between the lid and the bottom. This theory was tested by keeping the lid in room temperature and only bringing it in the freezer room when placed on top of the cylinder. Two cores with room temperature lids were tested, resulting in one broken core and one core which showed promising results. The intact core still had a clear line, but the line was closer to the top of the core which created an even smaller area above the line. However, since only two cores were tested and only one remained intact, this theory does not have a clear answer.

The absorbance measurements showed promising results regarding creating a standard ice core. All cores showed the same curve pattern, even the left curve in Figure 13. This curve was the first created, which might explain why the curve is not centered to the scale, resulting in some parts of the curve not showing. The curve to the right in Figure 13, Sample 1 which uses 50°C water, looks very different from all other curves created. Since this only occurred with one core, and the procedure for making the core remained the same for all cores measured, it might be because of measurement error.

The thin sections shown in Figures 14-16 were produced to evaluate the growth direction of the needles in the cores. The three samples show a somewhat consistent growth direction, vertically, but varies from sample to sample. When compared to Wei et. al. (2020) and Gharamti et. al (2021), the thin section analysis in this thesis shows a more erratic growth pattern. It should be noted that Wei et. al. (2020) and Gharamti et. al. (2021) has much larger setups than in this thesis. The Aalto Ice tank is so large that the experiment takes on a whole other level. The cores produced in this thesis, which fit in the palm of your hand, does not have much space to play around with, creating three different thin section structures. You can still notice the columnar ice growth direction, but it is not as clear as the thin sections when producing much larger ice samples.

The microplastic used in the microplastics experiment was white in color. The color of the microplastic might have changed the result since dark colored particles absorb light. This was not done because of limited time. The three curves with the different concentrations of microplastics does not differ much. This is expected since the same type of microplastic is used for all three cores. If three different types of microplastic were used in three different cores, the curves might not be as similar. Now, since all three cores absorb in the same part of the spectrum, the curves look very much the same.

4.2 Methods

It was made clear that keeping the water that was going into the cylinder molds at the right temperature for as long as possible was important. In the first round of experiments, the water was brought in too early which meant the water froze too early. To yield the best results, prepare the cylinder molds ahead of time while keeping the water at the correct temperature outside of the lab area and only bring in the exact amount in a small beaker when it is time to pour it into the mold.

Most of the cores were made with a metal cylinder without a flange in the bottom of the cylinder, but some of the cores were made with a metal cylinder bottom with a flange as shown in Figure 1 and 6. This did not seem to impact the resulting core; however, it does impact how easy it is to remove the metal cylinders from the mold. When both the top part and bottom part of the mold consists of metal cylinders without a natural stop, it can become difficult to remove the core from the mold. When the bottom metal cylinder does have a flange, it is much easier to remove and in turn also remove the top metal cylinder. The flange also helps with inserting the mold into the insulation. The cylinder is quite sensitive when the metal bottom does not have a flange, and pressing too hard on it causes it to be inserted further into the mold. This in turn makes it very difficult to remove it after the freezing process.

The insulation method was also a testable variable. A few cores were tested with a different insulation method, where the foam insulation tube was not closed ahead of time, but instead closed after the cylinder was placed inside. This variable helped with the effectiveness of the experimental setup since it was easier to place the insulation around the mold when it was not closed. It did not have a significant effect on the result, and in the following experiments the normal, already closed insulation was used.

The cylinder molds used were somewhat flexible, causing some of the cores to be slightly tilted. In the future to produce better ice cores, a more rigid structure is preferred. However, the mold cannot be too rigid since this can cause the mold to break. It is important to keep the metal bottom straight in the cylinder, and to place the metal top carefully so not to cause the tilting of the core.

The microplastics experiment needs further improvement. Having the microplastic sit at the bottom of the core is not ideal, and this might have affected the resulting absorbance curve. When testing the core setup with microplastics in upcoming research, attention needs to be paid to the dispersal of the microplastics inside the core.

4.3 Study limitations

Figure 25 shows three defect cores. The core in Figure 25A is not in full contact with the top metal part, which means the surface is not flat. A flat surface on the top and bottom of the core is crucial for accurate light spectrometer measurements. To avoid this, the amount of water poured into the mold was adjusted, and the metal cylinder lid was placed carefully in the mold making sure to go all the way to the water surface. Figure 25B shows a core broken in half. The cores which turned out this way were already broken when removed from the mold, and why this happened remained unclear. It might be because of internal stress. Eliminating this occurrence is important as to not waste time or material. The core in Figure 25C is tilted because of the flexible cylinder mold. When placing the bottom metal cylinder inside the mold, it needs to be pushed straight in. If it is slightly tilted, the core will turn out like this. A tilted core means less accurate absorbance measurements.

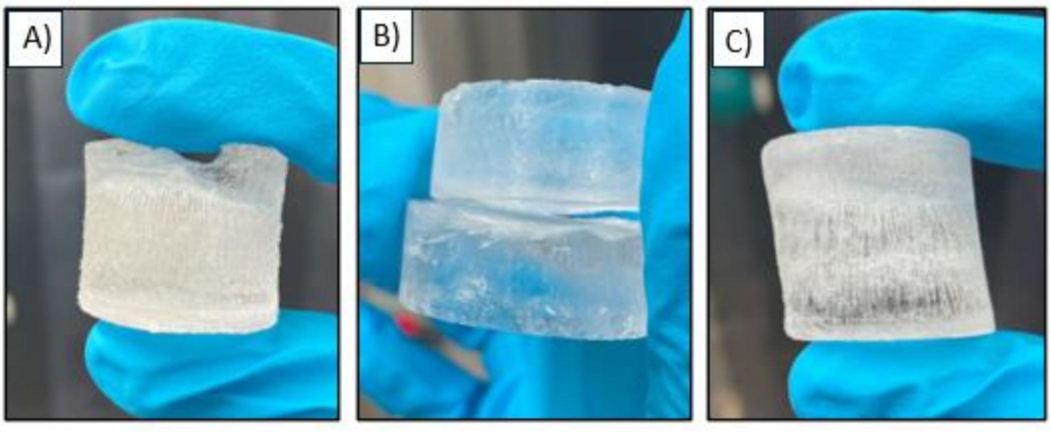

Figure 25: Defect cores.

4.4 Further research topics

The knowledge gained from this study is important for further research on lab-grown ice cores. To produce even better cores, it might be interesting to examine why some of the cores break in the mold. This thesis only tested one type of microplastic due to time constraint. Testing several types of microplastics and examining their absorbance curve is the natural next step. I would also like to suggest testing a wider range of water temperatures, to investigate if 50°C is the ideal temperature. Testing other variables is also a part of improving on the method, for example the amount of snow poured into the mold. In this thesis, only one amount of snow was tested (one small spoonful). If there was more time, I would have liked to test this variable as well.

5. Conclusion

The cores produced with the developed method shows promising results. The absorbance curves for the cores looks similar. The thin section analysis for three of the cores shows varied needle growth, but with vertical growth direction. The microplastics experiment was a good first attempt but needs further improvement. In order to study the link between microplastics and how it might affect light absorption in ice, more research is needed.

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