Analysis of replication casting of ice surfaces

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Summary

To more easily facilitate the amorphous behavior of ice in surface measurement a casting method is very useful. But for such a method to hold any significance a validation method is necessary. The difficulty of measuring ice surfaces means that an evaluation of the actual casting material would be very useful. The authors propose a measurement of dilation invariable frequency analysis of different surfaces and casts to decide upon the relevance of this method.

Keywords:
friction, replication, cast, formvar, microscopy, Fourier transform

Abstract

When dealing with ice friction, naturally, the ice surface becomes very interesting. But to analyze it is not that easy, it is ill suited for optical or mechanical measurements, and many high magnification methods require vacuous conditions, something that immediately alters the ice surface. Shelf life of an ice surface is also negligible. Therefor a good replication procedure would be very useful.

In this work we have opted to try the traditional polyvinylethylenedichloride (commonly known as formvar) and compare those results with three other replication materials from the dental industry, commonly used for replicating other surfaces, for example railroad tracks.

The materials were analyzed with Fourier transform, to get the frequency spectra of the surface, this could then be directly compared between the different casts to discern the resolution of the material, or ultimately the analysis method.

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Summary

The microscopic analysis of an ice surface is very difficult, due to the nature of the ice. The optically transparent[1][2], brittle and very environmentally sensitive surface[3][4][5] is hard to analyze in a manner that does not render the results useless from damage or errors in measurements.

The ice surface is ill suited for contact microscopy, like Atomic Force Microscopy (AFM)[6][7][8] or other methods of sliding a probe over the surface. Furthermore the ice surface is transparent, so even cold room optical microscopy is not feasible. Due to the vacuous atmosphere Scanning Electron Microscope (SEM) is not an option.

In this paper the authors look at some casting techniques to try and reproduce the surface with a substance much better suited for optical and mechanical measurements, as well as having a longer shelf life and being easier to handle. Different evaluations have been considered, where the frequency information is used as a measure of resolution, comparing the resolution loss of different casting materials.

The casting materials used are different products from the dental industry, as well as polyvinyl formvar[9], a dissolved polymer that is very useful for casting of ice surfaces.

Keywords:
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1 Introduction

Ice friction is an interesting problem since it affects human civil engineering in so many different ways. Surface structure is of great interest for friction studies, especially since the importance of its influence is debated.

The temperature affects the friction severely, with the ice getting much more slippery close to 0 °C. It is also intuitive that the surface structure will affect this, the question is, how much. To find this out, different ice surfaces must be measured. Something that is very hard to do in situ, due to optical transparency and mechanical brittleness in ice.

This article aims to justify the use of casts on ice to determine surface structures to an agreeable precision. Such a cast should be easy to apply, have a short cure time, long shelf life, be inexpensive and not environmentally dangerous. Traditionally polyvinyl formvar (commonly known as formvar) dissolved in ethylene dichloride is used, but it would simplify greatly if other, less toxic and easier to handle, casting materials could be used. The authors have tried a collection of materials commonly used in tribology, originally from the dental industry. Those have been compared to formvar casts with frequency resolution in mind, to see what size the minimal protrusions and pits are.

The casts, being chemically and environmentally inert, will be much better suited for storage for later data retrieval, and also for more advanced analysis methods, like diffractomicroscopy, scanning electron microscopy (SEM) and atomic force microscopy (AFM). Ice from different environments can also more readily be compared, and maybe even casted to the negatives to recreate the same structure.

The surface is analyzed with Fourier transform, to see which wavelengths are dominating over the sample. Wavelengths that can't be distinguished from the noise are wavelengths that the method can't resolve. But if we have a sharp decline before this point, we have reached a point where the casting material is unable to attain the finer details of the surface. This is a limiting factor in our method.

2 Theory

A purely random surface would possess bumps and irregularities of any size. But the casting material, especially in the freezing temperature that it is being casted in, will probably not be able to fully accommodate all of those, therefor the resolution of the casting material need to be found. The authors propose to accomplish this with with a frequency analysis. The power spectra will have a distinct part that corresponds to the frequencies present in the cast, then an irregularity will occur when the casting material is no longer able to resolve the surface correctly.

The power spectra, according to

$$P(\omega) = \left|\mathcal{F}\Big(z(x)\Big)\right|, \tag{1}$$

where $\mathcal{F}$ is the Fourier transform of $z(x)$, our measurement in the x direction, transforming distance x into wavelength ω where $P(\omega)$ is the power spectra of the absolute value $|\ |$ of the Fourier transformed signal. This represents the power of each wavelength in the sample. A finely polished material will experience a bias to wards high frequencies, whereas a material that has been worked with a specific tool will experience a bias in a tool specific wavelength. In Figure 1 we see a comparison between a casting material and the surface that was casted.

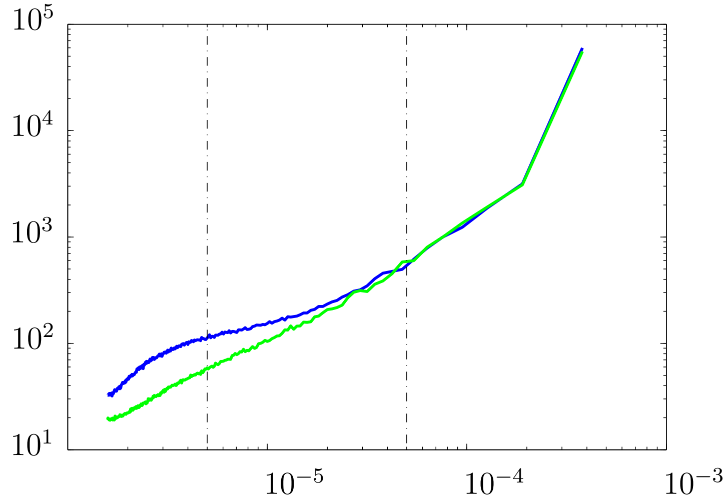

Figure 1: *This displays how the casting material Master Exact(whole line) follows the general wavelength trend of the aluminum(dotted line), then starts deviating around* 0.5 mm *(right vertical line), a dip is seen around* 50 μm *(left vertical line) betraying the maximum resolution of the Master Exact.*

Figure 1 demonstrates how the casting material follows the trend of the material pretty well, but starts to deviate at small wavelengths. This is a trend that is seen in both artificially created signals as well as measured ones. The worked aluminum seems to have a fairly even distribution of frequencies, whereas the casting material lacks spectra in the smaller wavelengths. Something that is plausible to correspond to minimum grain size. But the resolving power seems to be affected much much earlier.

Generally an average of many different power spectra are done over a surface, since any irregularity, that is so common, will affect the power spectra significantly. An average will give us the general trends of the sample and a general idea of what we can expect in resolving power.

3 Methodology

The materials tested were Master Exact, Flexitime Easy Putty, Alginate and compared to a standard of formvar. The materials are commonly used for warmer casting of metals, so testing is essential. Master Exact is a binary liquid, mixed together and hardened over time. Flexitime Easy Putty consists of a binary putty, mixed together and kneaded into a paste. Alginate is a powder mixed with water to form a paste. Formvar is polyvinyl dissolved in ethylene dichloride, the dichloride evaporates and the plastic hardens, letting the solvent dissolve through channels in the polymer.

The casting materials, tools and ice was cured in the same climate chamber at −10 °C for at least 2 hours. The different materials was mixed and allowed to regain freezing temperature after begin worked with for at least 15 minutes, before being applied, with gentle pressure and then weighted down with a carved aluminum profile. The aluminum profile also works as a heat sink, removing excess heat from the curing process. The formvar does not require this, since it is in liquid state, and the chemical reaction is vaporizing, so it does not change the surface temperature significantly. The casts then needed up to 4 hours to cure completely, and even then, removal was tricky with some of the materials, the ice was visibly damaged by the removal.

Alginate, being a water based casting material, did not work very well with ice at all, freezing to the surface it undoubtedly affected it. Furthermore the substance was not very well suited for diffraction microscopy. Flexitime, being a putty, did not fill in the pores in the ice very well and was also hard to read in the diffraction microscope. It was very easy to remove from the sampling area though. Master exact was applied in more of a paste, but not as readily removed. The surface area was easy to see in microscope though, and could be measured for its texture. Some air bubbles remained though. Certain surface structures could be seen in the casts with the naked eye, which looked promising. Due to the problems with Flexitime and Alginate, this article will center upon comparing formvar with Master Exact.

The structural analysis was conducted on a Veeco 3D Mems diffraction microscope. Ice casts on both formvar and Master exact were measured, the data can be seen in figure 2.

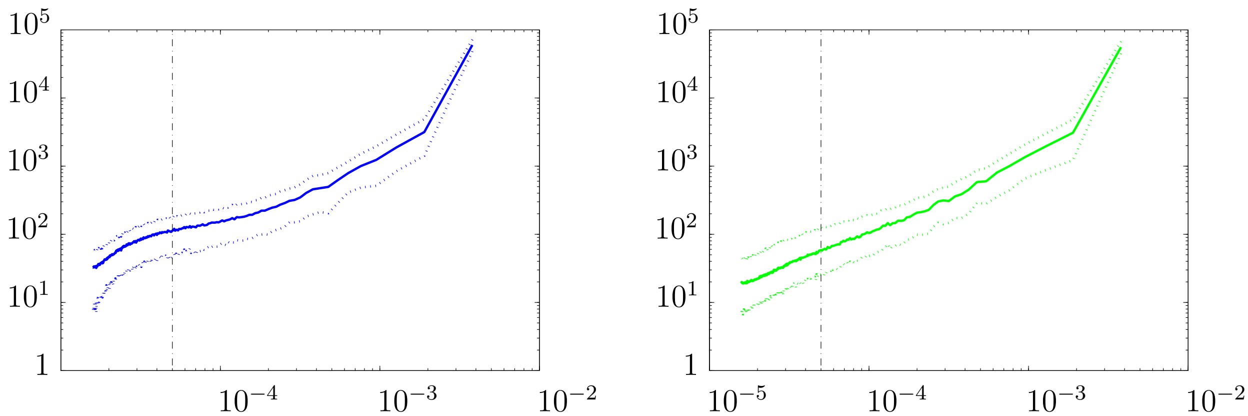

Figure 2: *To the left we have a power spectra of Master Exact, where we can see the sharp dip at the resolving power of the cast, the thin dashed lines above and below is one standard deviation from the thick line representing the mean. The right graph is the same average over an ice sample of formvar, where no such dip can be discerned. One standard deviation is represented by the dashed lines above and below. The wavelengths are in* m *and the power is just a representative value. (Note, the relative standard deviation is quite close to 0.6, constantly.)*

This was done to compare the resolving power of Master Exact and formvar. Furthermore, the aluminum was also casted, in the same conditions as previously, to be able to compare the aluminum surface with the Master exact directly, as seen if figure 1.

The data was evaluated both along the straight scan lines of the diffraction microscope, as well as transversal to them. Then Fourier transformed in each direction, power spectra were calculated and an average of each wavelength was found. Those average powers where then compared between the Master Exact and straight aluminum sample. The same was done with the measurements of ice, but only qualitatively compared, since the same area of ice could not be measured with both methods.

4 Experimental results

No tests has yet been done to discern if the nm scale structure is of any importance. But we have seen indications that the maximum resolution that Master Exact can manage is around $50\,\mu$m, but we have a definite drop in precision at around 0.5 mm. This also means that we have a tool to discern if any of those discrepancies are of interest.

5 Conclusion

Master exact seem to be able to recreate surface irregularities down to μm scale at least. The question that remains to be answered is if this is enough to say anything about the friction of ice, or if it is the mechanics on even smaller scale that really is of interest. At the very least this offers a tool for analysis of the surface to maybe discern what structures are of importance.

It would also be interesting to observe the deterioration of the material as the cast is made, to try and discern how much is actual etching or mechanical destruction of the material, and how much is done solely by the process of removal of the cast.

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