Ice Alloys

A Materials Science Lab for High School Students

Richard Hendrick
Nazareth Academy
Rochester, New York

Ice Alloys

A Materials Science Lab for High School Students

Richard Hendrick
Nazareth Academy
Rochester, New York

Introduction

During World War II, an eccentric individual named Geoffrey Pyke along with Max Ferdinand Perutz, a prominent scientist, convinced the Allies that a durable form of ice called Pykrete could be used to build giant 600 meter aircraft carriers. Pykrete is a mixture of wood pulp and ice that is reputed to be three times stronger than regular ice and take much longer to melt.

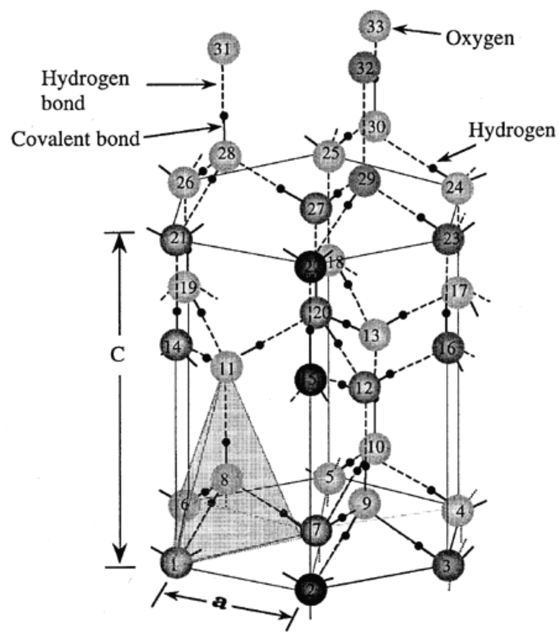
In this lab students will test the properties of Pykrete and ice to determine if these claims are true. In addition they will design and test their own version of Pykrete in an effort to improve its strength and thermal properties.

Background

Steel is an alloy of iron. In the mid 1700's steel was developed for commercial use in items such as cutlery. In the 1800's the mass production of steel allowed it to become an important building material. An alloy is a combination of two or more elements. At least one of the constituents is a metal. The resulting material has metallic properties different from those of its original components. Alloys are usually designed to have physical traits that are more desirable than those of their components. For instance, steel is stronger than iron, one of its main elements.

Native populations in arctic regions have a long history of using ice as a construction material. In more recent times, ice has been used to build important structures such as airport runways and roads in the remote polar regions. The properties of natural ice and snow have made it difficult to work with and so some efforts have been made to develop "alloys" of ice to improve it. This is analogous to metallurgical alloys which were developed to produce properties that were superior to metals found in nature.

Ice Structure and Formation

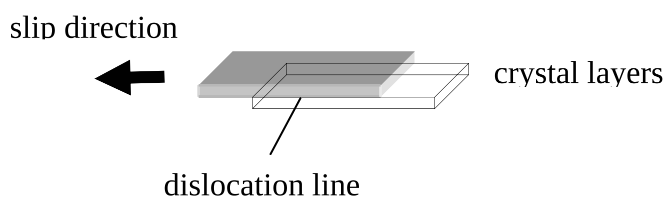


Crystal structure of hexagonal ice (Science Volume 134)

Ice possesses 12 different crystal structures, plus two amorphous states. At ordinary low pressures the stable phase is termed ice I. There are two closely related forms: hexagonal ice Ih, whose crystal symmetry is apparent in the shape of snowflakes, and cubic ice Ic.

The grain size, shape, and orientation of ice can exhibit a considerable variety. The key factor is the thermal-mechanical history of the ice.(Shulson 1999) Consider glacial ice that is formed under snow pressure. It is often deformed, melted, and recrystallized to form a complex layered microstructure as it flows downward under the influence of gravity.

The Fracture and Deformation of Ice



Ice is typically thought of as being brittle at low temperature and deforming at high temperature. Ice behavior is in fact more complicated than this. Ice is characterized as brittle-plastic. If ice is suddenly subjected to stress brittle fracture results even near the melting point temperature. This is a result of the stacked layers of the hexagonal crystal structure. At high temperature these layers dislocate and slip over one another like a stack of cards resulting in deformation. When a load is quickly applied brittle fracture occurs because the moving dislocations cannot move fast enough to keep up with the applied load. At lower temperatures the rate of deformation decreases but still occurs when a load is applied over a period of time to a fixed location.

Ice Alloys

Three major types of material additives have been tested in an effort to increase the strength and decrease the deformation of natural ice.

- Dispersed particulate material with high elastic modulus and high strength Example: Powdered kaoline reduced deformation but didn't help the strength.

- Fibrous material having a high elastic modulus and high strength.
  Example: Fiberglass produced a tenfold increase in strength and dramatically reduced deformation but was not biodegradable.

- Fibrous material having good ductility and moderate strength.
  Example: Wood fiber (Pykrete) increased strength by a factor of three and increased resistance to deformation from shock loading.

Pykrete

The traditional formula for Pykrete is a combination of water and 14% sawdust by volume that is allowed to freeze. In fact, any wood pulp will work and the water can be replaced by shaved ice or snow that is compacted and allowed to refreeze. This makes Pykrete a simple, readily available material to work with.

Pykrete Strength at Low and High Temperatures

The relative strength of Pykrete over ice, as shown in the table below results from the wood pulp influencing the dislocations along the slip plane. Impurities tend to concentrate at the dislocations and inhibit motion. In addition the wood pulp can impose a more ordered structure so that more work is required to move a dislocation.

Fresh Ice with Sawdust Added (-17 C)

Addition (%)	Modulus of Rupture (kg/cm^2)
0.0	22.5
0.8	22.7
2.5	35.0
9.0	60.0
14.0	66.7

W.D. Kingery

At higher temperature atoms have increased mobility. This creates a condition where dislocations can shift or "climb" to adjacent planes making it easier for dislocations to move past blocking impurities. This deformation prior to fracture or "creep" is inhibited by the fibrous nature of wood pulp. The mixture of pulp and ice creates a material matrix that is able to disperse and carry much of the applied stress. This results in a noticeable decrease in deformation rate.

Teacher Notes

Audience: Regents Physics Students grades 10 + 11
Intro to Engineering Stuents grade 9

- Both groups are **very** familiar with PASCO equipment

Materials:

PASCO 500 or 750 interfaces	class set
Computers with Data Studio Software	class set
PASCO Temperature Probes	class set
Force Sensor	one
Home Made Fracture Force Bracket	one (not that hard to make)
Assorted Beakers/Glssware	class set
Molds made from PVC	24 10 cm tubes per class
Toilet Paper	my source of wood pulp
Cooler/Refrigerator	1
Ice cube trays	2

Expected Time: Two 60 minute lab periods

Biggest Problem: Learning how to make consistent samples

Assesment: My standard lab report (included)

New York State Standards
Standard 1 Physical Setting Physics
Scientific Inquiry

- Students will use mathematical analysis, scientific inquiry, and engineering design, as appropriate, to pose questions, seek answers, and develop solutions.

- Key Idea: The central purpose of scientific inquiry is to develop explanations of natural phenomena in a continuing, creative process.

- Performance Indicators--Students:
  learn to ask "why" questions to seek greater understanding concerning objects and events they have observed and heard about

National Science Standards:

CONTENT STANDARD A: Abilities necessary to do scientific inquiry

- Understandings about scientific inquiry

CONTENT STANDARD G: Science as a human endeavor

- Nature of scientific knowledge

Copy of My Physics Lab Report Procedure

I General Instructions

Lab reports are an important part of this course. Your lab grades will have a significant impact on your overall grade in physics. **All labs must be completed** and checked in order for a student to be eligible for the midterm and final exams.

- Physics lab reports are due after two full letter day cycles by **3:00** P.M.

- Late labs will lose 1 point for each **school** day the lab is late.

II The "7" Basic Lab Report Requirements

1. Heading

Name and Lab Period Date lab was done

Title of Lab

2. Problem Statement

What is the goal of the lab? What problem will be solved during the lab exercise? The problem statement may or may not be written as a question.

3. Procedure

State that you followed the lab procedure exactly as written

or

give a **short**, narrative account of any changes in the lab procedure. Describe in detail any variation from the written directions and **why** you did it.

You must include at least one neat, well labeled **diagram** to help explain your work.

4. **Data**

All data should be recorded in an organized, logical manner. Use data tables to show what you measured and recorded. Include appropriate units will all data. **Graphs** should be included as part of this section.

5. **Calculations**

Calculations are mathematical arguments and are very important. All calculations must be indicated. Calculations should be shown in the following manner:
- **Write** an equation which relates to the data
- **Rearrange** the equation to solve for the desired unknown
- **Substitute** the data into the equation along with appropriate units
- **Solve** the equation using your calculator
- **State** the answer with correct units and enclose it in a box

6. **Sources of Error**

Unavoidable sources of error and uncertainties of measurement should be identified. **Percent difference calculations** should be made when required.

7. **Conclusion**

End your lab report with a conclusion. A conclusion must relate back to the problem statement and make a **comprehensive summary** of the lab.

III Quality of Work

All labs should be neat, organized, and legible. You must follow the rules of use for the **English Language**.

Follow all appropriate conditions for scientific notation, significant figures and problem solving.

Do not "fudge" data to arrive at what you think is a correct answer. Problems with accuracy should be solved by checking your procedure or explained in your sources of error section.

You may **Consult and Collaborate** with your lab partner(s) and peers but do not copy another person's work.

Keep in mind that I always expect the **Highest Quality Work** from you.

IV Grading

Completed labs will be graded on a scale of 1 - 10
If all basic lab requirements were completed a grade of **7** will be awarded.

Deductions

1 point will be deducted for each basic lab requirement that is not correctly completed.

Examples: Missing Conclusion -1
Missing Graph -1
Diagram has no labels -1

Additional points will be deducted for
Poor Spelling (more than 3 incorrect words) -1
Poor Grammar (more than 3 errors) -1
Disorganized or Messy lab -1

Extra Points

1 point will be added each time a basic lab requirement is exceeded.

Examples: Lab is typed +1
Exceptionally well written conclusion +1
Lab is turned in on the next school day +1
A "Spiffy" computer diagram +1

Resources

Schulson Erland M, The Structure and Mechanical Behavior of Ice, *JOM*, Vol. 51(2), (1999), pp. 21-27,

Kingery W. D., Ice Alloys (Current Problems in Research), *Science*, New Series, Vol. 134, No. 3473. (Jul. 21, 1961), pp. 164-168

Web Pages

http://www.cabinetmagazine.org/issues/7/floatingisland.php

http://www.geocities.com/Broadway/1928/pykrete.htm

http://www.nature.com/materials/news/march2002.html
www.strangematterexhibit.com
http://en.wikipedia.org/wiki/Pykrete
http://en.wikipedia.org/wiki/Project_Habbakuk

Acknowledgements:

The Nazareth Schools, Rochester New York
National Science Foundation
Cornell University
Cornell Center for Materials Research Faculty and Facilities Managers
Nev Singhota
Alexa Sabanegh
Kevin Dilley
Ken Smith
Sven Pedersen
Jaret Herter

Ice Alloys: A Materials Science Lab using Pykrete
Concepts: Fracture Force, Cooling Curves

EQUIPMENT NEEDED

* PASCO 500/750 Interface and Computer with Data Studio Software
* PASCO Temperature Sensor
* PASCO Force Sensor mounted in bracket (Front of room)
* Two 100 ml Beakers
* One 100 ml Graduated Cylinder
* Large (1000 ml) container of water at room temperature (Front of room)
* Ice and Pykrete Samples (In Cooler)
* Molds for Ice and Pykrete

Background

- **What is material science?** Materials science is the study of the structure, properties, performance, and processing of substances to determine how new and useful things can be created.

- **What is an alloy?** An alloy is a combination of two or more elements. At least one of the constituents is a metal. The resulting material has metallic properties different from those of its original components. Alloys are usually designed to have physical traits that are more desirable than those of their components. For instance, steel is stronger than iron, one of its main elements.

- **What is Pykrete?** During World War II, an eccentric individual named Geoffrey Pyke along with Max Ferdinand Perutz, a prominent scientist, convinced the Allies that a durable form of ice called Pykrete could be used to build giant 600 meter aircraft carriers. Pykrete is a mixture of wood pulp and ice that is reputed to be <u>three times stronger than regular ice and take much longer to melt</u>.

PROBLEM STATEMENT

Students will work in groups to test and compare strength and thermal properties of plain ice with Pykrete. They will then use this information to design and test an improved version of Pykrete. This “alloy” will be called Pykrete-2.

★ Since the ice and Pycrete are sensitive to temperature changes it is important that each group carefully **<u>read through the set of directions before proceeding</u>**.

PROCEDURE A

Part I

In this part of the lab you will use a **temperature sensor** to measure and record the amount of time it takes <u>ice</u> to undergo a temperature change of -10 C.

1. Connect the Data Studio interface to the computer, turn on the interface and then turn on the computer.

2. Connect the temperature sensor to analog channel A.

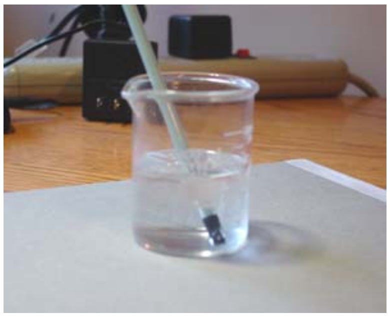
3. Open the Data Studio file titled **Temperature Change.DS**

   The setup window should show the temperature sensor associated with channel A and a graph of Temperature vs. Time will be displayed. The sensor does not need to be calibrated.

4. Use a graduated cylinder to measure out 50 ml of water from the container in the front of the room that is at room temperature. Pour the water into the beaker and place the temperature sensor in the beaker.

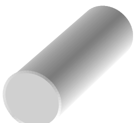
5. Hit the **Start** button and collect data for 10 seconds to make sure everything is working correctly and that the beaker and water are at the same temperature.

6. Use a paper towel to quickly remove an ice cube from the cooler and place it in the beaker as shown in the picture below. Immediately hit the **Start** button to begin data collection.



   You should see the temperature smoothly decrease on the graph. There is no need to stir the water and in fact for best results try not to shake or disturb the beaker. You do not need to monitor the sensor. It is set to stop collecting data after a 10 degree temperature drop has occurred. Since this will take some time you should proceed to part II.

PART II



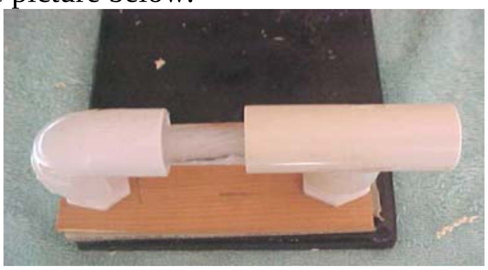
In this part of the lab you will use the **force sensor mounted in a special bracket** in the front of the room to measure and record the amount of force needed to fracture ice and then pykrete.

It would be very difficult for you to fracture an ice cube so the samples used to find the fracture force are 10 cm rods with a diameter of 1.5 cm. Remember that ice and Pykrete are temperature sensitive. Try to test the rods as quickly as possible to get good results.

1. Open the Data Studio file titled **Fracture Force.DS**
   The setup window should show the force sensor associated with channel A and a graph of Force vs. Time will be displayed.

2. Hit the **Tare** button on the force sensor to set it to zero.

3. Use a paper towel to quickly remove an ice rod sample and slide it into the holder as shown in the picture below.



4. Hit the **Start** button to begin collecting data. Use a smooth, firm motion to bring the force sensor down on the rod increasing the force until the rod breaks. **Be careful not to pinch your fingers!** You should see a graph with a distinctive peak that decreases rapidly. The peak represents the fracture force.

5. **Repeat** the procedure substituting a Pykrete rod for the ice.

7. Record your results for ice and Pykrete on the same graph and save it to your disk.

8. Place the broken rods in the waste container not in the sink.

PART III

In this part of the lab you will use a **temperature sensor** to measure and record the amount of time it takes Pykrete to undergo a temperature change of -10 C.

By now the ice sample from Part I should be finished. Remove the temperature sensor and let it warm up. Leave your first beaker and ice cube sample on your desk since it might be interesting to observe later.

1. When the sensor has warmed up **Repeat** steps 4 – 6 of the Part I procedure substituting a Pykrete cube for the ice.

2. Record the data for Pykrete on the same graph as the ice.

3. Save this graph to your disk.

DATA ANALYSIS

Graphical Analysis

Examine your graphs and determine:

- How long it took the ice to lose 10 C
- How long it took the Pykrete to lose 10 C
- How much force did it take to fracture the ice rod
- How much force did it take to fracture the Pykrete rod

Organize this information into a Data Table for your group.

Class Discussion

- Each group will share their results.
- Each group will present a theory that explains their results.
- The class will use the class data to answer the problem statement and decide what data (if any) should be added to their data table.
- The class will attempt to provide a unified theory that explains the class results.
- Without changing the original water and paper pulp ingredients, what are some things you could do to improve the Pykrete?

PROCEDURE B Pykrete-2 Design and Synthesis

1. Students work within the lab group to come up with **one** different arrangement/new formula for the mixture based on test results of Pykrete.

- Record what you have changed to produce Pykrete-2.
- Record why you made the changes that you did.
- Record how you think your Pykrete-2 will behave compared to Pykrete.

2. Use provided materials to carefully make your version of Pykrete-2
    - Submit to teacher for freezing

Day 2 -- Day 2

3. Repeat Testing Procedure A on Pykrete –2
    - Record Results

Class Discussion

- Each group will share their results.

- Each group will present a theory that explains their results
- The class will use the class data to answer the problem statement and decide what data (if any) should be added to their data table.

- What is the best arrangement/formula for Pykrete-2?

- What are the advantages of a Pykrete snowman?

ASSESMENT

- Standard lab report and grading

EXTENSION

- Why weren't the Pykrete aircraft carriers ever built?