# *SALT & SURFACE: THE FASTEST WAY TO MELT ICE*

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## Abstract

The time it takes for ice to melt is crucial for many applications, such as de-icing of roads, sidewalks, and vehicles. In severe storms, slippery conditions can also cause traffic build-ups, major accidents, and delays in emergency service response times. In this project, two factors that may affect the time it takes to melt ice were examined: salt content in ice and the thermal conductivity of the surface ice is in contact with. The experiment considered three different salt contents (0 wt%, 5 wt%, and 15 wt%) and four different surfaces (stainless steel, wood, plastic, and glass). The melting time was the fastest for the combination of ice containing 15 wt% salt in contact with stainless steel, while it was the slowest for ice containing 0 wt% salt in contact with plastic. The effect of increasing salt on the time it takes to melt is consistent with the Freezing Point Depression mechanism. The variation between the melting times on different surfaces is explained by their different thermal conductivities. These results allow us to understand the factors affecting the time taken for ice to melt, which has broad applications.

## Rationale

All over the world, de-icing roads, sidewalks, and vehicles is a huge problem. Icy roads require slower speeds and can cause reduced pavement friction and vehicle crashes. 24% of weather-related crashes are due to slushy, snowy, or icy roads, which kills over 1,300 people and injures over 116,800 people per year.[1] Snow and ice control, including using road salt, costs local agencies over 2.3 billion dollars annually.[1]

Since the 1930s, the United States has been using road salt to melt ice. Back then, an estimated 5,000 tons of salt was used per year, while that number has jumped to 20 million metric tons today.[2] Road salt is very effective for melting ice because of how salt interacts with water microscopically. When the salt trucks drive on snowy/icy roads, the dispersed salt gets mixed with the crushed snow/ice and dissolves. The experiment replicates this scenario by measuring the time it takes to melt ice containing dissolved salt. However, road salt is bad for the environment, as it can kill vegetation, harm fish and other aquatic life, and degrade buildings, bridges, and pipes.[2] Therefore, using the optimal quantity of road salt is crucial, as well as knowing the factors that impact the time it takes to melt ice.

In this experiment, the effect of salt on the melting point of ice was examined, as well as the effect of a surface's thermal conductivity on the melting point of ice. Since roads are made from concrete, this experiment uses glass as one of the surfaces, as they have very similar thermal conductivities; glass has a thermal conductivity of 0.8 W/mK, while concrete typically has a thermal conductivity of 0.9-0.95 W/mK.[3]

## Hypothesis

Ice with the highest salt concentration (15 wt%) and in contact with the surface with greatest thermal conductivity (in this case, stainless steel) will melt the fastest.

## Research Plan

### Materials

- filtered water
- 2 ice trays
- iodized salt
- measuring cup
- measuring spoons
- glass
- wood
- plastic
- metal
- stopwatch
- pen and paper
- phone camera
- freezer

### Procedure

1. Fill the measuring cup with 250 mL of filtered water.
2. Pour 2 tsp of water into a slot in the ice tray.
3. Repeat step 2 five more times for five other slots.
4. Set the freezer's temperature to 1°F. Carefully place the ice tray into the freezer for 4 hours.
5. Remove the ice tray from the freezer. Remove four ice cubes and place one ice cube each on a different surface: glass, wood, plastic, and metal.
6. Start the stopwatch.
7. Take pictures every 5 minutes until the ice cubes finish melting.
8. Note down the time it takes the ice cubes on each surface to completely melt.
9. Stop the stopwatch after all the ice cubes are fully melted, which can be visually determined once all air bubbles are separated, and there is only a puddle of water visible.
10. Empty out the ice tray and the measuring cup and dry the surfaces.
11. Calculate 5 wt% salt for 250 mL of water:
    a. Create a ratio of the eutectic composition for salt water. 23.3 wt% of salt in water is equivalent to 2.54 lbs of salt in 1 gallon of water. [4]
    b. Using this ratio, calculate the value of 5 wt% salt for 250 mL of water.
12. Fill the measuring cup with 250 mL of filtered water.
13. Add 5 wt% salt to water and mix vigorously until the salt is fully dissolved.
14. Repeat steps 2-10 for the ice tray with the saltwater mix.
15. Calculate 15 wt% salt for 250 mL of water using the procedure in step 11.
16. Fill the measuring cup with 250 mL of filtered water.
17. Add 15 wt% salt to the water and mix vigorously until the salt is fully dissolved.
18. Repeat steps 2-10 for the ice tray with the saltwater mix.

19. Repeat steps 1-18 two more times. Take the averages of all three trials and create graphs to show the trends.

## Risk and Safety

This project does not require any safety procedures.

***Figure 1: Materials for freezing ice containing 0 wt% salt (pure ice)***

***Figure 2: Materials for freezing ice containing 5 wt% salt***

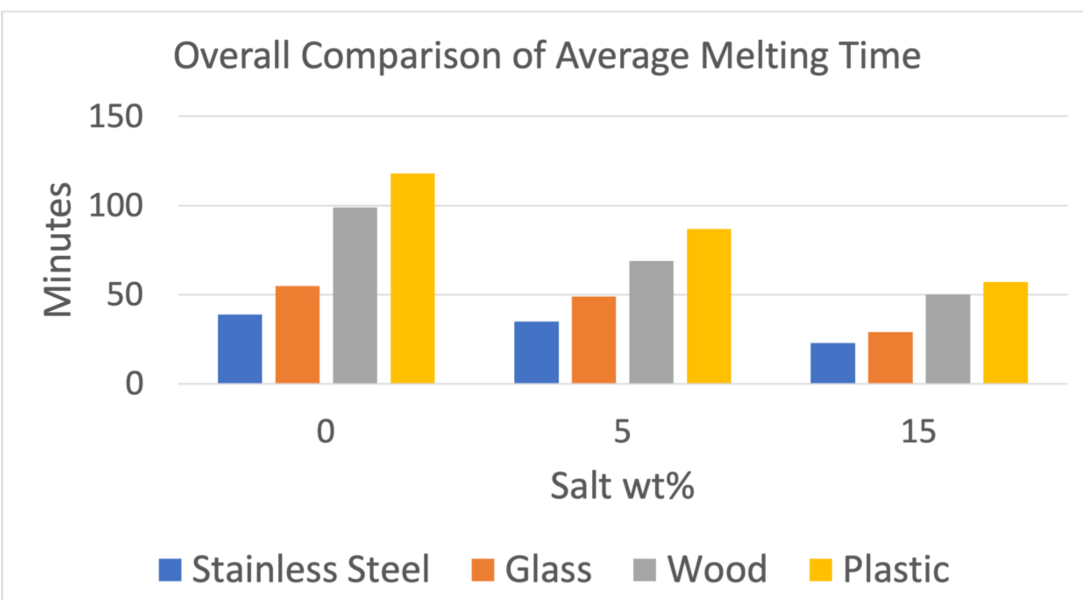
## Results

In all the experiments, the ice with the highest salt content melted the fastest. Ice in contact with the surface with the highest thermal conductivity in the experiment (stainless steel) melted the fastest as well. When the two factors were considered in combination, in every trial, ice containing 15 wt% salt in contact with stainless steel melted the fastest, with an average melting time of 23 minutes, while ice containing 0 wt% salt in contact with plastic melted the slowest, with an average melting time of 118 minutes.

*Table 1: The averages, standard deviations, and standard errors for all trials, salt contents and surfaces*

| Salt Content | Surface | Average Time to Fully Melt (minutes) | Standard Deviation | Standard Error |
|---|---|---|---|---|
| 0 wt% | Stainless Steel | 39 | 4.04 | 2.33 |
| 0 wt% | Wood | 99 | 7.77 | 4.48 |
| 0 wt% | Plastic | 118 | 9.54 | 5.51 |
| 0 wt% | Glass | 55 | 4.16 | 2.40 |
| 5 wt% | Stainless Steel | 35 | 1.53 | 0.88 |
| 5 wt% | Wood | 69 | 7.64 | 4.41 |
| 5 wt% | Plastic | 87 | 3.61 | 2.08 |
| 5 wt% | Glass | 45 | 3.06 | 1.76 |
| 15 wt% | Stainless Steel | 23 | 3.46 | 2.00 |
| 15 wt% | Wood | 50 | 7.81 | 4.51 |
| 15 wt% | Plastic | 57 | 7.23 | 4.18 |
| 15 wt% | Glass | 29 | 3.46 | 2.00 |

*Figure 3: Average melting times for all salt contents on all surfaces*



The figures below consistently show that ice containing higher salt contents melts faster than ice containing lower or no salt contents. Each figure shows the average melting time for 3 trials on a given surface for different salt contents.

***Figure 4: Average Time to Fully Melt (Stainless Steel)***

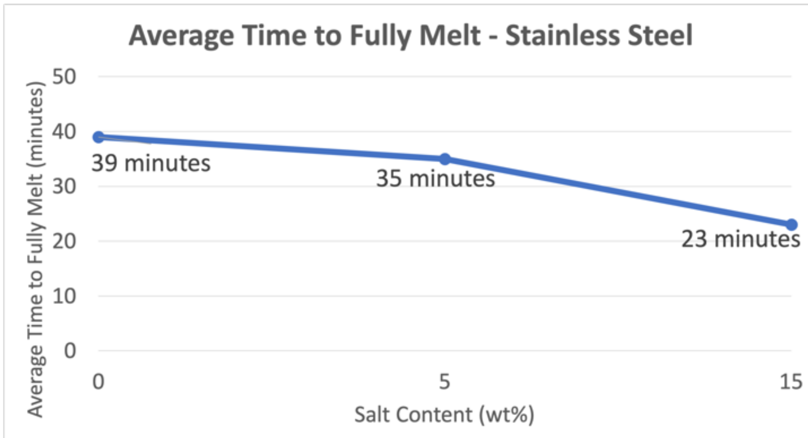



***Figure 5: Average Time to Fully Melt (Glass)***

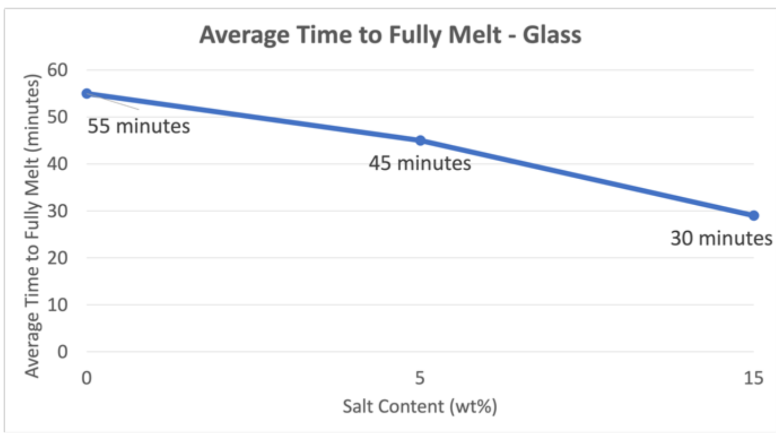



***Figure 6: Average Time to Fully Melt (Wood)***

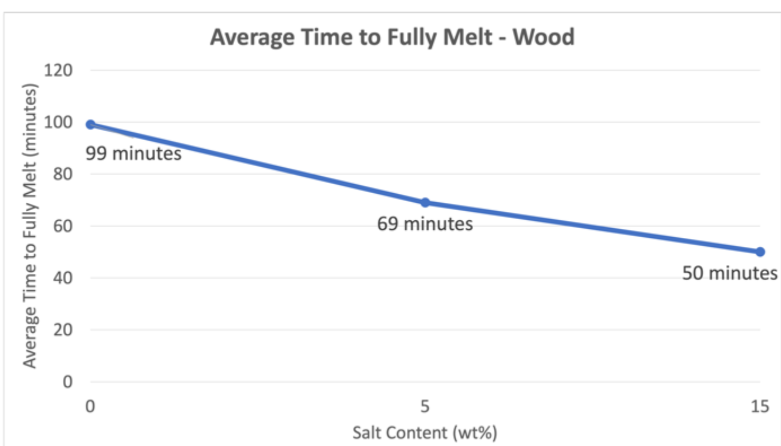
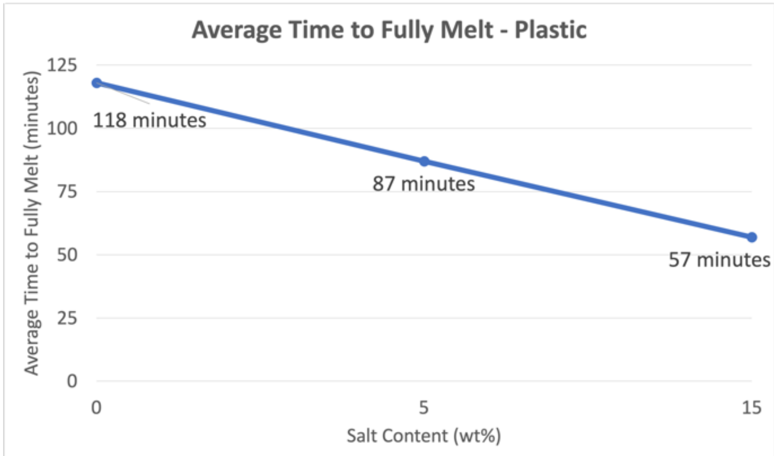


*Figure 7: Average Time to Fully Melt (Plastic)*




The figures below consistently show that ice in contact with surfaces with higher thermal conductivities melts faster than ice in contact with surfaces with lower thermal conductivities. Each figure shows the average melting time for 3 trials on each of the four surfaces for a specific salt content.

*Figure 8: Average Time to Fully Melt (0 wt% Salt)*

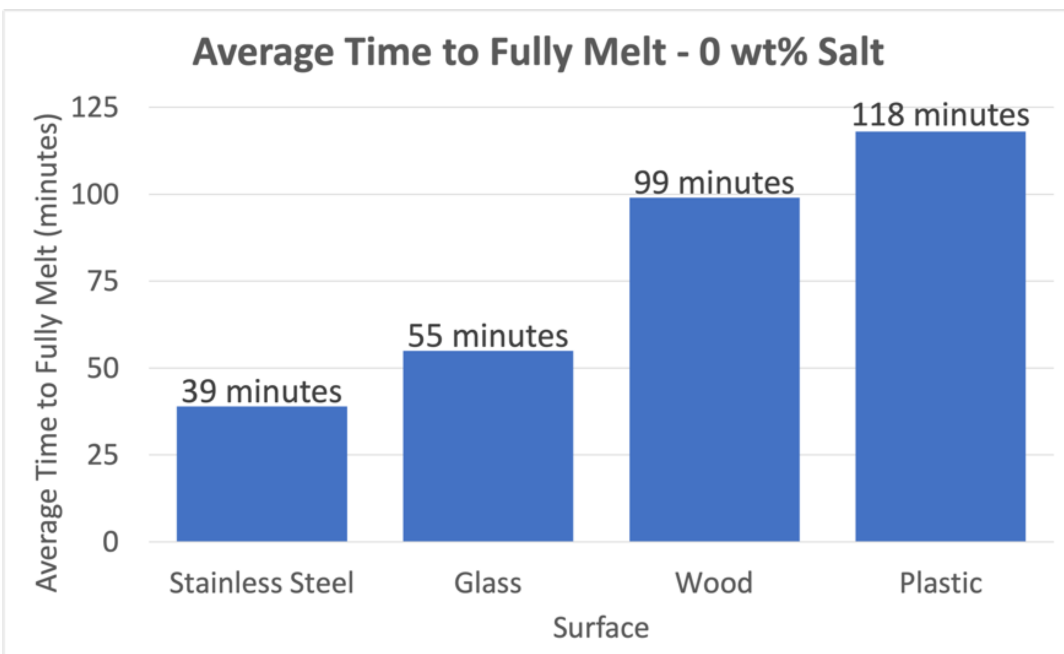


*Figure 9: Average Time to Fully Melt (5 wt% Salt)*

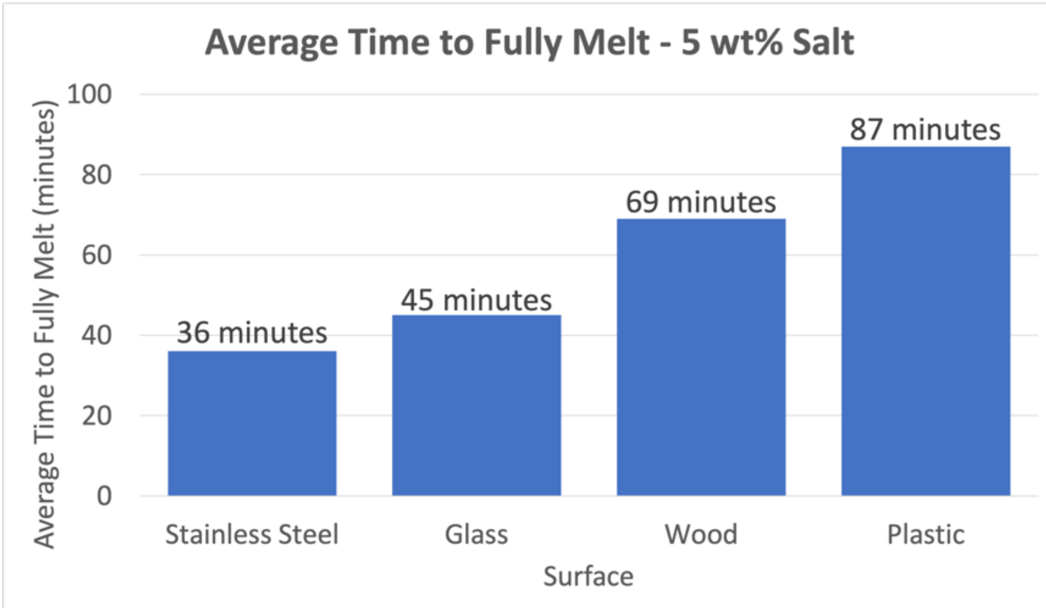
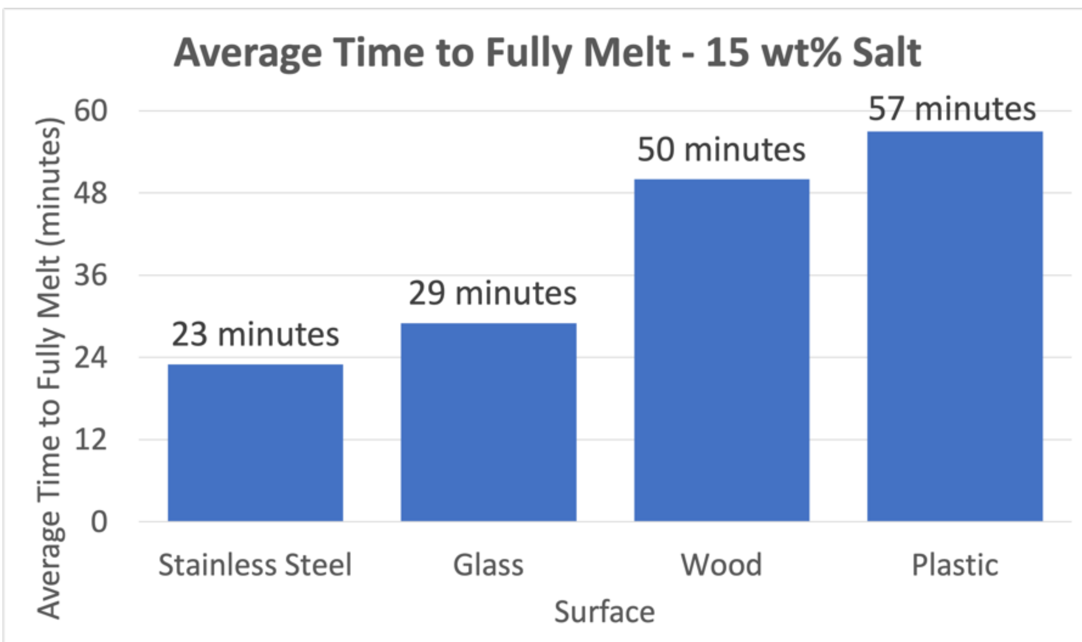



*Figure 10: Average Time to Fully Melt (15 wt% Salt)*




Tables 2-5 show a visual comparison of all the surfaces with a given salt content. On surfaces with higher thermal conductivity, the puddles of water around the ice become larger, as seen in the pictures of ice in contact with stainless steel. The amount of ice melted at different time intervals drastically increases with higher salt contents, as seen in table 5.

*Table 2: A visual comparison of pure ice (0 wt% salt) melting at different times and on different surfaces*

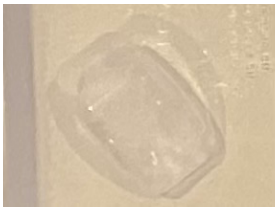
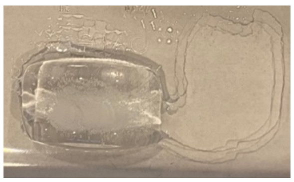
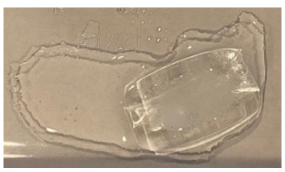
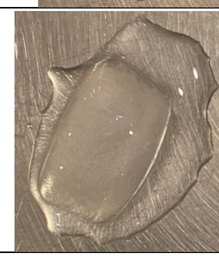
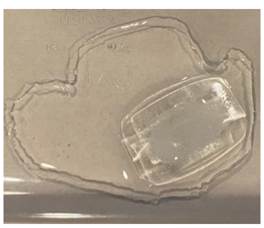
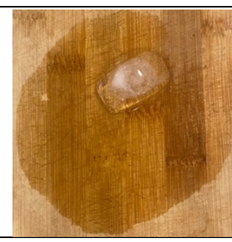
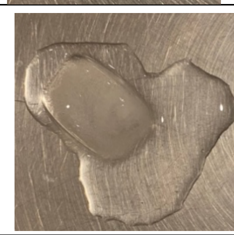
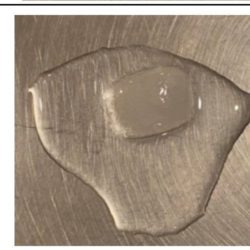
| Time | Glass | Plastic | Wood | Stainless Steel |
|---|---|---|---|---|
| 0 min |  |  |  |  |
| 10 min |  |  |  |  |
| 15 min |  |  |  |  |
| 20 min |  |  |  |  |
| 30 min |  |  |  |  |

*Table 3: A visual comparison of ice with 5 wt% salt melting at different times on different surfaces*

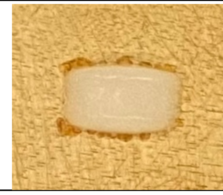
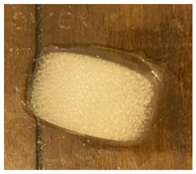
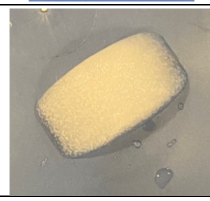
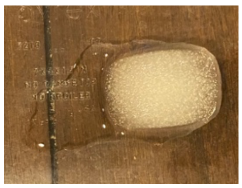
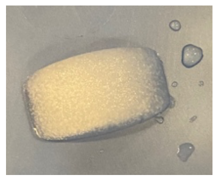
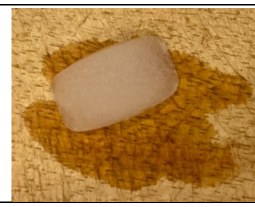
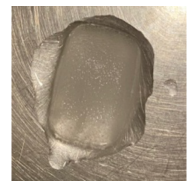
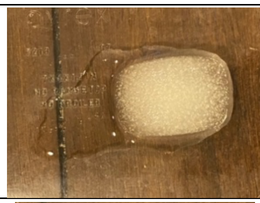
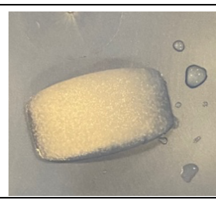
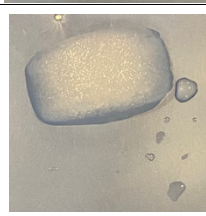
| Time | Glass | Plastic | Wood | Stainless Steel |
|---|---|---|---|---|
| 0 min |  |  |  |  |
| 10 min |  |  |  |  |
| 15 min |  |  |  |  |
| 20 min |  |  |  |  |
| 30 min |  |  |  |  |

*Table 4: A visual comparison of 15 wt% salt melting at different times on different surfaces*

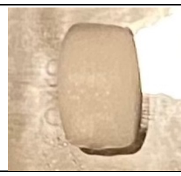
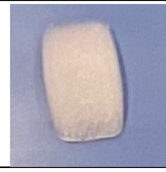
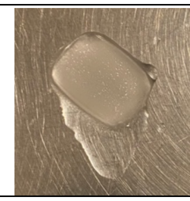
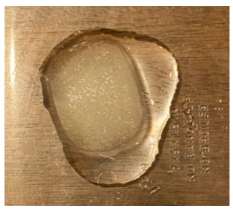
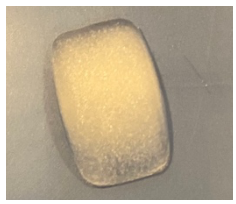
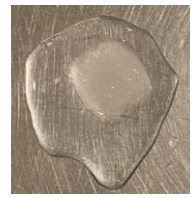
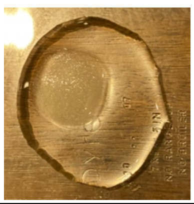
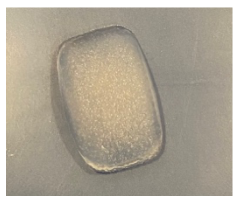
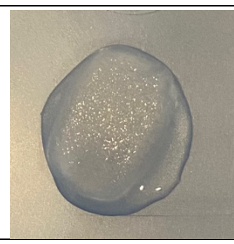
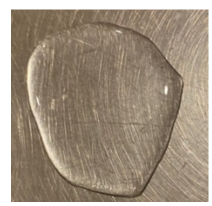
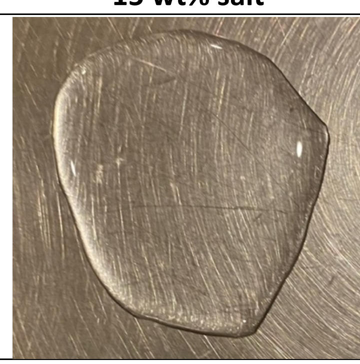
| Time | Glass | Plastic | Wood | Stainless Steel |
|---|---|---|---|---|
| 0 min |  |  |  |  |
| 10 min |  |  |  |  |
| 15 min |  |  |  |  |
| 20 min |  |  |  |  |
| 30 min |  |  |  |  |

*Table 5: Comparison of different types of ice melting at 30 minutes on stainless steel*

| 0 wt% salt (pure water) | 5 wt% salt | 15 wt% salt |
|---|---|---|
|  |  |  |

## Discussion

Analysis of the data shows that a consistent trend is observed for all surfaces and salt contents. Ice in contact with stainless steel melted the fastest, while ice in contact with plastic melted the slowest. The melting time significantly decreased with higher salt content. The melting time also decreased for surfaces with higher thermal conductivities (for example: stainless steel) as compared to surfaces with lower thermal conductivities (for example: plastic).

Standard deviations for average melting times varied from ± 1.53 minutes for ice containing 5 wt% salt in contact with stainless steel to ± 9.54 minutes for ice containing 0 wt% salt in contact with plastic. This further supports the statement that the results were consistent and reproduced in all three trials.

The results demonstrate that two factors clearly impact the melting times. Ice containing higher salt contents melts faster than ice containing lower or no salt content. Ice melts faster on surfaces with higher thermal conductivities, while ice melts slower on surfaces with lower thermal conductivities. When the two factors are considered in combination, ice with higher salt content in contact with surfaces with higher thermal conductivity melts the fastest.

***Figure 11: A water – NaCl phase diagram taken from https://www.tf.uni-kiel.de/matwis/amat/iss/kap_6/illustr/i6_2_2.html, the University of Kiel***

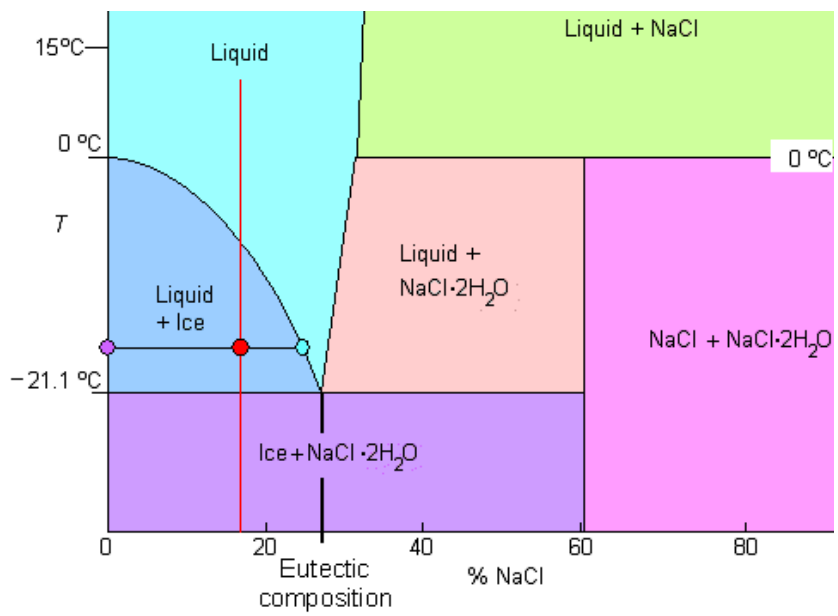



Figure 11 shows a water-salt phase diagram. This illustrates many different states of matter, but for this experiment, the phase remained in the Liquid + Ice region, as the salt levels stayed below 23.3 wt%, or the eutectic composition. This is the point where adding more salt cannot lower the freezing point any further, and salt cannot stop ice from freezing. The curve going across the Liquid + Ice section is called the Freezing Curve and demonstrates the effect of adding salt to water on the freezing point. The different sections are explained below:

- **Ice + $NaCl.2H_2O$** - Compositions found are ice and a hydrated sodium chloride mixture.
- **Liquid + $NaCl.2H_2O$** – Compositions found are water and hydrated sodium chloride mixture.
- **NaCl + $NaCl.2H_2O$** – Compositions found are salt and a hydrated sodium chloride mixture.
- **Liquid + NaCl** - Compositions found are water and salt.

Ice with a higher salt composition melted faster due to the Freezing Point Depression mechanism. The ions from salt (Na+ and Cl-) separate, after dissolving in the water, and prevent bonds between $H_2O$ molecules, which stops ice from forming. This can be seen in the salt-water phase diagram shown in Figure 11; adding salt decreases the freezing point of water, as colder temperatures are required to bring the $H_2O$ molecules closer together. The Freezing Point Depression applies to icy roads as well, which is why road salt is used. This experiment only used 15 wt% salt at the maximum and a temperature of 1°F, which is less than the eutectic composition. These values were chosen so that the phases remained in the Liquid + Ice region, as show in Figure 11 above, to observe the Freezing Point Depression.

*Figure 12: Thermal conductivity of the surface versus average melting times. Thermal conductivities taken from http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html, Georgia State University*

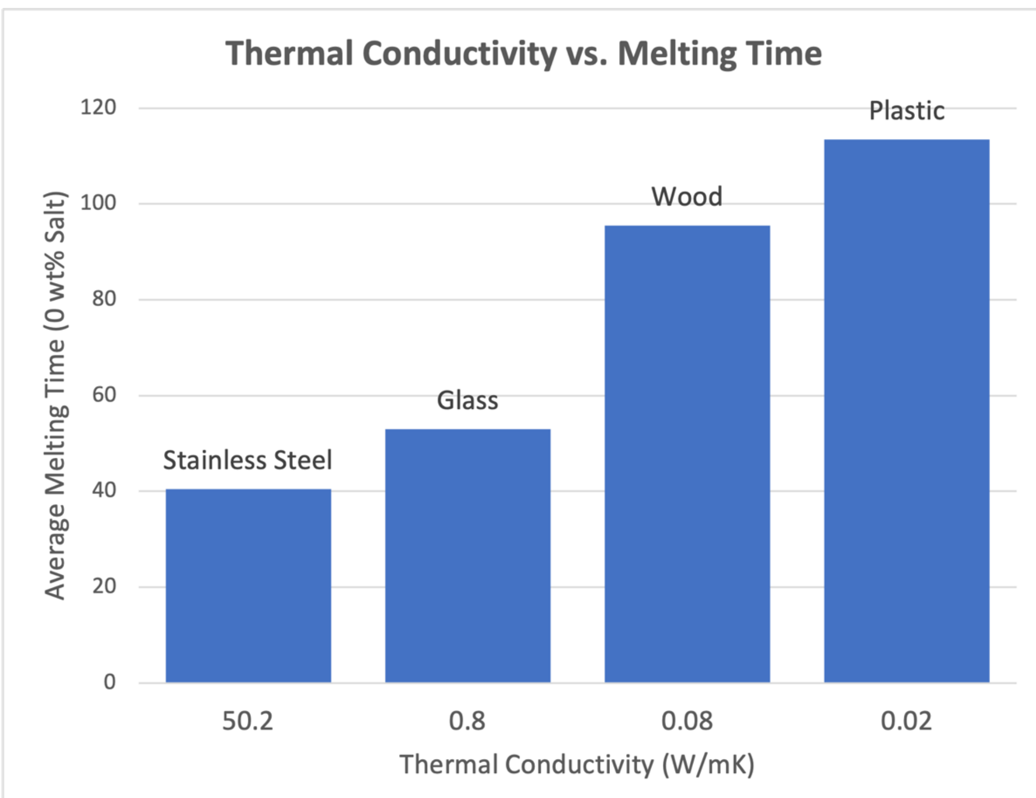


Figure 12 shows the thermal conductivities of the surfaces used in this experiment. As the thermal conductivity increases, the melting time decreases. High thermal conductivity values mean the surface has more free electrons which are able to carry heat more efficiently.

Ice in contact with stainless steel melted faster because of better heat transfer from the surface to the ice. Ice melted faster in contact with stainless steel than plastic due to the higher thermal conductivity of stainless steel (Figure 12). Metals, such as stainless steel, conduct heat better because they have greater amounts of free electrons that can move freely and carry heat. Insulators, such as plastic, have electrons tied to the atom, causing a lack of free electrons.

The average standard error is ~5%, which is in within acceptable limits. This allows us to establish clear trends due to consistent results. However, using a visual method to determine whether an ice cube had fully melted may have resulted in slightly inaccurate melting times. Using an optical microscope to magnify the melting ice cube could help record more precise melting times.

In the future, it would be interesting to research the effect of different surface structures on the melting time of ice. For example, investigating if air pockets within a surface would affect the time it takes for ice to melt. The effect of different solutes on the melting time of ice is also an interesting research topic, as it may lead to finding a more environmentally friendly way to de-ice roads and sidewalks. Understanding the difference in thermal conductivities between room temperature water and cold water would also be interesting to research, as well as the effect of air flow on the surface of ice on the melting time. Lastly, simulating the de-icing of roads would be a very interesting topic for future research.

## Conclusion

Both parts of the hypothesis were supported. A higher salt content in ice does decrease the melting time of ice. When ice is in contact with a surface with a higher thermal conductivity, the melting time decreases, due to better heat transfer. The Freezing Point Depression is crucial in understanding factors that can help de-ice roads, sidewalks, and vehicles.

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2. https://www.uvm.edu/seagrant/outreach/road-salt-water-quality-salt-savvy-champlain#:~:text=How%20much%20salt%20do%20we,in%20the%20U.S.%20each%20year, **Lake Champlain Sea Grant**

3. https://www.fhwa.dot.gov/pavement/sustainability/articles/pavement_thermal.cfm, **U.S. Department of Transportation**
4. https://clearroads.org/project/20-02/ (First video: “Educational Video Describing the NaCl Phase Diagram) **Clear Roads Research Program**
5. https://www.tf.uni-kiel.de/matwis/amat/iss/kap_6/illustr/i6_2_2.html, **University of Kiel**
6. https://www.britannica.com/story/why-does-salt-melt-ice#:~:text=But%20you%20may%20be%20asking,will%20break%20into%20its%20elements, **Encyclopedia Britannica**
7. http://hyperphysics.phy-astr.gsu.edu/hbase/Tables/thrcn.html, **Georgia State University**
8. https://farside.ph.utexas.edu/teaching/316/lectures/node13.html#:~:text=Metals%20are%20good%20conductors%20(both,move%20freely%20throughout%20the%20metal, **Farside Physics, University of Texas**
9. https://clearroads.org/project/20-02/ (First video: “Educational Video Describing the NaCl Phase Diagram) **Clear Roads Research Program**