Structures of Materials

Principle: The properties of materials are determined by structure and structure can be tailored in predictable ways through processing.

# Introduction

Understanding structure will provide us with the basics in which we can predict properties, manipulate structure (and therefore properties) through processing, prevent material failure and add a sense of wonder about the world around us.

Let’s look at some historical failures caused by an inadequate understanding of material behavior.

1. Failure of pipe organs in medieval churches in cold climates. (come back to this one again after discussing Bravais lattices)
2. The Collapse of the Tacoma Narrows Bridge (1940)
3. The Space Shuttle Challenger Disaster (1986)

# Classifying Structures

It is convenient to classify structure at different length scales and discover what properties can be affected at each scale. Here we will organize our lessons according to 4 structural levels as follows.

1. Atomic Structure
   1. Bonding
   2. Electron configuration
2. Atomic Arrangement
   1. Crystalline Solids
   2. Amorphous Solids
3. Microstructure
   1. Polycrystalline
   2. Crystal structure changes
   3. Compositional changes
4. Macrostructure
   1. Presence of stress concentrators
   2. Overall design

# Atomic Structure

# Atomic Arrangement

# Microstructure

# Macrostructure

Introduction:

<https://fb.watch/s63mncI9Ks/> screen shots:

A silver object on a tile floor

Description automatically generatedA piece of paper on a tile surface

Description automatically generated

**Story Outline: The Tale of Tin Pest and Historical Implications (Pewter 91% Sn)**

**See video** [**https://youtu.be/Hb0VoQ-xQhU?feature=shared**](https://youtu.be/Hb0VoQ-xQhU?feature=shared) **for live transformation.**

**Introduction:**

* Start with the dramatic setting of Napoleon's invasion of Russia in 1812. Emphasize the harsh winter conditions and the immense challenges faced by the army.
* Pose a question: "What if a simple material failure contributed to one of the greatest military disasters in history?"

**Background on Tin Pest:**

* Explain the phenomenon of tin pest: how tin transforms from its metallic form (white tin) to a brittle, non-metallic form (gray tin) at temperatures below 13.2°C.
* Use visuals to show the structural change in tin and how it affects the material properties.

**The Legend:**

* Describe the popular story of how the tin buttons on the soldiers' uniforms crumbled in the freezing temperatures, leading to difficulties in keeping their clothing fastened.
* Discuss the possible consequences: soldiers unable to keep warm, leading to greater suffering in the already harsh conditions.

**Scientific Explanation:**

* Dive into the science behind phase transitions and why temperature changes can drastically alter material properties.
* Link this to the broader context of materials science: how understanding the properties of materials is crucial in designing and selecting the right materials for specific applications.

**Debunking the Myth:**

* Address the fact that while this story is compelling, there is no concrete historical evidence that button failure significantly impacted Napoleon’s campaign.
* Highlight the importance of critical thinking and verifying historical anecdotes with scientific evidence.

**Modern Relevance:**

* Connect the story to modern examples where material failures have had significant impacts, such as the Challenger Space Shuttle disaster due to O-ring failure, or how materials selection is crucial in designing smartphones, medical devices, and more.
* Discuss how materials science continues to evolve and prevent such failures in today's technology and infrastructure.

**Engagement Activity:**

* Conduct a small experiment or demonstration showing a phase transition in a material, if possible, or use interactive simulations.
* Encourage students to think about other historical events or modern scenarios where material properties play a critical role.

**Conclusion:**

* Reiterate the importance of materials science in everyday life and historical events.
* Pose another thought-provoking question: "How might our understanding of materials science change the future?"

Did we learn our lesson: lead free solders in 1980s through early 2000s. 96.5% Sn, 3%Ag, 0.5% Cu -- touted for better mechanical performance at high temperatures but what about the Sn at low temperatures?

Another similar story: Flow of window glass in Williamsburg

Another: Chemistry textbooks suggesting covalent bonds are weak since water has low melting point.

APPENDIX:

**1. The Collapse of the Tacoma Narrows Bridge (1940)**

**Concepts: Structural Engineering, Material Properties, Resonance**

* **Story:** The Tacoma Narrows Bridge, nicknamed "Galloping Gertie," famously collapsed due to aeroelastic flutter. The story demonstrates the importance of understanding material properties and structural dynamics.
* **Lesson Focus:** Discuss how different materials respond to stress and strain, and the importance of designing structures to withstand dynamic forces. Highlight the role of resonance and material fatigue.
* **Engagement:** Show the famous footage of the bridge collapse and analyze what went wrong. Conduct a small experiment with a simple structure and different materials to illustrate resonance and material behavior.

**2. The Space Shuttle Challenger Disaster (1986)**

**Concepts: Material Failure, Temperature Effects, Engineering Ethics**

* **Story:** The Challenger disaster was caused by the failure of an O-ring seal in the solid rocket booster, exacerbated by cold temperatures. This tragedy highlights the critical role of materials selection and testing.
* **Lesson Focus:** Discuss how temperature can affect material properties and the importance of rigorous testing and ethical decision-making in engineering.
* **Engagement:** Analyze the materials used in the O-rings, their properties at different temperatures, and discuss the ethical responsibilities of engineers in ensuring safety.

**3. The Development of Stainless Steel**

**Concepts: Corrosion Resistance, Alloying, Material Innovation**

* **Story:** Stainless steel was developed in the early 20th century to combat the problem of rusting in standard steel. Its creation involved the discovery that adding chromium to steel significantly improved its corrosion resistance.
* **Lesson Focus:** Introduce the concept of alloying and how adding different elements can change the properties of a base metal. Discuss the importance of corrosion resistance in various applications.
* **Engagement:** Conduct a simple corrosion experiment with different metals and alloys. Show examples of stainless steel applications and discuss why it is preferred over other materials in certain situations.

**4. The Failure of the Boston Molasses Tank (1919)**

**Concepts: Material Stress, Safety in Design, Thermal Expansion**

* **Story:** In 1919, a large storage tank of molasses in Boston burst, releasing a wave of molasses that caused significant damage and loss of life. The disaster was due in part to poor construction materials and design.
* **Lesson Focus:** Discuss the importance of understanding material stress and safety factors in design. Highlight the role of thermal expansion and contraction in materials.
* **Engagement:** Analyze the materials used in the tank’s construction and why they failed. Perform a demonstration of thermal expansion using metal rods or strips to show how temperature changes can affect material dimensions.

**5. The Rise and Fall of the RMS Titanic (1912)**

**Concepts: Metallurgy, Brittleness, Impact Resistance**

* **Story:** The sinking of the Titanic involved not just an iceberg but also brittle fracture of the ship's steel hull. This story can illustrate the importance of material toughness and impact resistance.
* **Lesson Focus:** Introduce metallurgical concepts such as grain structure, brittleness, and toughness. Discuss how materials respond to impact and stress, especially at low temperatures.
* **Engagement:** Examine samples of steel with different grain structures, conduct impact tests (e.g., Charpy impact test), and discuss how material selection could have influenced the Titanic’s fate.

**6. The Invention of Kevlar**

**Concepts: Polymer Science, High-Strength Materials, Innovation**

* **Story:** Kevlar, invented by Stephanie Kwolek in 1965, is a high-strength material used in bulletproof vests and many other applications. Its development showcases innovation in polymer science.
* **Lesson Focus:** Discuss the chemical structure of Kevlar and how it contributes to its high strength and lightweight properties. Highlight the broader impact of material innovations on safety and technology.
* **Engagement:** Show examples of Kevlar applications, discuss the process of polymerization, and compare Kevlar’s properties to other materials used for similar purposes. Conduct a hands-on activity demonstrating the strength of different fibers.

**7. Graphene: The Material of the Future**

**Concepts: Nanomaterials, Electrical Properties, Material Science Innovation**

* **Story:** Discovered in 2004, graphene is a single layer of carbon atoms arranged in a hexagonal lattice, known for its exceptional electrical, thermal, and mechanical properties. It has the potential to revolutionize many industries.
* **Lesson Focus:** Introduce the concept of nanomaterials and their unique properties. Discuss potential applications of graphene in electronics, materials engineering, and beyond.
* **Engagement:** Show videos of graphene being produced and used in various applications. Discuss current research and future possibilities for graphene-based technologies. Conduct a simulation or visualization of graphene’s structure and properties.

These stories not only provide historical context but also illustrate the practical importance of materials science principles, making the subject more engaging and relevant for students.

8. Thermomechanical fatigue in lead free solder joints. 218K – 398K

Several different types of metal parts

Description automatically generatedA screenshot of a computer

Description automatically generated

Problem for electronics circuits? Seems to be more of a problem for bulk samples but are we sure?