Thermal Processing of Metals

Grade Band: Middle School-High School	**Topic:** Thermal Processing of Metals

Brief Lesson Description:
Students analyze how heat treatment affects the properties of metal using bobby pins.

Performance Expectation(s):
MS-PS1-2: Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.

HS-ETS1-3: Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

HS-PS1-7: Use mathematical representations to support the claim that atoms, and therefore mass, are conserved during a chemical reaction.

Specific Learning Outcomes:
Students will explore the effects of thermal processing on metals, particularly on their structure and properties.
Students will analyze changes in the physical properties of a bobby pin after heating and cooling.
Students will evaluate different thermal treatment processes for metals and how they apply to real-world manufacturing.

Narrative / Background Information

For this lesson on the thermal processing of metals, students are expected to have a basic understanding of atomic structure, chemical bonds, and the physical properties of materials. Familiarity with concepts such as heat, temperature, and phase changes will help students grasp how thermal energy affects metal properties. Prior knowledge of mechanical properties like strength, ductility, and elasticity, as well as the ability to measure and interpret physical changes in materials, will be beneficial. Basic lab skills, including data collection and analysis, are also expected to ensure students can effectively conduct experiments and draw conclusions from their results.

Science & Engineering Practices:

Analyzing and Interpreting Data
Analyze and interpret data to determine similarities and differences in findings (MS-PS1-2)

Constructing Explanations and Designing Solutions
Evaluate a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria, and trade off considerations (HS-ETS1-3)

Using Mathematics and Computational Thinking
Use mathematical representations of phenomena to support claims. (HS-PS1-7)

Connections to Nature of Science

Science Knowledge is Based on Empirical Evidence
Science knowledge is based upon logical and conceptual connections between evidence and explanations. (MS-PS1-2)

Disciplinary Core Ideas:

PS1.A: Structure and Properties of Matter
Each pure substance has characteristic physical and chemical properties (for any bulk quantity under given conditions) that can be used to identify it. (MS-PS1-2)

PS1.B: Chemical Reactions
Substances react chemically in characteristic ways. In a chemical process, the atoms that make up the original substances are regrouped into different molecules, and these new substances have different properties from those of the reactants. (MS-PS1-2)

The fact that atoms are conserved, together with knowledge of the chemical properties of the elements involved, can be used to describe and predict chemical reactions. (HS-PS1-7)

ETS1.B: Developing Possible Solutions
When evaluating solutions it is important to take into account a range of constraints including cost, safety, reliability and aesthetics and to consider social, cultural, and environmental impacts. (HS-ETS1-3)

Crosscutting Concepts:

Energy and Matter
The total amount of energy and matter in closed systems is conserved. (HS-PS1-7)

Patterns
Macroscopic patterns are related to the nature of microscopic and atomic-level structures. (MS-PS1-2)

Connections to Engineering, Technology, and Applications of Science

Influence of Science, Engineering, and Technology on Society and the Natural World

New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology. (HS-ETS1-3)

Scientific Knowledge Assumes an Order and Consistency in Natural Systems

Science assumes the universe is a vast single system in which basic laws are consistent. (HS-PS1-7)

Possible Preconceptions/Misconceptions:

1. **"All metals behave the same when heated."**
   Students may believe that all metals will react similarly to heat and cooling processes, not understanding that different metals have unique properties and may require different treatments.
2. **"Heating metal causes a chemical change."**
   Many students may think that heating a metal always results in a chemical change, such as burning or combustion, when in fact, thermal processing often involves physical changes (such as altering the internal structure) rather than chemical changes.
3. **"Quenching makes metal softer."**
   Some students may think that cooling hot metal quickly (quenching) will make it softer, while in reality, quenching typically makes metal harder and more brittle.
4. **"Once metal is cooled, its properties can't be changed again."**
   Students might assume that after metal is cooled, it cannot be reprocessed or that its new properties are permanent. They may not understand that heating, quenching, and tempering are processes that can be repeated or adjusted to achieve different results.
5. **"Metal always expands when heated and contracts when cooled."**
   While metals typically expand when heated, students may not understand that thermal processing can also cause changes in the internal structure (such as grain size) that affect flexibility, strength, and other properties beyond simple expansion and contraction.
6. **"Metals are strong and rigid."**
   Students may have the preconception that metals are always strong and rigid and may not realize that their properties can be manipulated through processes like annealing (which makes metal more ductile) or tempering (which adjusts brittleness).
7. **"Thermal processing is only for blacksmiths or in ancient times."**
   Some students might believe that the heating and shaping of metals is an old-fashioned skill used only by blacksmiths or in primitive societies, not realizing that modern industries like aerospace, automotive, and medical device manufacturing rely heavily on precise thermal processing techniques.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Discussion Prompt: ***"What happens to metals when they are heated?"*** Have students share and then show this short video or animation of a blacksmith working with hot metal to shape tools or weapons.

Ask students to share their thoughts on ***how heating metals might affect their strength and flexibility***. Briefly introduce the concept of thermal processing.

Relate to NGSS standard **MS-PS1-2**, discussing ***how heating a substance can cause a change in its properties.***

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Students will explore how the properties of metals are changed using heat by participating in the demonstration "Thermal Processing of Bobby Pins" from the Ceramic and Glass Industry Foundation.

In this activity, students will see how thermal treatment of a normal steel bobby pin can influence its mechanical properties, especially strength, ductility, and deflection. This is shown using a control sample, an annealed sample, and a quenched sample.

Prior to conducting the demonstration, watch the demonstration video to ensure safety protocols are in place. Use the provided ***discussion questions*** from the demonstration to guide student thinking throughout the lesson.

EXPLAIN:

Use the Ed Puzzle "What Quenching and Tempering does to swords?" for students to learn about the science of heat processing metals.

After the Ed Puzzle, Discuss the molecular changes that occur during thermal processing:

1. Annealing: Softens the metal by heating and slowly cooling it, making it more ductile.
2. Quenching: Rapidly cooling metal to harden it, often making it more brittle.
3. Tempering: Reheating quenched metal to reduce brittleness while maintaining strength.

Relate to HS-ETS1-3 by discussing the trade-offs in selecting different thermal treatments (e.g., hardness vs. flexibility in manufacturing).

ELABORATE: Applications and Extensions:
Have students explore how these processes are applied in various industries. For example:

- How is annealing used in creating flexible metal components?
- Why is quenching used in making tools like hammers or blades?

Ask students to research and present on a real-world application where thermal processing is critical. Possible applications to assign include:

1. **Automotive Manufacturing**: The use of heat treatment to enhance the strength and durability of car components, such as crankshafts, gears, and suspension springs.
2. **Aerospace Engineering**: How thermal processing is used to improve the heat resistance and structural integrity of airplane parts like turbine blades and landing gear.
3. **Tool and Die Making**: The role of quenching and tempering in creating strong, wear-resistant tools like hammers, wrenches, and industrial cutting blades.
4. **Surgical Instruments**: Heat treatment processes are applied to stainless steel surgical tools to balance hardness and corrosion resistance.
5. **Construction Materials**: The use of heat-treated steel in building skyscrapers, bridges, and other infrastructure to enhance strength and flexibility under stress.
6. **Weapons and Armor Manufacturing**: Historical and modern applications of thermal processing in crafting swords, armor, and other military equipment to optimize hardness and toughness.
7. **Bicycle Frame Manufacturing**: How different heat treatments affect the strength, weight, and flexibility of metal used in high-performance bicycle frames.
8. **Energy Sector (Pipelines)**: The use of thermal processing to increase the toughness and corrosion resistance of steel pipes used in oil, gas, and water transportation.
9. **Jewelry Making**: Annealing and other heat treatments are used to soften precious metals like gold and silver, making them easier to shape without breaking.
10. **Shipbuilding and Marine Engineering**: The application of thermal treatments to enhance the corrosion resistance and strength of metals used in ships and submarines, especially in saltwater environments.

Discuss the environmental and economic considerations in choosing different metal processing techniques (linking back to HS-ETS1-3).

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Discussion questions are found in bold italics throughout the lesson and can be used to check student understanding. Additionally, the scores from the EdPuzzle and student presentations in the elaborate portion of the lesson can also be used to check for student understanding.

Summative Assessment (Quiz / Project / Report):
Group Discussion: Ask students to share their findings from the bobby pin activity, focusing on how heating and quenching altered the bobby pin's properties.

Data Analysis: Have students create graphs to represent the change in flexibility before and after heating the bobby pin. They can plot force vs. deformation.

Exit Slip: Students will answer the following questions:

- How did the thermal processing affect the bobby pin's properties?
- What trade-offs might occur when selecting thermal treatments for different types of metal products?
- How do thermal processes conserve mass (linking to **HS-PS1-7**)?

Elaborate Further / Reflect: Enrichment:
Thermal Processing Design Challenge:
Students can engage in a real-world engineering challenge where they design a metal tool or part (e.g., a car engine component or a surgical instrument) that must undergo thermal processing to optimize its performance. They will choose an appropriate thermal treatment (annealing, quenching, tempering) based on the desired properties (e.g., flexibility, hardness, corrosion resistance). They must justify their choices considering factors like cost, environmental impact, and product reliability, aligning with **HS-ETS1-3**.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competency Addressed: Self-Awareness, Self-Regulation, Responsible Decision Making

Objective: Students will reflect on the concept of change over time, both personally and in their environment, and develop strategies to embrace and adapt to changes in their lives.

Lesson Structure:

1. Opening Activity – Reflecting on Change (5 minutes)

- **Prompt**: "Think about one thing in your life that has changed over the past year (e.g., new friends, different hobbies, changes in school)."
- **Pair-Share**: Ask students to share with a partner one personal change they've experienced recently. If comfortable, a few students can share with the whole group.
- **Write on Board**: As students share, write key words like "growth," "challenge," "new experiences," or "learning" on the board to highlight common themes related to change.

2. Discussion – Why Is Change Important? (5 minutes)

- Lead a discussion around the importance of change and growth:
  - **Ask**: "Why do you think change is important? How does it help us grow?"
  - Discuss how change helps people develop new skills, perspectives, and resilience. Highlight that while change can be challenging, it's also an essential part of learning and improving over time.
- **Anchor the Concept**: Relate change to nature (e.g., seasons changing, plants growing) or use an example of a caterpillar turning into a butterfly to emphasize that change leads to growth and transformation.

3. Journaling/Reflection – My Personal Changes (5 minutes)

- **Activity**: Have students take out a piece of paper or journal.
- **Prompt**: "Write down one way you have changed for the better over the past year. It could be a new skill you've learned, a way you've improved, or something you've gotten better at. How did this change happen? What helped you grow?"
- After writing, invite a few volunteers to share their reflections with the class, emphasizing how positive change often comes from facing challenges or new situations.

4. Mindful Strategy – Embracing Future Changes (5 minutes)

- **Introduction**: Explain that change can sometimes be unexpected or hard, but having strategies can make it easier to handle.
- **Breathing Exercise**: Guide students in a brief mindfulness activity to practice being open to change.
  - **Steps**:
    1. Ask students to sit comfortably and close their eyes.
    2. Instruct them to take deep, slow breaths, focusing on the sensation of breathing.
    3. As they breathe, ask them to silently repeat the phrase: "I can grow through change."
    4. Continue this for about 2-3 minutes, allowing students to calm their minds and feel more accepting of upcoming changes.

5. Closing – Takeaway (2-3 minutes)

- Wrap up the lesson by reminding students that change is a natural and necessary part of life. Encourage them to be open to change, knowing that it can lead to personal growth, new opportunities, and resilience.
- **Exit Prompt**: Before leaving, ask students to write down or share one way they can embrace change positively in their lives moving forward.

INTERDISCIPLINARY CONNECTIONS/IDEAS

History: The Role of Metals in Ancient and Modern Societies

Students research how the discovery and manipulation of metals (e.g., bronze, iron, steel) shaped human history and technological advancements. They can explore the impact of metalworking on ancient civilizations, such as the transition from the Bronze Age to the Iron Age, and how modern thermal processing techniques revolutionized industries like transportation and construction. Students can present timelines or reports linking metallurgy to historical developments and their influence on society.

Mathematics: Calculating Heat Transfer and Energy Efficiency

In this activity, students will use mathematical formulas to calculate the energy required to heat metal objects (e.g., bobby pins) to specific temperatures. They will analyze the efficiency of different heat sources and thermal processes by applying equations for heat transfer ($Q = mc\Delta T$) and energy conservation. This exercise will integrate algebra and physics, requiring students to manipulate variables and perform unit conversions while interpreting the results in the context of material science.

Art: Metal Sculpture and Crafting
Students create artistic metal sculptures using bobby pins or other metal objects that they have thermally processed (heated, bent, quenched). They will explore the creative side of metallurgy by shaping and altering the physical properties of metals to design their artwork. This activity connects engineering and art, encouraging students to understand how artists and blacksmiths have used heat to manipulate metal for centuries, blending functionality and aesthetics.

Materials Required for This Lesson/Activity	
Quantity	**Description**
3	Steel Bobby Pins
1	Cup with Twine
1	C-Clamp
1	Ruler
1	Bunsen Burner
1	Pair of pliers or tongs (to hold bobby pin during heating)
300	Pennies
1	Cup Filled with Cold Water

Lesson Created by Jess Noffsinger
For questions please contact
info@usasciencefestival.org