

Materials Fracture:

A Module Developed for Hands-On Learning

Contact Information: Corinne E. Packard, Department of Metallurgical & Materials Engineering, Colorado School of Mines, cpackard@mines.edu

Authors: Allison Perna, Anna Braun, Henry Q. Afful, Jai Sharma, Corinne E. Packard

Date of creation: June 2022

Publisher: Colorado School of Mines

How to Cite: A. Perna, A. Braun, H. Q. Afful, J. Sharma, C.E. Packard, “Materials Fracture: A Module Developed for Hands-On Learning.” 2022. PDF file.

Funding Information: This work was supported by an NSF CAREER grant, DMR 1352499.

Description:

This document is a lesson plan for a short module describing how materials fracture for STEM outreach. Colorado State science standards addressed by the module are included. The module is readily adapted for students in grades 1-12. The module was originally drafted for presentation to children aged 7-13 at the Rocky Mountain Camp for Dyslexic Children, thus activities are largely hands-on, driven by physical concepts, and do not rely heavily on reading or writing skills.

Science Standards Addressed (From the Colorado Department of Education)

<https://www.cde.state.co.us/apps/standards/>

Standard 1 - Physical Science

- 1. Second grade: Outcome b:** Analyze data obtained from testing different materials to determine which materials have the properties that are best suited for an intended purpose. (2-PS1-2) (*Clarification Statement: Examples of properties could include, strength, flexibility, hardness, texture and absorbency.*) (*Boundary Statement: Quantitative measurement is limited to length.*)
 - 0. Elaboration:** PS1: A Structure and Properties of Matter: Different kinds of matter exist (e.g., wood, metal, water), and many of them can be either solid or liquid, depending on temperature. Matter can be described and classified by its observable properties (e.g., visual, aural, textural), by its uses and by whether it occurs naturally or is manufactured. Different properties are suited to different purposes. A great variety of objects can be built up from a small set of pieces (e.g., blocks, construction sets). Objects or samples of a substance can be weighed, and their size can be described and measured.
- 2. Second grade: Outcome a:** Plan and conduct an investigation to describe and classify different kinds of materials by their observable properties. (2-PS1-1) (*Clarification Statement: Observations could include color, texture, hardness and flexibility. Patterns could include the similar properties that different materials share.*)
- 3. Fifth grade: Outcome b:** Make observations and measurements to identify materials based on their properties. (5-PS1-3) (*Clarification Statement: Examples of materials to be identified could include baking soda and other powders, metals, minerals and liquids. Examples of properties could include color, hardness, reflectivity, electrical conductivity, therm. al conductivity, response to magnetic forces and solubility; density is not intended as an identifiable property. Does not include density or distinguishing mass and weight.*) (*Boundary Statement: At this grade*

level, mass and weight are not distinguished, and no attempt is made to define the unseen particles or explain the atomic-scale mechanism of evaporation and condensation.)

Objective: Introduce materials science and fracture analysis. Explain and demonstrate the concept of materials fracture and relate it to material structure.

Materials:

- For Materials Science introduction
 - Photo book
- For Fracture Analysis introduction
 - Photo book of material fracture
 - Fracture samples if accessible
- For Student Activities:
 - A bag of pretzel sticks or rods (enough for ~2 per student)
 - Tootsie Rolls (2 per student)
 - Jolly Ranchers (1 per student)
 - Magnifying glasses (1 per student or per group)
 - It is advised to have a few extras of each (pretzels, Tootsie Rolls, and Jolly Ranchers) for demonstration and mishaps.
 - Other candy may be used at the instructor's discretion.
 - Hand sanitizer
 - Napkins
 - Trash bag

Timeline:

1. Introduction (10 min)
2. Activity and discussion (20 min)
3. Post-activity discussion (10 min)

Procedure:

1. Introduction to materials science and fracture analysis

Background on materials

Materials science is the study of how “stuff” (usually solid stuff) works. Materials are the substances used to make things we use in our everyday lives (examples: glass, plastics, metals, ceramics). Materials have been instrumental in human development for all of recorded human history – we have even named entire historic ages after them (e.g. stone age, bronze age, silicon age).

Metals such as bronze and steel were used to make weapons. Today, they are used in a range of applications from vehicles and aircraft to buildings and bridges. Ceramics – specifically pottery – were used to hold water and food. Production of clay ceramics dates back to 24,000 BC. Today, ceramics cover a wide breadth of properties and applications spanning from vegetable peelers to brake pads to space shuttle tiles. Polymers such as plastics are used in home goods, toys, clothing, food and drink packaging, electronics, and more. In the last century, we've entered the “silicon age” meaning we use silicon and other electronically active materials to make computers, cell phones, sensors, solar panels, lasers, and other electronics. As you can see, materials are instrumental to most human technologies.

Materials science and fracture analysis

Materials science is the study and development of solid materials using physics, chemistry, and engineering. In materials science, we connect a material's properties and performance to its internal structure (from the atomic to micro scale) to fully understand the material's behavior in different situations and why it behaves in those ways. One situation people care about is when the material breaks. The study of how materials break is called fracture analysis. Knowing how much force and what kind of force a part can withstand before it deforms or breaks (i.e. fractures) informs engineers on how to design parts for their designated use to ensure safety and performance.

Materials typically undergo brittle or ductile fracture when they experience a force (i.e. a "load") (images provided). When a ceramic material breaks, it is often by brittle fracture. That means the ceramic breaks with a relatively clean surface and has minimal deformation before fracture. Metals often break by ductile fracture. The metal deforms before snapping. The type of load (e.g. tension, compression, torsion) and other factors such as temperature also influence how the material will fracture.

Introduction Talking Points

- Materials are essential to society and are used in nearly every manmade item.
- Materials are so important that we've named entire ages in human history based on the most significant materials used at the time (e.g. stone age, bronze age, silicon age).
- Some different kinds of material classes are metals, ceramics, and polymers (plastics).
- Materials science is the study of how and why "stuff" (i.e. materials) works. Materials scientists connect a material's atomic arrangement and microstructure to its physical properties and performance in different situations.
- One of the most important situations people care about is when a material breaks (i.e. material failure or fracture).
- Material failure can be catastrophic (e.g. Liberty ship), minor (e.g. a broken drinking glass), or something in between. (Images provided)
 - For younger groups, the "three little pigs" story can demonstrate how under the same conditions (wolf blowing) some materials (straw) will fail and others (bricks) will not.
- When ceramics break, their fracture surface often looks like a "clean break" (e.g. broken dinner plates or coffee mugs). Ceramics do not stretch before breaking. This is called *brittle fracture*. (image provided)
- Some other materials can stretch or bend before they break apart (e.g. paper clip). This is called *ductile fracture*. (image provided)
- Sometimes parts break before we want them to. If we can figure out how something broke, we can often do something to the material that changes it so that it doesn't break as easily next time.
- Fracture analysis is the science of figuring out how things break. It's forensics for materials and today, we're the detectives!
- Knowing how a material will fracture in different types of situations helps engineers design parts for their designated use to ensure safety and performance.
- Example: Bone fracture: knowing how someone's bone broke helps doctors treat their patients properly (image attached)

- Discussion points:
 - Ask students if they've ever broken a bone, how doctors treated it, how long it took to fix. Different kinds of bone fractures are treated differently, same with manmade objects.
 - Ask students if they've ever broken an object or seen one break. What was it made of? How did it break? Different materials will break differently. Example for discussion: if we drop a glass cup and a plastic frisbee, which one will probably break?

2. Activity

- a. Have students work in groups of 2 or 3.
- b. **Important safety note:** Students will be handling food. Take necessary steps to ensure health safety (e.g. hand washing, hand sanitizer, each student touching their own food, giving out untouched food after the activity)
- c. **Preparation:** Activity 6 requires the Tootsie Rolls to be refrigerated ahead of time.
- d. Give each student or group two Tootsie Rolls, a Jolly Rancher, and two pretzel sticks.
 - i. For younger students, only provide Tootsie Rolls and pretzel sticks. Pre-fracture the Jolly Ranchers for students according to "fracture activity 3."
- e. For each fracture activity:
 - i. Ask the students to investigate the candy and pretzels and discuss their observable physical properties (hard vs. soft, stretchy vs. rigid, dense vs. light / porous vs. non-porous, whatever physical properties are grade-appropriate).
 - ii. Have the students break the candy/pretzel in the specified manner. See image provided on different loading modes. For younger students or other students for whom breaking candies might be a hazard, the instructor may break the treats for them and pass them around.
 - iii. Have students to look at the fracture surface with a magnifying lens.
 - iv. Ask them to describe what happened to the candy/pretzel during fracture.
 - v. Encourage them to discuss in groups.
 - vi. Ask students which type of fracture applies (ductile or brittle).
 - vii. Ask students to connect the physical properties of the candy/pretzel to the type of fracture (ductile fracture for the soft and flexible Tootsie Rolls, brittle fracture for the hard and non-porous Jolly Ranchers, brittle fracture that requires less force for the hard and porous pretzels).
- f. **Fracture activity 1:** Tootsie Roll in tension
 - i. Holding it at both long ends, pull the Tootsie roll apart (schematic of tension loading provided).
 - ii. This resembles very ductile fracture. Highlight that the material deformed before it fractured.
- g. **Fracture activity 2:** Tootsie Roll in torsion
 - i. Hold the Tootsie Roll at both long ends. Twist the Tootsie Roll until it comes apart (schematic of torsion provided).
 - ii. This resembles very ductile fracture, but the material twists, too.
 - iii. Explain to students that different kinds of loads (i.e. forces) can the same material to fracture differently.
- h. **Fracture activity 3:** Jolly rancher
 - i. This may be left to the instructor for safety. Chisel in half or bend the Jolly Rancher until it fractures (schematic of bending provided).

- ii. This resembles brittle fracture. Highlight that the Jolly Rancher didn't deform before it broke
 - 1. Note that warm Jolly Ranchers might deform before fracture, meaning it has some ductile behavior.
- i. **Fracture activity 4:** Pretzels in bending
 - i. Hold the pretzel at both ends. Bend the pretzel (schematic of bending provided).
 - ii. This resembles brittle fracture.
 - iii. Ask students why they think the pretzel and the Jolly Rancher look different but both break by brittle fracture.
 - 1. Possible answers: different material properties (the pretzel has air pockets, the Jolly Rancher does not) cause them to break differently and with different ease.
- j. **Fracture activity 5:** Pretzels in tension
 - i. Hold the pretzel at both ends. Pull the pretzel apart (schematic of tension provided).
 - ii. Note: Some pretzels may crumble if gripped too tightly at the ends.
 - iii. This resembles brittle fracture.
 - iv. Ask students to compare these pretzels to the pretzels fractured under bending.
- k. **Fracture activity 6:** Cold Tootsie Rolls in torsion
 - i. Ask students if they think the cold Tootsie Roll will experience more or less brittle fracture than the room temperature Tootsie Roll. Ask for example from their own life of cold objects breaking.
 - ii. Use refrigerated Tootsie Rolls.
 - iii. Hold the Tootsie Roll at both long ends. Twist the Tootsie Roll until it comes apart (schematic of torsion provided).
 - iv. Ask students to compare to the room temperature Tootsie Roll.
 - v. The Liberty Ship images provided are an example of ductile-to-brittle transition that occurs when temperature is lowered.
- l. Challenge them to work through the discussion questions.
- m. All finished. Let the students eat the candy/pretzels except the instructor-chiseled jolly ranchers (hand out extras if necessary).

Discussion Questions:

1. Think about the material properties (soft vs. hard, porous vs. non-porous (or dense if above 5th grade)). Why do you think each candy broke the way it did?
2. How do you think the Jolly Rancher would fracture if it was porous like the pretzel?
3. How do you think the tootsie roll would fracture if it was cold?
4. What kind of real-life material is the Jolly Rancher similar to? (ceramic)
5. If you were building a gingerbread house to be structurally sound, how would you use the candy and pretzels? Why?
6. What things in your daily life do you expect to break via ductile fracture? By brittle fracture? Relate this to their physical properties.

Prepared By:

Allison Perna, Anna Braun

Developed with:

Henry Quansah Afful, Jai Sharma, Corinne Packard

References:

[1] Callister, W. D., & In Rethwisch, D. G. (2010). *Materials science and engineering: An introduction*.

Materials Science

- Ceramics
 - Historical: pottery



- Modern
 - Vegetable peeler



- Ceramic brake pads



- Aerospace tiles



- Toilets/Sinks/Tubs



Metals

- 3D printed complex metal parts



<https://3dprintingindustry.com/news/airbus-and-sigma-labs-partner-to-qualify-metal-3d-printing-for-aerospace-159332/>

- Building materials



- Vehicle bodies



Also in cars:

- Polymer tires
- Glass windows
- Metal body
- Electronics inside

Polymers

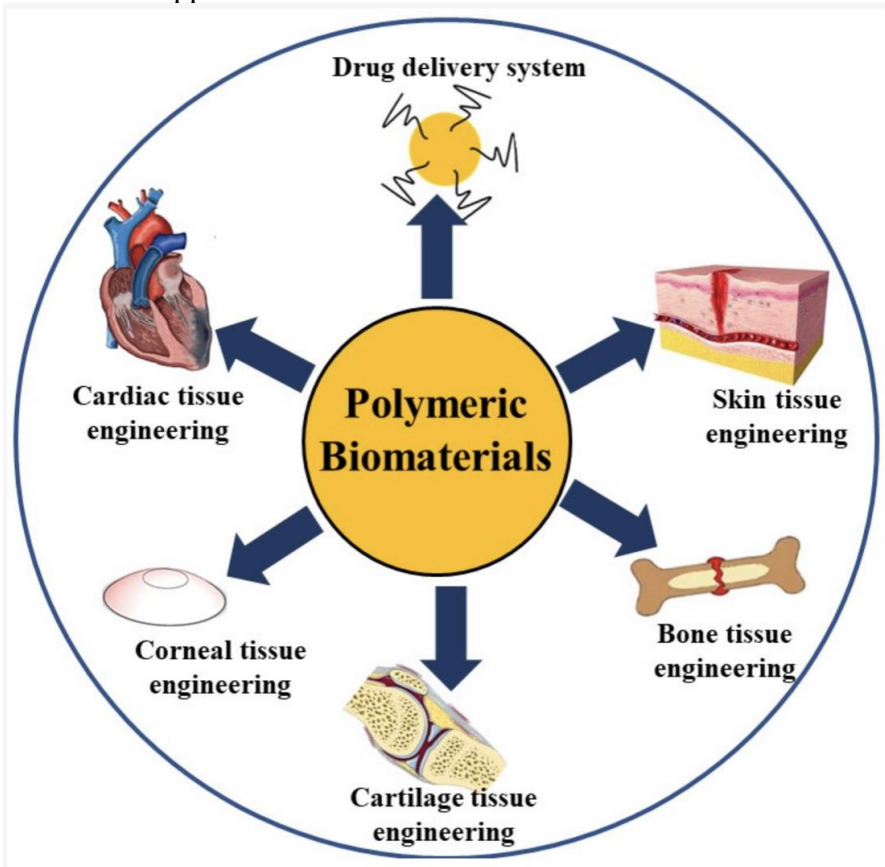
- Plastic products



- Food packaging



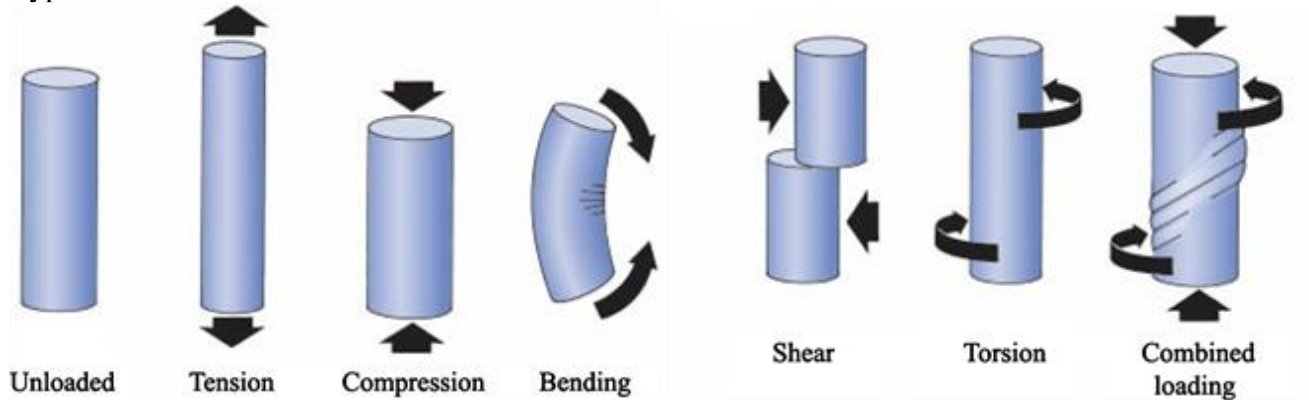
- Biomedical applications



<https://www.mdpi.com/2073-4360/13/17/3015/htm>

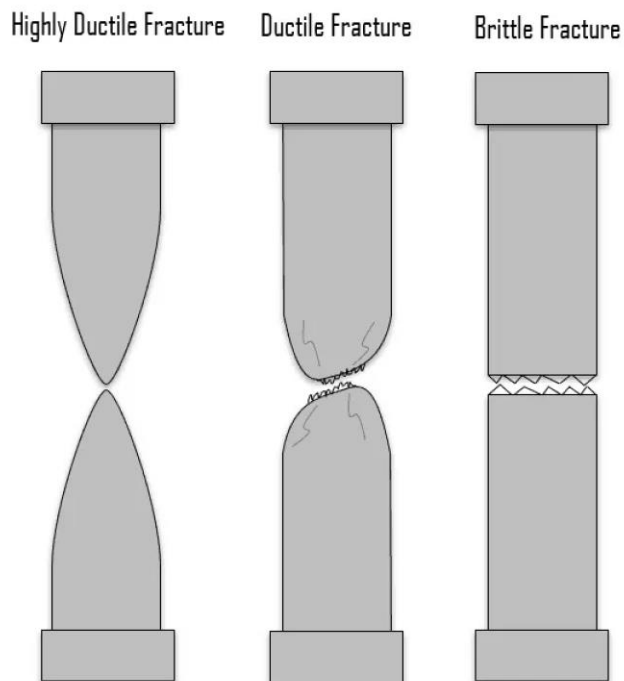
Fracture

Types of loads that can cause fracture:



- <https://www.scirp.org/journal/paperinformation.aspx?paperid=106782>

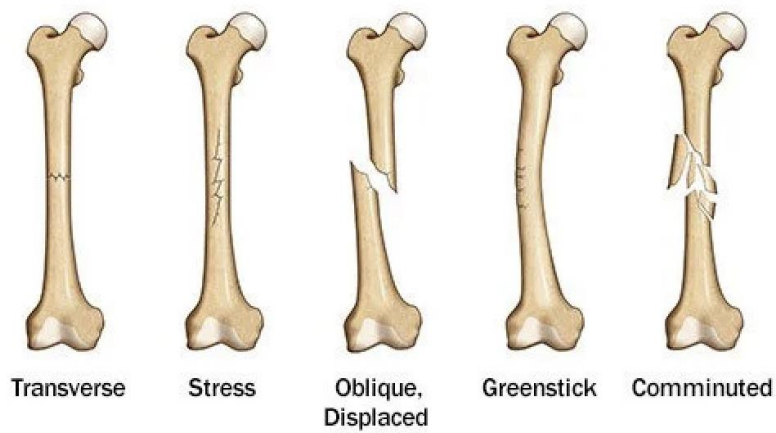
Types of fracture: Brittle vs. Ductile



- <https://www.nuclear-power.com/nuclear-engineering/materials-science/material-properties/toughness/fracture-of-material-fracture-mechanics/>

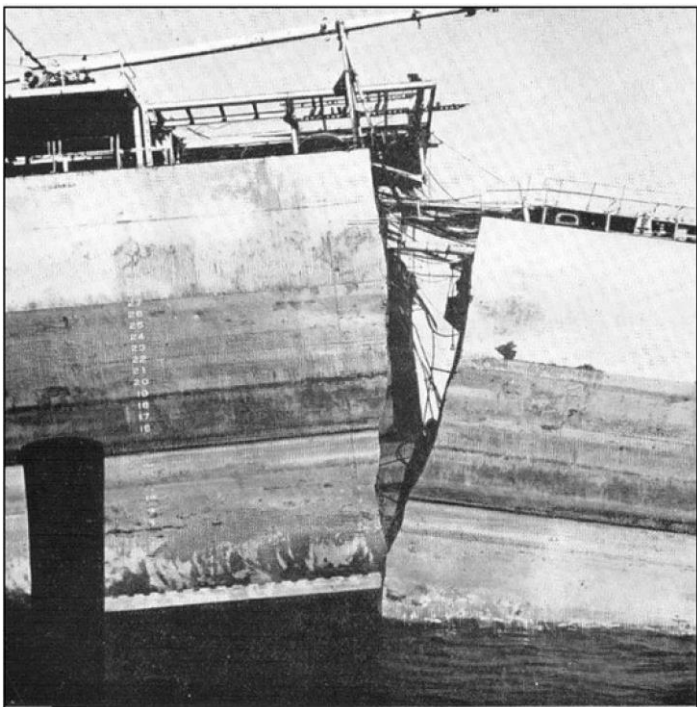
Examples of fracture in the real world:

- Broken bones



- https://www.emedicinehealth.com/bone_fracture_broken_bone/article_em.htm
- Liberty ship with brittle fracture

The steel hulls became more brittle at lower temperatures (called a “ductile to brittle transition”), resulting in catastrophic failure via brittle fracture.



<https://www.mdpi.com/2078-1547/7/2/20/htm>



<https://hal.archives-ouvertes.fr/cel-01636731/document>

- Broken pottery



- Broken windshield

