Fracture Behavior with Cheese

Learning Objectives	1) Students will apply their knowledge of fracture to predict how different cheeses will fail. 2) Students will discuss how geometry plays a role in fracture behavior.
Time	~60 minutes
Topics	1) Mechanical testing to characterize fracture properties 2) Stress concentrators 3) Simulations of stress (computational materials science)

Before the Lab:

Supplies to buy every time you run the activity:

1) Two different types of cheese. Choose cheese with different types of fracture.

Cheese Type	Fracture Type
Mozzarella	Ductile
Feta	Intergranular
Parmesan	Cleavage
Colby Jack	Ductile and/or Intergranular
Muenster	Ductile
Extra Sharp Cheddar	Cleavage

Supplies to buy as needed:

1) Paper plates for the cheese
2) Gloves for those who are lactose intolerant
3) A knife and toothpick to make the notches in the cheese

Prior Knowledge Recommended for Instructor:

1) Familiarity with basic mechanical properties
   - Stress vs. strain graphs for brittle vs. ductile materials
   - Three-point bend testing
2) Basic understanding of material fracture
   - Understand the difference between different types of fracture mechanisms

Prior Knowledge Recommended for Students:

1) Types of bonding
   - Covalent, non-covalent, ionic

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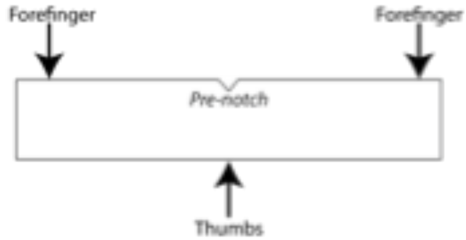
Lab Set-up:

1) Break students up into pairs. Half the groups will receive Extra Sharp Cheddar Cheese (or another cheese that demonstrates failure via cleavage) and half the groups will receive Muenster cheese (or another ductile cheese). Arrange the groups so that groups with different cheeses are sitting close to each other to encourage sharing their results after the experiment.
2) Before the students arrive, make sure each group has:
   - One plate with five cheese samples (suggested minimum). Each sample should be approximately 2 inches x 1 inch.
     - Two (min.) cheese samples with sharp notch
     - Two (min.) cheese samples with blunt notch
     - One (min.) cheese sample with no notch
   - Gloves (if requested by the participant)



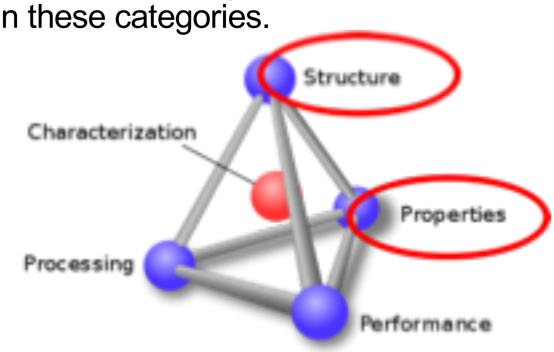
3) Pre-notch all of the cheese samples (see three-point bend test figure above). The sharp notch is made using a knife to make a small slice. The blunt notch is made using a knife to cut a small wedge and then a toothpick to smooth out the edges. Video available on website for sample prep and fracture test

Pre-lab Questions:

The lecture before this lab should explain the basics of fracture and the types of fracture mechanisms.

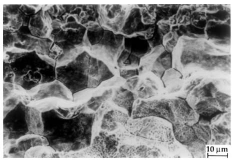
1) The cheese fracture activity fits into the structure and properties categories of the tetrahedron. Please explain why cheese fracture fits in these categories.

Cheese fits into the structure and properties categories because the type of bonding in the cheese affects the way it fractures, which is a mechanical property.

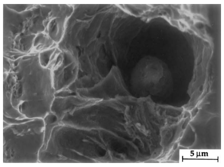


2) Match the type of fracture to its fracture surface

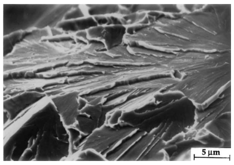
Intergranular



Ductile Fracture



Cleavage



Fracture Behavior with Cheese

Running the Lab:

1) Have the students sit in pairs at their stations. Explain they will be handling cheese. Offer gloves to those who are lactose intolerant or would prefer not to handle cheese with their bare hands.
2) They should have already answered the pre-lab questions. Ask the students if they had any unresolved questions about the pre-lab questions.
3) Instruct the students to read all of the directions.
4) Do not give them the instructions verbally. The goal is to get the students to read everything and think about why they are doing what they are doing. At this point let them jump in but encourage them to raise their hands if they have questions.

Expected Results from Three-point Bend Tests:

We provide students with more than one of the same geometry because there are often defects that impact the way the specimens fail. By inspecting more than one specimen, students can also explore the real-life variability of failure analysis. The chart below is completed to provide the instructors with some insight about both types of cheese in each geometry; however, students would only be working with one type at a time. The examples below do not include any descriptions of intergranular fracture. We have found that these cheeses (e.g. feta or Colby jack) can be a little frustrating for students. Instead, we suggest that you provide a few examples to demonstrate intergranular fracture.

Sample	Crack nucleation	Crack propagation (Straight or zig-zag?)	Fracture surface (Ductile Fracture, Cleavage or Intergranular?)
Sharp notch #1 (for Extra Sharp Cheddar)	*The crack should start directly from the sharp notch.*	*Most cracks will propagate directly across the specimen (i.e. straight)*	*Extra sharp cheddar should demonstrate cleavage-like behavior with signature "river-pattern" markings*
Sharp notch #2 (for Muenster)	*The crack should start directly from the sharp notch.*	*Most cracks will propagate at an angle to the original notch (~45º). Often this results in a more jagged or zig-zag propagation path.*	*Muenster cheese typically displays ductile fracture behavior. The zig-zag crack path and void formation ahead of the crack are signatures of this.*
Blunt notch #1 (for Extra Sharp Cheddar)	*The crack is still expected to start from the notch.*	*While there may be more variation than found with the sharp cracks, most will still propagate straight across the specimen.*	*The fracture surface should still have signatures of brittle cleavage fracture.*
Blunt notch #2 (for Muenster)	*The crack may start at the notch, but is just as likely to start somewhere else.*	*This crack path is still likely to be zig-zaggy, but will also be the most unpredictable.*	*Still ductile fracture.*
No notch	*For either type of cheese, without a notch, the crack can start anywhere.*	*Without a pre-notch, the crack is much more difficult to predict and the students will likely have to apply more force to initiate one.*	*This will depend on the type of cheese, but the signatures of fracture should be the same as observed with the pre-notched samples.*

Discussion Points:

1) What does your fracture surface look like for each cheese? For each type of notch?
2) Did all of your samples fail the same way? Can you rationalize why or why not?

Fracture Behavior with Cheese

You Will Be Able To:

1) Explain why geometry is important to fracture behavior
2) Justify you experimental observations of fractured cheese

Simulations of Stress in Cheese

You've seen how cheeses break when they have different initial crack geometries. Now you'll use some computer software called OOF2 to get an idea for how the initial geometries concentrate stress in different locations and cause different kinds of fractures. Each group will be assigned to simulate a different initial fracture geometry (due to time constraints), which you will present at the end. What you will see once you have finished the simulation is a visual representation of where stress builds up in the cheese as it is initially strained (as you strained it, using the three-point method.)

Notes to the instructor: Nanohub, and OOF2 especially, can be kind of finicky.

Try to use a browser with javascript support (Safari and Firefox are usually better than Chrome), and if the display cuts out, try refreshing the page before assuming the worst. Sometimes it really will just break for no adequately explained reason and the simulation will have to be rerun (this is the case if there's a connection error of some kind, in our experience.)

If refreshing the page doesn't work you can try going to the student's "dashboard" and launching from currently-running sessions.

One other thing to note is that some of these simulations could take 5-10 minutes to fully set up and solve, especially ones with more complex meshes (kinked crack in particular.)

If the particular crack file will not load correctly just have them run a different crack.

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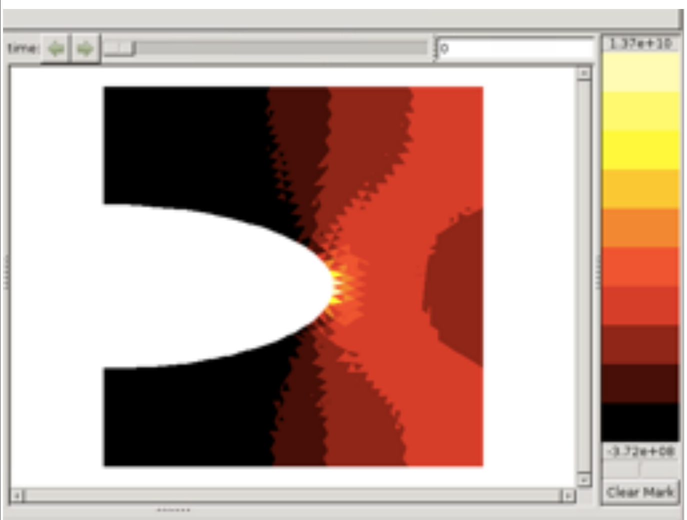
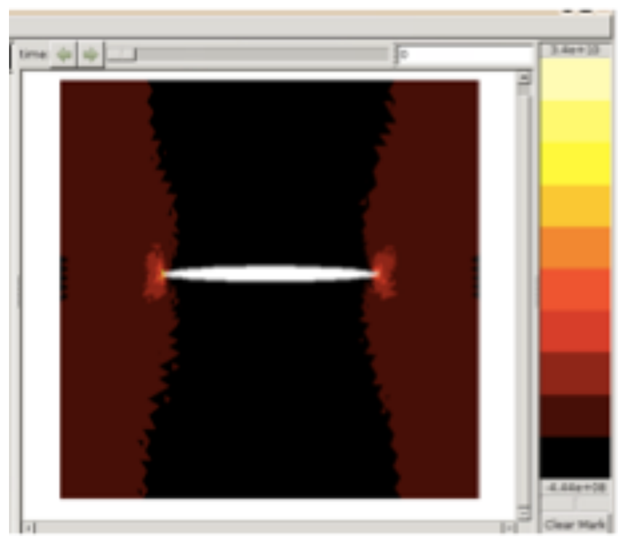
Example Solution Images:

These won't look identical from group to group because there are random steps in the OOF2 setup, but they should be a solid guide for what to look at. Note that if they don't uncheck their original image file, their images may not appear to have as much contrast as these do. Also, generally these can be most easily created by just screenshotting the Nanohub images. Note also that the scales on the color bars are different, which may be relevant.

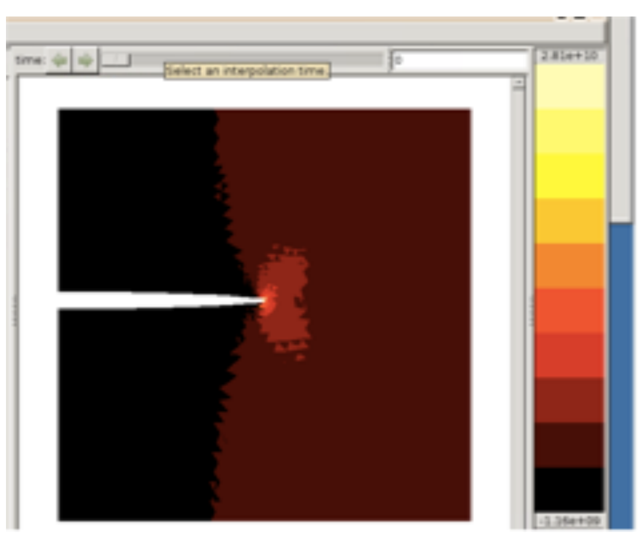
Blunt Crack



Center Crack



Narrow Crack



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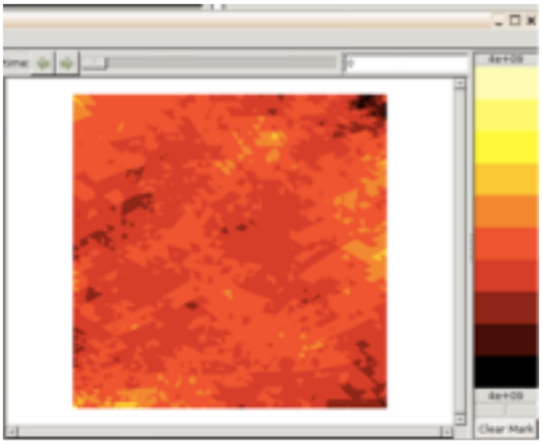
Example Solution Images (cont.)

No Crack



- *No crack: the color variations are just noise as the whole field is subjected to a uniform stress*
- *Blunt crack: smallest range of tensile to compressive stresses, with the most gradual changes between contours – likely to result in more ductile fracture at higher loads*
- *Center crack: much larger range of stress and much more localized*
- *Narrow crack: highly localized fields at the crack tip, the crack tip radius and the loading direction the most relevant parameters*

Discussion Points:

What you are looking at is a scaled color map of the stress intensities at various locations around an initial fracture shape (or no shape, if you are simulating without an initial crack)

1) Can you link this picture to one of the fracture behaviors you observed when you were breaking the cheese? Is this the picture you would expect?
See summary above for description and rational of stress concentration fields. When a crack propagates:

- *no crack will nucleate and fail at random points along the specimen;*
- *blunt crack is likely to have a zig-zag crack path (ductile tearing, especially in the "softer" cheese);*
- *center crack should propagate on the tensile side of the bending specimen first, but if loaded in pure tension (as demonstrated in this simulation) both sides should fail simultaneously in much the same way that the sharp crack would although at different loads*
- *narrow crack should propagate in a zig-zag pattern for softer cheese and in a straight path perpendicular to the crack tip for harder cheese*

2) What kind of fracture behavior do you think you have modeled? Explain.
As noted above, this depends not only on the crack geometry but also on the stiffness

3) Compare your simulation results to the results of the other groups. From the simulations and the experiments, how does initial geometry play a role in crack propagation?

Guide the campers towards the conclusions noted above