Materials Science Mini Kit: The Science of Silly Putty®

Lesson Plan: Overview and Safety

Lesson Objective

To demonstrate the unique property of time-dependent strain behavior in viscoelastic materials using Silly Putty®. To demonstrate the different responses of Silly Putty® when stretching it at different speeds.

Experiment Description

This experiment will explore the physical properties of non-Newtonian fluids like Silly Putty®. Students will be tasked with exploring how the rate of stretching, pulling, and squeezing Silly Putty® influences its mechanical response. Silly Putty® can be cooled to explore fracture.

Materials List

Items provided in the kit

- Silly Putty® (for demonstration)

Items to be supplies by teacher/school

- additional Silly Putty® (for students to follow along)

Optional:

- Play Doh for comparison

Safety Precautions

Silly Putty® is a **choking hazard**

- Do not allow children to put Silly Putty® in their mouths or attempt to swallow it.
- Silly Putty® is non-toxic but should not be ingested.

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Lesson Plan: Background Information

Background Information

What is Silly Putty®?

Silly Putty®, rubber, and plastics all belong to a category of materials called polymers. Polymers are made up of long repeating chains of identical molecules called "monomers." One important characteristic or "property" of polymers is how they behave when being manipulated with an applied stress like being stretched or squeezed when played with. Silly Putty® is moldable but will also tend to relax into a puddle when left alone. Materials scientists call this property viscoelasticity. Elasticity is the ability of a material to recover from applied stress like a rubber band that can be stretched but still hold the same shape after being released. The viscosity of a material describes how quickly and easily it flows. For example, syrup has higher viscosity than water.

The type of response (elastic or viscous) of Silly Putty® depends on how long and how quickly a force is applied. Long and quickly are defined by the observer to describe a timescale of the experiment. If a force is applied over a short timescale (short amount of time), Silly Putty® will behave elastically and resist reshaping. On the other hand, if a force is applied over a long timescale, Silly Putty® will behave plastically like a viscous liquid and slowly relax into a puddle.

From these two behaviors it is understood that the physical response of Silly Putty® is time-dependent. Two important properties are used to describe this response: stress and strain. Stress refers to the force per area being applied to the Silly Putty®. An easy way to conceptualize stress is by thinking about how snowshoes work: by distributing weight over an increased area, the stress is lowered, and you don't puncture the snow surface to sink into it. Strain is a metric that describes the deformation of a material with respect to its original shape and size. In Silly Putty®, strain is rate-dependent and has a supplemental descriptor strain rate to describe how deformation, measured as strain, changes over time. Pulling something apart slowly would have a low strain rate (slow deformation), and something that is pulled apart quickly has a high strain rate (fast deformation).

High Strain Rate Example: Dropping a Silly Putty® ball from hip-height onto a hard floor

What happens: The ball bounces nearly back up to hip height. As described by Newton's Third Law of Motion, the ball exerts a force on the ground, and the ground exerts an equal but opposite force on the ball, so it bounces.

Why: The ball hit the floor so quickly that the molecular bonds in the Silly Putty® didn't have time to absorb the impact. This means that the Silly Putty® experienced a high strain rate and therefore, behaved *elastically*.

Low Strain Rate Example: Leaving a ball of Silly Putty® on a table for 3 minutes

What happens: The ball relaxes and flattens into a puddle shape.

Why: Gravity exerts a force on all parts of the ball the entire time it's sitting on the table, so the molecular bonds have time to react and let the Silly Putty® flow into a puddle. This means that the Silly Putty® experienced a low strain rate and therefore behaved *viscously*.

In materials science, the mechanical properties of Silly Putty® are explained by how its atoms are bonded together. Silly Putty®, like most polymers, is made up of long chains of molecules. These chains of molecules can be randomly arranged and tangled together like a bowl full of spaghetti. The chains are held together by strong covalent bonds, but separate chains within the polymer are held together by weak bonds called crosslinks. Part of what makes Silly Putty® a unique material is that it is able to break and reform these crosslinks many times. **Figure 1** shows a schematic of how viscoelastic polymer chains, like those in Silly Putty®, are impacted by high and low strain rate.

Viscoelastic polymers require time for the long chains to slide and move past each other. The crosslinking between chains of the polymer are relatively weak and begin breaking when a stress is applied. At low strain rates, the polymer has enough time to accommodate this sliding and rearranging of the chains. At high strain rates, there isn't enough time for the polymer to accommodate the stress through sliding, and it snaps or fractures. This is what creates jagged, glass-like broken edges in soft materials.

Note: Some behavior of Silly Putty® is best observed at certain temperatures. Silly Putty® that has been kept in the freezer will shatter like a plate when dropped. This type of break/fracture is called a brittle fracture. In contrast, room temperature Silly Putty® will bounce like a bouncy ball when dropped. Low temperatures reduce the amount of energy that bonds have available to respond to forces, leading to them breaking apart when a high strain is experienced. Instead of stretching, the bonds break.

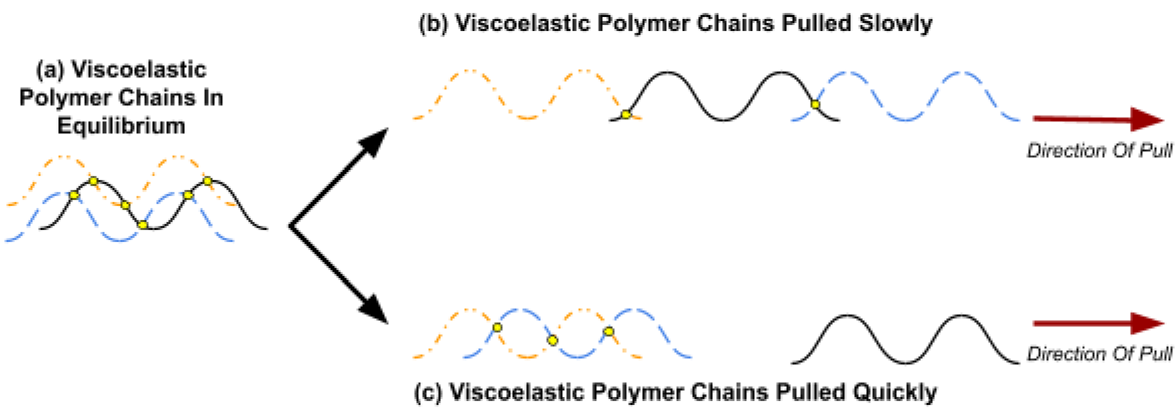

Figure 1. (a) Three identical viscoelastic polymer chains shown in equilibrium with crosslinks between chains marked in yellow. **(b)** The same three viscoelastic polymer chains pulled apart slowly with plenty of time for the chains to slide past each other. Notice how the length has increased, yet the three polymer chains are still connected with each other via crosslinks. This shows what happens internally as Silly Putty® is pulled and stretched into different shapes. **(c)** The same three viscoelastic polymer chains pulled apart quickly. Notice how without the time to rearrange themselves in an orderly fashion, all the crosslinks have broken, and one chain is pulled free. This shows what happens internally when Silly Putty® is pulled quickly and breaks apart into separate pieces or fractures.

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Lesson Plan: Background Information

Keywords

brittle fracture: a type of deformation usually seen in ceramics characterized by sharp jagged edges along the fracture surfaces where the material broke and separated.

crosslinking: the formation of strengthening bonds between chains in a polymer.

deformation: the change in shape or size of an object.

elastic deformation: deformation of a material that doesn't permanently change its shape; the material *will* return to its original form.

elasticity: a material's ability to *temporarily* deform (such as stretch or squish) when stress is applied or when struck but resist permanent deformation and *return* to its original shape when the stress is removed.

plastic deformation: deformation of a material that does permanently change its shape; the material *will not* return to its original form.

polymer: a material that is made up of repeating units of smaller pieces called monomers.

strain: a measure of deformation of an object calculated as a ratio between the change in length with deformation over the original length.

strain rate: a metric describing deformation of material over time calculated as a ratio of strain over time.

stress: the force per area exerted on an object, measured in units of pressure.

viscoelastic material: a material that exhibits the behavior of either an elastic solid or a viscous liquid depending on the time-scale of observation.

viscosity: a material's resistance to flow arising from internal friction. Viscous fluids like molasses or honey (especially at cooler temperatures) might be described as thick, sticky, slow-moving, and not runny, and they become less viscous (i.e. more runny) as the temperature increases.

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Lesson Plan: Teaching Instructions

Experimental Procedure

1. Roll the Silly Putty® into a solid ball and drop it onto a table to demonstrate the way that the ball bounces. Be sure to point out the initial height before the drop as well as the height the ball bounces back to.
    a. This showcases the behaviors of an elastic solid.
    b. The time-scale of the collision with the table is only some small fraction of a second. Compare this with the much slower process of reshaping the putty by hand.
    c. As the ball bounces it will (mostly) return to its original shape in an example of elastic deformation.
2. Take the solid ball and stretch it into a long strand. Point out that Silly Putty® holds this new shape without returning elastically to its previous shape as a ball. Use the strand to demonstrate the way that the putty slowly flows and stretches under its own weight.
    a. The initial stretching showcases the plastic deformation of an elastic solid.
    b. The subsequent flow of the putty showcases viscous flow.
3. Flatten the Silly Putty® into a disc and quickly tear it apart into two separate pieces. Draw attention to the way that the surface between the two pieces resembles a brittle fracture like what might be observed in broken glass or a ceramic plate.
    a. The fracture will look different depending on the speed and twist that is applied.
4. Roll the Silly Putty® into a ball and rest it on the table. Point out the way that it gradually collapses under its own weight.

Cleanup and Resupply

- Silly Putty® can be cleaned from fabric using rubbing alcohol, hand sanitizer, or liquid dish soap
- Using ice to cool Silly Putty® may make it easier to remove cleanly from materials like fabric and hair.
- Silly Putty® will not stick to clean hard surfaces.

Tips for Success and Troubleshooting

- The demonstration can be done with one container of Silly Putty® manipulated by the instructor in view of the whole group, or students can follow along with their own putty to observe each mechanical behavior up close.
- Each step in the demonstration showcases a few specific behaviors which should be pointed out as they occur rather than being summarized at the end.
- The last step may take several minutes to become apparent. This time can be used to ask discussion questions or to illustrate connections between the background information and the demo.
- If a whiteboard is available, it may be helpful to reproduce some version of **Figure 1** to illustrate the behavior of the polymer chains in question at each junction of the demonstration.
- Some behaviors will be easier for students to observe when the Silly Putty® is at a specific temperature. The brittle fracture in Step 3 may be more pronounced if the material is chilled. The slow viscous flow in Step 4 will be faster and easier to see if the putty has been warmed by handling.

Materials Science Mini Kit: The Science of Silly Putty®

Lesson Plan: Discussion Prompts

Before the Experiment

What are the forms of matter? Are there any exceptions?

Solid, liquid, and gas are the primary forms of matter. Plasma (eg. lightening) and Bose-Einstein Condensate are valid but may be out of the scope of the learners.

Do some substances display properties of multiple forms of matter (e.g., solid and liquid)?

Yes, viscoelastic materials like Silly Putty® have properties associated with both solid and liquid materials. Other viscoelastic materials include toothpaste, ketchup, and oobleck (cornstarch and water slurry).

During the Experiment

How does the Silly Putty®'s behavior compare to an elastic solid like a rubber band? How does it compare to a viscous liquid like honey?

After the Experiment

What observations surprised you?

Did knowing what was happening at a microscopic scale make it easier to visualize what was happening in the material?

Why doesn't the Silly Putty® ball bounce back to the original height that it is dropped from?

The Silly Putty® ball is not a perfectly elastic material. This means that part of the response is plastic and results in energy being dissipated throughout the material as permanent deformation. No response on earth is perfectly elastic. There are friction forces that act in all collisions and lead to some energy being lost in the form of heat.

Materials Science Mini Kit: The Science of Silly Putty®

Student Handout

1. Do you think Silly Putty® is a solid or a liquid? Why? What science concepts would you mention to convince a classmate?

2. What is one way that we could alter the behavior of Silly Putty® without changing the material itself?

3. How important is time when describing the behavior of this material? Why?

Materials Science Mini Kit: The Science of Silly Putty®

Student Handout: Example Answers

1. Do you think Silly Putty® is a solid or a liquid? Why? What science concepts would you mention to convince a classmate?

Example answer: Silly Putty® is a solid material. It has a definite volume and shape. It can't be squeezed into a container like a gas in a balloon. It also doesn't take the shape of the container it's in like water in a glass. Silly Putty® can flow like a really viscous liquid (eg. honey) because it is a viscoelastic material, but it holds its shape if squeezed or stretched.

2. What is one way that we could alter the behavior of Silly Putty® without changing the material itself?

Example answer: We could look at Silly Putty® of different temperatures. At lower temperatures, Silly Putty® moves slower. It will be less stretchy and might even snap apart. At higher temperatures, Silly Putty® will be more stretchy and will snap at higher strain and faster strain rates. We could also look at the effect of strain rate. If Silly Putty® is left to sit on a table it will flow into a puddle. If Silly Putty® is slowly stretched by gravity or by hand, it will plastically deform but it won't snap into pieces. If Silly Putty® is stretched or molded quickly, it will plastically deform and it might even break into pieces under brittle fracture.

3. How important is time when describing the behavior of this material? Why?

Example answer: It depends on what you're trying to study and how long you want to study it! If a geologist cares about how a rock formed and eroded, they'll care about millions of years worth of its chemical and physical properties. But, if someone is trying to use that rock to make a stone wall, they only care about what its properties will be for 50 or so years (will it crack during use). The time scale of how quickly a material will change over time matters a lot. In the case of Silly Putty®, it reacts quickly enough to be a fun material to play with.