Property Changes in Polymers due to Crosslinking: Slime

Kyle Bates-Green

Objectives: Students will be able to describe a physical behavior of a polymer material in terms of movement of polymer chains. Students will conduct an experiment and connect the properties of the samples produced to the variables in their production.

Key Words: Polymer, Crosslinking, Secondary bond

Activity: Classroom polymerization experiment

Time Required: One 45 minute class period

Grade levels: Adapatable from Middle School and up

Equipment and Supplies needed:

- Personal Protective Equipment
  - Safety goggles
  - Lab aprons
  - Long pants and closed-toed shoes
  - Available eye wash stations and sinks
- 50ml 4% polyvinyl alcohol (PVA) solution per sample
- ~25ml 4% sodium borate (borax) solution per 5 samples
- food coloring
- 1x 5oz paper cup per sample
- 1x wooden craft stick per sample
- 1x sealable plastic bag (snack/sandwich size) per sample

Instructor background and notes:

In this module we will make samples with the same components but with differing amounts. This will cause different densities of hydrogen secondary bonds to form between polymer chains. These different compositions can be expected to have differing properties: A larger amount of sodium borate will create more crosslinks between PVA chains, so we can expect a stiffer and tougher plastic when more borax is added. This is not a polymerization reaction, rather only the formation of secondary bonds. Though the links are not covalent, the term "crosslink" will be used to refer to the polar secondary bonds attracting the hydroxyl groups of both reagents. Because the reagents added will be 4% active ingredient and 96% water, students will understand that the differences in the properties are not due to dilution and only due to crosslinking.

Polyvinyl alcohol, PVA, is a thermoplast with a simple repeat unit, as shown in figure 1. Each hydroxyl (alcohol) functional group has a dipole – a partial negative charge on the electronegative oxygen and a partial positive charge results for its bound hydrogen.

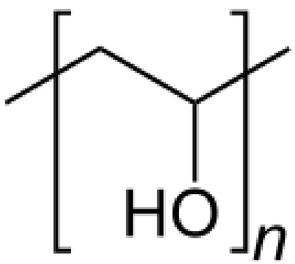

Figure 1 PVA structure, by Jü via Creative Commons https://commons.wikimedia.org/wiki/File:Polyvinyl_Alcohol_Structural_Formula_V1.svg

Sodium borate, borax, is a mineral compound that becomes borate anions when in solution, shown in figure 2. The structure as a whole has a net negative charge of 1, and a dipole in each hydroxyl group.

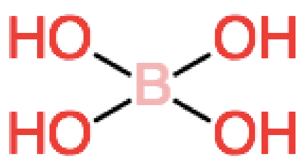

Figure 2 Borate structure

The crosslinks created between PVA chains are formed by borate ions. For example, a partial positive charge on a PVA hydroxyl H is attracted to a partial negative charge on a borate hydroxyl O.

When creating your diluted solutions, PETE bottles with squeeze/squirt caps are recommended for containing the PVA solution. Consider that any water impurities in making the solutions may have effects on the slime crosslinks. When students are measuring 50ml amounts of PVA, it can be challenging to get the fluid to settle in a graduated cylinder and then pour well into a cup, due to its viscosity. A good way to help students in problem solving is to lead them to the conclusion that they can measure 50ml of water, pour it into a cup, mark the height of the meniscus, and then use that line to measure PVA directly into the cup instead.

In the experiment, we recommend 5 samples. For class management you might have each group make one composition, or have each group make their own full set of samples, depending on available time and materials.

Instructors may also consider using additional equipment for characterizing samples. Digital scales will allow students to see if any mass is gained or lost in the crosslinking reaction, and to see how much mass is lost if they dry their samples at the end.

Classroom Experiment – Creating Crosslinked Slime

Procedure:

Wear your protective gear during sample preparation.

Sample prep:

1) Add 50ml PVA solution in a paper cup
2) Choose a color to distinguish this sample and record your choice. Add 1-2 drops of that food coloring to your sample.
3) Add the appropriate amount of sodium borate according to your sample matrix. *Wash immediately if sodium borate / borax solution comes into contact with eyes or any other sensitive body tissue*.
   Here is an example matrix:

Sample #	Sample Color	4% Polyvinyl alcohol	4% Sodium borate
1		50	1
2		50	2
3		50	4
4		50	6
5		50	10

4) Stir your sample immediately, using a craft stick for 20 seconds. Scrape the bottom, sides, and corners of the cup to ensure that all PVA has a chance to react with the borax.
5) Pour the contents of your cup into a sealable bag, remove as much air as possible, seal the bag, and knead the product as it reacts. Be careful not to rupture the bag.
6) Wash hands to remove any borax residue.

Sample testing:

1) After you feel sure the samples have stopped reacting, remove the "slime" from their bags and investigate their properties.
2) Slowly stretch each sample. How do they differ from each other?
3) Quickly stretch each sample. How does this differ from adding stress slowly?
4) Let the slime flow under gravity between fingers or through a funnel. What behavior do you see? How does flow speed correlate with borax concentration and stretching behavior?
5) Roll each sample into a ball and bounce it on a hard, clean laboratory surface. Does "bounciness" correlate with flowing behavior or toughness?
6) Create a chart or table listing the different properties you can think of. Describe the appearance of these properties quantitatively for each sample.
7) Come up with a quantitative measurement you are able to make using materials at hand. For example, you might time how long it takes for a sample set on top of a hole of a certain size to touch the table 10 centimeters below. Record these results and see if they agree with your qualitative measurements.
8) Try stretching portions of each sample out on a counter overnight, or otherwise drying the slime out. Do this with non-crosslinked PVA solution as well. Investigate the properties of the material formed after water has left the sample.

Discussion

Was there a concentration of sodium borate at which the changes due to crosslinking ceased to increase? Across concentrations, did properties always change the same amount? Discuss your results as a class.

Student Evaluation Questions:

1. Describe the existence of crosslinks between polymer chains as if you were writing to a beginning chemistry student who just learned what a covalent bond is.
2. If the borate molecule were replaced by a molecule with the same ability to form crosslinks, but with long chains leading to the hydroxyl groups instead of short bonds, how might the behavior of the slime change?
3. Identify the repeat unit and the monomer molecule of PVA. When manufactured, is PVA made from this monomer? Cite a source for what chemical precursor PVA is made from.
4. If your class came up with a shared quantitative measurement to record in step 7, share your results with all other groups. Create a spreadsheet of the full class' results and find the mean and standard deviation. Do you

feel that the measurement was useful? Were there any inconsistencies in methods of collecting the measurement?

Reference:

This module is adapted from:
Slime: Classroom demonstration of property change due to crosslinking, Andrew Nydam and Debbie Goodwin, http://materialseducation.org/educators/matedu-modules/docs/Slime.pdf

This work is part of a larger project funded by the Advanced Technological Education Program of the National Science Foundation DUE #1400619