Materials Processing – A Piece of Cake!
Cakes: A Novel Method for Illustrating Processing-Structure-Property Relationships in Materials

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Abstract:
Juniors in materials science and engineering at Virginia Tech are given an assignment for MSE4424-Materials Processing 2 in which they must bake a cake from scratch and bring it to class the first day. With as many as 15 cakes to examine with respect to characteristics such as microstructure, porosity, surface texture and possible defects due to improper processing, the concepts relating processing, structure and properties are introduced. These concepts are reinforced throughout the semester through laboratory experiments as the class works with raw materials, various processing techniques, heat treatments and characterization/testing.

Key Words: Materials Processing; Processing-Structure-Property Relationships

Target Grade Levels:
This activity has been used in a college level materials processing laboratory course. The students baked cakes at the beginning of the semester and studied them as an introduction to the course. The activity was repeated at the end of the semester after the students had learned processing and characterization techniques. However, this activity can be used with students as early as first grade, but the discussion of the relationships resulting from the activity and the engineering applications must be geared specifically to the audience.

Mode of Presentation: Preparation is outside of class; analysis is conducted in class.

Prerequisite Knowledge: Extensive prior study is not required. This activity can be tailored to the audience.

Objectives: The primary goal of this exercise is to familiarize students with the concept of processing-structure-property relationships.

Equipment and Supplies
Raw Materials:

- Cake mix (Note: It would be preferable that students make their cakes from scratch, but most use a cake mix.)
- Eggs
- Flour
- Butter

Preparation Equipment:

- Cake pan or muffin tins
- Mixer (hand or electric)
- Oven
- Cooling rack

Demonstration equipment:

- Knife or cake cutter
- Wax paper
- Paper plates
- Plastic forks and knives
- Icing (optional)
- Variety of kitchen scales and analytical balances
- Calipers
- Slides
- Optical microscopes

Curriculum Overview and Instructor Notes

The concept of the processing-structure-property relationship is fundamental to the study of materials science and engineering (MSE). This relationship is the core of a larger "manufacturing stream" that governs everything from the choice of raw materials to characterization and testing methods to evaluation of final product performance. Figure 1 is just one possible schematic representation of this concept.

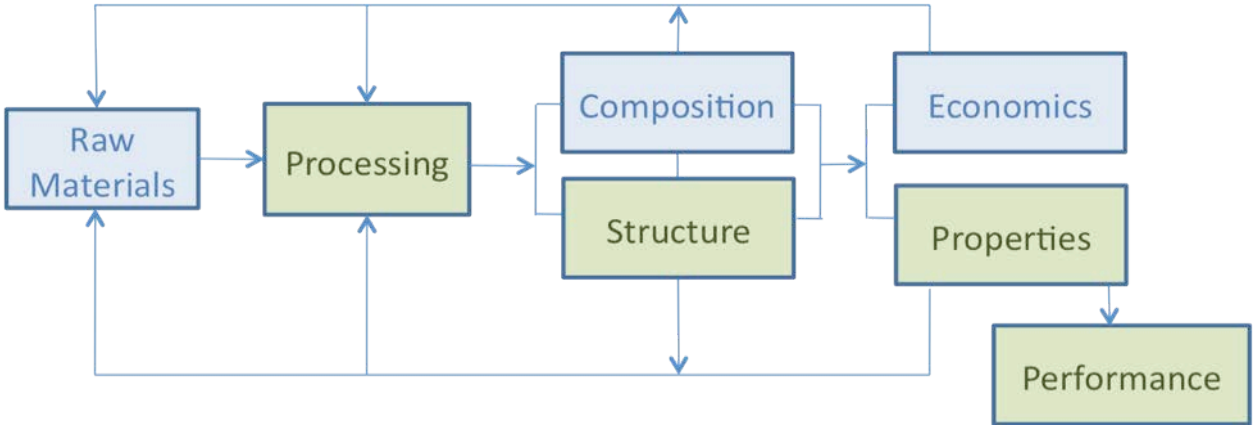


Figure 1: A representation of the critical components in the processing-structure-property relationship common to most materials systems. Adapted from Clark, David E.

Laboratory classes are a vital component of the academic program for materials engineering students. While college students in MSE nationwide are taught this fundamental concept in many of their lecture classes, it is in the associated laboratories that the opportunity presents itself to translate theory into practice. For some students, this step constitutes a significant leap.

The idea that materials do not always behave as they do in the ideal cases upon which the formulas and theories are based is foreign to students who have not had the opportunity for hands-on experience. It is for these students that the labs are most enlightening.

The challenges for an instructor of a laboratory on materials processing are to (1) teach engineering students the skills associated with various processing methods (in this case, ceramics processing such as glass melting and casting, powder processing, sol-gel processing, extrusion, slip casting), and (2) relate the exercises to familiar examples of processing to which all of the students can relate. For this class, the real-life example is cooking.

Procedure

Students are given an assignment to bake a cake (no icing) and bring it to class on the first day. At the beginning of class, one of the cakes is iced and set aside. The class starts with a question to the students, "What do you think this class is about?" A brief discussion of their perceptions is followed by the instructor's viewpoint. Then, the cakes!

Wax paper is spread out on a table in the front of the classroom. The students are asked to place their cakes, still in the pans, on the table and gather around so they can see. The following are the points of discussion:

- *Surface Morphology/Texture*: A visual inspection of the tops of the cakes provides the first indication of the quality of the underlying structure.

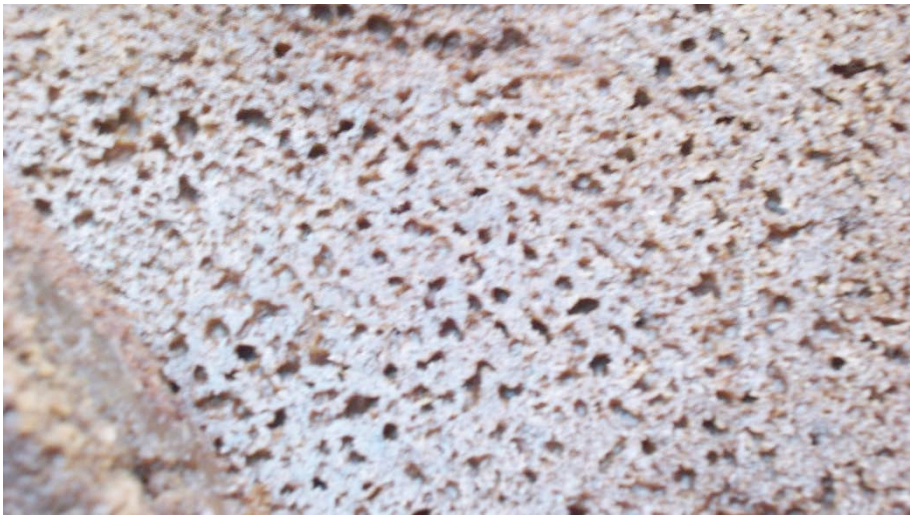
- *Mold Release*: The pans are turned upside down to remove the cakes. Some do not come out of the pans while others release easily. A discussion of mold release agents and choice of mold (pan) follows.

- *Bottom Surface Morphology/Texture*: A visual inspection of the bottoms of the cakes gives the students an idea of the differences between surfaces exposed to heat directly and those that are formed against a container wall.

- *Pore Structure to Evaluate Homogeneity*: The cakes are halved and the cross-sections are analyzed. Pore sizes, pore size distribution and types of pores are (open versus closed) are examined. Students are asked to use a caliper to measure the pore sizes across a defined area and record their results for further analyses.

- *Density to Evalu*ate *Homogeneity*: Students are asked to evaluate the homogeneity of their cakes using density measurements. No instruction is provided as to the selection of sample size or location. Each student or team of students selects or is provided with a balance or kitchen scale, plastic knife and calipers. They must then determine the optimal sampling method and make geometric and weight measurements of each sample. In the discussion period to follow, they must justify their selection of samples and how this selection gave the optimal evaluation of the homogeneity of their cakes. A discussion of the measurement techniques and of the experimental errors relating to sampling, weighing (due to scale/balance limitations) and geometric measurements is conducted.

- *Optical Analyses*: The students take a thin slice of their cakes and place them on a slide or other substrate of appropriate size. They are asked to include the top surface in their sections. These samples will be placed in an optical microscope later in the class to better examine the structures. A comparison between the surface layer and the interior is made. Depending on the cake, the differences range from negligible to significant.



For a discussion related to coatings, icing may be applied to some of the cakes at the beginning of the class period. These coated cakes are evaluated in cross-section as to penetration depth of the coating and the effects of the coatings on the surface textures. To make this part of the experiment more meaningful or the results more dramatic, the instructor can ice sections of a cake at different times following baking so the surface texture and penetration depth are affected by the temperature of the "substrate."

Finally, to evaluate performance, the students perform compression tests to determine the "sponginess" of the cakes at the edges and the centers, and the ultimate test – taste!

Throughout the exercise, a discussion can take place either formally or informally, with the entire class or individual groups. Some possible points of discussion:

1. How is the surface texture (top and/or bottom and/or sides) affected by the following:
    a. Heat treatment schedule?
    b. Shape and material of mold (pan)?
    c. Use and type of mold release agent?
2. Is there a noticeable difference in pore size and distribution? What are some of the reasons for observed differences?
3. When determining homogeneity in a material:
    a. What methods/properties can be used?
    b. Is sampling method important?
    c. Is sample size important?
    d. What about 3D aspects?
4. What type of errors can be anticipated when making measurements?
    a. Is one measurement instrument the same as another?
    b. Do all measurements need to be made by one individual? Why?
5. What is the difference between *precision* and *accuracy*?

There are many points of conversation and analogies between many materials and materials processes when incorporating baking into a processing laboratory.

Notes for the Instructor:
This lab is fun for all involved and provides an excellent opportunity to review the entire process-structure-property relationship. In teaching evaluations, the students indicate that it makes the class material more "real" and sets a tone that laboratories are not simply laborious efforts with minimal payoff. It has become evident that this exercise builds a level of rapport between students as well as between students and instructor. Most of all, make it fun; make it engaging. Five years after graduating, it will be the cakes they remember every time they fire a sample in the lab!

This exercise has been performed as a demonstration laboratory for freshmen engineering students at other universities. In this case, the cakes are baked by the instructor. It is useful to intentionally incorporate defects in the cakes by

- Using improper ratios of ingredients (too many eggs or too few; wrong amount of sugar)
- Baking them at temperatures too low or too high to achieve a good "sample"
- Using different baking pans
- Altering the "mold release agents" (no butter; no flour or too much flour; spray coating vs. oil)

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Evaluation of the Activity:
Student evaluation questions (discussion or quiz):

After comparing cakes baked by different students,

1. Explain how differences in heat treatment schedules causes changes in
   a. surface texture
   b. pore size and distribution
   c. density of the product
   d. homogeneity of the product

2. How do you measure the homogeneity of the produce? What methods can you use to measure homogeneity?
3. Explain the difference between *precision* and *accuracy* in a measurement such as that for homogeneity.

Instructor evaluation questions:

1. At what grade level was this module used?
2. Was the level and rigor of the module what you expected? If not, how can it be improved?
3. Did the activity work as presented? Did they add to student learning? Please note any problems or suggestions.
4. Was the background material sufficient for your discussion with the students? Comments?
5. Did the activity generate interest among the students? Explain.
6. Please provide your input on how this module can be improved, including comments or suggestions concerning the approach, focus and effectiveness of this activity in your context.

Course evaluation questions (for the students)

1. Was the activity clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions?
4. Was the instructor able to answer your questions?
5. Was the importance of materials testing made clear?
6. What was the most interesting thing that you learned?