Ceramic Slip Casting

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Abstract

Ceramic materials play an important role in the world around us. Many industries utilize ceramics for both industrial and consumer products. Some examples of ceramics that can be found in the home are fiberglass insulation, TV screens and glass articles of all kinds as well as coffee mugs, dinner place settings and decorative knickknacks. Slip casting ceramics is relatively simple and inexpensive compared to making parts with metals. In addition, slip casting is easy to demonstrate and can be incorporated as an experiment in the classroom or lab. This module focuses on the slip casting method using a gypsum plaster mold and making an alumina or clay-based part; it also demonstrates the limitations of slip casting relative to defects and voids that can alter the properties of the final product. This module is appropriate for advanced high school or college level programs. Depending on the availability of equipment and supplies this activity can be applied in a classroom demonstration or lab experiment for the students.

Module Objectives:

This demonstration or lab provides an introduction to the slip casting method and how basic ceramic parts can be created. It also provides the background information required to understand how internal defects and imperfections alter the properties of ceramics.

Student Learning Objectives:

- Describe the general properties of ceramics
- Demonstrate the slip casting process
- Identify the limitations of slip casting
- Discover how slip cast materials can have defects and small voids that are not readily visible on the surface
- Understand how defects and imperfections can alter the properties of ceramics

MatEd Core Competencies Covered:

0.B	Prepare Tests and Analyze Data
0.D	Demonstrate General Technical Competence
1.C	Demonstrate Laboratory Skills
4.A	Demonstrate Effective Work with Teams
7.E	Describe the General Nature and Behavior of Ceramics and Glasses
8.A	Demonstrate the Planning and Execution of Materials Experiments
15.A	Describe Structure, Properties, and Processing of Ceramics

Key Words: Slip Casting, Ceramics, Material Properties, Material Processing

Type of Module: PowerPoint presentation with lab or in-class demonstration, dependent upon availability of supplies and equipment

Time required: two 50 min sessions

Pre-requisite Knowledge: Basic Chemistry

Suggested prerequisite: none

Target grade level: Advanced High School, Introductory College/Technical School

Table of Contents: check final

Equipment and Supplies Needed:

- PowerPoint projection system
- Electric Furnace
- Plaster of Paris*
- Ceramic powder*
- Binder and Deflocculant*
- Trimming tool*
- Small item or yogurt cup to be used as a model for the molding*
- Ceramic samples for discussion*
- Medium square plastic container(s)
- Spatula/mixing sticks
- Large mixing bucket(s)
- Measuring cups
- Small scale

- 1 liter plastic bottle with cap
- Funnel

*materials can be found in most art and hobby stores

Curriculum Overview and Notes for Instructor

In studying the slip casting method we can gain a better understanding of how materials can be utilized to create simple or more intricate parts for various industries. It is important to learn about the various components that make up the slip casting method as it is one of the most widely used today for the production of ceramics in industry.

First and foremost, it's necessary for the students to have a greater understanding of the basic technique in which gypsum-plaster molds are created. Gypsum, plaster, or Plaster of Paris is one of the most commonly used materials for the production of porous molds for slip casting. It is used because it has the property of absorbing water into the porous plaster from a particulate-water suspension called a slurry or slip. For example with a clay-based slurry, removal of the water leaves behind a relatively strong clay object. The plaster mold reproduces fine details in molds that can be easily trimmed and manipulated. Gypsum plaster is made by heating gypsum to approximately 300°F (150°C) in the following reaction:

$$2CaSO_4 \cdot 2H_2O \rightarrow 2CaSO_4 \cdot O \cdot 5H_2O + 3H_4O\ (released\ as\ steam)$$

It's very inexpensive since it is found all over the earth and is quite abundant in supply. The name Plaster of Paris comes from a large deposit at Montmartre in Paris. Typically, Plaster of Paris can be found in art, hardware and hobby stores. When the Plaster of Paris powder is mixed with water, it re-forms into gypsum.

Figure 1: gypsum in powder form ** http://www.famousminechem.net

One important thing to know is that the ratio of water to gypsum in the mold suspension will have a direct effect on the time it takes to remove water from the cast. The advantage of this technique is that it's inexpensive and time-efficient for casting complex parts when compared to other conventional methods. When Gypsum is mixed with water it hardens. The reaction is very exothermic, the mixture heats up quickly.

Figure 2: mixture of plaster and water ** nesbetminiatures.blogspot.com

BE SURE TO MINIMIZE HANDLING OF MATERIAL WITH BARE HANDS AS IT CAN CAUSE SEVERE BURNS

It is important to wear safety goggles in gloves while mixing the gypsum and water suspension. The chemical reaction is exothermic and may cause skin irritation. Wash hands if some of the mixture comes in contact with skin. The increase in the temperature of the mixture is due to the physical and chemical changes the gypsum undergoes when it interacts with water and starts to harden.

There are three parts to the slip casting method, which will be covered in detail in the following sections.

Making a Gypsum Mold

After the water and gypsum have been mixed thoroughly it is poured into a container and allowed to sit until it is firm. Two techniques are given here to make a plaster mold to replicate a model. Mold soap is used to prevent the plaster from sticking to the container or the model.

1. Place the model into the bottom of the container and carefully seal the edges around the model with plastic clay so the plaster cannot run under the model. Pour the liquid mixed plaster over the model to obtain at least 1 inch plaster thickness all around the model. Once the plaster is set, remove it from the container and remove the model.

2. Pour the mixed liquid plaster into a container and watch carefully as it sets. At the point that the plaster begins to become firm, press the model into the surface and hold it there for a little while as the mix hardens. Once the mold is set, remove the model carefully so as not to disturb details that will remain.

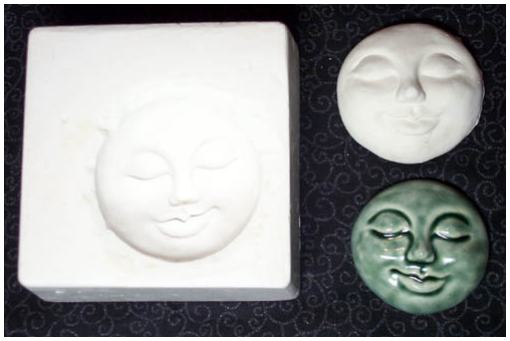

Figure 3: Plaster mold with model and final cast piece ** wetcanvas.com

Wait until the gypsum is completely dried. This can be achieved by placing the mold in a dry environment for several hours. A dry oven can be useful at this point but do not exceed 120^{o}F or you will destroy the plaster mold. Be sure to check to see if there are undercuts, areas in the mold that can cause the green body ceramic to catch during removal. If there is an undercut, details and possibly the entire ceramic piece can be ruined. Use a trimming tool or sand paper to remove any undercuts or specific details that you want to eliminate from the final cast.

Preparing a Ceramic Slip/Slurry

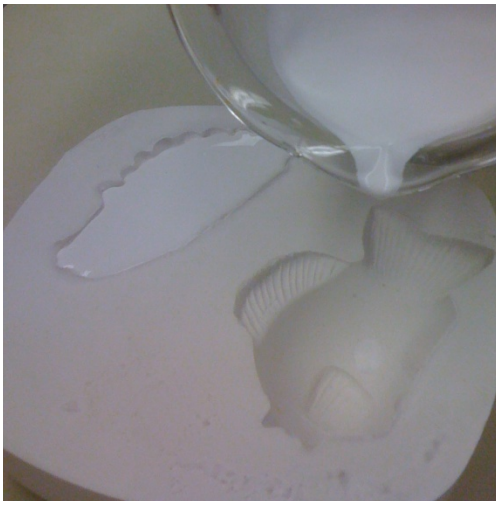

Figure 4: Pouring ceramic slurry into a plaster mold

A slip/slurry is a ceramic suspension. Depending on the type of ceramic you want to create the ceramic suspension will vary. This is mainly based on the type of kiln or furnace that will be used to fire the ceramic cast piece. Additional chemicals are required to maintain a uniform consistency of your slip as well as being free of clots. Binders and deflocculants are often used to increase the strength of the ceramic, and prevent settling, clotting of the ceramic particles and by thinning out the suspension. **(A recipe for one type of ceramic slurry is found in the appendix)**

Prepare the slurry using water, alumina (or another ceramic powder), a binder and the deflocculant using a spatula or hand mixer to ensure complete mixing. A ready-mix clay slip can be obtained at hobby or pottery supply shops. Slowly pour the ceramic suspension into the mold (Figure 4). The ceramic particles will start to settle against the plaster as the water is drawn from the suspension into the plaster mold. Additional slurry can be added as needed. The ceramic particles left behind will form a thin skin that will gradually thicken as additional slurry is added. Once the desired wall thickness is achieved pour off any remaining fluid and then allow the ceramic particulates time to become dry e enough to handle.

Ceramic Final Product Pre and Post Firing

Once the ceramic green body is firm and mostly dry, remove it carefully and let it air dry. Later in the day or the following day, depending on the dryness of the ceramic, place the piece(s) in the electric furnace to be fired. The ceramic green body can be glazed pre or post firing. The temperature and times will vary depending on the ceramic mixture used. During the next class period display the cast pieces along with ones that are pre-fired.

This exercise can be carried out as a demonstration, individually, or in groups. If used in a demonstration, emphasize safety and if there is time, prepare various mixtures changing the ratio of water to powders for the ceramic mixtures. Encouraged the students to be involved by visually inspecting the samples to determine differences, as well as to make predictions on how the material properties would be affected by the different variations of mixes.

The overall set-up, fundamental concepts and analysis are summarized in the PowerPoint presentation.

Module Procedure

First Session

1. Discuss what makes something a ceramic. (see definitions and PPT)

2. Display identical samples of ceramics that were purchased and discuss the importance of slip casting and the varying factors that are involved. Be sure to show the students samples of a ceramic material.

3. Ask the students if they can find any defects on the sample(s) and if they can predict if the material has other defects internally. How they would go about finding this out and how they would eliminate the defects?

4. Obtain or prepare samples that are broken into sections. Display the sectioned/broken pieces of the sample to the students as this will allow them to see that sometimes there are imperfections in materials that are not apparent on the surface.

   TAKE CARE TO NOT HAVE STUDENTS HANDLE THE BROKEN PIECES. CERAMICS CAN BE VERY SHARP AND CAUSE CUTS THAT ARE NOT INITIALLY VISIBLE.

5. Show the PowerPoint presentation and discuss each slide.
   a. Slide 1: Introduction to slip casting
   b. Slide 2-4: Definitions for words associated with slip casting
   c. Slide 5: Key Concepts
   d. Slide 6: Equipment and supplies needed
   e. Slide 7: How to choose your model (part to be duplicated)
   f. Slide 8-14: Method
   g. Slide 15-16: Safety and Pictures of various ceramics
   h. Slide 17-20: Q & A, Summary and Definitions
   i. Slide 21-22: Acknowledgements and Contact Information
6. Perform demo/lab

Demonstration

Have students gather around as you prepare a mold and the ceramic slip/slurry. Detailed instructions for each step in the clip casting method can be found in the appendix

Class Experiment

Prepare a shortened handout or place the instructions on the board. Have students (groups of 3-5) make a mold, prepare a ceramic slip/slurry and make a cast part.

Once the ceramics have been cast and are removed from the molds, place them in a safe place that is free of humidity so they can dry before being fired.

As an additional activity and to help students understand the concept of slip casting of ceramics, have them compare cast samples to samples that have been fired. Do this by dropping samples on a hard surface. This will show the students the toughness of the fired samples compared to the ones that are not fired.

Ask the students to identify possible variables that can affect a final casting of the material and have them explain what effect the variables in the slip casting method have and why they are important.

If various (identical) castings were made, ask students to compare them for flaws or differences, ask them what they would do in order to prevent these flaws from occurring in future castings and why.

7. Conduct a class discussion on the exercise to determine what the students have learned. Were their predictions correct?

Repeat the PowerPoint in order to solidify/emphasize specific concepts. Have your students answer the experimental analysis questions and to identify variables that could possibly cause the results to change.

Supporting Materials and References

Please see accompanying PowerPoint

Optional:

Lab report - Have students report, presenting their final product and discuss any variables involved in differences in the slip cast ceramic in order to reiterate the key concepts involved in the slip casting technique covered in this module.

Acknowledgments

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Student evaluation (discussion/quiz)

1. If castings were made, did you find the process to be difficult? Was it what you expected? If not, please explain.
2. Is there a difference in each casting if you used an identical mold? Explain.
3. Why is it important to have the model placed into the gypsum mold before it solidifies?
4. How does sample preparation affect the final casting?
5. Can you name a few examples of ceramics that have been produced commercially?
6. Could you see or feel any differences in the molding material after it was mixed? If so, why do you think this occurs?

Instructor evaluation

1. What grade level and class was this module utilized for?
2. Were the students able to grasp the key concepts introduced in the module?

3. Was the level and rigor of the module acceptable for the grade level of the students? If no, how can it be improved?
4. Was the demonstration/lab work as outlined? Did it help the students in learning the material? Were there any problems encountered?
5. Was the background on slip casting sufficient for your understanding and for the discussion with the students?

Any comments and/or suggestions on improving this module are encouraged.

Course evaluation questions

1. Was the demonstration/lab clear and understandable?
2. Was the instructor's explanation comprehensive and thorough?
3. Was the instructor interested in your questions or concerns?
4. Was the instructor able to answer your questions thoroughly and to your satisfaction?
5. Was the importance of slip casting made clear?
6. What was the most interesting thing that you learned about in regards to slip casting?

Definitions

Ceramic – inorganic, nonmetallic solids generally made by mixing clay, earthen elements, powders, and water and shaping them. Once shaped, it is fired in a high temperature oven known as a kiln/electric furnace.

Binder – polymer additive that helps to increase the material properties of the ceramic.

Deflocculant – Chemical additive used to prevent particles from coming out of suspension as well as thinning of suspensions in order to prevent flocculation.

Exothermic –Reaction that releases energy in the form of heat, light and or sound.

Green body – Ceramic created from slip casting prior to being fired or sintered.

Gypsum – Soft mineral composed of calcium sulfate dehydrate. Mined in quarries then ground into powder for a variety of uses. Gypsum plaster is made by heating gypsum to approximately 300^{o}F (150^{o}C).

Slip/Slurry – Watery mixture of water, clay and other chemicals that keep the suspension uniform and clump free such as deflocculants and binders.

Slip Casting – Technique used to create ceramic parts by pouring specialized (slip) liquid into plaster molds. A green body piece is made from the ceramic particles settling and forming a thick layer. Once settled the piece is removed and allowed to dried before firing.

Undercuts – Features in a mold that cannot be produced by a single mold (makes it difficult to remove a green body ceramic without causing damage to the piece)

Plaster Preparation

Typical plaster consistency for slip casting is 70. This means its 70 parts by weight water to 100 parts by weight of plaster. If unsure you can find detail instructions online. Be sure to use room temperature water. The setting process begins when the mixing starts. The fast you mix it the faster it will harden.

Materials required:
Plastic bucket
Safety Gloves
Stirring Stick or Spatula
Room Temperature Water
Milk Carton

1. Place a volume of room temperature water that is slightly greater than the desired mold volume in a clean plastic bucket. A good weight ratio of water to plaster is 70 parts water to 100 parts plaster.
2. Sift the appropriate amount of plaster powder evenly into the water until you can visibly see it on the surface of the water.
3. Allow it to soak 2 minutes before mixing.
4. Stir the mixture with a paint stick or spatula slowly without agitation in order to avoid entrapment of air. Stir it for approximately 5 minutes or until the mixture becomes creamy and there is about an eighth of inch coating that remains on a stir stick when it is dipped into the mix.
5. The mix should have a nice creamy consistency.
6. Pour the mixture slowly and evenly into the mold without entrapping any air.

The molds have to be thoroughly dried before use. Depending on the size and wall thickness of the mold, drying at room temperature may take several days. You can use a drying oven. Be sure not to exceed temperatures that are over 120 °F.

Plaster will harden in place. In order to dispose excess plaster, pour it into a disposable container such as a milk carton. Allow it to harden. If the plaster has hardened in the mixing bucket just flex the walls, it will break off. Clean out the bucket. Dirty mixing containers should not be used to mix additional plaster.

Do not clean any implements and containers by rinsing plaster down the drain. It will harden in the drain.

Choosing a Mold and Model

There are alternatives methods that can help demonstrate slip casting.

Cup shaped models are used. The cavity is filled with slip, allowed to build up to a desired wall thickness, and then excess slip is poured off leaving a thin walled container. Small household items may be used as well as long as they are free of undercuts.

Once plaster is prepared you have two options in creating your mold.

Option 1:

You can do one of two things to create your mold.

> You can use a hollow shape such as a yogurt cup and pour around it. Hold it in place by using sand or a stick in order to reduce buoyancy. Be sure to keep the cup in place until the plaster begins to harden.
>
> Ask students if they would use a Yoplait shaped cup, of not. Why?
>
> Or
>
> Pour plaster into a square plastic container or Tupperware. Wait until the plaster is semi firm and place the model firmly into the plaster. Once plaster is set carefully remove the model to ensure that the details will not be disturbed.

Option 2:

Before the plaster is prepared build a mold box. A mold box is created by making a box comprised of four sides that are held together with external cords on a flat bottom base. The sides and bottom joints of the mold box are sealed with ordinary plastic clay.

Place the model upside down on the box base seal the edges with clay and cover the outside lightly with soap. Mold soap or any ordinary house soap can be used to prevent plaster from sticking to the box and the model.

Prepare the plaster then pour it over the model carefully until the mold box is filled.

Why is it important to use a regular yogurt cup and not a cup like a Yoplait container in this type of mold preparation?

Clay Based Suspension (Slip)

Clay base suspensions, called slips can be obtained from pottery supply or bobby stores. Get assistance to choose a slip that is appropriate for your firing equipment.

Alumina Slip recipe

This can be adjusted to however much slip is needed for the demonstration or experiment. Follow these steps in order or the slurry will not mix completely

1. Dissolve about 1wt% Darvan (or other deflocculant) into a prepared container of water
2. Add 1wt% PVA (or other binder)
3. Once the binder and deflocculant have been fully dissolved, add in 30wt%alumina.
4. Mix until homogeneous
5. Place the slurry using a funnel into a plastic container and seal it with a cap

The slurry should look bright white and little thicker than the consistency of milk. If mixed correctly following the instructions above the alumina particles should stay suspended and not settle on the bottom of the container. If it starts to settle immediately add a little more deflocculant.

Wt% means that it's based on the amount of liquid you are using. You want for 5% of saltwater, you'd mix 5 grams of salt into water that will end up being a total volume of 100ml.

Additional information

Here are some helpful sources that offer tips, instructions, and information that can aid in the demonstration, and experimental portion of the module.

http://www.usg.com/rc/data-submittal-sheets/industrial-plasters-cements/usg/usg-no1-pottery-plaster-data-en-IG1366.pdf

The Essential Guide to Mold Making & Slip Casting by Andrew Martin 2007