

Polyurethane resin method for the production of density cubes.

This guide is intended for a person familiar with the use of power tools and certain wood working and simple fabrication techniques.

The guide will provide instructions on how to replicate the set of density cubes for ACASE's Cubes and Liquids assessment activity. These cubes, as of the current version of cubes and liquids, consist of the following:

- 6 x 6 x 6 cm cube weighing 200g
- 4 x 4 x 4 cm cube weighing 200g
- 6 x 6 x 6 cm cube weighing 215g-235g
- 1 x 1 x 1 cm weighing roughly 1.1g

(Please note that all measurements are approximate and actual volume and mass of the cube can vary by 1% from the numbers listed here.)

Introduction:

Two part polyurethane casting resins provide an ideal substance for producing items with varying densities. The resins can be fortified with additives such as glass micro-balloons which serve to lower the density of the cured product, or solid glass spheres which serve to increase the density of the product. Very accurate densities can be achieved by this method after determining the appropriate ratio of filler material to resin.

Production set up:

Required materials and tools
Polyurethane resin (two parts, a pre-polymer and a curative)
Micro-balloon filler material
Lead shot and steel BBs (to increase the weight of the smaller cubes).
Mold release agent
Plastilene or regular clay
A drill press and Forstner drill bits
A chop saw (using an inexpensive generic blade is recommended)
Graduated cylinder or veterinary syringe
Disposable measuring cups, 250 ml variety and 500 ml variety
Rustoleum sandable primer
Rustoleum spraypaint

Highly recommended tools
Stationary 1 or 2 inch belt sander
Hand held vibrating sander

A list of where to find the materials online will be included at the end of this write up.

Making the molds:

Molds are necessary to the casting process and they must be fabricated by you, or purchased within the tolerances of the cubes to be created. They can be made by mitering a 45 degree angle on both sides of strips of plexiglass or acrylic with a table saw. The objective is to make two long tubes with interior dimensions of 6 x 6 cm and 4 x 4 cm. These tubes can be glued together using a strong adhesive such as PL Premium construction adhesive (available at any hardware store in the caulking section). The material the molds are made out of is very important due to the low viscosity of the polyurethane resin, plastic is vastly preferred to any wood as it has closed pores and the resin will not infiltrate the “grain” or surface. If the mold is made from wood and this happens you will never get the hardened resin out without destroying the casting or the mold. If plastic is unavailable to you, using a very fine grain wood or particle board which is then sealed with multiple coats of lacquer might work.

Making these molds can be quite tricky if you are unfamiliar with the technique. My preferred method is to lay each mitered strip down side to side so that their edges are touching, and place strips of duct tape across them. They can now be folded into a perfect square, provided your mitered angles are correct. Put a bead of adhesive down each mitered edge, fold the tube up and secure it closed, I used disposable “zip” ties which can be found in any hardware store. String or rope ought to work as well. There will probably need to be some clean-up of excess adhesive from inside the mold after it has dried.

Alternatively you can use prefabricated items as your molds. Extruded aluminum square tubing is almost of the perfect substitute for a hand made mold. It has the disadvantages of being somewhat expensive, and not having the exact dimensions of the finished cubes. You can remove excess material from the finished cube by sanding and achieve the correct dimensions that way however.

A piece of plastic or metal to place the bottom end of the mold on is necessary. The mold is place on this and the cracks are sealed using plastilene or clay. The resin is then poured into the mold through the top.

The final requirement for these molds is that they be of satisfactory length. The ideal length you are want is at least between 14 and 16 centimeters for the 6 x 6 cm mold and 9 to 11 centimeters for the 4 x 4 cm mold. Enough to cast a “bar” of plastic which can be cut on the chop saw into two separate cubes of the appropriate dimension. There are two reasons for this. One is that casting a cube to “exact” size is difficult to do without having deformations on the top or bottom surfaces. The other is that it is faster to produce two cubes at a time instead of one.

Cube Production:

Now that the molds are completed and your materials are all assembled, the actual production of the cubes can begin. Each category of cube is produced differently and thus will be described separately. Remember in all cases that molds must be prepared with release agent prior to casting!

6 x 6 x 6 cm, 200g cube

This cube is produced by adding micro-balloon filler material to the resin in the

correct proportion that the cured result is of the proper density. The exact proportion of filler to resin is something a little bit of experimentation is required to determine. I would start with 70g of filler to 500g of mixed resin. Remember, that means adding 35g of resin to each half of the resin prior to mixing. When measuring amount of micro-balloon filler it is important to keep in mind that the material compacts greatly, so to keep measurements consistent it must be measured in its most compacted state. I used graduated cylinders, which I filled with the micro-balloons and then repeatedly vibrated (banged lightly on the table). As it was vibrated the volume decreased, eventually the decrease ceased when it was most compacted. A better solution, which I didn't think of at the time I was producing cubes would be to use a veterinary syringe. The micro-balloons can be sucked into the syringe, and then placing your finger over the opening the syringe can be used to compact them.

Casting is done by mixing equal part of the polyurethane resin and stirring gently so as not to introduce any bubbles. Each part of resin should have an equal amount of micro-balloons well mixed into it prior to the mixing of the resin. When the resin halves are thoroughly mixed, they are poured into the mold and allowed to cure. If there are any bubbles, these can be removed by very quickly by gently passing the flame from a propane plumbing torch over the surface of the mixed resin. Start far from the mixture, and gradually move closer until the bubbles pop, move quickly so as not to burn the mixing container, mold or resin. The curing reaction is very fast with the right type of resin, taking place in under 2 minutes for the initial hardening and allowing about 15 minutes for a complete cure.

Using 450ml of resin in a 6x6cm mold of the proper length should yield a finished product that can be cut with a chop saw into two 6x6x6 cm cubes. These cubes should weight slightly more than 200g as excess weight can be removed via sanding. While some experimentation may be needed to achieve the correct micro-balloon to resin ratio, I recall adding 35ml of compacted micro-balloons to each half of the resin prior to mixing. So 70ml total of compacted micro-balloons to 450ml of resin should get you into the correct density range.

4 x 4 x 4 cm, 200g cube

This cube is the most difficult to produce. Initially you must produce appropriately sized cubes of nothing but resin. These are then drilled with a large Forstner bit (1 1/4" approximately) to create a large opening. Lead is added to this opening and then the opening is filled with resin again and allowed to harden. Achieving exactly 200 grams this way again requires experimentation, but if the end result is off, a small drill bit hole can be made around the area where the lead was introduced and filled with steel BBs and sealed up with resin. Take care not to drill out any of the lead or the total weight will be greatly affected! Again, the goal is to slightly overshoot 200g and remove material by sanding to bring the weight down. Determining the amount of lead needed should be done by weighing the drilled cube with the lead on a scale, remember that the resin you refill the hole with adds some weight too (about 9 or 10 g). The lead balls can easily be cut into pieces with wire cutters or needle nose pliers (with a clipper section) as an entire pellet can throw you far past the target weight when you're close.

Getting enough lead to fill the drill hole might be difficult unless it is melted. This process isn't necessary, as the lead balls can be hammered flat and stacked, but

melting is easier. All that is needed is a piece of flat steel and a copper plumbing fitting of slightly smaller diameter of the drill bit hole. Place the copper fitting on top of the steel, try to ensure that the steel's surface is smooth so that no molten lead leaks out the bottom. Put as many pieces of lead as you can fit inside the copper fitting and then heat them with a plumber's propane torch. The lead should melt, allow it to cool off and solidify, once solid introduce some more on top of it and repeat the process until you've melted all the pieces. Your final product should be a lead cylinder that should fit easily inside drilled hole.

Once the lead is placed in the hole a small amount of resin needs to be added, allow it to overflow the drill hole slightly as the excess can be removed through sanding. It is best to do this step with multiple cubes at once so resin isn't wasted.

Remember lead is toxic! Wearing gloves is a good idea while working with it. Make sure that you are in a well ventilated area when melting lead to avoid breathing any fumes. Always wash your hands after working with lead. These few steps greatly increase your safety while working with the material.

6 x 6 x 6 cm, 215-235g cube

This cube is traditionally called the "mystery cube". It doesn't need to have a specific density as it isn't engineered to float in water but sink in alcohol. You can simply use pure resin to create this cube. Alternatively, if you add a small amount of micro-balloon filler you can make cubes of a density that will sink in water, but float in a salt water solution. This is essentially done by the same process as making the original 6 x 6 x 6 cm cubes only using less filler. Having a final weight of 215-220g will be sufficient to float in a low concentration salt water solution. Note: When making a salt water solution use kosher salt or pickling salt! Other salts contain additives which will turn the solution slightly murky. Another note: The weight difference between this cube and the 200g cube is very hard to detect by hand, so to avoid confusion in the class room it is a good idea to make a slight marking somewhere on the surface of the mystery cube prior to painting.

1 x 1 x 1 cm, 1.05g cube

This cube can be made from a 6 x 6 x 6 cm cube of pure resin. You need only take this cube, and cut a 1 cm slice off it. This slice should be a 6 x 6 x 1 cm piece of resin. You can then cut it into 1 x 1 x 6 cm bars. These cuts can be done (with great care!) on a chop saw. The 1 x 1 x 6 bars can be cut into small pieces with a utility knife or X-acto knife. Cut them slightly longer than 1 cm and sand them down to 1 x 1 x 1 cm.

Finishing:

Note on painting: Paint and primer add to the weight of the completed cube. This needs to be taken into account before the painting process begins as the objective is to have the two 200g cubes weigh the same as one another. Paint adds approximately 2.5g to the total weight of a 6 x 6 x 6 cm cube and approximately .3g to .5g to the weight of

the 4 x 4 x 4 cm cube. It is best to paint all the large cubes first, and then alter the weight (via sanding) of the small cubes so that they pair up with a large cube. Make sure they weight .3g to .5g less than the painted large cube to have the closest match after they are painted themselves.

Now you should have your final castings. These must be sanded down to remove any surface imperfections as well as to achieve an exact weight. The belt sander is the best tool to use for this task. Once they are adequately sanded the vibrating hand held sander can be used with a high grit sand paper to prepare them for painting.

The next step is painting the cubes. Painting should be done in a well ventilated area. While not absolutely necessary, using primer first will produce much better results than if you just use paint. Resting the cubes on plastic drinking cups is the best method I found for the painting process. Place them so that they are resting on the cup with one corner pointing up and one corner “inside” the cup. The cube should only be resting on three specific points where its edges intersect the rim of the cup. Spray each of the 3 exposed sides. Allow them to dry and flip the cube and spray the opposite 3 sides. Once primed you should sand them again with the highest grit sand paper you used, 320 or 400 grit is best. The sandable primer should have filled any tiny cracks or gouges left by the rough sanding done initially (these will show up with glossy paint on them, so this is an important step). Since you are sanding most of the primer off, it does not affect the total weight of the cube dramatically.

Now the cubes can be painted. For best results you should mask the 3 sides which aren't exposed to the paint so no overspray covers them. Put a substantial layer of paint on but be careful not to cause any drips. Allow it to dry completely. Depending on the weather this should take several days, Rustoleum states on their can that it takes 48 hours for the paint to completely dry at 70 degrees Fahrenheit with 0 percent relative humidity. Mask the painted side, and apply a coat of paint to the opposite side. Allow this coat to dry, remove the masking tape and you're finished!

Materials Locations (online and off line)

Polyurethane Resin - HYPERLINK "<http://www.bare-metal.com/Pathway%20Polymers-Por-A-Kast-Polyurethane-Resin-Casting.html>" <http://www.bare-metal.com/Pathway%20Polymers-Por-A-Kast-Polyurethane-Resin-Casting.html>

Micro-balloon filler - HYPERLINK "<http://www.bare-metal.com/Mold-Release-Agents-Bronze-Power-Microbulb-Solid-Spheres.html>" <http://www.bare-metal.com/Mold-Release-Agents-Bronze-Power-Microbulb-Solid-Spheres.html>

Lead Shot and BBs – BBs can be found at almost all local sports stores or Wal-Mart,

Lead can be carried locally, or alternatively bought online at HYPERLINK

"<http://possibleshop.com/ball-bullet.htm>" <http://possibleshop.com/ball-bullet.htm> (one box should be enough to make 10 cubes)

Mold release - HYPERLINK "<http://www.bare-metal.com/Mold-Release-Agents-Bronze-Power-Microbulb-Solid-Spheres.html>" <http://www.bare-metal.com/Mold-Release-Agents-Bronze-Power-Microbulb-Solid-Spheres.html> (Mold Release 531)

Plastilene clay – can be found at local art stores or alternatively bought online at HYPERLINK

"http://compleatsculptor.com/Merchant2/merchant.mvc?Screen=PROD&Store_Code=tcs1&Product_Code=57105&Category_Code=CLAY"

http://compleatsculptor.com/Merchant2/merchant.mvc?Screen=PROD&Store_Code=tcs1&Product_Code=57105&Category_Code=CLAY

Graduated cylinders - HYPERLINK

"http://scientificsonline.com/product.asp_Q_pn_E_3037525"

http://scientificsonline.com/product.asp_Q_pn_E_3037525

Veterinary syringes - HYPERLINK

"http://syringesupplies.com/?mainURL=%2Fstore%2Fproducts.html"

<http://syringesupplies.com/?mainURL=%2Fstore%2Fproducts.html>

Aluminum square tubing can be found in short sections at - HYPERLINK

"http://www.onlinemetals.com/merchant.cfm?id=69&step=2&top_cat=60"

http://www.onlinemetals.com/merchant.cfm?id=69&step=2&top_cat=60

The rest of the items on the list can be found at hardware stores, both local ones and national chains like Home Depot.