



Air-Powered Soft Robotic Gripper

by [hahvahdsquah](#) on March 5, 2013

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Intro: Air-Powered Soft Robotic Gripper

Credits: The soft robot technology in this project was originally developed in the [Whitesides Group](#) at Harvard University. For more details about the development of the technology and its uses, see the papers [Soft Robotics for Chemists](#) and [Multi-Gait Soft Robot](#). These instructions were developed by a postdoctoral researcher (Dr. Ben Finio) in the [Creative Machines Lab](#) at Cornell University (PI: Prof. Hod Lipson). The work at Cornell was sponsored by the National Science Foundation (DRL-1030865) and the Motorola Foundation.

"Soft robots" are all the rage in the robotics research community right now. Forget what you usually think about robots and machines - gears, pulleys, circuit boards, aluminum and steel. These robots are made out of soft, stretchable rubbers and plastics, and driven by things ranging from compressed air to chemical reactions and materials that change shape due to electrical current or voltage. Existing robots include a [robot worm that can survive being hit with a hammer](#), a [rolling soccer-ball shaped robot](#), a [gripper filled with coffee beans](#), and even an [artificial octopus tentacle](#).

This project will describe how to make simple, air-powered soft robots that are made from silicone rubber, and shaped using a 3D printed mold. The project is based on a [soft robotic gripper](#) and a [walking soft robot](#) originally developed by the Whitesides Group at Harvard University. The project requires access to a 3D printer, or you can order a 3D printed mold from an online printing service like Shapeways or iMaterialise.

Required Materials

- Ecoflex 00-30 (one "trial kit" is enough to make 5-10 robots depending on size)
- 1/16" ID, 1/8" OD polyethylene tubing* (part number 5181K15 at [McMaster-Carr](#)), about one foot per robot
- 1/8" ID, 1/4" OD silicone rubber tubing* (part number 5236K832 at [McMaster-Carr](#)), about one inch per robot
- Squeeze bulb: we recommend the "Polaroid Super Blower with Hi Performance Silicon Squeeze Bulb", available at [Amazon.com](#) and [ritzcamera.com](#).
- 3D printed mold (STL file available as an attachment to this page)
- Plastic cafeteria tray or metal baking tray
- Disposable rubber gloves
- Scissors
- Plastic cups
- Coffee stirrers or popsicle sticks
- Paper towels for clean-up
- (Optional) toaster oven. **Do not use an oven that you also use for food.**

Note: all of the materials for this project are re-usable except for the silicone rubber. The tubing is very cheap (less than a dollar per foot) so it is not very economical to ship in small quantities - it can't hurt to purchase a few feet of both polyethylene and silicone tubing, in order to make multiple robots.



File Downloads



4-leg-gripper.STL (129 KB)

[NOTE: When saving, if you see .tmp as the file ext, rename it to '4-leg-gripper.STL']

Step 1: 3D printed mold

You will need to order or print a 3D printed mold (download the file from the Introduction page). If you do not have access to a 3D printer, you can order a mold from an online vendor like Shapeways or iMaterialise. Be sure to choose a material with a **smooth surface finish** - otherwise it will be difficult (or impossible) to remove the cured silicone rubber from your mold.



Step 2: Prepare silicone rubber mixture

Safety note: Ecoflex is a brand of silicone rubber used for molding made by Smooth-On Inc. Ecoflex comes in two bottles, containing Part A and Part B. Parts A and B are liquids - when mixed together, they will solidify and form silicone rubber (in 4 hours at room temperature, or 10 minutes at 150 deg F). The materials are non-toxic, and harmless once cured. However, according to the Material Safety Data Sheet (MSDS), "repeated or prolonged" exposure to the unmixed materials (Part A and Part B) can cause mild skin irritation. We recommend wearing disposable gloves when handling unmixed material. If you do get Part A or B on your skin, just wash it off with soap and water.

Mix parts A and B of the Ecoflex in a 50/50 ratio by volume, using a paper or plastic cup. You do not need to use all of your Ecoflex - fill one cup (the one pictured here is a 9oz cup), put the lids back on your Ecoflex jars, and save the rest of the material to make more robots later. Stir the mixture for about two minutes.



Step 3: Pour mixture into mold

Slowly pour the mixed Ecoflex into your 3D-printed mold. The material is very viscous so it will flow slowly - do not pour too fast! Fill the mold to the top edge. Once filled, wait about five minutes for air bubbles to rise out of the mixture. You can "pop" air bubbles with a coffee stirrer, pencil or pen to speed the process along.



Step 4: Pour mixture onto tray

Pour your remaining Ecoflex onto your baking tray or cafeteria tray. Make sure you form a puddle large enough to completely surround the outer perimeter of your plastic mold (if you didn't mix enough in Step 2, you can mix more). If you are making multiple robots, you can fill the entire tray. The layer should be several millimeters thick.



Step 5: Let rubber solidify

You should now have uncured Ecoflex poured into your plastic mold and your tray. Let the material sit for 4 hours, and it will cure (solidify) at room temperature.

Optional : if you have an oven available, and are using a **metal** tray, you can bake the material for 10 minutes at 150 degrees Fahrenheit. **Safety notes:**

- 1) **Do not** use an oven that is also used for food.
- 2) **Do not** put a plastic cafeteria tray in the oven.
- 3) Double-check the melting temperature of the material of your 3D-printed mold. The plastic pictured here is ABS, which will not melt at 150 deg F, but your material may be different.



Step 6: Check that rubber has solidified

After 4 hours at room temperature (or 10 minutes in the oven at 150 deg F), your Ecoflex should be solid. Poke the material with your finger - it should have a rubbery feel, but no longer be gooey. It should also become slightly more opaque (compare the picture in this step to the one in the previous step). If the material is still liquidy and sticks to your finger, it needs more time to cure.

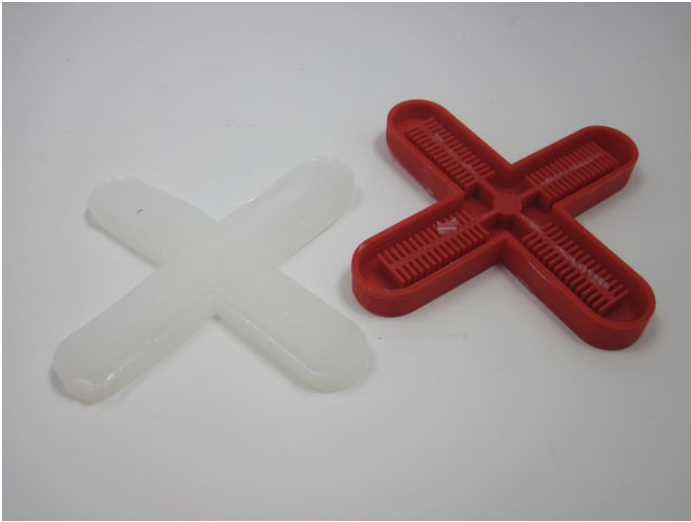
Warning : if you used an oven, your metal tray and mold will be hot. Use oven mitts to remove them from the oven, and let them cool before handling directly.



Step 7: Remove rubber from mold

Carefully peel the cured silicone rubber out of the mold, starting with the outer edges. Be careful and peel slowly - if you peel too quickly, the material might rip. **Do not** remove the sheet of cured rubber from the tray yet.





Step 8: Mix a fresh batch of silicone rubber

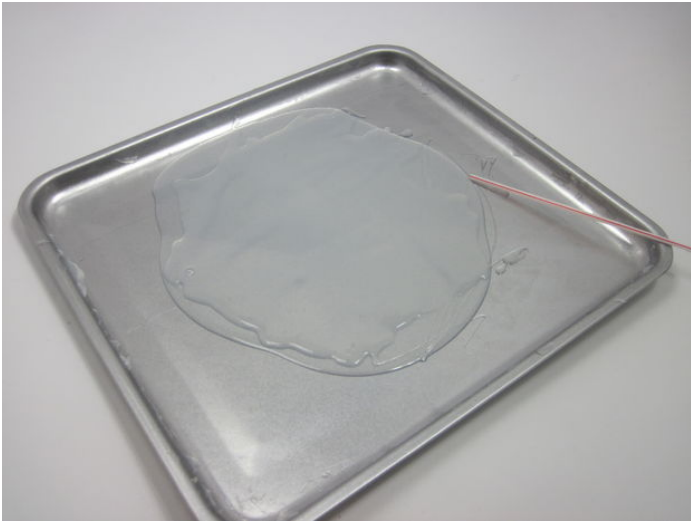
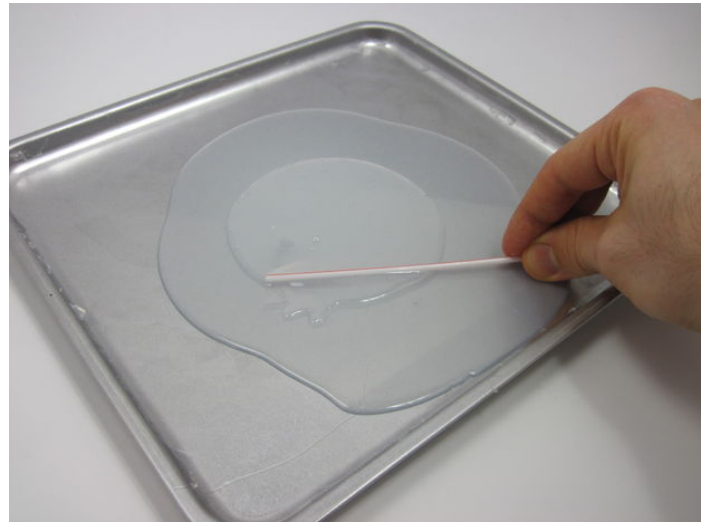
Using a new cup, mix a new batch of Ecoflex in a 50/50 ratio of Parts A and B. You only need a small amount for this step - enough to apply a thin, even coating about 1mm thick over the flat sheet on your baking tray.



Step 9: Spread thin layer of new silicone rubber on top of cured layer

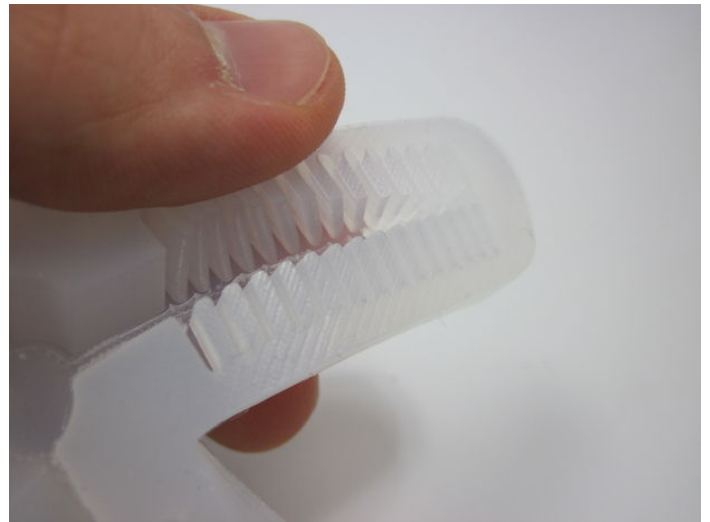
Spread a **thin, even** layer (about 1mm thick) of freshly-mixed silicone rubber on top of your cured sheet. This forms a "glue" layer to bond the top and bottom halves of your robot together. Using a paper towel to smear the material around can be helpful. This step is crucial - if you use too much silicone rubber, it will clog the air channels in your robot. If you don't use enough, the two layers will not bond together.

After you have poured the material on and spread it around, give it about two minutes to settle before moving to the next step.



Step 10: Place top half of robot face-down on new layer of silicone rubber

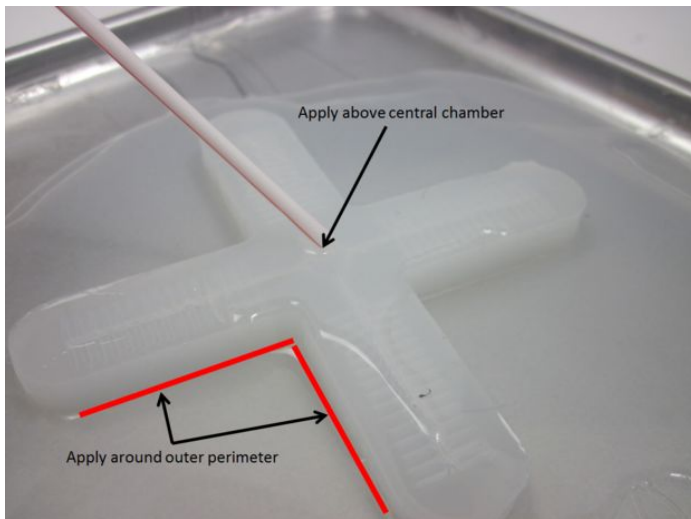
Take the piece of cured rubber that you removed from your mold in Step 7. This is the top half of your robot. One side of it should be smooth, and one side should have exposed ridges that will form the interior air channels of your robot. Carefully place the top half onto the fresh layer of new silicone **with the air channels facing down**.



Step 11: Seal the outer perimeter of the robot

Using a coffee stirrer or popsicle stick, apply an additional layer of fresh silicone rubber (you can mix some more if you don't have any left over from Step 8) around the outer perimeter of the robot (the bottom edge, that is in contact with the layer on the tray). This will help prevent air leaks.

Examine the top of the robot for embedded air bubbles. You can apply a small blob of silicone directly above these bubbles - this will strengthen that area, and prevent your robot from popping. You should also add some reinforcing silicone directly above the large, circular central chamber in the robot



Step 12: Let "glue layer" solidify

Wait 4 hours at room temperature (or 10 minutes in an oven at 150 deg F - follow the safety notes from Step 5) for the "glue layer" to solidify, bonding the top and bottom layers of the robot together. Check that the new layer and seal around the outer perimeter of the robot are solid and rubbery (no longer gooey/liquidy) before proceeding to the next step.



Step 13: Remove sheet from tray

Carefully peel the entire sheet up from your tray. Be careful to peel slowly so you do not tear the rubber.

If you used an oven, wait for the tray to cool before touching it.



Step 14: Cut out robot with scissors

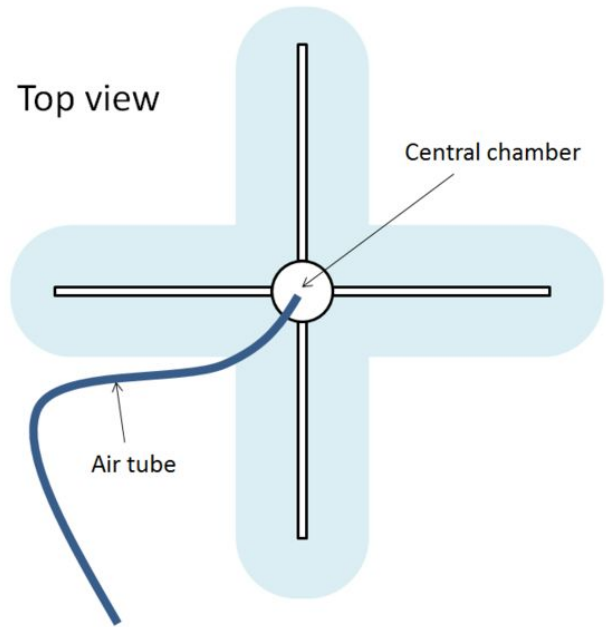
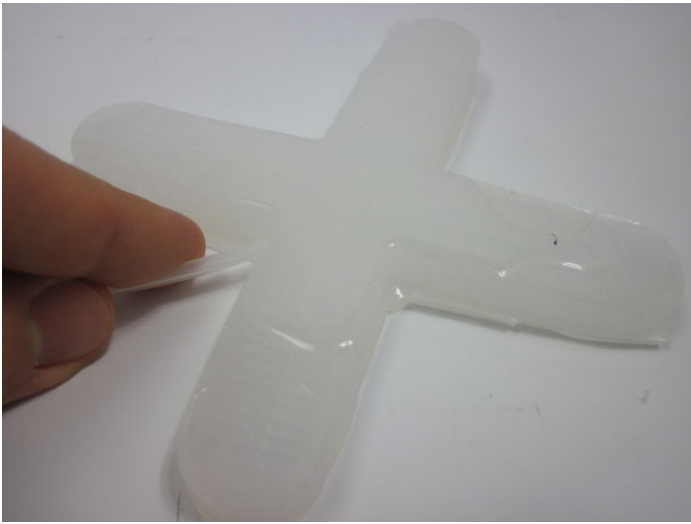
Use scissors to cut around the outer perimeter of the robot, removing excess material. Be careful not to cut into the robot and puncture the air channels. It is OK to leave a little extra material around the edges just to be safe.



Step 15: Puncture robot with air tube

Cut roughly a one-foot section of the polyethylene tubing. Cut one end of the tubing at a 45 degree angle so it is pointy - this will make it easier to insert the tubing into the robot.

Puncture the robot from the side, at a 45 degree angle in between two of the "legs". Aim for the circular central chamber that connects the four air channels. It may help to use something sharp, like the tip of a pencil or a paper clip, to make the hole before you insert the tubing. Make sure that the end of the tube winds up in the central air chamber.



Step 16: Connect squeeze bulb

Cut a one-inch segment of rubber tubing. Use this piece as an adapter to connect your polyethylene tubing to the squeeze bulb.

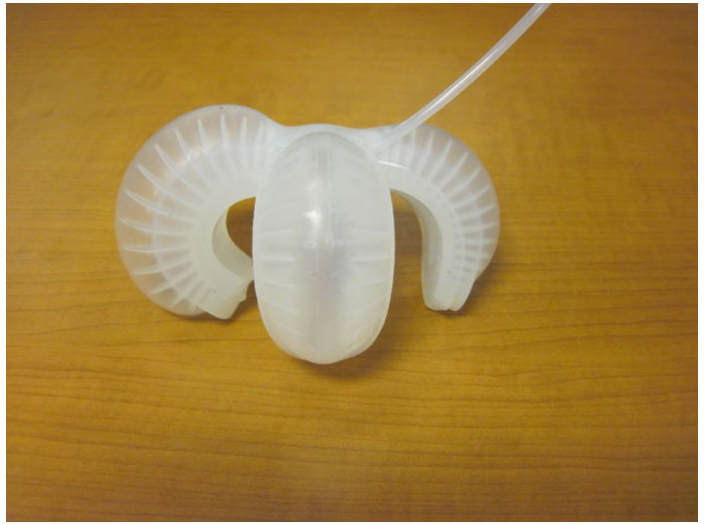
Note: if you are using the Polaroid Super Blower, remove the small rubber piece at the end of the plastic nozzle, and 1/8" ID rubber tubing should fit directly onto the plastic nozzle. If you are using a different brand squeeze bulb, you may need to use an additional piece of rubber tubing with a different diameter as an adapter (such as the one pictured here).



Step 17: Inflate!

Inflate your brand-new robotic gripper! It may take more than one squeeze of the squeeze bulb to fully inflate your robot. Can you use it to lift different objects?

Be careful not to over-inflate your gripper - the material is very durable but it will pop eventually. If your gripper doesn't work on the first try, go to the next step for troubleshooting tips.





Step 18: Troubleshooting

Gripper not working? Here are some troubleshooting tips you can try.

Check for air leaks . If your gripper doesn't inflate at all, listen and feel for air leaks when you squeeze the bulb. If you do have air leaks, you can patch them up with a fresh layer of silicone rubber, let the material cure, then try again.

Check for clogged channels . Hold your gripper up to a bright light and look at the interior air channels. Can you see them in all four legs? If you can only see parts of the channels, or can't see them at all, they are probably clogged, which means you used too much "glue" in Step 9. Unfortunately there is no way to repair this - you will have to start from the beginning. Luckily, you should have plenty of Ecoflex left over, and your mold, squeeze bulb and tubing are all re-usable.

Make sure the tip of the air tube is in the central chamber. Hold your gripper up to a light and look for the tip of the air tube. Did it make it all the way in to the central chamber? If you didn't fully puncture the outer wall of the robot, or pushed the tube too far and into the opposite wall, then the end will be sealed shut by rubber, and prevent air from getting into the channels. Wiggle the air tube until the tip is free in the central chamber.

Some legs inflate better than others . If all four of your legs don't inflate symmetrically, first check each individual leg for clogged air channels, as described above. If none of the channels are clogged but the legs still don't inflate symmetrically, you can layer some extra silicone on the legs that are inflating the most - this should make it harder for them to inflate, allowing more air pressure to divert to the other legs. The material has "nonlinear" behavior - this means that, instead of always inflating gradually with air pressure, it could not inflate at all and then suddenly "jump" and inflate. So, if one leg is slightly weaker than the others (maybe due to some slight differences in wall thickness from the molding process), it might inflate first while the others don't inflate at all. Strengthening this leg with additional silicone may prevent this.

Related Instructables



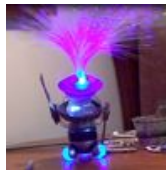
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Comments

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randofo says:

Mar 11, 2013. 10:35 AM [REPLY](#)

Nice! I was doing some 3D printed hydraulic robotic experiments lately and was wondering how you did this. Thank you for sharing your process.



hahvahdsquah says:

Mar 11, 2013. 11:16 AM [REPLY](#)

Thanks! I didn't actually work on these robots at Harvard, but ran a K-12 outreach program in the school of engineering - kids always loved videos of these robots, and parents and teachers were always asking how they could make them. The Creative Machines Lab at Cornell (where I am now) does a lot with low-cost 3D printing so this project was a perfect fit.
