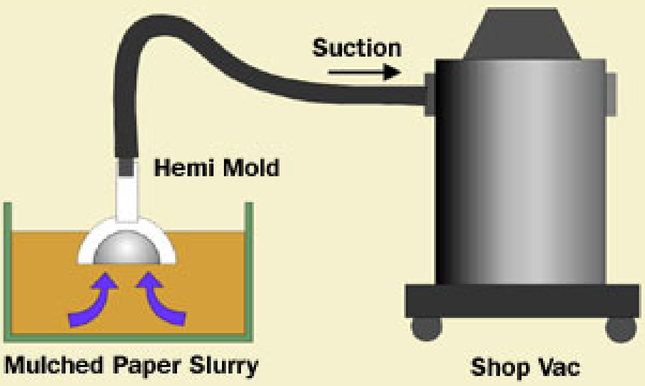
Technique...

Making Vacu-Form Hemispheres



Summary:
This method of producing home-made paper hemispheres for use in making round shells represents a breakthrough in the quest for affordable hemispheres for the pyro hobbyist. The method was adapted from methods employed by the commercial paper recycling industry and brought to the pyro world for the first time by Octavio Aguiar of the Florida Pyrotechnics Arts Guild in April of 2001.

Materials:

- Newspaper or low-grade recycled kraft
- 4,6,8 & 10 inch plastic shell hemi, female side
- One foot lengths of 1-1/2" PVC pipe
- Fiberglass cloth
- Epoxy & epoxy thickener (microfibers, sawdust etc)
- 10 inch square sheet of 1/8" plastic (acrylic, plexiglass etc.)
- Paraffin or mold release
- Spandex or Lycra material
- 1/8" elastic bands
- 4 inch dia. rubber ball

Tools:

- Shop Vac
- Blender
- Drying frames
- Small Dremel type hobby drill
- 1/16" drill bit
- 1 inch disposable brushes
- Latex Gloves

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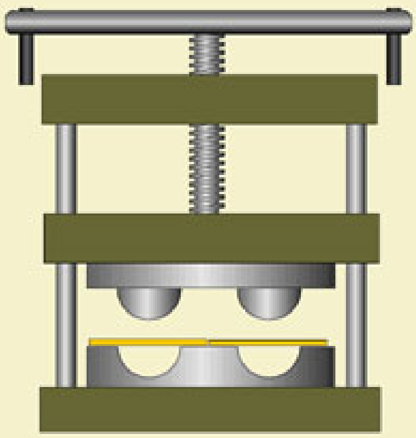

Figure 1: Flywheel type hemi press.

Methods of Hemisphere Construction:
There are currently three general methods of constructing paper hemispheres for use in making round shells. The most common method used in industry is to press a stack of special "daisy" shaped disks into a mold under high pressure. Both Chinese and Japanese hemispheres are made in this way, although the latter are generally of higher quality. The chinese often use a manually operated flywheel type press as shown in Figure one, which can gang-press four or more hemispheres at a time.

The second method, used mainly by hobbyists building small quantities of shells, involves pasting layers of paper over a wax coated ball, then cutting the paper along the equator and removing the two hemispheres from the ball when dry. While this does result in nice, smooth hemispheres, this method has the disadvantage being quite time consuming and requires a seperate mold for each hemi to be made in one sitting.

The third method, least known and barely used until recently, involves the use of paper mulch. First investigated by Dave Allen in the early 90's, a method was devised where newspaper was soaked in water, blended into pulp, formed into a thin sheet and then pressed over a ball shaped mold. However, this method also suffered from the need for a seperate mold for each hemi to be formed, and the finished hemispheres had problems with wrinkles where the excess paper bunched up around the edges.

A second attempt at making paper mulch hemispheres was made a few years later by Phil Martinez using shredded paper insulation. The paper was blended with dextrin, bentonite and wheat paste, then pressed between a male and female mold. Due to the inconsistencies in wall thickness of the finished hemispheres, along with the need for properly dimensioned male and female molds, the method never really caught on.

It was not until ten years later that Octavio Aguiar finally solved the challange of making acceptable hemispheres in a timely fashion from paper mulch. At the time of this writing, over a hundred shells have been built and tested using the methods described here, many of them winning first place in various competitions. There is no question that the method produces shells that function every bit as good as those using commercial hemispheres. While constructing the various sized molds involves a bit of work, it is not beyond the capabilities of the average pyro who has fabricated such things as ball mills, wooden tooling etc. All parts are available off the shelf in local retail stores, making for a good weekend project.

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Figure 2: Mold made from plastic shell hemis, PVC and a plastic ring.

Figure 3: A 6" fiberglass mold with spandex filter cap.

Figure 4: An 8" mold with filter cap in place. Outer casing was made from a flower pot.

Constructing the Mold:

While the method of making vacu-form hemispheres is quite simple, building the mold will probably be the sticking point for most people. The basic mold consists of an outer casing with a nested casing of the desired hemi size inside of it, as shown in Figure 2. The inner hemi is held in place by a retainer ring, which must be cut from a sheet of thin material such that the O.D. of the ring fits just inside the outer casing and the I.D. of the ring equals the O.D. of the inner hemisphere. A piece of PVC pipe modified to fit your shop vac hose is glued to the bottom of the outer casing.

The difference in diameter between the outer casing and the inner casing should be about two inches, which will leave a one inch flange around the hemispheres as they are ejected from the mold. This flange serves to strengthen the wet hemi after it is ejected onto a screen for drying, and help maintain roundness as the paper shrinks upon drying. The flange is later cut off with scissors when the hemi is fully dried.

Making Plastic Molds:

The simpelest way to make a mold is to use two plastic hemispheres used to make plastic ball shells. A four inch mold would have a four inch hemi nested inside a six inch hemi. A six inch mold would have a six inch hemi nested inside an eight inch hemi. The inner hemi should be the male half, so that there is no notch inside the inner lip. The outer hemi should be the female half, so that the notch inside the lip serves to support the retainer ring.

Fabricating the ring is the tricky part of building the molds. If you are familiar with using a router table to cut circles with a pin jig, then the job is an easy one. However, most people probably do not have such a setup and will have to use hand tools such as a coping saw or a metal nibbler tool. The material used for the ring should not be too thick or it will create a dead zone for suction around the lip of the mold. A 1/16" thick acrylic sheet works well, as does formica counter top material.

Once the ring is made, it must be glued to the inner plastic hemi with epoxy or other strong adhesive. The joint must be able to withstand repeated pressing against the inside of the mold when making the hemis. If there is any kind of time fuse nipple on the plastic hemi, it should be shaved off. Hemis where the time fuse hole is already bored through the case should not be used, but may work if nothing else is available. The hole will cause a nipple to be formed on the paper hemi after it is formed.

With the ring glued in place, the entire inner piece must be drilled full of small holes as densely as possible. Holes ranging from 1/32" to 5/64" will work, with the larger hole saving some time spent drilling. It is easiest to use a small Dremel tool for this task, preferably with a low speed setting to keep

Figure 5: A set of 4", 6" and 8" molds.

from melting the plastic and guming up the drill bit. Start at the top of the hemi and work down the sides, keeping the holes about 1/8" on center and spaced evenly from each other. Clamping a small piece of wood so that it extends beyond the edge of the table makes a good resting fixture for holding the hemi while drilling the holes in the sides. The flange must also be drilled out in the same way. For a six inch mold, the drilling process can take several hours, but once it's done the hard part is over.

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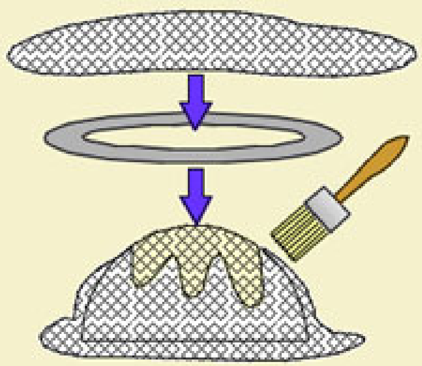

Figure 6: Applying fiberglass over plastic hemi.

Making Fiberglass Molds:

While making the inner part of the mold using plastic shell hemispheres is the quickest and easiest way to get the job done, it has the disadvantage of creating hemispheres that are slightly undersized. Due to the fact that the paper mulch will shrink as it dries, the mold has to be slightly larger than the desired size of the finished hemisphere. In the case of six inch hemispheres, the hemi will lose about 1/4" inch of its diameter as it dries, resulting in a hemi that is about 5-1/8" O.D. After a 1/8" thick paste layer has been applied, the final shell O.D. will only be 5-3/8", resulting in a rather lose fit in the average 6" mortar.

In order to create a standard commercial sized 6" hemi, a larger mold can be made by fiber glassing over the outside of a 6" plastic hemi, then removing the mold. The extra work created by the fiberglass step is more than compensated by the fact that drilling the holes through the fiberglass goes twice as fast as drilling through the plastic. Another advantage is the fact that the ring can be more securely fastened by sandwiching it between fiberglass layers when making the mold.

The first step in making the fiberglass type mold is to coat the hemisphere to be molded over with a non-stick substance such as paraffin or mold release. The mold will still be difficult to remove when it dries, but would be impossible otherwise. A heat gun can be of use when distributing paraffin over the surface of the plastic hemi.

Next the prepared hemi is placed on a sheet of wax paper and a sheet of fiberglass cloth placed over it such that the cloth extends beyond the edges of the hemi by over an inch. A high quality marine epoxy such as West System or MAS is then used to wet down the cloth so that it is spread evenly across the surface of the hemi with no air bubbles or wrinkles. The cloth should form a flange around the edge of the hemi, such that it lays out flat on the wax paper.

After the first layer of glass cloth is wetted out, the retainer ring is pressed down over the hemi so that it fits snug around the rim, resting on top of the fiberglass flange. A second sheet of glass cloth is then placed over the assembly and wetted out as before. This effectively sandwiches the retainer ring between two layers of fiberglass. The cloth will want to pull away from the rim where the ring meets the hemi wall, creating an air pocket. Some vigilance is required to keep working this problem area until there are no air bubbles and the epoxy sets enough to prevent the cloth from sliding out of position.

The epoxy should be allowed to set up to the point that it is almost dry but still slightly pliable. Usually about eight hours, depending on the temperature. The plastic hemisphere will be quite difficult to remove regardless of how it was prepped, and the fiberglass mold will usually get turned inside out during the process. Use a small knife to pry around the edges of the mold and separate it from the plastic hemi. As you work the flange end free, it becomes necessary to actually force the mold to fold over itself as if taking off a sock. This will produce some stress marks in the epoxy, but will not effect the shape of the final mold. Once about half the mold has been pried off it should be possible to extract the plastic hemi by force. The deformed mold can now be popped back into position and smoothed out. The mold is then allowed to fully cure before drilling.

Drilling out the fiberglass mold will go much quicker than the plastic mold, as the fiberglass turns to dust and there is no problem with the drill bit clogging. Holes can be made almost as fast as you can move the drill, but care must be taken not to dwell on each hole too long or the bit will easily side cut the hole and make it larger.

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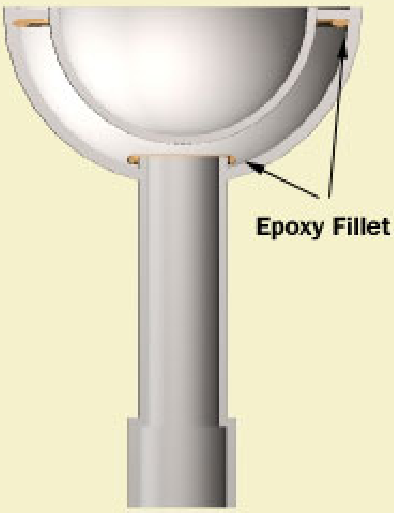

Figure 7: Attachment of mold components.

Finishing the Mold:
Before the drilled out "screen" part of the mold is glued to the inside of the outer shell, the suction pipe must be glued into place. This pipe is a piece of PVC that is sized according to what will attach to your shop vac. Shop vac hoses vary in size, so you will have to find what works best. In the event that your vac hose does not fit inside any standard sized PVC pipe, as is the case with Craftsman hoses, a slip coupling can be created by heating one end of the PVC pipe with a heat gun until it becomes pliable, then forcing the vac hose into the pipe. The PVC will stretch around the vac hose once it is hot, then it is allowed to cool with the vac hose inside. Once cooled off, the PVC will retain the new shape and your hose will now fit snugly into the socket.

A hole is now cut into the bottom of the mold so that the pipe fits inside. This can be a tricky hole to cut in the bottom of a plastic hemi, but a Dremel with a tile cutting bit will do the job. A serrated hobby knife may also do the trick. Place the pipe on the hemi and trace around its diameter to get the hole's outline.

With the hole cut out, the pipe is inserted so that 1/4" protrudes beyond the inside wall of the hemi, then a bead of thickened epoxy is run around the inside seam to hold it in place.

Once the epoxy cures and the pipe is securely in place, another bead of epoxy or liquid nails is run around the lip of the case where the perforated screen will sit. When setting the inner screen into the adhesive, be careful not to allow any holes to become clogged with epoxy. The finished mold should look like Figure 7.

Making the Filter Cap:
In order to prevent the paper mulch from being sucked through the holes in the screen and clogging it up, a cloth barrier is placed between the screen and the mulch. The material used for this cloth should be capable of stretching in both directions, such as spandex or lycra material. The percentage of spandex can be as low as 10% and still be flexible enough to work.

A circle of the material is cut about four inches larger than the diameter of the mold it is to fit over. A 3/8" hem is then sewn into the edge of this circular piece in order to hold an elastic band. The band is threaded through the hem after it is completed by attaching a small safety pin to the tip of the elastic band and working it through a small break in the hem. The elastic is drawn until the desired tension is achieved, then tied off in a knot. The filter should be able to fit over the mold without sliding off when the material is stretched all the way down into the bottom of the cavity.

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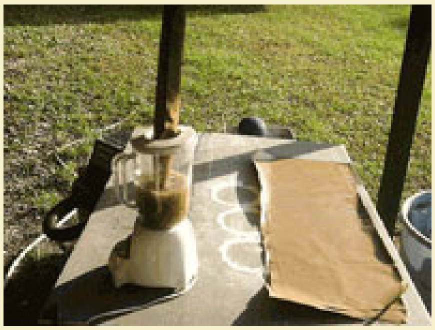

Figure 8: Mulching recycled kraft in a blender.

Figure 9: Mulched paper diluted with water.

Setting Up the System:
Once you have your mold completed, you are ready to go into production. The only other things you will need are the shop vac, blender, a small rubber ball a few inches less in diameter than the hemi mold and a mulch tank that holds five gallons or more (plastic Rubber Maid storage boxes work great). Drying screens will also accelerate the the drying process, but are not totally necessary.

Due to the volumes of mulch that must be pulverized, the larger the blender you have the better. The one pictured in Figure 8 has a 9 cup capacity, which must be loaded twelve times to make a five gallon batch of mulch. This is the bottleneck of the process, which could be vastly improved with an industrial blender if the cost were not prohibitive.

The shop vac should be the wet-dry variety with a dust filter that removes when used to suck up water. The one used in this process is a 3.5 HP Craftsman model, but smaller ones will probably work as well.

Preparing the Mulch:
The original mulch composition specified by Octavio consisted of a blend of newspaper and recycled kraft in a ratio of 50:50. While using 100% newspaper also works, the added kraft paper makes the finished hemi stiffer and stronger. The tensile strength of these hemis are so weak that no matter what you use it will have no effect on the break, but a hemi that tears too easily can rip at the edges when compacting two fully loaded hemis together. Paper manufactures suggest adding starch to the mulch in order to strengthen the final product.

The mulch I have adapted for this process uses 100% recycled kraft with wheat paste as the stiffener. The kraft is a very poor quality recycled variety available in most home improvement centers as "builders paper." The low wet strength of this paper is ideal for blending it into mulch, as virgin kraft would be very difficult to mulch. The paper is also cheap, at around $7.00 for a 130 foot roll. One roll will make about 75 sets of six inch hemispheres, resulting in a cost of about 11 cents per shell (compared to $2.50 for imported hemis).

Start by cutting twelve strips from the roll, each measuring a foot wide by three feet long. These strips are then stacked up, folded in half and submerged in water until they are completely soaked. This type of paper also absorbs water very fast, so you need not wait long.

The soaked stack of paper is now laid out on a table next to the blender, as shown in Figure 8. The process is best done outdoors with a garden sprayer close at hand, as it is messy and requires lots of water. The blender is first filled with about 5 cups of water, then run at its highest setting. A single paper strip is rolled up length wise and fed in through the hole in the top of the blender lid as shown in figure 8. The feed rate should be slow so that excessive stress is not placed on the blender motor. Allow the blender to run a few seconds after the entire roll has been chewed up, perhaps rolling the next sheet while you wait.

This process is repeated for each of the twelve strips, each time dumping the mulched contents into your mulch tank and refilling the blender with water. When all the strips are blended, add three cups of water and blend in wheat gluten (the wallpaper type) until it is so thick that it no longer can spin fast enough to create a vortex. This paste mixture is then added to the mulch tank with the rest of the brown paper mulch. The mixture is finally diluted with water until you have about four or five gallons. The consistency should be fairly thick, but there is no exact amount required. If the mixture is too thin, then the mold will have to be submerged longer, while having it too thick will result in big globs stuck to the mold when it is removed. Cupping a hand full of mulch should retain the amount of paper shown in Figure 9.

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Figure 10: Removing loaded mold from tank.

Figure 11: Flattening mulch with rubber ball.

Figure 12: Flattened mulch ready for removal.

Drawing Hemis from the Mulch Tank:
With your tank of mulch completed, you are now ready for the fun part. Make sure you have enough screens or trays to store all the hemis that can be made from your entire batch of mulch, as the wheat paste component will prevent you from being able to store the mulch very long without it going sour. You must also remember to dump the water from your shop vac immediately when finished, or it will sour with a foul smell after a day or two.

With the filter cap on the mold and the mold attached to the shop vac hose, power up the vac and submerge the mold into the mulch. Slowly move the mold up and down for about six seconds, then remove it and quickly observe the amount of mulch that has stuck to the mold. Once the mold is removed, it can not be resubmerged to pick up additional mulch, as it immediately flattens out and blocks further passage of water. The amount of mulch extracted can vary, but it is good to error on the thick side. The proper amount should look like Figure 10. A bit of practice will be required in order to get the feel for how long to submerge the mold and how much extracted mulch is enough. Bad or damaged hemis can be scooped out of the mold and returned to the tank, where they dissolve back in with the rest of the mulch. This allows lots of practice without actually wasting any material.

Once the mold is removed from the tank, it will immediately begin to flatten to the state shown in Figure 10. This process can be accelerated by holding the mold up high so that the water trapped in the low point of the hose is emptied into the shop vac tank. Once the excess water has been removed, the mulch will still have irregularities in the surface. These should be smoothed down by using a rubber ball small enough to fit into the mold cavity, as shown in Figure 11. Rolling the ball around while pressing down on it should create the results shown in Figure 12.

At this point the hemi is ready to be ejected from the mold. This is the stage that will likely give people the most problems, as doing it incorrectly will damage the fragile hemi. The trick is to turn off the shop vac, remove the mold from the hose and get it positioned a few inches above your drying screen as fast as possible. Depending on how smooth your filter cap material is, the mold may even eject by itself. If not, you will have to blow into the suction pipe to force the hemi out of the mold. Ideally, the hemi should drop to the screen as the mold is slowly pulled away from it.

There are several problems that can occur at this stage of the process, and you will likely have to scrap the first five or more attempts back into the mulch bucket until you can get the hang of it. A trouble shooting chart has been provided at the end of this article for tips on how to correct defects that may occur.

Figure 13: Six inch hemis ready for drying.

It is important that the finished hemispheres are round and smooth as shown in Figure 13. Any wrinkles in the surface will become greatly amplified as the hemi dries. Even the smoothest hemispheres will develop a rough textured surface due to the shrinkage when drying, but wrinkles that appear when the hemi is still wet will result in overly ragged hemispheres when dry. Such a defect will show through the pasted paper of the finished shell, making it unattractive and possibly even effecting the break.

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Figure 14: Assorted hemis drying in a dehumidified dry-box with circulated air.

Figure 15: Cutting the flange off of dried hemis.

Figure 16: Cleaning up the edges on a disk sander.

Finishing the Hemispheres:
The hemispheres are very fragile in their wet state, and there is no way to effectively smooth out dents if you accidentally push your finger into one. It is best to place them in a safe place and get them dry as fast as possible. An enclosed drying box as shown in Figure 14 will not only protect them from accidental damage, but the dry circulated air will dry a full load in just 24 hours. The hemis may also be placed out in the sun for drying, turning them over once the outside is dry.

After they are dry, the excess flange around the rim is cut off with a pair of sharp scissors as shown in Figure 15. The circular scraps of flange may be collected over time and then recycled back into mulch using the blender.

For a perfectly flat edge that shows no gaps when the hemi sets are put together, a disk sander can be used to level them off as shown in Figure 16. The hemi must be held exactly at the center of rotation to keep from being thrown by the sander.

Due to slight differences in the thickness of each hemi, it is often necessary to pair them up to find sets that fit each other the best. They can then be numbered and stored in a stack, as shown in Figure 17.

Using Vacu-Form Hemispheres:
One disadvantage to the recycled paper material is it's high absorption rate. The hemi must be essentially waterproofed on the outside prior to pasting, otherwise the water from the paste will quickly absorb into the hemi, making them soggy and easily deformable.

Some people prefer to spray paint the hemis with a varnish or shellac based paint prior to fusing and assembly. Another method is to apply a single layer of masking tape strips over the shell after it has been loaded and assembled. Either method is effective for preventing the absorption problem, and also decreases the amount of time required for the shell to dry.

Advantages of Vacu-Form Hemispheres:
There are a few advantages when using this type of hemisphere over commercial hemispheres. Due to the low density of the paper, there is very little tensile strength relative to the outer paste layer. This means that the hemi has no effect on the containment of the shell during the burst, which is actually a desirable characteristic. You will not find shell fragments from a ball shell made with vacu-form hemispheres where the casing broke on a flat line at the hemisphere junction as you often do with the stronger commercial hemispheres. Shell fragments are often very small, with the inner hemi material not even attached to the pasted paper.

Figure 17: Completed sets of 8", 6" and 4" hemispheres.

Another advantage is in the application of ring shells of the type where the ring stars are hot glued to the hemi wall. The hemi material is very flakey, allowing the star to easily rip free of the casing upon burst instead of clustering together on a fragment for a few thousandths of a second before burning free, resulting in an imperfection in the ring pattern.

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Figure 18: Finished shells utilizing vacu-form hemispheres. Note the vacu-form lift cups.

Other Uses for Vacu-Forms:
While vacu-form technology is easily suited to making hemispheres for round shells, there are other areas where it can also prove useful. A four inch hemi that is trimmed with a small amount of the flange left in place makes a perfect lift cup for six inch shells. The sturdy cup is much less susceptible to lingering sparks burning through it when dropped in a hot mortar, compared to the few layers of paper traditionally pasted over the lift bag in round shells.

Thin four inch hemis also make ideal containment hemis for the inner petal of six inch double petal shells. The soft paper can easily be vented with an awl for flame propagation purposes, compared to drilling out commercial paper or plastic hemis when venting inner petal hemis. Likewise, six inch hemis can be used inside eight and twelve inch shells.

Further development can lead to multiple molds capable of casting more than one hemi at a time. It may even be possible to attach four separate six inch hemi molds together using PVC pipe fittings on the suction stem, allowing faster production.

When Mr. Aguiar originally approached commercial manufactures of recycled paper products to have them make hemispheres for the hobby industry, they planned to use 3 by 8 foot frames with 75 six inch hemi molds each. The entire cycle for such commercial operations was about 45 seconds per frame set-- 10 seconds submerged in the pulp, followed by a 20 second drying period before being blown off the frame. The estimated production was 4500 per hour, resulting in a cost of 5 cents per piece!

Until demands warrant the initial investment in making commercially produced recycled paper products available for the fireworks industry, those hobbyists wishing to tinker with the technology can do so with minimal costs and tooling.

Trouble Shooting Guide

Problem	Probable Cause
Top of hemi has wrinkles.	Blowing out mold too close to the screen. Filter cloth too tight. Hemi too thin, submerge for longer period to acquire more mulch.
Hemi too thin around bottom edge.	Not enough holes drilled around flange seam joint, try drilling at an angle to vent dead space where the ring connects.
Hemi not ejecting from mold.	Clean filter cloth between each hemi. Try smoother material for filter cloth. Blow into suction pipe.

Hemi collapses after ejecting onto screen, or bottom edge compresses right above the flange.	Ejecting from too high above screen. Crushing it by moving mold downward while blowing out. Hemi too thin, submerge for longer period to acquire more mulch.
Mold will not pick up enough mulch.	Mulch too thin, too much water was added. Too much wheat paste was added. Mulch not deep enough, transfer to a smaller container. Shop vac doesn't have enough suction.
Hemi too thick.	Process consumes more water than mulch, so more water must be occasionally added to the mulch tank. Submerge for shorter time period.
Hemi ejects before mold can be positioned over screen.	Filter cloth is too tight or too smooth. Try placing an inflated balloon into the cavity and removig the hemi onto the balloon, then transferring it from the balloon to the screen.

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