Tool Tip...

Making Ball Mill Jars

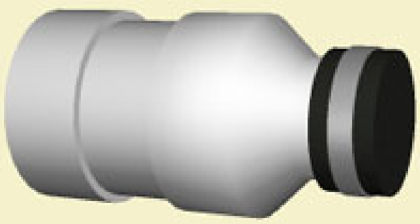

Figure 1: Standard "Sponen" PVC jar.

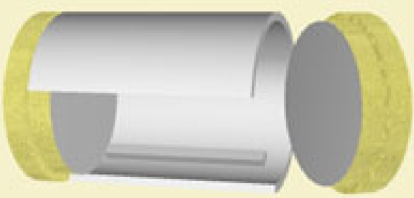

Figure 2: PVC jar with flush fitting ends.

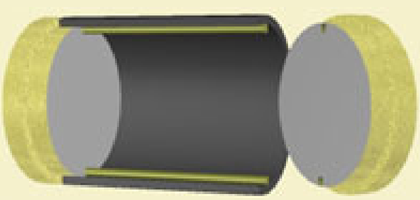

Figure 3: HDPE jar with brass rods for lift bars.

Introduction:
Ball mill jars are an important part of the design of any ball milling system. There are as many designs for home made milling jars as there are ball mills. Perhaps the most widely used milling jar, made popular by Lloyd Sponenburg when first published in his well known book "Ball Milling Theory and Practice for the Amateur Pyrotechnician," is the type shown in Figure 1. This jar is made from 6" PVC pipe fittings, making it a rather quick and easy jar to make. A 10" segment of pipe is fitted with a solid end cap on one end and a reduction cap on the other end. A removable rubber cap is used to seal the jar using a pipe clamp.

While this type of jar is easy to make, it has a few disadvantages. On the usability side, the small opening makes it difficult to extract large nitrate balls that can sometimes form when over milling KNO3 in a damp climate. It also makes it hard to clean off the sides of the jar when powder becomes caked to the sides. Due to the costs of the PVC fittings, it is one of the more expensive types of jars to construct. The total parts cost can run about $20 per jar, and one typically needs at least 3 jars when dedicating them to certain materials. While the jar is quite rugged and easily hosed off for cleaning, the strong construction results in a more powerful and fragmented explosion in the rare event of a milling ignition.

The jar shown in Figure 2 uses the same 6" PVC body, only with home made end plugs. These plugs are cheap to make and allow full access to the jar walls when removing caked up powder. A rubber seal around the outside (not shown) prevents the powder from leaking around the edges of the plugs. The plugs are made from particle board and held in place by only two screws on each end. While my initial thoughts were that haveing end plugs that were not firmly attached could allow the jar to sustain an ignition without causing

Mill jars that have been detonated under controlled conditions reveal that the lead media do not actually travel far at all. It is the fragmentation from the burst jar that is the greatest safety hazard. Figure 3 shows an even safer jar that is made from a segment of HDPE pipe instead of PVC. Since there are no adhesives capable of gluing anything to HDPE, the internal lift bars can not be fastened to the walls of the jar unlessed tapped and screwed from the outside. The design shown here shows loose fitting brass bars that slide into holes in both ends of the end caps. These holes do not run all the way through the caps, thus there is no extra areas to seal against potential powder leaks.

All three jars shown in Figures 1-3 must have at least two lift bars for efficient operation. Trying to save a little work by omitting the lift bars will result in longer milling times, as the media will lose some efficiency due to slippage along the pipe wall. Lift bars add extra crevices for powder to cake in, so you don't want to install any more of them than you have to. I have found that two works just as well as four, with considerably less powder caking problems.


Figure 4: Hexagonal food storage container and 6" PVC sleeve.

The jar shown in Figure 4 is perhaps the simplest and cheapest type that can be constructed. A hexagon shaped food storage container with a large flip lid can be found in many department stores. This container happens to wedge nice and tight into a segment of 6" diameter PVC. The hexagon shape of the container eliminates the need for any lift bars, so you need only cut a piece of 10" long PVC pipe and wedge the container into it. A pipe clamp must be used to secure the lid from accidentally flipping open during operation. While I have not used this type of jar myself, I am guessing that some extra measures must be taken to prevent powder leaks from around the rim of the lid.


Figure 5: Container wedges tightly into sleeve.

While this last method of jar construction is certainly cheap, fast and easy, it will not last very long before the soft plastic of the inner container wears through.

Since the jars shown in Figures 1 and 5 are easy to build, the remainder of this article will show how to make the type of jar with home made end plugs shown in Figure 2 and 6.

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Figure 6: PVC jar described in this article.

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Figure 7: Tracing PVC ends onto particle board.

Figure 8: Gluing inner and outer disks together.

Figure 9: C-clamps used to laminate disks together.

Making the Lids:
Each lid required for this jar are made from two disks cut from 3/4" particle board. One disk is the diameter of the inside of the jar, while the other disk is the diameter of the outside of the jar. Both disks are glued together to form the finished lid.

Begin by tracing the outside of your jar onto a piece of 3/4" particle board. Just in case there is any defect in the roundness of the jar, make an alignment mark as seen in Figure 7. The same procedure is repeated for tracing disks using the inside of the jar.

You will now need to cut out the two larger disks and the two small disks using something like a band saw or saber saw. Figure 8 shows some wood glue smeared onto one of the smaller disks prior to clamping it onto a larger disk. Three C clamps or other type of strong clamp are used to laminate the disks tightly together, as seen in Figure 9. It is important to make sure the smaller disk is centered on the larger one, otherwise the lid will have a lopsided overhang. Scrape away any excess glue that seeps out between the disks before it has a chance to dry, otherwise it will cause a gap when the lid is placed on the jar.

Particle board is being used because it is very flat, doesn't warp and will break away from the jar easily in the event of an explosion. It will deform if soaked with water though, so it may be desirable to coat the finished lids with polyurethane, Krylon or some other waterproofing.

The surface of the lid that resides inside the jar will be exposed to a lot of friction from the milling media. If the bare wood were not protected, there would be lost of wear and sawdust being chipped off into the compositions being milled. For this reason, a sheet of 1/16" Formica laminate is glued to the ends of both lids. This is the kind of material used on kitchen counter tops and is quite resistant to wear. Each lid should last several years before the laminate ever shows any sign of wear.

Cut two pieces of Formica that are larger than the smaller side of the lid. These can be scraps obtained from a counter shop, wood shop or cut from a larger sheet available in home supply stores. A new sheet is usually 8ft x 30 inches and costs about $25, so try and find some scraps from a cabinet shop. The pieces do not have to be square or overhang by a certain amount. The overhang will be trimmed, so they only need to fully cover the bottom of the lid.

Formica laminate is attached using contact cement, which is a type of glue that is brushed onto both surfaces to be attached and then allowed to dry for about 15 minutes, as seen in Figure 10. The strongest type of contact cement is the "original" stinky stuff, not the newer low fume or neoprene based stuff.

Figure 10: Applying contact cement to disks and Formica scraps.

Figure 11: Using a router with a laminate bit to trim the excess overhang.

Once the glue is dry to the touch, the two pieces are pressed together. The pieces will permanently stick together and you can not slide them into position afterward, so make sure you position them correctly. Using a rubber mallet to tap down the Formica surface ensures that the pieces are well bonded.

After the pieces are glued together, the excess overhang can be immediately trimmed. This is done using a router with a special bit for trimming laminate. Figure 11 shows a router table with a laminate bit being used to trim off the excess laminate around the edges of the lid.

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Figure 12: Lift bar strips cut from a section of the PVC pipe.

Figure 13 Gluing lift bars into place.

Figure 14: Using a threaded rod with two nuts to hold lift bars flat.

Installing Lift Bars:
Lift bars will substantially increase the efficiency of your ball milling jar. The purpose of lift bars is to prevent the media from sliding on the bottom of the jar as it rotates. This sliding action reduces the amount of tumbling that takes place, thus reducing the grinding action. The amount of slipping taking place during milling can actually be detected by sound. The idea sound of a well tuned jar is a constant clacking of milling media. Repeated patterns of clacking followed by silence is an indicator of slippage. Constant silence would be 100% slippage.

In this 6" diameter jar, two lift bars is all you really need to prevent slipping. The lift bars can be made by sawing 3/8" strips from a section of PVC pipe using a band saw. Figure 12 shows a pile of lift bars made in this way. The advantage to cutting lift bars form the same pipe you will be milling in is that the bars will fit the contour of the pipe wall. They are also made of the same material, so the PVC adhesive will hold them solidly to the jar wall.

For a 10" long jar, your lift bars will be about 8-1/4" long. If you make them too long then the lid will rest against them and cause a gap at one or both ends. Test fit both lids with the lift bars set in place to make sure they are short enough.

Before gluing the lift bars in place, use sand paper to rough up the bottom of the lift bars and the surface they will be glued to. Use standard PVC cement to coat the back of the lift bars, install one lid in the bottom of the jar, then hold the bars in place using spring clamps shown in Figure 13. The bars should com into contact with the jar lid at the bottom.

Attaching the Lids:
Next remove the bottom of the jar and secure the other side of the bars with spring clamps. In order to force the center part of the lift bars against the jar wall for a better glue job, use a section of threaded rod with a nut on each end so that the nuts can be spun out to apply force on each end. The threaded rod should fit between the lift bars with only a 1/4" clearance when the nuts are threaded all the way back.

Once the lift bars are dry, you are ready to attach both lids. These are held in place by 3/4" long brass or stainless steel screws, with two screws on each end. The screws should be the tapered flat head type, and they will need to be counter sunk into the jar wall so that they do not stick out. Drill the larger counter sink hole first, to a depth of about half the jar wall thickness. Drill the smaller through hole second, then install the lid and use the holes as a guide to drill a still smaller pilot hole into the side of the lid. The placement of these side holes should be 3/8" down from the edge of the jar.

The bottom lid of the jar will never need to be opened, so you can seal around the bottom gap with a strip of duct tape as seen in Figure 15. This will insure that no powder will leak out during operation.

Figure 15: Attaching bottom with screws and sealing with duct tape.

Finishing the Jar:
Next you will need to make two rubber seals using sections cut from a rubber tire inner tube. The inner tube I use measures 7" across when flattened down, and the bands are cut to be 3" thick. These bands are stretched over each end of the jar (with great difficulty I must admit) and aligned flush with each end. The purpose of these rubber bands is to seal the lid seam from leaking powder as well as to give the jar extra traction on the rollers and reduce wear on the ball mill roller bars.

Because the continuous forces experienced by the bands during use can cause them to slide around on the jar, they must be secured in place using duct tape. Figure 18 shows how one continuous piece of duct tape is wound starting from the middle of one band, across the jar and ending on the other band.

Figure 16: Rubber seals cut from an inner tube.

Figure 19 shows how the top seal is pealed down to access the screws when opening and closing the jar. You know have a ball mill jar that is leak proof, durable, explosion resistant, easy to open and clean and features no external nuts or bolt heads to catch on anything.

Design Notes:
When I first designed the jar shown here, it was my hope that an accidental ignition during milling or handling would result in the ends blowing out of the pipe instead of fragmenting the PVC. I recently detonated one of these jars at FPAGs Spring Festival as a demonstration, using an identical jar charged with real lead media and an 800g charge of fully milled meal powder. The jar was loaded, sealed up, fused and placed into a 2 ft deep hole in the ground.

Figure 17: Rubber seals strapped onto both ends of jar.

To my surprise, the jar exploded violently into many fragments. The duct tape around the jar helped to reduce the number of fragments, but the jar was shredded all the same. The majority of the lead media was left in a hot pile at the bottom of the hole, but a few pieces did make it out of the hole and land a few feet away.

Due to the sheer amount of energy contained in a typical 800g batch of finely milled meal powder, it would be impossible to design a jar that would not seriously injure the user in the extremely rare event that it should detonate in his possession. It has been noted that PVC does not show up on x-rays, which would make any accident that ever occurred more difficult to operate on. The optimal choice of jar material from a safety standpoint would be a section of large diameter HDPE. Making a shorter jar from larger diameter pipe not only creates a bigger escape hole to vent the pressure during a detonation, it eliminates the fragmented PVC shrapnel issue. Since ball mill explosions are very rare, and explosions with the operator present are even more rare, the safety concerns mentioned here are really more about peace of mind than any real necessity.

Figure 18: Duct tape wrapped around seals and jar to prevent sliping.

Note that the milling efficiency of ball mill jars actually increases as the diameter increases, but only when you have it properly charged with 50% by volume of media. This is because the milling action takes place on the angled slope of the media pile. So the longer that slope is then the more milling will take place per revolution. The length of this slope is equal to the diameter of the jar, so as the diameter increases then so does the amount of powder being ground up. Thus if two jars have the same volume, but one is a shorter jar with a bigger diameter and one is a longer jar with smaller diameter, the short and fat one will actually mill faster.

Since an 8" diameter jar that is only 5.5" long has the same milling capacity and media charge as a 6" diameter jar that is 10" long, using the shorter 8" jar would not only result in faster milling, but would allow you to fit more jars on your milling machine at the same time!

For an improved milling jar over the one described in this article, I recommend cutting a 6" segment of 8" HDPE mortar pipe and plugging the ends as already described. Brass or aluminum bars can be locked into the end disks as seen in Figure 3. This will give you a safer, compact and more efficient jar to work with.

Figure 19: Rubber seal pealed back on working end of jar to access the two screws.

Figure 20: Simulating a mill explosion with a live jar.

Figure 21: The fragmented remains of the ball mill jar after detonation.

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