Technique...

Round Shell Pasting Methods

by Kyle Kepley

Introduction:
The process of applying pasted strips of paper to a round shell is probably the most tedious and dreaded aspects of making paper round shells. When compared to the quick results obtained from gluing together a set of plastic hemispheres, it is not hard to see why most people choose to make plastic ball shells instead.

However, the superior strength of paper over plastic gives the burst excellent containment, which allows a variety of break charges to be used successfully. Paper ball shells do not have to be broke as hard as plastic shells in order to get a nice round break. Thus, it is easier to dial in a break charge with a paper shell, making blind stars less of a problem. Some builders choose a hybrid approach of building plastic shells and then strengthening them with a few layers of pasted paper. This requires less layers of paper and thus saves time.

There are some cases where plastic simply can not be used, such as shoot sites where plastic fallout is not allowed. The use of plastic shells as inserts inside of larger shells also can cause problems, as the extreme heat and pressure of a large shell break will melt and crush plastic inserts in the brief instant before the shell opens.

Note that break charges specified for plastic and paper shells are not interchangeable. A break charge that works in a plastic shell can not be used in a paper shell or the stars will likely be blown blind. Likewise, a break charge specified for a paper shell will produce a poor break in a plastic shell.

The average mid sized ball shell requires about an hour to paste correctly regardless of the method used. Trying to save time by using wider strips of paper, applying fewer layers or using thicker paper usually gives inferior results.

For more information on how to determine the number of layers to paste for a given shell size, as well as how to calculate the number of strips required to finish a shell of any diameter, see this month's Design Notes section.

Figure 1: Soaking strips in paste pan.

Preparing the Strips
All the methods of ball shell pasting illustrated in this article require paper strips in some format. Regardless of which method you use, all strips of paper must be cut prior to pasting, soaked in paste, broken in and then applied to the shell one at a time.

While each strip could be pasted and broken in one at a time, such a procedure would make an already time consuming process even more time consuming. The fastest way to get all the strips pasted and broken in is to break them all at once.

A flat pan is filled with about three cups of thin paste, or more depending on what size shell you are making. All the strips are then submerged into the paste one at a time so that both sides of

Figure 2: Breaking in the strips.

Figure 3: Ready to apply.

each strip come into contact with the paste. Simply dumping all strips into the paste at once would result in dry spots between some strips. Thus it is necessary to submerge one strip at a time, spreading them into a layer that fills the entire pan as you go. The strips are easier to remove from the pan if each new layer runs perpendicular to the layer beneath it. When the pan is filled it should look like Figure 1.

The mat of pasted strips can now be crumpled up into a ball and squeezed in order to break the paper. The color of the strips should turn to a darker brown as the paper becomes saturated with paste, as seen in Figure 2. Kneed the paste into the paper by crushing it into the pan from different angles.

Once the paper is thoroughly impregnated with paste, flatten it back out onto your work table so that the strips may easily be removed from the stack.

One traditional method of preparing pasted strips for oriental ball shells, as documented by Shimizu in Fireworks, the Art, Science and Technique, does not involve breaking the paper. The paste is applied to only one side of a full sheet of paper, then quickly cut into strips using a large paper cutter. In this case the paste used does not contain much water in order to keep the paper from becoming too mushy to cut. Since the paper will not be as pliable as strips that are soaked in paste and broken in, the paper must be thinner than usual so that they will lay flat against the shell. Thinner paper requires that more layers be applied to obtain the necessary thickness.

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Figure 4: The 3-strip pattern.

Figure 5: Working the pattern around the shell.


Figure 6: End view of strip pattern.

The Three Strip Method:
This pasting method was adapted from Westech technical paper L-603 by Ralph Degn. It is my own preference due to the fact that the strips are easy to prepare (no special shapes), they are all the same size, each layer maintains the same orientation and the position of the strips can be adjusted as necessary to keep the shell perfectly round.

The width of the strips are approximately 1/16th of the circumference of the shell O.D., and the length is 1/3 the circumference. Using these dimensions, it will take roughly 30 strips to complete one time around the shell, which is actually two layers of paper due to the fact that each strip overlaps by half the width. The weight of the paper can be up to 70lb for 6" shells and larger, but a lighter weight must be used as the shell diameter decreases. The curvature of smaller shells does not permit thicker paper to lay down flat when pasted.

Begin by placing a flag of masking tape over the exposed time fuse in order to protect it from the paste. This flag can also be used to keep track of your starting position for the first strip so that you know when you have completed a layer. The shell is easier to work with if it is resting on a tubular stand to keep it from rolling around. PVC couplings work good for this purpose.

The strips are applied in a three strip pattern that repeats as you progress around the shell. The first strip starts from the time fuse, the second strip is centered directly in the middle of the shell, and the third strip ends on the pole opposite the time fuse. Each strip overlaps the one before it by half the width at the equator of the shell. The overlap will be slightly more toward the two poles.

This three-strip pattern eliminates the pileup of overlapping paper that would occur at each pole if full length strips were used. If the shell does begin to take on a slight egg shape during pasting, the first and third strips of the pattern can be shifted toward the middle of the shell, which reduces the overlap at both ends.

Each new layer is pasted over the previous layer in exactly the same way. There is no need to orient successive layers in different directions, which eliminates the need to even keep track of layers so long as you know how many strips are required to complete the necessary number of layers and have only prepared that many strips.

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Figure 7: First three strips in place.

Figure 8: Thick paper results in lumpy shell.

The Shimizu Method:

This pattern of strip placement is described by Shimizu on page 250 of Fireworks, the Art, Science and Technique. The strips are quite wide, being 1/8th the circumference of the shell, and three different lengths are required for each layer.

Only seven strips are required for each layer, making this one of the fastest pasting methods. However, since there is no overlapping of paper, it will take the application of two full layers (14 strips) to equal one layer of the 3-strip or tapered strip methods. In addition, more time is spent flattening the paper down due to its excessive width. Shimizu states that the shell should be rolled with a rolling board to help flatten out the wrinkles, and that only one layer should be applied at a time between drying.

While drying each layer one at a time may work in a production environment where many shells are being made in parallel, it is impractical and unnecessary for the hobbyist to follow this procedure. It is more common for the amateur builder to apply half the layers on a 5" or 6" shell, dry the shell, then apply the other half. Larger shells require more paste/dry sessions as the diameter increases. Applying too much paper all at once can cause the shell to become mushy and result in a flat spot where it is resting while drying.

For this wide strip method, the grain of the paper should run parallel to the width of the strips. Because these strips are so wide, the paper needs to be thinner than other pasting methods so that the paper will lay down with minimal wrinkles. The shell pictured in Figure 8 was a 6" pasted using 70lb virgin kraft, which resulted a rather pruneish look when finished. Despite the deformed surface, the shell still broke symmetrically.

The first strip is the longest and wraps all the way around the shell, starting and ending at the time fuse. The second two strips are less than half this length, as they run at right angles to the first strip from top to bottom. The second and third strips should not overlap the first strip by much. The last four strips will fill in the remaining quadrants shown in Figure 7. They should be long enough to just cover the unpasted area with a minimal of overlap.

One defect in this pattern is that there is an asymmetrical overlapping of paper towards the two ends of the shell, which can result in a slight oblong shape after many layers are applied. One technique to try and avoid thick spots is to alternate the orientation of each successive layer so that the thick spots are distributed evenly across the shell. This method also helps mix up the grain direction, giving the shell a more even tensile strength. This is similar to how plywood is made stronger by having the grain run in opposing directions for each layer. Even if the pattern was only alternated between the three perpendicular axes the results would still be improved.

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Figure 9: Full length tapered strips.

Figure 10: Cutting patterns on 100 sheets at once with a band saw jig.

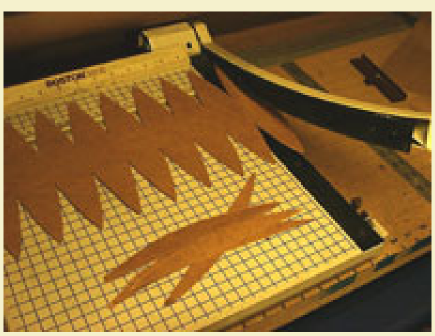

Figure 11: Cutting strips from pattern sheets to obtain tapered strips.

The Tapered Strip Method:

The tapered strip method is probably one of the most simple pasting methods to apply. Thin strips, with a width of about 1/16th of the shell circumference and a length of 1/2 the circumference, are tapered at each end as shown in Figure 9. The taper reduces the excessive overlap that occurs at the poles of the shell, preventing the shell from becoming egg shaped. Since the paper becomes quite thin at each end, it is necessary to use virgin kraft to keep from having problems with the paper tearing during the pasting and breaking process.

The first layer is applied by running the strips from the time fuse down the side of the shell perpendicular to the seam. Each strip overlaps the previous strip by one half the width, making one complete round equal to two layers of paper. Successive layers should be rotated in order to alternate the grain direction of the paper as well as to prevent a weak spot from forming where the ends of all the strips meet. Since the tensile strength of the paper is stronger in the direction that the grain runs, having the grain run in different directions for each layer should create a more uniform resistance to pressure in all directions.

Commercial manufacturers often use this method as the final finish layer on their shells, since it has the cleanest appearance. Some manufactures (Lidu for example) use this method for all layers, pasting each layer in a different orientation as mentioned above.

One drawback to this method is the time spent cutting the strips to the proper shape, as well as the wasted paper that results. The cutting process can be made faster by cutting stacks of paper on a band saw with a wooden template jig as shown in Figure 10. A stack of paper is sandwiched between two plywood templates, which are clamped via bolts that keep the paper from shifting during cutting. Over 100 sheets can easily be cut at one time this way, although a template jig must be constructed for each size shell you plan to make. Once the stack of paper has been cut, the strips are made by cutting them from the patterns as shown in Figure 11.

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Figure 12: Pattern sheets pasted and ready to apply.

Figure 13: Rolling on a pattern sheet.

The Globe Pattern Method:
This method is of my own creation and was inspired by the patterns used to wrap paper maps of the Earth onto spinning globes. The maps are created using the same jig pictured in Figure 10, only they are used as one large strip that is rolled around the shell and pleated down. The length of the strip is obviously equal to the circumference of the shell, and the width is equal to one half the circumference.

The pattern is calculated using this calculator, which prints out a set of data points that must be graphed to scale on a piece of cardboard. This will give you one half of one gore (gore refers to one of a number of tapered 2D strips that are used to create a curved 3D surface). The pattern is then traced over and over, side by side, until you have the number of gores that you specified when you ran the calculator.

The fewer gores you use, the easier it will be to make the patterns. On the other hand, large gores will not lay flat on the shell without wrinkling. I find that at least 10 gores is necessary for a mid sized shell.

Each pattern sheet will count as one layer of paper, since there is very little or no overlap. Like the tapered strip method, each successive pattern sheet should be applied in a different direction than the previous sheets. This will mix up the grain direction and prevent any weak spots.

The obvious drawback to this method is the necessity to fabricate the special pattern sheets. This method can also result in a lumpy shell unless thinner paper is used and/or the number of gores is 12 or more.

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Figure 14: Applying paste to stacks of full-length strips.

Figure 15: Breaking the paper.

Figure 16: A shell pasting assembly line.

The Assembly Line Method:
Like most things in manufacturing, techniques change when mass production is required. Having many workers available to paste many round shells in one session allows techniques to be used that will decrease the overall production time for each shell. The technique described here may be used when groups of friends or guild members pool their labor together for making a lot of shells at once.

First a large quantity of paste is prepared using a blender to make the mixing go faster. A five gallon bucket of paste will do about 50 shells. Small pans of paste are distributed to each table where pasting will be done, which will be used to prime the dry shells and rewet strips when necessary. The remainder is placed at the strip pasting station.

Two people are dedicated to pasting and breaking the strips of paper. This process involves laying out several 36" lengths of 3/4" wide virgin kraft strips in parallel, then brushing paste onto them using a large brush (see Figure 14). Once a thick layer of paste covers all the strips, another layer of strips are placed directly over them, only offset from one end in a stair-step fashion. Not placing the strips directly over each other allows them to be pulled apart easier. Paste is again applied to the new layer of dry strips, then more successive layers are stacked on top until they are about six layers thick. The stacks of strips are then folded up like accordions and squished back and forth in order to break the paper. The resulting wads, shown in Figure 15, are then left to sit so the paper soaks up the paste and becomes softer. When the color of the paper has changed to a dark brown, then the strips are ready for application. When done correctly, there should be no dry spots on the strips when they are pulled apart.

About ten pasting stations will keep pace with the two people making the pasted strips. Figure 16 shows the pasting operation underway. The loaded shells are supported on cylindrical collars to keep them from rolling around during pasting. The dry shell is initially primed with a layer of paste before applying any strips. The long strips are torn to the desired size as they are applied to the shell, which eliminates the need to cut strips to size prior to pasting and breaking the paper. When production involves the same task repeated hundreds of times such as this one, even small amounts of time saved by removing unnecessary steps can multiply into a considerable amount of time shaved off the process as a whole.

A pasting pattern of one long strip and one short strip is applied such that each strip overlaps the previous by half it's width. Thus, one full application of strips equals two effective layers of paper. The long strip reaches half the circumference of the shell, while the shorter strip falls a few inches short of each end. The shorter strip helps eliminate excessive overlapping of paper at the end points, which can make the shell oblong and possibly prevent it from

Figure 17: Drying tables.

Figure 18: 30 finished shells produced in about five hours.

fitting in the mortar. The long strips should not overlap each other at the ends or large lumps will form. The pattern of one long strip followed by a short strip is continued until one full layer has been applied.

After each paste layer is completed, the shells are placed on a drying table with a fan blowing air across them, as seen in Figure 17. By the time one layer had been applied to all the shells, the first ones completed are dry on the surface. Shells were are then removed in order of dryness and another paste layer is applied. In order to keep the shells from getting mixed up, two tables are used. One table holds shells with x number of layers, while the second table holds shells with x+1 layers. When all shells have progressed from the x table to the x+1 table, then the next layer is ready to be applied.

Because the shells are continuously being dried as they are being pasted, all six layers can be applied in one session without the need to force dry the shells when they are finished. Only an hour after the last layer is applied, the completed shells will be dry to the touch and can be rolled out to smooth them down.

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Final Notes:
Regardless of which method I use, I prefer to paste all the layers required at once and then force dry the shell using a fan or a drying chamber. This seems to produce a stronger and denser shell when dry, as compared to pasting only a few layers at a time and drying them in between. It is important to accelerate the drying of the shell if all layers are being applied at once, especially if water sensitive hemispheres such as the vacu-form type are being used. Long dry times can cause water to leech into home-made hemispheres, soften them and then deform the shell upon drying.

While shells can not become driven in the way stars can, it does take longer for them to dry when many layers are applied at once. If layers were applied one at a time and fully dried before the next layer was applied, the way Shimizu describes, the shell can actually be ready to shoot sooner than if all layers were pasted at once and then dried. This is a rather inefficient way of building just a single shell, but works well when building many shells together as a group.

Having made many paper round shells, I have tried everything I can think of to shorten the time required for pasting. But regardless of which method I've used, it's difficult to get the time down below 4 minutes per layer (includes the time spent pasting and breaking the paper). There are some ingenious builders who have built machines for automating the paste process, usually involving the use of gummed paper tape being spooled off a large roll onto the shell, which is rotated slowly in a cradle. Unfortunately, building such machines is beyond the abilities of the average hobbyist.

Some time can be saved by purchasing your paper pre-cut into strips of the desired width, such as those sold at pyrosupplies.com. I've been using the PyroSupply strips for over a year, and find the quality and wet-strength of the paper is ideally suited for making ball shells.

The bottom line is if you want to shoot paper, you have to do the time!

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