Strip Pasting Calculations for Paper Ball Shells

Introduction:

Whenever you fire a really nice paper ball shell in the presence of other pyros, you will likely receive two questions: "what did you break that with?" and "how many paste layers?" While the break charge will depend on the volume of space available and the type of effect desired, the thickness of the shell casing for a given caliber of shell tends to be a constant. There are special cases where a shell is required to have a weak break, such as parachute shells and go-getter shells that need to pop out their contents without throwing them across the sky, but the typical star shell requires a certain amount of confinement to achieve a good effect.

With large shells over 8" diameter, the thickness of the paste layer can mean the difference between getting out of the gun intact or rupturing into a flowerpot. With smaller shells, an overly thin paste layer will reduce the size and symmetry of the spread. Burst charges such as KP, which require a buildup of pressure in order to reach their maximum strength, can result in pathetic puffs of stars in an under-pasted shell.

While the most reliable method of determining the correct thickness of the paste layer is through experimentation, it would be nice to have a general starting point to work from. Shimizu has provided a formula for just such a purpose in his book "Fireworks, the Art, Science and Technique." This "traditional" formula is stated as follows:

N = 5.6 D(cm)/J(kg/cm)

Where N is the required number of layers, D is the outside diameter of the hemisphere to be pasted and J is the mean value of the tensile strength of the paper to be used. The J value must be measured for the type of paper you will be using, which is done by measuring the tensile strength of the paper in directions both parallel and perpendicular to the grain of the paper. These two values are added together and divided by two to get the final J value.

The constant of 5.6 was most likely arrived at by working backwards from a known number of pasted layers taken from a sample of working shells and equating this to the diameter and paper strength used for these shells. If you wish to work in English units of pounds and inches instead of the metric system, this constant is adjusted for the new units and becomes:

N = 79.5 D(in)/J (lb/in)

The remainder of this article illustrates how to measure the J value for your paper and use this formula. Measured values for different types of paper are presented, and a chart is tabulated that gives the number of layers required for common shell sizes.

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Figure 1: Bar clamps used in tensile strength measurement device.

Figure 2: Another view of the bar clamps, held in place with a bench vise.

Figure 3: Aluminum plates and emery cloth used to evenly clamp the ends of paper strips.

Measuring Tensile Strength of Paper:
The setup for measuring the tensile strength of paper shown to the left operates by hanging weight from strips of paper and gradually increasing the weight until the strip pulls in half. The weight is then measured and recorded.

Paper strips of a fixed width must be prepared in sets of two for each type of paper being tested. The grain should be parallel to the strip length for one sample (grain long), and perpendicular to the length for the other sample (grain short). Any width of paper may be used, but making them either one inch wide or one centimeter wide helps simplify your calculations. Otherwise you will have to divide your breaking point weight by the width of the strip to get the desired number. Using strips wider than one inch will require an inconvenient amount of weight to break, while going under one centimeter may not even support the minimum clamp and bucket assembly weight. I used one inch wide strips for my tests.

Bar clamps are used to grip each end of the paper strips as tightly as possible. A small piece of emery cloth is first folded around the ends of the strips in order to prevent the paper from slipping from the jaws of the clamp. Each end is then sandwiched between flat pieces of aluminum as shown in Figure 3. This ensures that the entire width of the paper will be clamped, allowing tension to be distributed evenly across the paper. Failing to clamp the paper evenly across its width will result in an uneven distribution of tension, causing premature failure and an inaccurate tension measurement. This problem will also occur if the paper is not positioned exactly perpendicular to the floor when hanging from the clamps.

The upper bar clamp is mounted in a bench vise as tightly as possible. It should hang over the edge of the bench so that buckets of sand can be suspended from the second clamp. A large catch bucket is placed under the suspended buckets in order to catch them and their contents when the strip breaks.

It is necessary to keep the bottom clamp balanced so that it does not bend the paper as the weight is increased. If the entire length of the paper strip is not kept in a straight line then you will be measuring some combination of tensile strength and shear strength when it fails, giving you a number that is lower than the actual tensile strength. Thus, two buckets are used to balance the clamp, as seen in Figure 1.

Sand is slowly introduced into each bucket, alternating between the two in order to keep the bottom clamp level. If you know it is going to take over 20lbs of sand to break the paper, you can start off with a 10lb dumbbell weight in the bottom of the bucket as shown in Figure one. When you start getting close to where you think the paper will break, slow down the rate of adding sand. Your anticipation of the break point will build to the point that you will jump and dump any sand in your scoop when the paper finally fails and the buckets crash to the floor.

When the paper breaks, simply weigh everything that fell into the bucket and record the number. Repeat the process for the second strip and use the following formula to compute the J value:

J = (T1 + T2)/2

Where T1 and T2 are the two weights you measured divided by the width of the paper strips.

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Test Results:
Several grades and weights of paper were used for conducting the tensile strength tests. The highest quality paper samples were obtained from PyroSupplies.com (www.pyrosupplies.com), a new online supplier to the pyrotechnics community that has managed to scour the planet for the best quality papers and string for making fireworks. These samples were contrasted by some very low quality recycled and grocery bag papers in order to demonstrate the amount of labor that can be saved by using good paper.

The results of three trials were averaged together for each type of paper. Each trial consisted of two tensile strength measurements, one for each grain orientation.

Table 1. Tensile Strength Measurements for Various Paper Samples.

Paper Type	Tensile Strength #1 (grain short)	Tensile Strength #2 (grain long)	J Value
70 lb Virgin Kraft (pyrosupplies.com)	23 lb/in	36 lb/in	29.5 lb/in 5.28 kg/cm
60 lb Virgin Kraft (pyrosupplies.com)	33 lb/in	28 lb/in	30.5 lb/in 5.46 kg/cm
60 lb Grocery Bag (Publix)	18 lb/in	20 lb/in	19 lb/in 3.40 kg/cm
60 lb Recycled Kraft (office supply store)	20 lb/in	29 lb/in	24.5 lb/in 4.38 kg/cm
40 lb Natural MGB Virgin Kraft (pyrosupplies.com)	15 lb/in	25 lb/in	20 lb/in 3.58 kg/cm

Plugging the numbers from Table 1 into Shimizu's formula gives the results below. The diameters used in the calculations were those of standard Chinese strawboard hemispheres. No layer counts are given for combinations where the paper would be too thick or too thin for pasting the given shell size.

Table 2. Paste Layer Requirements for Common Shell Sizes.

Paper Type	3"	4"	5"	6"	8"	10"	12"
Hemisphere O.D.	2-3/8"	3-3/8"	4-3/8"	5-3/8"	7-1/4"	9-1/8"	10-3/4"
70 lb Virgin Kraft (pyrosupplies.com)	X	X	X	14	20	25	29
60 lb Virgin Kraft (pyrosupplies.com)	X	X	11	14	19	24	28

60 lb Grocery Bag (Publix)	X	X	18	22	30	38	45
60 lb Recycled Kraft (office supply store)	X	X	14	17	24	30	35
40 lb Natural MGB (pyrosupplies.com)	9	13	17	X	X	X	X

While recycled kraft paper lays down against the shell easier when pasting, it also tears easier during manipulation and, as this table shows, can result in more than 30% more layers to achieve the same strength as a high quality virgin kraft paper. The extra work might not seem like much for a small shell, but can add up to several additional hours when making a 10" or 12" shell.

Depending on the type of burst charge used and the strength of your paste, you may find that you can use a few less layers than shown here and still get good results. Keep in mind that many pasting methods where the strips overlap result in two actual layers of paper each time the pattern is worked one turn around the shell. Thus the application of 14 layers only seems like 7 layers when applied. Also note that odd numbered layer requirements must be rounded up one layer if your paste method results in two layers per round.

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